# North Wiltshire District Council

## Water Resources Development Strategy Study for the Wilts & Berks Canal

November 2007

**Prepared for:**

**North Wiltshire District Council**
Monkton Park
Chippenham
Wiltshire
SN15 1ER

**Prepared by:**
Grontmij
1st Floor
10 Beacontree Plaza
Gillette Way
Reading
RG2 0BS

**T** +44 (0)113 262 0000
**F** +44 (0)113 262 0737
**E** tim.jolley@grontmij.co.uk

Report Status: Final

Job No: P0000377200

| | Name | Signature | Date |
|---|---|---|---|
| Prepared By: | Jason Ball | pp. T-Jolley | 16/11/07 |
| Checked By: | Tim Jolley | Craig Jolley | 16/11/07 |
| Approved By: | Craig Gerry | Craig Gerry | 16/11/07 |

**APPENDIX 2 – WATER RESOURCES REGULATIONS ............................................... III**

## EXECUTIVE SUMMARY

Grontmij has been commissioned by North Wiltshire District Council, on behalf of the Wilts & Berks Canal Trust (W&BCT), to identify and appraise the potential short and long term water resource options for restoring the Wilts and Berks Canal between the River Thames at Abingdon and the Kennet and Avon canal at Semington. This study includes the North Wilts Canal (NWC) which will link the main canal and the Cotswold Canal at Cricklade.

An Interim Report was issued in February 2007 for the North Wilts Canal between Purton Road Bridge and Cricklade. The Interim Report considered the water resource options for the NWC in isolation from the main canal to support an application to the Big Lottery Fund for development of the Cricklade Country Way, of which the NWC is a part. This final report addresses the water resource implications of restoring the whole canal.

This report presents the findings for the main Wilts and Berks Canal including the NWC.

A water balance model of the Wilts & Berks Canal was developed for each of four sections: Western Mainline, Summit, Eastern Mainline and the North Wilts Canal. Potential sources include direct abstraction from rivers, off-line storage, existing reservoirs, aquifers and other sources such as urban drainage and agricultural runoff. The model was applied for the 32 year period (1974 to 2006) for which daily river flow data is available. Three seepage scenarios (10 mm/d, 20 mm/d and 1.75 Ml/km/wk) and three boat movement scenarios (1000, 2000 and 4500 boats per year for the main canal and 1000 and 1500 boats pre year for the North Wilts Canal) were considered leading to nine loss scenarios in total. The model included transfers of water between adjacent sections and hence allowed the study to consider the large scale management of water resources. Surface water catchments much smaller than 5 $km^2$ were not considered in the analysis.

The river flows for the catchments upstream of each abstraction point (assumed to be where the watercourse intersects the canal route) were derived from the most representative local gauging station scaled using catchment area and Standard Average Annual Rainfall (SAAR).

It was assumed that abstractions could occur all year round. Hands-off flow rules were based on information presented in the CAMS and consultation with the EA. Target percentage takes were based on UKTAG guidance but were not used as constraints on abstraction.

The model was used to determine the storage required for each loss scenario and for three levels of service: an average year (e.g. 1979), the driest year (1975) and the 1 in 5 year level of service. The level of service indicates how frequently the water level will fall below the navigable depth unless demand control measures such as restrictions on lock operations were introduced.

The results of the water balance conclude that the water balance can be closed provided that sufficient off-line canal side storage can be secured. For the lowest loss scenario (10 mm/d seepage and 1000 boat movements) the total demand of 14.44 Ml/d can be met provide that some 4.92 Ml/d can be off-line storage in an average year. For this loss scenario the required storage varies from 1798 Ml in an average year to 3612 Ml in the driest year.

Cost estimates have been derived based on standard Grontmij unit rates and a simple model of storage. They exclude survey costs, land costs and spoil removal and should only be use as indicators of the scale of the solution at this time. They do, however, demonstrate that the cost of excavation is the primary cost in building new storage. The indicative cost of new reservoir

storage for an average year is £40.6M with an operation cost of £3M the capital costs increase to £82.1M if navigable depth is to be maintained during the driest year in the 32 year record.

The study concludes that canal lining is required to guarantee an average seepage loss of 10 mm/d. It is acknowledged that a puddle clay liner can in theory give seepage rates of as low as 1 mm/d, however, until a detailed assessment is available of the ground conditions and the clay to be used it is not advisable to assume an average rate lower than 10 mm/d.

The potential yield of existing reservoir sources (Coate Water and Tockingham Reservoir) were assessed, however, they were not progressed as potential sources due to environmental constraints and the sensitivities of existing users. Should their designations change then these sources could be reconsidered.

The key environmental impacts associated with providing water for the canal are related to water quality, both in terms of the sources feeding the canal and discharges from the canal into storage reservoirs or watercourses. All abstractions and discharges will be subject to consent by the Environment Agency with associated limits on water quality parameters. The outline Environmental Impact Assessment (EIA) identifies designated areas and sensitive species and habitats. Furthermore the outline EIA suggests areas where the restoration of he canal and the creation of reservoirs might give environmental benefits.

Through the course of this desk-based study it has become apparent that significant uncertainties remain with respect to the yield of potential sources and the losses from a restored canal. Therefore a strategy is proposed to assist the W&BCT to resolve these uncertainties and ascertain the feasibility of potential sources. New storage is costly, however, the need for storage can only be reduced through the detailed assessment of other potential sources identified in this study. A hydrological and engineering assessment of existing reservoirs, the study of existing boreholes and the assessment of potential aquifer sources together with the study of urban drainage systems would allow the W&BCT to develop a solution that minimises the need for new reservoirs. The environmental aspects of potential sources must be assessed in parallel with any water resource assessment as water quality will be an important factor in determining the viability of a specific source.

# 1 INTRODUCTION

Grontmij has been commissioned by North Wiltshire District Council, on behalf of the Wilts & Berks Canal Trust (W&BCT), to identify and appraise the potential short and long term water resource options for restoring the Wilts and Berks Canal between the River Thames at Abingdon and the Kennet and Avon canal at Semington. This study includes the North Wilts Canal (NWC) which will link the main canal and the Cotswold Canal at Cricklade.

An Interim Report was issued in February 2007 for the North Wilts Canal between Purton Road Bridge and Cricklade. The Interim Report considered the water resource options for the NWC in isolation from the main canal to support an application to the Big Lottery Fund Living Landmarks programme for development of the Cricklade Country Way, of which the NWC is a part. This final report addresses the water resource implications of restoring the whole canal.

Section 2 gives the background to the canal with specific reference to water resources. It summarises the history of the canal and notes the key conclusions from previous studies.

Section 3 gives a summary of the method used in the study to allow the reader to place the subsequent sections in context. The overall approach to each source and demand type is discussed together with the approach taken in assessing the canal water balance.

Sections 4 and 5 describe in detail the potential sources and demands and explains the approach taken to quantifying these factors.

Section 6 presents the water balance model used in the study and gives the results of the assessment.

Section 7 provides an assessment of water resource options.

Section 8 presents the environmental aspects of the water resource solutions.

Section 9 presents the conclusions of this study and presents a water resource strategy framework for the canal.

Section 10 presents the recommendations from the study.

# 2 BACKGROUND

## 2.1 Historical Background

Construction of the Wilt & Berks Canal, originally connenced in 1792 and opened in 1810, linking the Kennet and Avon canal near Trowbridge, with the river Thames near Abingdon. The North Wilts Canal, which was opened on 2nd April 1819, linked the Wilts & Berks Canal at Swindon to the Thames & Severn Canal at Latton.

The history of the canal and its development is explained in detail by Dalby, L.J (1986) while a general overview is available on the Wilts & Berks Canal Trust's web site (http://www.wbct.org.uk/overview.htm). A summary of this history is given here to indicate the general nature of the original canal and to describe how the original water resource demands of the canal were met.

The Canal Enabling Act received Royal Assent on 30th April, 1795. With respect to water resources the Act gave the Proprietors power to take water from "all such springs as may be encountered in excavating the canal, and also from all rivers, springs, brooks, streams and watercourses which are or shall be found within a distance of 2,000 yards from any part of the canal or branches." Furthermore, the Proprietors were given powers to utilise a feeder from the supplies of Wanborough Mill and a reservoir in Coate Valley.

The Act also imposed a number of constraints on the water resources of the canal. It states that water could not be taken from the River Avon between Trowbridge and Stanley Abbey and that water could only be taken from Tockenham Water, Trow Lane Water and Wootton Bassett Brook between 10th June and 10th September. In addition, abstracted was not permitted from the Wootton Bassett Brook when it was flowing out of bank. The Act also protected the rights of Mills and the owners of Meadow Lands by requiring the Proprietors to pay compensation should the canal impact the power supply to a Mill or the value of Meadow Land.

Existing water rights were protected by the Act which stipulates that the canal was to be puddle to prevent seepage to adjacent land. Proprietors were required to construct drains to convey water from adjoining lands. Proprietors were given a duty to maintain drains and power to clean adjoining ditches.

The sufficiency of the canal's water resource together with pressure from existing users of water is an ongoing theme throughout the history of the canal. Dalby reports that during construction, in 1799, William Whitworth reported that the original estimate of the available water for the canal may have been too generous and he identified an additional reservoir site at Trow Lane (Tockenham). The reservoir was to have an area of 9 acres and to be 8½ feet deep giving sufficient storage for 514 locks. Whitworth noted that the storage would be doubled by raising the head by a further 5 feet.

Pressures surfaced again in 1811 when Dalby reports that prior to the Annual General Meeting of the Wilts & Berks Canal of 6th April 1811 there was unrest amongst shareholders at least partially caused by the fact that the canal was not navigable for some months. Whitworth denied that water supplies were not sufficient. He indicated that Wroughton and Wanborough Brooks were sufficient to meet up to 47 locks per day in the driest season, increasing to 100 for 7 months of the year. He noted that additional sources could be used on either side of the summit including the River Marden at Calne and Beckett Brook at Shrivenham.

The NWC was opened on 2nd April 1819, 9 years after the Wilts & Berks Canal and Severn and Thames Canal Companies had agreed to the project. In 1820 the Wilts & Berks Canal and NWC companies merged and the water rights of the two Companies were combined in a single Act.

Following the decision to proceed with the NWC in 1810 a number of water resource projects are reported by Dalby including a borehole north of Swindon and the Coate Water Reservoir. The borehole was abandoned in 1820 while Coate Water, completed in 1822, was used through until 1914 when the canal was officially abandoned before Swindon Borough Council took ownership of the reservoir.

As a result of commercial pressures, largely caused by the development of the railways and the decline of Somerset coal, together with increased competition for the canal's water supplies, the canal entered a period of decline between 1841 and 1877. Dalby reports that in 1873, the Company lost its legal challenge to prevent Swindon Waterworks Company from diverting Wroughton Brook into its reservoir. The judgement had serious implications for the supply of the canal in general as it concluded that the canal Company had no exclusive rights to waters they claimed.

After 1877 the canal rapidly began to fall into disrepair as a result of reduced levels of maintenance such that by 1894 it is reported that up to a depth of 2ft of silt had accumulated in the canal restricting the loads that boats could carry.

The Act of Abandonment received Royal Assent on 31st July 1914 and the canal was formally closed. Swindon Borough Council took ownership of the parts of the canal in and around Swindon including Coate Water Reservoir. The rest of the canal was allowed to fall into disrepair.

Arrangements were subsequently put in place to sustain the water supply of landowners to the West and East while the NWC was to receive no water.

## 2.2 Previous Reports

Griffiths (1986) carried out an indicative water balance for the restored canal based on local knowledge using an assumed bed width of 10m and seepage rate of 4.7 mm/d.

Allen & Harris (1994) carried out an indicative water balance for the western section and NWC. They adopted a seepage rate of 20 mm/d and an evaporation rate of 4.5 mm/d to give a water demand of 1.9 Ml/km/d. This figure excluded any allowance for lockage losses.

Scott Wilson (1998) carried out the first comprehensive study of the water resources for the canal as a part of a feasibility study into the restoration of the whole canal. Scott Wilson developed a monthly water balance model of the whole canal to assess the historic water balance, the water balance for the restored canal and to assess the water resource options for the restored canal. They concluded that the historical water balance of the canal could be closed with a seepage value of between 10mm/d and 20mm/d depending on the contribution from groundwater sources, drainage from adjacent land and the extent to which back pumping was used. For a restored canal they concluded that new water sources would be essential if the canal was to be maintained at a navigable depth. Even assuming that by-pass losses were minimised and back pumping was fully utilised, the estimated annual water supply of the order of 4,200 Ml would be required. This estimate assumed the minimum seepage rate of 10 mm/d was achievable.

The Scott Wilson (1998) study considered a range of options to increase the supply to the canal and to manage demands. While the options considered were extensive there was little data available on new sources to allow analysis to be carried out with confidence. As a result the study had to rely on assumed yields and estimated flows. The indicative assessment suggested that if all new sources identified were exploited then the water balance could only be closed if the seepage rate could be reduced an average rate of 4.9 mm/d. If a more realistic rate of 10 mm/d was assumed then there is a shortfall of 2034 Ml (49% of the required resource). No solution was suggested to resolve this problem beyond a statement that increasing the capacity of the new storage reservoirs would have to be considered.

# 3 OVERVIEW OF WATER RESOURCE METHODOLOGY

## 3.1 General Approach

The general approach, as is standard for a water resource study, has been to establish that there is sufficient supply to meet the forecasted demands of the canal with sufficient surplus to ensure a sufficient level of resilience. The level of resilience is defined by the extent to which the W&BCT is prepared to accept that demand control measures may have to be used to ensure that the depth of water in a canal remains above the minimum depth required for navigation.

With respect to the provision of public water supply the level of service is strictly controlled and monitored by the industry's regulators. However, for canals there is no equivalent industry standard and standards vary from one canal to another. British Waterways does not recommend a standard for restored canals that they manage. Standards for existing canals vary from the one extreme where there has been no record of a canal falling below navigable depth to the other where a canal can fall below navigable depth on average once every three years. In reality, there is a balance between the restoration cost and the level of service and it is this balance that is the key factor in determining the level of service to be adopted for a restored canal.

A required level of service has not therefore been defined for this study. It was agreed with the W&BCT that it was more appropriate to present the supply demand balance based on the simulated water balance for the period of record and to assess the level of service that is achievable for alternative water resource options.

Assessment of the Water Resources methodology for a canal is set out in the document *Managing Water Resources*: *A good practice guide to navigation authorities* (AINA, 2005). This document gives the typical sources and demands on a canal as shown in Table 3.1.

| **Sources** | **Demands** |
|---|---|
| Rivers | Lock Operations |
| Reservoirs | Evaporation and transpiration |
| Streams, Ditches and Brooks | Leakage, seepage and percolations |
| Groundwaters | Abstractions and water sales |
| Discharges | Feeds to other waterways and watercourses |

**Table 3.1 - Sources and demands**

The method adopted to estimate the potential for each source is dependent on available data. Potential sources are described in detail in Section 4 and demands are described in Section 5.

| **Component** | **Method** |
|---|---|
| Rivers | Inflows from river sources are based on gauged flows from representative gauged catchments. Flows are transferred to the point of abstraction using scaling.<br><br>Gauged flows are adjusted to reflect any major upstream abstractions and discharges that could potentially impact on the water available at the point of abstraction.<br><br>A hands-off flow (HOF) condition is applied to each point of abstraction based on information published in the appropriate Catchment Abstraction Management Strategy (CAMS) and from discussion with the Environment Agency (EA).<br><br>Abstraction is considered to occur all year round subject to HOF conditions above. |
| Reservoirs | Reservoirs enable the variable inflows to be balanced to meet the variations on demand.<br><br>For new reservoirs, the minimum volume required to meet the variations in demand was estimated using a water balance model. |
| Streams, ditches and brooks | Abstractions from streams, ditches and brooks have been treated in the same way as for rivers.<br><br>Intercepting streams, ditches and brooks is in effect the same as abstracting from a river directly and would be treated as such for licensing purposes. |
| Groundwaters | Aquifers were identified and yields assessed based on historic information and natural recharge. |
| Discharges | Discharges were not considered as a viable direct source the restored canal. However, consideration was given to allowing for discharges upstream of an abstraction point. Surface water drainage systems (Urban drainage) may well provide useful top-up water to the canal provided that the variations in runoff are balanced by more reliable sources and they do not lead to water quality problems. |
| Lock operations | Indicative boat numbers, based on guidance from British Waterways and the W&BCT were used to assess the sensitivity to lock operations.<br><br>Lockage was calculated based on the number of lock operations and the dimensions of a lock. It is assumed that for each lock operation a volume of water equivalent to the area of the lock multiplied by the lock rise is discharged to the lower pound. |
| Evaporation and Transpiration | Potential evapotranspiration (PET) for a grass reference crop was obtained from the Met Office Rainfall Evaporation Calculation System (MORECS). The PET was converted to the open water evaporation rate (Eo) using a monthly factor. |
| Leakage, seepage and percolation | Estimates of total losses were based on general values for restored canal provided by British Waterways and estimates based on previous studies.<br><br>Seepage rates were estimated based on the results of previous studies and an assessment of the underlying geology. |
| Abstraction and water sales | Not relevant for this study. |
| Feeds to other waterways and watercourses | While there are no direct feeds from the canal to other waterways it was assumed when water exceeds the capacity of a section it is either discharged to an adjacent section or lost from the canal system.<br><br>It is assumed that water discharged from the terminal locks is returned to the canal by back pumping. |

**Table 3.2 - Water resource methodology**

Section 6 describes the assessment of the water balance of the canal in detail. A daily water balance model was developed to enable a range of supply and demand scenarios to be tested. The use of a daily time step is important to allow the hands-off flow (HOF) constraints to be applied and to permit an accurate analysis of the level of service. Monthly time steps are sufficient to assess the overall water balance but do not yield sufficient information on the performance of the canal.

The period for which the assessment was carried out was based on the available records of gauged flow and rainfall and the need to capture the important low flow events for the potential river sources. The period 1974 to 2006 was selected as it was common to all gauging data and because the period includes the important low flow periods of 1975/76 and 1989/90.

For modelling purposes the canal was divided into four sections: the Western Mainline, Summit, Eastern Mainline and the NWC (Figure 3.1 a-c); each section containing a number of pounds. The model was developed to allow water to be conveyed from one section to another in order to represent by-pass flow and back pumping. The options for water resources are discussed in detail in Section 7 (These included by-pass flows, back pumping and storage reservoirs).

The options identified in this study should be regarded as indicative as they are based largely on a desk-based assessment with additional qualitative information gathered during two field visits. The Brief for this study did not include for any field measurements of river flows or water quality. The assessment of potential reservoir sites in particular is indicative as they have been based on map-based information and suggestions from the W&BCT.

Section 7 also presents an engineering appraisal for the most promising option. The appraisal considers the likely size and configuration of the proposed solutions and uses unit costs based on Grontmij experience to build up indicative construction and operation costs.

The outline environmental appraisal in Section 8 is a desk-based assessment of the potential impact of the proposed water resource solutions on sensitive habitats and species. This is an indicative study at this time and aims to identify potential issues that may require more study were any of the options to be progressed.

## 3.2 Stakeholder Liaison

The project has progressed through liaison with the Project Steering Group and liaison with individual stakeholders as required. The response of stakeholders to any proposed water resource solutions will be an important factor in the ultimate success of the Trust in restoring the canal. With respect to water resources the key stakeholder is the Environment Agency (EA) who regulate abstractions and discharges. Any strategy must be viable from a regulatory perspective before other issues are considered. Therefore, the focus of the initial stakeholder liaison has been to satisfy any water resource concerns of the EA.

Early consultation with stakeholders has largely been through meetings, telecoms and correspondence. This approach has been effective in explaining the purpose of the study and as a means of exploring specific issues and concerns.

A stakeholder meeting was held on 2nd February to present the options for the NWC. This meeting was successful in gaining general agreement to the approach and the preferred options. A stakeholder meeting was not held for the main canal as it is was felt to be too early in the restoration process and individual stakeholder meetings were felt to be more effective to explore issues in depth.

The stakeholders who have been contacted to date are given in Table 3.3 below.

| Stakeholder | Issue |
|---|---|
| W&BCT | Background information, reference documents, design standards, local information. |
| North Wiltshire District Council | Maps of the CCW, to approve data requests to the Environment Agency |
| Environment Agency Thames Region and South West Region | Data requests, discussion of water resource regulation and conservation issues |
| British Waterways | Standards for restored canal, typical values for restored canals, guidance on method. |
| Swindon Borough Council | Information on Coate Water Reservoir |
| Natural England | Information on Coate Water Reservoir |
| Thames Water plc | Information on the Upper Thames Major Resource Development |

**Table 3.3 - Stakeholder liaison**

# 4 SOURCES

## 4.1 Introduction

Potential sources have been identified through a review of previous studies, a review of map-based information, a discussion with the W&BCT and a discussion with the EA and other stakeholders.

## 4.2 River Sources

A number of minor water courses are identified by Dalby as original sources of the canal. These sources were originally selected on the basis of their proximity to the canal route and the constraints imposed by existing water users (primary mill owners and canal operators). They were not solely selected on the basis of their hydrological yield.

Scott Wilson (1998) considered the impact on existing licensed abstractions and proximity to the canal route to identify catchments with the potential for abstraction and storage.

For this study, catchments which are crossed by the canal were identified and treated as potential sources. Smaller sub-catchments were grouped together into catchments where catchment characteristics are similar and where they lie within in the same Water Resource Management Unit (WRMU) as defined in the appropriate Catchment Abstraction Management Strategy (CAMS). These catchments are listed in Table 4.3 and shown in Figure 4.1; Appendix 1.

| ID | Name | Catchment Source at Canal Intersection | Description | Issues | Data | CAMS Status | Comments |
|---|---|---|---|---|---|---|---|
| 1 | Kennet and Avon Canal | At canal's western terminus | Draw water directly from the Kennet and Avon Canal and use back pumping to transfer to higher pounds. | It is known that the water resources of the Kennet and Avon canal are limited and that British Waterways has previously signalled concern over any transfer of resource to the Wilts & Berks Canal. The operation of the canal has been raised by stakeholders as one of six "prime concerns" for the overall resource assessment management (RAM) results and CAMS. | | | This is not considered in the water resource analysis |
| 2 | Semington Brook | HA53-01 | Chalk and Greensand aquifers are the source of spring flows to the headwater of Semington Brook. The middle reaches of the Semington Brook flow over areas of Kimmeridge clay and Ampthill Clay before it crosses a small outcrop of Corallian at its confluence wit he Summerham Brook. The lower reaches meander over Oxford Clay and Kellaway Beds before the confluence with the River Avon below Melksham. Soils in these latter areas are slowly permeable, loamy and clayey. The river includes the Worton Stream, Poulshot Stream, Summerham Brook and Milebourne Stream. There is limited urbanisation, which includes the town of Devizes, with the dominant land use being agriculture including arable production. | The Kennet and Avon Canal abstracts water from this catchment (unlicensed). Large surface water abstraction in the upper reaches of the river ( including the feed for the Kennet & Avon Canal from the Summerham Brook and a tributary of Semington Brook) as well as numerous small abstractions (see section 2.3.1 of the Bristol and Avon CAMS). | The EA maintain a gauging station at Semington. The record commenced in October 1953.The EA also maintains 4 rain gauges in the catchment | WRMU 7 (Semmington Brook), Assessment Point 1: No water available | "No water available" is the sustainable limit of a WRMU and implies that there is enough water to meet the needs of the environment and no resource recovery is required. Licences will continue to be granted until the WRMU reaches the boundary of "no water available" |

| ID | Name | Catchment Source at Canal Intersection | Description | Issues | Data | CAMS Status | Comments |
|---|---|---|---|---|---|---|---|
| 3 | Avon Tributary | HA53-07-01 | A small tributary with a catchment size of 8.5 $km^2$ entering the River Avon north of Melksham with the headwaters rising to the north of Chittoe. | | Ungauged catchment | WRMU 2 (Bristol Avon), Assessment Point 5: No water available | "No water available" is the sustainable limit of a WRMU and implies that there is enough water to meet the needs of the environment and no resource recovery is required. Licences will continue to be granted until the WRMU reaches the boundary of "no water available" |
| 4 | River Marden | HA53-10-1 | A major tributary entering the Avon near Chippenham. It includes the headwaters above Calne and the tributaries of the Abberd Brook and Cowage Brook. The CAMS reports that its quality varies along its length. The upper reaches flow over Gault outcrop before incising rocks and reaching the Oxford Clays. These clays are relatively resistant and impermeable and so the river flows on an alluvium bed. The upper reaches exhibit the characteristics of a chalk stream and the river is ecologically significant for this reason. It is generally of "good" quality although stretches vary. There is limited urbanisation, which includes the town of Calne, the dominant land use is agriculture. | Licences for two large surface water abstractions in the upper reaches plus a small number of small licences in the middle and lower reaches. | The EA maintain a gauging station at Stanley. These records commenced on January 1970. The EA also maintains 2 rain gauges in the catchment. | WRMU 7 (Semmington Brook), Assessment Point 2: No water available | "No water available" is the sustainable limit of a WRMU and implies that there is enough water to meet the needs of the environment and no resource recovery is required. Licences will continue to be granted until the WRMU reaches the boundary of "no water available" |
| 5 | Cade Burna | HA53-11-1 | A small catchment of $6km^2$ draining to the River Avon north of Chippenham and upstream of the confluence with the River Marden. It is a relatively impermeable catchment as it flows over Oxford Clay. | | | WRMU 2 (Semmington Brook), Assessment Point 5: No water available | "No water available" is the sustainable limit of a WRMU and implies that there is enough water to meet the needs of the environment and no resource recovery is required. Licences will continue to be granted until the WRMU reaches the boundary of "no water available" |

| ID | Name | Catchment Source at Canal Intersection | Description | Issues | Data | CAMS Status | Comments |
|---|---|---|---|---|---|---|---|
| 6 | Brinkworth Brook | HA53-13-3 | The river is likely to be spring fed from the Chalk and Upper Greensand outcrops in the West. The catchment is largely impermeable as it flows over beds of Kimmeridge Clay and Oxford Clay. In its upper reaches there is a small outcrop of Corallian. | | | WRMU 2 (Semmington Brook), Assessment Point 5: No water available | "No water available" is the sustainable limit of a WRMU and implies that there is enough water to meet the needs of the environment and no resource recovery is required. Licences will continue to be granted until the WRMU reaches the boundary of "no water available" |
| 7 | River Ray | HA39-02-9 | The River Ray drains a catchment of about 80km$^2$ that rises south of Wroughton and flows northwards to join the Thames at Water Eaton about 1.5km to the east of Cricklade. The surface geology of the catchment is predominantly Kimmeridge Clay south of Swindon and Oxford Clay north of Swindon with outcrops of corallian limestone around Moulden Hill and drift deposits that generally follow the course of the river. The river flows adjacent to the canal between Purton Bridge and Moulden Hill Country Park (MHCP). The river crosses the canal, flows through the park and then flows parallel to the canal some 1km to the east. | The CAMS reports that low flows are augmented by discharges and that the ecology has adapted to these augmented low flows. Dry weather flow consent data provided in the CAMS indicates that flows are augmented by 32.6 Ml/d. However, the Ray is largely a clay catchment with a relatively rapid response to rainfall.<br><br>The EA has indicated that the upper reaches of the River Ray, upstream of Chiseldon STW, are ecologically sensitive. | EA gauges flow at Water Eaton just upstream of the confluence with the Thames. | WRMU 2 (Rivers Ray, Cole, Ock and Ginge Brook), Assessment Point 5; No water available. | Technically the status has been overridden to “no water available” due to the over-abstracted nature of the lower Thames. |
| 9 | Wroughton Brook | HA39-02-16-1, HA39-02-18-1 & HA39-02-18-2 | A tributary to the River Ray. There may be potential to develop winter storage in this catchment south of the M4 | CAMS restrictions | | WRMU 2 (Rivers Ray, Cole, Ock and Ginge Brook), Assessment Point 5; No water available. | Technically the status has been overridden to “no water available” due to the over-abstracted nature of the lower Thames. |

| ID | Name | Catchment Source at Canal Intersection | Description | Issues | Data | CAMS Status | Comments |
|---|---|---|---|---|---|---|---|
| 10 | River Key | HA39-01-1 | The River Key drains an area of 29km$^2$. The river rises to the west of Purton and flows north-east to its confluence with the Thames at Cricklade. The catchment is underlain by Oxford Clay with alluvial deposits following the course of the river.<br><br>The River Key crosses the Wilts & Berks canal via an aqueduct about 1km south of Cricklade. It then flows parallel to the proposed canal route some 300m to the east until it passes under Swindon Road just east of the canal terminus. | | Ungauged but similar in natural character to River Ray | The River Key was not assessed as part of CAMS, so doesn't have a resource status and is not included in a WRMU | Technically the status has been overridden to "no water available" due to the over-abstracted nature of the lower Thames. |
| 11 | River Cole | HA39-03-1 to HA39-03-8 | The River Cole flows from its source in Swindon northwards to its confluence with the River Thames near Lechlade. The River Cole receives flows from tributaries, e.g. Tuckmill Brook, draining the chalk escarpment of the Thames basin. | The EA has indicated that there is a local low flow issue with respect to Odstone Brook and that flow constraints on any new licence would be likely. | The EA operate a gauging station at Inglesham | WRMU 2 (Rivers Ray, Cole, Ock and Ginge Brook), Assessment Point 4; No water available. | Technically the status has been overridden to "no water available" due to the over-abstracted nature of the lower Thames. |
| 12 | River Ock | HA39-04-1 to HA39-04-10 | The River Ock flows from its 3 head springs at Little Coxwell, Compton Beauchamp and Woolston for 38 km along the Vale of White Horse to its confluence with the River Thames at Abingdon. It falls 60m from source to mouth and flows over the Corallian Series receiving contributions from a number of spring-fed tributaries. | The EA has indicated that there are low flow issues associated with the upper River Ock. Some of the springs are used for local supply. | The EA operate a gauging station at Abingdon | WRMU 2 (Rivers Ray, Cole, Ock and Ginge Brook), Assessment Point 3; No water available. | "Water available" at local scale but overridden to "no water available" due to the over-abstracted nature of the lower Thames. |

**Table 4.1 - River Sources**

### 4.2.1 CAMS and Resource Availability

The abstraction from potential surface water sources is constrained by rules set out in the relevant CAMS documentation and through consultation with the EA. These are summarised below. A description of the regulatory issues pertaining to the Bristol Avon and Thames area CAMS is given in Appendix 2.

**Bristol Avon CAMS**

This CAMS governs abstraction from potential surface water sources supplying the Western Mainline canal section. The Semington Brook catchment and the Marden catchment all lie within WRMU 7 whereas the Avon tributaries including Cade Burna and Brinkworth Brook all lie within WRMU 2. Both of these WRMUs have a status of "no water available".

The EA CAMS state that licences will continue to be issued until the boundary of 'no water available' is reached. Once the boundary is approached it is unlikely that new licences will be issued or existing licences increased.

For the purpose of this study a precautionary approach was taken to resource availability. The following assumptions were adopted:

- From the CAMS technical document and from discussions with EA South West it was established that there is a year round HOF of the natural flow exceeded for 76 percent of the time ($QN_{76}$) at Bathford gauging station on the River Avon (AP5). For the purposes of this study a local HOF of $QN_{76}$ has been assumed at the Semington Brook at Semington and River Marden at Stanley gauging stations also. Local issues on the reaches used for abstraction may mean the HOF will differ from this.
- The dry weather flow consented discharges from the sewage treatment works (STW) would be treated as HOF on the premise that these flows sustain summer low flows and\or the dependent ecology.
- A target take of 10% of the natural flow has been adopted for flows above the $QN_{76}$ threshold. This parameter is not used as a physical constraint upon abstraction but as a target to guide the abstraction strategy. The target is consistent with the lower limit as recommended by the Water Framework Directive UK Technical Advisory Group (WFD UK TAG, 2006).

Table 4.2 shows the local naturalised HOF and major STW discharges and major abstractions adopted from the Bristol Avon CAMS and from consultation with the local EA office at the gauging stations used in this study.

| Gauging Station | Local HOF $QN_{76}$ (Ml/d) | Major STW Discharges (Ml/d) | Major Abstractions (Ml/d) |
|---|---|---|---|
| Semington Brook at Semington | 47.3 | 6.33 | 3.84 |
| Marden at Stanley | 32.7 | 5.15 | 1.94 |

**Table 4.2 - Local HOF, Major STW Discharges and Major Abstractions assumed in this study.**

### Vale of White Horse and Thames Corridor CAMS

These CAMS documents pertain to the resources supplying the Summit, Eastern Mainline and North Wilts canal sections.

The Rivers Ray, Key, Cole, Ock and Ginge Brook are grouped into WRMU 2 in the Vale of White Horse CAMS (VWHCAMS). The status of WRMU 2 is "water available", however, this is overridden by the status of the downstream assessment point on the Thames at Kingston which is classified as "over-abstracted". Hence, WRMU 2 is given a status of "no water available".

The VWHCAMS states that any abstraction within WRMU2 would be subject to a local HOF condition and a HOF condition of the $Q_{50}$ at Kingston (Thames Corridor CAMS). This was confirmed at a meeting with the Thames Region of the Environment Agency (EA). Furthermore, it was confirmed by the EA that any local HOF condition would be assessed on a case by case basis.

Again for the purpose of this study a precautionary approach was taken to resource availability and HOFs. The following assumptions were adopted:

- It is assumed that the dry weather flow consented discharges from the STW would be treated as HOF on the premise that these flows sustain low flows and\or the dependent ecology.
- From discussions with the EA and taking guidance from the VWHCAMS Technical Document, it is assumed that water is available locally with a HOF of $QN_{95}$.
- If the gauged flow at Kingston on the River Thames is below $Q_{50}$ (1780 Ml/d) then no abstraction will be allowed. This over-rides the local HOF condition.
- A target percentage take (for flows above HOF) of 10% was adopted (note that this target was not used as physical constraint to abstraction). This is precautionary and is consistent with the lower limit as recommended by the Water Framework Directive UK Technical Advisory Group (WFD UK TAG, 2006).

Table 4.3 shows the local naturalised HOF, the HOF at Kingston on Thames and the major STW discharges and major abstractions adopted for this study from the VWH CAMS and from consultation with the local EA office.

| Gauging Station | Local HOF $QN_{95}$ (Ml/d) | Thames Corridor CAMS $Q_{50}$ at Kingston (Ml/d) | STW dry weather consented discharges (Ml/d) |
|---|---|---|---|
| Ock at Abingdon | 20.7 | 1780 | 6.81 |
| Cole at Inglesham | 7.5 | 1780 | 2.0 |
| Ray at Water Eaton | 6.8 | 1780 | 32.6 |

**Table 4.3 – HOFs, Major STW Discharges and Major Abstractions assumed in this study.**

## 4.3 Groundwaters

The objective of this study is to review the options for the use of groundwater to supply water to the Wilts & Berks canal, which runs through the sub-catchments of Rivers Ock, Cole, Ray, forming part of the Thames Catchment, and the Rivers Upper Avon, Marden and Lower Avon, which form part of the Bristol Avon catchment. This section considers the hydrogeology of both the major and minor aquifers in the immediate vicinity of the canal route and possible issues associated with groundwater resources development.

### 4.3.1 Geology and Hydrogeology

The geology of the area, together with the proposed canal route is summarised in Table 4.4 below and shown in Figure 4.2a-d; Appendix 1.

| **Stratigraphy** From BGS Maps 253, 266, 252, 265 | | | **Average Thickness** | **Lithology** |
|---|---|---|---|---|
| **Group** | **Formation** | **Member** | **(m)** | |
| Chalk | Upper Chalk | Undivided | 125 | Soft white chalk with numerous flints |
| | Middle Chalk | Undivided | 58 | Chalk with some flints |
| | Lower Chalk | Zig Zag Chalk | 50 | Chalk with plenus marls at top |
| | | West Melbury Marly Chalk | | Marly chalk |
| Upper Greensand | Upper Greensand | Melbury Sandstone | 10-50 | Glauconitic sandstone |
| | | Boyne Hollow Chert | | Sand with common chert |
| | | Shaftsbury Sandstone | | Glauconitic sand and sandstone |
| | | Cann Sand | | Glauconitic sandstone |
| Gault | Gault | Undivided | 27-60 | Mudstone with thin basal pebble bed |
| Portland | Portland Beds | Undivided | 8 | Sand and limestone |
| | Kimmeridge Clay | | 53-152 | Mudstone |
| Corallian | Upper Corallian | Red Down Sand/ Ironsand | 0-5 | Sand and sandstone |
| | | Red Down Clay | 0-21 | Mudstones, siltstones |
| | | Coral Rag | 5-15 | Limestones |
| | Lower Corallian | Undivided, except for Highworth Limestone | 21 | Intercalated mudstones, siltstones, silts, sandstones, sands and limestone |
| | Oxford Clay | Undivided | 170-215 | Mainly clays and shales. Some sand lenses |
| | Kellaways Beds | Kellaways Sand | 3-4 | Sands and silty mudstones. |
| | | Kellaways Clay | 25-60 | Clay |
| Great Oolite | Cornbrash | Undivided | 5-10 | Fissured limestones and marls |
| | Forest marble | Undivided | 20-30 | Clay, shelly and oolitic limestone |
| | Great Oolite | Undivided | 20-40 | Oolitic limestone |

**Table 4.4 - Solid geology underlying the tributaries catchments of the River Thames and Avon.**

For much of its length the canal route runs over low permeability clays, which have little/no potential for groundwater abstractions. However the major aquifers of the Chalk, Lower Greensand and Great Oolite outcrop or are encountered at depth in the vicinity of the canal route. The minor aquifers encountered include permeable Drift (primarily river terrace gravels), the Upper Greensand, Corallian Group (and in particular the Coral Rag), and Kellaways Sand Member. A sand unit within the Kimmeridge Clay and the Kellaways Sand may contribute additional resources.

The bedrock aquifer units that could potentially be developed to supply the canal are described below in stratigraphical order together with drift aquifers, while their location and yield, water quality and environmental constraints are summarised in Table 4.6. The resource development opportunities and constraints are based on information provided in the BGS aquifer properties manuals (BGS, 1997 and 2000), the CAMS (EA, 2004, 2005 and 2006), an earlier feasibility report (Scott Wilson, 1998), correspondence held by, and discussions with canal trust personnel, as well as from discussions with staff from the EA Thames and South West regions.

A list of abstraction boreholes for which the BGS hold records on their Geoindex website is given in Table 4.5, together with the principal aquifer unit(s) encountered. The locations of these boreholes are shown on geological maps given in Figures 4.3a-d; Appendix 1. It should be noted that many of these boreholes will not be currently licensed for abstraction and it is likely that a significant number of them are no longer used for supply.

**Chalk and Upper Greensand**

Chalk and Upper Greensand outcrop to the south of the canal route between Swindon and Wantage. The strata dip to the south southeast and therefore do not subcrop below the route of the canal itself.

The Chalk comprises a soft, pure, micro-porous limestone that is largely composed of fragmented planktonic calcareous algae (coccoliths) with some layers of flint. It is considered to be a major aquifer, with groundwater flow primarily through fractures. As a consequence, flow can be rapid and flow patterns are governed by fracture geometry, connectivity and size. Only the top 50 - 60m of the Chalk is deemed productive as the fracture networks are very poorly developed below this depth. Local aquifer transmissivities range from 0.5 – 8000$m^2$/d, but average at approximately 570$m^2$/d in the vicinity of the canal, with higher values found in the river valleys. Specific yield (unconfined storage) and storativity (confined storage) are estimated at between 0.01-0.03 and $10^{-1}$ – $10^{-3}$ respectively (BGS, 1997). In this area, the majority of the Chalk outcrop consists of Lower Chalk, of which the bottom 30m comprises low permeability Chalk Marl. Yields of up to 4000$m^3$/d have been recorded in the Lower Chalk.

The Upper Greensand consists of glauconitic, calcareous, generally fine-grained sandstone. It is generally in hydraulic continuity with the overlying Chalk, although the connection is poor in the catchments of the rivers Cole and Ock due to the presence of the low permeability Chalk Marl. Flow within the Upper Greensand is both intergranular and through fractures, and large lithological variations result in hydrogeological complexity. Direct recharge is limited by the restricted outcrop area and most recharge comes from leakage from the overlying Chalk. The Upper Greensand is most productive further to the east in Oxfordshire, and supports only a few springs and private abstractions in proximity to the canal route, where it is more clayey. No transmissivity and storage data are available for the Upper Greensand in this area.

Groundwater flow in the Chalk and Upper Greensand is to the southeast, flowing towards the Rivers Kennet and Lambourn. However groundwater highs on the Marlborough Downs (south of Swindon) produce some localised flow to the north and north-west, resulting in a line of springs along the edge of the downs.

### Lower Greensand

The Lower Greensand comprises a complex series of clays and sands of variable thickness and with varying degrees of cementation. The Lower Greensand outcrops to the east of the canal route in the Marden Catchment and to the north of the route around Uffington and Baulking, as well as subcropping beneath river terrace deposits further east at Grove. It is considered to be a major aquifer and despite the small outcrop area, high storage and generally good quality water mean that it is a reliable water resource, particularly in southeast England. However, BGS (1997) indicates that it is not considered to provide a significant resource in this area, although BGS records show that there are (or were) a few abstractions from the aquifer in proximity to the canal route. No aquifer properties data are available for the area (BGS (1997)).

### Portland and Purbeck Groups

The Portland and Purbeck beds comprise limestone and sandstone/sand respectively and are present as small, isolated outliers (younger rocks surrounded by older rocks) at old Town, Swindon and to the southeast. They are underlain by, and probably in hydraulic continuity with a sandy unit, which is stratigraphically located near the top of the Kimmeridge Clay, a predominantly argillaceous sequence. BGS (2000) does not give any details about the hydraulic properties of these outliers, but the resource potential will be limited by the small outcrop areas. During a site visit in December 2006, springs were observed issuing from the base of the sandy unit in Old Town, Swindon, and a flow rate of 80 – 170m$^3$/d was estimated. It is also possible that the sandy unit contributes some resource to the Portland Beds around Bourton in the Cole catchment.

### Corallian Group

The Corallian group comprises a series of minor aquifers of which the Coral Rag is considered to be the principal aquifer unit (EA, pers. comm.), although BGS records indicate that there are also a number of private abstractions from the Red Down Sand. The outcrop area of the group is fairly extensive, extending from Lyneham, southwest of Swindon, through Wootton Bassett, northwest Swindon and Shrivenham, to Stanford in the Vale and Charney Bassett further to the east. The strata dip gently to the south, becoming confined by the overlying Kimmeridge Clay along the central stretch of the canal route, and by the Kimmeridge and Gault clays further east. The Corallian also outcrops to the east of the southern stretch of the canal route, to the east of Melksham and Lacock, and around Calne in the Marden catchment, although the canal route itself crosses only the older Oxford Clay in this area.

Transmissivities typically range from 150 -1100m$^2$/d with specific yields of between 0.02 – 0.08m$^3$/s. The high levels of down faulting in the Swindon area could locally hydraulically isolate the confined aquifer from the areas of outcrop, restricting flow and yield. Water quality is known to deteriorate a few km down dip into the confined aquifer, with increased salinity due to the presence of connate water. Redox changes mean that concentrations of other parameters can increase, in particular iron, although the position of the mixing zone between the two water quality types will depend on both recharge to and abstraction from the aquifer units.

**Kellaways Formation**

The Kellaways Sand Member of the Kellaways Formation comprises 3 to 4m of fine-grained sands and calcareous sandstones, but is generally confined by the Oxford Clay, a thick sequence of clays and shales. Outcrops are limited to small, isolated areas to the east of the Upper Avon and along Brinkworth Brook and recharge may be further restricted by faulting, which may locally hydraulically isolate the confined aquifer from the outcrop. Nevertheless, significant yields have been reported between Seagry and Christian Malford (Upper Avon Catchment), although to the north yields reduced to less than 85m$^3$/d with increasing salinity.

**Great Oolite Group**

The Great Oolite Group comprises between 80 and 90m of oolitic and shelly limestones with intervening marls, mudstones and clays. The group is considered by BGS (1997) to be a major aquifer and principal aquifer units include the Cornbrash and Great Oolite formations, although the basal part of the Forest Marble (26 – 28m thick at Malmesbury) can also be water bearing. Along the southern stretch of the canal route, this group is confined by the Oxford Clay, although it outcrops extensively to the west in the Cotswolds. Groundwater flow is primarily through fractures and as a consequence yield is strongly dependent on fracture geometry, connectivity and size. There are a number of Great Oolite abstractions around Melksham and Lacock, where transmissivities of 750 - 1500m$^2$/d and a single storativity value of 3.8 x $10^{-3}$ have been reported (BGS, 1997), but yields are likely to decrease sharply further north and east as the aquifer becomes increasingly confined. Furthermore, extensive faulting in the area may hydraulically isolate parts of the confined aquifer from the recharge areas to the west. Nevertheless, BGS records indicate that one or two abstraction boreholes have been drilled adjacent to the canal north of Lackock, at Foxham and Dauntsey Lock, near Bradenstoke.

**Drift**

Potential resources may be available from alluvial sands and gravels in the river valleys, for example around Melksham and Lacock, and from river terrace deposits in the Ock catchment to the north of Wantage. However, given that these are likely to be in direct hydraulic continuity with surface water courses (for example Letcombe Brook north of Wantage), it is likely that the EA would apply the same licensing restrictions with respect to low flows as to direct surface water abstractions.

Yields and water quality could be expected to be good from these drift aquifers, but they are susceptible to pollution.

There are currently 73 licensed abstractions within 500m of the canal route. At this time, it is unknown which abstractions are operational and unfortunately little recent yield data is available. In some areas artesian conditions can occur, and springs can be found at various locations within the local area.

Old borehole records, from 1898, at Rodbourne Cheney borehole (SU 1438 8710), indicate a yield from the Corallian Strata of approximately 220m$^3$/day. An 8 hour pumping test carried out at Blunsdon Abbey (SU 1378 8978) in 1952, provided a yield from the Corallian Strata of 134m$^3$/day and further tests in 1959 give a yield of between 65 m$^3$/day and 164m$^3$/day. Both of these wells were located in the unconfined Corallian Strata.

The BGS map indicates that the Great Western Railways boreholes intersect the Kellaway and Great Oolite minor aquifers, although these boreholes have now been abandoned due to lack of water and poor water quality. These boreholes access water from both the confined Corallian and confined Great Oolite strata. Records from these wells date back to 1885, suggest that the majority of the water drawn from these boreholes is from the overlying Corallian beds where the water quality is higher. Water from within the Kellaways Sand and Great Oolite aquifers was highly saline and rose to the pumping level over time at times of pump operat rates of 109m$^3$/day.

A list of abstraction boreholes in the area is given in Table 4.5 below, showing both the location and the probable main water producing strata for each borehole.

| Catchment | Name | Easting | Northing | Depth | Year Drilled | Main water bearing units | ID no. on Geological Map |
|---|---|---|---|---|---|---|---|
| Cole | Parsonage Fm. Chiseldon | 418940 | 180120 | 41.2 | 1902 | Chalk / Upper Greensand groups | HA39-03-AB1 |
| Cole | New Farm Chiseldon | 419100 | 179100 | 30.5 | | Chalk / Upper Greensands groups | HA39-03-AB2 |
| Cole | Burdrop Farm 1&2 | 417000 | 179700 | 37/47 | | Chalk Group | HA39-03-AB3 |
| Cole | Chiseldon 1&2 | 417630 | 179240 | 7 | 1990 | Chalk Group | HA39-03-AB4 |
| Cole | Foxhill Estate | 420880 | 181560 | 6.4 | | Chalk Group | HA39-03-AB5 |
| Cole | Wanborough Plain | 421700 | 180680 | 79 | 1982 | Chalk Group | HA39-03-AB6 |
| Cole | Martin's Field | 419210 | 179940 | 26.8 | | Chalk/Greensands groups | HA39-03-AB7 |
| Cole | Foxhill Stud Farm | 422700 | 181700 | 60.2 | | Chalk/Greensands groups | HA39-03-AB8 |
| Cole | Holkham Garage | 423280 | 188460 | 24.4 | 1945 | Corallian Group | HA39-03-AB9 |
| Cole | Acorn Way | 423370 | 188550 | 23.2 | 1934 | Corallian Group | HA39-03-AB10 |
| Cole | Bourton | 423750 | 186600 | 81.5 | | Corallian Group | HA39-03-AB11 |
| Cole | Broadleaze Farm | 426000 | 189500 | 9.1 | | Corallian Group | HA39-03-AB12 |
| Cole | Galleyherns Farm Shrivenham | 426800 | 188800 | 50.9 | 1989 | Corallian Group | HA39-03-AB13 |
| Cole | Galleyhearns Farm | 426890 | 188780 | 34.4 | | Corallian Group | HA39-03-AB14 |
| Cole | Upper Wanborough | 421210 | 181970 | 50.3 | 1932 | Upper Greensand | HA39-03-AB15 |
| Cole | Callis Hill | 421630 | 183330 | 18.3 | | Upper Greensand | HA39-03-AB16 |
| Cole | Home Farm | 422100 | 183400 | 18.3 | | Upper Greensand | HA39-03-AB17 |
| Cole | Foxhill | 423450 | 181130 | 78.3 | | Upper Greensand | HA39-03-AB18 |

| Catchment | Name | Easting | Northing | Depth | Year Drilled | Main water bearing units | ID no. on Geological Map |
|---|---|---|---|---|---|---|---|
| L. Avon | Melksham No 1 | 390880 | 164650 | 133.4 | 1975 | Great Oolite | HA53-LA-AB1 |
| L. Avon | Lacock No 1 | 390880 | 168710 | 55 | 1971 | Great Oolite | HA53-LA-AB2 |
| L. Avon | Market Gardens Lacock | 391090 | 168130 | 30.2 | 1932 | Great Oolite | HA53-LA-AB3 |
| L. Avon | Melksham Spa | 391300 | 162700 | 107.1 | 1815 | Great Oolite | HA53-LA-AB4 |
| Lower Avon | Lacock No.3 | 389760 | 169090 | 48.7 | 1974 | Great Oolite | HA53-LA-AB5 |
| Lower Avon | Co-Op Society Depot, Melksham | 389930 | 164420 | 158.5 | 1932 | Great Oolite | HA53-LA-AB6 |
| Lower Avon | 5 Spa Road Melksham | 390100 | 164810 | 50.3 | | Great Oolite | HA53-LA-AB7 |
| Lower Avon | Wilts United Dairies Melksham | 390180 | 164100 | 82.3 | | Great Oolite | HA53-LA-AB8 |
| Lower Avon | Melksham Power Station | 390400 | 163700 | 76.5 | 1922 | Great Oolite | HA53-LA-AB9 |
| Lower Avon | Market Gardens Lacock | 391230 | 167920 | 3.7 | | River Terrace Deposits | HA53-LA-AB10 |
| Marden | Lacock No 2 | 392050 | 169260 | 58.4 | 1971 | Great Oolite | HA53-10-1 |
| Marden | Foxham | 398100 | 177200 | 128 | | Great Oolite | HA53-10-2 |
| Marden | Peterborough Arms Dauntsey Lock | 399610 | 180160 | 79.6 | 1926 | Great Oolite | HA53-10-3 |
| Ock | Paddock Nursery | 427540 | 189110 | 45.7 | 1980 | Corallian Group | HA39-04-1 |
| Ock | Church Farm Baulking | 432220 | 190630 | 97.6 | 1969 | Corallian Group | HA39-04-2 |
| Ock | Challow | 434710 | 190280 | 106.7 | 1932 | Corallian Group | HA39-04-3 |
| Ock | Petwick Farm, | 435490 | 190700 | 97.5 | | Corallian Group | HA39-04-4 |
| Ock | Hill House, Challow | 436340 | 189900 | 110.6 | 1909 | Corallian Group | HA39-04-5 |
| Ock | Challow Marsh Farm | 437250 | 190100 | 76.8 | 1896 | Corallian Group | HA39-04-6 |
| Ock | Upper Circourt Farm | 437590 | 191060 | 50.9 | 1899 | Corallian Group | HA39-04-7 |
| Ock | R A F, Grove | 439270 | 189860 | 61 | 1941 | Corallian Group | HA39-04-8 |
| Ock | Salvage Depot | 445210 | 191690 | 91.4 | 1940 | Corallian Group | HA39-04-9 |
| Ock | Steventon | 445280 | 192650 | 56.7 | 1933 | Corallian Group | HA39-04-10 |
| Ock | Drayton | 447840 | 194400 | 61.6 | 1929 | Corallian Group | HA39-04-11 |
| Ock | Wingfield Bowles | 448740 | 194180 | 217.9 | 1924 | Corallian Group | HA39-04-12 |
| Ock | Sutton Courtnay P.S. | 449890 | 193470 | 61.9 | 1921 | Corallian Group | HA39-04-13 |
| Ock | The Manor House Sutton Courtenay | 450270 | 194150 | 47.2 | 1909 | Corallian Group | HA39-04-14 |
| Ock | Sutton Courtenay | 450280 | 193990 | 51.2 | 1905 | Corallian Group | HA39-04-15 |
| Ock | Culham Manor 1-3 | 450300 | 195000 | 39.6 | 1925 | Corallian Group | HA39-04-16 |
| Ock | Culham House | 450410 | 195170 | 44.5 | 1939 | Corallian Group | HA39-04-17 |
| Ock | Home Farm Culham | 450550 | 195120 | 38.6 | 1938 | Corallian Group | HA39-04-18 |
| Ock | Cowleaze Farm | 428240 | 188860 | 41.8 | | Lower Greensand | HA39-04-19 |
| Ock | Manor Farm Uffington | 430650 | 189480 | 51.8 | 1999 | Lower Greensand | HA39-04-20 |
| Ock | Church Farm Baulking | 431800 | 190650 | 24.4 | | Lower Greensand | HA39-04-21 |
| Ock | Woodhill Farm | 438220 | 189860 | 80.5 | 1923 | Lower Greensand | HA39-04-22 |

| Catchment | Name | Easting | Northing | Depth | Year Drilled | Main water bearing units | ID no. on Geological Map |
|---|---|---|---|---|---|---|---|
| Ock | South Oxfordshire Equestrian Centre | 443870 | 192270 | 6.1 | | Lower Greensand | HA39-04-23 |
| Ock | Godfrey's Farm | 440030 | 189130 | 4.9 | 1935 | Drift | HA39-04-24 |
| Ock | Picked Mead | 444520 | 192570 | 5.5 | 1978 | River Terrace Deposits | HA39-04-25 |
| Ock | Drayton | 448090 | 193450 | 10 | | River Terrace Deposits | HA39-04-26 |
| Ock | Brook Farm | 448800 | 193560 | 6.1 | | River Terrace Deposits | HA39-04-27 |
| Ock | Windyridge | 448820 | 193780 | 1.8 | | River Terrace Deposits | HA39-04-28 |
| Ock | Sutton Wick | 449370 | 194350 | 2.9 | | River Terrace Deposits | HA39-04-29 |
| Ock | Lady Place Sutton Courtenay 1-7 | 450190 | 193680 | 6.1 | | Upper Greensand | HA39-04-30 |
| Ray | Prince Alexander Hosp. Wroughton | 415100 | 179200 | 70 | 1975 | Chalk Group | HA39-02-1 |
| Ray | Toot Hill Farm | 412470 | 183520 | 73.2 | | Coral Rag & Oxford Clay | HA39-02-2 |
| Ray | Railway Works (South) | 414070 | 185210 | 75 | 1885 | Coral Rag & Oxford Clay | HA39-02-3 |
| Ray | Okus Road | 414130 | 183490 | 134.2 | 1975 | Coral Rag & Oxford Clay | HA39-02-4 |
| Ray | Finebush Nurseries | 410840 | 182150 | 32 | 1990 | Corallian Group | HA39-02-5 |
| Ray | Railway Works (North) | 414070 | 185210 | 224.4 | 1885 | Great Oolite and Kellaways Sand | HA39-02-6 |
| Ray | Finebush Nurseries | 410840 | 182150 | 32 | 1990 | Kimmeridge Clay | HA39-02-7 |
| Ray | Home Farm | 425630 | 189040 | 4.6 | | Kimmeridge Clay | HA39-02-8 |
| Ray | Burderop Wood | 415860 | 180620 | 15.2 | 1940 | Upper Greensand | HA39-02-9 |
| Upper Avon | Allotment Gardens Lyneham 1&2 | 402900 | 180200 | 16/17 | 1935 | Corallian Group | HA53-UA-AB1 |
| Upper Avon | Beaufort Brewery | 407100 | 182000 | 35/42 | 1913 | Corallian Group | HA53-UA-AB2 |
| Upper Avon | Whitehall Farm Lacock 1&2 | 391600 | 169000 | 72/62 | 1972 | Great Oolite | HA53-UA-AB3 |

**Table 4.5 - Location and probable main water bearing strata of boreholes.**

| Catchment | Principal Aquifer Unit(s) | Map ID | Location | Typical BH depth (m) | Estimated Maximum Yield per Borehole | Potential Quality Issues | Potential Environmental Issues | CAMS status | CAMS Strategy for new consumptive licences |
|---|---|---|---|---|---|---|---|---|---|
| Thames, Ock | Chalk (contributions from Upper Greensand) | 1 | White Horse Hill (South of Uffington) to Wantage. The canal route in this area largely runs across Gault Clay. The overlying Chalk and Upper Greensand are absent along the route, but outcrop approximately 2km to the south. | <20m in outcrop area | 1 Ml/d. | None identified. | Impacts on chalk springs that feed tributaries of the Ock, including Uffington Brook and Letcombe Brook at East Challow. The EA has indicated that there are low flow issues associated with the River Ock. Some of the springs are used for local supply. | Vale of White Horse WRMU 2 GWMU No Water Available at Low Flows | Water may be available locally if water abstracted is returned to the catchment upstream of the Ock confluence with the Thames, as the “no water available” status at this assessment point overrides the “water available” status of the upstream catchment. No new consumptive licences groundwater hydraulically connected to rivers will be granted at low flows and certainly not without HOF conditions, although new abstractions not in hydraulic continuity may be licensed, subject to the usual licensing determination process. |
| | Upper Greensand | 2 | Compton Beauchamp, Kingston Lisle, Childrey and East Challow. (canal route runs 100 – 200m north of Upper Greensand outcrop). | No borehole records in area | 0.15Ml/d, but yield may be much less. Aquifer yield will be limited by aquifer thickness, the linear nature of the outcrop and discharge through springs that may be present at the aquifer boundary with the Gault Clay. | None identified. | Potential impact on springs and base-flow to tributaries of the River Ock, particularly Letcombe Brook at East Challow, which is perceived by the EA to have low flow issues (as is the case for the River Ock itself). | Vale of White Horse WRMU 2 GWMU No Water Available at Low Flows | Water may be available locally if water abstracted is returned to the catchment upstream of the Ock confluence with the Thames, as the “no water available” status at this assessment point overrides the “water available” status of the upstream catchment. No new consumptive licences groundwater hydraulically connected to rivers will be granted at low flows and certainly not without HOF conditions, although new abstractions not in hydraulic continuity may be licensed, subject to the usual licensing determination process. |
| | Lower Greensand | 3a | North of Uffington | 80m | 1Ml/d. Aquifer thickness and hydraulic isolation of individual aquifer units by intervening stream valleys may limit yield, although BGS records indicate a number of existing/former abstraction boreholes. There may be some hydraulic continuity with the underlying Corallian aquifer where the Kimmeridge Clay is absent. | Potentially poor water quality. Existing aquifer usage restricted due to possible high iron. | Impact on local groundwater abstractions and on base-flow to the upper River Ock. The Ock is considered by the EA to have low flow issues. | Vale of White Horse WRMU 2 No Water Available at Low Flows | Water may be available locally if water abstracted is returned to the catchment upstream of the Ock confluence with the Thames, as the “no water available” status at this assessment point overrides the “water available” status of the upstream catchment. No new consumptive licences groundwater hydraulically connected to rivers will be granted at low flows and certainly not without HOF conditions, although new abstractions not in hydraulic continuity may be licensed, subject to the usual licensing determination process. |
| | | 3b | 3-4km north east of Wantage | <20m | Aquifer is overlain by River Terrace Deposits, and is likely to receive recharge through these, although subcrop is limited. | None identified, but susceptible to surface pollution | Potential impact on base-flow to Ock tributaries and to other groundwater abstractions. | | |
| | Corallian | 4 | North of canal route around Grove. | | 0.15Ml/d. Aquifer is confined by Gault Clay and Kimmeridge Clay, and is several km down dip of outcrop area, so yields may be poor. However BGS records do show some abstraction boreholes in this area (although these could now be abandoned). | Water quality may deteriorate down dip from outcrop area. | Impact on local groundwater abstractions. | Vale ofWhite Horse WRMU 2 No Water Available at Low Flows | Water may be available locally if water abstracted is returned to the catchment upstream of the Ock confluence with the Thames, as the “no water available” status at this assessment point overrides the “water available” status of the upstream catchment. No new consumptive licences groundwater hydraulically connected to rivers will be granted at low flows and certainly not without hands off flow conditions, although new abstractions not in hydraulic continuity may be licensed, subject to the usual licensing determination process. |
| Thames, | Chalk | 5 | Odstone Hill, | | 1 Ml/d. | None identified. | Impact on chalk springs at the | White Horse | Water may be available locally if water |

| Catchment | Principal Aquifer Unit(s) | Map ID | Location | Typical BH depth (m) | Estimated Maximum Yield per Borehole | Potential Quality Issues | Potential Environmental Issues | CAMS status | CAMS Strategy for new consumptive licences |
|---|---|---|---|---|---|---|---|---|---|
| Cole | (contributions from Upper Greensand) | | Ashbury and Compton Beauchamp (Canal route runs largely over Kimmeridge Clay, 2 – 3km north or northwest of the Chalk / Upper Greensand outcrop,.) | | | | base of escarpment, Odstone Brook and on local abstractions. The EA has indicated that there is a local low flow issue with respect to Odstone Brook and that flow constraints on any new licence would be likely. | Vale of WRMU 2 GWMU No Water Available at Low Flows | abstracted is returned to the catchment upstream of the Ray/Cole confluence with the Thames, as the "over-abstracted" status of the Thames at this assessment point overrides the "water available" status of the upstream catchment. No new consumptive licences groundwater hydraulically connected to rivers will be granted at low flows and certainly not without HOFconditions, although new abstractions not in hydraulic continuity may be licensed, subject to the usual licensing determination process. |
| | Upper Greensand | 6 | Wanborough and Little Hinton | <20m | 0.25Ml/d Unconfined aquifer at least 0.5km east or southeast of canal route. Limited outcrop area and thickness may limit yields, although aquifer is likely to be hydraulically connected to the unconfined Chalk to the south and east. | None identified | Impact on springs at boundary with Gault Clay and on flows in River Cole headwaters. | Vale of White Horse WRMU 2 GWMU No Water Available at Low Flows | Water may be available locally if water abstracted is returned to the catchment upstream of the Ray/Cole confluence with the Thames, as the "over-abstracted" status of the Thames at this assessment point overrides the "water available" status of the upstream catchment. No new consumptive licences groundwater hydraulically connected to rivers will be granted at low flows and certainly not without HOF conditions, although new abstractions not in hydraulic continuity may be licensed, subject to the usual licensing determination process. |
| | Lower Greensand | 7 | Southeast of Bourton (1km east of canal route at nearest point). | | 0.25 Ml/d, but yield may be negligible The limited aquifer thickness and outcrop area will restrict yields, although there may be a contribution from underlying Kimmeridge Clay sand unit., which has small outcrop to north (see below) | Possible high iron | Potential impact on flow in River Cole headwaters. | Vale of White Horse WRMU 2 No Water Available | Water may be available locally if water abstracted is returned to the catchment upstream of the Ray/Cole confluence with the Thames, as the "over-abstracted" status of the Thames at this assessment point overrides the "water available" status of the upstream catchment. No new consumptive licences groundwater hydraulically connected to rivers will be granted at low flows and certainly not without HOF conditions, although new abstractions not in hydraulic continuity may be licensed, subject to the usual licensing determination process. |
| | Portland Beds with contributions from sand unit within underlying Kimmeridge Clay | 8 | Bourton | 80m | 0.15Ml/d. Outcrop area is 1km southeast of canal route. Yield is likely to be constrained by limited outcrop area. | None identified | Potential Impact on local abstractions and on river flows in River Cole headwaters | Vale of White Horse WRMU 2 No Water Available at Low Flows | Water may be available locally if water abstracted is returned to the catchment upstream of the Ray/Cole confluence with the Thames, as the "over-abstracted" status of the Thames at this assessment point overrides the "water available" status of the upstream catchment. No new consumptive licences groundwater hydraulically connected to rivers will be granted at low flows and certainly not without HOF conditions, although new abstractions not in hydraulic continuity may be licensed, subject to the usual licensing determination process. |
| | Corallian (Confined aquifer) | 9 | South of Stratton St Margaret (north of canal route) and Bourton (south of canal route) | | 0.15Ml/d, but may be much less. Yield constrained by limited thickness of productive aquifer units (principally the Coral Rag), fracture network geometry and outcrop area, as well as by local faulting, which may hydraulically isolate aquifer in proximity to canal route | Red Down Sand unit within Corallian can contain high iron. | Potential impacts on local abstractions, springs and river flows in River Cole headwaters | Vale of White Horse WRMU 2 No Water Available at Low Flows | Water may be available locally if water abstracted is returned to the catchment upstream of the Ray/Cole confluence with the Thames, as the "over-abstracted" status of the Thames at this assessment point overrides the "water available" status of the upstream catchment. No new consumptive licences groundwater hydraulically connected to rivers will be granted at low flows and certainly not without HOF conditions, although new abstractions not in |

| Catchment | Principal Aquifer Unit(s) | Map ID | Location | Typical BH depth (m) | Estimated Maximum Yield per Borehole | Potential Quality Issues | Potential Environmental Issues | CAMS status | CAMS Strategy for new consumptive licences |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | from much of the recharge area(s). | | | | hydraulic continuity may be licensed, subject to the usual licensing determination process. |
| | Corallian (Confined / unconfined aquifer) | 10 | Shrivenham (Groundwater unit on boundary between Cole and Ock catchments) | 40m | 0.15Ml/d, but yields can be much less.<br>Yield constrained by limited thickness of productive aquifer units (principally the Coral Rag) outcrop area and fracture network geometry, as well as by local faulting, which may hydraulically isolate aquifer in proximity to canal route from much of the recharge area(s).<br>Groundwater levels can be artesian. | Red Down Sand unit within Corallian can contain high iron. Running sand can also be an issue if the Highworth Grit (at the base of the Coral Rag) is penetrated. | Potential impacts on local abstractions, springs at the base of the scarp and river flows in the River Ock and tributaries of the River Cole (Bower and Tuckmill brooks).<br>The EA has indicated that groundwater resources are available in principle, subject to a review of local impacts. | Vale of White Horse WRMU 2<br>No Water Available at Low Flows | Water may be available locally if water abstracted is returned to the catchment upstream of the Ray/Cole confluence with the Thames, as the "over-abstracted" status of the Thames at this assessment point overrides the "water available" status of the upstream catchment.<br>No new consumptive licences groundwater hydraulically connected to rivers will be granted at low flows and certainly not without HOF conditions, although new abstractions not in hydraulic continuity may be licensed, subject to the usual licensing determination process. |
| Thames, Ray | Chalk (contributions from Upper Greensand) | 11 | East and west of Wroughton | >20m | 0.5 Ml/d.<br>Extensive Chalk outcrop. Canal route runs over Chalk confined by Gault and Kimmeridge Clay, while existing and former abstraction boreholes appear to be in unconfined Chalk. This suggests confined Chalk transmissivity and yield may be limited. | None identified, although confined Chalk water quality may be poor. | Impacts on local springs (e.g., Markham Bottom) and flows in tributary to River Ray. Possible impacts on local groundwater abstractions | Vale of White Horse WRMU 2<br>No Water Available at Low Flows | Water may be available locally if water abstracted is returned to the catchment upstream of the Ray/Cole confluence with the Thames, as the "over-abstracted" status of the Thames at this assessment point overrides the "water available" status of the upstream catchment.<br>No new consumptive licences groundwater hydraulically connected to rivers will be granted at low flows and certainly not without HOF conditions, although new abstractions not in hydraulic continuity may be licensed, subject to the usual licensing determination process. |
| | Portland and Purbeck Beds | 12 | Old Town, Swindon railway cutting | N/A | 0.08 – 0.175 Ml/d (estimated during site visit in December 06).<br>Springs issuing from base of sand unit (outlier) within Kimmeridge Clay. The outcrop area is limited. | Contaminants associated with urban runoff as very short travel time to springs | Impact on flow in tributary to Ray. | Vale of White Horse WRMU 2<br>No Water Available at Low Flows | Water may be available locally if water abstracted is returned to the catchment upstream of the Ray/Cole confluence with the Thames, as the "over-abstracted" status of the Thames at this assessment point overrides the "water available" status of the upstream catchment.<br>No new consumptive licences groundwater hydraulically connected to rivers will be granted at low flows and certainly not without HOF conditions, although new abstractions not in hydraulic continuity may be licensed, subject to the usual licensing determination process. |
| | Lower Greensand, Portland and Purbeck Beds | 13 | Immediately south of Coate | No borehole records in area | 0.25Ml/d, but could be much less.<br>These units form an outlier within the Kimmeridge Clay, overlain to the south by Gault Clay.<br>Sustainable yields could be limited in proximity to the canal route due to limited outcrop area and limited aquifer thickness. Faulting may hydraulically isolate part of the recharge area. | Potential high iron from Greensand. | Impacts on other abstractors and on base-flow to and/or springs supplying the Ray tributaries. | Vale of White Horse WRMU 2<br>No Water Available at Low Flows | Water may be available locally if water abstracted is returned to the catchment upstream of the Ray/Cole confluence with the Thames, as the "over-abstracted" status of the Thames at this assessment point overrides the "water available" status of the upstream catchment.<br>No new consumptive licences groundwater hydraulically connected to rivers will be granted at low flows and certainly not without HOF conditions, although new abstractions not in hydraulic continuity may be licensed, subject to the usual licensing determination process. |
| | Corallian | 14 | West of Swindon | 30 – 80m | 0.15 Ml/d, but yield can be negligible.<br>Sustainable yields from the confined aquifer in proximity to the canal route | Aquifer usage more than a few km down dip (south) of the outcrop area is generally restricted as water quality deteriorates. | Impacts on other abstractors and on base-flow to and/or springs supplying the Ray tributaries.<br>The EA has indicated that the upper reaches of the River Ray, | Vale of White Horse WRMU 2<br>No Water Available at | Water may be available locally if water abstracted is returned to the catchment upstream of the Ray/Cole confluence with the Thames, as the "over-abstracted" status of the Thames at this assessment point overrides the |

| Catchment | Principal Aquifer Unit(s) | Map ID | Location | Typical BH depth (m) | Estimated Maximum Yield per Borehole | Potential Quality Issues | Potential Environmental Issues | CAMS status | CAMS Strategy for new consumptive licences |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | could be limited due to limited outcrop area, limited aquifer thickness and faults potentially hydraulically isolating the confined aquifer from recharge areas. | | upstream of Chiseldon STW, are ecologically sensitive. | Low Flows | “water available” status of the upstream catchment.<br>No new consumptive licences groundwater hydraulically connected to rivers will be granted at low flows and certainly not without HOF conditions, although new abstractions not in hydraulic continuity may be licensed, subject to the usual licensing determination process. |
| Bristol Avon Upper | Corallian | 15 | Chessley Hill | N/A | Yield unknown but likely to be very limited. | The resource potential from boreholes or springs at the boundary with the Oxford Clay is likely to be extremely limited due to the small outcrop area. | Impacts on springs at the boundary with the Oxford Clay | Bristol Avon WRMU 7<br>No Water Available | Consumptive licences may be granted, although these will have time limits and may also have conditions attached (low flow constraints) |
| | Corallian | 16 | Wootton Bassett | 30 – 60m | 0.02-0.15 Ml/d.<br>Sustainable yields could be limited in proximity to the canal route due to limited outcrop area and limited aquifer thickness. Faulting may hydraulically isolate confined aquifer from recharge areas.<br>There may be some potential from springs issuing at the boundary of the Corallian and Oxford Clay. | Aquifer usage more than a few km down dip of the outcrop area is generally restricted as water quality deteriorates. However, water quality in the unconfined aquifer is likely to be good. EA indicated that local water quality might be affected by landfill | Impacts on other abstractors. Impacts on springs at the boundary with the Oxford Clay and/or base-flow to the top of Brinkworth Brook. | Bristol Avon WRMU 7<br>No Water Available | Consumptive licences may be granted, although these will have time limits and may also have conditions attached (low flow constraints) |
| | Corallian | 17 | Bradenstoke and Lyneham (unconfined aquifer 0.5 – 1km S and SE of canal at nearest point) | 20m (unconfined aquifer location) | 0.15 - 0.25 Ml/d. | Water quality is generally good, although there may be potential pollution originating from RAF Lyneham (historical aviation fuel spills). | Impacts on other abstractors. Potential impact on spring flows at boundary with Oxford Clay | Bristol Avon WRMU 7<br>No Water Available | Consumptive licences may be granted, although these will have time limits and may also have conditions attached (low flow constraints) |
| Bristol Avon (River Marden) | River Gravels | 18 | West Tytherton (1.5km NW of canal route at nearest point) | | 0.25 Ml/d, possibly more | Susceptible to contamination. | Gravel aquifer hydraulically connected to the River Avon, therefore potential impact on low flows. | Bristol Avon WRMU 7<br>No Water Available | Consumptive licences may be granted, although these will have time limits and may also have conditions attached (low flow constraints) |
| | Lr Greensand and Corallian | 19 | Bancroft Hill and Wick (0.5km E of canal at nearest point) | | 0.25 - 0.5Ml/d.<br>Corallian outcrop area is limited close to the canal route and yields are therefore likely to be small. Underlying Greensand may contribute additional yield | Possible high iron | Impact on other abstraction boreholes. Potential impact on spring flows at boundary with Oxford Clay | Bristol Avon WRMU 7<br>No Water Available | Consumptive licences may be granted, although these will have time limits and may also have conditions attached (low flow constraints) |
| | Great Oolite | 20 | Foxham (3km WSW of Lyneham) and 1km north of Bredenstoke | 80 – 130m | ~0.25Ml/d<br>The Great Oolite is confined by Oxford Clay along canal route. Transmissivity and yield are likely to decrease down dip in confined aquifer. | Water quality is likely to deteriorate down dip in confined aquifer | Impact on other groundwater abstractions | Bristol Avon WRMU 7<br>No Water Available (CAMS shows only Great Oolite west of River Avon in GWMU 5 (over licensed) | Consumptive licences may be granted, although these will have time limits and may also have conditions attached (low flow constraints) |
| Bristol Avon (Great Somerford to Kennet | River terrace deposits | 21 | Avon flood plain, immediately to the west of the canal route | <10m | 0.25 Ml/d | At risk from surface contamination. | Gravel aquifer hydraulically connected to the River Avon, therefore potential impact on low flows. | Bristol Avon WRMU 2<br>No Water Available | Consumptive licences may be granted, although these will have time limits and may also have conditions attached (low flow constraints) |

| Catchment | Principal Aquifer Unit(s) | Map ID | Location | Typical BH depth (m) | Estimated Maximum Yield per Borehole | Potential Quality Issues | Potential Environmental Issues | CAMS status | CAMS Strategy for new consumptive licences |
|---|---|---|---|---|---|---|---|---|---|
| and Avon Canal) | Lower Greensand and Corallian | 22 | East of Lacock | No borehole records in area | 0.25 Ml/d. Sustainable yields are likely to be extremely variable and very dependent on aquifer thickness and fracture geometry. | Possible high iron and salinity. | Potential impact on spring flows at boundary with Oxford Clay and on local abstractions. | Bristol Avon WRMU 2 No Water Available | Consumptive licences may be granted, although these will have time limits and may also have conditions attached (low flow constraints) |
| | Great Oolite | 23 | Around Melksham and Lacock and to the northeast of Lacock. | 50 – 90m (Melksham) 30 – 70m (Lacock) | 0.5 Ml/d. The aquifer is largely confined by Oxford Clay along canal route. The yield is likely to be greatest near or in unconfined aquifer (>1km to west of Lacock, where most abstraction boreholes are located). Also, local faults, particularly the Lacock Fault, could hydraulically isolate aquifer units from recharge areas to the northwest. | Public water supplies to west around Chippenham indicate good quality water, however quality likely to decline further east and southeast in the confined aquifer. | Potential impacts on current abstractions, including major public water supply boreholes. Potential impact on springs at base of escarpment. | Bristol Avon GWMU 5 / WRMU 9 Over-licensed | Consumptive licences are very unlikely to be granted without significant low flow constraints. This means that the source would only be able to be used during periods of higher flow. |

**Table 4.6 - Summary of North Wiltshire and Berkshire Canal Groundwater Option**

## 4.4 Existing Storage

### 4.4.1 Coate Water Reservoir

The Coate Water reservoir, which is located some 2 km east of Wroughton, originally supplied the Wilts & Berks Canal before the canal was closed in 1914. The reservoir has subsequently become a local nature reserve and has high amenity value (angling, rowing, etc). The site has been designated as a SSSI (site of national nature conservation importance) and is now jointly managed by Natural England and Swindon Borough Council.

Levels in the reservoir are managed according to a site management plan agreed between Natural England and Swindon Borough Council. Swindon Rangers Service reports that levels are maintained such that they do not vary more than about 100mm. It is understood that water levels are drawn down in late summer/early autumn to expose mud flats. It is reported that reservoir spill is discharged via a small stream to the River Cole.

Swindon Borough Council inspects the reservoir for compliance with the Reservoir Act 1975. They report that inspections occur every three to four years and that levels are drawn down via a siphon spillway

The theoretical yield of the reservoir has been assessed and is presented in Section 7 but due to the sensitivity of the ecology to changes in water level, the sensitivity of stakeholders to water level changes and the high engineering costs associated with transferring discharges from the reservoir to the River Ray and onto the canal it is not considered a viable water resource option.

### 4.4.2 Tockenham Reservoir

Tockenham Reservoir is reported to be in the ownership of the Bristol, Bath and Wiltshire Amalgamated Anglers (Scott Wilson, 1998). The reservoir had a capacity of 273 Ml and an approximate catchment area of 4 $km^2$. The reservoir discharges water into a tributary of Brinkworth Brook. The theoretical yield of the reservoir has been assessed and is presented in Section 7.

## 4.5 Other Sources

### 4.5.1 Agricultural Runoff

Runoff and drainage from agricultural areas adjacent to the canal represents a potential source. The main issues with agricultural runoff are:

- Reliability during the summer
- Regulation
- Water Quality

The fields adjacent to the canal provide potential for topping up the canal during wet periods. Field drains feeding into the restored canal were observed during a site visit on 14 December 2006, examples can be found on the main canal near Wharf Farm. However, during average summers when the water table falls below the level of typical field drains and rainfall tends to runoff via surface drainage paths these sources will not be reliable.

In cases where field drains intercept the water table (even during summer periods) and discharges are in effect contributing to the base flow of the river catchments, it is unlikely that these discharges would be licensed. From discussions with the local EA regions the impact of abstractions on low flows is an issue prevalent in the Avon, Ray, Ock and Cole catchments.

There is a risk that the water quality of agricultural runoff would lead to long term problems with water quality as contaminants accumulate in the canal. Further work would need to be carried out to assess this risk prior to developing these sources.

For the purposes of this study agricultural runoff has not been considered a primary source. It is accepted, however, that existing discharges will serve a useful purpose in topping up the canal and may well reduce the demand for water during wet periods.

## 4.6 Urban Runoff

Runoff from existing and planned urban areas represents a potential source. Examples of this already exist just north of Purton Bridge and at Grove Top near Wantage. Major urban areas along the canal include Melksham, Wootton Bassett, Swindon, Wantage and Grove. Surface water drainage from RAF Lyneham is another potential source depending on the current destination of runoff. However, the Northern Development Area to the east of Moulden Hill is perhaps the area with most potential as an urban drainage source. Urban runoff sources have the same three risks as agricultural runoff:

- Reliability during the summer
- Regulation
- Water Quality

Summer runoff is limited to storm runoff and is unreliable (generally more so than agricultural runoff). While balancing ponds or sustainable urban drainage systems (SUDS) can provide storage to both, increase the reliability and make better use of discharges they are generally too small to provide reliable flow during the summer. The issue of regulation and the impact on dry weather flows is also a risk for urban runoff, the most significant issue associated with urban drainage is water quality. As with agricultural drainage the use of urban drainage can lead to the accumulation of contaminants if not removed prior to entering the canal or diluted through managing flows within the canal.

For the purpose of this study urban runoff will not be treated as a source.

### 4.6.1 Effluent Re-Use

When considering rivers it is assumed that the discharges from sewage treatment works are protected by HOF conditions as advised by the EA. In this study sewage treatment discharges are often significant proportions of low flows, therefore sustaining the river flow and any dependent ecology.

The CAMS provide information on artificial influences in each assessment point and this is information is used in this study. The Vale of White Horse CAMS provides more detailed information on consented discharges. However, the spread of this information is not available in the Bristol Avon CAMS.

### 4.6.2 Imports

The proposed reservoir development at Abingdon, known as the Upper Thames Major Resource Development (UTMRD), is part of Thames Water’s Water Resource Plan for the next 25 years. The proposed site lies on the route of the restored canal between the A338 and the A34, NW of the village of Steventon. Provision has been made in the development plans for the routing of the restored canal along the western side of the reservoir.

From Grontmij's discussions with Thames Water, the UTMRD plans have not assessed the water supply to a restored canal. A separate abstraction licence would be required to supply water to the canal from the reservoir as well as an abstraction licence for public water supply.

Furthermore, it is anticipated that the releases of water into the Auxiliary Discharge Channel, which may form part of the canal route, may from time to time be made, either as part of a regulation release for downstream abstraction or on instruction by the EA, for example, as part of a consent requirement. No indication is made of the frequency of these releases and there is no indication whether releases could be made purely for the benefit of a restored canal.

For the purposes of this study it is therefore assumed that the use of this resource is not available.

# 5 CANAL DEMANDS

## 5.1 Introduction

The AINA good practise guide identifies the following demands for a typical canal:

- Leakage, seepage and percolation
- Evaporation and transpiration
- Lock operation
- Third party abstractions and water sales
- Feeds to other waterways and watercourses

These are discussed in more detail in the following sections.

## 5.2 Leakage, Seepage and Percolation

Seepage is the diffuse loss of water via the bed and sides of a canal. It is dependent on the characteristics of the bed, the level of water in the canal and the surrounding groundwater level.

The indicative water balance analysis carried out by Scott Wilson (1998) shows that seepage and leakage are likely to be the most significant losses from the canal. Seepage rates of 10 mm/d, 20 mm/d and 30 mm/d were used to assess the need for canal lining. Scott Wilson (1998) concluded that the water balance could be closed with a seepage rate of between 10 $mmd^{-1}$ and 20 mm/d. Furthermore, they state that a permeability of less than 20 mm/d is attainable for a canal liner of Gault, Kimmeridge or Oxford clays on puddling.

AINA define leakage as the serious and unplanned loss of water via defined channels from the canal. The Scott Wilson report made no allowance for leakage apart from lock leakage. The AINA guidance states that serious leakages can be expected to be rapidly detected, isolated and the leak checked and remedial works carried out. The guidance advises that leakage does not need to be taken into account in an assessment of the normal water demands. This was confirmed through discussion with British Waterways.

The Scott Wilson report includes lock leakage although the basis for the estimate of 51 Ml is not clear.

A leakage, seepage and percolation loss of between 10 mm/d and 20 mm/d has been adopted for this study. The lower figure of 10 mm/d represents the losses for a fully lined canal with allowance for variable ground conditions, material properties, workmanship and unplanned leakages. Canal seepage and the basis for this range will be discussed further in Section 7.3.

British Waterway’s assume an average loss rate of 1.75 Ml/Km/Wk for a canal in good condition (AINA, 2005). This loss rate includes evapotranspiration as well as leakage, seepage and percolation losses. This figure (which is equivalent to a loss rate of 24 mm/d assuming a constant water depth of 1.37m for the minimum restored cross section given in Figure 6.1) is also considered in this study.

## 5.3 Evaporation and Transpiration

Evaporation will occur from open water while transpiration losses will occur from vegetation within and adjacent to the canal. The estimation of both these losses is complex and dependent on local conditions such as water depth, vegetation type and height and meteorological variables such as wind speed, solar radiation and humidity.

As stated previously, the average loss rate scenario of 1.75 Ml/Km/Wk includes leakage, seepage and percolation losses. This is the approach recommended by British Waterways.

For seepage loss rate scenarios of 10 mm/d and 20 mm/d, evaporation from the canal has to be considered as an additional loss. For this study evaporation is considered using MORECS data. Table 5.1 shows the monthly evaporation profile used in this study. MORECS square 158 covers the Western Mainline, Summit and North Wilts Canal area and MORECS square 159 covers the Eastern Mainline area. The actual evaporation from the canal water surface is dependent on the surface area.

| Month | Open Water Evaporation [mm/d] | |
|---|---|---|
| | MORECS Cell 158 | MORECS Cell 159 |
| January | 0.3 | 0.3 |
| February | 0.4 | 0.4 |
| March | 0.8 | 0.8 |
| April | 1.3 | 1.3 |
| May | 2.2 | 2.2 |
| June | 2.4 | 2.4 |
| July | 2.5 | 2.5 |
| August | 2.1 | 2.1 |
| September | 1.3 | 1.3 |
| October | 0.8 | 0.7 |
| November | 0.4 | 0.4 |
| December | 0.3 | 0.2 |

**Table 5.1 - Monthly open water evaporation profile (Equivalent daily rate of mm/d)**

### 5.4 Lock Operation

The movement of water through locks is a function of boat movement, lock design and operation. For the purposes of this study a range of boat movements have been assumed based on guidance from British Waterways and the Project Steering Group. Guidance from British Waterways suggests that a fully restored canal connected to the Kennet and Avon in the west and the Thames in the east could typically expect between 1,000 and 9,000 boat movements per year with an average of between 4,000 and 5,000 boat movements per year on the main section and an average of 1,000 to 2,000 on the North Wilts Canal section. Given this guidance the following values were adopted for the study:

i) 1,000 boat movements for all sections
ii) 2,000 boat movements for the Western Mainline, Summit and Eastern Mainline sections and 1,000 boat movements for the North Wilts Canal.
iii) 4,500 boat movements for the Western Mainline, Summit and Eastern Mainline sections and 1,500 boat movements for the North Wilts Canal.

It has been assumed that for each lock operation a volume equivalent to the lock area multiplied by the lift will be discharged through the lock.

## 5.5 Feeds to Other Waterways and Watercourses

Excess water is lost from canals via spillways. These spillways are required to balance any inflow variations and so maintain a constant water level. It has been assumed that excess water can be lost from any canal pound via a spillway or passed to a downstream section via a by-pass channel. This ensures optimum use of water and minimises spills.

## 5.6 Summary of Loss Scenarios

There are 9 loss scenarios adopted in this study, namely 10 mm/d, 20 mm/d and 1.75 Ml/Km/Wk each considered with 1,000, 2,000 and 4,500 boat movements per year. The losses from these scenarios are summarised in Table 5.2 to illustrate the relative magnitude of each type of loss. It has been assumed that the minimum seepage loss attainable is 10 mm/d and the maximum loss is 1.75 Ml/km/wk (which is approximately equivalent to 24 mm/d) (see Section 7.3 for full description of canal seepage).

| Section Description | Length (km)[1] | No. of Locks | Losses from Lock Operations per year (Ml/d) | | | Seepage Loss[2] (Ml/d) | | Evaporation (Ml/d)[2] | BW Average Loss Rate[3] (Ml/d) |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1000 boats | 2000 boats | 4500 boats | 10 mm/d | 20 mm/d | | |
| Western Mainline | 42.7 | 32 | 0.34 | 0.68 | 1.53 | 4.51 | 9.02 | 0.70 | 10.68 |
| Summit | 13.5 | 17 | 0.34 | 0.68 | 1.53 | 1.42 | 2.83 | 0.22 | 3.38 |
| Eastern Mainline | 37.2 | 20 | 0.34 | 0.68 | 1.53 | 3.94 | 7.88 | 0.61 | 9.30 |
| North Wilts Canal | 14.5 | 12 | 0.22 | 0.22[4] | 0.33[4] | 1.53 | 3.05 | 0.23 | 3.63 |
| Total | 107.9 | 81 | 1.24 | 2.26 | 4.92 | 11.4 | 22.78 | 1.76 | 26.99 |

[1] The section lengths are inclusive of lock lengths.
[2] The seepage loss varies depending on the wetted perimeter of the canal section and therefore figures given are dependent on source availability. The losses are taken from the average year scenario for losses of 10 mm/d and 1000 boat scenario and 20 mm/d and 1000 boat scenario respectively. The evaporation loss is taken from the 10 mm/d and 1000 boat scenario.
[3] British Waterway's loss value of 1.75 Ml/Km/Wk
[4] In the water balance analysis the North Wilts Canal is assumed to have 1,000 boat movements when other sections have 2,000 boat movements and 1,500 boat movements and 4,500 boat movements per year.

**Table 5.2 - Canal Demand Scenarios.**

The losses for the NWC presented in the interim report were calculated based on the bed width of the canal rather than the wetted perimeter as adopted in Table 5.2. In reality the seepage will depend on the water level in the canal and the water table level. During wet periods it is expected that the local water table will rise above the bed level of the canal and as a consequence seepage rates will fall. For the purpose of this study a worst case has been assumed and the wetted perimeter adopted for the calculation of seepage.

# 6 WATER BALANCE

## 6.1 Introduction

A water balance model of the Wilts & Berks Canal was developed for each of four sections: Western Mainline, Summit, Eastern Mainline and the North Wilts Canal. The model considers the potential sources of the canal (as described in Section 4) and canal losses (see Section 5) as well as the canal geometry and operational assumptions such as boat movements. This section describes the assumptions behind the water balance in detail and presents the water balance of the canal, the storage required to maintain a closed water balance and the level of service for a given level of storage. The level of abstraction from sources is presented together with a consideration of their impact on local water sources. Further description of the water balance model and assumptions are described in Appendix 4.

## 6.2 Methodology

Surface water abstraction provides one of the likeliest sources to maintain an operational restored canal subject to the constraints discussed previously and with off line storage to maintain summer losses. Also the existence of daily gauged flow data reflecting seasonal variation in source availability provides more robust assessment of the yields and storage required compared to assessments of, say, groundwater resources and existing storage options. Therefore to complete the water balance analysis only surface water abstractions and off line storage is considered.

For the four canal sections the water balance is calculated over a 32 year period from 1974 to 2006 using daily time series flow data. Monthly evaporation and rainfall data was included in the water balance (Daily rainfall data were received from the EA but were not included in the analysis due to time limitations and the very low impact this source has on the overall water balance).

The water balance is assessed for the 9 loss scenarios presented in Section 5. The water balance considers the use of all potential surface water sources as shown in Figure 4.1 and Section 4. Surface water catchments much smaller than 5 $km^2$ are not considered in the analysis.

The inflows for the catchment areas at the abstraction points (assumed to be where the watercourse intersects the canal route) are derived from the local gauging stations with similar catchment characteristics (i.e. base-flow index as measured by BFIHOST). The gauged flows are scaled by catchment area and Standard Average Annual Rainfall (SAAR) obtained from the Flood Estimation Handbook (FEH CDROM Version 2.0) to obtain a derived inflow series (see
Table 6.1).

The abstraction from potential surface water sources is available all year round subject to the local and regional HOF rules based on the relevant CAMS documentation and licensing consultation with the EA as presented in Section 4.1.

| Western Mainline Source ID | Gauging Data Used | Catchment Area ($km^2$) | SAAR (mm) | Scaling Factor |
|---|---|---|---|---|
| HA53-07-1 | Semington | 8.53 | 720 | 0.056 |
| HA53-10-1 | Stanley | 98.79 | 724 | 0.996 |
| HA53-11-1 | Stanley | 5.27 | 712 | 0.052 |
| HA53-13-3 | Stanley | 29.16 | 714 | 0.290 |
| HA53-13-5 | Stanley | 4.96 | 718 | 0.0496 |
| Total | | 162.84 | | |
| | | | | |
| **Summit Source ID** | **Gauging Data Used** | **Catchment Area (km2)** | **SAAR (mm)** | **Scaling Factor** |
| HA39-02-16-1 | Water Eaton | 6.10 | 714 | 0.076 |
| HA39-02-18-1 | Water Eaton | 4.40 | 724 | 0.056 |
| HA39-02-18-2 | Water Eaton | 5.64 | 709 | 0.070 |
| HA39-03-1 | Abingdon | 5.56 | 742 | 0.025 |
| HA39-03-4 | Abingdon | 9.53 | 725 | 0.042 |
| Total | | 31.23 | | |
| | | | | |
| **North Wilts Canal Source ID** | **Gauging Data Used** | **Catchment Area ($km^2$)** | **SAAR (mm)** | **Scaling Factor** |
| HA39-01-1 | Water Eaton | 28.96 | 705 | 0.357 |
| HA39-02-9 | Water Eaton | 70.65 | 700 | 0.869 |
| Total | | 99.61 | | |
| | | | | |
| **Eastern Mainline Source ID** | **Gauging Data Used** | **Catchment Area ($km^2$)** | **SAAR (mm)** | **Scaling Factor** |
| HA39-03-5 | Abingdon | 14.45 | 712 | 0.062 |
| HA39-03-6 | Abingdon | 15.27 | 708 | 0.066 |
| HA39-03-7 | Abingdon | 11.92 | 695 | 0.050 |
| HA39-03-8 | Abingdon | 4.22 | 683 | 0.017 |
| HA39-04-1 | Abingdon | 5.76 | 686 | 0.024 |
| HA39-04-2 | Abingdon | 4.46 | 686 | 0.018 |
| HA39-04-5 | Abingdon | 6.59 | 703 | 0.028 |
| HA39-04-7 | Abingdon | 21.43 | 704 | 0.092 |
| HA39-04-9 | Abingdon | 12.54 | 625 | 0.046 |
| HA39-04-10 | Abingdon | 6.41 | 593 | 0.023 |
| Total | | 103.05 | | |

**Table 6.1 - Catchment areas and SAAR for surface water catchments at canal intersection. Catchment Area and SAAR taken from Flood Estimation Handbook CD ROM Version 2.**

A schematic of the canal cross section is shown in Figure 6.1 and the key parameters by section are shown in **Table 6.2**

**Table 6.2**The mass balance approach is used to calculate the variation in volume and water depth in each section of the canal. It is assumed that the minimum depth at which the canal is navigable is 1.37m and the desirable depth is 1.5m. If the water level exceeds the desirable depth then the water is assumed to be lost via spillways. If the water level falls below 1.37m then the canal section is assumed to be in deficit.

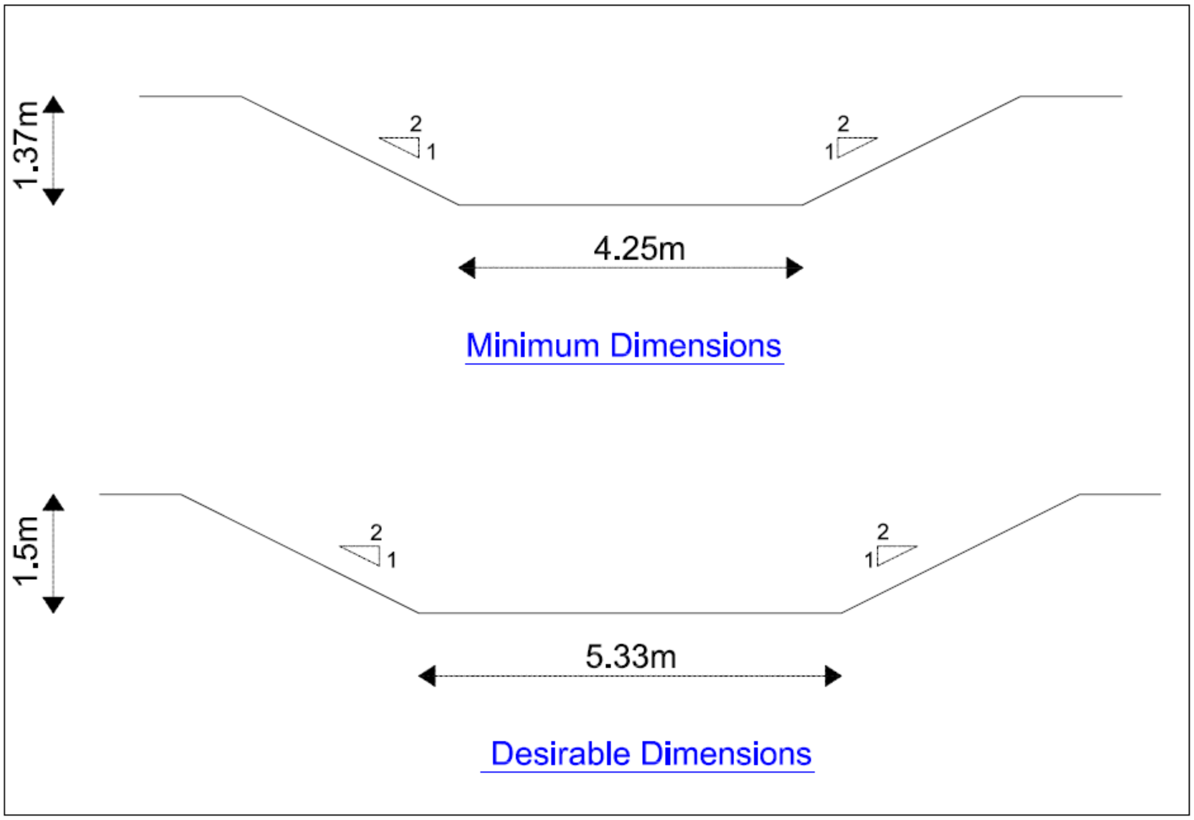


**Figure 6.1 – Schematic of Canal Cross Section**

The model includes the facility to store water from any potential source. This water can then be transferred to the canal during periods of deficit (i.e the level falls below 1.37m). If a resource becomes available this will be taken in preference to available storage. Any excess will be assumed to enter storage.

Transfers between the sections are considered in the model. Lockage losses from the Summit section are assumed to transfer 'downstream' to the other sections depending on the boat traffic in that section. The opportunity for spills from the Summit section to transfer to the other sections when these are in deficit was also considered but the effect was found to be very minor.

| | Units | Western Mainline | Summit | Eastern Mainline | North Wilts Canal |
|---|---|---|---|---|---|
| Canal Length | m | 41,977 | 13,116 | 36,748 | 14,229 |
| Total Length of Locks | m | 723 | 384 | 452 | 271 |
| Total Canal & Lock Length | m | 42,700 | 13,500 | 37,200 | 14,500 |
| Total Volume at Min. Depth | $m^3$ | 404,162 | 126,759 | 353,272 | 137,077 |
| No. of Locks | No. | 32 | 17 | 20 | 12 |

| | Units | Western Mainline | Summit | Eastern Mainline | North Wilts Canal |
|---|---|---|---|---|---|
| Lock Length | m | 22.6 | 22.6 | 22.6 | 22.6 |
| Lock Width | m | 2.2 | 2.2 | 2.2 | 2.2 |
| Lock Depth | m | 1.37 | 1.37 | 1.37 | 1.37 |
| Average Fall/Rise of Lock | m | 2.5 | 2.5 | 2.5 | 1.6 |
| Min Bed Width | m | 4.25 | 4.25 | 4.25 | 4.25 |
| Desirable Bed Width | m | 5.33 | 5.33 | 5.33 | 5.33 |
| Bank Slope | No. | 1 in 2 | 1 in 2 | 1 in 2 | 1 in 2 |

**Table 6.2 - Key parameters by section in the water balance model**

The water balance is presented for an average year, the driest year and for a Level of Service of 1 in 5 years. The year is reported as the water year (which commences on 1st October). The average year was selected as 1979 as this is the year closest to the 50% percentile of runoff for flow data used. The driest year common to all sections was 1975 as defined by the flow data and this year is used for presentation here although the driest year in Western Mainline and North Wilts Canal was 1990.

A level of service of 1 in 5 years assumes that the canal will fail, on average, once every 5 years. In the 32 year period considered in the water balance this means the canal would be expected to fail 6.4 times. Therefore considering all sections together it is assumed the water year ranked 7th in the 32 year series is used to indicate the year that can just meet a level of service of 1 in 5 years. This water year is 1976.

The approach adopted in this study shows an improvement over the water balance presented in the Scott Wilson (1998) report in that it:

- Considers explicit and specific sources to meet the losses from the canal.
- Considers abstraction restrictions (HOFs) as stated in the current CAMS and from discussions with the EA
- Estimates a daily rather than monthly water balance to more accurately calculate the flow available.
- Considers the utilisation of storage and abstraction all year round thus reflecting dry periods in both winter and summer.

Moreover, this approach closes the water balance whereas Scott Wilson (1998) assumed that the deficit in the canal supply-demand-balance not satisfied by the potential river sources could be met from other sources.

## 6.3 Differences in Approach to Cricklade Study

The approach adopted for the water balance differs to that presented in the NWC Interim Report issued in March 2007 for the Purton Road Bridge to Cricklade pounds. This is summarised below:

- Better use of available data – use of daily gauged flow data rather than Lows Flows 2000 to infer available resources. This will reduce uncertainty in the assessment.
- Use of a daily water balance model rather than a lumped seasonal water balance model enables critical dry periods to be analysed and the probability of the canal being in deficit to

be established. The lumped seasonal approach was limited to selected wet, average and dry year analysis without reference to return period or duration.

- Use of the Kingston on Thames flow data together with the CAMS HOF condition of $Q_{50}$ provides a more accurate representation of water availability than the naturalised $Q_{50}$ HOF on the River Ray.

## 6.4 Analysis

### 6.4.1 Loss Scenario – 10 mm/d and 1000 boat movements

The results of the water balance analysis are presented for a canal loss of 10 mm/d and 1000 boats. The results of all canal loss scenarios are presented in Appendix 3. The water balance by canal section is presented in Table 6.3 - Annual water balance for an average year, driest year and reference year for Level of Service of 1 in 5 years. Levels of abstraction are also shown. Losses at 10 mmd-1 and 1000 boat movements. For an average year, the driest year and for the 1 in 5 year level of service reference year.

For the average year the percentage of water taken from the surface water sources varies between 2.7% and 9.2% by volume depending on the section. Abstraction rates vary between 3.2 Ml/d and 8.2 Ml/d depending on the section with a maximum abstraction rate on any given day of between 3.6% and 12% of the river flow. Abstractions exceeded the 10% target take (for flows above the HOF) in two sections (Eastern Mainline (12%) and Summit (11.7%)). This is ultimately a consequence of the high volume of these 2 sections compared to the available surface water catchment area sources. The storage required to maintain a navigable canal for an average year is 1798 Ml (Given by section in Table 6.5)

For the driest year the amount of storage required to maintain the canal at a navigable depth increases significantly to 3612 Ml. Volumes of abstraction and average abstraction rates generally increase also (Table 6.5).

If the canal sections are allowed to fail (i.e. go below minimum navigable level) once every 5 years then the amount of storage required reduces (Table 6.5) and subsequently a deficit appears. For a level of service of 1 in 5 years the canal will fail between 6 and 7 times (6.4 times) in the 32 year period. The years of failure noted in the 1974 – 1996 period were 1976, 1989-1992, 1997 and 2005. Figure 6.2 shows the relationship between the total storage required to achieve a specified level of service and was derived from multiple model runs using a range of storage values**Error! Reference source not found.**. Note that the y-axis is plotted on a logarithmic scale showing that the level of storage required tends to increase exponentially with level of service.

The canal losses are marginally lower in the dry year than the average year. This is a function of lower canal water levels which lead to reduced evaporation and seepage.

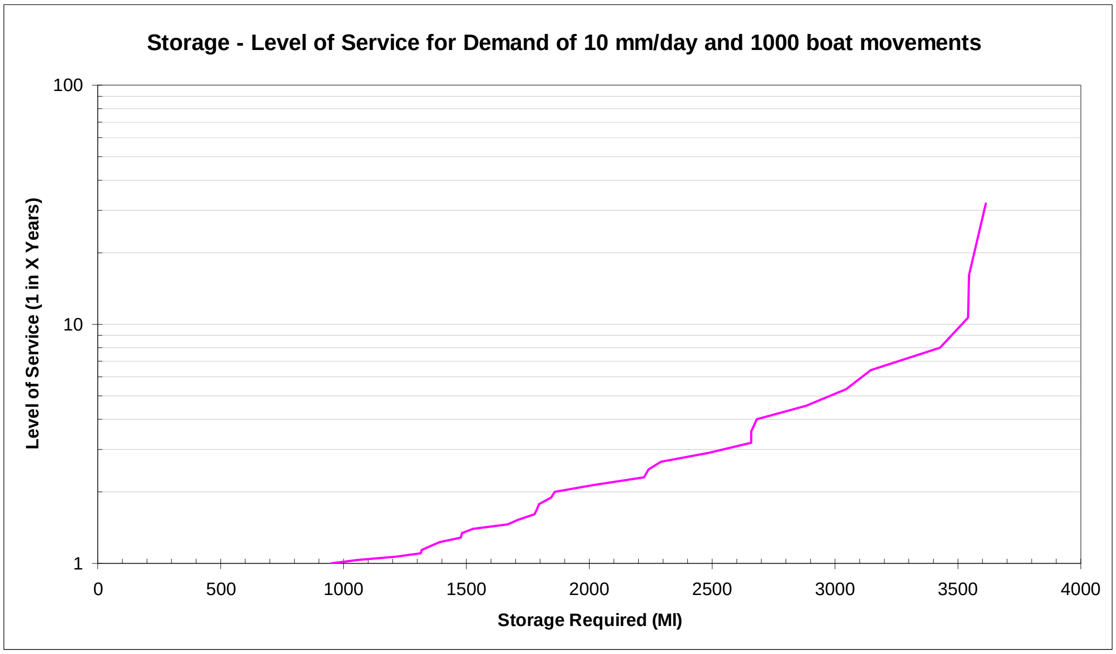


**Figure 6.2 - Level of Service – Storage Relationship for a canal demand of 10 mm/d and 1,000 boat movements per year.**

Figures 6.3 to 6.6 show the impact of abstraction on the flow duration curves (FDC) for the major gauging stations with a loss scenario of 10 mm/d seepage and 1,000 boat movements. The impact of abstraction is most marked at Stanley (Figure 6.3) where the inclusion of a HOF at $QN_{76}$ is very obvious

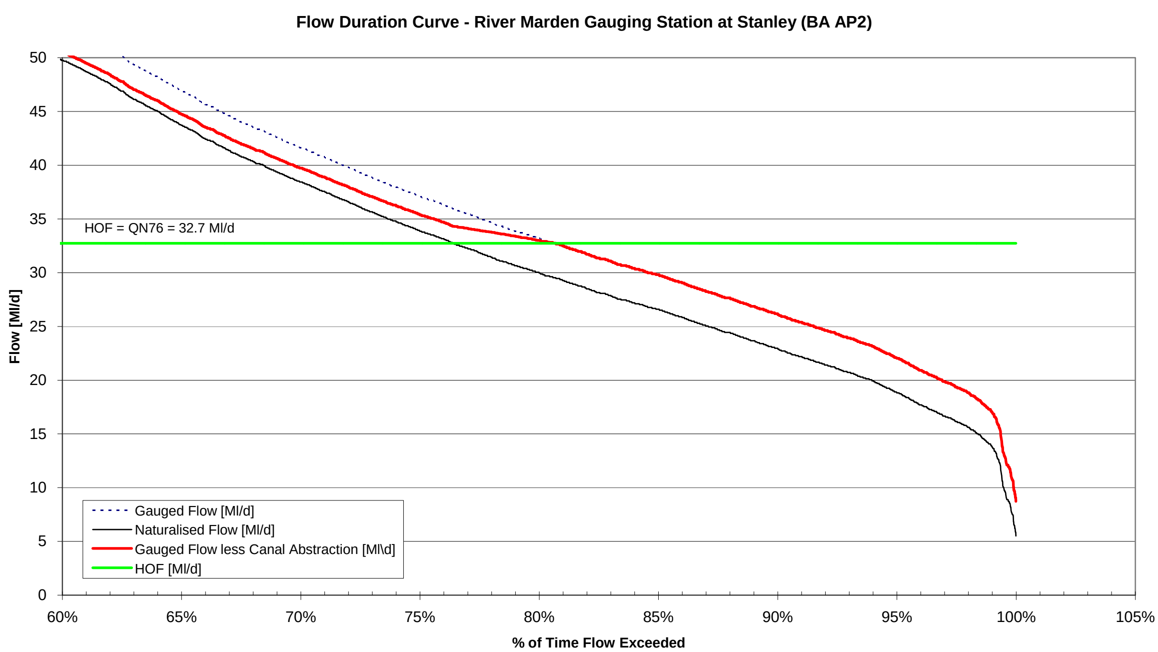


Figure 6.3

The impact of abstraction on the Rivers Ock, Cole and Ray is less marked because the overriding control on abstraction is the regional HOF condition of $Q_{50}$ at Kingston which does not always coincide with the local $Q_{95}$ HOF conditions on the 3 rivers resulting in a more gradual increase as flow increases.

The impact on the River Ray (Figure 6.4) is small with the FDC (with abstraction) starting to deviate from the gauged flow at around Q60. On the Rivers Cole and Ock the impact on abstraction is more marked reflecting the greater abstraction required to support the Summit and Eastern Mainline sections. The FDC (with abstraction) for the River Cole and Ock begins to deviate from the gauged flow at about Q60 (Figure 6.5) and Q50 (Figure 6.6) respectively.

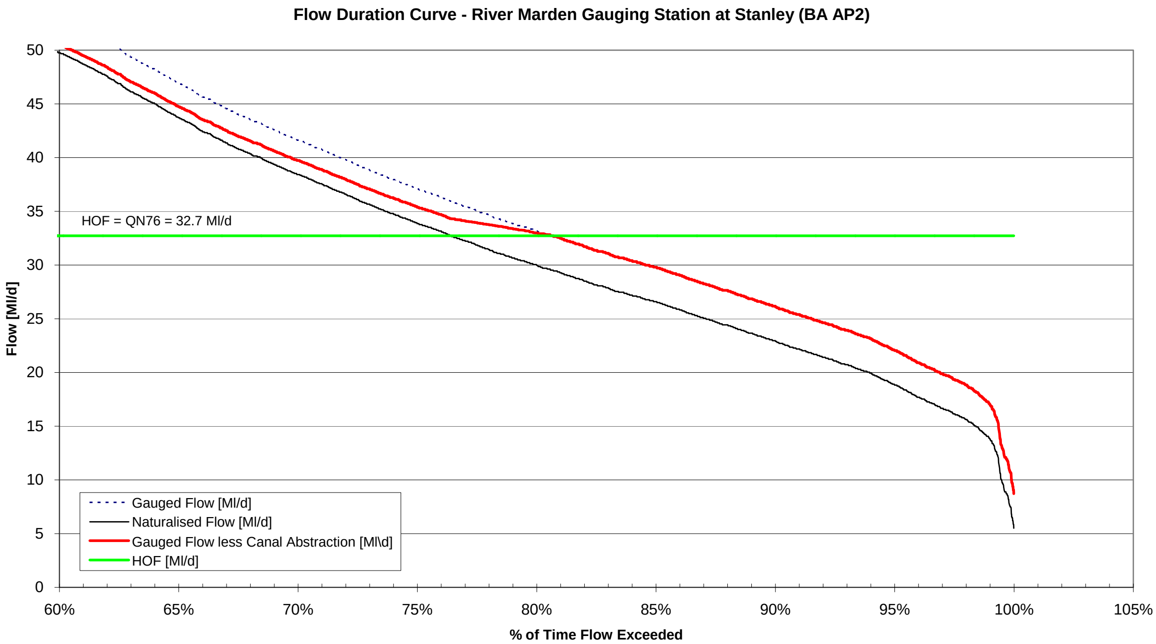


**Figure 6.3 - Flow Duration Curve for River Marden at Stanley showing the effects of abstraction for canal supply.**

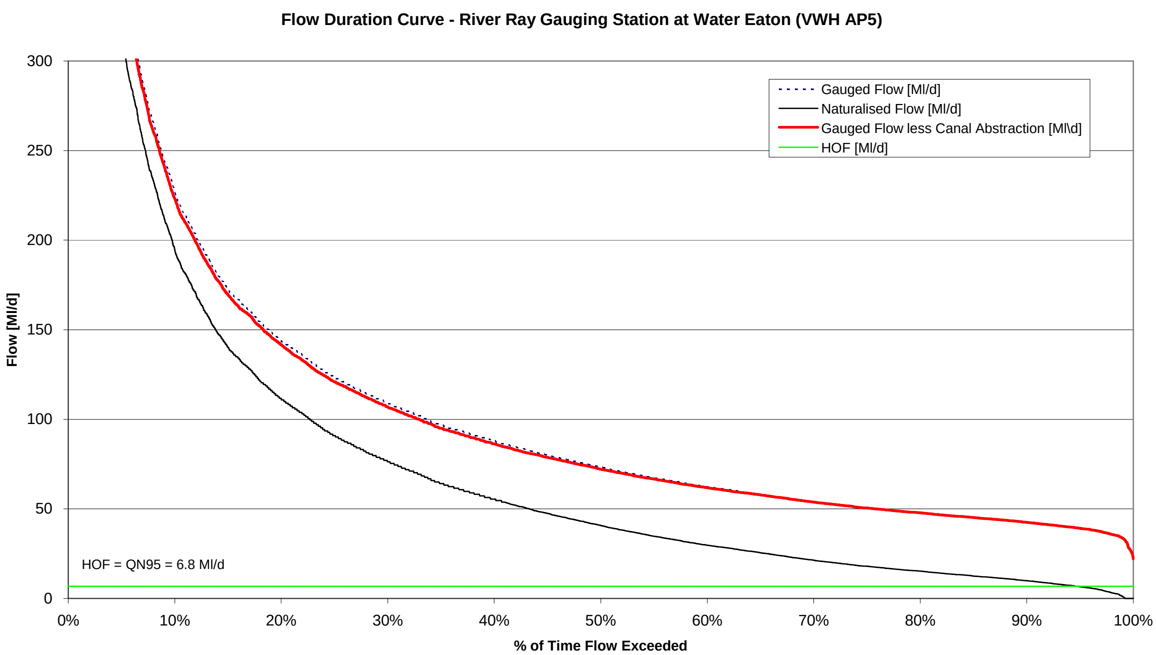


**Figure 6.4 - Flow Duration Curve for River Ray at Water Eaton showing the effects of abstraction for canal supply.**

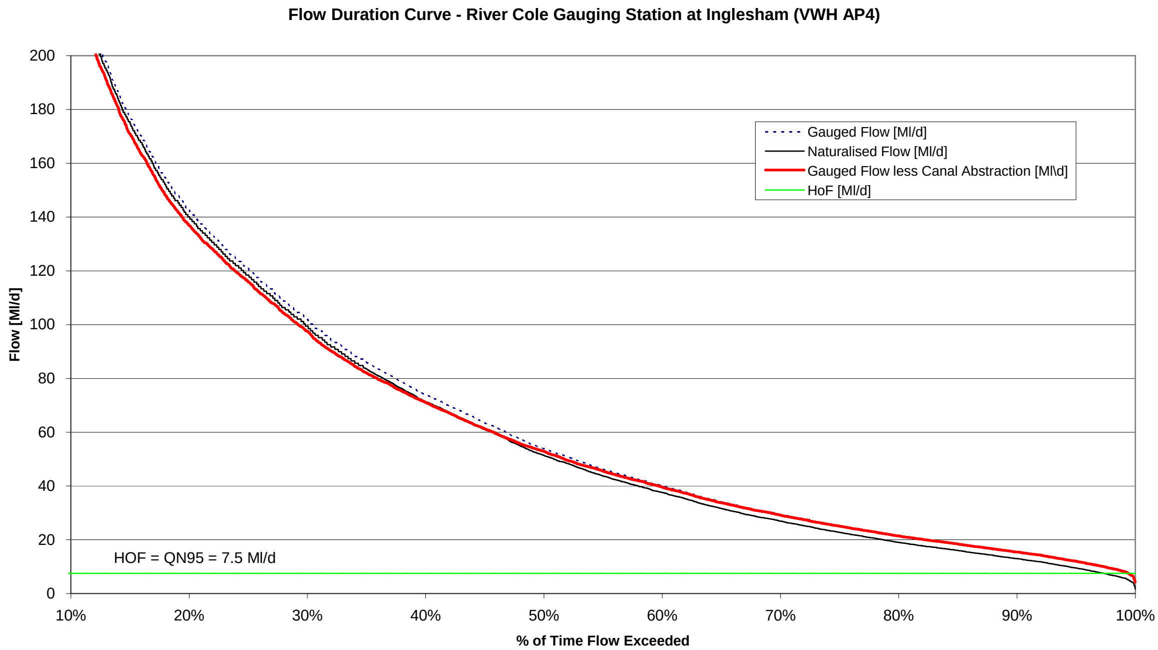


**Figure 6.5 - Flow Duration Curve for River Cole at Inglesham showing the effects of abstraction for canal supply.**

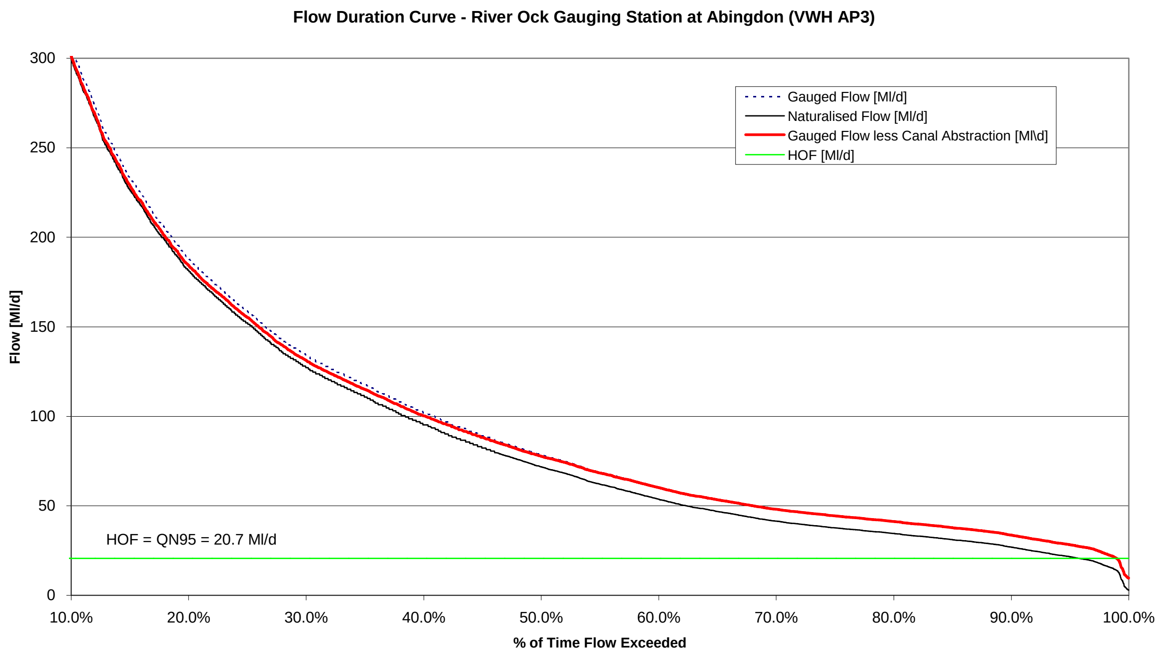


**Figure 6.6 - Flow Duration Curve for River Ock at Abingdon showing the effects of abstraction for canal supply.**

| | Average Year | | | | Level of Service - 1 in 5 years | | | | Dry Year | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Canal Losses [Ml/d][1] | 1.99 | 5.57 | 4.90 | 1.98 | 1.96 | 5.52 | 4.81 | 1.95 | 1.95 | 5.47 | 4.81 | 1.94 |
| Direct Abstraction [Ml/d] | 1.16 | 4.01 | 2.90 | 1.08 | 0.73 | 3.10 | 1.68 | 0.71 | 0.39 | 2.29 | 0.94 | 0.45 |
| Supply from Storage [Ml/d] | 0.82 | 1.43 | 1.88 | 0.79 | 1.22 | 2.30 | 3.01 | 1.13 | 1.51 | 3.06 | 3.62 | 1.37 |
| Direct Precipitation [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Transfers from Other sections [Ml/d] [2] | 0.00 | 0.12 | 0.12 | 0.12 | 0.00 | 0.12 | 0.12 | 0.12 | 0.00 | 0.12 | 0.12 | 0.12 |
| Change in Storage [Ml/d] [3] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.13 | 0.01 |
| Deficit [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | | |
| Max % Abstraction of Flow above HOF taken on any day[4] | 12.0% | 5.0% | 11.7% | 3.6% | 12.0% | 5.0% | 11.7% | 3.6% | 12.0% | 5.0% | 11.7% | 3.6% |
| % of Flow Abstracted above HOF | 9.2% | 3.4% | 8.4% | 2.7% | 12.0% | 4.1% | 11.7% | 3.6% | 12.0% | 3.5% | 11.7% | 3.6% |
| Abstraction Rate [Ml/d] over the period (No. of days water is abstracted) | 3.40 | 5.52 | 8.19 | 3.19 | 6.61 | 5.60 | 15.85 | 6.20 | 9.52 | 11.06 | 22.79 | 8.87 |
| No. of days water is abstracted | 213 | 360 | 213 | 213 | 108 | 352 | 108 | 108 | 73 | 247 | 73 | 62 |
| Average Rate Supplied from Storage [Ml/d] (over the No. of days storage is used) | 1.89 | 3.29 | 4.49 | 1.78 | 1.92 | 3.91 | 4.47 | 1.77 | 1.89 | 4.91 | 4.46 | 1.81 |
| No. of days storage is used | 159 | 136 | 153 | 161 | 233 | 181 | 246 | 232 | 293 | 227 | 296 | 275 |

**Table 6.3 - Annual water balance for an average year, driest year and reference year for Level of Service of 1 in 5 years. Levels of abstraction are also shown. Losses at 10 mmd-1 and 1000 boat movements.**

[1] Canal Losses include seepage, evaporation and lockage losses.
[2] Flow discharged via locks from adjacent sections.
[3] It represents the difference between the volume in the canal at the start and end of the year.
[4] The percentage take of flows at the point of abstraction when flow exceeds HOF
[5] There might be minor rounding errors due to use of 2 d.p

| | Average Year | | | | Level of Service - 1 in 5 years | | | | Dry Year | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Canal Losses [Ml/d] [1] | 4.97 | 12.21 | 10.83 | 3.95 | 4.97 | 12.21 | 10.83 | 3.95 | 4.97 | 12.21 | 10.83 | 3.95 |
| Direct Abstraction [Ml/d] | 2.82 | 8.46 | 5.94 | 2.11 | 1.63 | 6.72 | 3.39 | 1.29 | 0.94 | 4.94 | 1.88 | 0.83 |
| Supply from Storage [Ml/d] | 2.14 | 3.06 | 4.21 | 1.62 | 3.34 | 4.80 | 6.76 | 2.43 | 3.98 | 6.58 | 8.14 | 2.87 |
| Direct Precipitation [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Transfers from Other Sections [Ml/d] [2] | 0.00 | 0.68 | 0.68 | 0.23 | 0.00 | 0.68 | 0.68 | 0.23 | 0.00 | 0.68 | 0.68 | 0.23 |
| Change in Storage [Ml/d] [3] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.13 | 0.02 |
| Deficit [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | | |
| Max % Abstraction of Flow above HOF taken on any day[4] | 29.0% | 11.0% | 24.4% | 7.4% | 29.0% | 11.0% | 24.4% | 7.4% | 29.0% | 11.0% | 24.4% | 7.4% |
| % of Flow Abstracted above HOF | 23.0% | 7.2% | 18.1% | 5.4% | 29.0% | 8.8% | 24.4% | 7.4% | 29.0% | 8.1% | 24.4% | 7.4% |
| Abstraction Rate [Ml/d] over the period - no of days water is abstracted | 8.53 | 11.56 | 17.44 | 6.40 | 16.79 | 11.62 | 34.30 | 12.58 | 24.67 | 21.91 | 50.24 | 18.41 |
| No. of days water is abstracted[5] | 212 | 364 | 212 | 212 | 108 | 362 | 108 | 108 | 73 | 283 | 73 | 62 |
| Average Rate Supplied from Storage [Ml/d] | 4.75 | 6.79 | 9.87 | 3.56 | 4.77 | 7.78 | 9.75 | 3.58 | 4.89 | 9.89 | 9.90 | 3.64 |
| No. of days storage is used | 165 | 138 | 156 | 166 | 255 | 185 | 253 | 248 | 297 | 243 | 300 | 288 |

**Table 6.4 - Annual water balance for an average year, driest year and reference year for Level of Service of 1 in 5 years. Levels of abstraction are also shown. Losses at 1.75 Ml/Km/Wk and 4500 boat movements.**

[1] Canal Losses include seepage, evaporation and lockage losses.
[2] Flow discharged via locks from adjacent sections.
[3] It represents the difference between the volume in the canal at the start and end of the year.
[4] The percentage take of flows at the point of abstraction when flow exceeds HOF
[5] This is abstraction from all intakes so abstraction may occur 365 days pre year.
[6] There might be minor rounding errors due to use of 2 d.p

| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
|---|---|---|---|---|
| Storage Required for an Average Year (Ml) | 300 | 523 | 687 | 287 |
| Storage Required for the Driest Year (Ml) | 553 | 1212 | 1321 | 525 |
| Storage Required for a Level of Service of 1 in 5 Years (Ml) | 447 | 835 | 1099 | 412 |
| Deficit in Storage for Level of Service 1 in 5 Years [Ml] | 106 | 378 | 222 | 114 |

**Table 6.5 - Required reservoir storage and\or deficit for an average year, the driest year and 1 in 5 year level of service reference year. Losses at 10 mmd-1 and 1000 boat movements (See Appendix 3 for all scenarios).**

The required reservoir storage for the NWC compares to 206Ml for the same seepage rate (calculated over the bed width) but for 500 boat movements and for a length of 7.5km. Its not possible to simply scale the storage requirement with canal length as storage due to the non-linear behaviour of the canal to inflows. The value given in Table 6.5 does lies within the range of reservoir storages presented in the Interim Report (90Ml to 392 Ml/d).

### 6.4.2 Loss Scenario – 1.75 Ml/Km/Wk and 4,500 boat movements

The loss scenario with greatest demand on the system is presented here to show the variation in the levels of abstraction and storage required to maintain a navigable canal. The water balance and abstraction statistics are presented in table 6.5 and the storage required is presented in table 6.6.

Under this scenario canal losses equal 32.05 Ml/d in an average year. Abstraction volumes above the HOF condition vary between 5.4% and 23% in an average year and up to 29% in the driest year. The maximum % abstraction constraint of 10% allowed on any one day has to be relaxed in all but the NWC to achieve a viable water balance. The storage requirement is much greater with 4,025 Ml required to meet demand (compared to 1,798 Ml for the 10 mm/d 1,000 boat scenario). This difference is more pronounced in the driest year (8,138 Ml c.f. 3,612 Ml). These results imply that the abstraction can be maintained within the target take of 10% flow above HOF without either a substantial increase in reservoir storage or a substantially reduction in the level of service.

| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
|---|---|---|---|---|
| Storage Required for an Average Year (Ml) | 782 | 1117 | 1536 | 590 |
| Storage Required for the Driest Year (Ml) | 1453 | 2618 | 2972 | 1095 |
| Storage Required for a Level of Service of 1 in 5 Years (Ml) | 1217 | 1753 | 2467 | 887 |
| Deficit in Storage for Level of Service 1 in 5 Years [Ml] | 235 | 865 | 505 | 208 |

Table 6.6 - Required reservoir storage and\or deficit for an average year, the driest year and 1 in 5 year level of service reference year. Storage Requirements for Losses of 1.75 Ml/Km/Wk and 4500 boat movements (see Appendix 3 for all scenarios)

### 6.4.3 Summary of All Loss Scenarios

Table 6.7 presents a summary of the total storage and losses for each loss scenario and for each hydrological scenario. The full water balance details for each scenario are given in Appendix 3.

| | | Storage Required (Ml/d) | | | Canal losses (Ml/d) | | |
|---|---|---|---|---|---|---|---|
| | | Average Year | Driest Year | 1 in 5 year | Average Year | Driest Year | 1 in 5 year |
| 10 mm/d seepage and 1000 boats per year | Summit | 300 | 553 | 447 | 1.99 | 1.96 | 1.95 |
| | Western Mainline | 523 | 1212 | 835 | 5.57 | 5.52 | 5.47 |
| | Eastern Mainline | 687 | 1321 | 1099 | 4.90 | 4.81 | 4.81 |
| | North Wilts Canal | 287 | 525 | 412 | 1.98 | 1.95 | 1.94 |
| 20 mm/d seepage and 1000 boats per year | Summit | 522 | 960 | 796 | 3.4 | 3.34 | 3.34 |
| | Western Mainline | 976 | 2230 | 1534 | 10.09 | 10.01 | 9.89 |
| | Eastern Mainline | 1290 | 2469 | 2065 | 8.85 | 8.69 | 8.68 |
| | North Wilts Canal | 536 | 983 | 803 | 3.51 | 3.45 | 3.44 |
| 1.75 Ml/km/wk seepage and 1000 boats per year | Summit | 582 | 1084 | 899 | 3.73 | 3.73 | 3.73 |
| | Western Mainline | 1082 | 2517 | 1699 | 11.02 | 11.02 | 11.02 |
| | Eastern Mainline | 1439 | 2788 | 2321 | 9.64 | 9.64 | 9.64 |
| | North Wilts Canal | 592 | 1101 | 983 | 3.84 | 3.84 | 3.84 |
| 10 mm/d seepage and 2000 boats per year | Summit | 358 | 658 | 536 | 2.34 | 2.31 | 2.31 |
| | Western Mainline | 490 | 1181 | 808 | 5.91 | 5.87 | 5.82 |
| | Eastern Mainline | 717 | 1378 | 1151 | 5.24 | 5.15 | 5.15 |
| | North Wilts Canal | 286 | 526 | 417 | 1.98 | 1.95 | 1.94 |
| 20 mm/d seepage and 2000 boats per year | Summit | 579 | 1066 | 886 | 3.75 | 3.70 | 3.69 |
| | Western Mainline | 931 | 2178 | 1509 | 10.44 | 10.36 | 10.25 |
| | Eastern Mainline | 1316 | 2520 | 2103 | 9.19 | 9.03 | 9.02 |
| | North Wilts Canal | 527 | 966 | 785 | 3.51 | 3.45 | 3.44 |
| 1.75 Ml/km/wk seepage and 2000 boats per year | Summit | 639 | 1190 | 990 | 4.08 | 4.08 | 4.08 |
| | Western Mainline | 1111 | 2573 | 1739 | 11.36 | 11.36 | 11.36 |
| | Eastern Mainline | 1466 | 2839 | 2358 | 9.98 | 9.98 | 9.98 |
| | North Wilts Canal | 588 | 1092 | 885 | 3.84 | 3.84 | 3.84 |
| 10 mm/d seepage and 4500 boats per year | Summit | 501 | 922 | 763 | 3.23 | 3.20 | 3.20 |
| | Western Mainline | 563 | 1323 | 919 | 6.76 | 6.72 | 6.66 |
| | Eastern Mainline | 786 | 1509 | 1255 | 6.10 | 6.00 | 6.01 |
| | North Wilts Canal | 288 | 529 | 417 | 2.09 | 2.06 | 2.05 |

| | | Storage Required (Ml/d) | | | Canal losses (Ml/d) | | |
|---|---|---|---|---|---|---|---|
| | | Average Year | Driest Year | 1 in 5 year | Average Year | Driest Year | 1 in 5 year |
| 20 mm/d seepage and 4500 boats per year | Summit | 722 | 1329 | 1113 | 4.64 | 4.58 | 4.58 |
| | Western Mainline | 1004 | 2321 | 1607 | 11.29 | 11.21 | 11.09 |
| | Eastern Mainline | 1385 | 2651 | 2206 | 10.05 | 9.88 | 9.87 |
| | North Wilts Canal | 529 | 969 | 787 | 3.62 | 3.56 | 3.55 |
| 1.75 ml/km/wk losses and 4500 boats per year | Summit | 782 | 1453 | 1217 | 4.97 | 4.97 | 4.97 |
| | Western Mainline | 1117 | 2618 | 1753 | 12.21 | 12.21 | 12.21 |
| | Eastern Mainline | 1536 | 2972 | 2467 | 10.83 | 10.83 | 10.83 |
| | North Wilts Canal | 590 | 1095 | 887 | 3.95 | 3.95 | 3.95 |

**Table 6.7 - Required reservoir storage and canal losses for an average, the driest and 1 in 5 year level of service reference year.**

# 7 WATER RESOURCE OPTION ASSESSMENT

## 7.1 Approach

The water balance analysis presented in Section 6 indicates that a large volume of storage and/or direct abstraction and support through the summer months is required to maintain a water balance and hence a navigable canal. The lowest canal loss scenario was presented because even at losses at this level analysis indicates that a substantial storage volume is required to maintain a navigable canal. This storage increases significantly at higher loss scenarios.

Similarly the water balance presented only considers surface water abstractions and no other sources. This is a reflection of the greater certainty in the availability of water, given CAMS restrictions, as well as the availability of daily gauged flow data. Other sources have much less certainty in water availability either due to physical or environmental constraints or lack of knowledge.

Our approach to the water resource option assessment is therefore to consider options in order of increasing uncertainty. The options will be discussed in the following order:

1. **Surface water abstraction and supporting storage** – the assessment will present potential locations of storage and engineering costs, together with the assumptions behind these costs.

2. **Demand management** – the assessment will present options for demand management, and in particular, the use of canal liners, and associated engineering costs based on an assessment of the geology over which the restored canal passes. Other options such as back pumping are also considered.

3. **Groundwater sources** – areas of potential resource development from the review of groundwater sources presented in Section 4 are considered.

4. **Existing storage** – utilisation of storage at Tockenham reservoir and Coate Water are considered in more detail to assess the potential to reduce reliance on the development of new storage facilities.

5. **Other sources** - potential urban and agricultural runoff sources are not considered due to the lack of information pertaining to their location and to their potential yields. While the field visits, discussions with Project Steering Group and the review of previous reports has identified urban runoff as a potential source this study has established that sufficient data for yield analysis is not available without additional work. The recommendations presented in section 10 discuss how these sources may be assessed in future.

## 7.2 Surface Water Abstraction and Storage

### 7.2.1 Introduction

The optioneering of engineering solutions for the proposed supply of water to the Wilts & Berks Canal was completed in order to provide approximate costs for the civil and electrical works associated with the successful operation of the canal throughout drier months through the provision of storage. Conveyance of water to an off channel storage facility as well as conveyance of water from the storage facility to the respective portion of the canal has also been addressed.

The outline assessment has been completed without any topographical survey information and several assumptions on infrastructure such as power supply, access and availability of materials have been made. In conjunction with the high, medium and low seepage scenarios cost estimates have been prepared to accommodate respective storage and conveyance systems to indicate the resulting range of results.

### 7.2.2 Conceptual Design Methodology

For the purposes of the conceptual design, the canal and water supply scheme has been split into the following components;

i. Canal refurbishment in specific portions with different liner types.
ii. Abstract water from the identified resource.
iii. Supply Water to the identified areas for Storage.
iv. Storage of Water.
v. Supply of Water to the Canal Pounds.
vi. Overflows from the Canal and the Water Storage Locations.

### 7.2.3 Water Abstraction Locations

Indicative reservoir locations have been identified based on the following criteria:

- Within close proximity to the source and the canal to minimise engineering costs
- Not sited on a designated or non-designated protected area
- Founded below ground level to maintain the natural flood plain storage
- Preference given to sites on clay to minimise lining costs
- Sited so as to avoid any infrastructure such as roads, railways and buildings

The conveyance of water from the points of abstraction to the storage reservoir(s) are assumed to be done by mechanical means i.e. pumps with a varying length of rising main connecting to the water storage reservoir. At this stage it was assumed that suitable power supply point is available within 1km from the pumping facility.

Provision has been made for single duty pump and one standby pump arrangement at each pump station to facilitate uninterrupted supply during maintenance or breakdowns. No provisions for alternative power supplies have been provided. For the outline costs it has been assumed that the pumps will each be working for 12 hrs per day.

In all cases provisions have been made for standard brick building for the pump stations. Rising mains are taken as buried UPVC in all cases.

Provision has been made for Telemetry control between storage reservoirs, pumping station and abstraction point at each abstraction.

Pumping station capacities and associated infrastructure have been sized for demand scenarios associated with losses of 10 mm/d and 1,000 boat movements upstream.

### 7.2.4 Water Storage Locations

Potential locations for storage reservoirs have been identified for each pound. These locations are as shown in Figure 7.1; Appendix 1. At this stage it has been assumed that the storage will be provided below ground to comply with advice from the EA on avoiding any increased flood risk as a result of building reservoirs in the floodplain. The below ground storage volumes have been calculated assuming vertical sides and a maximum depth of 1.5m. At this stage, the sizing of the storage has made no allowance for the effects of sedimentation.

Seepage and groundwater infiltration are not assumed to be issues in the layout and costing of the storage locations. From a review of the geological information available storage reservoirs have been located on Oxford Clay areas and this should avoid the need for a special liner material for the reservoirs.

No provision has been made for land acquisition, access roads, safety or security fencing or any emergency overflow structures.

### 7.2.5 Water Supply to the Canal

Abstractions from each of the storage locations to the canal in each pound are assumed to be done by mechanical means (i.e. pumps) with a varying length of rising main connecting to the water storage reservoir. For the purposes of costing it has been assumed that the length of rising main required is calculated from the proposed water storage location to the top end of the canal pound. At this stage it was assumed that suitable power supply point is available within 1km from the pumping facility.

Provision has been made for single duty pump and one standby pump arrangement at each pump station to facilitate uninterrupted supply during maintenance or breakdowns. No provision for alternative power supplies has been provided. Rising mains are taken as buried UPVC lines in all cases.

Provision has been made for Telemetry control between storage reservoir, pump station and canal at each abstraction.

Summarised costs to provide storage and to convey water from the river to storage and from the storage point to the canal are given in **Figure 7.1**.

| Ref | Storage Average Year (Ml) | Storage Driest Year (Ml) | Based on Average Year | Based on Driest Year | O&M Costs for Average Year (7.5%) | Cost Per Ml/d | Location in Cricklade Study |
|---|---|---|---|---|---|---|---|
| WM01 | 79 | 183 | | | | | |
| WM02 | 134 | 310 | | | | | |
| WM03 | 72 | 166 | | | | | |
| WM04 | 131 | 303 | | | | | |
| WM05 | 107 | 249 | | | | | |
| WM Total | 523 | 1,212 | **£7,152,000** | **£19,622,000** | **£536,000** | **£2,330,000** | |
| S01 | 90 | 166 | | | | | |
| S02 | 79 | 145 | | | | | |
| S03 | 53 | 98 | | | | | |
| S04 | 79 | 145 | | | | | |
| S Total | 300 | 553 | **£8,667,000** | **£15,768,000** | **£650,000** | **£4,031,000** | |
| EM01 | 110 | 212 | | | | | |
| EM02 | 102 | 195 | | | | | |
| EM03 | 105 | 201 | | | | | |

| Ref | Storage Average Year (Ml) | Storage Driest Year (Ml) | Based on Average Year | Based on Driest Year | O&M Costs for Average Year (7.5%) | Cost Per Ml/d | Location in Cricklade Study |
|---|---|---|---|---|---|---|---|
| EM04 | 35 | 67 | | | | | |
| EM05 | 27 | 52 | | | | | |
| EM06 | 61 | 118 | | | | | |
| EM07 | 112 | 214 | | | | | |
| EM08 | 103 | 198 | | | | | |
| EM09 | 33 | 64 | | | | | |
| EM Total | 687 | 1,321 | **£17,363,000** | **£33,071,000** | **£1,302,000** | **£4,115,000** | |
| NW01 | 41 | 75 | | | | | R001 |
| NW02 | 41 | 75 | | | | | R002 |
| NW03 | 41 | 75 | | | | | R003 |
| NW04 | 41 | 75 | | | | | R004 |
| NW05 | 41 | 75 | | | | | R005 |
| NW06 | 41 | 75 | | | | | R006 |
| NW07 | 41 | 75 | | | | | |
| NW Total | 287 | 525 | **£7,435,000** | **£13,651,000** | **£558,000** | **£4,590,000** | |
| | | | | | | | |
| **TOTAL** | 1,798 | 3,612 | **£40,618,000** | **£82,112,000** | **£3,046,000** | | |

**Table 7.1 - Summarised Costs for Surface Water Abstraction, Storage and Supply for All Sections in an Average and Driest Year.**

The capital costs for infrastructure (pump stations, rising mains, telemetry) are based on 2 scenarios; average year and driest year in the 32 year record period for a loss scenario of 10 mm/d / 1,000 upstream boat movements.

The scenarios above reflect the maximum demand scenarios for each pumping station and the infrastructure have to be sized to meet the worst case scenario. At this stage it would most likely mean that the infrastructure should be sized to meet worst case scenario and that operating rules be adapted to suit specific seasonal requirements.

Cost per Ml/d varies between £2.3M-£4.6M for provision of this resource option subject to the assumptions stated in section 7.2.7

### 7.2.6 Yearly operational and maintenance costs

The yearly running costs will include provision for electricity supply and usage, maintenance on pump stations and other infrastructure as well as provision for costs for the operation of the pump stations and associated works.

The annual operational and maintenance costs for pump stations and associated infrastructure are, based on experience, in the region of 7.5% of the outlay capital costs. The annual operational and maintenance costs for canal and storage reservoirs are much less, mainly due to energy and infrastructure type. In general a figure of £18,000/km/year (Halcrow, 2002) is used for maintenance on canals. This figure could obviously be influenced by various factors and the choice of liner, traffic and flow regime in the canal will have an influence on the total cost for each pound.

At this stage only an operation and maintenance costs figure for the pump stations and associated infrastructure as described above has been prepared. The expected annual costs per section are reflected in Table 7.1 above.

In addition to capital and operation and maintenance costs mentioned above there will be a charge for abstraction. These charges are determined by the EA and are based on the annual volume, the season of abstraction, the type of source to be abstracted from and the loss. The charges, based on the EA 2007-08 charging scheme (http://publications.environment-agency.gov.uk/pdf/GEHO0307BMFQ-e-e.pdf?lang=_e ) are given in for a total loss of 10 mm/d and 1,000 upstream boat movements per year.

It is assumed that a canal would be treated as a high loss by the EA and the source is unsupported. The standard unit rate for Thames Region for 2007/08 is £13.05/1000m$^{3}$ and for the South West Region is £19.44/1000m$^{3}$. However, it is noted that some of the abstraction licenses may be regarded by the EA as Transfer Licenses in which case they would not be subject to an annual charge.

| Average Year Scenario | Abstraction Required (Ml) | Annual Charge |
|---|---|---|
| Thames Region | 3150 | £61,236 |
| South West Region | 1986 | £25,908 |
| Total | 5136 | £87,144 |

**Table 7.2 - Summary of Abstraction Charges (Figures rounded to nearest £ and Ml; taken from Table 6.3)**

### 7.2.7 List of Assumptions

The following general assumptions have been made during the optioneering of engineering solutions and estimation of costs;

- Topographical Levels are unknown to any usable accuracy.
- It is assumed that all elements of getting flow from the abstraction point to the canal require a pumped arrangement.
- Engineering Design is a desktop analysis and can be considered outline feasibility for the purposes of getting order groups of cost associated with various options
- Above ground storage has not been considered.
- Below ground storage (shallow basins with minimal perimeter bunding from earth embankments) has been adopted for all storage options to ensure that reservoir safety requirements do not become an issue. This approach also complies with EA advice that it is unlikely that consent would be given for above ground reservoirs in the floodplain.
- Below Ground storage is assumed to be rectangular in cross section with constant water depths
- No additional costs are allowed for disposal of excavated material.
- Costs for pumping stations, electrical supply, telemetry and pipelines have been amended based on a £/m3 of volume required.
- Costs for the electricity supply could vary significantly from those given. Confirmation will be required from the local power company
- Costs exclude any allowance for land purchase costs, replacing / relocation of existing infrastructure
- Storage volumes make no allowance for sedimentation.

- Storage volumes make no allowance for free board.
- No allowance is made for back pumping arrangements
- Costs make no allowance for a lining material in the storage reservoirs
- Surface area required for storage has not been cross checked against available land
- No geological interpretation has been done on material characteristics in storage options or feasibility for other civil infrastructure.
- All abstraction licenses will be classified as Full Licenses by the EA
- The loss factor is assumed to be high for abstraction charges.
- The source is unsupported for the abstraction charging scheme.
- The 2007/08 abstraction charging scheme is a reasonable basis for future costs.

### 7.3 Canal Liners

In general there are several engineering methods being utilised worldwide to reduce seepage losses from canals.

The application of the different lining methods are linked to various factors such as geological conditions for the specific pound of canal, availability of natural materials close to the specific area, environmental conditions around the specific area, habitat requirements / constraints, long term maintenance considerations, specific land usage in the surrounding areas, foundation requirements from associated structures, topography and erosion prevention etc.

The basic principle is that the lining of the canal would greatly contribute to the reduction of seepage losses. Seepage losses are accepted from various BW reports to be as much as 75% of the total losses in the canal system. The consequence of an improved liner would thus be reduced seepage loss and thus a reduced volume of required storage in an off channel reservoir.

With reference to experience gained by BW in the construction and maintenance of canals we have accepted that at this stage of the project only three lining types will be investigated. The theoretical reduced seepage rates are shown for each based on existing figures from reports used as reference for this study.

- Puddled clay liners
  A realistic seepage rate of 1 mm/d can be achieved after successful completion of puddling on typical Oxford clays in a 1000 mm deep layer.

- Reinforced Concrete liners
  A realistic seepage rate of 1 mm/d can be achieved after successful completion of 100mm reinforced concrete liner.

- Bentonite / geotextile combination
  A realistic seepage rate of 5 mm/d can be achieved after successful installation of geotextile and bentonite combination matting on the in situ material.

To what degree these theoretical seepage rates can be achieved will depend on site-specific conditions (such as ground conditions and groundwater level), the quality of the materials and the experience of the contractor. Consequently, this study has adopted an average loss of 10mm/d with canal lining in place.

### 7.3.1 Impact of Geology

Geological information has been collated at desk top level. Different geological zones along the canal route are shown on Figures 4.2 a-d; Appendix 1. Seepage calculations and requirements for different lining methods have been based on the different materials expected in each pound. The area of each section underlain by a specific material was expressed as a percentage of the total section length and is shown in Table 7.3.

| Section | Description of Geology | Section Length (m) |
|---|---|---|
| Summit | 100% Kimmeridge and Gault Clay | 13,500 |
| Western Mainline | 7% Drift; 93% Oxford or Kimmeridge Clay | 42,700 |
| Eastern Mainline | 100% Clay; Kimmeridge and Gault | 37,200 |
| North Wilts | 66% Oxford Clay; 34% Drift | 14,500 |

**Table 7.3 – Description of Underlying Geology under Proposed Canal Route**

Any portion of the canal which is not underlain by clay or low permeability material was considered to be susceptible to potential high seepage losses. Different liners were investigated for these portions of canal and alternatives compared on practicality, potential seepage reduction and price. Because of the general occurrence of clay in each pound it was assumed that a sufficient volume of suitable natural liner material is available.

The success of the lining would be dependent upon a number of factors including the skill of those laying the material and also the quality of the clay available on site. A more detailed material investigation needs to be done before final designs can be started. Site investigation needs to be undertaken to confirm overall assumptions on material occurrence, material properties and availability of materials.

### 7.3.2 Cost Estimate Summary

As explained above, lining of the canal to reduce leakage/seepage would involve either puddled clay, concrete or bentonite matting. Each of these would have a cost implication which could typically range from £420/m for puddle clay lining to £580/m for concrete lining (not reinforced) to £635/m for a bentonite matting.

For a puddle clay liner with material available locally as expected in most of the pounds on the Wilts & Berks Canal the above unit costs can be reduced to £230/m and with the percentages listed in the table above a total cost for lining all the required portions are shown in Table 7.4 and as a cost per Ml/d in Table 7.5. It is assumed that local puddled clay will be used where it is available.

The values in table 7.4 below reflects the total estimated costs for the different types of liner or liner combinations required over the total length of the different sections of the canal. From the unit rates assumed above it is clear that a 100% puddle clay liner (local sourced or imported) will be more economical than using proportionate concrete or bentonite liners. The percentage increase for the concrete or bentonite liners are however only 5-6% respectively higher than the clay liner option and with the level of geotechnical information available at this stage these alternatives should not be discarded. Alternative liner material could still be required where specific conditions dictate that clay liner is not feasible.

| Section | Description Of Geology | Section Length (m) | Puddled clay | | | Concrete | Bentonite |
|---|---|---|---|---|---|---|---|
| | | | £420/m | £230/m | Total | £580/m | £635/m |
| Summit | 100% Kimmeridge and Gault Clay | 13,500 | | 3,105,000 | 3,105,000 | 0.00 | 0.00 |
| Western Mainline | 7% Drift; 93% Oxford or Kimmeridge Clay | 42,700 | 1,255,380 | 9,133,530 | 10,388,910 | 1,733,620 | 1,898,015 |
| Eastern Mainline | 100% Clay; Kimmeridge and Gault | 37,200 | | 8,556,000 | 8,556,000 | 0.00 | 0.00 |
| North Wilts | 66% Oxford Clay; 34% Drift | 14,500 | 2,070,100 | 2,201,100 | 4,271,700 | 2,859,400 | 3,130,500 |
| **Total** | | | 3,325,980 | 22,955,630 | **26,321,610** | **4,593,020** | **5,028,565** |

**Table 7.4 - Lining Cost over section length**

The values in table 7.5 below are based on the same unit rates as for table 7.4 but the costs are now expressed in terms of £/Ml/d for total reduction in losses per section of the canal. Only the 10mm/d per 1,000 boat movement scenario is shown at this stage. The unit costs presented in Table 7.5 show that lining is significantly cheaper than reservoir storage.

| Section | Canal Loss (Ml/d) | Seepage (Ml/d) | Seepage After Liner (Ml/d) | Reduction in Canal Loss (Ml) | Puddled Clay - Cost Per Ml/d | Concrete - Cost Per Ml/d | Bentonite - Cost Per Ml/d |
|---|---|---|---|---|---|---|---|
| Summit | 1.99 | 1.41 | 0.141 | 1.27 | £ 2,446,809 | | |
| Western Mainline | 5.57 | 4.52 | 0.452 | 4.07 | £ 2,553,813 | £ ,426,160, | £ 466,572 |
| Eastern Mainline | 4.9 | 3.94 | 0.394 | 3.55 | £ 2,412,860 | | |
| North Wilts | 1.98 | 1.53 | 0.153 | 1.38 | £ 3,102,179 | £ 2,076,543 | £ 2,273,457 |

**Table 7.5 – Expected Cost per Ml for Loss Scenario 10 mm/d / 1,000 boats – average year for full use of various canal liners described above.**

## 7.4 Back pumping

Back pumping is a common approach to minimising canal losses and is used particularly to minimise lockage losses associated with upstream boat movements. Back pumping was not considered explicitly in the canal loss scenarios tested but it is suggested (BW, pers. comm.) that this can reduce lockage losses by up to 15%. For the boat movement scenarios considered in this study between 0.05 and 0.23 Ml/d could be saved from back pumping. Back pumping is regarded as standard for modern canals to ensure that optimum operating efficiencies can achieved. However, there is no benefit in progressing the analysis until the uncertainties in canal losses and potential new storage have been reduced.

## 7.5 Groundwater Options

The EA have identified the aquifer units in the vicinity of the canal as having a CAMS status of ‘no water available’. It is very likely that no new consumptive licences will be granted where the groundwater is hydraulically connected to the rivers. This is particularly true at low flows where hands-off flow conditions may be applied. It is more likely that licences will not be granted if surface water abstractions identified in this study are granted licences for abstraction. Licences where abstractions are not in hydraulic continuity with the river may be granted.

However, potential sources for further investigation include the Corallian aquifer near Shrivenham which the EA have stated they may consider for further abstraction in principle. This could supply the Eastern Mainline section and reduce the requirement for storage and/or surface water abstraction. This source may have a potential yield of up to 0.15 Ml/d but this could be much less. Any abstraction may also impact on spring flows identified for surface water abstraction above (HA39-03-7 and HA39-03-8) and would likely be subject to HOF restrictions if a licence is granted.

Abstraction from the Corallian aquifer near RAF Lyneham may provide additional resource of between 0.15 Ml/d and 0.25 Ml/d for the top of the Western Mainline section. There may be quality issues due to historic aviation fuel spills at RAF Lyneham and any potential abstraction could impact on other local abstractors in the area. There may also be an impact on spring flows although no surface water abstraction has been identified in the analysis in Section 4 and 6.

Other groundwater sources with potential yields up to 1 Ml/d have been identified in the Ock and Cole catchments. However, these catchments have low flow issues. Potential abstractions from the Chalk, Corallian and River Gravels may have impacts on other abstractors in the area as well as potentially impacting on low flows.

There are many uncertainties in developing groundwater sources. Firstly drilling and pump testing may not yield water of sufficient quantity or quality. It is likely that abstraction will be not permitted or restricted during the summer months when water is required most. From the water balance analysis it is clear that the Summit and Eastern Mainline would benefit from groundwater abstraction. However, unless abstraction can be made during the summer then the storage requirement, as identified above, will not change.

There may be a number of water quality issues from groundwater sources such as high iron content as well as contaminants from historic pollution incidents, e.g. RAF Lyneham. The impact of groundwater quality, either fed directly or via off-line storage, on the existing and future ecology of the canal would need to be assessed before an abstraction licence is granted (see Section 8).

## 7.6 Other Storage Options

### 7.6.1 Coate Water and Tockenham Reservoir

A theoretical derivation of the yields available from Tockenham reservoir and Coate Water is shown in Table 7.1. The yields have been derived assuming the storage given in Scott Wilson (1998) and an inflow series derived from the Stanley and Abington Flow series respectively. The inflow series have been derived according to SAAR and catchment area obtained from the Flood Estimation Handbook (FEH CDROM version 2.0) as presented in Section 6. Behavioural analysis of the reservoir storage has been undertaken to determine the theoretical yields given 2 scenarios; constrained and unconstrained operation of the reservoirs. Unconstrained operation assumes that water is taken without constraint and the storage reaches 20% once during the 32 year period. The yield determined under the constrained operation of the reservoir assumes that the reservoir storage never falls below 80% during the 32 year period. In the absence of depth – area relationships for the reservoirs this scenario mimics a reservoir with managed water levels.

It is noted that this yield derivation has many uncertainties including uncertainty in inflows derivation and uncertainty in the actual level of storage which exists due to sedimentation or alterations to the original reservoir construction. Any detailed assessment would require rainfall and reservoir inflow monitoring and derivation of the actual volume / depth from a reservoir survey.

In section 4 it was stated that the utilisation of Coate Water (in part a designated SSSI) is unlikely due to the sensitivity of the ecology to changes in water level, the sensitivity of stakeholders to water level changes and the high engineering costs associated with transferring discharges from the reservoir to the River Ray and onto the canal it is not considered a viable water resource option.

It should be noted that spills from Coate Water could be abstracted further downstream on the River Cole. In the water balance presented in Section 6 these would be abstracted as part of the HA39-03-6 sub-catchment and be put into canal side storage at EM02 (Figure 7.1b; Appendix 1).

Tockenham reservoir, as stated in Section 4 and is under private ownership by the Bristol, Bath and Wiltshire Amalgamated Anglers. The reservoir spills into a tributary of Brinkworth Brook, which crosses the route of the proposed canal. An estimation of the reliable yield suggests about 1.3 Ml/d could be abstracted under unconstrained operation.

No discussions have been held with the organisation and no knowledge was held by the EA about the management of the reservoir. An opportunity may exist to purchase water; however, this has not been explored further here. A reliable yield of 0.7 Ml/d may be realistic subject to the uncertainties as discussed for Coate Water above.

There may be opportunities to augment the natural inflows into the reservoir by either surface water drainage from RAF Lyneham or by pumping raw water from nearby groundwater sources identified in Section 4 and discussed above. This would effectively increase the yield of the reservoir but by how much would be uncertain without detailed assessment.

The reservoir could supply water to the top of the Western Mainline section and would reduce the reliance on building new storage and reduce the impact of abstraction on the River Marden.

| | **Tockenham Reservoir** | **Coate Water** |
|---|---|---|
| Catchment Area [km2] | 3.48 | 8.00 |
| Assumed Storage [Ml] | 273 | 555 |
| Inflow series derived from | Stanley | Abingdon |
| | | |
| **Unconstrained Operation** | | |
| Reliable Yield (Ml/d) | 1.26 | 1.9 |
| Min Storage in Driest Year | 20% | 20% |
| | | |
| **Constrained Operation** | | |
| Reliable Yield (Ml/d) | 0.72 | 1.1 |
| Min Storage in Driest Year | 80% | 80% |

**Table 7.6 - Theoretical Reservoir Yields - Constrained and Unconstrained Reservoir Operation**

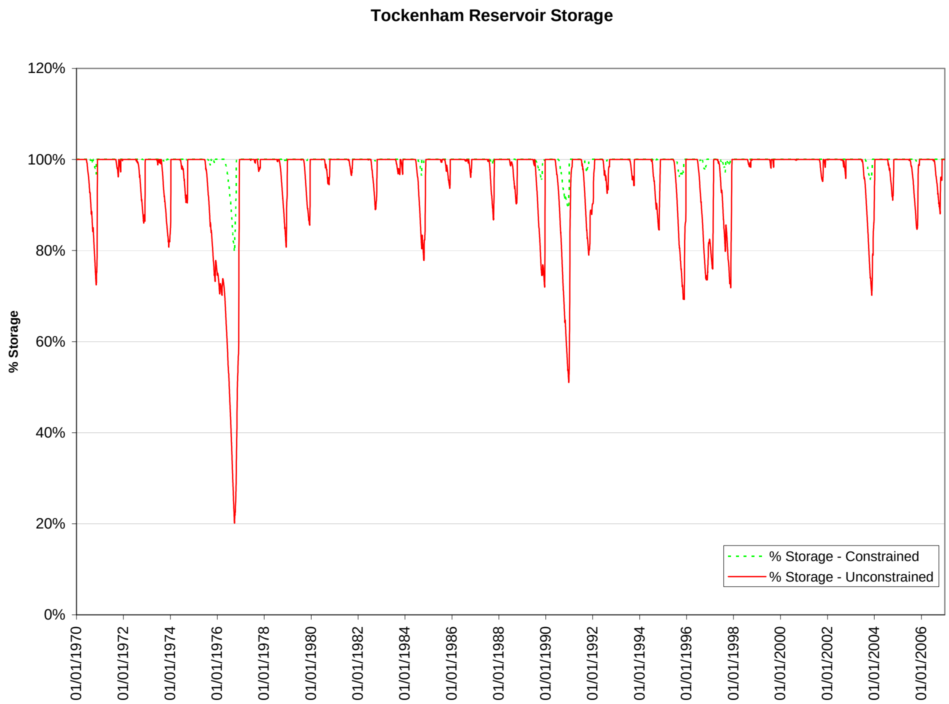


**Figure 7.1 – Theoretical Behavioural Analysis of Tockenham Reservoir Storage, Constrained and Unconstrained**

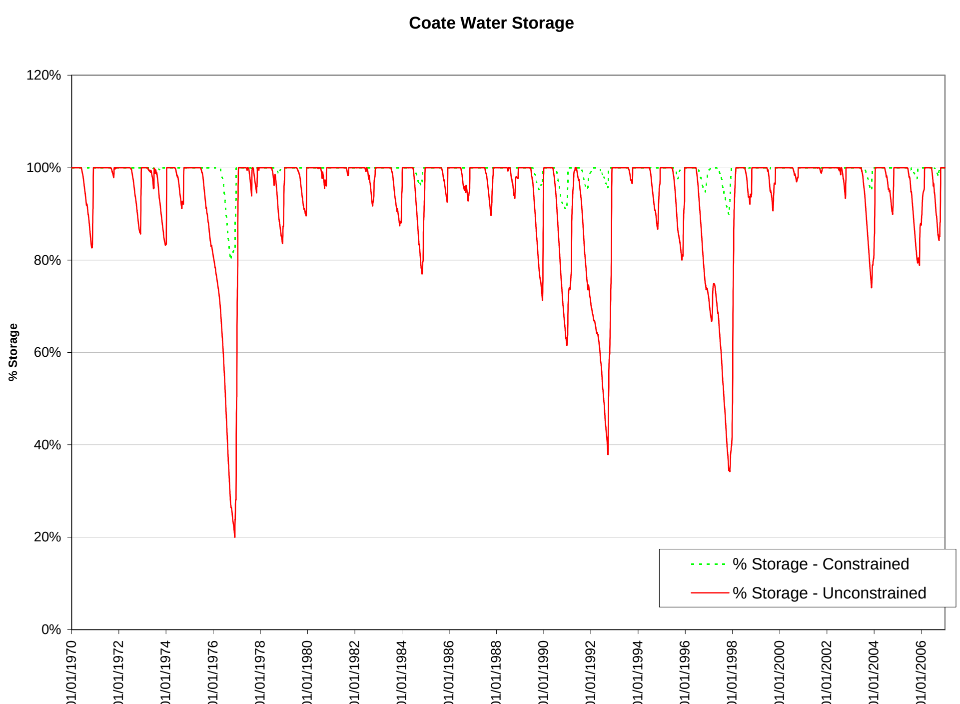


**Figure 7.2 - Theoretical Behavioural Analysis of Coate Water Reservoir Storage, Constrained and Unconstrained**

### 7.6.2 Online Storage

Online storage is effectively storage within direct hydraulic connection with the canal and could include wider and deeper canal pounds and marinas, such as the proposed marinas at the terminae to the NWC. This offers limited extra volume to maintain the canal at navigable depth albeit with increased evaporation and seepage losses. The only additional volume available from this storage is the additional width multiplied by the difference between maximum depth and minimum navigable depth (1.5 m and 1.37 m in the analysis above). If used in conjunction with other source options and demand management such as back pumping then it may provide some water resource benefit. The wider economic and functional benefits of canal widening and development of marinas are the key drivers and not water resources and hence is not considered as a standalone water resource option. The water balance model can be reconfigured in the future to incorporate any increased sections or marinas and the analysis repeated.

# 8 OUTLINE ENVIRONMENTAL APPRAISAL

## 8.1 Introduction

The supply of water to the restored canal will have a number of potential environmental consequences which need to be taken into consideration. The Interim Report for the North Wilts Canal produced in March 2007 included consideration of the environmental issues associated with the actual provision of water to the canal in the first instance and then to the maintenance of supplies once the canal is operational. A separate Environmental Impact scoping report to support a funding bid to the Big Lottery Fund for the Cricklade Country Way (of which the NWC is a part) was produced by Peter Brett Associates, which covered the impacts associated with the construction and operation of the NWC section. No detailed EIA is currently being undertaken for the remaining sections of the Wilts & Berks Canal.

## 8.2 Method

The scope of this commission does not include a detailed investigation and assessment of environmental impacts associated with the provision of water resources for the Wilts & Berks Canal. The study has therefore focused on the key environmental risks facing the scheme and also the potential opportunities for environmental benefit that may be derived.

The approach to the assessment has essentially been via desk study work together with site visits, interaction with the project hydrologists and through consultation with key stakeholders (Environment Agency, Natural England, Wilts & Berks Canal Trust and North Wiltshire District Council). Discussion also took place with Peter Brett Associates with regard to issues on the NWC. The latter was particularly important as they were undertaking environmental field surveys and had useful background information.

## 8.3 Environmental Baseline

The environmental baseline along the canal route has been established mainly through a review of available literature and data searches including the following sources:

- MAGIC website: www.magic.gov.uk
- Landmark Envirocheck Report (PBA)
- Scott Wilson (1998) report
- Environmental Agency website: www.environment-agency.gov.uk
- Swindon Borough Council website: www.swindon.gov.uk
- North Wiltshire District Council website: www.northwilts.gov.uk
- Natural England website: www.naturalengland.gov.uk
- Swindon Gateway Project EIA: www.swindongateway.co.uk
- North Wessex Downs AONB: www.northwessexdowns.org.uk

Consultation has also taken place with key stakeholders. Site visits to look at key areas of the canal route and potential locations for winter storage reservoirs and water supply points were undertaken on 14th December 2006, 6th February, 10th and 11th May 2007.

Broadly speaking, the environment along the route of the Wilts & Berks Canal is predominantly rural in nature with arable farmland and open fields being the main land use. On the NWC section at the Moulden Hill end of the canal it becomes a little more urban although this is really only at the point where the canal passes under Purton Road. Some of the meadows are within the floodplains of the River Ray and River Key and are subject to periodic inundation during periods of heavy rain. A similar situation is evident along the main Wilts & Berks sections. As the canal approaches Swindon from the south-west the urban influence is more obvious even though it runs along the south side of the town. At this point the M4 runs close by; the canal passes beneath it at the western end of the proposed Wichelstowe development (the "Front Garden"). In future, along this stretch the canal would pass through several new housing developments until it passes beneath the A419 near the junction with the M4 at the eastern end of Swindon.

From here, the canal runs north almost parallel to the A419 before turning north-east and then east towards Wantage and Abingdon.

**Plate 1 - River Ray at Moulden Hill, west of the country park**

There are no statutory designated nature conservation sites within the canal route corridor. Table 8.1 below lists the statutory sites located within 2km of the canal and their key features.

| Site Name | Location | Status | Habitat |
|---|---|---|---|
| North Meadow Cricklade | SU 094946 1km north of Cricklade | NNR, SAC, SSSI | Species-rich lowland hay meadow |
| Elmlea Meadows | SU 068937 1.5km NW of Cricklade | SSSI | Species-rich lowland meadow |
| Upper Waterhay Meadow | SU068937 2.5km west of Cricklade | SSSI | Species-rich lowland meadow |
| Stoke Common Meadows | SU 064904 2km west of Purton on Stoke | SSSI | Species-rich lowland meadow |
| Haydon Meadow | SU 120890 1km north of Mouldon Hill | SSSI | Species-rich lowland meadow |
| Coate Water | SU 188820 1km south of Swindon | SSSI | Lake, semi-natural woodland and wet meadows. Important for wildfowl (inc. overwintering) |
| Burderop Wood[1] | SU 165810 1.5km south of Swindon | SSSI | West ash-maple and acid pedunculate oak-hazel-ash woodland |

**Table 8.1 - Statutory nature conservation sites within 2km of Wilts & Berks Canal (including the NWC section)**

[1] Burderop Wood also lies within the North Wessex Downs Area of Outstanding Natural Beauty (AONB) which extends along a large part of the land south of the M4 corridor south of Swindon.

The area east of the A419 at the south-eastern corner of Swindon (near Coate Water), where the canal passes beneath the road before heading north towards Wanborough, is within the North Wessex Downs Area of Outstanding Natural Beauty (AONB). The AONB boundary also extends west along the south side of the M4 to include Burderop Wood. Reconstruction of the canal within the AONB will need to be sympathetic to the landscape setting.

The main watercourses in the study area include the River Ray which flows south to north through Swindon up to its confluence with the River Thames to the east of Cricklade. At the southern end the river flows close to and in places, immediately adjacent to the old canal route. The Environment Agency monitors water quality (chemistry and biology) at several locations along this river including the Haydon Wick reach near Moulden Hill Country Park. The latest data obtained from the Agency's website (2005) indicates that for both chemical and biological quality, the river is Grade B, Good.

The smaller River Key is located towards the Cricklade end of the North Wilts canal.

Within Moulden Hill Country Park there is a small lake which is understood to be fed by groundwater. It is a managed waterbody and is used for recreation including angling.

**Plate 2 - Moulden Lake looking south east towards Swindon**

It is understood that some Phase 1 habitat surveys have been carried out to support the EIA for the CCW scheme therefore some ecological information is available. However, this has not been reviewed as part of this commission. It is understood that a number of protected species such as great crested newts, bats and badgers are known to inhabit the area and therefore the potential impacts on them and their habitats will need to be considered as the water supply options are developed.

Along the main canal route, the other main river is the River Cole, which south to north, east of Swindon up to Cricklade where it joins the River Key. A number of brooks and other watercourses run through the area and these are discussed in earlier sections of this report.

Water quality within the River Cole is listed by the Environment Agency (2000 data) as being Grade B where the Lenta Brook joins the river south of Acorn Bridge (A420 and railway crossing) south-west of Shrivenham.

**Plate 3 - Spring source at Calne**

**Plate 4 - River Cole south-west of Shrivenham**

### 8.4 Environmental Constraints and Possible Mitigation Measures

Providing a sustainable supply of water to the canal, both to fill it after completion of the restoration work, and subsequently to maintain sufficient water to allow navigation, comes with a number of potential environmental risks. As noted in earlier sections, there are several potential options for supplying the canal. At this stage, the environmental considerations have been kept to a generic level focusing on potential risk.

The primary sources of water for the canal are likely to be the Rivers Ray, Key and Cole, however, due to CAMS restrictions the volumes of water that can potentially be drawn off may be limited. A number of other minor watercourses are located throughout the canal length and potential exists to draw water from them. The details of such abstractions are provided and discussed in earlier sections of this report. Groundwater may also be used for topping up as well as surface run off and land drainage. The main risks are considered to be:

- Abstraction from ground or surface water resources which may affect protected sites (statutory and non-statutory) such as flood meadows, wet woodland and wetlands.
- Creation of new reservoirs or storage channels in adjacent habitats may affect protected terrestrial species of flora and fauna, such as badgers, reptiles, grassland plants.
- Restoration of currently dry sections of the canal may similarly impact terrestrial species using the old channel.
- Linking currently wet sections may adversely affect wildlife already present, potentially including great crested newt, water vole, important aquatic insects such as water beetles, dragonflies etc.
- All construction work has potential to negatively affect species and habitats. Widespread surveys for bats, badgers, newts, reptiles etc are likely to be required.
- The potential contamination of groundwater and the impact of any hydraulic connectivity in those areas where the canal passes through permeable strata.

There will inevitably be impacts on habitats and species that have established along the line of the canal and within the sections that have already been subject to some restoration work. The latter have, in most cases, started to become overgrown. Where there is water within the canal basin, new aquatic and fringe habitats have established leading to potential for protected species such as great crested newts to be present. Such species are subject to statutory protection and therefore future restoration work will need to be done in accordance with relevant nature conservation legislation and regulations such as the Wildlife and Countryside Act 1981, as amended. Mitigation to offset the loss of, or damage to these habitats and species will almost certainly be required. However, the loss of habitat must be viewed in the context of the overall canal restoration project which will result in a substantial amount of new aquatic and fringing habitat being created.

**Plate 5 - Restored section near Moulden Hill. Note the spread of vegetation into the main channel**

**Plate 6 Letcombe Brook at Wantage**

Some of the more specific risks are discussed below.

### 8.4.1 Abstraction from Rivers and Watercourses

It is proposed that the main rivers identified in the area will be the primary source of water for most of the canal. Any abstractions will generally be carried out during the winter months when flows in the rivers are above the $QN_{50}$ threshold. In and of itself, this should not result in any adverse impacts to the biological communities within the rivers. It will be important to ensure that water taken from any river is of a suitable quality for introduction to the canal and storage reservoirs. Any abstraction of base flow volume would have potentially more serious effects on in channel and riparian species although the Environmental Agency would generally not allow abstraction to take place under low flow conditions.

Once operational there would be a need to ‘top up’ the canal on a regular basis, particularly during the summer months when water losses through evaporation, seepage and from boat traffic would be greatest. The storage reservoirs would need to be designed and managed in order to maintain an acceptable level of water quality and minimising the risk of algal blooms establishing. Transfer of water to the canal is likely to be subject to licensing by the Environment Agency.

Abstraction of water from other minor watercourses will need to consider the potential impacts on the aquatic ecology and riparian habitats associated with them and also any habitats these watercourses sustain downstream of abstraction points. Reductions in flow rate, water depth and/or water quality could adversely affect the delicate ecological balance some distance away.

It is understood that even in the early stages when the canal is not connected at either end, the Wilts & Berks Canal Trust plans to operate a small number of cruises for visitors to enjoy the canal. Water will move down the canal as boats go through the locks. At the bottom of the navigation water will require to be discharged, stored or back-pumped. At this time it has been assumed that a storage reservoir will be constructed into which water can be directed with the option of back pumping this water further up the canal. Alternatively, water may be discharged into the River Thames. Whichever option is pursued, there will be a need for a discharge licence which will impose water quality limits. Once fully operational with boats regularly navigating along the canal, the water will become turbid caused by propeller action and boat wash. This is a normal situation in canals as a result of the generally shallow water and relatively deep draught of narrowboats. During particularly dry periods water levels within the canal may fall significantly which would exacerbate the turbidity problem.

If the storage reservoir option is developed, there is potential for reed beds to be included to provide a natural treatment for the water including settling out mud and silt. Similar schemes could be incorporated in to the storage reservoirs elsewhere along the canal. Discharges at other locations could incorporate silt traps prior to release into watercourses or to land drains. The potential impact on land drainage flows will need to be considered as the construction of small reservoirs could alter how some areas of farm land drain, which in turn could adversely impact crops.

The potential to construct fewer, larger storage reservoirs with pumping facilities to serve several sections of the canal should be considered in order to minimise land take and habitat/farm land loss. Any storage reservoir will have impacts on the landscape character and visual amenity of the area. Careful siting and design will be required to minimise the impact.

## 8.5 Opportunities for Environmental Gain

As with any development, there are often opportunities to achieve environmental benefits. In the case of the Wilts & Berks Canal the key opportunities are:

- Primary habitat creation – canal, inner and outer margins may benefit wildlife, such as water vole and dragonflies, assuming water quality and vegetation structure are good.
- Secondary habitat creation – storage reservoirs and transfer channels in adjacent areas may represent ecological improvements on the existing situation. Most of the land along the canal is farmland which generally has low biodiversity.
- Related ecological gain – if well vegetated margins of canal area are created, with ecotone[2] between the canal and surrounding farmland, a continuous movement corridor for species such as bats, reptiles, amphibians will be created, assisting dispersal and foraging activities of these groups.

Other potential non-environmental enhancements include:

- Education - signboards could be erected at key locations to explain the history of the canal and local significance.
- Recreation – in addition to the obvious benefits of introducing boating, the canal could also offer opportunities for angling, walking and nature conservation.

## 8.6 Conclusion and Recommendations

The key environmental impacts associated with providing water for the canal are related to water quality, both in terms of the sources feeding the canal and discharges from the canal into storage reservoirs or watercourses. All abstractions and discharges will be subject to consent by the Environment Agency with associated limits on water quality parameters.

[2] Transitional/buffer zone between habitat types

Once the preferred combination of water sources and storage facilities is determined, it is recommended that further detailed studies be undertaken to establish water quality and the appropriate design parameters for treatment systems such as reed beds etc. This will enable the optimum operating conditions for the canal to be established and incorporated in to the engineering design for the future restoration works.

At present, restoration of the canal is being undertaken in a piecemeal fashion on a small scale, usually with the permission of the relevant landowners, with short sections of the canal basin being cleared and reprofiled and lock structures re-constructed. However, given the overall length of the canal it is very unlikely that the restoration could continue as small discrete elements and therefore the full restoration will almost certainly require planning consent from the relevant planning authorities and be supported by a detailed Environmental Impact Assessment. Under the Town & Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1999, as amended, construction of inland waterways is included within Schedule 2 as infrastructure development where the area of work exceeds 1 hectare.

Although a restoration project, the fact that much of the canal is now overgrown or, in places, has been built over, means that it will essentially need to be re-constructed. In some places a new route will need to be identified in order to pass around obstacles that cannot be easily removed (e.g. buildings) or where landowners will not consent to the canal following its original route across their land. As such, the canal might be considered new development in planning terms. From the observations made during the various site visits, rich habitats have established along the canal and although (as noted in 8.4) new habitats will be created as a result of the restoration, a detailed habitat map of the existing canal and ecological assessment of the impacts of the restoration will be required.

**Plate 7 - Newly established habitat (Wootton Bassett)**

The Environment Agency will want to see a detailed assessment of the water resource and associated environmental impacts arising from the construction and operation of the full canal system.

Other issues that will need to be addressed include but are not limited to:

- Land use and community severance
- Landscape and visual impact
- Land drainage

- Changes to Local Amenity – inc. potential nuisance from boating activities
- Transport – disruption due to construction of bridges across the canal
- Waste management – disposal of excavated spoil from the canal channel

It is therefore recommended that early consultation with the relevant planning authorities is undertaken to establish the need for and potential scope of any EIA.

It is also recommended that a detailed masterplan for the restoration of the canal be developed which identifies areas for major construction activities, enhancement potential areas, phasing of restoration and the strategy for obtaining necessary planning and other consents.

# 9 CONCLUSIONS AND STRATEGY

The results of the water balance conclude that a closed water balance can be obtained with the utilisation of surface water abstractions and off line storage supplementing demand during the year. For a demand of 10 mm/d and 1000 boat movements, a demand of 14.44 Ml/d can be met from surface water abstraction and storage. The off-line storage required to maintain the canal navigable in an average year (1979) is 1798 Ml. This increases to 3612 Ml to maintain navigation in the driest year in the 32 year record (1975). It should be noted that to achieve an average seepage rate of 10 mm/d it is assumed in this study that the canal would have to be lined.

British Waterways suggest figures of 1.75 Ml/Km/Wk (which equates to 24mm/d) and average boat movements of 4,500 for a restored and linked canal. This equates to a demand of 32 Ml/d with storage requirements varying from 4,036 Ml in an average year to 8,160 Ml in the driest year. This is more than twice the demand of the lowest scenario and when considering the engineering costs of excavation for the lowest demand scenario clearly indicates that demand management through restricted boat movements. Moreover, the relatively low cost of lining would suggest that it would be more economic to line the canal to reduce the volume of new reservoirs required.

For an average year the cost per Ml/d for canal liner varies between £2.4M to £3.1M for a puddled clay liner. This compares to the cost of providing storage with surface water abstraction of between £2.3M - £4.6M per Ml/d. The cost per Ml/d for storage does not include land acquisition costs and therefore will underestimate the total cost. It is therefore more economic to reduce losses through lining the canal as far as is practical to reduce the volume of storage required.

The costing presented in this study indicate that the cost of achieving sufficient water resources for a navigable canal would be £68.2M comprising of £27.6M for the canal lining and £40.6M for new storage. These are only indicative costs at this stage and are designed to show the relative magnitudes of the different options and the scale of the challenge. The operational and maintenance costs are of the order of £3M but again this is an indicative value and is dependent on the capital cost.

The costs of water resources also need to be balanced with the level of service required by the canal operator. The need for new reservoirs can be minimised through accepting the need for demand management. However, even if an "average year" level of service is accepted there is clearly a need for new storage to balance the seasonal variations on abstractions.

Where possible the % of flow abstracted above the HOF was restricted to 10% in line with the UK TAG Guidelines on the implementation of the WFD. However for higher loss scenarios this constraint had to be relaxed at a number of intakes in order to achieve a viable water balance. For the lowest demand scenario (10 mm/d seepage and 1000 boats) the constraint was not broken. However for the BW suggested figure of 1.75 Ml/Km/Wk and boat movements of 4,500 per year, abstraction for the Eastern Mainline and Summit can vary from 23% to 29% and 18% to 24% from an average to dry year for each section respectively. Abstraction for the NWC and Western Mainline section remain below the 10% threshold for this canal. Local low flow or ecological issues in the headwaters of the Ock, Cole and Ray may limit or prevent abstraction at this level.

While a number of uncertainties exist, which the W&BCT will need to address before an optimal water resource strategy can be established, this report can conclude that a viable water resource strategy exists in principle. The following 4 step process is suggested as a strategy for reducing the key uncertainties:

1. **The viability of the canal under low loss conditions.** The viability of the canal increases with decreasing losses. However, demand management either by provision of back pumping, restrictions on boat movements or the use of canal liners either reduces income or increases capital and operational costs. From the analysis in Section 7 the unit cost of this report suggests that a canal liner should be considered prior to building storage. Therefore it is recommended that the W&BCT considers the options for canal liners and other demand management measures in more detail to determine whether the costs are prohibitive to the restoration of the canal. In addition it is recommended that a detailed assessment of boat movements is undertaken in conjunction with BW. This will help provide more robust canal loss scenarios.

2. **The viability of existing storage**. It is highly unlikely that Coate Water could be developed as a resource because of stakeholder interests and ecological impacts on the designated SSSI. Tockenham reservoir is under private ownership and it is recommended that the Steering Group hold discussions with the Bristol, Bath and Wiltshire Amalgamated Anglers to assess whether any agreement could be made on the use of water from this source. The feasibility of re-connecting the canal with its original reservoir sources can only be explored through a more complete understanding of the hydrology of these reservoirs and the requirements of stakeholders. Development of existing storage would require a full yield assessment potentially requiring the monitoring of inflows, outflows, reservoir levels and sediment budget.

3. **The viability of the canal is dependent on providing new storage.** The engineering assessment suggests the costs of providing storage are large. The W&BCT needs to consider whether the costs are prohibitive to the restoration of the canal before any further investigations are undertaken bearing in mind that these costs do not include land acquisition costs. It is recommended that a feasibility study is undertaken to confirm the viability of the developing new reservoirs and their associated cost. This study would include site surveys, hydrological and engineering assessment, cost estimation and stakeholder liaison on a site by site basis. It is only through this level of study that the viability of new storage can be determined and hence the need to identify and assess other sources or demand control measures identified.

4. **The need to assess groundwater and other sources.** This study has identified the existence of numerous groundwater and other sources which may have the potential to supply a restored canal. The level of data available on each source is inadequate at this time for a hydrological and engineering assessment of their viability and reliability. Assessment of potential groundwater resources would require further desktop studies including the analysis of existing BGS records. Further discussions need to be held with the EA following this assessment before site surveys, exploratory drilling, pump testing and water quality sampling can be undertaken (subject to being granted a W32(3) consent).

If steps 1 to 4 above provide favourable outcomes then it is recommended that the W&BCT undertake more detailed feasibility studies to determine the viability of the sources discussed here. All studies should be undertaken in close cooperation with the EA to ensure any potential constraints to resource development are identified early.

This study identifies a number of potential surface water sources. Monitoring of flow and levels and water quality should be undertaken at these sources in liaison with the EA. The B&WCT should note that the EA may require monitoring prior to consenting abstractions.

# 10 FURTHER RECOMMENDATIONS

This study was undertaken largely at desk top level with the input of stakeholder consultation. Section 9 identifies a 4 step process for the Steering Group which this study recommends should be followed following this study. The proposed process focuses on undertaking more detailed feasibility studies, site surveys and source monitoring.

In addition to above the outline environmental appraisal makes recommendations on a number of key issues:

- Full restoration of the canal will almost certainly require planning consent from the relevant planning authorities and be supported by a detailed Environmental Impact Assessment.
- Due to rich habitats being established along the existing canal and the new habitats that will be created as a result of the restoration, a detailed habitat map of the existing canal and an ecological assessment of the impacts of the restoration will be required.
- It is also recommended that a detailed masterplan for the restoration of the canal be developed which identifies areas for major construction activities, enhancement potential areas, phasing of restoration and the strategy for obtaining necessary planning and other consents.

The water balance model presented in this study provides a basis on which yield and storage requirements can be assessed. It shows an improvement on the study by Scott Wilson (1998) in that it presents a detailed consideration of source availability in relation to the EA’s assessment of resource availability. There are a number of improvements which can be made to the approach:

- Consideration of evaporation in the model could be improved. Evaporation was represented as an average monthly profile which does not accurately reflect evaporation in a dry year. It is recommended that further work includes the use of time-series monthly or daily meteorological data from MORECS or other sources.
- Uncertainty in canal losses is considered by testing various demand scenarios in the water balance model. However, uncertainty in source availability and in particular, the uncertainty of the surface water sources has not been considered. It is recommended that further work be undertaken to assess the uncertainty of these sources to climate change impacts. Updated guidelines and climate change impact scenarios have been recently published by UKWIR and it is recommended these are considered in further work.

## 11 REFERENCES

Association of Inland Navigation Authorities (2005). Managing Water Resources: A Good Practice Guide to Navigation Authorities.

BGS 1971a: Geological Map, Sheet 253 (Abingdon) Solid and Drift Edition scale - 1:63,360 (1 inch: 1 mile).

BGS 1971b: Geological Map, Sheet 266 (Marlborough) Solid and Drift Edition, scale - 1:50,000.

BGS 1974: Geological Map, Sheet 252 (Swindon) Solid and Drift Edition, scale – 1:50,000.

BGS 1990: Geological Map, Sheet 265 (Bath) Solid and Drift Edition, scale – 1:50,000.

BGS, 1997: The Physical Properties of Major Aquifers in England and Wales. Hydrogeology Group. Technical Report WD/97/34 – Environment Agency R&D Publication 8.

BGS, 2000: The Physical Properties of Minor Aquifers in England and Wales. Hydrogeology Group. Technical Report WD/00/04 – Environment Agency R&D Publication 68

British Waterways (2003). Restoring the North Wilts Canal, Cricklade – Restoration Route Options Feasibility Study.

Dalby, J. L. (1986). The Wilts and Berks Canal. The Oakwood Press.

Environment Agency (2002). Enhanced low flow estimation at the ungauged site and modelling historical flow sequences at the ungauged site. Project Summary Report R&D Project 0638 and W6-021.

Environment Agency (2004). The Thames Corridor Catchment Abstraction Management Strategy.
Environment Agency (2005): The Bristol Avon Catchment Abstraction Management Strategy.

Environment Agency (2006). The Vale of While Horse Catchment Abstraction Management Strategy.

Halcrow (2002). The Wilts and Berks Canal Alignment at Melksham: Engineering Study Report July 2002 for the Wilts and Berks Canal Trust.

Scott Wilson Kilpatrick & Co. Ltd (1998). Restoring of the Wilts & Berks Canal, Feasibility Study. Final Report.

Shaw, E (1988). Hydrology in Practice.

WFD UK Technical Advisory Group (2006). UK Environmental Standards and Conditions (Phase 1), Final Report (SR1-2006), UKTAG, August 2006.

## APPENDIX 1 – SUPPORTING FIGURES

# APPENDIX 2 – WATER RESOURCES REGULATIONS

## APPENDIX 2 – WATER RESOURCES REGULATIONS

### Bristol Avon CAMS

The summit level and western main line of the main canal pass through the catchment of the catchment of the Avon. The EA's strategy for abstraction management in this region is set out in the Bristol Avon CAMS.

The region is split into 10 Water Resource Management Units (WRMU). These units include all major abstractions in the area and allow the resource assessment to take account of all major rivers and aquifiers. Only WRMU 2 (Bristol Avon) and 7 (Semmington Brook) are relevant to this study.

The state of both WRMU 2 and WRMU 7 are given as "no water available". This indicates that no water is available for licensing at low flows although abstraction may be permitted at higher flows with appropriate conditions.

The EA report that following a sustainability appraisal it was decided that the management of these units over the next CAMS cycle should remain at the status of "no water available", although licenses can continue to be granted until the unit moves to the boundary of "no water available" (Note that "No water available" is the sustainable limit of a WRMU and means there is enough water for the environment and there is no need for resource recovery).

The EA state that licenses will continue to be issued as normal until the boundary of "no water available" is reached. To remain within this status, all new licenses will have time limits and those issued may have some conditions. As the boundary of "no water available" is approached it is unlikely that new consumptive licenses or increases to existing consumptive licenses would be allowed during times of low flows in these units. Those issued are likely to have a flow constraint so these licenses are unlikely to be reliable throughout the year (This also applies to groundwater licenses unless appropriate constraints could be included in the licence). The resource availability status is an indication of resource availability at low flow; licenses may be issued for use at times of higher flows but contain a hands-off flow condition.

For the purpose of this study a local HOF constraint of natural $Q_{76}$ will be adopted for all surface water abstractions (based on guidance from the EA).

### Thames Corridor and Vale of White Horse CAMS

The North Wiltshire Canal (NWC) crosses the catchments of the Rivers Ray and Key. In its lower reaches it crosses the floodplain of the River Thames. The Rivers Ray and Key are covered by the Vale of White Horse Catchment Abstraction Management Strategy (VWHCAMS) while the upper reaches of the River Thames lie within the Thames Corridor Catchment Abstraction Management Strategy (TCCAMS).

The resource availability of the Ray, Cole, Ock and Ginge Brook returned a low flow resource availability status of "water available". However, this has been overridden to protect the status of the lower Thames and has been assigned a status of "no water available."

The VWHCAMS reports that both the fully licensed and recent actual scenarios are above the ecological flow objective for 100% of the 365 days of the year for the rivers Ray, Ock and Cole.

The VWHCAMS reports a surplus of 34.1 Ml/d and 31.8 Ml/d for the River Ray under the recent actual scenario and under the full licensed scenario at the 95 percentile flow (Q95). The flow exceeds the ecological flow objectives for 100% of the 365 indicating that surplus flow is available all year round.

However, as all the VWHCAMS rivers are tributaries of the Thames allowance had to be made for the status of the lower Thames. Consumptive abstraction from VWHCAMS rivers would lead to further reduction in the flows in the Thames causing the lower Thames to become further over-abstracted. Therefore a Hands-Off-Flow (HOF) constraint of the Q50 at Kingston Weir on the Thames will be applied to all new licences as well as a local HOF condition.

The TCCAMS gives the following policies on new abstractions:

| | |
|---|---|
| Consumptive Abstractions from Inland Waters (Rivers, Streams, Lakes, Ponds etc) | |
| Policy G1 | No licences will be granted allowing the abstraction of water in the summer months (April to October) for a consumptive use from an inland water except in cases which can be continuously monitored and with a condition prohibiting abstraction at times when river flows are below a prescribed flow. |
| Policy G2 | Winter abstractions from inland water will normally be allowed but will also contain a prescribed flow condition. |
| Non-consumptive Abstractions | |
| Policy G6 | Where a very high proportion (95% or more) of the water taken is returned to the source of supply upstream of or immediately downstream of the point of abstraction a licence will normally be granted provided that any by-passed stretch of channel is adequately protected against low flows. |
| Very Small abstractions "De minimus" | |
| Policy G7 | Very small abstractions for general agricultural, private water undertaking and occasionally other uses, may be allowed without the constraint of a prescribed flow, a prescribed level or a time limit. The cut-off limits for an individual abstraction for these concessions will normally be 5000 cubic metres (1.1 million gallons) per year and 20 cubic metres (4,400 gallons) per day. |
| Spray Irrigation | |
| Policy G8 | Spray irrigation abstractions from rivers will not be permitted in summer (April to October) but will normally be permitted in Winter with a prescribed flow constraint to protect low winter flows. |

| Abstractions from the Tideway of the River Thames | |
|---|---|
| Policy G11 | Abstraction from the tideway of the River Thames will normally be permitted providing there is no conflict with water quality and fisheries |

New Licences

i) Abstractions must cease when flow at Kingston Weir falls below Q50.
ii) The rights of any existing licence holders will be protected.
iii) No new consumptive licences at low flows
iv) Licences will be time limited (end date of 2013 and 21 year review)
v) Abstractions for the canal will be considered as consumptive
vi) Consumptive licences for groundwater can be considered where there is no hydraulic connectivity

The local HOF allowance will depend on factors such as:

i) Existing licences and HOF conditions
ii) Designated areas (SSSI, SAC) sensitive to water resources
iii) Non-designated areas
iv) Sensitive species/habitats

There is no surface water abstractions in the Ray catchment so there are no existing HOF to be considered.

There are 3 STW discharging into the Ray. Swindon STW discharge is the largest with a dry weather flow (DWF) consent of 41Ml/d.

All future licence applications are considered by the EA against the requirements of the Water Resources Act 1991 and Water Act 2003. CAMS do not negate the need for a local impact assessment for a licence application. **The EA will always assess the impacts of a proposed abstraction on the local environment and existing licence holders through a local impact assessment. This assessment may override the resource availability status as defined through the resource assessment**. Even if the strategy indicates that water may be available, the local assessment may prevent a licence from being issued.

A large licence held by Thames Water Utilities Ltd dominates authorised abstraction from the River Thames Corridor. The licence allows the company to abstract water from the Lower Thames to supply London. It accounts for 64% of the Thames Corridor CAMS authorised public water supply abstraction. An operating agreement between the Environment Agency and Thames Water Utilities Limited controls actual abstraction rates authorised by this licence. The agreement uses a control diagram that relates storage in the London reservoirs and the time of year to hands-off flow conditions at Kingston gauging station (this gauging station records the flow over Kingston weir). As the volume of water stored in the London reservoirs reduces, the HOF is reduced in three steps from 800 Ml/d to 300 Ml/d. The current policy of no consumptive abstraction in the summer months in Thames Region is designed, in part, to protect the conditions of this licence.

Thames Water Utilities Ltd holds a single licence that dominates authorised abstraction from the Upper Thames WRMU. The licence allows the company to abstract water from the River Thames to fill Farmoor reservoir which is used to supply Oxford, Swindon and Banbury. It is the only public water supply licence in the Upper Thames WRMU and accounts for virtually 100% of the total authorised abstraction in the Upper Thames WRMU. The licence authorises a maximum daily abstraction of 300 Ml but it is constrained by a licence condition relating to the flow at Farmoor gauging station. This constraint reduces the amount permitted to be abstracted during low flow periods.

The TCCAMS states that the EA encourage the use of storage reservoirs to store water for use during periods of scarcity. The use of storage reservoirs will help to alleviate the restrictions of no consumptive abstractions being allowed during the summer months (April to October inclusive). Before a reservoir can be filled during the abstraction period, river flows will need to be either at, or above, the prescribed flow level.

There are many options for off-stream reservoirs, so no explicit rules for determination are given. The Regional Water Resources Strategy supports the development of winter storage in the CAMS area.

The TCCAMS states that the HOF condition at Kingston gauging station is equivalent to the gauged Q50 (1780 Ml/d). This HOF value was approved by the National Water Resources Policy Manager and was outlined in the Thames Corridor CAMS Consultation Document. The HOF was selected primarily to prohibit consumptive summer surface water abstraction, which thereby mimics the previous licensing policy. The Q50 HOF offers the same level of protection to existing abstractors, navigation, water quality and the tideway as the previous licensing policy. In the Thames Corridor it was proposed to maintain the ban on consumptive summer surface water abstraction, so the new HOF will only operate in winter months. In a normal year the HOF will not be enforced, as flows should be high enough for winter abstraction. The HOF will only be enforced in a dry winter and therefore protects the Thames against deterioration of winter low flows.

Tributary CAMS do not have the seasonal ban on consumptive summer surface water abstraction like the Thames Corridor. However, by applying the Thames HOF to new and varied tributary licences all year round, means that in a normal year the HOF will be enforced in the summer to prohibit consumptive surface water summer abstraction. However if it is a wet summer abstraction may be allowed, conversely if it is a dry winter abstraction may be prohibited.

**Summary of the sustainability appraisal results for the Thames Corridor CAMS**

The table below summarises the current and target resource availability status for each water resource management unit and the preferred management options where a Tier 2 appraisal was undertaken.

| WRMU | Current resource availability status | Target - resource availability status | Preferred management option(s) |
|---|---|---|---|
| WRMU1 – Upper Thames | Over abstracted | Over abstracted | • Maintain current presumption against summer abstraction<br>• Investigate feasibility of changing to year-round constrained abstraction<br>• Investigate flow requirements of Oxford watercourses<br>• Encourage licence holders to voluntarily reduce abstraction |
| WRMU2 – Middle Thames | No water available | No water available | No tier 2 appraisal required |

| | | | |
|---|---|---|---|
| WRMU3 – Lower Thames( freshwater sections only) | Over abstracted | Over abstracted | • Maintain current presumption against summer abstraction<br>• Investigate feasibility of changing to year-round constrained abstraction<br>• Investigate flow requirements of Lower Thames and Tideway<br>• Encourage licence holders to voluntarily reduce abstraction |

For the purpose of this study the following assumptions have been adopted:

i) Abstraction only permitted from the Ock, Cole, Ray and Key when the flow at Kingston is above the HOF constraint of $Q_{50}$ (1780 Ml/d) at Kingston
ii) Local HOF constraint of natural $Q_{95}$ as applied at VWHCAMS AP5 on the Ray
iii) Consumptive abstractions of less than 20m3 will not be licensed.

## APPENDIX 3 – WATER BALANCE ANALYSIS

| Losses at 10 mm day and 1000 boat movements | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average Year | | | | Level of Service - 1 in 5 years | | | | Dry Year | | | |
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Canal Losses [Ml/d][1] | 1.99 | 5.57 | 4.90 | 1.98 | 1.96 | 5.52 | 4.81 | 1.95 | 1.95 | 5.47 | 4.81 | 1.94 |
| Direct Abstraction [Ml/d] | 1.16 | 4.01 | 2.90 | 1.08 | 0.73 | 3.10 | 1.68 | 0.71 | 0.39 | 2.29 | 0.94 | 0.45 |
| Supply from Storage [Ml/d] | 0.82 | 1.43 | 1.88 | 0.79 | 1.22 | 2.30 | 3.01 | 1.13 | 1.51 | 3.06 | 3.62 | 1.37 |
| Direct Precipitation [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Transfers from Other sections [Ml/d] [2] | 0.00 | 0.12 | 0.12 | 0.12 | 0.00 | 0.12 | 0.12 | 0.12 | 0.00 | 0.12 | 0.12 | 0.12 |
| Change in Storage [Ml/d] [3] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.13 | 0.01 |
| Deficit [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | | |
| Max % Abstraction of Flow above HOF taken on any day[4] | 12.0% | 5.0% | 11.7% | 3.6% | 12.0% | 5.0% | 11.7% | 3.6% | 12.0% | 5.0% | 11.7% | 3.6% |
| % of Flow Abstracted above HOF | 9.2% | 3.4% | 8.4% | 2.7% | 12.0% | 4.1% | 11.7% | 3.6% | 12.0% | 3.5% | 11.7% | 3.6% |
| Abstraction Rate [Ml/d] over the period (No. of days water is abstracted) | 3.40 | 5.52 | 8.19 | 3.19 | 6.61 | 5.60 | 15.85 | 6.20 | 9.52 | 11.06 | 22.79 | 8.87 |
| No. of days water is abstracted | 213 | 360 | 213 | 213 | 108 | 352 | 108 | 108 | 73 | 247 | 73 | 62 |
| Average Rate Supplied from Storage [Ml/d] (over the No. of days storage is used) | 1.89 | 3.29 | 4.49 | 1.78 | 1.92 | 3.91 | 4.47 | 1.77 | 1.89 | 4.91 | 4.46 | 1.81 |
| No. of days storage is used | 159 | 136 | 153 | 161 | 233 | 181 | 246 | 232 | 293 | 227 | 296 | 275 |

| Storage Requirements for Losses of 10 mm day and 1000 boat movements | | | | |
|---|---|---|---|---|
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Storage Required for an Average Year (Ml) | 300 | 523 | 687 | 287 |
| Storage Required for the Driest Year (Ml) | 553 | 1212 | 1321 | 525 |
| Storage Required for a Level of Service of 1 in 5 Years (Ml) | 447 | 835 | 1099 | 412 |
| Deficit in Storage for Level of Service 1 in 5 Years [Ml] | 106 | 378 | 222 | 114 |

| Losses at 20 mm day and 1000 boat movements | Average Year | | | | Level of Service - 1 in 5 years | | | | Dry Year | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Canal Losses [Ml/d] | 3.40 | 10.09 | 8.85 | 3.51 | 3.34 | 10.01 | 8.69 | 3.45 | 3.34 | 9.89 | 8.68 | 3.44 |
| Direct Abstraction [Ml/d] | 1.97 | 7.29 | 5.20 | 1.92 | 1.16 | 5.68 | 2.91 | 1.13 | 0.66 | 4.13 | 1.66 | 0.73 |
| Supply from Storage [Ml/d] | 1.43 | 2.67 | 3.53 | 1.47 | 2.18 | 4.21 | 5.66 | 2.20 | 2.63 | 5.64 | 6.76 | 2.57 |
| Direct Precipitation [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Transfers from Other Sections [Ml/d] | 0.00 | 0.12 | 0.12 | 0.12 | 0.00 | 0.12 | 0.12 | 0.12 | 0.00 | 0.12 | 0.12 | 0.12 |
| Change in Storage [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | -0.01 | 0.13 | 0.01 |
| Deficit [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | | |
| Max % Abstraction of Flow above HOF taken on any day | 20.0% | 9.0% | 20.0% | 6.0% | 20.0% | 9.0% | 20.0% | 6.0% | 20.0% | 9.0% | 20.0% | 6.0% |
| % of Flow Abstracted above HOF | 15.7% | 6.3% | 15.5% | 4.9% | 20.0% | 7.6% | 20.0% | 6.0% | 20.0% | 6.5% | 20.0% | 6.0% |
| Abstraction Rate [Ml/d] over the period - no of days water is abstracted | 5.82 | 9.99 | 14.96 | 5.81 | 11.29 | 10.00 | 28.94 | 11.25 | 16.43 | 19.14 | 42.13 | 16.33 |
| No. of days water is abstracted | 213 | 364 | 213 | 213 | 108 | 361 | 108 | 108 | 73 | 274 | 73 | 62 |
| Average Rate Supplied from Storage [Ml/d] | 3.18 | 5.95 | 8.27 | 3.15 | 3.20 | 6.95 | 8.13 | 3.14 | 3.23 | 8.47 | 8.18 | 3.25 |
| No. of days storage is used | 164 | 142 | 156 | 170 | 249 | 190 | 254 | 256 | 297 | 243 | 302 | 289 |

| **Storage Requirements for Losses of 20 mm day and 1000 boat movements** | | | | |
|---|---|---|---|---|
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Storage Required for an Average Year (Ml) | 522 | 976 | 1290 | 536 |
| Storage Required for the Driest Year (Ml) | 960 | 2230 | 2469 | 983 |
| Storage Required for a Level of Service of 1 in 5 Years (Ml) | 796 | 1534 | 2065 | 803 |
| Deficit in Storage for Level of Service 1 in 5 Years [Ml] | 165 | 696 | 404 | 180 |

| Losses at 1.75 Ml/Km/Wk 1000 boat movements | Average Year | | | | Level of Service - 1 in 5 years | | | | Dry Year | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Canal Losses [Ml/d] | 3.73 | 11.02 | 9.64 | 3.84 | 3.73 | 11.02 | 9.64 | 3.84 | 3.73 | 11.02 | 9.64 | 3.84 |
| Direct Abstraction [Ml/d] | 2.13 | 7.93 | 5.58 | 2.10 | 1.26 | 6.29 | 3.16 | 1.28 | 0.71 | 4.58 | 1.75 | 0.82 |
| Supply from Storage [Ml/d] | 1.59 | 2.96 | 3.94 | 1.62 | 2.46 | 4.60 | 6.36 | 2.45 | 2.97 | 6.32 | 7.64 | 2.88 |
| Direct Precipitation [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Transfers from Other Sections [Ml/d] | 0.00 | 0.12 | 0.12 | 0.12 | 0.00 | 0.12 | 0.12 | 0.12 | 0.00 | 0.12 | 0.12 | 0.12 |
| Change in Storage [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.13 | 0.02 |
| Deficit [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | | |
| Max % Abstraction of Flow above HOF taken on any day | 22.0% | 10.0% | 22.3% | 7.2% | 22.0% | 10.0% | 22.3% | 7.2% | 22.0% | 10.0% | 22.3% | 7.2% |
| % of Flow Abstracted above HOF | 17.3% | 6.9% | 16.9% | 5.4% | 22.0% | 8.4% | 22.3% | 7.2% | 22.0% | 7.3% | 22.3% | 7.2% |
| Abstraction Rate [Ml/d] over the period - no of days water is abstracted | 6.40 | 10.95 | 16.36 | 6.40 | 12.60 | 11.01 | 32.17 | 12.58 | 18.45 | 20.92 | 47.07 | 18.42 |
| No. of days water is abstracted | 212 | 363 | 212 | 212 | 108 | 361 | 108 | 108 | 73 | 278 | 73 | 62 |
| Average Rate Supplied from Storage [Ml/d] | 3.60 | 6.70 | 9.25 | 3.58 | 3.60 | 7.59 | 9.21 | 3.60 | 3.66 | 9.34 | 9.26 | 3.64 |
| No. of days storage is used | 162 | 139 | 156 | 166 | 250 | 187 | 252 | 248 | 296 | 247 | 301 | 289 |

| **Storage Requirements for Losses of 1.75 Ml/Km/Wk and 1000 boat movements** | | | | |
|---|---|---|---|---|
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Storage Required for an Average Year (Ml) | 582 | 1082 | 1439 | 592 |
| Storage Required for the Driest Year (Ml) | 1084 | 2517 | 2788 | 1101 |
| Storage Required for a Level of Service of 1 in 5 Years (Ml) | 899 | 1699 | 2321 | 893 |
| Deficit in Storage for Level of Service 1 in 5 Years [Ml] | 185 | 818 | 467 | 208 |

| Losses at 10 mm day 2000 boat movements | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average Year | | | | Level of Service - 1 in 5 years | | | | Dry Year | | | |
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Canal Losses [Ml/d] | 2.34 | 5.91 | 5.24 | 1.98 | 2.31 | 5.87 | 5.15 | 1.95 | 2.31 | 5.82 | 5.15 | 1.94 |
| Direct Abstraction [Ml/d] | 1.36 | 4.29 | 3.00 | 1.05 | 0.84 | 3.32 | 1.72 | 0.66 | 0.46 | 2.50 | 0.96 | 0.43 |
| Supply from Storage [Ml/d] | 0.98 | 1.34 | 1.96 | 0.78 | 1.47 | 2.27 | 3.15 | 1.14 | 1.80 | 3.04 | 3.78 | 1.36 |
| Direct Precipitation [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Transfers from Other Sections [Ml/d] | 0.00 | 0.28 | 0.28 | 0.14 | 0.00 | 0.28 | 0.28 | 0.14 | 0.00 | 0.28 | 0.28 | 0.14 |
| Change in Storage [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.13 | 0.01 |
| Deficit [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | | |
| Max % Abstraction of Flow above HOF taken on any day | 14.0% | 6.0% | 11.7% | 3.2% | 14.0% | 6.0% | 11.7% | 3.2% | 14.0% | 6.0% | 11.7% | 3.2% |
| % of Flow Abstracted above HOF | 10.8% | 3.6% | 8.8% | 2.7% | 14.0% | 4.2% | 11.7% | 3.2% | 14.0% | 4.2% | 11.7% | 3.2% |
| Abstraction Rate [Ml/d] over the period - no of days water is abstracted | 4.01 | 5.69 | 8.50 | 3.15 | 7.80 | 5.76 | 16.46 | 6.11 | 11.30 | 11.32 | 23.69 | 8.75 |
| No. of days water is abstracted | 213 | 361 | 213 | 213 | 108 | 354 | 108 | 108 | 73 | 253 | 73 | 62 |
| Average Rate Supplied from Storage [Ml/d] | 2.22 | 3.05 | 4.69 | 1.75 | 2.25 | 3.83 | 4.62 | 1.75 | 2.23 | 5.13 | 4.62 | 1.80 |
| No. of days storage is used | 161 | 128 | 153 | 164 | 238 | 168 | 249 | 238 | 295 | 216 | 298 | 276 |

| Storage Requirements for Losses of 10 mm day and 2000 boat movements | | | | |
|---|---|---|---|---|
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Storage Required for an Average Year (Ml) | 358 | 490 | 717 | 286 |
| Storage Required for the Driest Year (Ml) | 658 | 1181 | 1378 | 526 |
| Storage Required for a Level of Service of 1 in 5 Years (Ml) | 536 | 808 | 1151 | 417 |
| Deficit in Storage for Level of Service 1 in 5 Years [Ml] | 123 | 372 | 227 | 109 |

| Losses at 20 mm day 2000 boat movements | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average Year | | | | Level of Service - 1 in 5 years | | | | Dry Year | | | |
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Canal Losses [Ml/d] | 3.75 | 10.44 | 9.19 | 3.51 | 3.70 | 10.36 | 9.03 | 3.45 | 3.69 | 10.25 | 9.02 | 3.44 |
| Direct Abstraction [Ml/d] | 2.16 | 7.60 | 5.31 | 1.92 | 1.27 | 5.92 | 2.99 | 1.16 | 0.72 | 4.39 | 1.70 | 0.74 |
| Supply from Storage [Ml/d] | 1.59 | 2.55 | 3.61 | 1.44 | 2.43 | 4.15 | 5.76 | 2.15 | 2.92 | 5.57 | 6.90 | 2.54 |
| Direct Precipitation [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Transfers from Other Sections [Ml/d] | 0.00 | 0.28 | 0.28 | 0.14 | 0.00 | 0.28 | 0.28 | 0.14 | 0.00 | 0.28 | 0.28 | 0.14 |
| Change in Storage [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.13 | 0.02 |
| Deficit [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | | |
| Max % Abstraction of Flow above HOF taken on any day | 14% | 10% | 14% | 8% | 14% | 10% | 14% | 8% | 14% | 10% | 14% | 8% |
| % of Flow Abstracted above HOF | 17.3% | 6.4% | 15.8% | 4.9% | 22.0% | 7.7% | 20.9% | 6.4% | 22.0% | 7.3% | 20.9% | 6.4% |
| Abstraction Rate [Ml/d] over the period - no of days water is abstracted | 6.43 | 10.18 | 15.27 | 5.77 | 12.49 | 10.16 | 29.56 | 11.18 | 18.21 | 19.00 | 43.03 | 16.22 |
| No. of days water is abstracted | 213 | 364 | 213 | 213 | 108 | 362 | 108 | 108 | 73 | 278 | 73 | 62 |
| Average Rate Supplied from Storage [Ml/d] | 3.51 | 5.64 | 8.44 | 3.16 | 3.53 | 6.80 | 8.31 | 3.15 | 3.58 | 8.77 | 8.37 | 3.24 |
| No. of days storage is used | 165 | 139 | 156 | 167 | 251 | 185 | 253 | 249 | 298 | 232 | 301 | 286 |

| Storage Requirements for Losses of 20 mm day and 2000 boat movements | | | | |
|---|---|---|---|---|
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Storage Required for an Average Year (Ml) | 579 | 931 | 1316 | 527 |
| Storage Required for the Driest Year (Ml) | 1066 | 2178 | 2520 | 966 |
| Storage Required for a Level of Service of 1 in 5 Years (Ml) | 886 | 1509 | 2103 | 785 |
| Deficit in Storage for Level of Service 1 in 5 Years [Ml] | 179 | 669 | 417 | 181 |

| Losses at 1.75 Ml/Km/Wk 2000 boat movements | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average Year | | | | Level of Service - 1 in 5 years | | | | Dry Year | | | |
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Canal Losses [Ml/d] | 4.08 | 11.36 | 9.98 | 3.84 | 4.08 | 11.36 | 9.98 | 3.84 | 4.08 | 11.36 | 9.98 | 3.84 |
| Direct Abstraction [Ml/d] | 2.33 | 8.03 | 5.68 | 2.09 | 1.37 | 6.37 | 3.24 | 1.28 | 0.78 | 4.61 | 1.79 | 0.82 |
| Supply from Storage [Ml/d] | 1.75 | 3.04 | 4.02 | 1.61 | 2.71 | 4.71 | 6.46 | 2.42 | 3.26 | 6.47 | 7.78 | 2.86 |
| Direct Precipitation [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Transfers from Other Sections [Ml/d] | 0.00 | 0.28 | 0.28 | 0.14 | 0.00 | 0.28 | 0.28 | 0.14 | 0.00 | 0.28 | 0.28 | 0.14 |
| Change in Storage [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | -0.01 | 0.13 | 0.02 |
| Deficit [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | | |
| Max % Abstraction of Flow above HOF taken on any day | 24.0% | 10.0% | 23.1% | 7.2% | 24.0% | 10.0% | 23.1% | 7.2% | 24.0% | 10.0% | 23.1% | 7.2% |
| % of Flow Abstracted above HOF | 18.9% | 6.9% | 17.1% | 5.4% | 24.0% | 8.5% | 23.1% | 7.2% | 24.0% | 7.3% | 23.1% | 7.2% |
| Abstraction Rate [Ml/d] over the period - no of days water is abstracted | 7.01 | 11.13 | 16.67 | 6.36 | 13.79 | 11.20 | 32.78 | 12.50 | 20.23 | 21.27 | 47.97 | 18.30 |
| No. of days water is abstracted | 212 | 363 | 212 | 212 | 108 | 361 | 108 | 108 | 73 | 278 | 73 | 62 |
| Average Rate Supplied from Storage [Ml/d] | 3.93 | 6.84 | 9.42 | 3.55 | 3.93 | 7.73 | 9.36 | 3.57 | 4.02 | 9.49 | 9.46 | 3.61 |
| No. of days storage is used | 163 | 140 | 156 | 166 | 252 | 188 | 252 | 248 | 296 | 249 | 300 | 289 |

| **Storage Requirements for Losses of 1.75 Ml/Km/Wk and 2000 boat movements** | | | | |
|---|---|---|---|---|
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Storage Required for an Average Year (Ml) | 639 | 1111 | 1466 | 588 |
| Storage Required for the Driest Year (Ml) | 1190 | 2573 | 2839 | 1092 |
| Storage Required for a Level of Service of 1 in 5 Years (Ml) | 990 | 1739 | 2358 | 885 |
| Deficit in Storage for Level of Service 1 in 5 Years [Ml] | 199 | 835 | 481 | 207 |

| Losses at 10 mm day 4500 boat movements | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average Year | | | | Level of Service - 1 in 5 years | | | | Dry Year | | | |
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Canal Losses [Ml/d] | 3.23 | 6.76 | 6.10 | 2.09 | 3.20 | 6.72 | 6.00 | 2.06 | 3.20 | 6.66 | 6.01 | 2.05 |
| Direct Abstraction [Ml/d] | 1.85 | 4.54 | 3.26 | 1.07 | 1.10 | 3.52 | 1.88 | 0.69 | 0.62 | 2.63 | 1.06 | 0.44 |
| Supply from Storage [Ml/d] | 1.37 | 1.54 | 2.15 | 0.79 | 2.09 | 2.52 | 3.44 | 1.14 | 2.53 | 3.35 | 4.14 | 1.37 |
| Direct Precipitation [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Transfers from Other Sections [Ml/d] | 0.00 | 0.68 | 0.68 | 0.23 | 0.00 | 0.68 | 0.68 | 0.23 | 0.00 | 0.68 | 0.68 | 0.23 |
| Change in Storage [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.13 | 0.01 |
| Deficit [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | | |
| Max % Abstraction of Flow above HOF taken on any day | 19.0% | 10.0% | 13.3% | 8.2% | 19.0% | 10.0% | 13.3% | 8.2% | 19.0% | 10.0% | 13.3% | 8.2% |
| % of Flow Abstracted above HOF | 14.9% | 3.8% | 9.6% | 2.7% | 19.0% | 4.6% | 13.3% | 3.4% | 19.0% | 4.2% | 13.3% | 3.4% |
| Abstraction Rate [Ml/d] over the period - no of days water is abstracted | 5.53 | 6.15 | 9.28 | 3.19 | 10.79 | 6.22 | 17.99 | 6.19 | 15.73 | 12.27 | 25.96 | 8.86 |
| No. of days water is abstracted | 213 | 361 | 213 | 213 | 108 | 354 | 108 | 108 | 73 | 253 | 73 | 62 |
| Average Rate Supplied from Storage [Ml/d] | 3.07 | 3.45 | 5.14 | 1.78 | 3.06 | 4.16 | 5.06 | 1.77 | 3.10 | 5.46 | 5.08 | 1.82 |
| No. of days storage is used | 163 | 135 | 153 | 162 | 249 | 177 | 248 | 235 | 297 | 224 | 297 | 275 |

**Storage Requirements for Losses of 10 mm day and 4500 boat movements**

| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
|---|---|---|---|---|
| Storage Required for an Average Year (Ml) | 501 | 563 | 786 | 288 |
| Storage Required for the Driest Year (Ml) | 922 | 1323 | 1509 | 529 |
| Storage Required for a Level of Service of 1 in 5 Years (Ml) | 763 | 919 | 1255 | 417 |
| Deficit in Storage for Level of Service 1 in 5 Years [Ml] | 160 | 404 | 255 | 112 |

| Losses at 20 mm day 4500 boat movements | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average Year | | | | Level of Service - 1 in 5 years | | | | Dry Year | | | |
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Canal Losses [Ml/d] | 4.64 | 11.29 | 10.05 | 3.62 | 4.58 | 11.21 | 9.88 | 3.56 | 4.58 | 11.09 | 9.87 | 3.55 |
| Direct Abstraction [Ml/d] | 2.66 | 7.85 | 5.57 | 1.94 | 1.53 | 6.11 | 3.15 | 1.18 | 0.89 | 4.48 | 1.79 | 0.75 |
| Supply from Storage [Ml/d] | 1.98 | 2.75 | 3.79 | 1.45 | 3.05 | 4.41 | 6.04 | 2.16 | 3.64 | 5.93 | 7.26 | 2.55 |
| Direct Precipitation [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Transfers from Other Sections [Ml/d] | 0.00 | 0.68 | 0.68 | 0.23 | 0.00 | 0.68 | 0.68 | 0.23 | 0.00 | 0.68 | 0.68 | 0.23 |
| Change in Storage [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.13 | 0.02 |
| Deficit [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | | |
| Max % Abstraction of Flow above HOF taken on any day | 27.0% | 10.0% | 22.4% | 6.6% | 27.0% | 10.0% | 22.4% | 6.6% | 27.0% | 10.0% | 22.4% | 6.6% |
| % of Flow Abstracted above HOF | 21.4% | 6.5% | 16.6% | 4.8% | 27.0% | 8.0% | 22.4% | 6.6% | 27.0% | 7.3% | 22.4% | 6.6% |
| Abstraction Rate [Ml/d] over the period - no of days water is abstracted | 7.95 | 10.63 | 16.05 | 5.81 | 15.48 | 10.61 | 31.09 | 11.26 | 22.64 | 19.87 | 45.30 | 16.34 |
| No. of days water is abstracted | 213 | 364 | 213 | 213 | 108 | 362 | 108 | 108 | 73 | 278 | 73 | 62 |
| Average Rate Supplied from Storage [Ml/d] | 4.33 | 6.01 | 8.82 | 3.19 | 4.37 | 7.15 | 8.76 | 3.19 | 4.42 | 9.02 | 8.81 | 3.25 |
| No. of days storage is used | 167 | 141 | 157 | 166 | 255 | 188 | 252 | 247 | 301 | 240 | 301 | 286 |

| Storage Requirements for Losses of 20 mm day and 4500 boat movements | | | | |
|---|---|---|---|---|
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Storage Required for an Average Year (Ml) | 722 | 1004 | 1385 | 529 |
| Storage Required for the Driest Year (Ml) | 1329 | 2321 | 2651 | 969 |
| Storage Required for a Level of Service of 1 in 5 Years (Ml) | 1113 | 1607 | 2206 | 787 |
| Deficit in Storage for Level of Service 1 in 5 Years [Ml] | 216 | 713 | 445 | 182 |

| Losses at 1.75 Ml/Km/Wk and 4500 boat movements | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average Year | | | | Level of Service - 1 in 5 years | | | | Dry Year | | | |
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Canal Losses [Ml/d] | 4.97 | 12.21 | 10.83 | 3.95 | 4.97 | 12.21 | 10.83 | 3.95 | 4.97 | 12.21 | 10.83 | 3.95 |
| Direct Abstraction [Ml/d] | 2.82 | 8.46 | 5.94 | 2.11 | 1.63 | 6.72 | 3.39 | 1.29 | 0.94 | 4.94 | 1.88 | 0.83 |
| Supply from Storage [Ml/d] | 2.14 | 3.06 | 4.21 | 1.62 | 3.34 | 4.80 | 6.76 | 2.43 | 3.98 | 6.58 | 8.14 | 2.87 |
| Direct Precipitation [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Transfers from Other Sections [Ml/d] | 0.00 | 0.68 | 0.68 | 0.23 | 0.00 | 0.68 | 0.68 | 0.23 | 0.00 | 0.68 | 0.68 | 0.23 |
| Change in Storage [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.13 | 0.02 |
| Deficit [Ml/d] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | | |
| Max % Abstraction of Flow above HOF taken on any day | 29.0% | 11.0% | 24.4% | 7.4% | 29.0% | 11.0% | 24.4% | 7.4% | 29.0% | 11.0% | 24.4% | 7.4% |
| % of Flow Abstracted above HOF | 23.0% | 7.2% | 18.1% | 5.4% | 29.0% | 8.8% | 24.4% | 7.4% | 29.0% | 8.1% | 24.4% | 7.4% |
| Abstraction Rate [Ml/d] over the period - no of days water is abstracted | 8.53 | 11.56 | 17.44 | 6.40 | 16.79 | 11.62 | 34.30 | 12.58 | 24.67 | 21.91 | 50.24 | 18.41 |
| No. of days water is abstracted | 212 | 364 | 212 | 212 | 108 | 362 | 108 | 108 | 73 | 283 | 73 | 62 |
| Average Rate Supplied from Storage [Ml/d] | 4.75 | 6.79 | 9.87 | 3.56 | 4.77 | 7.78 | 9.75 | 3.58 | 4.89 | 9.89 | 9.90 | 3.64 |
| No. of days storage is used | 165 | 138 | 156 | 166 | 255 | 185 | 253 | 248 | 297 | 243 | 300 | 288 |

| **Storage Requirements for Losses of 1.75 Ml/Km/Wk and 4500 boat movements** | | | | |
|---|---|---|---|---|
| | Summit | Western Mainline | Eastern Mainline | North Wilts Canal |
| Storage Required for an Average Year (Ml) | 782 | 1117 | 1536 | 590 |
| Storage Required for the Driest Year (Ml) | 1453 | 2618 | 2972 | 1095 |
| Storage Required for a Level of Service of 1 in 5 Years (Ml) | 1217 | 1753 | 2467 | 887 |
| Deficit in Storage for Level of Service 1 in 5 Years [Ml] | 235 | 865 | 505 | 208 |

# APPENDIX 4 – THE WATER BALANCE MODEL – ASSUMPTIONS AND DESCRIPTIONS

## A4.1 Model Description

A daily water balance model was developed to allow water resource options to be assessed. The model carries out a simple volume balance over a daily time step whereby the difference between the aggregated inflows and outflows is equal to the change in stored water within the canal system (Figure A4.1).

Inflows comprised of abstractions, rainfall, transfers from upstream canal sections, and inflows from off-line reservoirs.

Outflows comprised of evaporaration, transfers to downstream canal sections and seepage.

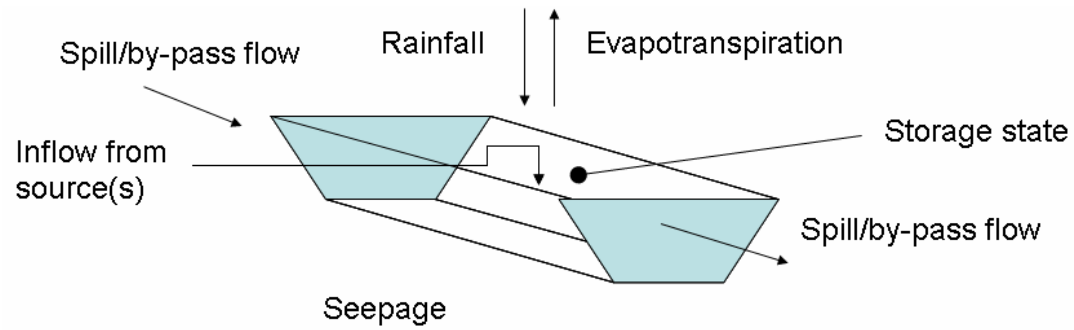


**Figure A4.1: A Schematic of the Water Balance Model for a Single Canal Section**
chan

The data sets and algorithms used to derive each of the water balance components are described in Table A 4.1 below. Every variable is transformed to units of Ml/d and each state is transformed to Ml.

| Variable/State | Data sources | Algorithm |
|---|---|---|
| Rainfall | MORECS monthly values (Square 158 cover the Western Mainline, Summit and North Wilts Canal area; and Square 159 covers the Eastern Mainline area) | Mean daily rainfall derived from monthly total and number of days per month. |
| Evaporation | MORECS monthly values (Square 158 cover the Western Mainline, Summit and North Wilts Canal area; and Square 159 covers the Eastern Mainline area) | Mean daily reference crop evapotranspiration (ETo) derived from monthly total and number of days per month. Daily evaporation derived as a factor of the ETo based on factors given in Shaw, E.<br><br>Evaporation is not included when lumped canal losses are used. |

| | | |
|---|---|---|
| Abstraction | Daily river flows for local gauging stations.<br><br>Hands-off flows based on CAMS and liaison with EA. | River flow derived from a representative local gauged flow using AREA and SAAR as scaling factors.<br><br>Local HOF for Thames Region based on $Qn_{95}$.<br>Regional HOF for Thames Region based on $Q_{50}$ at Kingston.<br><br>Local HOF for SW Region EA based on $Qn_{76}$. |
| Transfers | n/a | Outflows from adjacent canal sections. Outflows occur when the level in an adjacent canal section exceed the navigable depth. |
| Inflows from reservoirs | n/a | Water is drawn from reservoir sources when the level in the canal falls below the navigable depth. The HOF rules determine to what extent the demand for water is met from direct abstraction and reservoir storage. |
| Seepage | n/a | Seepage is calculated as the seepage rate (in mm/d) multiplied by the wetted area of the canal.<br><br>If the BW lumped loss value is used (Ml/km/wk) then the loss is calculated as the loss rate multiplied by the length of the section and divided by 7 (the number of days per week) |
| Canal storage | n/a | This is calculated as the difference between the water level at the start and end of the daily time step multiplied by the surface area of the canal section. The model is configured such that the navigable depth is always treated as the target level. |

**Table A4.1: The Water Balance Model Variables and States**

### A4. 2 Model Structure

The model is built using four spread spreadsheets in EXCEL, A source selection spreadsheet and three water balances spreadsheets one per each canal section.

Source selection – Spreadsheet (M001)

- The source selection spreadsheet lists all possible sources per each section of the canal and their associated characteristics. The user flags those sources that are to be active.
- A time series of flows is derived for each selected source using the flows for the local gauging station with similar catchment characteristics. The gauged flows are scaled by catchment area and Standard Average Annual Rainfall (SAAR) obtained from the Flood Estimation Handbook (FEH CDROM Version 2).
- Local and Regional HOF conditions are derived for each active source based on the respective CAMS (Sources within the Bristol and Avon CAMS, a local HOF of QN76 was applied, while for those sources within the Vale of White Horse CAMS a local HOF condition of QN95 and regional HOF condition of QN50 at Kingston was applied).
- The aggregated inflow (Input 1) in each section is obtained by adding each active water source after applied the above conditions.

Water Balance – Spreadsheets (M002 to M005)

<u>Time series input in the model are:</u>

- Direct abstractions (Input 1). This data is the aggregated inflow derived in the source selection spreadsheet (M001).

- Direct precipitation (Input 2), based on monthly averages using MORECS data, square 158 and 159. Square 158 cover the Western Mainline, Summit and North Wilts Canal area; and Square 159 covers the Eastern Mainline area. The input varies in each time step depending on the top width of the canal section.

- Potential Evaporation (Input 3), based on monthly averages using MORECS data, square 158 and 159. Square 158 cover the Western Mainline, Summit and North Wilts Canal area; and Square 159 covers the Eastern Mainline area. Input is a function of the canal top width.

- Transfers from other sections (Other). This input takes into account water being transferred from other sections through lock operation (lockage) and any spills. As boat usage is assumed to be uniform the lockage is distributed evenly through the year, and it is a function of the number boat movements per year and the lock dimensions.

<u>Canal Losses:</u>

Losses considered in the model are: Leakage, Seepage and Percolation; Evaporation and Transpiration; and Loch Operation.

Leakage, Seepage and Percolation:

- Leakage, seepage and percolation were combined into a uniform seepage rate (mm/d). Three seepages scenarios were used, a constant rate of 10mm/d; 20mm/d; and 1.75Ml/Km/Week. Unit selection is set within the model allowing to model different losses criterion.

- Seepage loss (Ml/d) is determined as a function of the wetted perimeter of the canal section and the length of the section. When Ml/km/week are selected seepage rate is determined as a simple function of the canal section length.

Evaporation:

- Evaporation was considered using MORECS data for the same squares used in the direct precipitation input. Based on monthly data and converting them into mm/d, evaporation loss is expressed as a function of the canal top width. Open water evaporation (Eo) is derived from the reference crop evapotranspiration (ETo) divided by a monthly factor (f) as given in Shaw, E.

Lockage:

- Lockage is estimated assuming a number of lock operations in each section distributed evenly through the year. This loss is a function of the number of lock operations and the volume of water in the lock.

- Water lost through lock operation is allowed to be recovered through back pumping with a specified efficiency. The default efficiency utilised in this model is 85%.

- Three lock operation scenarios were defined as follows:

| Section | No. of Lock Operations per year | | |
|---|---|---|---|
| | Low | Medium | High |
| **Western Mainline** | 1000 | 2000 | 4500 |
| **Summit** | 1000 | 2000 | 4500 |
| **Easter Mainline** | 1000 | 2000 | 4500 |
| **NWC** | 1000 | 1000 | 1500 |

Total losses:

- When British Waterways' criterion is applied (1.75Ml/Km/Week), seepages and evaporation are combined in a single loss, being a function of each section length and not of depth of water in the canal. The total loss is determined by adding lockage losses to this single loss.

- If the above criterion is not applied, total losses are determined by adding seepage losses; evaporation; and lockage losses.

Water Balance Calculation:

- The depth of water in the canal is assumed to be at its minimum value at the start of the simulation (1.37M), and reservoir sources are assumed to be at intake level (i.e. no initial storage).

- The model estimates the depth of water in the canal section at the start and end of each time step.

    - If canal depth is < 1.37m at end of the time step then:
        - Water is required from reservoir sources.
        - If reservoir sources are empty, the section and the canal fail, otherwise supply from storage occurs until the navigable water level is restored or the reservoir sources are empty.
        - The canal depth at the end of the time step is always 1.37m or lower (in cases where reservoir sources are not able to supply the total demand).

    - If 1.37m <= canal depth <= 1.5m; water is stored in the canal and the depth of water at the end of the time step will remain between these levels

    - If canal depth >=1.5m; canal dept is fixed to 1.5m and the extra volume is first transferred back into reservoirs. If reservoir sources are full then any excess is lost to downstream canal sections.

- The model estimates accumulative volumes spilled from the canal (stored in the reservoir sources) and volumes supplied from the canal. Post run analysis is required to define the minimum storage volume for each level of service specified.

- Direct abstraction supplied into the canal from water sources is estimated at each time step as the difference between water available as direct abstraction (Input 1) and spill water (when the level on canal is fixed to 1.5m and spill occurs). This ensures that direct abstractions are utilised efficiently.

Figure A4.2 below illustrates the application of the water balance model to the Western Mainline for a seepage loss scenario of 10mm/d and 4500 lock operations. This figure shows how the use of offline storage depends on the available input of from direct abstractions, showing how water level in the section fluctuates between 1.5m (maximum water level in the canal) and 1.37m, the minimum canal depth. Corresponding data for this scenario can be found in CD data - Spreadsheet “M002 – Water Balance Model – Western Mainline – 10 – 4500”

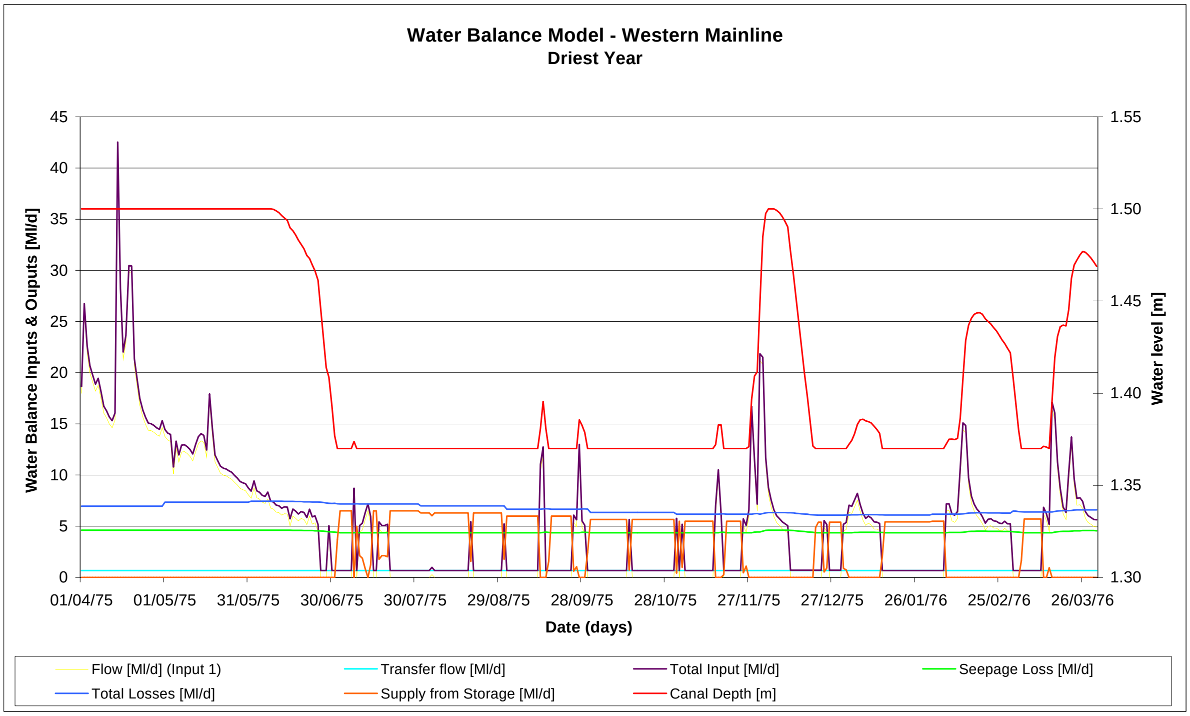


**Table A4. A – Water balance model for the Western Mainline, loss scenario of 10mm/d and 4500 boat operations.**

### A4.3 Water Balance Summary

A spreadsheet (Water Balance – Summary Results) was developed to summarise the water balance time series for each scenario. In these spreadsheets data is analysed taken into account hydrological year summering the following information:

Flow:

- Available flow for direct abstraction is shown for each canal section
- Accumulative spill is reset at the start of each hydrological year in order to be able to determine volume stored at during each year.
- Spill taken into the storage
- Flow abstracted above HOF condition
- Percentage of total flow taken

Pibot Tables:

Pibot tables were developed in order to determine canal losses; deficit; direct abstraction; number of day pumping into storage; number of days pumping into the canal; spill; and direct precipitation.

Summary Table:

This worksheet shows summary tables presented in this report which were created linking each cell into the corresponding data in the pibot table, for each section and level of service analysed.