The Wilts and Berks Canal Restoration

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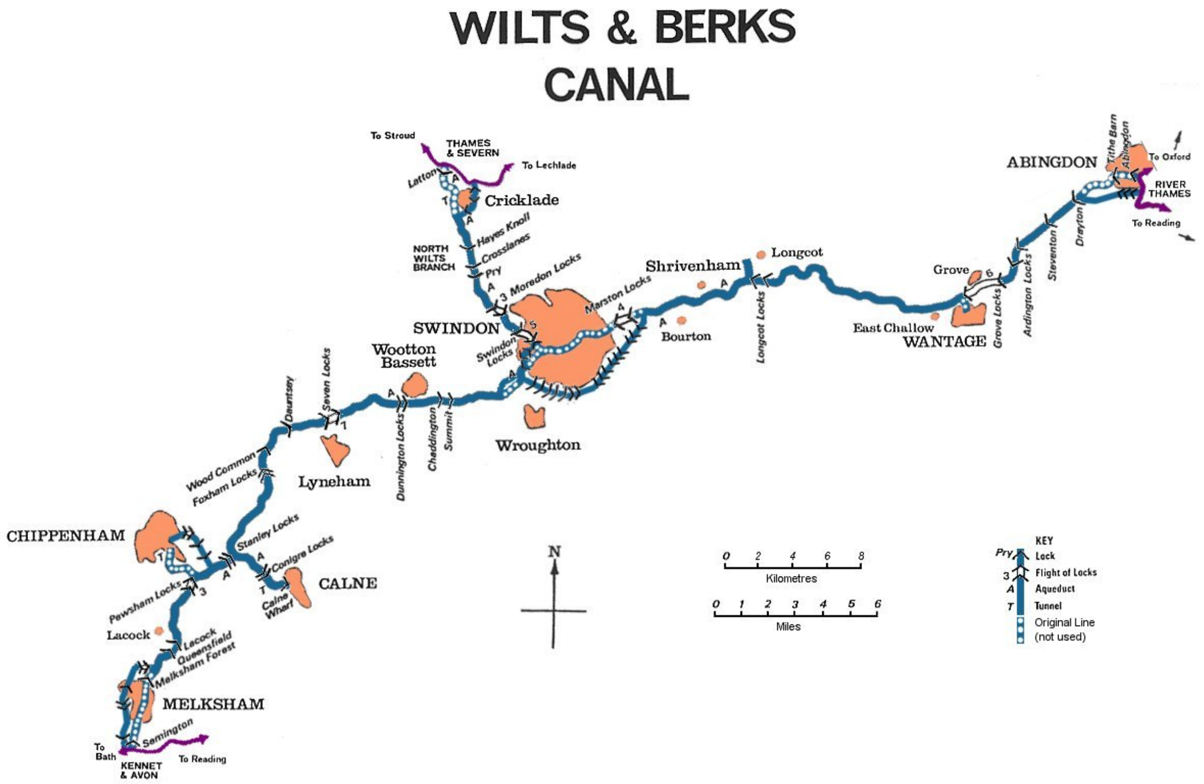

Figure 1: The Wilts and Berks Canal

Abstract

During the 19th Century, the Wilts and Berks Canal was a vital component in the transportation of coal across England. It was abandoned in the early 20th Century, and was left to decline. Today, the Wilts and Berks Canal Trust are planning to restore the canal. This report analyses the challenges that the reconstruction faces, and models the predicted boat movements along the canal. This aims to give an idea of how often each lock is used over a specified time period. Two models are produced: a discrete model, consisting of predetermined destinations, and a probabilistic model, which is built on predictions of a boat ending its journey at any given lock. These models give an indication of how much water is required for the canal to be navigable, and where potential pinch points along the system could occur. This leads to a discussion on the feasibility of restoring the canal.

Contents

1 Introduction

1.1 A History of the Wilts and Berks Canal

The initial proposal to build the Wilts & Berks Canal, also referred to as the W & B in this report, was made in 1793, with the Enabling Act of Parliament being passed in 1795 marking the official start of construction of the canal. [1] In 1810, after 25 years of construction, the W & B was finally opened and operational. It was 83.69km long (52 miles), and ran from the Kennet and Avon Canal junction at Semington through Swindon to the River Thames at Abingdon. The North wilts Canal was built in 1819, and connected the main line of the Wilts and Berks Canal to the Thames and Severn Canal at Cricklade [2]. The main purpose of the Wilts and Berks Canal at the time of construction was to transport coal across the country, because there was no other way to move coal long distances. At its peak use in 1837, over 43,000 tons of coal was being transported along the canal, which produces enough energy to power nearly 125,000 of today's light bulbs for a year [3] [4].

The Great Western Railway, which opened in 1841, was the main business competition for the canal. Indeed, the railway provided a far more convenient, efficient and faster mode of transport than the canal and as such, the canal lost the majority of its trading [5]. Following this loss of trade, there were numerous trade rejuvenation attempts as well as several attempts to close the canal [2]. In 1901 the Stanley Aqueduct was breached, which was located between the Chippenham and Calne junctions. The nearby canal sections ran dry, preventing any through boat traffic [5]. This resulted in the Canal Company applying for an Act of Abandonment and, 13 years later in 1914, the Wilts and Berks Canal was officially abandoned with the land being returned to its previous owners or sold off. Over time, the canal fell into general disrepair. Some sections were filled in and built over; other sections reverted naturally to fields and/or dense undergrowth [2].

Between 1946 and 1977, the Inland Waterways Association (IWA) worked to protect the nation-wide canal systems from becoming fully decrepit and forgotten. The Wilts and Berks Canal was thus rediscovered in 1977 after years of abandonment, and a new group was formed: the Wilts and Berks Canal Trust (WBCT), formerly the Wilts and Berks Canal Amenity Group. The WBCT worked originally to preserve the canal's remains, but then changed their purpose to restoring the canal fully, using as much of the old route as possible [2]. The fully restored Wilts and Berks Canal will link the Kennet and Avon Canal in the south to the Thames and Severn Canal to the north. Boats will be able to travel up and down the country without needing to detour east and travel up the River Thames. Another example of simpler boat travel is between Oxford and Bath via Cricklade and Swindon. These points are illustrated in figure 2.

1.2 Difficulties with Restoration

As with any restoration project, there exists a considerable array of complications that need to be addressed to complete the restoration. For instance, the growth of the towns along the old canal means the water will need to be redirected around them, and as such new segments of canal will need to be cut. Furthermore, the land through which the rebuilt canal will run is not all owned by the Trust, and there have been disagreements with landowners about allowing the canal to cut through their land. Moreover, the new canal will need to pass under roads and railways built over the abandoned canal. Should all these problems be solved by the Trust, then a planning permission being issued will start the reconstruction process.

An external company called Grontmij prepared a report for the North Wiltshire District Council in November 2007 investigating where the water for the canal would be sourced from [6]. Their Water Resources Development Strategy Study includes work on sourcing water for the canal, and the potential water losses of a static canal (seepage, evaporation). The study also looks at possible financial and environmental impacts of building and maintaining reservoirs. However, this report will mostly focus on the water requirements themselves rather than the financial and environmental impacts of those requirements.

1.3 Water Supply for the Original Canal

The Canal Enabling Act permitted the Wilts and Berks Canal Trust to abstract water from almost all water resources within 2000 yards of the canal, including rivers, brooks, streams and springs [7], the primary source being Coate Water, a 280,000m^2 reservoir constructed to the southeast of Swindon in 1928 with a capacity of approximately 555Ml [7]. After the canal's decommission in 1914, Coate Water became a leisure park and is now an important local nature reserve and Site of Special Scientific Interest (SSSI) under the name Coate Water Country Park [8]. Swindon Council have suggested that using Coate Water to supply water to the renovated canal would be unacceptable as the water currently in the lake needs to stay at a relatively stable level for the SSSI [9]. However, a small portion of Coate reservoir's water is reportedly released into the nearby River Cole, a tributary of the River Thames, at Marshgate, Swindon. As such, there is potential for water to be abstracted further downstream from the River Cole to supply the Wilts and Berks Canal [6].

In 1840, Tockenham Reservoir was constructed as a further water resource as a deficit still existed. Located approximately half way between Swindon and Chippenham and with a capacity of 273ML [10], it was the Wilts and Berks Canal's second largest source of water. However, the reservoir is currently in the possession of the Bristol, Bath and Wiltshire Amalgamated Anglers [9] and further enquiries into whether it would be feasible to use Tockenham Reservoir to supply water to the renovated canal need to be made. There is a spill from Tockenham Reservoir into Brinkworth Brook, a tributary of the Bristol Avon, which crosses the planned route of the restored canal, however it is unable to supply enough water to be considered a substantial source.[6].

The remaining water was supplied from a mixture of sources, including a large number of nearby springs. Despite this, there was still a huge water shortage which in turn had a major impact on the operation of the canal. The summer months had a particularly negative effect on the quantity of water in the canal due to a lack of stream flow and storage, coupled with high evaporation rates. Another huge factor contributing to the water shortage was the amount of seepage and leakage. Seepage loss occurs when water seeps through the canal bed and sides and is lost for irrigation whereas water lost from leakage travels through large openings in the bed and sides.

1.4 Water Supply for the Restored Canal

Currently there are a small number of short stretches of the canal that are in water and the only boat that runs regularly operates over 1km in the south of Swindon. Now that the restoration is underway, a main concern for the Wilts and Berks Canal Trust is how to access enough water to fill the canal to a substantial level. With Coate Water unusable and no guarantee that Tockenham Reservoir can be accessed again, the Trust have suggested that it would be hugely beneficial to construct a large number of small reservoirs alongside the canal as opposed to a small number of large reservoirs. This is due to larger schemes posing more of a threat to the environment, and because it could prove difficult to find areas big enough. As the summit of the canal is near Swindon, it would be most effective to construct new reservoirs there, using gravity as an advantage rather than a constraint. John Henn has also suggested that making the canal itself deeper and wider in places could prove beneficial as it can then act as its own reservoir.

Groundwater abstraction is the process of taking water from a ground source such as an aquifer beneath the surface, either temporarily or permanently and flow is normally through fractures in the source. [11] The Wilts and Berks Canal is primarily made up of a non-aquiferous clay base; 77.4% of the canal bed was constructed on the Kimmeridge, Gault and Oxford clay formations [9] . These clays have low permeability rates and so there is an extremely small possibility of groundwater being abstracted to other canals from these areas.

As of November 2007, 73 abstractions existed within 500m of the canal. [6]. These include several local aquiferous horizons which contain groundwater that could possibly be used to supply the W & B. However, they may require licenses from the Environment Agency to be suitable for abstraction [12]. The major and minor aquifers that exist near the proposed restored canal route include the Great Oolite, Corallian, Lower

Greensand and Chalk. The Corallian aquifer near Kemble, for example, could provide over 0.15Ml/day to the Western Mainline section of the canal [6].

Other potential sources of water include agricultural and urban runoff. Agricultural runoff occurs when rainwater (or melted snow) that has not been absorbed by the soil in farm fields runs over ground and is deposited in lakes or streams [13]. An example of this is a land drain that allows agricultural runoff to flow from Wharf Farm in Swindon into the restored W & B [6]. However, agricultural runoff can easily contaminate the canal by carrying pollution when it moves, so further developments would need to be made before it can be considered a primary source. Another concern with agricultural runoff is the summer months, as often the levels of water collected by the land drains is low and thus not a reliable source. As there are many key urban areas along the route of the canal, most notably Swindon, urban runoff from these areas can also be considered as a possible source.

Currently, the primary source of water that will allow the canal to be restored to an operational level is surface water abstraction: the removal of water from natural or artificial waterways containing freshwater, including lakes, rivers, streams and canals [14]. The Wilts and Berks Canal can be split into four sections: the Western Mainline, the Summit, the Eastern Mainline and the North Wilts Canal. Each of these has a different abstraction rate due to the different volumes and available surface water catchment area sources. It is assumed that abstractions from these sources is done by pumps. Surface water abstraction is the most effective during the winter months when flow from rivers is high. The Corallian aquifer in Shrivenham has the potential to be used as a source for surface water abstraction to supply the Eastern Mainline section [6].

There is a vast array of procedures that can be carried out before the construction of the W & B is complete to minimise the loss of water from seepage and leakage. The most effective course of action would be to manufacture the whole canal bed and sides from the same puddle clays that the majority of the original canal was built with, as it is the material with the lowest permeability, thus reducing water loss by seepage[15]. Another new technology that could be used for the restoration is a drainage blanket. This blanket is fundamentally a base underneath the clay that takes in any seepage and leakage. This method not only stops water from escaping but also pumps any water captured back into the canal [9]. Another popular method used to minimise loss of water from the canal, particularly during movement through locks, is back pumping: using pumps to move water from the lowest locks back upstream towards the summit.

1.5 Project Aims

In order to ascertain the precise amount of water required for the canal, it is essential to first find out how often each lock will be used. From this, coupled with the knowledge of the amount of water transferred through the canal per lock usage, the volume of water used by the system as a whole for a given amount of time can be calculated.

The lock usage can be estimated through the modelling of boat moments along the canal in a discrete and probabilistic method. The discrete model assigns each boat with a route, and then the boat must stick to that route until it reaches its destination; whereas the probabilistic model gives the boat a start point, allowing it to travel along the canal, with a probability of stopping at each lock or attraction.

After running the model, it is possible to analyse the results and give answers to questions such as:

- How do the water levels in different sections of the canal change over time ?
- What water sources will be required?
- Are there any pinch points that need to be considered?

2 Modelling the Canal

The model is built to simulate the movements of a number of boats in the canal over a week. A number of assumptions, inputs, outputs and aims are identified that the model will require and achieve.

The model is created to help locate the areas of the canal that require input water, while also looking to find the relevant volumes of water required. The model outputs the water volumes in the stretches of the canal between locks after a week has elapsed. This contains positive and negative volumes; it is important to find out which sections of the canal run dry and by what volume, and also which sections of the canal will flood and and by what volume. There is a minimum depth of water for a navigable canal identified as 1.37m [6]. Using this minimum depth, coupled with the final water volumes outputted by the model, the areas where the input water is required can be identified and the relevant volumes can thus be calculated.

2.1 Assumptions

The Grontmij study contains two suggestions for canal dimensions, minimum and desirable. It is assumed that all sections of the canal are of desirable dimensions, as shown in figure 3. These dimensions were taken by the Wilts and Berks Canal Trust to be definitive, and so this assumption is used for the model.

As a boat travels along any section of the canal, there will be locks to ascend or descend. It is assumed that the boat passes through every lock in its path, and that the boat cannot leave the canal mid-journey to avoid passing through locks.

There are two types of locks in the Wilts and Berks system: narrow and wide. Narrow locks are 2.47m wide and the larger locks are 4.57m wide, with both being 23m in length. Every lock will have a different depth depending on the heights of the adjacent canal sections. These depths are as stated in the information provided by the Wilts and Berks Canal Trust [16]. Using this data, it can be estimated that every lock has a specific lock volume, $x\text{m}^3$. This is labelled as such in figure 4.

When a boat ascends a lock, it enters the empty lock and the lower gate is fully closed. Water then drains into the lock from the upper section of the canal. It is assumed that the volume of water that drains into the lock is exactly the lock volume, $x\text{m}^3$. The boat rises with the water, and once it is level with the next stretch of canal, the water flow is stopped. The upper gate is then opened and the boat exits the lock. The reverse process occurs for a boat descending a lock. Figure 4 illustrates the ascent and descent of a lock. The assumption of $x\text{m}^3$ being fully and exactly displaced is made so that the water displacement through the canal system can be explored.

These dimensions fall within the possible dimensions of real boats, which can be between 9.14m (30ft) and 21.95m (72ft) long [17]. The most common boat width is 2.08m, which allows for overtaking and two-way travel. Despite both of these existing in real canal journeys, only two-way travel will be incorporated into the model. Overtaking is assumed to never happen as it is stated that all boats cruise at the same speed.

Boats can be hired from one of four bases: Pewsham, Wichelstowe, Blunsdon, and Shrivenham. Rental times can be 3, 5 or 7 days, and it is assume that hired boats must be returned to the place they were hired from. This translates to the model as the final destination of a hired boat being the same as it's original starting point.

There is a speed limit on all UK canals of 4 miles per hour (mph). Adding to the low speed limit, canal boats do not have brakes, and there are no steering capabilities when in reverse [18]. The model sets all boats to cruise at 2.8 mph (4.5 km/h), as canal boats tend to cruise below the speed limit, especially if the canal is busy.

The model is built around the assumption that all boats visit a certain amount of attractions, and then return to their starting point. A list of attractions was provided by the Trust, and it is assumed that attractions take the same length of time to visit. It is also assumed that the location of the attractions is at the closest lock to them. The inclusion of the attractions is discussed in more detail in the next section.

The model only simulates journeys that happen in the Wilts and Berks Canal system. Boats do not leave the system to join other canals, and boats do not join the system from external canals. In other words, the Wilts and Berks Canal model will be closed.

The canal has a number of side branches, and these link to the main line in two ways, their junctions being either at locks or mid-canal. The junction of the Calne branch with the main line is immediately North of Stanley Top Lock. It is therefore assumed that this junction to be at the lock. The junction of the Chippenham branch with the main line is about 100m south of Stanley Bottom lock, and the junction of the North Wilts branch with the new main line occurs about 500m west of Wichelstowe Lock [19]. These two junctions are mid-canal. The nature of the junctions is important to the model, as the junctions will have a larger volume of water than the main canal. Due to the data provided not accounting for this, it is assumed that all junctions occur at locks.

2.2 Model Inputs

The model has a number of different variables that will change the boat movements over a week. These variables include: the number of boats in the system; the classification of people on a boat; how long the boat is hired for; the attractions that a boat will be going to, and the resulting journey path taken. The number of boats in the system is simply given as an input number. The classification of the people on the boat is done in 3 categories: retired, family and romantic couples. These groups of people are the main users of canal boats in the UK [20]. This allocation of people to a boat is generated randomly in the model.

2.2.1 Attractions

In order to be able to input the list of attractions to the model, the attractions are classified into two groups: major attractions and minor attractions. Table 1 illustrates how an attraction is classified as a major or minor attraction. This classification is generated from the total score of 5 different categories, where each attraction is given a score from 1 to 5 in each category. The categories are as follows: how welcoming the attractions are for retired, family and romantic couples, the attraction's potential for walkers or hikers, and how good (friendly) the attraction is for families. This second family rating is a more general one, and includes those who are not on a boat.

The category ratings are assigned using online descriptions, in particular TripAdvisor reviews when they are available. The reviews are not available if the attraction has not been built yet, and for these cases, a review for the most similar place possible is used. Summing the points for each category gives the total score. A place of interest with total score equal or greater than 18 (out of 25) is classified as a major attraction, and places of interest with total scores less than 18 are considered minor attractions. The discrete model only uses the total scores from the five-point rating system, and the probabilistic model uses the major and minor attraction classes.

2.2.2 Generating a Route

To model a boat's movements, the journey path needs to be known. The journey route is created in a number of steps. It is already assumed that the journey of a boat is dependent only on the attractions that the boat goes to. Taking an instance of a boat and its location in the system, the highest-scoring nearby attractions are found using the K-nearest neighbour classification. From this list, the most appropriate attractions are selected for the boat's occupants. To help identify the location of a boat in the system, the canal is split into 8 sections, which allows journey paths to be considered as combinations of these sections. Additionally, a boat's location is dependent on where the boat was hired from, and, as stated, there are 4 locations for boat hire. The canal is sectioned so that a boat hire location is at one, or both ends of a section.

The final layer of classification over the route of a boat is the length of the journey. The assumption that boats are hired for 3, 5 or 7 days translates to journey length as short, medium or long journeys. Journeys are sorted into these categories by the time taken to complete a round trip. This includes the assumption that boat journeys start and finish in the same location. A journey time of up to 20 hours is considered a short journey; 20 to 35 hours is considered a medium-length journey; and journey times of more than 35 hours is considered a long journey. This final layer of classification results in journey length being a model input. When the classification file is called, it selects the highest rated appropriate route selected from the route generator, based on the mean attraction ratings along each route. From this, the best attractions for the boat will be outputted to generate a unique journey for the ratings and length initially stated.

2.2.3 Lock Data

Every lock has a specific lock volume, $x\text{m}^3$, and this volume is fully and exactly displaced. As the model runs, the usage of each lock is recorded, so that the volume of water used at each lock can be found, and also the movement of the water in the system as a whole. Because the direction of each lock is known, this movement of water through the canal can be tracked. The model outputs a graph showing the water volumes in each section of the canal after a set time of boat movements. From this, the height of the water in that section is calculated, and the required volume of water for the canal to remain navigable can be found.

2.3 Discrete Model

Together with the various inputs described in the above sections, the discrete model simulates the movements of boats in the canal. It is named as such because each instance of a boat is a discrete and countable item, as opposed to modern traffic flow models. In these modern models, the traffic is modelled at a fluid entity. This discrete model is chosen because the number of canal boats is significantly lower than the number of cars that interact with each other. On a canal, the boats are too separated to be considered as a fluid. Also, the attractions and destinations of each journey are discretely specified prior to the boat's journey.

To produce a model of the canal system, an adjacency matrix is created to show how the locks are connected to each other. Values in the matrix represent the time taken to travel between two connected locks. Once this matrix has been generated it is possible to create a graph of the canal system, where each lock is represented by a node. The map can be seen in figure 5. Attractions are modelled as being located at a lock. This enables the graph of the network to be used to find the amount of times each lock is operated.

When a boat is generated, it has a randomly-assigned classification over the group of people on board the boat (retired, family, couple). The destination is found as discussed in section 2.2.2. Using Dijkstra's algorithm on the graph of the canal system, the path to the destination and the time taken to reach the destination can be calculated.

By looking at the route generated for each boat, the number of times each lock is used can be seen. Summing this for every boat finds the total number of operations on each lock. This data is used to find the water supply and demand to different sections of the canal after a set time of operation. This is explored more in section 3.1

To find the pinch points, a simulation is run where the boats move forward until they reach a lock. When a boat reaches a lock, a condition is set that the boat must wait if the lock is already in use. If there is a queue for the lock, boats must wait until they reach the front of the queue. Boats also wait until the lock is in the correct state for them to enter it: ascending boats must enter an empty lock, and descending boats must enter a full lock. All of these waiting times are added to the individual boat travel times. Figure 6 shows the total waiting times for each boat.

2.4 Probabilistic Model

To establish the expected usage of each lock along the Wilts and Berks Canal, a probabilistic model is built based on data from the Kennet and Avon Canal. Due to the present state of the Wilts and Berks Canal, there is not sufficient lock usage data, and so data from the neighbouring Kennet and Avon Canal system is modelled. It is assumed that canal operations behave in the same manner in both networks. The lock usage data spans 3 years, from 2014 to 2016 [21]. It is possible to model this data as a training set, and then use it to predict how locks will be used in the Wilts and Berks Canal system. The effect of attractions around the locks is also incorporated into this probabilistic model.

Firstly, every lock in the Wilts and Berks Canal is classified by how attractive is it to stop there. The minor and major attraction classification described in section 2.2.1 is used in this model. If a lock has no nearby attractions, it is given an attraction score of 0. If a lock is situated next to a minor point of interest, it is given an attraction score of 1. If there is a major point of interest located near a lock, the lock is given an attraction score of 2. The Kennet and Avon locks are also classified in the same way, as illustrated in table 2.

This table also illustrates the lock usage proportion of each lock annually. This is calculated by dividing the usage of each lock by the total number of lock usages that year. There is found to be a correlation between the attraction rating and the lock usage; the most attractive locks have the greatest lock usages. An average proportion can be found, as well as a probability multiplier, as shown in table 3. The problem can be explicitly written as

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} 1 \\ 1.09 \\ 1.54 \end{pmatrix} x, \tag{1}$$

where x is the probability of a boat stopping at a lock with no attraction, y is the probability of a boat stopping at a lock with a minor attraction, and z is the probability of a boat stopping at a lock with a major attraction.

Multiplying out the vectors to solve for x, we find that $x = 0.27$ as follows.

$$x + y + z = 1 \tag{2}$$

$$x + 1.09\ x + 1.54\ x = 1 \tag{3}$$

$$x = 0.27 \tag{4}$$

Substituting equation 3 into 1, the following result is obtained.

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} 0.27 \\ 0.30 \\ 0.42 \end{pmatrix} \tag{5}$$

This is interpreted by the model as a boat having a 27% chance of ending its journey at that lock if it arrives at a lock with no attractions around it. Likewise, when the lock has a minor or major attraction nearby it, the probability of the boat concluding its cruise at that lock is 30% and 42% respectively. It is worth noting that the probabilistic model assumes every lock is independent from the others. It does not include the assumption that the boat's final destination is the initial starting point. Adding these values to the model will render a far more accurate estimation of all the trips made by each boat, and will help predict which locks will be used more along the system.

3 Results

3.1 How Much Water is Required?

The total amount of water which has been used by a single lock can be found by multiplying the amount of time the lock is used by the volume of the lock. This is then multiplied by $\frac{3}{4}$ due to the fact that in one of the possible four scenarios of a lock being used, no extra water is drawn into the lock. By doing this for each lock the amount of water that passes through them can be found. To find the amount of water in each section the canal is assumed to start with a cross sectional area as shown in Figure 3. By using the distance of each lock from the start of the Kennet and Avon the volume of the sections of canal between each lock can be calculated. By counting the locks which empty into the section as positive and the locks which drain from the section to be negative, the change in water volume can be found. After the new volume has been found the new height can be calculated as

$$h = \frac{-5.33 \pm \sqrt{5.33^2 - 8\frac{V}{L}}}{4}$$

where h is the new height, V is the volume of that section of canal and L is length of the section.

Once the canal has been modelled for a week, the new volumes and water levels were calculated for each of the sections, these are shown in Figure 8. It is clear from this plot that certain sections of the canal will have less than the minimum amount of water required to operate, while others have more water than they can hold and would flood. This is to be expected as a section of canal with no locks flowing into it will only ever lose water. The opposite is true for a section where locks only flow in, causing the lock to overflow. In order to keep the canal full it would be advisable to fill the section which become empty. another method would be to have all locks have an overflow and only fill the locks which have no inflows.

3.2 Pinch Points

Pinch points are sections of the canal where boats will have to wait due to the canal ahead being full. In order to find these points the amount of time total which boats spent waiting at locks was recorded and plotted in Figure 9, as one would expect the locks with the highest total wait times are those which are visited most frequently.

Alternatively, it is possible to find a pinch point by recording the maximum number of boat which are waiting at each lock throughout the simulation. After running the simulation 100 times, simulating 100 boats for each iteration, Figures 10 and 11 can be produced. It is noticeable that Figure 11 has the values for the locks either side of the marinas removed. The reason for this is that these values were much higher than the others, which is the result of one of the limitations of the model, where all the boats leave the marina at the same time. If this limitation were to be removed then the peaks in Figure 10 would disappear.

Figure 11 shows that there are sections of the canal where queues do not form as much as in others, for example locks 51 to 68 do not form on average a queue greater than 2 boats long. A pinch point would be found at a lock such as locks 44 and 45 where on average a maximum queue of 8 people forms. However this again could be due to a marina being located at 42.

4 Conclusion

4.1 Where to put the water

Water will need to be added to the canal in sections which do not have any locks draining into them, as over time these sections will only lose water to other sections of canal. There are also sections which will lose water despite having locks emptying into them. These sections lose water as boats will move up locks into these sections, draining water from, and then leave through the same lock they came via, draining the same amount of water again. In short, any section with a lock which drains from it which is used more than the locks draining into it will require water to be pumped into it. The amount of water will vary based on the attractions on the canal and number of boats on the canal. Both of these will vary throughout the year based on weather.

4.2 The Feasibility in Restoring the Wilts & Berks canal

In 1998, a study was made on the feasibility of restoring the W & B canal [9]. The study estimated that the total cost in reconstructing the canal would add up to a total figure of around £102.75 million (worth around £166M in today's money), with annual maintenance costs being around £0.45M (£0.73M today). Another study, dated in 2001, also concluded that while many adjustments to the canal's original course would need to be made due to the canal's surroundings having changed over the last hundred years, it would still be theoretically feasible to restore the canal [22]. On a purely financial view point, the report conducted monthly benefits analysis, the summary of which can be found in Table 4 (the values have been changed to account for inflation).

$$\frac{166}{(11 - 0.73)} = 16.16 \tag{6}$$

$$\frac{166}{(13 - 0.73)} = 13.53 \tag{7}$$

As such, should all estimations be correct, it would only take just over 16 years to see a profitable return in the investment of restoring the canal (6) (13.5 years if the Cotswold Canals are also restored (7)).

To accumulate enough water for the restored canal to be operational, both surface water and groundwater abstraction are essential as they are the only sources with the capability of supplying enough water to fill the canal to a substantial level. It is also crucial for the Wilts and Berks Canal Trust to construct a number of new reservoirs, particularly near the summit of the canal in Swindon. Investigations into the use of Tockenham Reservoir as a source should also be carried out as if usable, it could provide the Western Mainline with the majority of its water. Ensuring that the canal bed and walls are constructed with low permeability clay is essential in preventing the loss of water by seepage and leakage and keeping water levels constant.

4.3 Further Research

There is much scope for adding further detail to this report, which would render it even closer to reality. Indeed, the model within this report uses an average lock waiting time for each lock instead of using an accurate time for every individual lock. Adding individual lockage times to the model would drastically increase its accuracy with regards to the time it takes a boat to complete its journey. Furthermore, the model assumes a turning point is situated every 5km along the canal, when in reality the distances between them vary greatly. This affects the probabilistic model, and thus the predicted journeys of every boat, hence why adding accurate turning point positions would add another degree of accuracy to the model.

In the models there is a large and unrealistic assumption that all of the boats set off on their journeys simultaneously. This is highly unrealistic and leads to some of the results being skewed, demonstrated by Figure 10 for example, by finding data on when boats are hired and for how long the boats could be generated to leave at more realistic intervals which would lead to a more accurate model.

The attraction rating were generated without actually having visited the attractions, this could mean that the ratings are not as accurate as possible. By inputting more accurate ratings for the attractions the model would suggest which attractions each boat would wish to go to more accurately.

The Boats are generated with random category ratings, in reality there would be some correlation between each of these scores, for example if a boat has a high family rating they are unlikely to have a high romantic rating. Further research could look into the demographic of canal users to generate a more realistic rating system for the boats.

Another important factor to consider is that boats must stop navigating after a certain time during the day. Currently, the model does not necessitate that boats stop at the end of the day or in any particular place. As such, it is likely that the model displays boats still navigating during the evening, when in reality they should all have stopped at a mooring point along the canal.

To summarise, this report can be used by the Wilts and Berks Canal Trust as a general model which requires more, currently unavailable, data. Further research into the amount of boats and people using the canal coupled with more detailed information about the attractions would be needed to produce a more accurate model.

5 Figures and Graphs

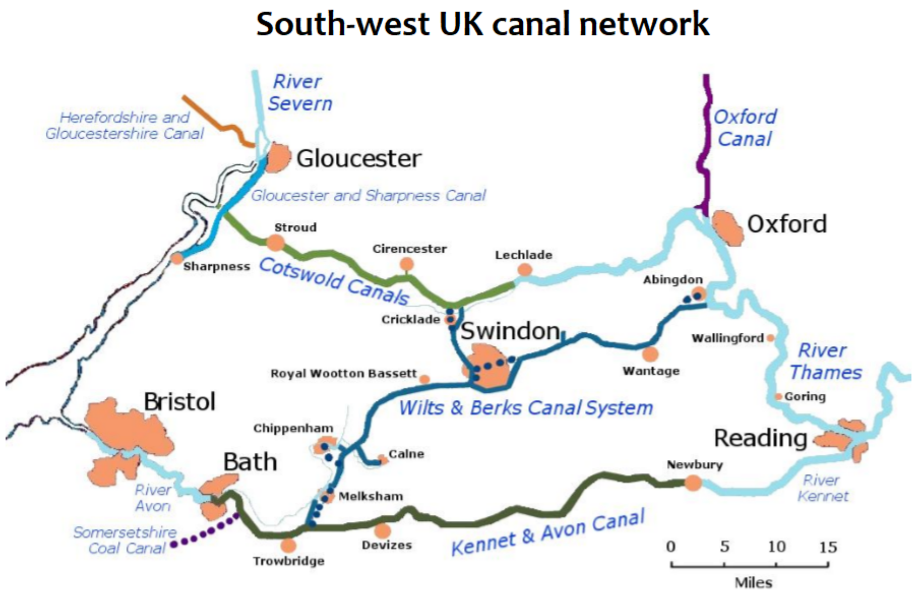

Figure 2: A map of the south-western canal networks, including the new Wilts and Berks Canal.

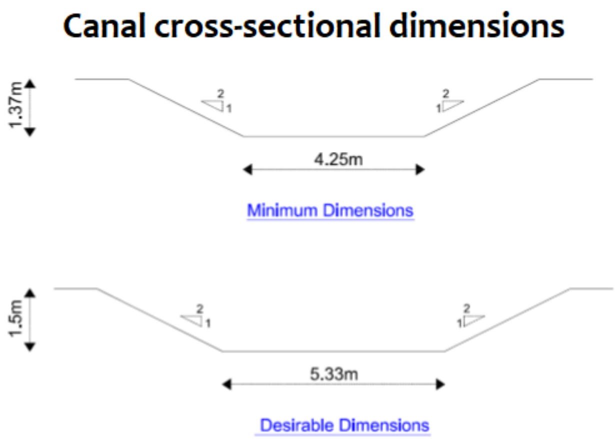

Figure 3: A cross-section dimensions for the Wilts and Berks Canal, as shown in the Strategy Study by Grontmij (figure 6.1 from section 6.2) [6].

Lock Name	Family Friendly Rating	Walking Rating	Retiree Boat Rating	Family Boat Rating	Romantic Rating	Total Score	Major(2) or Minor(1)
Forest Farm Basin	5	1	5	5	3	19	2
The Bell Inn	3	4	4	4	2	17	1
Lacock Village	2	4	3	3	3	15	1
Pewsham Locks	1	3	5	5	2	16	1
Pewsham Marina and Derry Hill	2	2	5	5	1	15	1

Table 1: A sample of attractions detailing the used scoring system for each point of interest along the W & B canal.

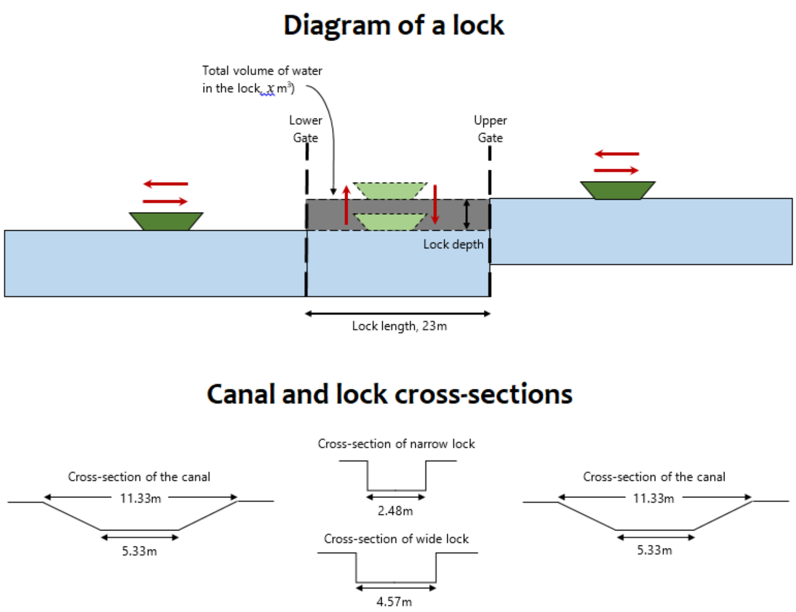

Figure 4: A side-on view of a lock, showing the lock volume. Cross-sectional dimensions also shown.

Site	**2014**	**2015**	**2016**	**Attraction Rating**	**Proportion 2014 (%)**	**Proportion 2015 (%)**	**Proportion 2016 (%)**
Lock 21, Seend	3468	3518	3792	2	13.57	13.15	13.72
Lock 15, Semington	3761	3841	3786	2	14.72	14.35	13.70
Lock 13, Bath	2577	2676	2771	2	10.09	10.00	10.03
Lock 85, Newbury	2282	2451	2521	2	8.93	9.16	9.12
Lock 78, Kintbury	2068	2190	2366	2	8.09	8.18	8.56
Lock 51, Wootton Rivers	1998	2269	2317	1	7.82	8.48	8.38
Lock 60, Crofton	1932	1990	2174	1	7.56	7.44	7.87
Lock 96, Padworth Middle	1834	2150	2100	1	7.18	8.03	7.60
Lock 76, Wire	1994	1994	1953	0	7.80	7.45	7.07
Lock 49, Maton	1845	1861	1939	0	7.22	6.95	7.02
Lock 71, Picketsfield	1790	1819	1918	0	7.01	6.80	6.94
Average	2322.6	2432.6	2512.5				
Total	25549	26759	27637				

Table 2: All of the known K & A locks with their respective attraction rating and lockage proportions.

Lock Attraction Rating	Average Proportion (2016)	Average Proportion (2015)	Average Proportion (2014)	Average Proportion (Overall)	Multiplier
2	11.03%	10.97%	11.08%	11.03%	1.54
1	7.95%	7.98%	7.52%	7.82%	1.09
0	7.01%	7.07%	7.34%	7.14%	1.00

Table 3: A table showing the average of the K & A lockage proportions.

	Without Cotswold Canals Restoration	With Cotswold Canals Restoration
Gross visitor expenditure	£29M	£32M
Income Retained	£11M	£13M
Permanent jobs created	730	790

Table 4: Summary of the benefits in restoring the W & B canal

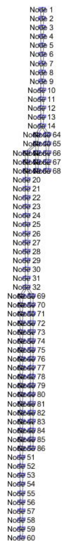

Figure 5: Graph showing the canal system with each node representing a lock

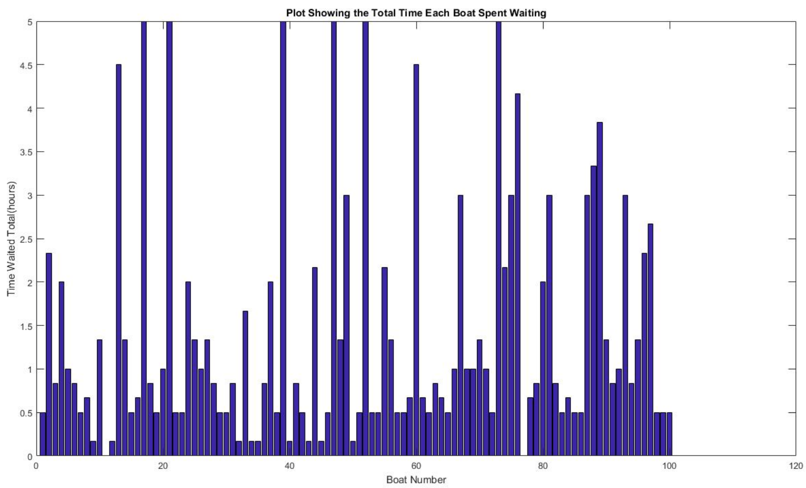

Figure 6: Plot of the amount of time each boat spent waiting along it's journey

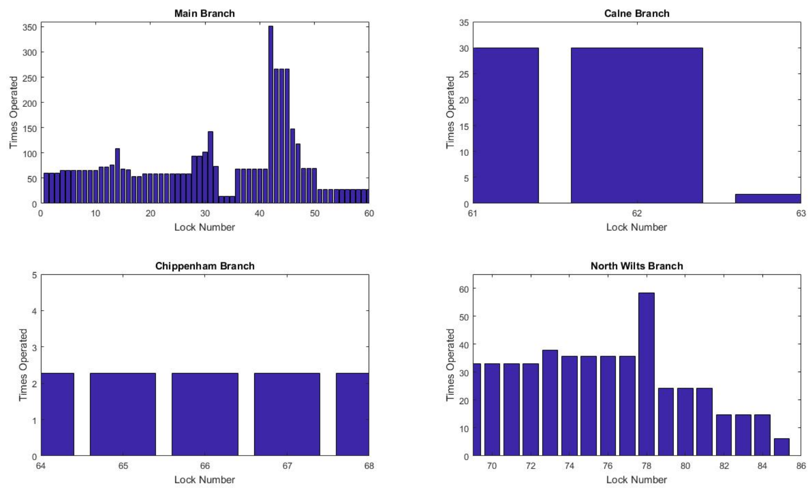

Figure 7: Plot showing the amount of times each lock was used over a week simulation with 300 boats

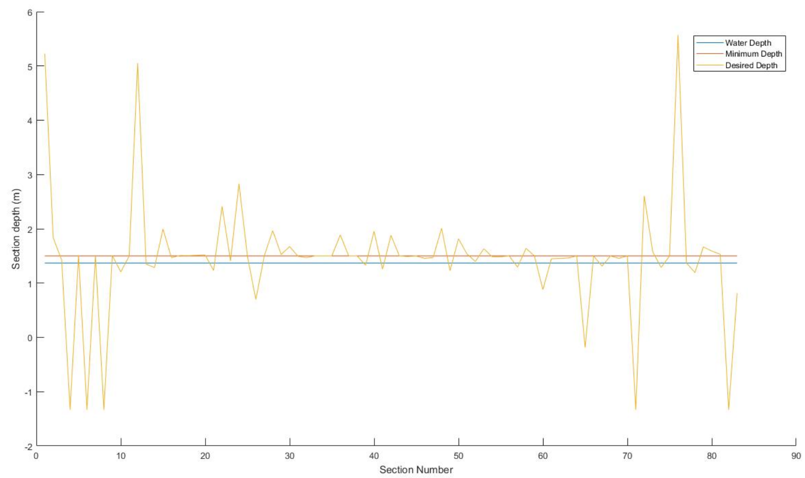

Figure 8: Plot showing the depths of canal sections with no water being added after a week of usage

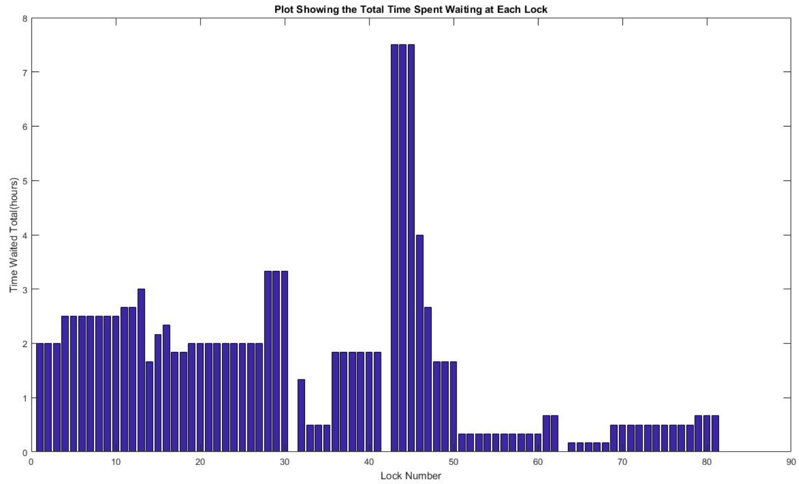

Figure 9: Plot showing the total time boats spent waiting at each lock

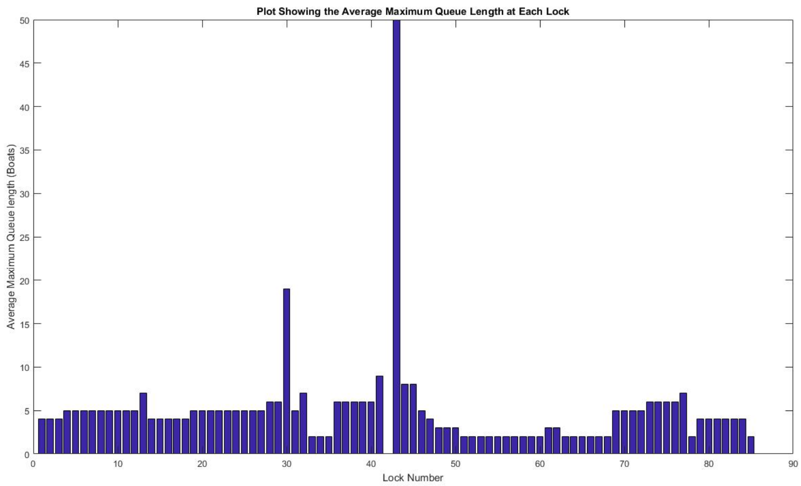

Figure 10: plot showing the Maximum wait times averaged for each lock

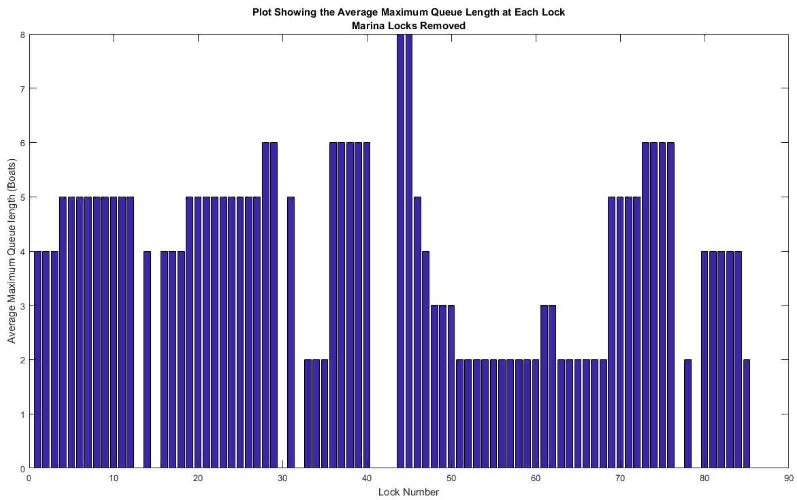

Figure 11: plot showing the Maximum wait times averaged for each lock, with the locks either side of marinas removed

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