ANNEX A2.4

Final Modelling Report

This document has been written in line with the requirements of the RAPID gate two guidance and to comply with the regulatory process pursuant to Severn Trent Water's and Affinity Water's statutory duties. The information presented relates to material or data which is still in the course of completion. Should the solution presented in this document be taken forward, Severn Trent Water and Affinity Water will be subject to the statutory duties pursuant to the necessary consenting process, including environmental assessment and consultation as required. This document should be read with those duties in mind.

Grand Union Canal Transfer SRO

Affinity Water, Severn Trent Water, Canal & River Trust

JBA consulting

Grand Union Canal Strategic Resource Option. Gate 2 Modelling Report

Final Report

October 2022

www.jbaconsulting.com

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Contract

This report describes work commissioned by Affinity Water, by purchase order AWP120016343 dated 18/05/2021. Affinity Water's representatives for the contract were [redacted]

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Purpose

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Executive summary

Introduction

This report describes the Grand Union Canal (GUC) strategic resource option (SRO) modelling prepared for the RAPID Gate 2 investigation of the strategic transfer of water from Severn Trent Water Limited's (STWL) Minworth wastewater treatment works (WwTW) to the Affinity Water supply area via the Grand Union Canal. The modelling undertaken built on hydrological and hydraulic modelling developed at Gate 1, and introduced water quality modelling to test the impact of the transfer both at the point of discharge and along the transfer route.

Scope

The project was undertaken in four phases:

Phase 1: Pound characterisation and scoping

- Pound characterisation. The purpose of the pound characterisation exercise was to combine the outputs of the Gate 1 investigations into a single dataset, to enable the Gate 2 investigations to focus on the key pounds.
- Specification of topographical and hydrological survey data collection. Drawing on the gap analysis undertaken at Gate 1 and using the pound characterisation to focus on higher-risk pounds, a detailed specification was developed for collection of hydrometric and topographic surveys.
- Upgrade of Aquator models to Aquator XV. Conversion of the Oxford Grand Union and Grand Union Tring Aquator models from v4.3 to XV to enable these and the Birmingham Canal Network models to be combined in order to properly test the operation of the transfer.
- Specification of work for Phase 3 and Phase 4. An integrated approach was taken to the detailed specification of the hydrological, hydraulic and water quality modelling of both baseline and with-scheme scenarios.
- **Phase 2: Field data collection**
- Hydrometric surveys. A hydrometric survey was carried out from November 2021 to March 2022, involving a combination of continuous water level monitoring and spot gauging using both hand-held and remote-control boat based Acoustic-Doppler Current Profilers (ADCPs).
- Topographic surveys. A topographic survey of structures along the transfer route options was undertaken between January and March 2022. In total, 162 bridges, 69 channel cross-sections, 73 by-weirs and 44 waste-weirs were surveyed.

Phase 3: Model development and enhancement

Phase 3 involved preparation, enhancement and validation of baseline models of the existing canal system. Early on during this phase the preferred route was agreed, involving a discharge to the Coventry Canal at Atherstone and abstraction from the Grand Union Canal at Atherstone. Three baseline models were prepared:

- Aquator model. The hydrological inflow boundaries to the combined Aquator model developed at phase 1 were fully updated for all feeder catchments. The model was subsequently validated for flows and volumes using the hydrometric survey and historical hydrometric data, resulting in revised baseline modelling of the period 1961 to 2021.

- Hydraulic model. The hydraulic model underwent a full rebuild, bringing together the new topographic surveys with additional information from The Trust, including the Water Control Manuals. Channel cross-sections, waste weirs, by-weirs, bridges, locks and tunnels were represented. The flow boundaries and lockage flows were defined using the Aquator model.
- Water quality model. Water quality impact was assessed using the Environment Agency's River Quality Planning (RQP) modelling suite. Water quality baselines were defined by a water quality monitoring programmes at three locations: Coventry Canal at Atherstone, GUC at Daventry and GUC at Leighton Buzzard.

Phase 4: Concept design

At Phase 4 the baseline models were adapted to represent the proposed transfer scheme. Transfer scenarios were tested based on three flow states and upon an assessment of annual demand from Affinity Water. The These scenarios were modelled as follows:

- Aquator model. The baseline and with-scheme models were run for the period 1961-2022.
- Hydraulic model. 57.5 Ml/d and 115 Ml/d scenarios were tested. The model was adapted to represent the pumps and bypasses that will be required to implement the scheme. This model was used to assess impacts on velocities, water levels, waste weir spills and flood risk.
- Water quality model. The RQP statistical model was used to assess the impact of the discharge at Atherstone, using the demand forecast to represent flows and sampled water quality from Minworth Wastewater Treatment Works (WwTW). This was used to identify where Minworth effluent could cause a deterioration of water quality, and if so to calculate the treatment improvements that might be required to prevent deterioration.

Integrated Design Schedule

The model development work has been carried out in parallel with other Gate 2 investigations, and built upon existing Canal & River Trust water resources models and Environment Agency hydraulic models. The project was developed in a collaborative manner involving regular engagement with Affinity Water, Severn Trent Water, Canal & River Trust, the Environment Agency and other consultants delivering parallel workstreams.

Results

Conclusions - the impact of the SRO on the Grand Union Canal

Water resource and water balance assessment

The Aquator water resource model was used to analyse the baseline and with-scheme operation of the canal using hydrology for the period 1961-2022. It was concluded that:

- The newly combined Aquator model, updated to Aquator XV and with fully revised and revalidated hydrology, provides a much improved platform for assessing the long-term performance of the SRO, as well as generating inflow boundaries for the hydraulic model.
- The modelling suggests that the SRO scheme can generally safely pass through the canal.

- Using the current Trust operational philosophy, some of the supply sources of the Trust appear to be impacted by increased demand for abstraction as a result of the scheme. This is because modelled constrictions in the existing system mean that water is lost to waste weirs in specific pounds and therefore needs to be replaced further downstream. This issue will be addressed at Gate 3 by testing and refining the emerging control philosophy in the hydraulic model, then replicating this within the Aquator model to test the long-term operation of the SRO, including during droughts.
- The Gate 2 Aquator simulations identify 12 years where summer failures are predicted, when the maximum demand of 115 Ml/d is not met. Several of the years identified are in line with national hydrological droughts. The deficit is between 10-30 Ml/d depending on the drought incident and typically last between 1-3 weeks. These occur in the model because during these periods, normal operating procedures in the canal are not occurring due to the canal levels dropping below normal operating levels. So, although the water is still supplied from Minworth, transfer of the full transfer flow through the canal is restricted due to lower-than-normal levels and a shortage of resource in the canal feeders. It is envisaged that this issue will be overcome at Gate 3 by developing an integrated control strategy combining the control objectives of the canal and the transfer. This will include both engineering works (by-passes and pumps), as well as devising a specific operational philosophy to activate back-pumps, maintain revised normal operating levels, minimize losses from the canal and include potential for storage efficiencies to the Trusts' assets.

Hydraulics assessment

Driven by the Aquator flow boundaries, the hydraulic model was developed to analyse the hydraulic impacts of the SRO on the canal system, including surge, velocity, water levels, headroom at bridges and spills over waste weirs.

- Results of an analysis of the potential for surge, especially in the event of pump failure coinciding with an opposing lock operation, emphasise that it is important to design the control philosophy and equipment such that it will fail safe, switching off pumping into a pound when water cannot be pumped out of that same pound. Assuming that this can be achieved, the results do not indicate significant negative impacts from surge, suggesting that this is not an issue requiring additional mitigation measures.
- Increased velocities above the threshold for navigation (0.3m/s) are not identified as a result of the transfer in open channels or at constricting structures including bridges, aqueducts and tunnels, with the exception of just one location, at the narrowest identified constriction on the transfer route located at Rose Boatyard near Bridge 30 on the Oxford Canal.
- In the 115Ml/d scenario, mean velocities will exceed the 0.05m/s threshold for many species of juvenile fish almost everywhere, with only very limited bands of lower velocity along beds and banks. The implications for fish populations should be considered by the environmental assessment.
- The model has demonstrated that, in the majority of pounds, water level rises will be moderate under both transfer scenarios. The steeper hydraulic gradient generated to convey the transfer flows, especially

115Ml/d, tends to raise water levels at the "upstream" end of each pound and lower levels at the "downstream" end.

- The predicted rises in water levels along the transfer route are not sufficient to adversely impact navigation headroom, although this issue needs to be rechecked at Gate 3 when some modelled water levels will change as the transfer controls are refined.
- Spills over waste weirs provides a variable picture. In many cases, where the weir is close to the "downstream" end of a pound, spills in the with-scheme scenario are reduced compared to the baseline. Other weirs, especially those at the "upstream" end of longer pounds, experience increased spills. In total, the scheme is predicted to result in an overall reduction in spill volumes.
- Water level control within and between pounds will require further work at Gate 3 to optimise the scheme to meet the objectives for navigation, conservation of water within the canal, minimisation of energy losses due to recirculation and managing flood risk. These Gate 2 results already indicate that achieving these objectives at either 57.5Ml/d or 115Ml/d is achievable.
- Six junctions of canals connecting at the same water level with the transfer route have been identified. The model predicts significant increases in water level at the Ashby Canal, Coventry Canal south of Hawkesbury and Oxford Canal from Braunston Junction to Napton Bottom Lock. Further detailing to extend the length of the Ashby and Coventry Canals is recommended, and results should be reviewed at Gate 3. There is potential to reduce the water level rises predicted by refining the representation of controls (pumps and bypasses) in the model.

Water quality assessment

A statistical water quality model was used to assess the impact of the transfer discharge at Atherstone, and any additional water quality impact downstream at Daventry and Leighton Buzzard. It concluded that:

- Of the 160 water quality determinands which have been modelled, results indicate that 47 may require treatment to higher than present standards in order to prevent deterioration in the receiving canal system, with a further 27 determinands failing at least one modelling test but not being subject to deterioration. The remaining 86 determinands pass all tests and in many cases would lead to improved water quality in the canals.

Recommendations for Gate 3

A range of recommendations are made for further development and refinement of the models as the design progressed through Gate 3. These are summarised as:

- Additional targeted hydrometric surveys and/or long-term flow and level gauging, as well as additional topographic surveys, including of bank levels in pounds sensitive to water level rises.
- Changes to improve the representation of operational controls for the transfer, within both the Aquator and hydraulic models, progressing as the control philosophy and engineering design is further developed.
- Further work in close partnership with the Trust to address anomalies in water levels identified by the Gate 2 models.

- Extension of the models to include the Ashby Canal (Aquator and hydraulic models) and the remainder of the Coventry Canal (hydraulic model) to represent the full volume of these pounds.
- A Flood Risk Assessment (FRA) will be required to support the Development Consent Order (DCO), in order to demonstrate that the scheme does not increase flood risk or any risks can be mitigated.
- The Gate 2 water quality impact assessment has focussed on a demand and discharge curve peaking at 115Ml/d. Further testing may be required to assess water quality impact for a peak discharge of 57.5Ml/d.
- Further water quality modelling is expected to be required to address a number of areas of uncertainty, including the treatment of determinands without an EQS, the emerging national approach to water quality and permitting of SROs, and addressing the future impacts of climate change on river quality as a result of lower summer flows and higher water temperatures.
- It is recommended that the water quality monitoring regime be continued at Minworth, Atherstone, Daventry and Leighton Buzzard. Developing a longer time-series of water quality data at these sites will improve statistical confidence in the data and hence any further modelling.

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Abbreviations

AA	Annual Average
BAT	Best Available Technology
BCN	Birmingham Canal Network
BOD	Biochemical Oxygen Demand
DCO	Development Consent Order
DO	Dissolved Oxygen
DWF	Dry weather flow
EA	Environment Agency
FRA	Flood Risk Assessment
EQS	Environmental Quality Standard
FIS	Fundamental Intermittent Standards
GUC	Grand Union Canal
GUS	Grand Union South
GUT	Grand Union Tring
HRU	Hydrological response unit
LOD	Limit of Detection
MAC	Maximum Allowable Concentration
mAOD	Metres Above Ordnance Datum
MPER	Metals Permitting (software package)
NWL	Normal Water Level
NOZ	Normal Operating Zone
OD	Ordnance Datum
OxGU	Oxford Grand Union
PC	Process Contribution
PEC	Predicted Environmental Concentration
PMB	Project Management Board
PNEC	Probable No-Effect Concentration

RMDV	Recommended Maximum Discharge Value
RQP	River Quality Planning (software package)
SRO	Strategic Resource Option
STWL	Severn Trent Water Ltd
UPM	Urban Pollution Management
WCM	Water Control Manual
WFD	Water Framework Directive
WTW	Water Treatment Works
WwTW	Waste Water Treatment Works

1 Introduction

1.1 Background

This report describes the Grand Union Canal (GUC) strategic resource option (SRO) modelling prepared for the RAPID Gate 2 investigation of the strategic transfer of water from Severn Trent Water Limited's (STWL) Minworth wastewater treatment works (WwTW) to the Affinity Water supply area via the Grand Union Canal. The modelling undertaken built on hydrological and hydraulic modelling developed at Gate 1, and introduced water quality modelling to test the impact of the transfer both at the point of discharge and along the transfer route.

1.2 Scope of works

The programme for the work began in May 2021 and was undertaken in four phases:

Phase 1: Pound characterisation and scoping

- Pound characterisation. The purpose of the pound characterisation exercise was to combine the outputs of the Gate 1 investigations into a single dataset. This was to enable the Gate 2 investigations to focus on the key pounds. These may be identified for operational, engineering, environmental or hydrological reasons and are the pounds where uncertainty is limiting the decision making and engineering design process or where environmental sensitivities mean that detailed evidence of impacts would be required and scrutinised, for example by the Environment Agency or other external stakeholders.
- Specification of topographical and hydrological survey data collection. The Gate 1 hydrological and hydraulic modelling identified areas of significant uncertainty in the hydrometric boundaries, representation of hydraulic structures. Drawing on the gap analysis undertaken at Gate 1 and using the pound characterisation to focus on higher-risk pounds, a detailed specification was developed for collection of hydrometric and topographic surveys. Alongside this engagement with Canal & River Trust identified that key data on operational control of the canal system was contained within their water control manuals.
- Upgrade of Aquator models to Aquator XV. For Gate 1 existing Aquator models were provided by Canal & River Trust. The Oxford Grand Union and Grand Union Tring models were produced in an older version of Aquator (Aquator 4.3). Converting these to the latest version of the software (Aquator XV) was a priority as it enabled the three models to be combined in order to properly test the operation of the transfer. Furthermore, Aquator XV contained improvements to the representation of locks, developed specifically for Canal & River Trust.
- Specification of work for Phase 3 and Phase 4. Combining with the pound characterisation and specification of survey data collection requirements, an integrated approach was taken to the detailed specification of the hydrological, hydraulic and water quality modelling of both baseline and with-scheme scenarios.

Phase 2: Field data collection

- Hydrometric surveys. A hydrometric survey was carried out from November 2021 to March 2022, involving a combination of continuous water level monitoring and spot gauging using both hand-held and remote-control boat based Acoustic-Doppler Current Profilers (ADCPs). This included a general survey of flow and water level in the canal, along with targeted surveys of pounds with significant spills over waste weirs, larger feeder sources and gauging of the complex interconnections of river and canal channels on the Grand Union South.
- Topographic surveys. A topographic survey of structures along the transfer route options was undertaken between January and March 2022. Priority was given to weirs in the vicinity of the hydrometric survey, bridges with potential to be narrow

or have low freeboard, and long pounds. In total, 162 bridges, 69 channel cross-sections, 73 by-weirs and 44 waste-weirs were surveyed.

Phase 3: Model development and enhancement

Phase 3 involved preparation, enhancement and validation of baseline models of the existing canal system. Early on during this phase the preferred route was agreed, involving a discharge to the Coventry Canal at Atherstone and abstraction from the Grand Union Canal at Atherstone. Three baseline models were prepared:

- Aquator model. The hydrological inflow boundaries to the combined Aquator model developed at phase 1 were fully updated for all feeder catchments. The model was subsequently validated for flows and volumes using the hydrometric survey and historical hydrometric data, resulting in revised baseline modelling of the period 1961 to 2021.
- Hydraulic model. The hydraulic model underwent a full rebuild, bringing together the new topographic surveys with additional information from The Trust, including the Water Control Manuals. Channel cross-sections, waste weirs, by-weirs, bridges, locks and tunnels were represented. The flow boundaries and lockage flows were defined using the Aquator model.
- Water quality model. Water quality impact was assessed using the Environment Agency's River Quality Planning (RQP) modelling suite. No baseline modelling was required as the water quality baselines were defined by a water quality monitoring programmes at three locations: Coventry Canal at Atherstone, GUC at Daventry and GUC at Leighton Buzzard. The Aquator model was used to define baseline flows in the canals at these locations.

Phase 4: Concept design

At Phase 4 the baseline models were adapted to represent the proposed transfer scheme. Transfer scenarios were tested based on three flow states (Table 1-1) and upon an assessment of annual demand from Affinity Water.

Table 1-1: Deployable Output levels and flow states tested

Deployable Output	Transfer discharge (DO +15%)	Instantaneous flow
100Ml/d	115Ml/d	1.33 m^3/s
50Ml/d	57.5Ml/d	0.67 m^3/s
25Ml/d	27.85Ml/d	0.32 m^3/s

These scenarios were modelled as follows:

- Aquator model. The baseline and with-scheme models were run for the period 1961-2022. In the with-scheme model, the inflow from Minworth was based on the SRO capacity and utilisation profile (Affinity Water, 2022).
- Hydraulic model. 57.5 Ml/d and 115 Ml/d scenarios were tested. The model was adapted to represent the pumps and bypasses that will be required to implement the scheme. This model was used to assess impacts on velocities, water levels, waste weir spills and flood risk.
- Water quality model. The RQP statistical model was used to assess the impact of the discharge at Atherstone, using the demand forecast to represent flows and sampled water quality from Minworth Wastewater Treatment Works (WwTW). This was used to identify where Minworth effluent could cause a deterioration of water quality, and if so to calculate the treatment improvements that might be required to prevent deterioration.

Figure 1-1 illustrates the phasing and the relationships between the model phasing. The Aquator modelling provide the hydrological boundaries for both the hydraulic model and the water quality models.

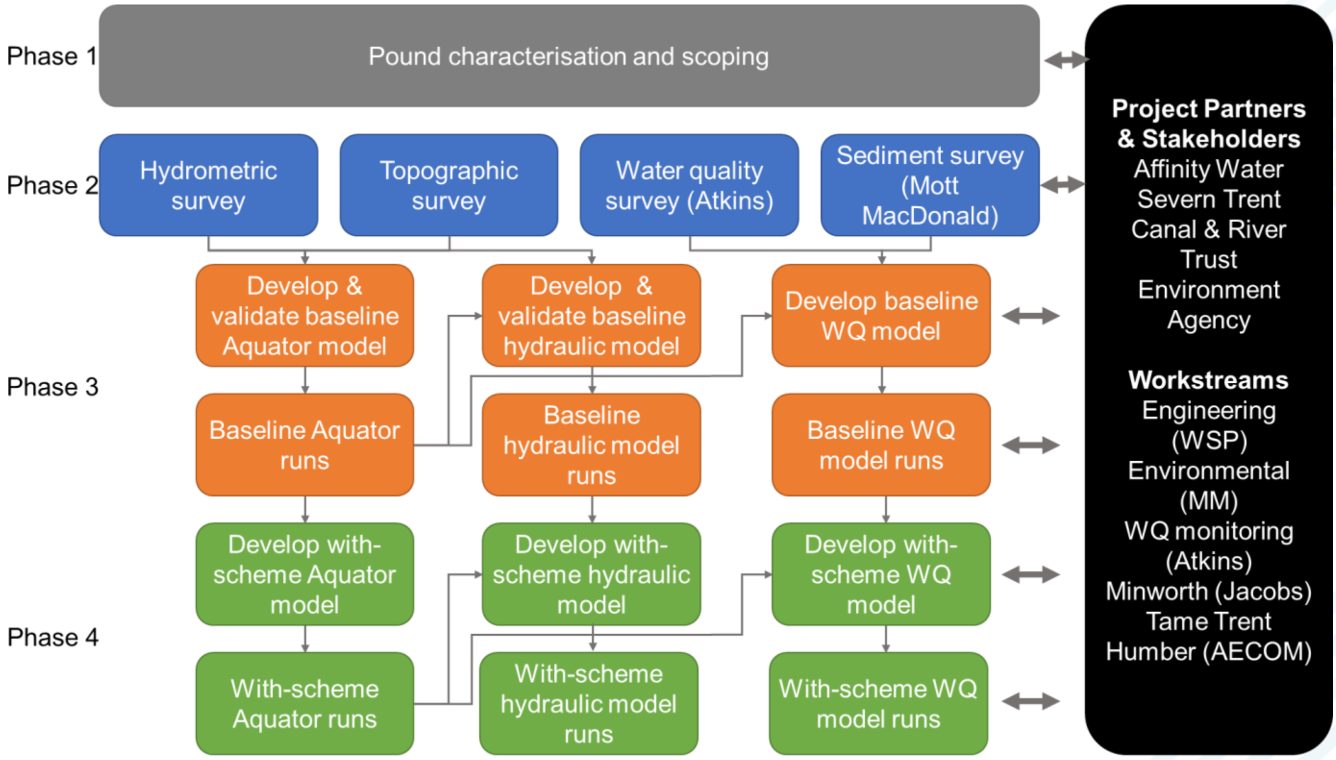


Figure 1-1: Phasing and relationship between modelling workstreams

1.3 Integrated Design Schedule

The model development work has been carried out in parallel with other Gate 2 investigations. Data and information has been shared between projects as far as possible, with the outcomes from other consultants work fed into the model development including focussing attention on sensitive areas where increased confidence in outputs is required for decision making and design.

The modelling work built upon existing Canal & River Trust water resources models and Environment Agency hydraulic models as the basis of the model development and collaborated with Canal & River Trust hydrologists during the process.

The project was developed in a collaborative manner, including:

- Weekly progress and technical meetings with Affinity Water and Canal & River Trust.
- Weekly technical updates with the engineering consultants WSP, plus regular updates with environmental consultants Mott MacDonald.
- Quarterly progress updates and presentations to the above plus Severn Trent Water Ltd (STWL), the Environment Agency.
- Formal review of draft deliverables.

1.4 Structure of this report and related reports

Table 1-2: The report structure

Section	Heading	Description	References to GUC annexes and other detailed reports
1	Introduction	This section	
2	Canal Components	A brief introduction to canal structures.	N/A
3	Pound characterisation	The Phase 1 work to collate spatial and non-spatial data from all of the Gate 1 studies at a pound level.	Pound characterisation table and GIS layer (JBA Consulting, 2021b)
4	Field surveys and data collection Field surveys and data collection	Summary of the topographic and hydrometric surveys	(Storm Geomatics, 2022)
5	Aquator modelling Aquator modelling	The development of the Aquator water resource model including revision of the hydrology, validation, baseline and with-scheme results.	A2.1
6	Hydraulic modelling	The development of the hydraulic model including update of structures, validations and baseline and with-scheme results.	A2.2
7	Water quality modelling	Water quality impact assessment utilising water quality sampling results from Minworth and the canal.	A2.3
8	Discussion and Recommendations	A summary of the main conclusions and recommendations for Gate 3.	N/A

1.5 Transfer Route

At the start of Gate 2, a short-list of input locations, routes and abstraction locations were under consideration. Discharge locations under consideration were numbers 1 Birmingham & Fazeley Canal at Minworth, 3 Coventry Canal at Atherstone and 6 Grand Union Canal at Leamington Trough Pound. Short-listed abstraction locations under consideration were, from north to south, Leighton Buzzard, Tring, North of Hemel Hempstead and The Grove, Watford. During the early part of the Gate 2 work, a preferred route was selected, involving discharge to the Coventry Canal at Minworth (via a pumped main from Minworth, then transfer via the Coventry Canal, Oxford Canal and Grand Union Canal to an abstraction and new Water Treatment Works (WTW) at Leighton Buzzard. The modelling assessments presented in this report have all, therefore, focussed on the preferred route, with the exception of the pound characterisation exercise, which was carried out during the period when the other short-listed options were still being considered.

2 Canal Components

2.1 System Components

The canal system components that are included in the models are described in this section of the report. Note that these components and their detailed representation in the models are discussed in more detail in annexes A2.1 and A2.2.

2.2 Pounds

Pounds are defined as the stretch of water between two canal locks. Typically, a canal pound is a long thin feature where:

- Flow velocities are very low and within a narrow band;
- Water level fluctuations are maintained within a narrow range known as the Normal Operating Zone (NOZ);
- Water level gradients are generally much shallower than in rivers;
- pound bed slopes are effectively zero; and
- Canal pound geometries are relatively uniform compared to natural watercourses.

2.3 Locks

Locks are chambers separated from the two reaches of a canal (pounds) or river each side of lock by gates through which vessels can pass upstream or downstream. The movement of water through a lock is complex and it depends on the specific lock design. In principle, the volume of water moved from the upstream pound to the downstream pound varies with the dimensions of the chamber, the upstream water level and, the number of boats passing through the lock. However, the mechanism of water transfer through a lock are complex and can include the following:

- Lockage: the volume of water transferred through a lock due to a boat using the lock. The Canal & River Trust produce an annual report of lockage across the canal network (Canal & River Trust, 2021) reports are available from 2001. Lockage is represented in the model using an annual profile based on this information (see Figure 2-1), which represents the annual variability of boat movements, which peak during the summer months.
- Gates: these are part of the lock components controlling water into or out of a lock to enable the water level in the chamber to be raised or lowered. In some cases when water levels in the upstream pound are high the gate then acts as a weir, transferring water downstream.
- Sluice: This feature is mounted in the lock gate. Similar to by-weirs, this type of gate is used to transfer water down lock flights.
- Paddle: A type of gate 'sluice paddle', sometimes used to feed water down the lock flights when a constant feed is required. Additionally a ground paddle is present which is utilised before the gate paddle to ensure boats travelling upstream are not submerged by water as the lock fills.
- Inter-lock losses: Volume of water lost out of the system through the lock bed and banks.
- Gate leakage: Volume of water that leaks through the lock gates and is transferred to the lower pound.
- Back-pump: Pumped systems that allows the transfer of water from the lower pounds to pounds higher up the network. They can be used to allow recirculation of lockage water or to meet water demand on the higher pounds and minimise the demand on sources supplying the canal.
- By-weirs: Designed to enable excess water in a higher pound pass down to a lower pound, bypassing a lock chamber. This is a separate structure to the gate

weir and often spills before the gate weir. The by-weir is designated as a different asset type to a waste weir.

Aquator software has a 'lock component' which was specially developed for the Canal & River Trust to be used in their canal water resources models. This component is flexible enough to model most of the locks within the canal network and a customised code can be written in Microsoft's Visual Basic for Applications (VBA) to represent non-standard locks with unusual behaviour. Water always has the potential to move from the upstream pound to the downstream pound and vice versa.

In the hydraulic model, the movement of water around locks via by-weirs and back-pumps is explicitly modelled, whilst the lockage flows between pounds is modelled as an abstraction/ input as calculated in the Aquator water resources model.

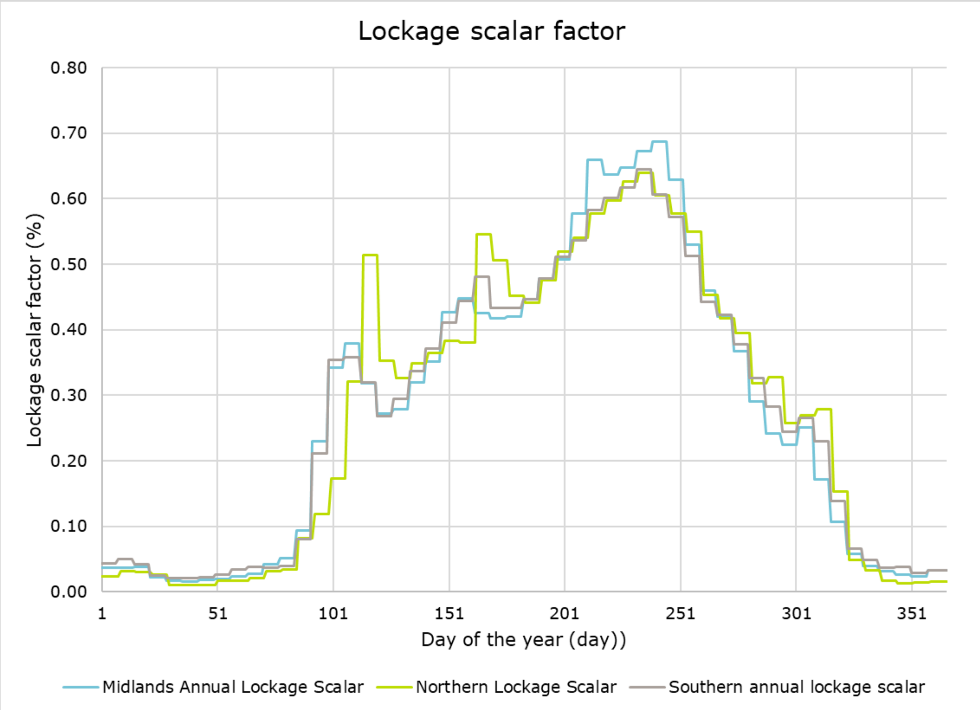


Figure 2-1 - Lockage annual profile

2.4 Pumps

Water can be moved against the gravity flow direction using back pumps, these are used to balance the water in the canal system and reduce the amount of water lost via spill in trough pounds. These are represented in the hydraulic and water resources models with their maximum capacities.

2.5 Weirs

Waste weirs in pounds and bypass weirs at locks are included in the water resources and hydraulic models using a combination of Canal & River Trust and new surveys as well as data contained in the Aquator models.

2.6 Bridges

There are more than 400 bridges on the shortlisted sections of canal under consideration at the commencement of Gate 2, around a quarter of these had navigational width data available from Canal & River Trust. An earlier investigation into canal transfers (Black & Veatch, 2016) identified two possible bridge constraints:

- There is a minimum bridge width required to maintain velocity below an acceptable level for navigation. If the bridge is too narrow, then it may be increased by removing the towpath. If the existing clear span is not sufficient, the bridge may need to be replaced.

- If the headroom underneath the bridge was reduced to less than 2.6m, the bridge would need to be reconstructed.

Bridges are not represented in the Aquator model as they do not impact upon volumes and overall transfer capacity. Within the hydraulic model, bridges with the potential to lead to high velocities or have restricted headroom were modelled as bridge units.

2.7 Aqueducts

Aqueducts are hydraulically significant as they are generally narrower than open sections of canal channel, and therefore higher velocities are anticipated when the transfer is in operation. They are represented as cross-sections within the hydraulic model, although specific cross-sections were not available for all aqueducts.

2.8 Tunnels

As with bridges, navigation in tunnels are potentially sensitive to changes in water level and velocity. They were represented in the hydraulic model as open channel sections based on the known dimensions at entrance and exit.

2.9 Components of flow

The canal is a complex system. The components that make up the water balance are summarised in Figure 2-2 below. Datasets are coloured according to their source (Affinity Water, Canal & River Trust, Thames Water, Environment Agency) with spill and overflows being calculated by the Aquator and hydraulic models. Arrows indicate whether water is an input to or export from the canal.

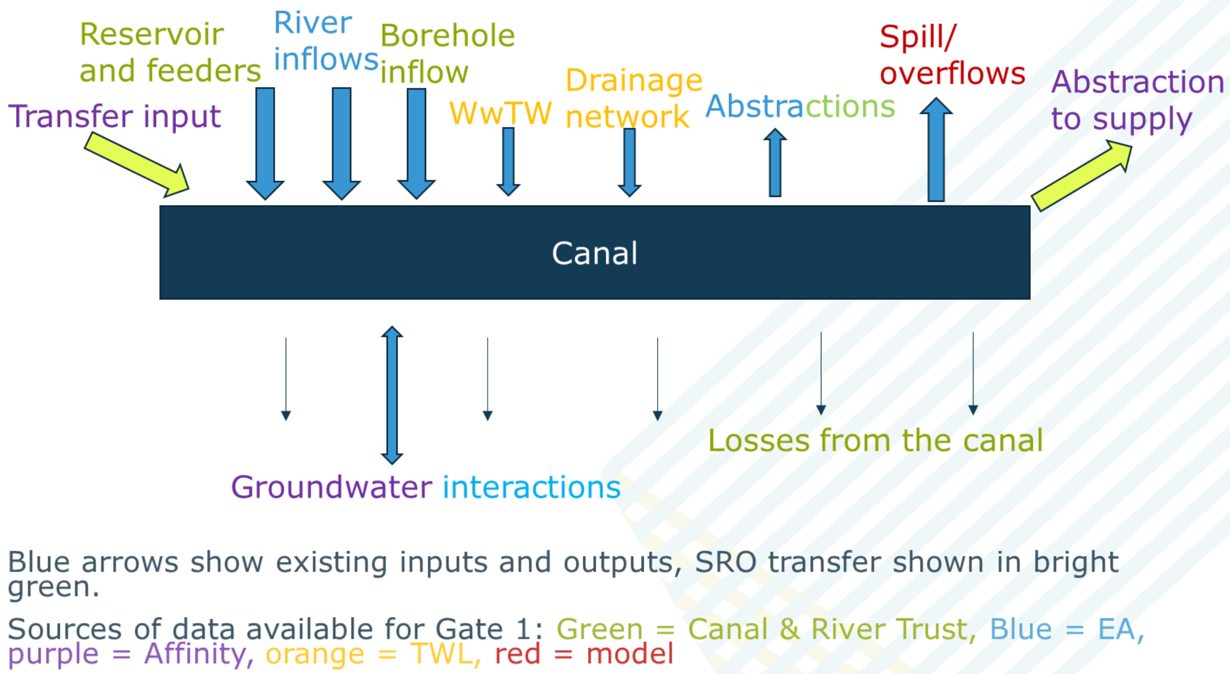


Figure 2-2: Water balance components and data sources

2.10 Water Control Manuals

The Trust's Water Control Manuals (WCM) were provided during the Gate 2 model development and provided a key source of information, in particular defining the Normal Operating Zone (NOZ). This defines, for each pound, the minimum and maximum water levels within which the canal should be proactively operated, as far as practicable. The largest NOZ range on the transfer route is 0.35m, the smallest 0.1m and the average 0.22m.

A Normal Water Level (NWL) is also defined for each pound, balancing unobstructed navigation with efficient use of water resources. In most pounds the NWL is 0.25 to 0.50m above the by-weir sill level. NOZ+ (the maximum water level) and NOZ- (the minimum) and the NWL are defined in relation to a Pound Datum Zero which is usually set at the by-weir sill level. One activity of the topographic survey was to level these weirs to Ordnance Datum (OD) so that NOZ and NWL could be converted to metres above Ordnance Datum (mAOD), to enable water levels in the model to be compared to NOZ and NWL.

The Water Control manuals also proved a useful source of information on back-pumps and waste weirs.

3 Pound characterisation

3.1 Introduction

The Pound characterisation process involved a description of the features and components of each pound on the various SRO route options under consideration and presenting these in a summarised or simplified format. The description of each pound has been broken down into the following sections:

- **Physical Parameters:** Description of the physical attributes/parameters of each pound including pound length, width, number of weirs, number of bridges, etc.
- **Operational Parameters:** These include flow velocity under normal conditions, conveyance lag, number of locks, number of pumps, interaction with other watercourses, etc.
- **Environmental Baseline:** This describes the existence or not, of water quality and hydrometric monitoring, the presence or absence environmental constraints including local nature reserves and sites of special scientific interests.
- **Wider Benefits:** Opportunities that could be capitalised upon as part of the development of the SRO including the incorporation of flood risk measures and development of recreational facilities.
- **Comments:** This section involves identifying and flagging up problem areas that may require further attention or exploration for improvement upon the Gate 1 workstreams, particularly, modelling. For instances, pounds that were lumped up in the Gate 1 models but may actually be better split up based on the complexity of features at sections for better representation.

3.2 Sources of Data

Data was obtained from various sources including GIS layers, Gate 1 model outputs and reports supplied by Affinity Water Ltd, Canal and River Trust (The Trust), Stantec and the Environment Agency (EA). Other sources include the EA's web service archive. The table below summarises the parameters and data sources used for the pound characterisation.

Table 3-1: Pound characterisation fields and data sources

Parameter Type	Parameter	Data Source
Physical Parameters	Length (km)	The Trust Asset GIS Layer
	Average Width (km)	The Trust Asset GIS Layer
	Embankment(s) Present?	The Trust Asset GIS Layer
	Embankment length (km)	The Trust Asset GIS Layer
	Canal Lined?	The Trust
	Connected to Flood Relief Channel (In or Out)?	The Trust
	Number of WL controls	The Trust Asset GIS Layer
	Name(s) of Controls	The Trust Asset GIS Layer
	Type of Controls (static/mechanical)	The Trust Asset GIS Layer
	Bridges	The Trust Asset GIS Layer
	Culverts	The Trust Asset GIS Layer
	Aqueducts	The Trust Asset GIS Layer
	Tunnels	The Trust Asset GIS Layer
	Length of high velocity 'pinch-points' (tunnels, bridges, etc.) km	The Trust Asset GIS Layer
	No. of intermediate lakes/reservoirs	The Trust Asset GIS Layer
	Name(s) of Intermediate lakes/reservoirs	The Trust Asset GIS Layer
	Area of intermediate lakes/reservoirs (km2)	The Trust Asset GIS Layer

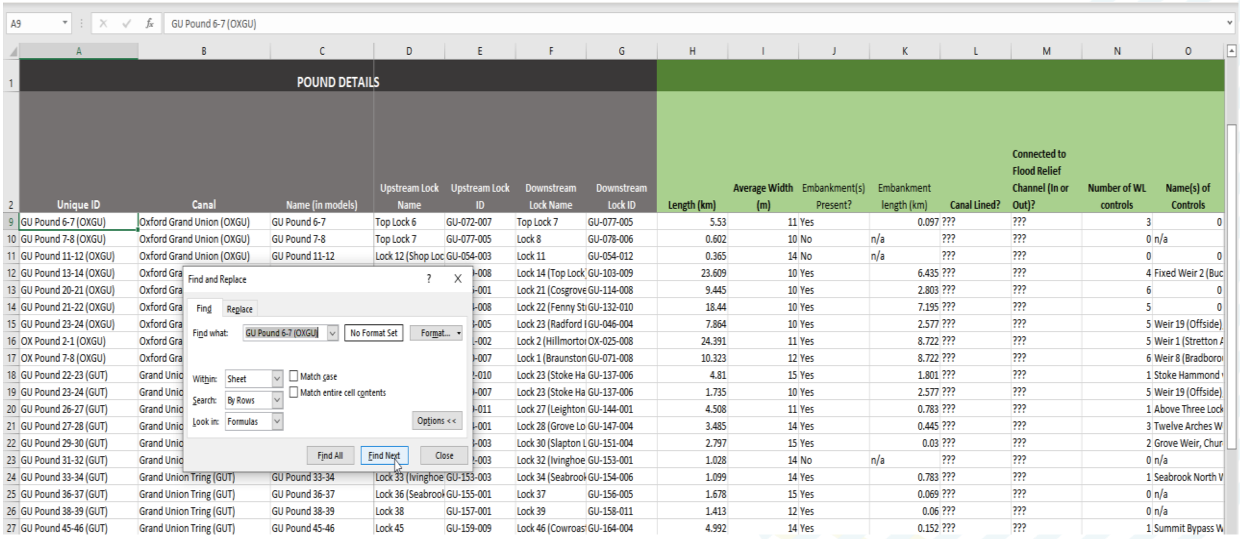
Parameter Type	Parameter	Data Source
	Physical 'Sensitivity' of Pound to flow changes	Computed from other parameters
	Indicative change in water level due to additional transfer flow	Flood Modeller hydraulic models' output
	Is the Pound part of a 'lumped' Pound in the model?	The Trust Models (Aquator)/hydraulic models schematics
Operational Parameters	Number of interactions with other watercourses: Inflows (controlled/uncontrolled, flow rates, reservoir or river source, etc.)	The Trust Models (Aquator)/hydraulic models schematics and model reports
	Name(s) of Watercourse(s)/Feeder(s)	The Trust Models (Aquator)/hydraulic models schematics and model reports
	Nature of interactions with other watercourses: outflows (number and location of waste weirs)	The Trust Models (Aquator)/hydraulic models schematics and model reports
	Number of GW interactions/sources	The Trust Models (Aquator)/hydraulic models schematics and model reports
	Name of GW Source(s)	The Trust Models (Aquator)/hydraulic models schematics and model reports
	Nature of GW interactions/sources	The Trust Models (Aquator)/hydraulic models schematics and model reports
	Conveyance lag (end-to-end) (hours) - Baseline	Flood Modeller hydraulic models' output
	Conveyance lag (end-to-end) (hours) - Transfer	Flood Modeller hydraulic models' output
	Velocity Under Normal Conditions (Baseline)	Flood Modeller hydraulic models' output
	Velocity Under Normal Conditions (Transfer)	Flood Modeller hydraulic models' output
	Number of locks	The Trust Models (Aquator)/hydraulic models schematics and model reports
	Number of lock flight pumps	Canal and River Trust (The Trust) asset shapefile
	Name of Pump(s)	The Trust Asset GIS Layer
	Operational control rules (Pumps)	The Trust operational guide
	Uncertainty over operational control rules (or representation in model) during baseline + transfer op. e.g. back-pumps or paddles	The Trust operational guide
	Impoundment design water level	The Trust operational guide
	Minimum levels (navigation) (m)	The Trust operational guide
	Bank Level at Key Points (or Freeboard Relative to Normal Water Level)	The Trust operational guide
Environmental Baseline	Any known (in-channel) environmental constraints	Stantec/Affinity (GIS Layer)
	Type/Nature of Environmental Constraint	Stantec/Affinity (GIS Layer)
	Sites of Special Scientific Interest	Stantec/Affinity (GIS Layer)

Parameter Type	Parameter	Data Source
	Local Nature Reserves	Stantec/Affinity (GIS Layer)
	WFD 2019 Overall Class	Environment Agency (EA) GIS layer/web service (Open Data)
	WFD 2019 Ecological Class	EA GIS layer/web service (Open Data)
	WFD 2019 Chemical Class	EA GIS layer/web service (Open Data)
	Existing hydrometric monitoring	The Trust Asset GIS Layer
	Existing water quality monitoring	EA GIS layer/web service (archive)
Wider Benefits	Flood risk benefits available through adjusted operation?	Stantec/Affinity (GIS Layer)
	Nature of flood risk benefits available through adjusted operation	Stantec/Affinity (GIS Layer)
	Additional recreational/amenity benefits available?	Stantec/Affinity (GIS Layer)
	Nature of additional recreational/amenity benefits available	Stantec/Affinity (GIS Layer)

3.3 Outputs

3.3.1 Pound Characterisation Spreadsheet

Each Pound was assigned a unique ID that allows the spreadsheet to be queried to obtain a snapshot or profile of any pound of interest, as illustrated in Figure 3-1 below. The spreadsheet is included in Annex A2.2, Appendix A.



	POUND DETAILS														
2	Unique ID	Canal	Name (in models)	Upstream Lock Name	Upstream Lock ID	Downstream Lock Name	Downstream Lock ID	Length (km)	Average Width (m)	Embankment(s) Present?	Embankment length (km)	Canal Lined?	Connected to Flood Relief Channel (In or Out)?	Number of WL controls	Name(s) of Controls
9	GU Pound 6-7 (OXGU)	Oxford Grand Union (OXGU)	GU Pound 6-7	Top Lock 6	GU-072-007	Top Lock 7	GU-077-005	5.53	11	Yes	0.097	???	???	3	0
10	GU Pound 7-8 (OXGU)	Oxford Grand Union (OXGU)	GU Pound 7-8	Top Lock 7	GU-077-005	Lock 8	GU-078-006	0.602	10	No	n/a	???	???	0	n/a
11	GU Pound 11-12 (OXGU)	Oxford Grand Union (OXGU)	GU Pound 11-12	Lock 12 (Shop Loc	GU-054-003	Lock 11	GU-054-012	0.365	14	No	n/a	???	???	0	0
12	GU Pound 13-14 (OXGU)	Oxford Gra			-008	Lock 14 (Top Lock	GU-103-009	23.609	10	Yes	6.435	???	???	4	Fixed Weir 2 (Buc
13	GU Pound 20-21 (OXGU)	Oxford Gra			-001	Lock 21 (Cosgrove	GU-114-008	9.445	10	Yes	2.803	???	???	6	0
14	GU Pound 21-22 (OXGU)	Oxford Gra			-008	Lock 22 (Fenny St	GU-132-010	18.44	10	Yes	7.195	???	???	5	0
15	GU Pound 23-24 (OXGU)	Oxford Gra			-005	Lock 23 (Radford I	GU-046-004	7.864	10	Yes	2.577	???	???	5	Weir 19 (Offside)
16	OX Pound 2-1 (OXGU)	Oxford Gra			-002	Lock 2 (Hillmortor	OX-025-008	24.391	11	Yes	8.722	???	???	5	Weir 1 (Stretton A
17	OX Pound 7-8 (OXGU)	Oxford Gra			-007	Lock 1 (Braunston	GU-071-008	10.323	12	Yes	8.722	???	???	6	Weir 8 (Bradboro
18	GU Pound 22-23 (GUT)	Grand Unic			-010	Lock 23 (Stoke Ha	GU-137-006	4.81	15	Yes	1.801	???	???	1	Stoke Hammond
19	GU Pound 23-24 (GUT)	Grand Unic			-007	Lock 23 (Stoke Ha	GU-137-006	1.735	10	Yes	2.577	???	???	5	Weir 19 (Offside)
20	GU Pound 26-27 (GUT)	Grand Unic			-011	Lock 27 (Leighton	GU-144-001	4.508	11	Yes	0.783	???	???	1	Above Three Lock
21	GU Pound 27-28 (GUT)	Grand Unic			-001	Lock 28 (Grove Lo	GU-147-004	3.485	14	Yes	0.445	???	???	3	Twelve Arches W
22	GU Pound 29-30 (GUT)	Grand Unic			-003	Lock 30 (Slapton L	GU-151-004	2.797	15	Yes	0.03	???	???	2	Grove Weir, Chur
23	GU Pound 31-32 (GUT)	Grand Unic			-003	Lock 32 (Ivinghoe	GU-153-001	1.028	14	No	n/a	???	???	0	n/a
24	GU Pound 33-34 (GUT)	Grand Union Tring (GUT)	GU Pound 33-34	Lock 33 (Ivinghoe	GU-153-003	Lock 34 (Seabrook	GU-154-006	1.099	14	Yes	0.783	???	???	1	Seabrook North W
25	GU Pound 36-37 (GUT)	Grand Union Tring (GUT)	GU Pound 36-37	Lock 36 (Seabrook	GU-155-001	Lock 37	GU-156-005	1.678	15	Yes	0.069	???	???	0	n/a
26	GU Pound 38-39 (GUT)	Grand Union Tring (GUT)	GU Pound 38-39	Lock 38	GU-157-001	Lock 39	GU-158-011	1.413	12	Yes	0.06	???	???	0	n/a
27	GU Pound 45-46 (GUT)	Grand Union Tring (GUT)	GU Pound 45-46	Lock 45	GU-159-009	Lock 46 (Cowroas	GU-164-004	4.992	14	Yes	0.152	???	???	1	Summit Bypass W

Figure 3-1: Pound Characterisation Spreadsheet

3.3.2 GIS Layer

Similarly, the GIS layer can be used to display the data spatially, or to query data in a specific area of interest, as shown in Figure 3-2.

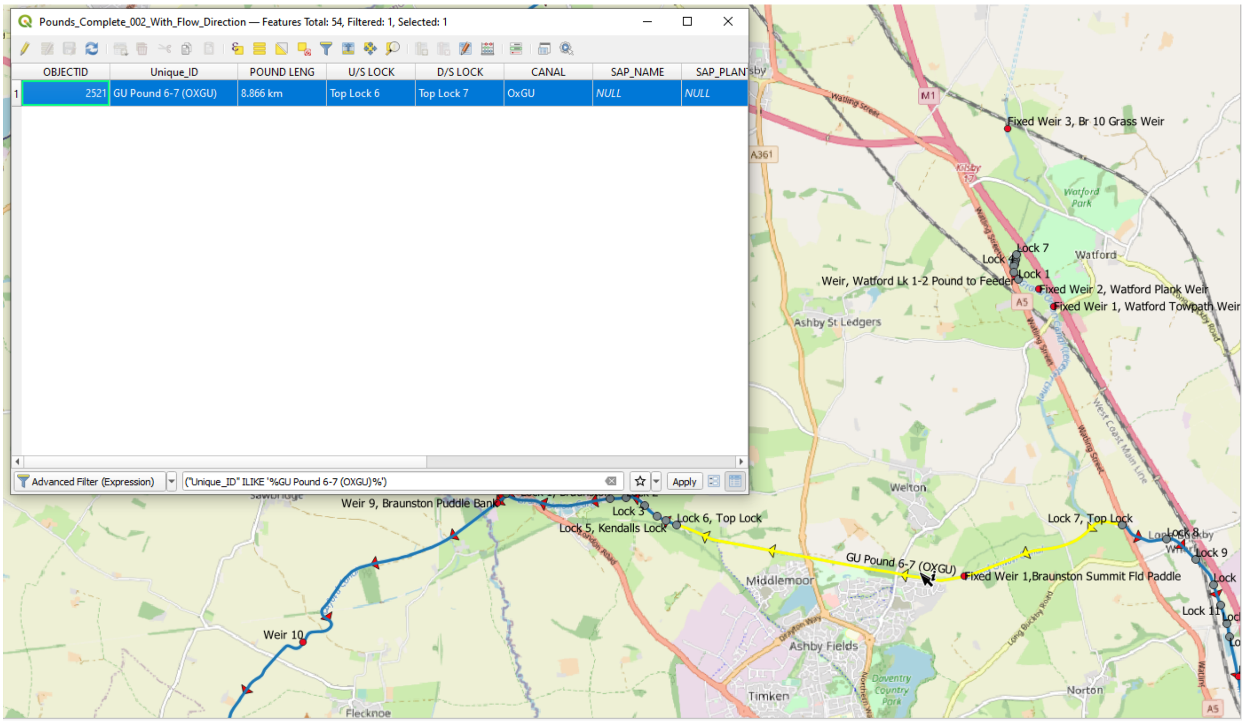


Figure 3-2: Pound Characterisation GIS displaying details of a pound.

4 Field surveys and data collection

4.1 Topographic survey

A topographic survey of the Grand Union Canal SRO transfer route was commissioned by the GUC SRO project management board (PMB) to facilitate the Gate 2 modelling, as recommended in Gate 1, to improve representation of structures and channel sections within the hydraulic model. The following criterion was used to specify survey sites:

- High priority was given to the locations where hydrometric survey and monitoring was planned to be carried out in order to verify data where it is currently available to gain more confidence in the datasets and, to make sure of having an accurate representation of those locations in the hydraulic model which will then be used to validate the model.
- Length of the pound was also considered, assuming that the increased hydraulic gradient required to convey the proposed transfer flow would have the greatest impact on water levels in the longest pounds, and features along these pounds might generate additional head losses or might increase their discharges. Additional canal cross-sections were therefore specified along pounds of 5km or greater length, to enable a more accurate representation of the bed levels and canal width.
- It was not feasible to survey all of the ~400 bridges on the route permutations being considered at the start of Gate 2, therefore bridge characteristics and location were considered when prioritising them for survey. All bridges on long pounds were selected for survey, with the exception of motorway bridges and railway bridges which were discarded as it was assumed that these structures are in general large and would not pose a flow constriction. The selection then focused on bridges located in urban areas, narrow bridges (width less than 3.5m), and type of bridge (arch). Whilst on site, the minimum channel was initial surveyed. Where this was less than 3.5m wide, a full bridge survey was conducted. At wider bridges a simplified survey was carried out capturing widths, height and springing points.

Figure 4-1: Waste weir connecting the Coventry Canal to the River Anker

The survey was undertaken by Storm Geomatics between January and March 2022. Asset types surveyed included bridges (both full and basic survey), channel cross sections, by-weirs and waste weirs. The number of locations surveyed for each asset type is summarised in Table 4-1. Locations of the assets surveyed are given in Figure 4-2.

Table 4-1: Count of asset types surveyed

Survey Type	Number of locations
Bridges	162
Channel cross-sections	69
By-weirs	73
Waste-Weirs	44

4.2 Hydrometric survey

A recommendation of Gate 1 was for collection of targeted hydrometric data, to allow for verification and improved confidence in the base model performance. A hydrometric survey of the Grand Union Canal SRO transfer route was therefore commissioned by Affinity Water to facilitate this project. The survey was undertaken by JBA Consulting and WHS over a period of 4 months, from November 2021 – March 2022. They key aims of this survey were to:

- Understand the relationship between canal level and spill over waste weirs in pounds which typically spill with current operation. This has been achieved by continuous level monitoring in pounds which were predicted to spill in the baseline model runs, spot flows of spill over the control weir (lowest weir in the pound, feeders and the flow over the by-weir at the upstream and downstream locks in the pound.
- Understand the relationship between flow in the canal (measured at by-weirs where flow bypasses locks) in adjacent pounds and along a canal stretch between summit and trough pounds. This has been achieved by a canal spot level and flow survey along the length of the transfer route, measuring canal level at the lowest weir in each pound, spill (if there is any) and flow at the upstream and downstream by-weirs.
- Verify the feeder input to the canal for the largest feeders. Feeders contributing more than 1 Ml/d in the Gate 1 baseline model runs have been spot flow gauged during the monitoring period.

Spot gaugings taken in the canal used Acoustic Doppler Current Profilers (ADCPs). ADCP's were chosen for use in the canal as they are more accurate at low velocities, which are characteristic of the canal, and to eliminate the need for entering the canal minimising risks to the survey teams. Where the ADCP could not be used such as in the smaller feeders and small by-weir channels, handheld flow meters were used.

Hydrometric survey was collected during the Winter period due to the timescales associated with meeting the Gated process deadlines, whereas the scheme is likely to be running at peak operation in summer. Canal operations are designed to conserve water in summer, so differences are expected in the system flow between these periods. However, spot gauging the canal in summer would have been a much more difficult task as boat movement is at its highest causing pound surging and disrupting measurements and velocities would have been lower making recording measurements more challenging. It also meant that the disruption to navigation was limited. It is worth noting that the period of survey was during a relatively dry winter period compared to the long-term average with river flows same period in the normal to below normal range.

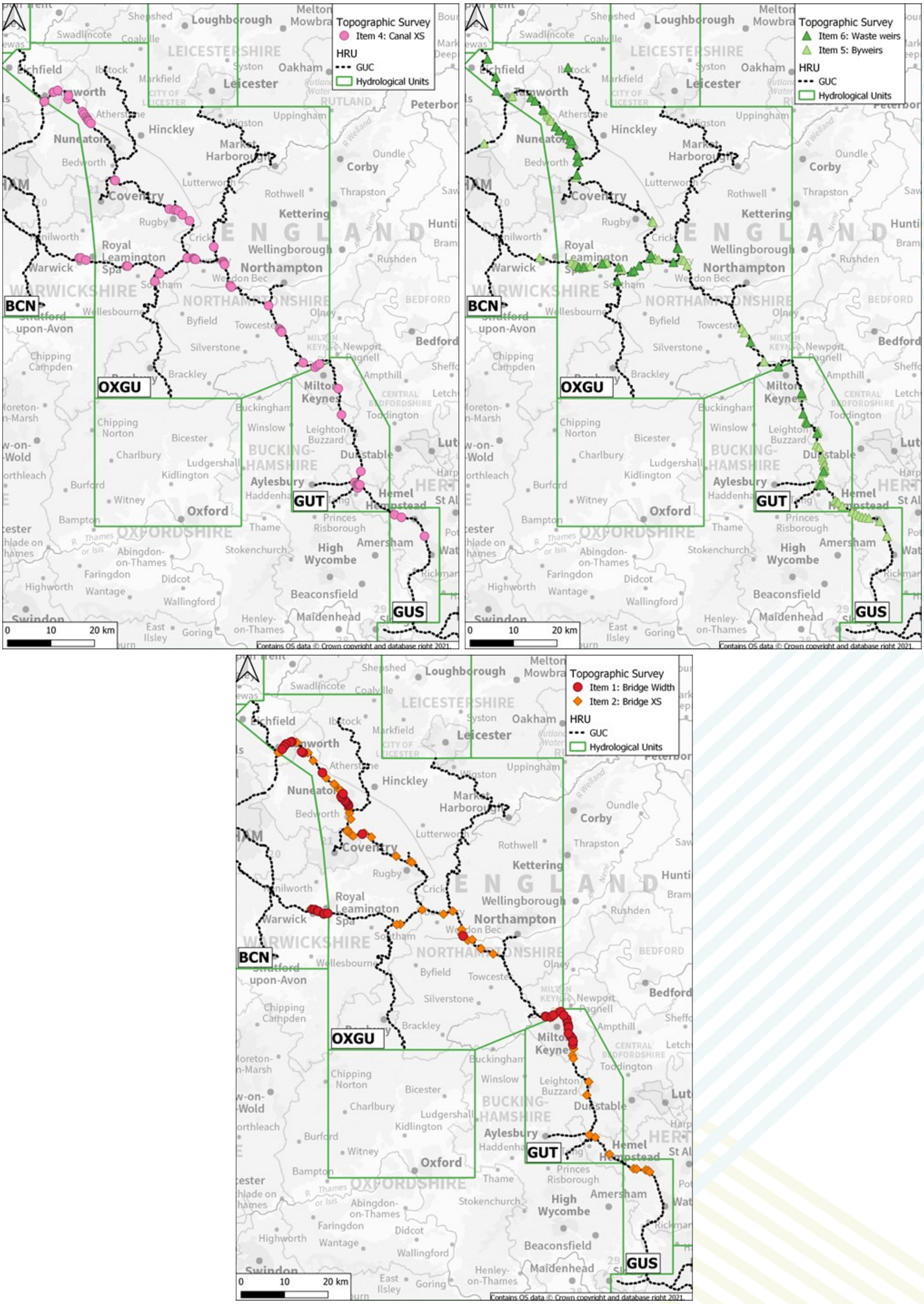


Figure 4-2: Locations of topographic survey (Canal cross sections- top left, Weirs-top right and bridges- below)

Figure 4-3: Flow gauging using the Acoustic Doppler Current Profiler mounted to a remote-controlled boat

Table 4-2 below summarises the different types of locations where gaugings were taken, and the total number of sites surveyed. These are mapped in Figure 4-4.

Table 4-2: Summary of gauging locations

Gauging Type	Number
By-weir at Junction	17
Downstream by-weir at lock	34
Feeder	5
Level	3
Pound Spill	18
Spot flow	21
Upstream by-weir at lock	33
Grand Total	**131**

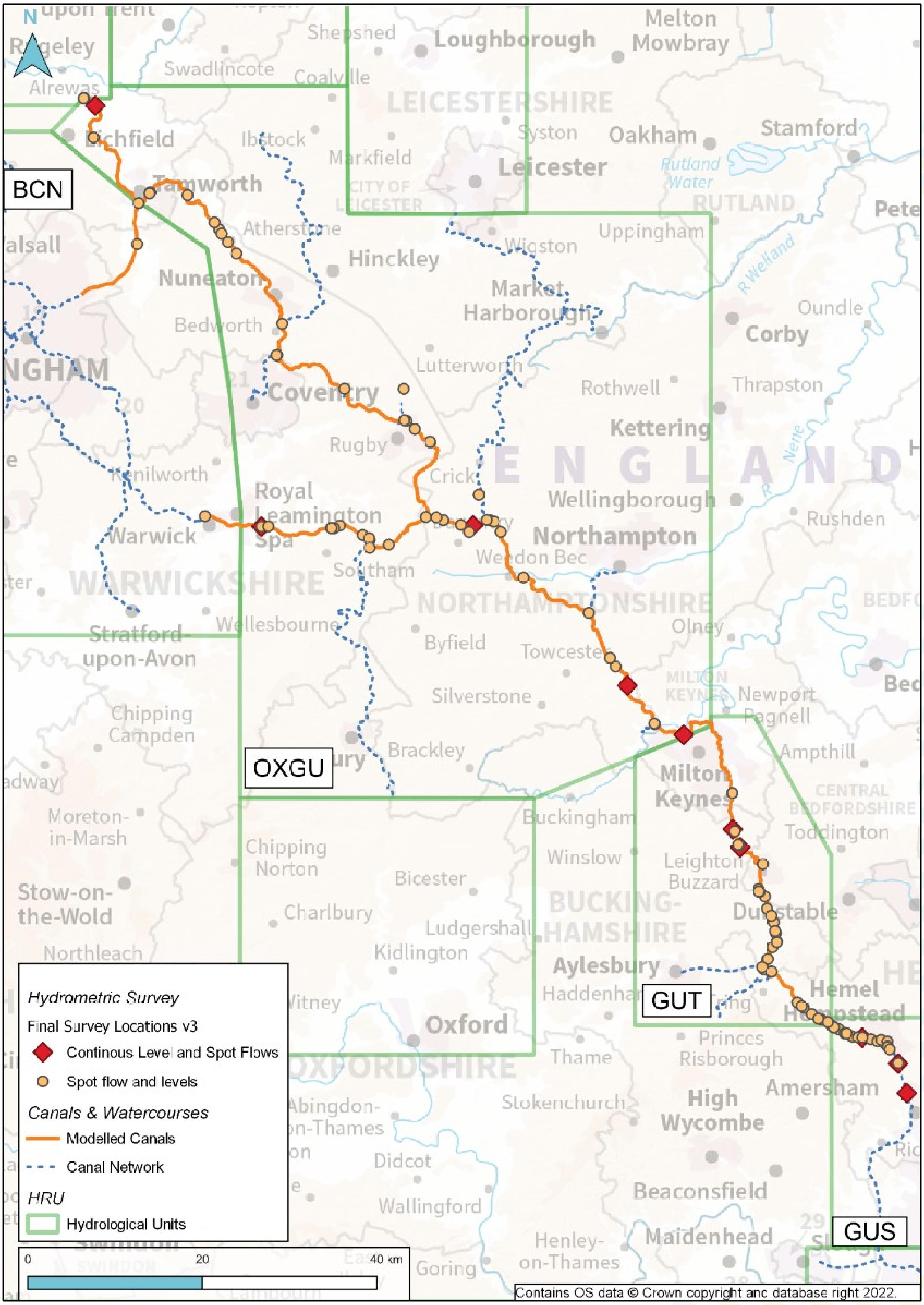


Figure 4-4: Locations of hydrometric survey sites

5 Aquator modelling

5.1 Model development

Under Phase 1 and 2 of this study (as recommended in Gate 1) the Trust's existing Aquator XV models of the Birmingham Canal Network (BCN), Oxford Grand Union (OxGU) and Grand Union Tring (GUT) have been combined into a single system model, hereafter referred to as the combined model as shown in Figure 5-1. Model tools to run multiple simulations and transfer data between the water resources and hydraulic models have been developed to increase efficiency, capacity for scenario runs and reduce the potential for manual errors in the process. Following on from the combination of the models into a single Aquator XV model, JBA was supplied with a new beta release version of Aquator XV which contained code to convert the model to use new components within canals: Canal Pounds and Canal Locks rather than Reservoirs and Locks as previously used.

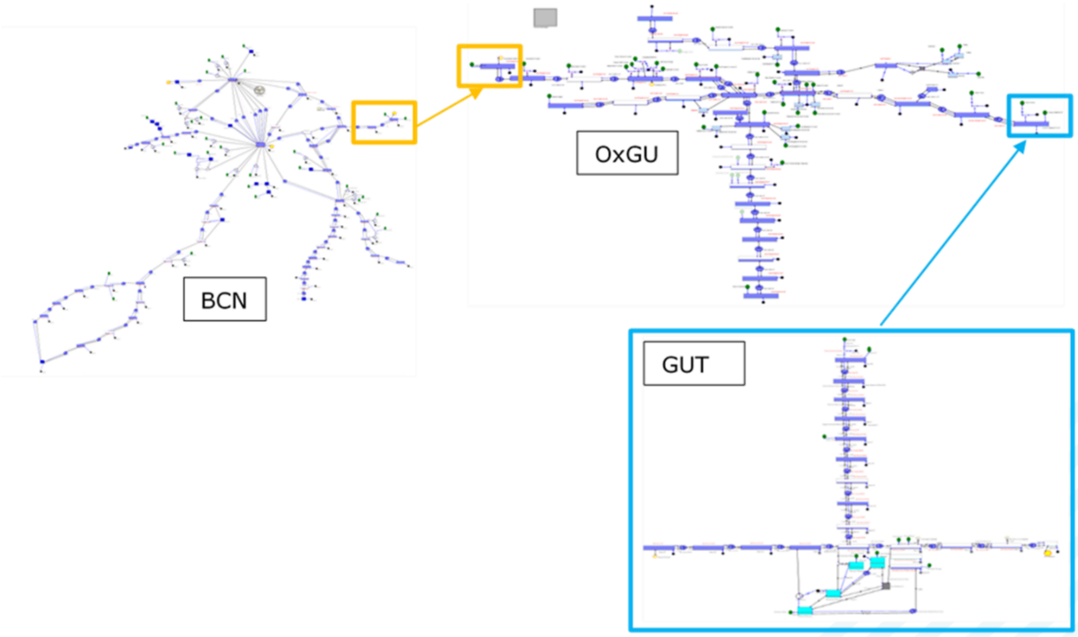


Figure 5-1: GUC combined model schematic

The inflows used in the Aquator XV model required updating. The original inflows in the model were based on a calibration from hydrometric data between 1997-1998. Since then, several additional gauges (owned by both the EA and The Trust) have been installed in the region and it was considered to be of great potential benefit to this project to update these inflows. Inflows for feeder catchments have been derived for the period 1961-2022 rainfall-runoff models have been calibrated for suitable donor gauges (Figure 5-2) and the results scaled to feeder catchments. In the spring-fed catchments of the Tring Summit group a mixed approach of both rainfall-runoff modelling and matching pairs analysis has been used based on available data and flow regime characteristics.

The resulting timeseries have been validated against spot flows and continuous gauge data (where available) and benchmarked against estimates derived from the LowFlows 2 software for each feeder catchment to ensure the flows were representative. Overall, all derived feeder flows are considered to be representative and appropriate for use in Aquator modelling. Limitations and uncertainty associated with the methods applied to derive flow series have been considered when using the Aquator model for modelling the baseline and with-scheme scenarios. More information can be found in the Aquator model report (Annex A2.1). Additional drought scenario flows for the period 2018-2019 have also been derived using observed data at donors, designed to sensitivity test model inflows on Aquator model results.

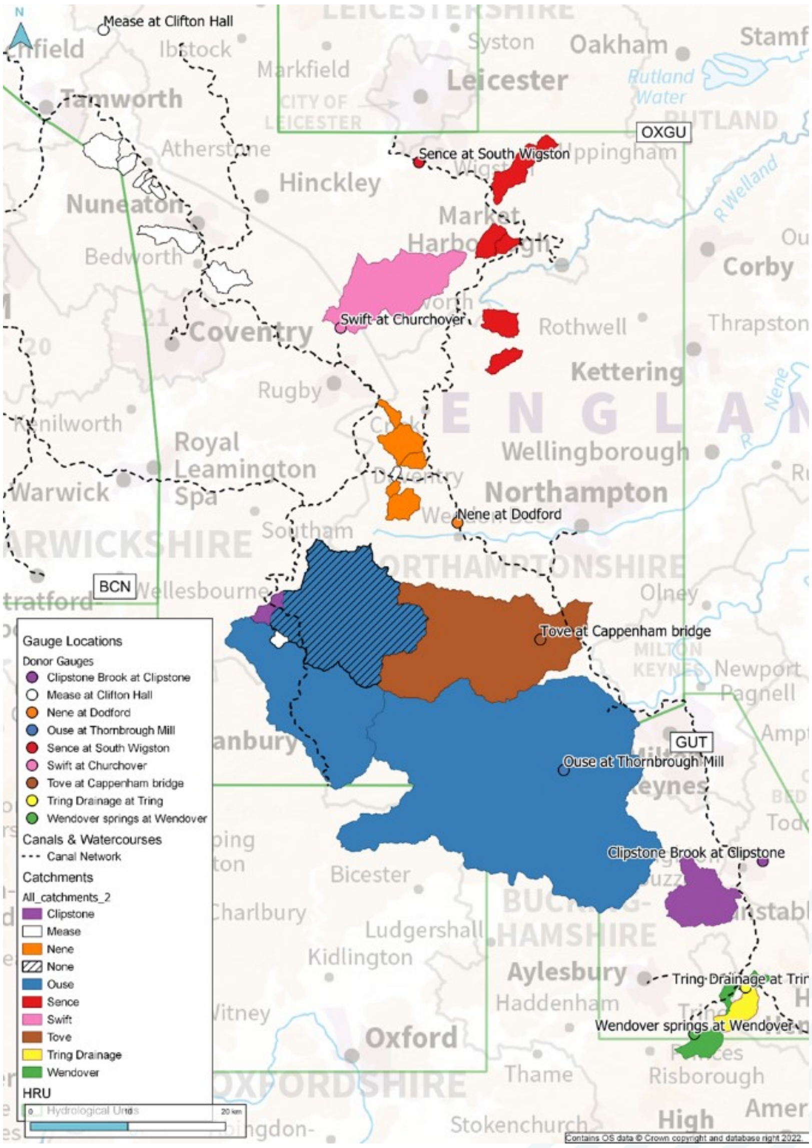


Figure 5-2: Feeder catchments and donor gauges

5.2 Model baseline results and validation

Updated inflows were imported into the baseline model and used to run the model for the period 1961-2022 for the purposes of validation of the baseline model. Aquator flows have been validated against the spot gauging undertaken during Phases 1 & 2 of this study as well as against observed long term flows at The Trust's gauges. These comparisons concluded that the model performance is reasonable, but there are still some limitations associated with modelling back-pump operation and by-weir flow movement. Most comparisons made are based on volume and flow estimates as level is not a primary variable that Aquator estimates with sufficient accuracy. The validation of pound water levels was carried out using the hydraulic model. More information can be found in the Aquator model report (Report A2.1).

To stress-test the Aquator model performance under very low flow conditions, a drought scenario analysis was undertaken. Historical inflow data were inserted into the Aquator model, and an exercise was undertaken comparing drought to baseline model runs for the 2017-2019 period. The effect of the drought scenario flows on Aquator model results is minimal. Generally, the changes to the abstractions from Tove, Ouse and Ledburn are small (less than 5% change compared to baseline scenario). Also, changes to the reservoir recharges broadly appear to be very small. This lends confidence to the calibrated flows used for the updated Aquator model and their ability to simulate drought conditions in the GUC canal system.

5.3 With-scheme results

Following development and validation of the Baseline model, the SRO transfer was input into the model, modelled as an input into the Atherstone Pound and as an abstraction (via a demand centre) at Leighton Buzzard. A series of changes were made in the model to facilitate the transfer including increases to back-pump capacities, increases to by-weir capacities and lowering control curves[1] (which are where necessary to allow for the additional flow to be stored in the pound before it moves down the system.

The with-scheme model has been run and the results analysed with key conclusions being as follows:

- There are 12 years where failures have been observed (see inset table in Figure 5-3), which are summer failures when the maximum demand of 115 Ml/d is not met. Several of the years identified are in line with national hydrological droughts. The deficit is between 10-30 Ml/d depending on the drought incident and typically last between 1-3 weeks. These occur because during these periods, normal operating levels in the canal are not met due to the canal levels dropping below these levels (which are prescribed in the canal operation manuals) because of lack of inflows to the system. So, although the water is still supplied from Minworth, it is not possible to move the entire flow through the canal due to lower-than-normal canal operating levels. The water in the model is mainly used to keep the canal pound volumes full and as close to the normal operating levels as possible.
- Comparison of annual canal feeder abstractions for the baseline and with-scheme scenarios suggest that generally the largest increases in annual abstracted amounts are related to changes in control curves made, increasing the amount of water abstracted from the feeders. These feeder abstractions are all limited however to the existing licence, with is never allowed to be exceeded.
- An attempt was made to amend the control curves for the pounds along the SRO transfer route to operate more seamlessly and minimise spillage, however this aspect needs more work at Gate 3. The activation of back-pumps is reliant on the control curve levels and as the system currently works, the with-scheme model abstracts more water from The Trust's reservoirs (Braunston Summit reservoirs and Tring Group reservoirs). This is because these are the sources that are used to fill the canal pounds to bring them back to a 'healthy' resource based on the current control curve rules. If this is addressed, there will not be as much water pulled from the reservoirs as it is not needed in reality (see section 7.3.5 from Annex 2.1).

Due to the limitations discussed in the previous bullet points, the impact of the scheme on pound spills has also been assessed and there are instances where there may be significant spill in the Atherstone pound when water cannot be moved through the back-pump to the upstream pound. This is because of the limitations on the control curve levels discussed. In these instances, there may be failures to meet the required demand at Leighton Buzzard and water may be pulled from other sources to increase the levels in the pounds that have been impacted. These are not

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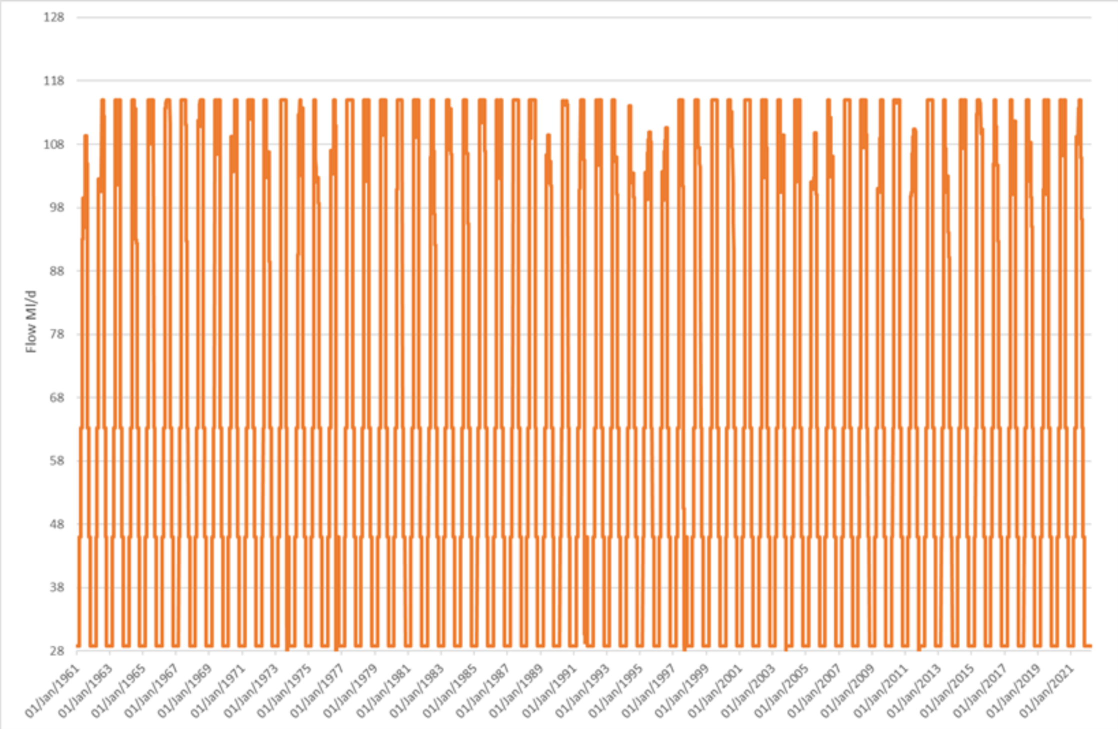
[1] A control curve is a curve that controls operation. It needs to be set on each pound so that resource state is calculated. Resource state is a parameter specifying if a source is healthy or not healthy on a given day based on volume of water present. This is the level in the pound that transfer to a lower pound would normally cease (see Annex 2.1 section 3.2 for more details on how the Aquator model works in the context of canal flow movement).

real failures of the system to supply but rather are because of model constraints. A comparison of volume drawn from the reservoirs versus spills in the source suggest that this mainly occurs when the SRO transfer water cannot move through the Atherstone or subsequent pounds through back-pumping and therefore spills and the reservoir sources are activated.

The modelled supply to the SRO demand centre is shown in Figure 5-3.



Year	1975	1976	1982	1991	1996	1997	2005	2006	2013	2016	2017	2018
Days	28	24	12	3	11	7	11	24	4	6	4	12
Total annual deficit (ML)	450	750	110	40	214	122	232	560	33	78	90	260

Figure 5-3: Supply to SRO demand centre , showing years with days of deficit when SRO demand is not met(scenario of 115 Ml/d)

5.4 Key Aquator modelling conclusions

Key conclusions from the above analysis are that the validated Aquator model adequately represents the canal system at its present state. However, based on the current operational regime, if the SRO is introduced without any change to the operating procedures, on some occasions not all the 115 ML/d reaches the demand area and as a results some of the supply sources of the Trust appear to be impacted. Constrictions in the system mean that water is lost to weirs in specific pounds and therefore needs to be replaced further downstream. There are locations, such as pounds and back-pumps, where ,operationally, the management of the canal will need to be changed to accommodate the volume of the transfer. Some of these changes have been attempted but a systematic change to these procedures is required and recommendations are discussed in section 8.

6 Hydraulic modelling

6.1 Model development

- The hydraulic model was prepared in Flood Modeller Pro, selected for its ability to model all of the hydraulic structures present within the canal and the transfer infrastructure, and, when the Grand Union South was being considered as part of the transfer route, river channels.
- At the start of Gate 2, it was also planned to undertake water quality modelling using the hydraulic model, which Flood Modeller Pro has capacity to do. Following advice from the Environment Agency, the water quality modelling platform was changed to RQP (see section 7), however the potential to use the model for water quality assessment in the future remains.
- The model build commenced upon completion of the topographic survey. By this time, the preferred route had been selected, which enabled the geographic extents of the hydraulic model to be tailored to that route. The model covers the following sections of Canal:
    - Coventry Canal from Lock 12 (Glascote Top Lock) to its junction with the Oxford Canal at Hawksbury Junction,
    - Oxford Canal from Hawksbury Junction to Lock 8 (Napton Bottom Lock),
    - Grand Union Canal from its junction with the Oxford Canal at Braunston Junction to Lock 30 (Slapton Lock),
    - Grand Union Canal from its junction with the Oxford Canal at Napton Junction to Lock 13 (Itchington Bottom Lock).
- Given the volume of updating and detailing required compared to the Gate 1 model, a full rebuild was carried out.
- Inflow boundaries from canal feeders were imported from the Aquator model, using a new data converter built for this project. Similarly, seepage and lockage flows through locks were imported from the Aquator model and represented as abstractions moving water from the higher side of each lock to the lower side.
- All other flow movements were modelled using hydraulic units defined in Flood Modeller. Channels, aqueducts and tunnels were represented as cross-sections, using geometry from The Trust's 50m interval bathymetric survey plus the 2022 survey.
- Locks were represented as two sluice gates, with a reservoir feature representing the lock chamber. By-weirs were represented as spill units, with paddles within letterbox by-weirs represented using orifices. Back-pumps were represented as abstractions, moving water upstream, controlled by water levels. This is illustrated in Figure 6-1.
- Bridges which constricted the flow were represented using two cross-sections to constrict the channel width and a bridge unit. Where a bridge did not constrict the channel width or have a limited headroom it was not modelled (typically larger and more modern road and railway bridges).
- Additional extra-detailed 1D models were constructed for GUC locks 23 to 24 and locks 30 to 31 to investigate velocities and the potential for sudden changes in water level as a result of surge, and a 3D Computational Fluid Dynamics (CFD) model was constructed to provide more insight into velocity profiles. These pounds were selected because they are pounds which will require pumping as part of the transfer, are short (and therefore more prone to the effects of surge) and, in the case of GUC locks 23 to 24, contains a constriction, a bridge and a waste weir.

- In the With-Scheme scenarios, several waste weirs were raised between CC Lock 1 and OX Lock 1 (Hawksbury lock) and between, OX lock 7 and 8. This was done to improve model stability allowing to stablish a constant transfer flow for the different scenarios. In addition, by-weirs that convey water in the opposite direction than the transfer flow, were also raised to avoid flow recirculation around these locks. Figure 6-2 illustrates the location of these raised features.
- In the with-scheme model, modelling issues have been identified in establishing a continuous conveyance of 115Ml/d (1.33m^3/s). This has meant that the maximum conveyance achieved in this scenario is 106Ml/d (1.23m^3/s) through the upstream pounds. At Leighton Buzzard, the target abstraction flow of 115Ml/d is achieved most time. However, there are short periods where the abstraction flow decreases to a value of 93Ml/d (1.1 m^3/s). Figure 6-3 illustrates the conveyance through Hawkesbury Lock (blue line) and the transferred flow abstracted at Leighton Buzzard (green line). To reiterate, this is a modelling constraint and not a physical constraint. We consider that the differences in velocities and water levels between 115Ml/d and 106Ml/d will be minor and therefore that this issue does not adversely impact the conclusions of this report, but that further work will be required at Gate 3 to overcome this issue.

For full details of the hydraulic model, please see the Hydraulic Model Upgrade (Build and Calibration) report (Annex A2.2).

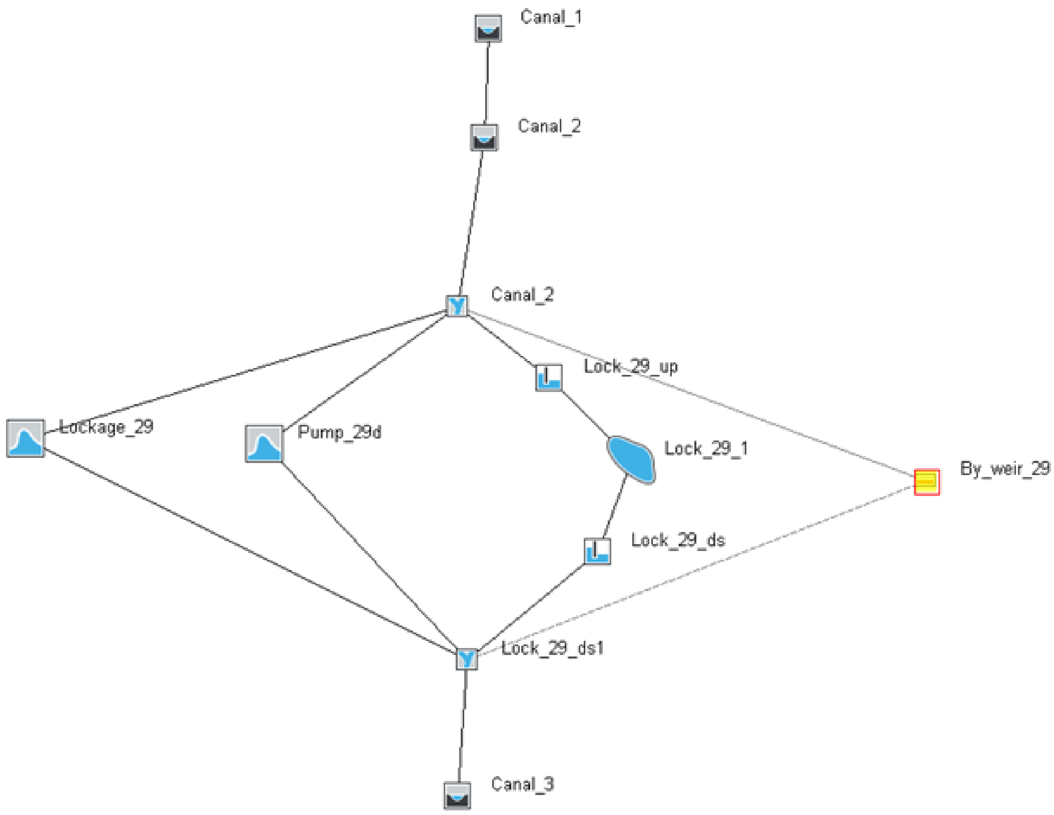


Figure 6-1: Representation of a lock in Flood Modeller Pro

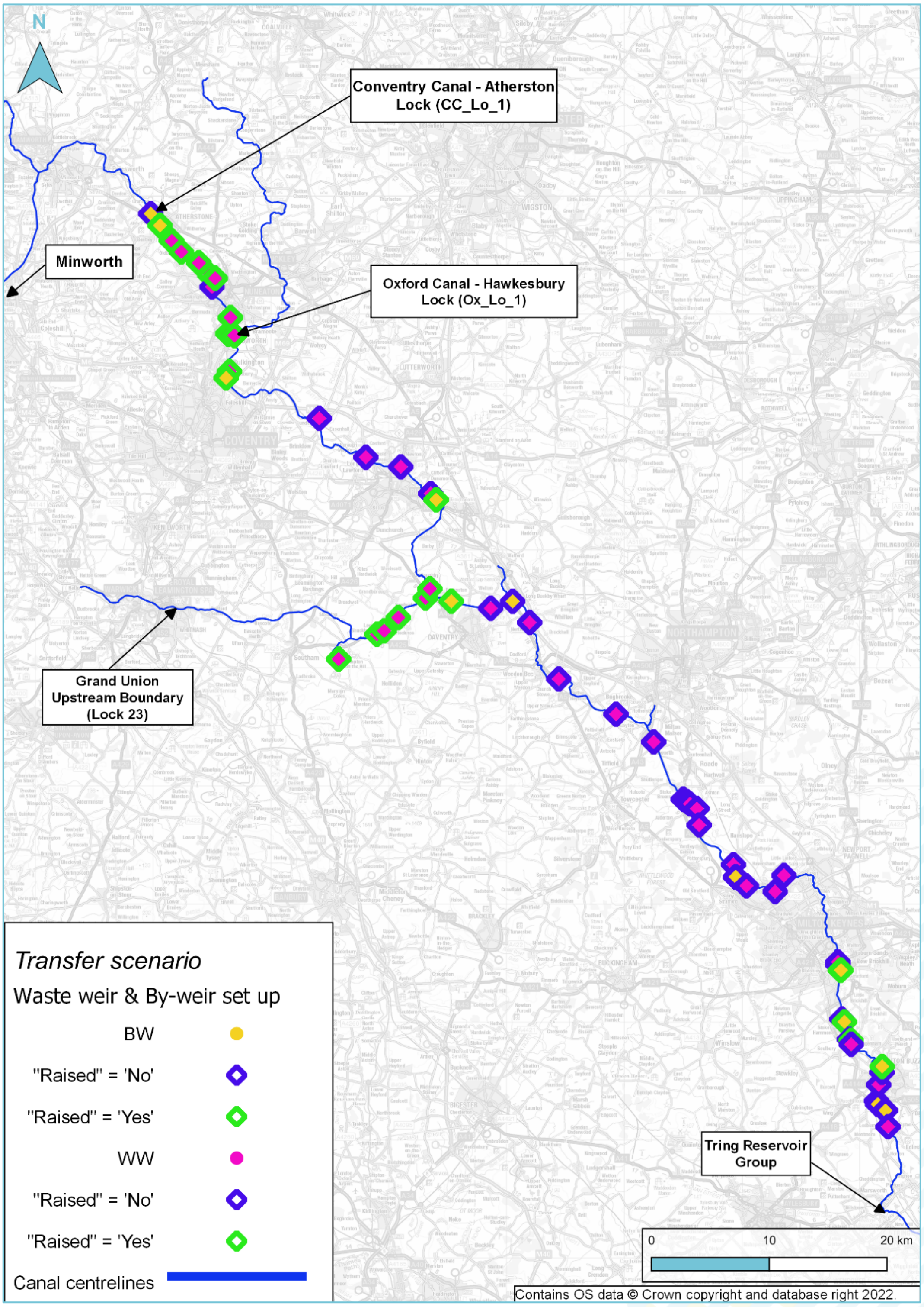


Figure 6-2: Setting of the waste weirs and by-weirs in the With-Scheme scenarios

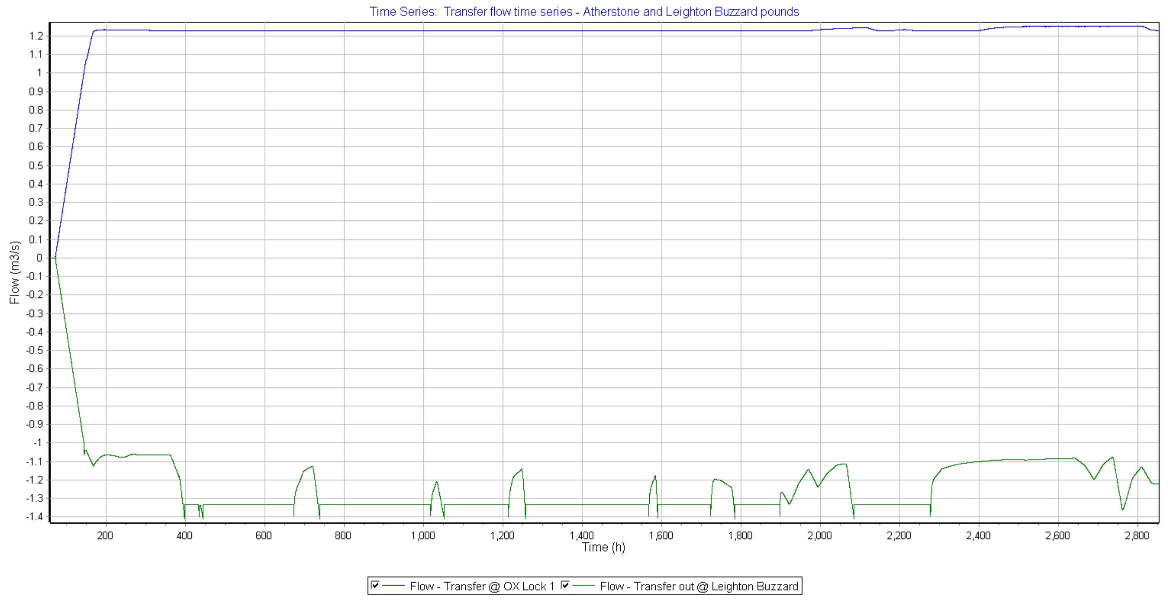


Figure 6-3: Conveyance through Hawkesbury Lock (OX lock 1) and transfer outflow at Leighton Buzzard

6.2 Model validation

- Continuous water level gauging was undertaken during the hydrometric survey at five pounds along the transfer route (plus at other pounds now lo longer within the preferred route). The observed daily mean water levels have been plotted against modelled levels for the period December 2021 to February 2022.
- The observed and predicted results have been normalised (using the long-term mean) in order to take out issues relating to differences in datum etc. Section 6.3.3 considers the model predicted water levels in relation to the Normal Operating Zone (NOZ) and Normal Water Level (NWL).
- The normalised plots are shown and discussed below:

GU Pound 6-7

Observed levels fluctuate within +- 0.05m of the mean. Some fluctuation is also observed in the model results in response to wet-weather events, but the timing of water level changes does not match the observed. This suggests that unmodelled factors, such as operational changes or peaks of boat movements may have impacted the observed levels.

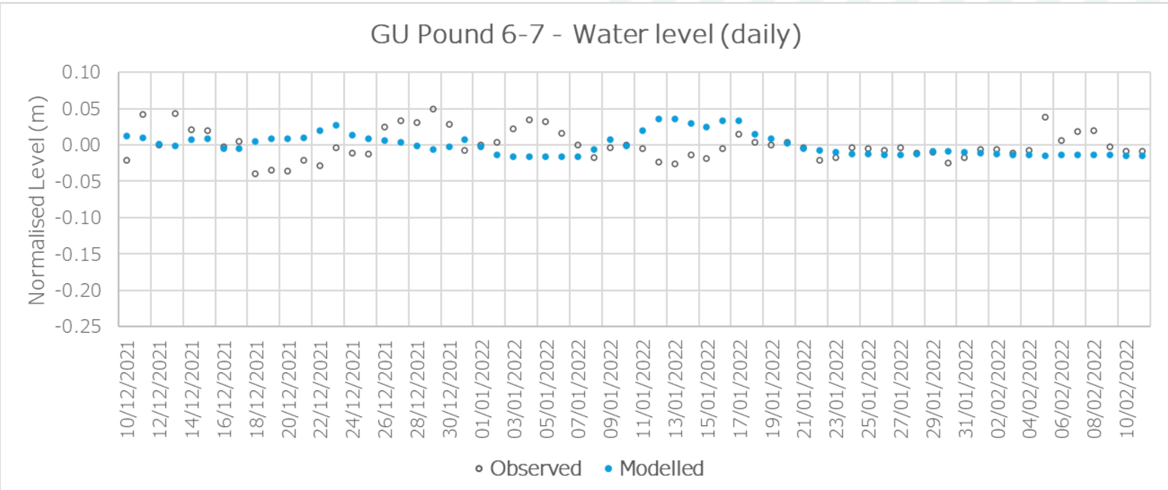


Figure 6-4: Observed vs predicted water levels, GU Pound 6-7

GU Pound 20-21

Observed levels are characterised by two peaks up to 0.2m above the mean, interspersed with periods of stable levels. The modelled water levels remain stable throughout the period. This suggests that unmodelled factors, such as operational changes or unidentified feeders may have impacted the observed levels.

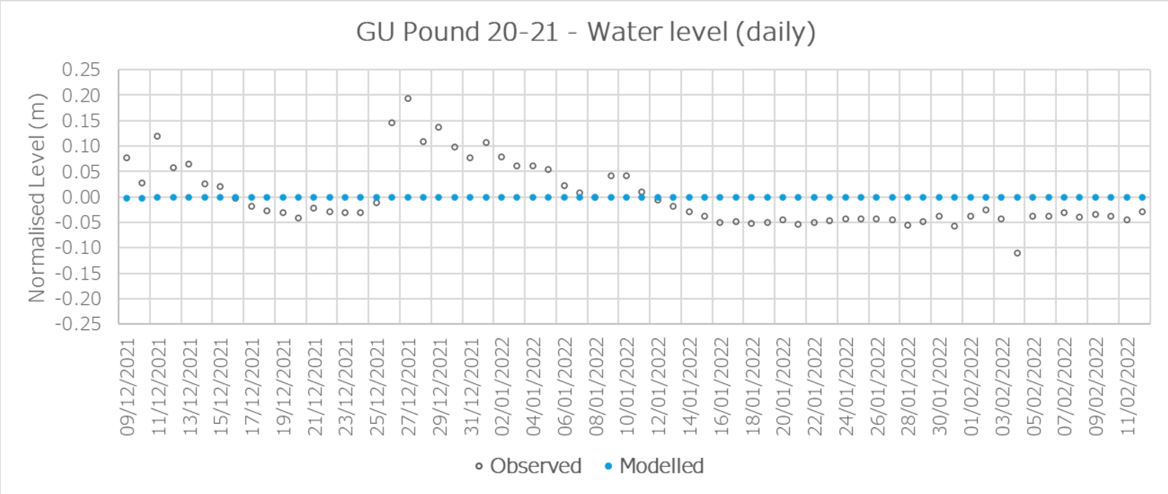


Figure 6-5: Observed vs predicted water levels, GU Pound 20-21

GU Pound 21-22

As in GU Pound 20-21, observed levels are characterised by two peaks up to 0.1m above the mean, interspersed with periods of stable levels. The modelled water levels remain stable throughout the period. This suggests that unmodelled factors, such as operational changes or unidentified feeders may have impacted the observed levels.

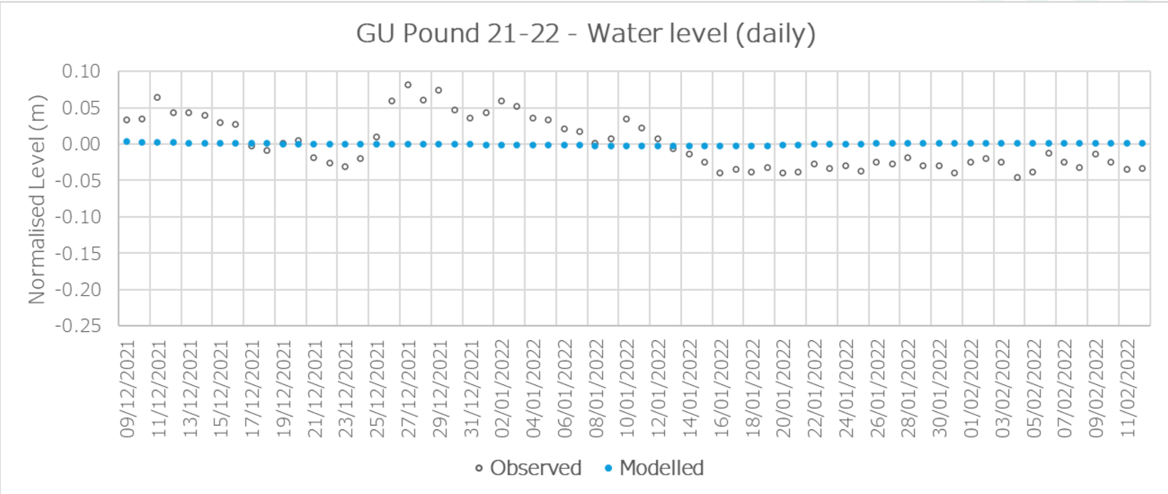


Figure 6-6: Observed vs predicted water levels, GU Pound 21-22

GU Pound 22-23

Observed levels fluctuate within +- 0.05m of the mean. The modelled results are consistent throughout. This suggests that unmodelled factors, such as operational changes or peaks of boat movements may have impacted the observed levels.

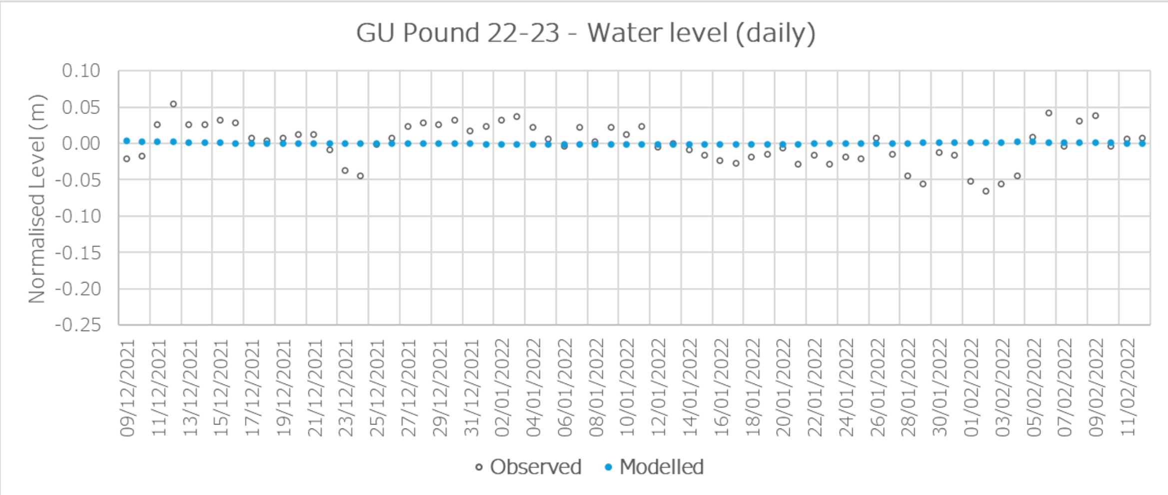


Figure 6-7: Observed vs predicted water levels, GU Pound 22-23

GU Pound 26-27

Observed levels show a sharp drop of 0.17m below the mean in late November, perhaps due to an operational change. Thereafter, water levels are generally around 0.05m higher than in early November, with several smaller fluctuations. The modelled water levels drop steadily by around 0.03m across the period, with no fluctuations. Again this suggests that unmodelled factors may have impacted the observed levels.

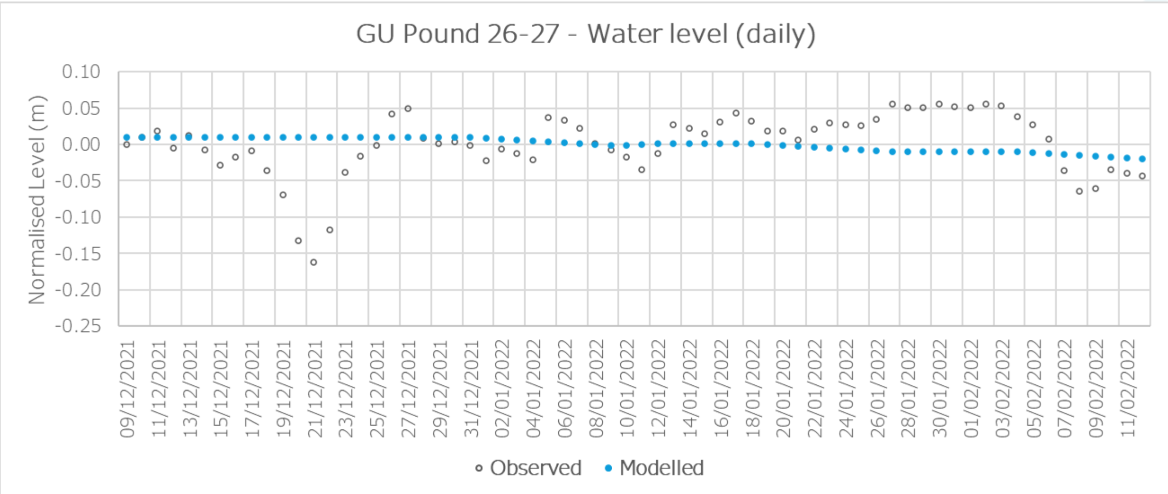


Figure 6-8: Observed vs predicted water levels, GU Pound 26-27

Conclusions

Observed results across all of the monitored pounds indicate greater variability of water level, and even in GU Pound 6-7, where some water level changes in response to wet weather are predicted, these do not match the timing of observed changes. This suggests a range of unmodelled factors may be impacting water levels. These might include operational changes, faults such as leaky lock gates, boater errors, or unmodelled surface water inflows to the canals. Of these, unmodelled surface water inflows may be most impactful, since they would be at their largest during flood events when the system's capacity would be under pressure from known inflows. This suggests that additional checks would be warranted to identify possible sources of inflows, alongside longer-term monitoring of flows and water levels.

6.3 Results

Full tabulated results are provided in Annex A2.2 Appendix D.

6.3.1 Surge

Surge describes the potential for rapid rises in water level in the canal as a result of hydraulic controls operating. For example, operation of a lock sends a wave of water along the lower pound, which then bounces off the downstream lock gate, gradually reducing in wave height and energy. Under normal operation this is would be a shallow wave of just a few centimetres height, barely noticeable and not presenting a hazard to canal users. In the context of the GUC transfer, pumps switching on and off, in particular in the event of failures in the pumping control system, could potentially lead to significant surge events and a number of undesirable outcomes, including:

- Spills over waste-weirs into adjoining watercourses,
- Rapid changes in water level impacting navigation, and
- Localised overtopping of banks.

The potential impact of such events is considered to be greatest on short pounds. With this in mind, extra-detailed models were built for two short pounds at GUC locks 23 to 24 (Stoke Hammond to Three Locks) and at locks 30 to 31 (Slapton to Horton).

In each case, three scenarios were tested, as shown in Table 6-1 and Figure 6-9:

Table 6-1: Surge scenarios

Scenario	Description
S1	Lock 1 closed, transfer flow on; Lock 2 opens and empties in 5 minutes; Lock 2 pump is off.
S2	Lock 1 closed, transfer flow on; Lock 2 opens and empties in 5min; Lock 2 pump is on but turned off during the 5 minutes Lock 2 gate is open.
S3	Baseline conditions Lock 1 closed, transfer flow off. Lock 2 open and empties in 5min.

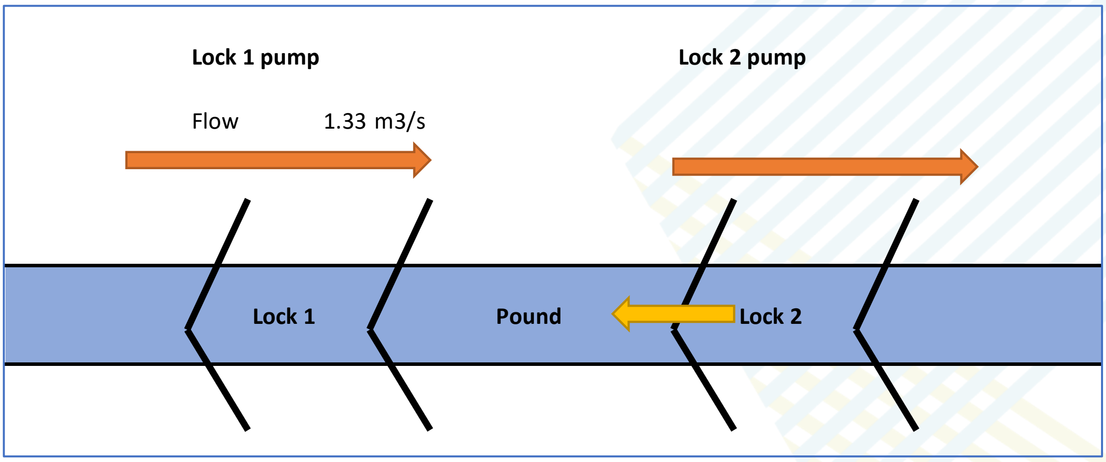


Figure 6-9: Schematic of surge tests

Results indicated that:

- Predicted wave surge amplitude was approximately 0.1m at the maximum in scenarios 1 and 2. This could cause brief overtopping at low points in the banks, but is not expected to pose a high level of risk to canal users.

- The models predicted similar water level increases at lock gates as those obtained using an empirical equation set out in The Trust's hydraulic design standard (British Waterways, 2012).
- Scenario 1 represents a worst-case failure of control systems, as it continues to pump water into the pound whilst the pump moving water out of the pound is assumed to be out of order. In this scenario, water levels would continue to rise until bank-overtopping occurs or levels are controlled by waste weirs, where present.
- In the more probable scenario 3, water levels are predicted up to 0.05m above the baseline operation of the canal (scenario 3). Such an increase was not predicted to lead to bank over-topping, and only small spills over the waste weir between locks 23 and 24 were predicted.
- The results emphasise that it is important to design the control philosophy and equipment such that it will fail safe, switching off pumping into a pound when water cannot be pumped out of that same pound. Assuming that this can be achieved, preventing scenario 1 from occurring, the results do not indicate significant negative impacts from surge, suggesting that this is not an issue requiring additional mitigation measures.

For full details of the surge testing, please see Annex A2.2 Appendix B.

6.3.2 Velocity

The GUC SRO transfer will lead to increased velocities along the transfer route. Increased velocities were identified as of potential concern on four fronts:

- Navigation of boats against the direction of flow, due to velocities being above the maximum speed of the craft, but also making steering through constrictions more difficult. Canal & River Trust advised that 0.3m/s should be considered a maximum velocity during normal operation of the transfer, and that velocities above this represent a hazard to navigation, particularly where present over longer distances through tunnels or aqueducts.
- When travelling against the direction of flow through bridge holes, boats have to work against the current. Increased propeller action can lead to bed scour.
- High velocities may impede the movement of fish within the canal, or even make whole stretches of the canal a more difficult habitat for species which prefer slow-moving or still water. GUC SRO environmental impact consultants Mott MacDonald advised that there are species present within the canal whose larval and juvenile stages are sensitive to velocities above 0.05m/s.
- Increased mobilisation of sediment. This aspect is addressed in the sediment sampling and analysis report (Annex B3.2.5).
- Increased scour risk both within channels and at historic structures. This aspect is addressed in the engineering report (Annex A1).

The impact of velocity was investigated in three ways:

- The two detailed test-case models (described in section 6.3.1 above) were used to investigate velocities at bridges and other constrictions, including considering the impact of entry and exit losses.
- Given that, at the 115Ml/d transfer, average velocities would exceed the 0.05m/s threshold identified for some fish species almost everywhere, a Computational Fluid Dynamics (CFD) model was used to investigate velocity profiles across channels and through constrictions.
- The full hydraulic model was analysed to identify structures where predicted water levels could exceed 0.3m/s.

The key results and conclusions were that:

Open channels

- In the baseline, mean and maximum velocities are predicted to be less than 0.05m/s virtually everywhere, with the exception of the Coventry Canal through Nuneaton and GUC for a short section in Leighton Buzzard. In both of these locations the mean velocity is between 0.05 and 0.06m/s.
- At 115Ml/d, average velocities exceed 0.05m/s almost everywhere, as anticipated.
- Maximum velocities are all below 0.3m/s in the 57.5Ml/d scenario, and are only predicted to exceed the 0.3m/s threshold for navigation at just one location, immediately south of Bridge 114, Bridge Street Leighton Buzzard, on the GUC, where maximum velocity of 0.31m/s is predicted with 115Ml/d. Mean velocities here are 0.14m/s with 115Ml/d, so this is considered to be a low risk.
- The CFD modelling indicates that, at the high transfer flow of 115Ml/d, there is expected to be only a very narrow band of water at bed and banks where velocities will remain less than 0.05m/s (see Figure 6-10).

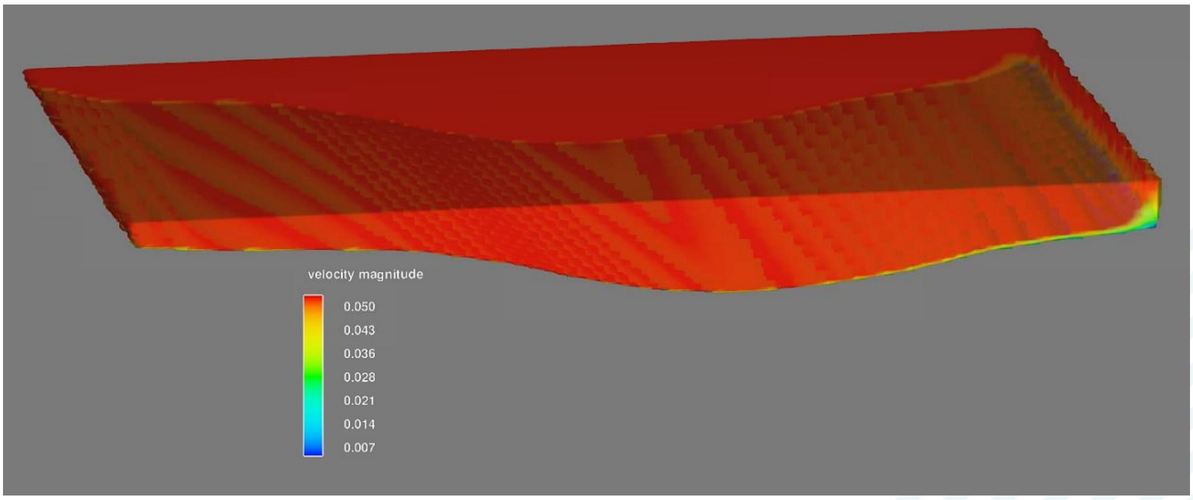


Figure 6-10: Modelled velocities (m/s) with 115Ml/d flow, 0.03m bed roughness

- At a transfer flow of 57.5Ml/d, there is a relatively broad band of water along the bed and both backs where velocities remain below 0.05m/s (Figure 6-11), and at the minimum transfer flow scenario of 23Ml/d, velocities below 0.05m/s would predominate across the majority of the channel. For an assessment of the impact of these velocities on fish resident in the canal, please refer to the Environmental Appraisal report (Annex B3.3.5).

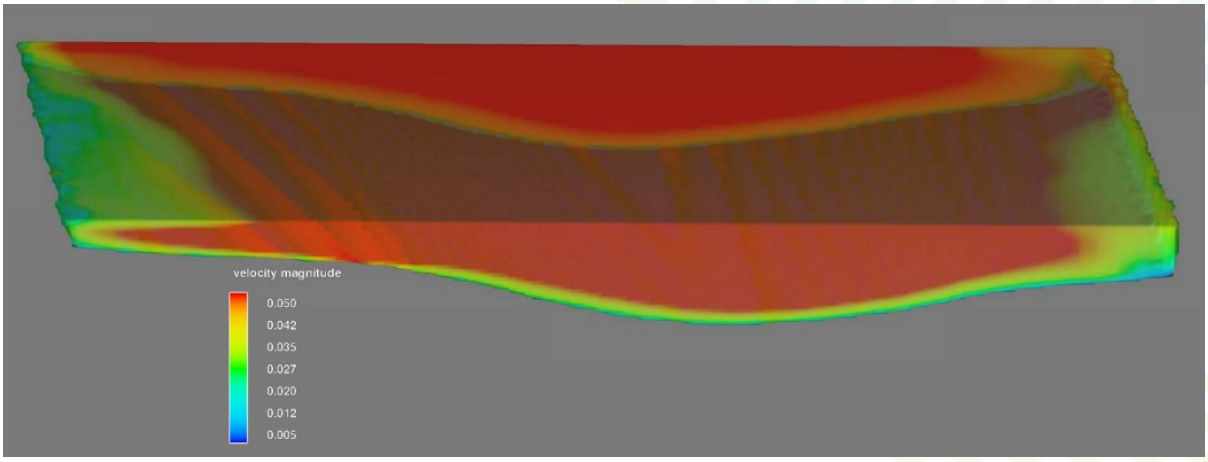


Figure 6-11: Modelled velocities (m/s) with 57.5Ml/d flow, 0.03m bed roughness

Bridges

- Within the detailed test-case model, velocities along a pound were tested with three bridge widths, based on actual bridges along the canal route, ranging from 2.69m to 4.46m at their narrowest width. At the high (115Ml/d) transfer flow scenario, maximum velocities remained below 0.3m/s in all except the 2.69m bridge width scenario at the narrowest constriction on the transfer route (not a bridge), at Rose Boatyard near Bridge 30 on the Oxford Canal.
- Testing using a detailed and simplified approach to representing the bridges indicated that there was no change to peak velocities between the two approaches. This confirmed that the model of the complete transfer route, which uses the simplified bridge modelling approach, is suitable for assessing maximum velocities at these structures.
- In the model of the full transfer route, velocities at bridges are predicted to remain below 0.3m/s, with the exception of GUC Bridge 114 in central Leighton Buzzard reports maximum velocity of 0.38m/s. Investigation of this location indicates that this is as a result of a model instability issue for just one time-step. The mean velocity at 115Ml/d is 0.18m/s, therefore this is not considered to be a location of concern.

Aqueducts

The route contains a large number of mainly very short aqueducts. Not all are explicitly modelled, but where they are, none are predicted to have velocities greater than 0.3m/s in the 115Ml/d scenario.

Tunnels

Predicted maximum velocities for the three tunnels on the route were as follows:

- Newbold Tunnel, Oxford Canal: 0.11m/s at 57.5Ml/d and 0.15m/s at 115Ml/d.
- Braunston Tunnel, GUC: 0.06m/s at 57.5Ml/d and 0.09m/s at 115Ml/d.
- Blisworth Tunnel, GUC: 0.04m/s at 57.5Ml/d and 0.06m/s at 115Ml/d.

These are well below the 0.30m/s threshold for navigation and therefore do not present a hazard to boat traffic.

For full details of the velocity modelling test case, please see Annex A2.2 Appendix C.

6.3.3 Water levels and flood risk

This section reports the predicted water levels in the baseline compared to the stated Normal Water Level (NWL), and changes in water levels between the baseline and the with scheme scenarios and the implications they have for water level management and flood risk. All model outputs presented here are per the wet period December 2013 to April 2014.

- Normal water levels (NWL) and the range of operational water levels (NOZ- & NOZ+) were obtained from The Trust's Water Control Manuals and water control points (GIS layer).
- Predicted minimum, mean and maximum water levels for the baseline and with scheme scenarios were derived for each pound and compared against the normal water levels (NWL) and the operation zone range.

Baseline vs. Normal Water Level (NWL)

- Figure 6-12 shows the comparison between the baseline simulation and the NWL, for each node in the model.
- In most locations, predicted mean water levels (Figure 6-12a.) are within +/- 0.15m of the NWL.
- Baseline water levels are predicted to be up to 0.3m below NWL in the Oxford Canal between locks 7 and 8. Engagement between JBA and the Trust has

improved the modelling of waste weir levels in this pound, but these results indicate that there may still be other factors causing an under-prediction of water levels, albeit much improved on previous model iterations. This should be rechecked when all aspects of water control are reviewed at Gate 3.

- The GUC Pound between locks 27 and 27, through Leighton Buzzard, is also predicted to operate some 0.2m below NWL.
- The comparison between predicted maximum water levels and NWL for the baseline case (Figure 6-12b.) exhibits a different pattern. Again, most pounds are predicted to remain within 0.15m of the NWL. The exceptions are GUC pounds 13-14, 21-22 and 22-23, which all predict water levels 0.15 to 0.20m above NWL.

a. Baseline mean WL vs Normal Operation WL	b. Baseline max WL vs Normal Operation WL

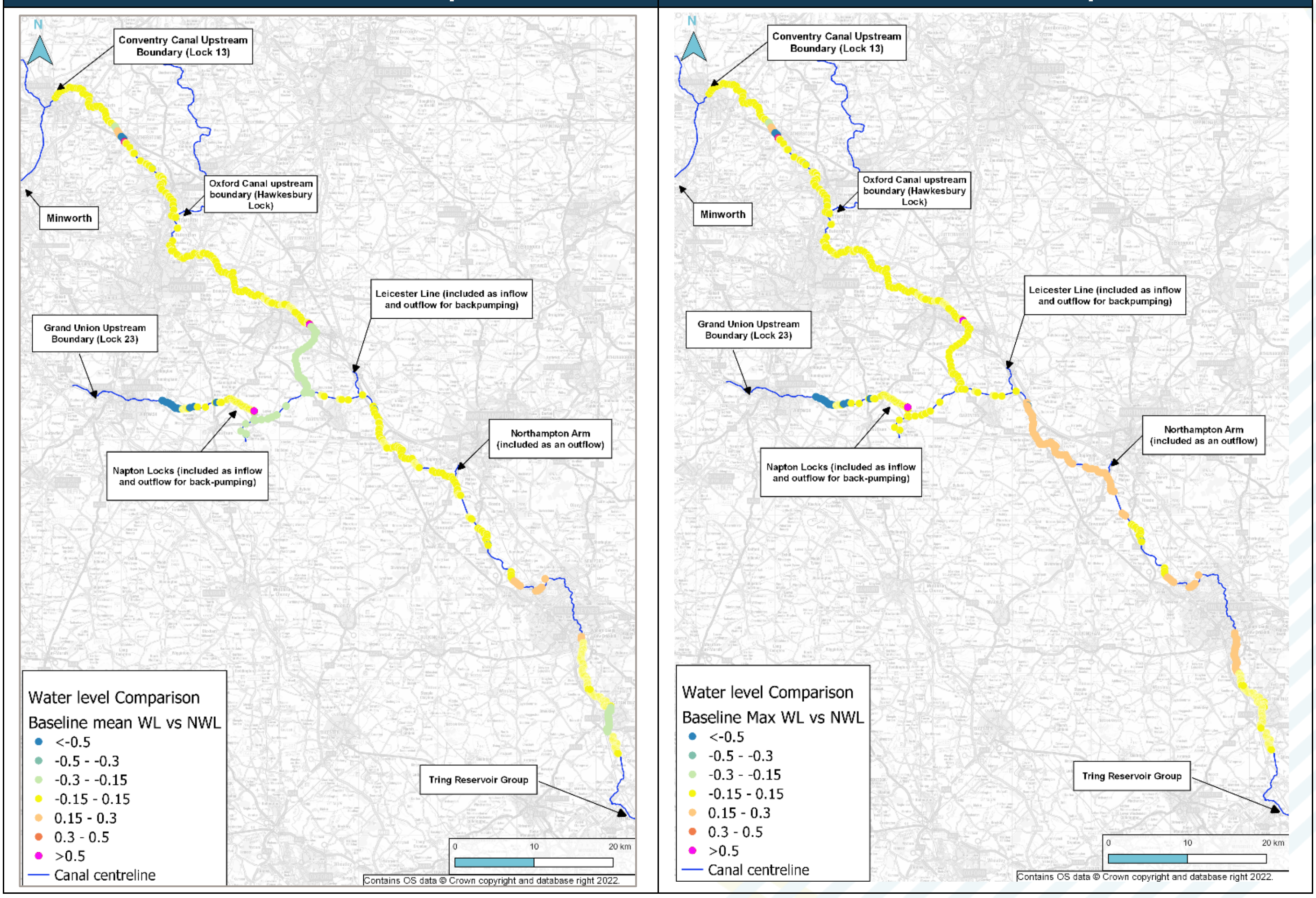


Figure 6-12: Water level comparison – Baseline vs Normal Water Level (m)

Baseline vs. with-scheme

- Figure 6-13 illustrates the comparison of both with scheme flow scenarios against the baseline, per each model node.
- In most locations, predicted mean water levels are within +/- 0.15m of the baseline for both the 57.5Ml/d and 115Ml/d target transfer rates.
- Areas of increases greater than 0.15 are predicted:
    - Between Atherstone and Nuneaton on the Coventry Canal with increases up to 0.32m at Atherstone, gradually reducing to 0.15m in Nuneaton, for 115Ml/d.

- Between Lock 1 (Hawkesbury Lock) and the M6 on the Oxford Canal, with increases up to 0.3m in the 115Ml/d scenario. Increases are below 0.15m in the 57.5Ml/d transfer scenario.

Oxford Canal Lock 7 (Hillmorton Top Lock) to Lock 8 (Napton) and the GUC from Braunston Junction to Lock 1 (Braunston, including increases up to 0.33m at Hillmorton with 115 Ml/d, and 0.29m with 57.5Ml/d.

T 57.5Ml/d max WL vs Baseline mean WL	T 115Ml/d max WL vs Baseline mean WL

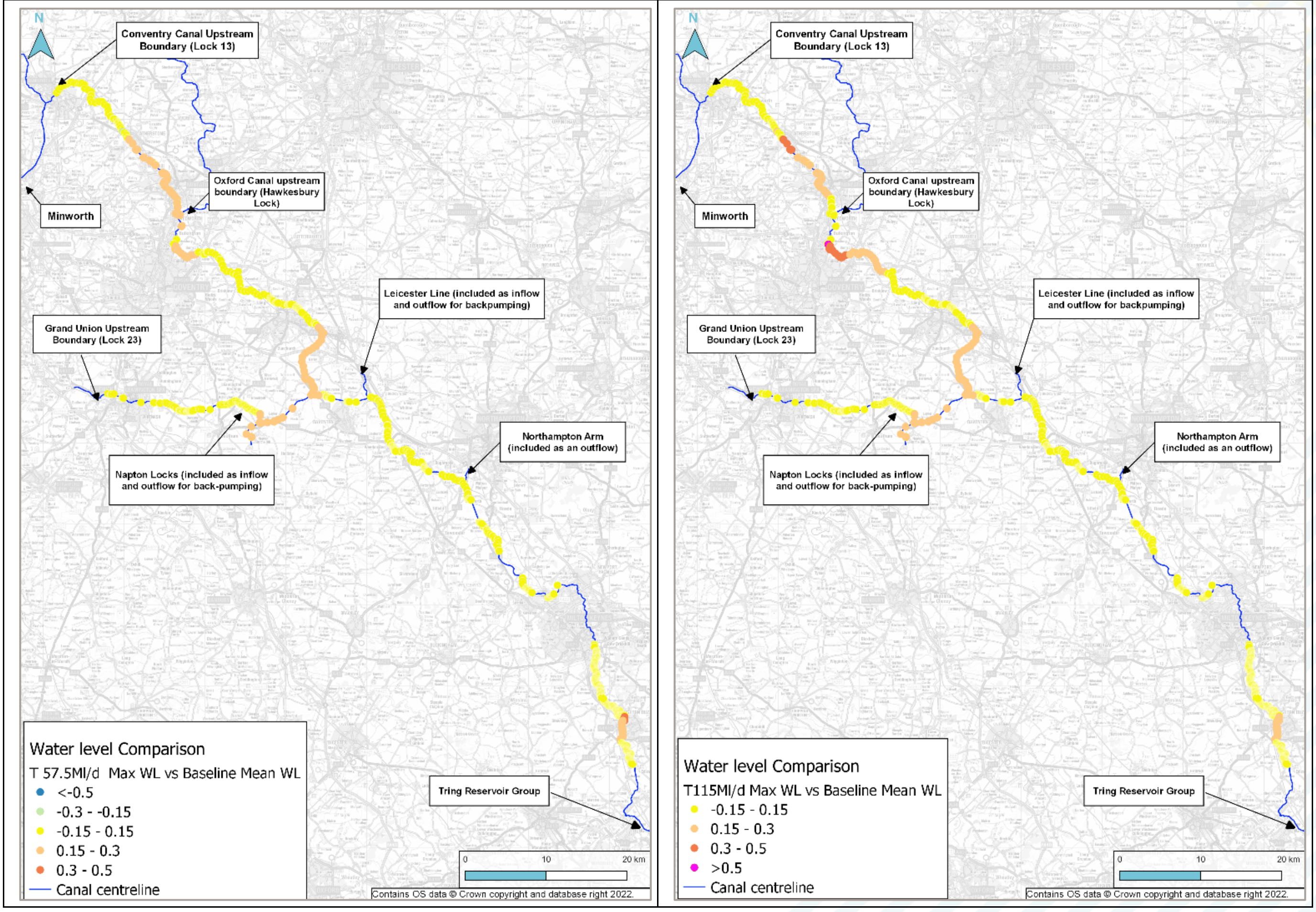


Figure 6-13: Water level comparison – with scheme scenarios vs Baseline (m)

Tabulated results

Table 6-2 presents a comparison between the operation levels and the predicted mean water levels for the baseline and both with scheme scenarios (as average water values per canal pound for the simulated period December 2013 to April 2014). Light green cells indicate the locations where predicted mean water levels are within the Normal Operating Zone. Light blue is used to indicate the locations outside of the operational range. Of the 12 pounds with a NOZ and NWL to compare against:

- Eight pounds are predicted as within the NOZ for baseline and both transfer flow scenarios.
- OX Pound 7-8 is below the NOZ in the baseline, but within it in the with-scheme scenarios.
- GU Pounds 13-14 and 21-22 are above the NOZ in all scenarios.
- GU Pound 27-28 is below the NOZ in all scenarios.

The same approach is used in Table 6-3 which compares maximum predicted water levels (existing operational vs baseline and with scheme). It also shows the water level range, defined as the difference between the maximum and minimum water level recorded in any node within each pound.

Table 6-2: Comparison of existing operation water levels and predicted mean water levels for the baseline and with scheme scenarios (mAOD)

Canal pound	NOZ-	NWL	NOZ+	Baseline	T 57.5Ml/d	T 115Ml/d
CC Pound 1-1	92.21	92.275	92.32	92.25	92.45	92.45
OX Pound 2-1	92.49	92.56	92.61	92.51	92.55	92.58
OX Pound 7-8	98.07	98.117	98.22	97.84	98.11	98.09
GU Pound 6-7	108.9	108.95	109.05	109.01	109.01	108.98
GU Pound 7-8 (**)	-	-	-	106.58	106.57	106.53
GU Pound 13-14 (*)	89.79	89.79	89.89	89.92	89.92	89.91
GU Pound 20-21	72.69	72.84	72.99	72.88	72.87	72.82
GU Pound 21-22 (*)	71.36	71.41	71.48	71.64	71.54	71.54
GU Pound 22-23	71.35	71.51	71.65	71.64	71.54	71.52
GU Pound 23-24 (*)	74.21	74.28	74.38	74.25	74.24	74.22
GU Pound 26-27	80.36	80.51	80.66	80.45	80.41	80.4
GU Pound 27-28 (*)	82.44	82.59	82.74	82.39	82.38	82.32
GU Pound 29-30	86.39	86.54	86.69	86.53	86.53	86.53

(*) known differences between The Trust's control point information and surveyed crest levels

(**) data not available

Table 6-3: Comparison of existing maximum operation water levels and predicted maximum water levels for the baseline and with scheme scenarios (mAOD)

Canal pound	Maximum water levels (mAOD)				Water level range (m)			
	NOZ+	Base_ line	T57.5 Ml/d	T115 Ml/d	NWL	Base_ line	T57.5 Ml/d	T115 Ml/d
CC Pound 1-1	92.32	92.29	92.51	92.58	0.11	0.05	0.27	0.36
OX Pound 2-1	92.61	92.52	92.68	92.85	0.12	0.04	0.22	0.43
OX Pound 7-8	98.22	98.11	98.14	98.14	0.15	0.65	0.06	0.08
GU Pound 6-7	109.05	109.07	109.1	109.08	0.15	0.09	0.14	0.16
GU Pound 7-8	- (*)	106.64	106.64	106.6	-	0.09	0.11	0.08
GU Pound 13-14	89.89	89.96	90.01	90.06	0.1	0.06	0.13	0.22
GU Pound 20-21	72.99	72.89	72.88	72.88	0.3	0.02	0.02	0.08
GU Pound 21-22	71.48	71.7	71.58	71.61	0.12	0.17	0.07	0.15
GU Pound 22-23	71.65	71.7	71.56	71.57	0.3	0.17	0.05	0.11
GU Pound 23-24	74.38	75.81	75.81	75.81	0.17	2.37	2.37	2.37
GU Pound 26-27	80.66	80.56	80.42	80.42	0.3	0.15	0.01	0.03
GU Pound 27-28	82.74	82.68	82.69	82.69	0.3	0.41	0.44	0.49

(**) data not available

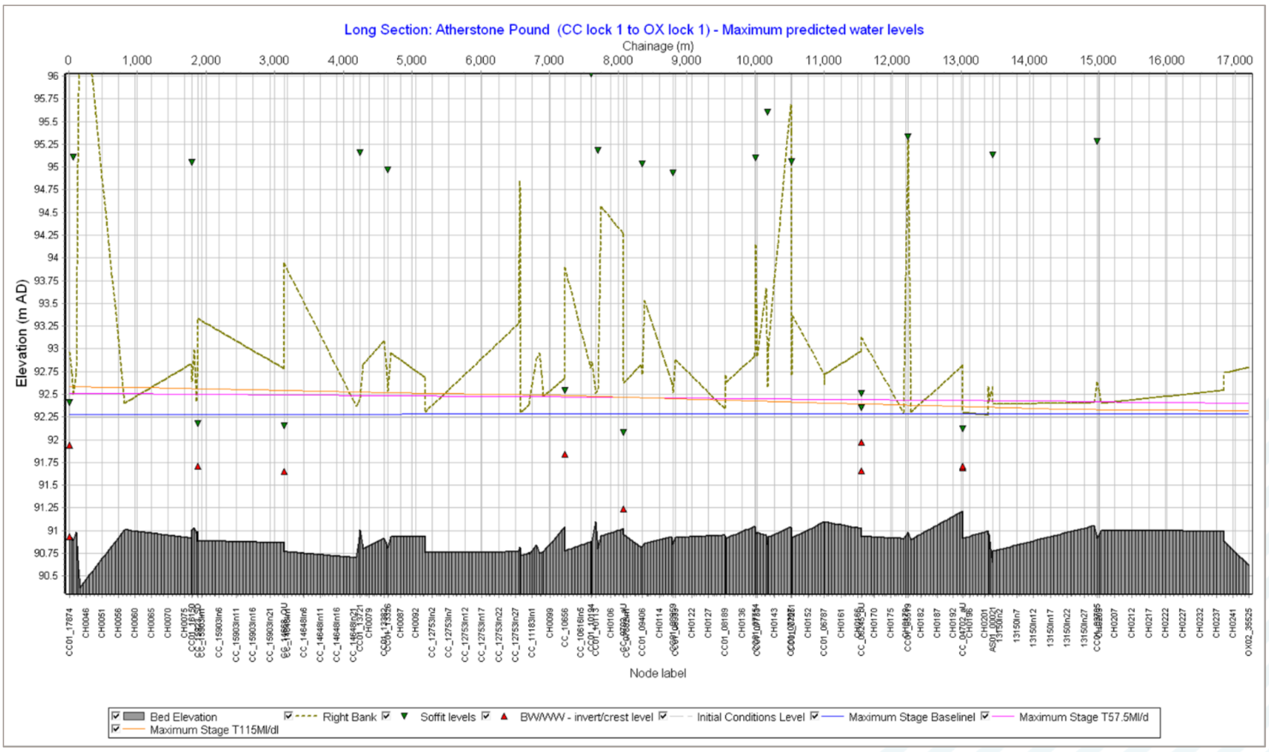
Focus on specific pounds

Here we focus on the results in three pounds to further explore the model results.

CC Pound 1-1

This is the longest pound on the transfer route. A long profile showing maximum predicted water levels for the baseline and with scheme, for the Atherstone pound CC Pound 1-1 is presented in Figure 6-14. Predicted water levels for the baseline scenario are 0.23m lower than NOZ. Significant improvements have been made in the representation of this pound following engagement with the Trust, but this indicates that there may be a remaining issued keeping water levels below the NOZ in the model.

In the with-scheme scenarios, water levels are raised by around 0.3m at the upstream end of the pound. The with-scheme results illustrate a characteristic behaviour between both target transfer flows, where the 115Ml/d scenario shows the larger increase at the "upstream" end and larger decrease at the "downstream" end of the pound (lower variations in head are predicted for the 57.5Ml/s target flow). Larger drop in head is usually predicted at the downstream end of the pound where uphill pumping takes place. This effect is caused by the operational rules of the pumps that were used in this phase of the study which will need to be revised when the study progresses to Gate 3, when further detail of the control philosophy and structures can be represented in the model.



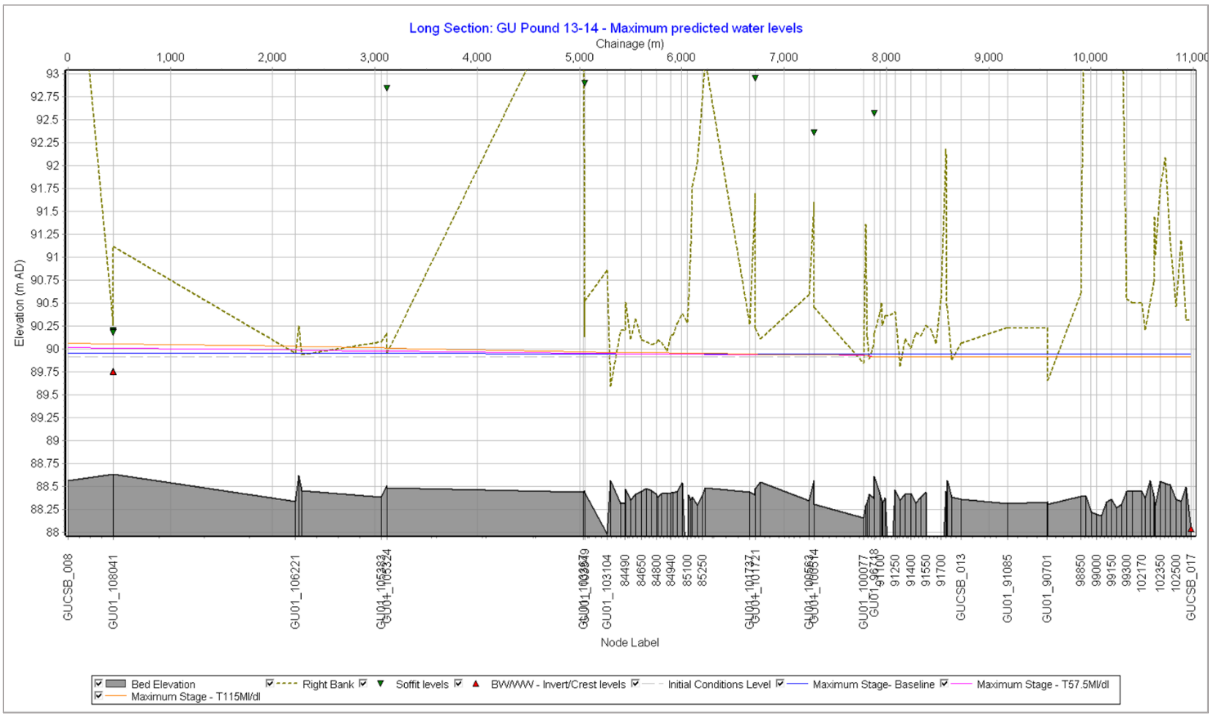
Note: Length of the pound ~17.2km

Figure 6-14: Predicted maximum water levels at Atherstone pound 'CC-Pound 1-1' (mAOD)

GU Pound 13-14

Figure 6-15 shows GU Pound 13-14, the results of which are typical of the predictions for the majority of the transfer route. It illustrates the slightly steeper hydraulic gradient that is generated in the transfer scenarios compared to the baseline. This leads to a slight increase in water levels at the "upstream" end of the pound, but at the "downstream" end the with-scheme water levels are virtually unchanged from the baseline. This gradient is steeper in the 115Ml/d scenario.

At several points along this pound, the bank level (dotted green line) dips below the water level, even for the baseline. This is expected to be due to anomalies in the LiDAR data used to identify bank heights. The EA LIDAR is quoted as having a Root Mean Square Error (RMSE) of 0.15m. The banks of canals and rivers are known to be problematic to LiDAR capture, given the presence of water and, often, of trees. Consideration should be given, at Gate 3, to a topographic survey of bank heights (on both banks to identify low points on any pounds where the transfer is predicted to increase water levels above the NOZ.



Note: Length of the pound ~11.0km

Figure 6-15: Predicted maximum water levels at GU Pound 13 - 14 (mAOD) –

GU Pound 21-22

Long section shows the upper part of pound GU Pound 21-22 (Figure 6-16). The water levels are higher than the NOZ for all scenarios, but more so in the baseline, indicating that the baseline model may be over-predicting water levels. The three points at which the bed level drops are a graphical display issue and not representative of the actual bed level used to assess conveyance in the model. The long-section shows a pronounced drop in water levels, a result of headlosses at the Iron Trunk Aqueduct and V6 Aqueduct.

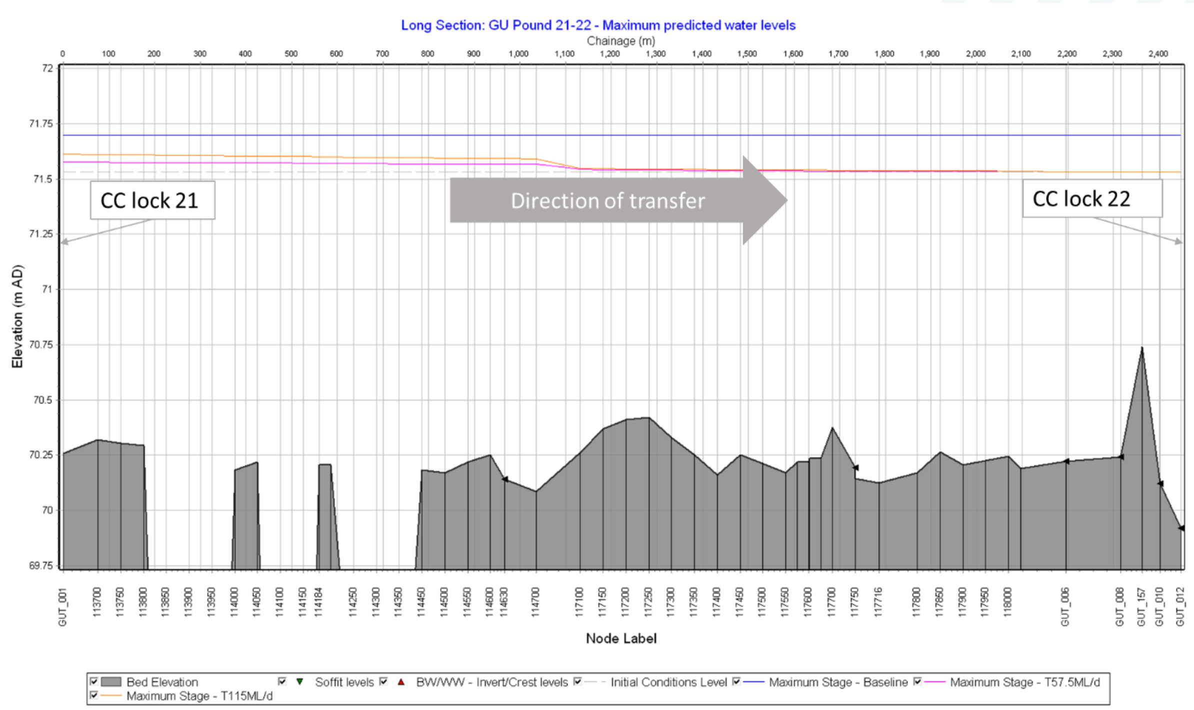


Figure 6-16: Predicted maximum water levels at GU Pound 21 - 22 (mAOD)

In conclusion, the results for the majority of pounds indicate that the scheme can be operated with moderate water level changes at both 57.5 and 115Ml/d. At the higher flow, a slightly steeper hydraulic gradient is generated which can raise water levels at the upstream end of longer pounds, and lower levels at the downstream end. At Gate 3 these sensitive pounds can be optimised to identify a solution which operates within the NOZ but which minimises the need for bank-raising. This will include more detailed representation of the actual pumping arrangement. The Gate 2 model pumps directly from the pounds, whereas the proposed arrangement will include a weir to spill water from the canal into a sump containing the pumps.

Headroom at bridges

Checks on the available headroom at bridge structures were carried out to determine whether the proposed transfer scheme might have an impact on navigation. Table 6-4 illustrates the predicted available headroom at different locations. The Canal and River Trust recommended maximum craft headroom is shown in the second column (Canal & River Trust, 2022), and the Trust confirmed that this is the best available measure of headroom. All headroom values have been estimated using the maximum predicted water levels and, the soffit levels collected in the topographic survey commissioned for this phase of the study. It shows that the predicted minimum headroom is 2.35m along the Atherstone pound in the 115/d scenario – notably this is within the 2.08m maximum craft headroom for this pound.

Two bridges on GU Pound 13-14 (bridges 29 and 36) are showing headroom values less than the maximum craft headroom for this pound, in both the baseline and scheme simulations. As shown in Table 6-2, the modelled water levels in this pound are above the NOZ in baseline and with-scheme results. We therefore conclude this results is highlighting a model control issue rather than an actual issue of concern as a result of the scheme, which would only raise the water levels by 0.01 to 0.03m at these bridges.

Table 6-4: Predicted available headroom at various bridge structures (m)

Canal Pound	Trust maximum craft headroom (m)	Chainage (m)	Soffit level (mAOD)	Headroom (m) Baseline	Headroom (m) T 57.5 Ml/d	Headroom (m) T 115 Ml/d
CC Pound 1-1	2.08	60	95.112	2.83	2.6	2.53
		4234	95.16	2.88	2.68	2.64
		7599	96.023	3.74	3.55	3.55
		8348	95.03	2.75	2.57	2.57
		8798	94.935	2.65	2.48	2.48
		9997	95.103	2.82	2.65	2.68
		10170	95.6	3.32	3.15	3.18
		13451	95.13	2.85	2.69	2.75
		14976	95.28	2.99	2.86	2.95
		1006	95.19	2.67	2.51	2.35
OX Pound 1-2	2.07	2636	95.33	2.81	2.66	2.5
		4975	95.15	2.63	2.5	2.38
		5673	95.58	3.06	2.94	2.83
		19701	95.6	3.08	3.09	3.12
GU Pound 13-14	2.67	5512	92.84	2.89	2.86	2.83
		9401	92.902	2.96	2.95	2.94

Canal Pound	Trust maximum craft headroom (m)	Chainage (m)	Soffit level (mAOD)	Headroom (m) Baseline	Headroom (m) T 57.5 Ml/d	Headroom (m) T 115 Ml/d
		12395	92.95	3.01	3.01	3.01
		13492	92.36	2.42	2.43	2.42
		17928	92.57	2.63	2.65	2.66

6.3.4 Spill over waste weirs and by-weirs

The Gate 2 results indicate that overall across the 110 day simulation, the GUC SRO transfer will, without adjustments to weir levels, lead to a decrease in the total spill volume through all waste weirs, from ~18,500m^3 in the baseline to 16,700m^3 at 57.5Ml/d and 14,800m^3 at 115Ml/d. This result is somewhat counter-intuitive, however, as has been illustrated, the transfer leads to a steeper hydraulic gradient, resulting in a modelled lowering of water levels at the "downstream" end of many pounds. Many of the waste weirs are located at these downstream ends of pounds. This result will need to be closely monitored as further details of the transfer controls are added to the model at Gate 3.

Table 6-5 summarises waste weirs and by-weirs spills at different locations through the transfer route, and records the spill volume (in megalitres) over the entire simulation (110 days).

- Values reported in the table are at locations where the total spill volume is greater than 100Ml, with smaller spills filtered out.
- By-weirs were raised to avoid recirculation of water around locks where the direction of the transfer flow is uphill (Figure 6-2).
- A number of waste weirs were raised along 'CC-Pound 1-1' and 'OX-Pound 7-8' (Figure 6-2) in the transfer scenario to aid with model stability. On these waste weirs, lesser spill volumes are predicted for the transfer scenarios than the baseline.
- Model outputs shows that the operation of the transfer pumps have an impact on the total predicted spill volume from waste weirs. The larger the target transfer flow, the steeper the hydraulic gradient and larger the drop in head at the "downstream" end of the pound, resulting in a reduction in spill volume from waste weirs situated close to the pump. This can be identified as negative changes in columns 'T 57.5 vs BL' and 'T 115 vs BL.'
- This effect may be exaggerated by the way that the transfer pumps are represented in the model as pumping directly from the pound, rather than spilling via a new weir into a pump sump. Thus the Gate 3 modelling will need to detail-in this configuration and optimize the levels of the new weir and existing waste weirs such that each pound remains within the NOZ but significant increases in waste weir spills are avoided.
- The largest total spill volume is predicted on the GU-Pound 27-28 (Leighton Buzzard pound), at Bozenham weir (SAP ID: GU-106-003), for the baseline and with scheme scenarios.
- Total predicted spill volumes through waste weirs and by-weirs for the baseline scenario are displayed in Figure 6-17, while Figure 6-18 illustrates the changes in total predicted spill volumes between both target transfer flows and the baseline. Both figure focus on features along the main transfer route.
- Future model runs will be required to optimise each pound to obtain optimal water level control which minimises increases in waste weir spills without the need for excessive bank raising. This should take into account present-day operations by

The Trust to adjust waste weir levels (for example using stop logs), and how these might need to change when the transfer is operating with significantly higher flows and the potential for flow and water level changes in response to demand for the transfer.

Table 6-5: Total spill volume over the entire simulation time (Ml)

Pound name	Uphill lock	Down hill lock	Model label	Type	Base-line (BL)	T 57.5 Ml/d	T 115 Ml/d	T 57.5 vs BL	T 115 vs BL	T 115 vs T 57.5
CC Pound 1-1 (*)	CC_L1	Ox_L1	CC_10622_SU	WW	0	588	746	588	746	158
			CC_00711_SU	WW	0	473	0	473	0	-473
OX Pound 2-1 (**)	OX_L2	Ox_L1	sweir1us	WW	0	462	2857	462	2857	2395
			weir3nus	WW	269	0	0	-269	-269	0
GU Pound 6-7 (**)	GU_L7	GU_L6	Lock7b_BWU	BW	1090	0	2091	-1090	1001	2091
			GU_112602_SU	WW	1191	1050	181	-141	-1010	-869
GU Pound 7-8 (**)	GU Summit Pound 7-8		GU_110594U	BW	859	767	394	-92	-465	-373
GU Pound 13-14	GU_L13	GU_L14	GU_108021_OU	WW	0	977	2396	977	2396	1419
			weir3us	WW	1125	1217	1424	92	299	207
GU Pound 20-21 (**)	GU Trough Pound		GU_74253gU	BW	785	578	180	-207	-605	-398
			GU_74253fU	BW	640	441	0	-199	-640	-441
			GU_74253eU	BW	630	434	0	-196	-630	-434
			GU_74253dU	BW	560	369	0	-191	-560	-369
			GU_74253cU	BW	754	539	136	-215	-618	-403
			GU_74253bU	BW	549	362	0	-187	-549	-362
			GU_74253aU	BW	586	386	0	-200	-586	-386
			weir10bus	WW	528	133	0	-395	-528	-133
			GU_80532_SUS	WW	1403	846	0	-557	-1403	-846
GU Pound 27-28 (**)	GU_L28	GU_L27	GU01_44046a	WW	1352	1353	866	1	-486	-487
			GUT_weir10us	WW	5857	5470	3393	-387	-2464	-2077
			GUT_weir11us	WW	274	239	120	-35	-154	-119

(*) Pounds where waste weir and by-weir were raised for the transfer scenarios

(**) Pounds where by-weirs were raised for the transfer scenarios to avoid recirculation of water on uphill locations

(***) Bozenham weir (SAP ID: GU-106-003)

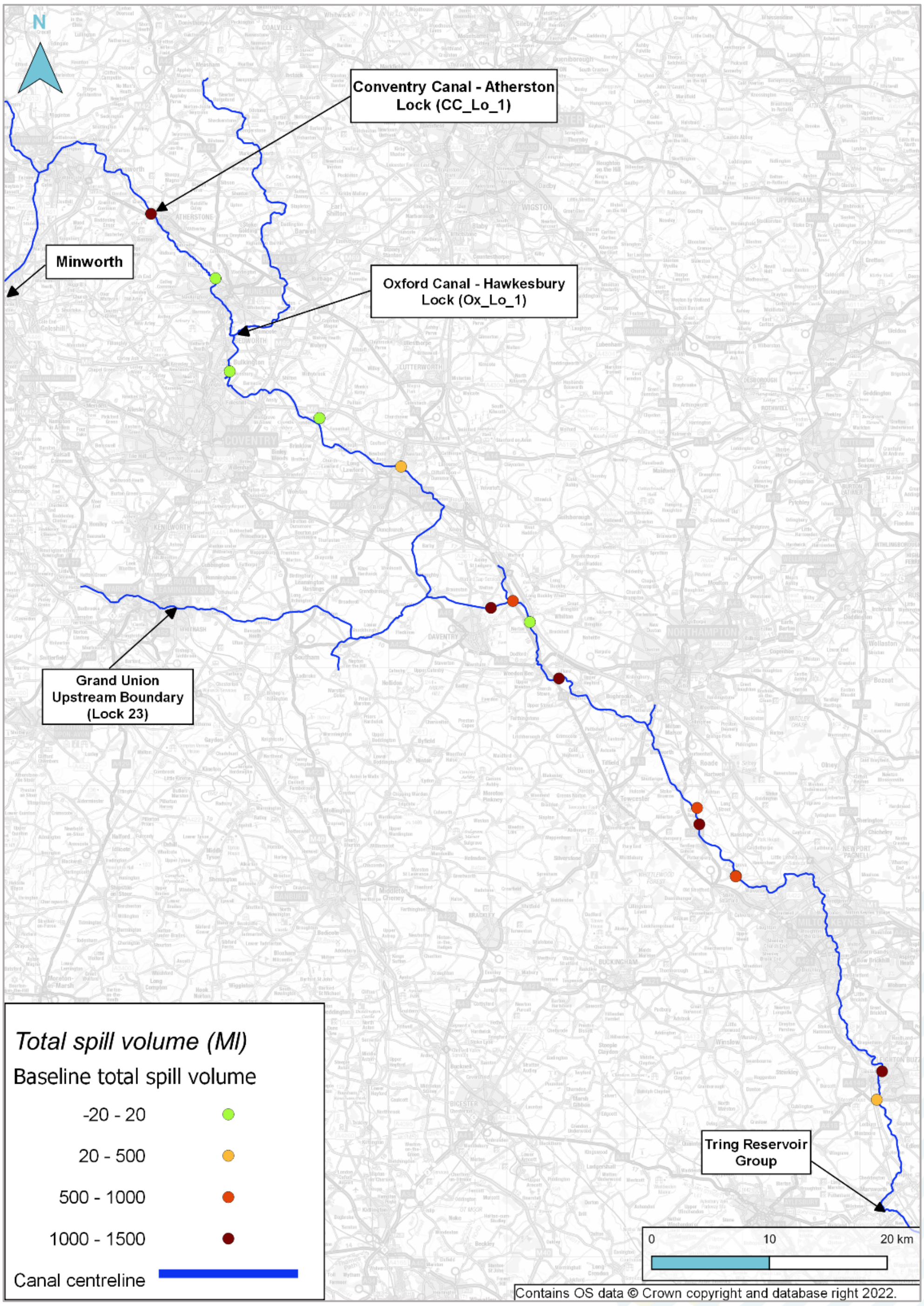


Figure 6-17: Total spill volume Baseline (Ml)

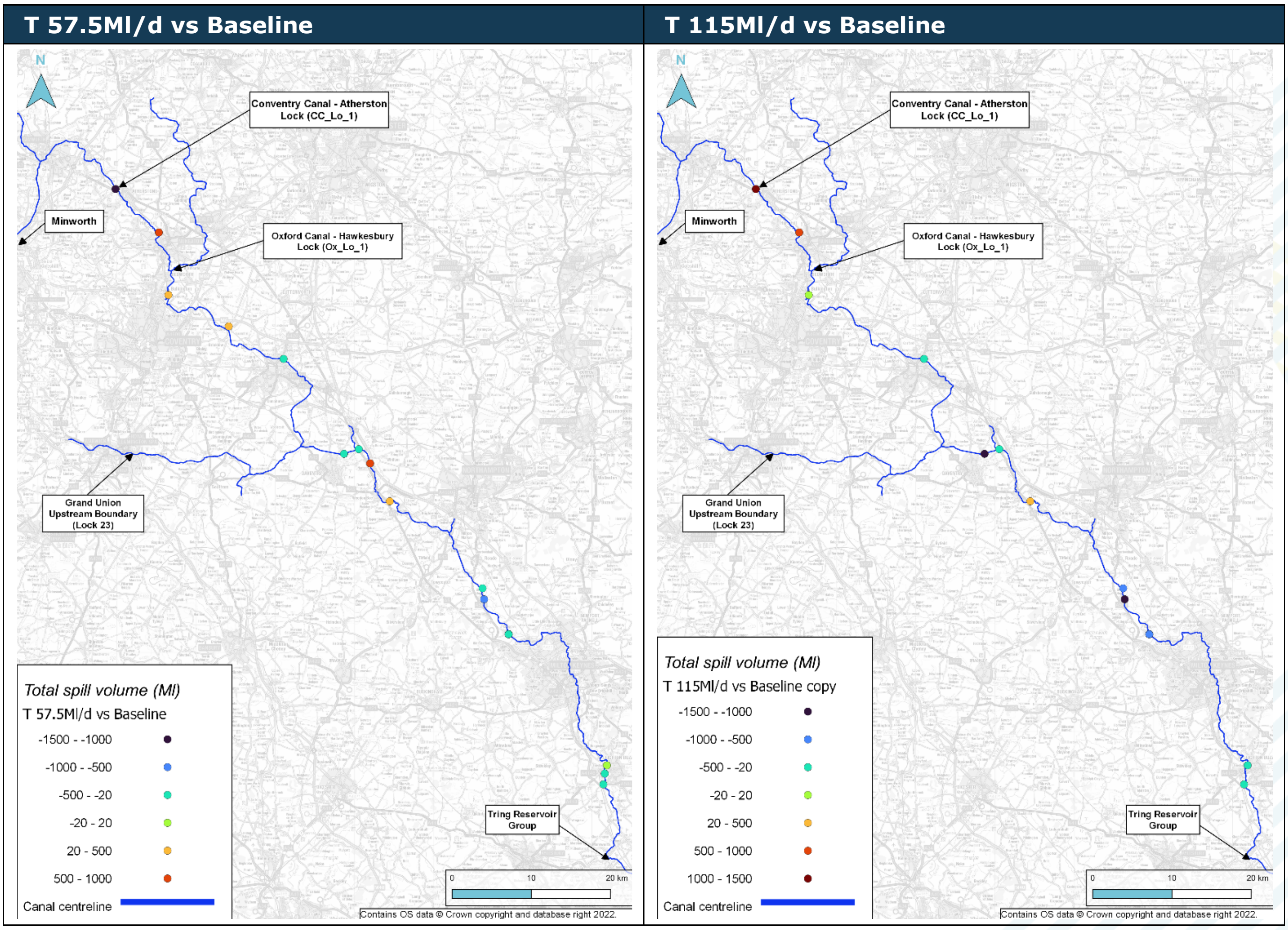


Figure 6-18: Total spill volume comparison – with scheme scenarios vs Baseline (Ml)

6.3.5 Canal junctions

Along the transfer route, there are 6 junctions, where canal pounds not on the transfer route connect with it. At these locations, the scheme has the potential to raise water levels in the connected pounds, and in some locations to lose water out of the transfer route. Below we have identified these locations, the impacts of the scheme without any additional mitigations or controls in place, and the types of mitigations that might be required.

Coventry Canal and Ashby Canal at Marston Junction

The Ashby Canal from Marston Junction to its terminus at Snarestone Wharf is 35km long with no locks. It is represented in the model with the first 130m of the Ashby canal from the junction, including waste weir 1 (AS-001-002). Results indicate that the baseline model is 0.02m above the NOZ upper limit if 92.23mAOD. With the 115Ml/d scenario, water level rise of 0.1m to 92.35m is predicted, and therefore the need for bank raising along the Ashby Canal needs to be considered. No spill is predicted over the modelled waste weir 1 (AS-001-002) in any of the scenarios.

Further detailing of the Ashby Canal would be recommended for Gate 3, to represent the entire 35km length in the hydraulic model. Consideration should be given to the storage impacts of the Ashby Canal on the transfer, as 0.1m of water level rise on the Ashby Canal would equate to over 50Ml of storage. This may be beneficial in some circumstances (providing additional storage capacity), but could detrimentally impact the transfer, for example by delaying the progress of water beyond this pound following a switch-off of the transfer, or by increasing losses due to seepage and evaporation.

Given the length of the pound, consideration should be given to whether installation of a lock close to the junction would be preferable to bank raising, although this will need to consider the impact on navigation. A new lock would permit water levels in the Coventry Canal to rise during transfer operation, without raising water levels in the Ashby Canal.

Figure 6-19: Coventry Canal and Ashby Canal at Marston Junction

Coventry Canal and Oxford Canal at Hawkesbury Junction

The Oxford Canal joins the Coventry Canal via Hawkesbury Lock, with water levels lower on the Coventry Canal side. In the with-scheme model, a new pump is represented to lift water from the Oxford Canal to the GUC. The Coventry Canal is represented up to the Lock. The remainder of the Coventry Canal pound from the South of Hawkesbury to the centre of Coventry, some 9km, is not modelled.

Results predict that water levels in the Coventry Canal south of Hawkesbury will rise by 0.15m as a result of the 115Ml/d transfer, however this may be an over-estimate as a result of how the new pump is represented in the model. It is not anticipated that water levels would be an issue, because the new pump to be installed as part of the SRO will enable water level control in this pound. Further detailing of the pump configuration is required at Gate 3.

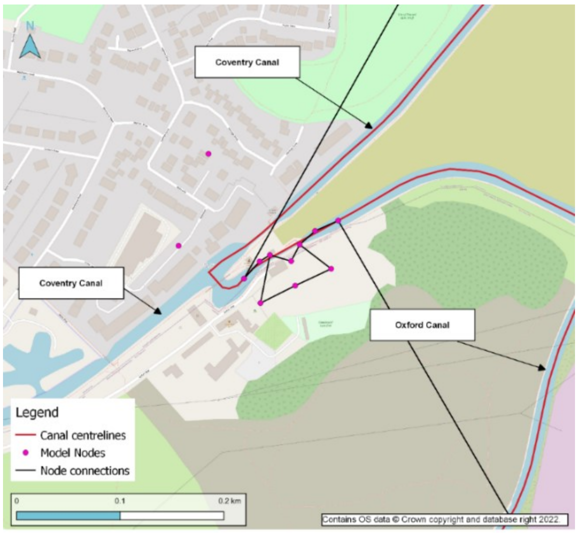


Figure 6-20: Coventry Canal and Oxford Canal at Hawkesbury

Oxford Canal and Rugby Arm at Rugby

The Rugby Arm, which is 330m in length has not been modelled, there are no locks on the arm. Water levels in the Oxford Canal at this junction are predicted to only rise by around 0.02m as a result of the transfer (57.5Ml or 115Ml), and to remain within the NOZ, therefore no detrimental impacts on water levels are predicted in the Rugby Arm.

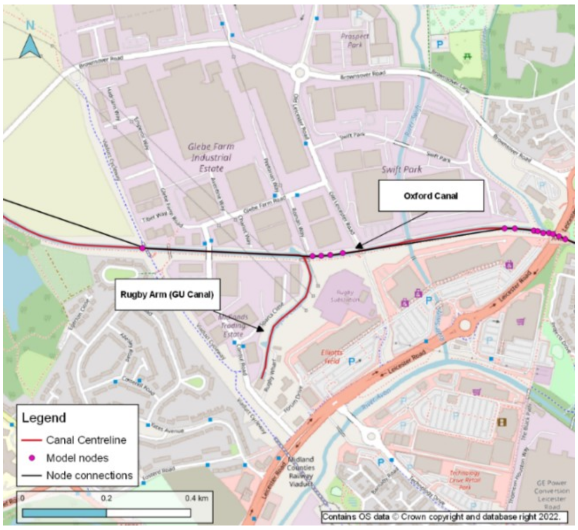


Figure 6-21: Oxford Canal and Rugby Arm at Rugby

Oxford Canal and Grand Union Canal at Braunston Junction

The connection of the Oxford and Grand Union canals at Braunston Junction is modelled with an open junction unit which connects three normal-width canal sections. The Oxford Canal is modelled to the south of the junction as far as the next lock, No. 8 at Napton Bottom Lock, a distance of 11km. The model predicts that water levels at this junction will rise by up to 0.27m 115Ml/d and 57.5Ml/d. Water levels in the baseline are predicted as being below the NOZ, indicating a control issue in the model at this location.

Results indicate no detrimental impact on water levels in the Oxford Canal south of Braunston Junction as a result of the transfer, however this point will need to be rechecked at Gate 3 once further detailing of the transfer controls is added to the model.

Given the length of the pound, if water levels do rise substantially, consideration should be given to whether installation of a lock close to the junction would be preferable to bank raising, although this will need to consider the impact on navigation. A new lock would permit water levels in the Oxford Canal north of Braunston Junction and the GUC to rise during transfer operation, without raising water levels in the Oxford Canal to the south of Branston Junction.

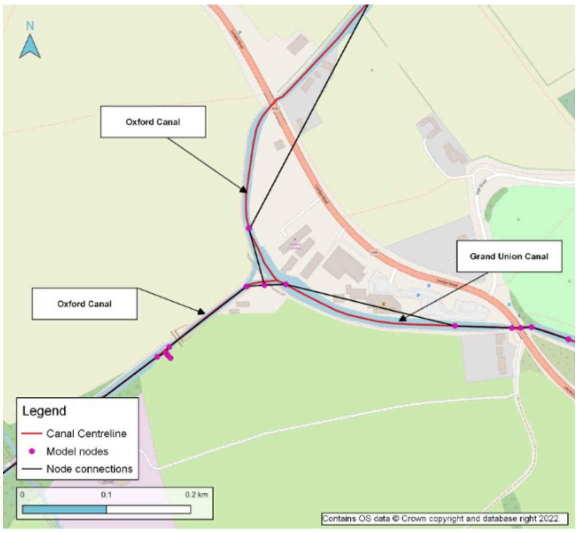


Figure 6-22: Oxford Canal and Grand Union Canal at Braunston Junction

Grand Union Canal and Leicester Line at Norton Junction

The Leicester Line of the Grand Union Canal from Norton Junction to the first lock (Watford Lock) is 4.4km long. It is represented in the model using abstraction (outflow) and two Discharge/Time boundaries (QTBDY/inflow) units. Water levels in the Oxford Canal at this junction are predicted to fall slightly as a result of the transfer (57.5Ml or 115Ml), and to remain within the NOZ, therefore no detrimental impacts on water levels are predicted in the Leicester Line. The slight drop in level is a result of the modelling of the new transfer bypass immediately downstream at the Long Buckby flight. This new asset will need to be further detailed in the model at Gate 3.

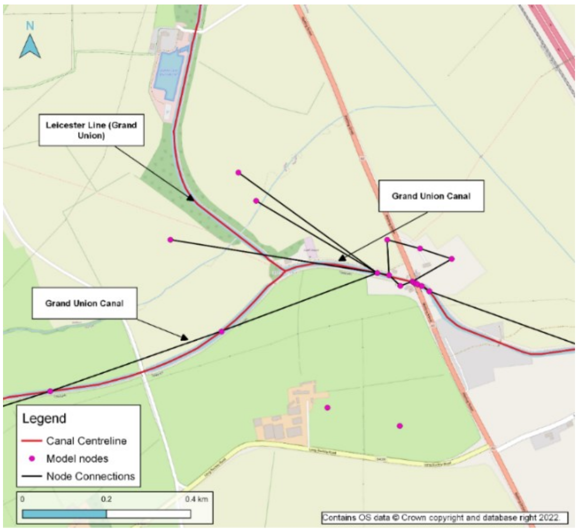


Figure 6-23: Grand Union Canal and Leicester Line at Norton Junction

Grand Union Canal and Northampton Arm at Gayton Junction

The Northampton Arm which joins the Grand Union Canal has been modelled with an abstraction unit to represent the loss of volume from the Grand Union Canal. The Northampton Arm extends into the centre of Northampton where it joins the River Nene. It is approximately 1.2km from the junction with the Grand Union Canal to the first lock, Lock 1. Water levels in the GUC at Gayton Junction are predicted to fall by around 0.03m as a result of the transfer (57.5Ml or 115Ml), and to remain within the NOZ. The fall in water levels is likely the result of the representation of the transfer infrastructure at this point. This will need to be addressed in the model, but no detrimental impacts on water levels are predicted in the Northampton Arm.

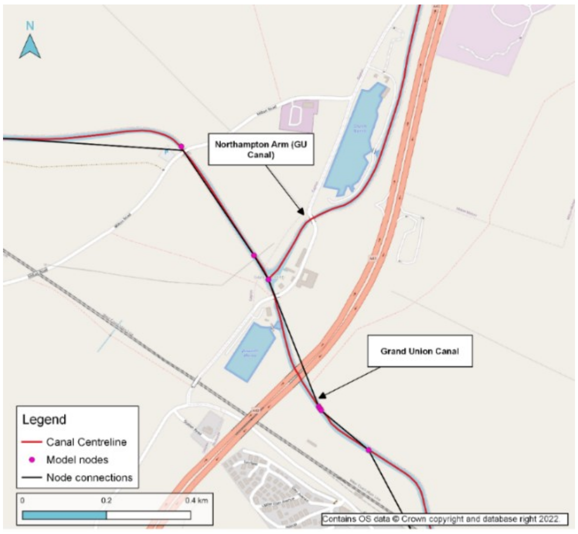


Figure 6-24: Grand Union Canal and Northampton Arm at Gayton Junction

Conclusion

In conclusion, the model predicts significant increases in water level at the Ashby Canal, Coventry Canal south of Hawkesbury and Oxford Canal from Braunston Junction to Napton Bottom Lock. Further detailing to extend the length of the Ashby and Coventry Canals is recommended, and results should be reviewed at Gate 3. There is potential to reduce the water level rises predicted by refining the representation of controls (pumps and bypasses) in the model.

7 Water quality modelling

7.1 Model development

7.1.1 Developing the methodology

The approach we have taken to assess water quality impacts, both at the point of discharge and further down the transfer route, was developed through engagement with the Environment Agency. Whilst the EA are in the process of developing a nationally consistent approach to the environmental permitting of SRO transfer schemes, the approach taken followed existing EA operational instructions on the permitting of hazardous chemicals and elements in discharges to surface waters (Environment Agency, 2019), continuous discharges of sanitary determinands and nutrients (Environment Agency, 2014) and on assessing no deterioration under the WFD (Environment Agency, 2012).

For full details of the water quality model, please see the Water Quality Impact Assessment report (Annex A2.3).

7.1.2 Screening

Screening is the application of simple tests to assess whether the proposed discharge of a substance is likely to be potentially significant to water quality, in which case it should be modelled. Screening of determinands with an Environmental Quality Standard (EQS) was undertaken in line with EA operational instructions (Environment Agency, 2019). For those determinands which did not have an EQS defined, it was agreed with the EA to screen out if the mean and 95-percentile concentrations at the downstream site were worse than the modelled mixed mean and 95-percentile downstream of the proposed discharge at Atherstone, because in such cases the transfer could only improve, not deteriorate, water quality.

The Environment Agency also advised that all determinands sampled at both Minworth WwTW and the point of discharge to the Coventry Canal at Atherstone should be modelled. Therefore, for assessing impact at Atherstone, the screening was undertaken but not applied. For downstream assessment at Daventry and Leighton Buzzard, it was agreed that screening should be applied.

7.1.3 Modelling

- Modelling was undertaken within the EA's River Quality Planning (RQP) suite. The Monte Carlo model was used for this assessment, with the exception of bioavailable metals (copper, lead, manganese, nickel and zinc) which used the Metals Permitting (MPer) tool. Monte Carlo and MPer use a stochastic approach to predict future water quality as a result of a new or changed discharge. Future water quality is predicted using statistical distributions of the flow and water quality of both the receiving water (here the canal) and the discharge (here treated effluent from Minworth WwTW).
- Results can be analysed to determine whether a deterioration would occur as a result of the discharge, either as a percentage deterioration or in relation to an Environmental Quality Standard (EQS). Both Annual Average (AA) and Maximum Allowable Concentration (MAC) EQSs can be tested. The modelling process is shown in simple schematic form in Figure 7-1.
- Flow statistics were determined for the proposed discharge using the demand profile for the GUC SRO developed by Affinity Water (Affinity Water, 2022), based on monthly variations in flow from 27.85Ml/d to 115Ml/d. This resulted in an annual mean flow of 50.90Ml/d.
- Baseline flow statistics for the canal were derived from the updated and validated Aquator model (see Annex A2.1). These resulted in mean flows of between 3.63Ml/d (at Leighton Buzzard) to 5.36Ml/d at Atherstone. So the proposed

discharge flows are an order of magnitude greater than flows in the receiving canal. Given this, the quality of the discharge is likely to dominate the quality of water downstream in the canal.

- The quality of the existing Minworth WwTW effluent and the canal at Atherstone were derived from analysis of the water quality sampling up to and including sampling round 13 (Atkins, 2022) and Annex B1.4. Sampling was undertaken at nine locations, of which four sites are of interest to this study (the remainder not being significant following the selection of the preferred route for the transfer):
  - Site 1, Minworth WwTW final effluent. Note that this is sampling the present-day final effluent (which will receive further treatment prior to discharge into the Canal).
  - Site 3, Coventry Canal at Atherstone Top Lock
  - Site 5, Grand Union Canal at Daventry
  - Site 6, Grand Union Canal at Leighton Buzzard
- The water quality sampling data was analysed and cleaned following EA guidance on dealing with samples below the Limit of Detection (LOD), outliers and step-changes.
- The modelled, mixed water quality downstream of the proposed discharge at Atherstone was used to define the quality of the water being transferred (the "discharge" in RQP terms) in to Daventry and Leighton Buzzard. This was a conservative approach, as it did not allow for any decay, further dilution or deposition of substances along the transfer route.

For each determinand three scenarios were modelled;

- Impact of the discharge at existing concentrations,
- Treatment required to meet the target (EQS), and
- Treatment required to prevent deterioration.

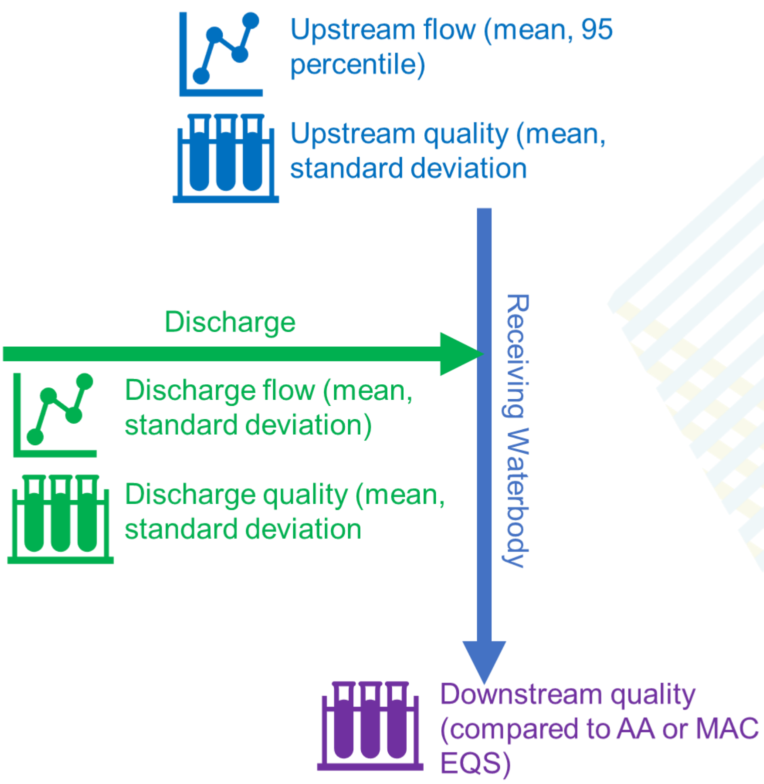


Figure 7-1: Schematic of the RQP modelling approach

7.2 Model validation

Validation of this type of stochastic water quality model of a future discharge relies primarily on checks to the input data:

- Discharge flow statistics: being based on a modelled assessment of future demand and deployable output for the GUC SRO, this could not be checked against observed data, but the deployable output assessment was peer reviewed prior to application.
- Canal flow statistics: based on results from the Aquator model, which was validated against both long-term telemetry and a short-term water level and flow survey conducted over November 2021 to January 2022.
- Water quality statistics: sampling results were subject to quality assurance checks by the laboratories and by consultants Atkins, and further data cleaning in line with EA guidance was undertaken as described in section 7.1.3.

Following a review of initial results with the Environment Agency, sensitivity testing was carried out to test the sensitivity of results to modeller decisions:

- Sensitivity test 1 - Replacing outlier values removed from the observed data,
- Sensitivity test 2 - Test for the impact of the transfer running at maximum flow of 115Ml/d, and
- Sensitivity test 3 - Test model sensitivity to the correlation coefficients used for river flow and quality and for effluent flow and quality.

In general it was found that the results were not sensitive to these tests.

7.3 Results

7.3.1 Water quality impact at the point of discharge, Atherstone

A total of 160 determinands were sampled at both Minworth WwTW (site 1) and the Coventry Canal at Atherstone (site 3), and were modelled using RQP. Considering first the Water Framework Directive tests for percentage and class deterioration:

- For 61 of these substances, the current Minworth effluent is cleaner than the Coventry Canal, so the discharge would lead to an improvement in water quality.
- For an additional 59 substances, the increase in concentration in the Canal would be less than 10% (or less than 3% where currently the water quality is classed as Bad); these are considered not to deteriorate under Water Framework Directive.
- The remaining 40 substances are predicted to lead to a deterioration and therefore may require additional treatment to prevent this. Of these, 16 determinands have 50% or more of their discharge or canal samples qualified as less-than the LOD. These determinands are identified in Annex A2.3 and their results should be treated with extra caution.

Considering the hazardous chemical tests:

- 88 pass all of the hazardous chemicals modelling tests.
- 42 determinands do not have either an AA or MAC EQS and therefore the hazardous chemicals modelling tests cannot be applied.
- 30 determinands fail one or more of the modelling tests. For 18 of these, the EQS is already exceeded in the Coventry Canal.

Considering possible future treatment requirements, 41 determinands would require improvements in treatment of between 1% and 93% to prevent all modelled deterioration at Atherstone. Note that for 19 of these, 50% or more of the discharge or canal samples are qualified as less-than the LOD. Results for these determinands should be treated with extra caution.

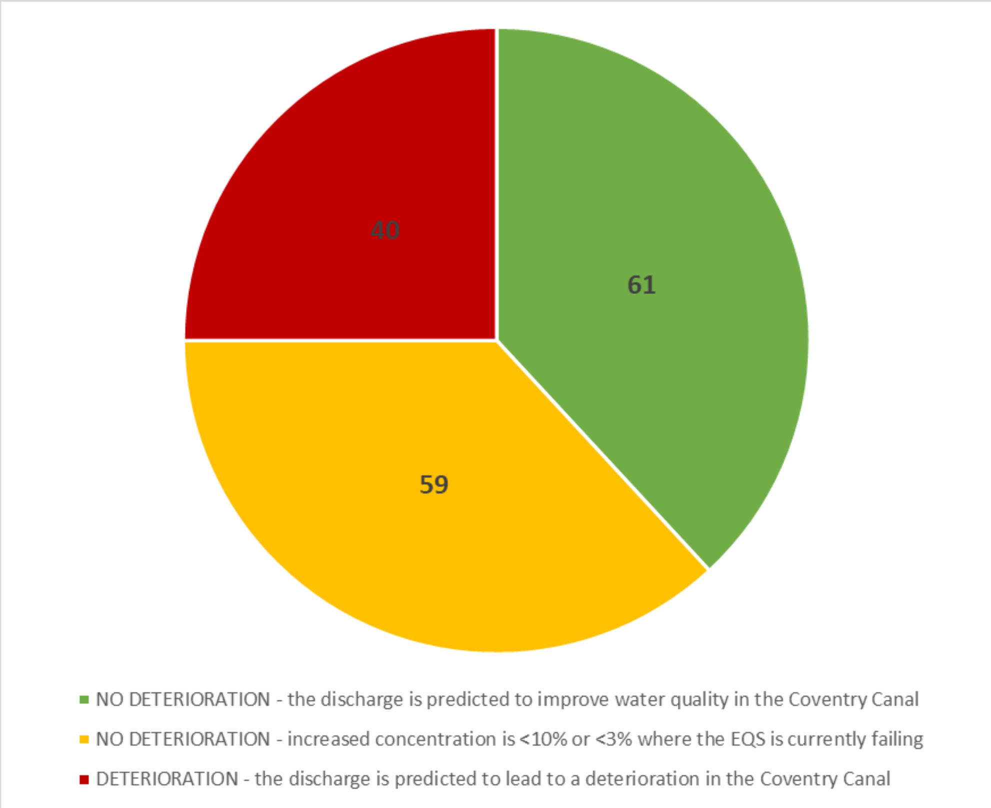


Figure 7-2: Deterioration impacts, Coventry Canal at Atherstone

7.3.2 Water quality impact downstream on the GUC

- Following a screening assessment, a total of 38 determinands required modelling at Daventry and 31 at Leighton Buzzard. The remaining determinands (where sampled) are considered to be not significant at these locations.
- Of these two sites, Daventry is the most sensitive to impact from the transfer, with 14 determinands predicted to fail one or more of the hazardous chemicals tests, 31 predicting a percentage deterioration and 8 a WFD class deterioration.
- For most determinands where a reduction in the discharge concentration would be required to prevent a deterioration, preventing deterioration at Atherstone would also be sufficient to prevent deterioration downstream. There are some exceptions, with 11 determinands being most sensitive at Daventry, and 9 being most sensitive at Leighton Buzzard (see A2.3, section 8). In total, 47 determinands were identified where some improvement to current concentrations might be required in order to prevent deterioration at site 3, 5 or 6.

7.3.3 Summary of water quality impacts

A summary of all results is provided in Table 7-1, and a full listing of the results for every determinand at all three assessment locations is provided in Annex A2.3 Appendic C.4, which identifies a total of 74 determinands which fail one or more tests at one or more locations and might therefore require an increased level of treatment. This number is higher than the 47 determinands reported as requiring additional treatment to prevent deterioration to the Annual Average at one or more of the locations assessed (see A2.3, section 8), which was tested and reported in line with EA guidance (Environment Agency, 2019). Further advice is awaited from the Environment Agency on their approach to environmental permitting of SROs. Until this is available it is advised to consider treatment options which would prevent all deterioration (47 determinands), but to be mindful that there are 27 additional determinands (74 minus 47) which do fail one or more tests but which wouldn't cause a deterioration at any of the three assessment sites. This illustrates all failure/deterioration risks, for which potentially the EA may require additional treatment of some or all of these additional determinands. However, as illustrated in Figure 7-2 (which focuses on the impact to the Coventry Canal at Atherstone), the transfer is predicted to lead to an improvement in water quality for a greater number of determinands than the number that would deteriorate.

Table 7-1: Summary of water quality results with key deterioration results highlighted

Test	Result	Number of determinands		
		Site 3 Atherstone	Site 5 Daventry	Site 6 Leighton Buzzard
Screening	Not significant	75	7	1
	No AA EQS	50	36	16
	Potentially significant (a)	35	21	12
	Mean or 95%ile < site 3 (b)	N/A	17	19
	Passed on to modelling (a+b)	160 (all, as requested by EA)	38	31
Hazardous chemicals modelling tests	Pass all	88	10	10
	No AA or MAC EQS	42	14	15
	Fail one or more tests	30	14	6
WFD class deterioration	Class improvement	3	0	1
	No class deterioration	91	9	11
	No AA or MAC EQS	42	15	14
	Continue to fail EQS	22	6	2
	New EQS failure	2	8	3
WFD percentage deterioration	No deterioration	120	7	11
	Deterioration	**40**	**31**	**20**
Treatment required to meet AA EQS	No AA EQS	50	14	12
	No additional treatment required	93	14	14
	Not possible to meet EQS	7	1	2
	EQS could be met with treatment reductions	10	7	3
Treatment required to prevent deterioration (AA)	No deterioration predicted	119	7	11
	Deterioration could be prevented with treatment reductions	**41**	**29**	**20**

Note: As discussed above, 47 determinands are reported as requiring additional treatment to prevent deterioration to at least one location. There is significant overlap between the determinands requiring this at the three locations assessed, hence the number 47 does not appear in the table above.

8 Discussion and Recommendations

8.1 Conclusions - the impact of the SRO on the Grand Union Canal

8.1.1 Water resource and water balance assessment

The Aquator water resource model was used to analyse the baseline and with-scheme operation of the canal using hydrology for the period 1961-2022. It was concluded that:

- The newly combined Aquator model, updated to Aquator XV and with fully revised and revalidated hydrology, provides a much improved platform for assessing the long-term performance of the SRO, as well as generating inflow boundaries for the hydraulic model.
- The modelling suggests that the SRO scheme can generally safely pass through the canal.
- Using the current Trust operational philosophy, some of the supply sources of the Trust appear to be impacted by increased demand for abstraction as a result of the scheme. This is because modelled constrictions in the existing system mean that water is lost to waste weirs in specific pounds and therefore needs to be replaced further downstream. This issue will be addressed at Gate 3 by testing and refining the emerging control philosophy in the hydraulic model, then replicating this within the Aquator model to test the long-term operation of the SRO, including during droughts.
- The Gate 2 Aquator simulations identify 12 years where summer failures are predicted, when the maximum demand of 115 Ml/d is not met. Several of the years identified are in line with national hydrological droughts. The deficit is between 10-30 Ml/d depending on the drought incident and typically last between 1-3 weeks. These occur in the model because during these periods, normal operating procedures in the canal are not occurring due to the canal levels dropping below normal operating levels. So, although the water is still supplied from Minworth, transfer of the full transfer flow through the canal is restricted due to lower-than-normal levels and a shortage of resource in the canal feeders. It is envisaged that this issue will be overcome at Gate 3 by developing an integrated control strategy combining the control objectives of the canal and the transfer. This will include both engineering works (by-passes and pumps), as well as devising a specific operational philosophy to activate back-pumps, maintain revised normal operating levels, minimize losses from the canal and include potential for storage efficiencies to the Trusts' assets.

8.1.2 Hydraulics assessment

Driven by the Aquator flow boundaries, the hydraulic model was developed to analyse the hydraulic impacts of the SRO on the canal system, including surge, velocity, water levels, headroom at bridges and spills over waste weirs.

- Results of an analysis of the potential for surge, especially in the event of pump failure coinciding with an opposing lock operation, emphasise that it is important to design the control philosophy and equipment such that it will fail safe, switching off pumping into a pound when water cannot be pumped out of that same pound. Assuming that this can be achieved, the results do not indicate significant negative impacts from surge, suggesting that this is not an issue requiring additional mitigation measures.
- Increased velocities above the threshold for navigation (0.3m/s) are not identified as a result of the transfer in open channels or at constricting structures including bridges, aqueducts and tunnels, with the exception of just one location, at the narrowest identified constriction on the transfer route located at Rose Boatyard near Bridge 30 on the Oxford Canal.

- In the 115Ml/d scenario, mean velocities will exceed the 0.05m/s threshold for many species of juvenile fish almost everywhere, with only very limited bands of lower velocity along beds and banks. The implications for fish populations should be considered by the environmental assessment.
- The model has demonstrated that, in the majority of pounds, water level rises will be moderate under both transfer scenarios. The steeper hydraulic gradient generated to convey the transfer flows, especially 115Ml/d, tends to raise water levels at the "upstream" end of each pound and lower levels at the "downstream" end.
- The predicted rises in water levels along the transfer route are not sufficient to adversely impact navigation headroom, although this issue needs to be rechecked at Gate 3 when some modelled water levels will change as the transfer controls are refined.
- Spills over waste weirs provides a variable picture. In many cases, where the weir is close to the "downstream" end of a pound, spills in the with-scheme scenario are reduced compared to the baseline. Other weirs, especially those at the "upstream" end of longer pounds, experience increased spills. In total, the scheme is predicted to result in an overall reduction in spill volumes.
- Water level control within and between pounds will require further work at Gate 3 to optimise the scheme to meet the objectives for navigation, conservation of water within the canal, minimisation of energy losses due to recirculation and managing flood risk. These Gate 2 results already indicate that achieving these objectives at either 57.5Ml/d or 115Ml/d is achievable.
- Six junctions of canals connecting at the same water level with the transfer route have been identified. The model predicts significant increases in water level at the Ashby Canal, Coventry Canal south of Hawkesbury and Oxford Canal from Braunston Junction to Napton Bottom Lock. Further detailing to extend the length of the Ashby and Coventry Canals is recommended, and results should be reviewed at Gate 3. There is potential to reduce the water level rises predicted by refining the representation of controls (pumps and bypasses) in the model.

8.1.3 Water quality assessment

A statistical water quality model was used to assess the impact of the transfer discharge at Atherstone, and any additional water quality impact downstream at Daventry and Leighton Buzzard. It concluded that:

- Of the 160 water quality determinands which have been modelled, results indicate that 47 may require treatment to higher than present standards in order to prevent deterioration in the receiving canal system, with a further 27 determinands failing at least one modelling test but not being subject to deterioration. The remaining 86 determinands pass all tests and in many cases would lead to improved water quality in the canals.

8.2 Recommendations for Gate 3

8.2.1 Hydrology and Aquator Modelling

Further work will be required at Gate 3 to address:

- Location and magnitude of changes to the operations of the canal to activate back-pumps.
- Location and nature of engineering solutions to allow for increased flow to by-weirs needs to be added to the model.
- Operational rules to manage levels for the pounds along the SRO transfer route to operate more seamlessly and minimise spillage. The activation of back-pumps is reliant on these levels and as the system currently works, it shows more of an

impact on The Trust's reservoirs as these are the sources that are used to fill the pounds to bring them back to a 'healthy' resource based on the current control curve rules. If this is addressed, there will not be as much water pulled from the reservoirs as it is not needed in reality.

- Addition of the Ashby Canal interactions into the Aquator model. At the moment, this is represented in a crude way which will need to be refined to assist decision making for mode or operations and engineering works required to ensure transfer does not interact with the Ashby canal.
- Additional hydrometric survey of key locks and pounds at summits, junctions and troughs are also recommended, or alternatively (or in combination) installation of long-term telemetered gauges to help validate changes to canal operations to accommodate the transfer volume in the canal pounds.
- Flood hydrology estimates will be required to support the FRA for the DCO (see next paragraph).

8.2.2 Hydraulics

- The model calibration and baseline assessment has identified a number of anomalies around waste weir and Normal Operating Zone (NOZ) levels. Improvements were achieved through engagement with the Trust, and these should continue to be investigated at an early workshop with The Trust. This should take into account present-day operations by The Trust to adjust waste weir levels (for example using stop logs), and how these might need to change when the transfer is operating with significantly higher flows and the potential for flow and water level changes in response to demand for the transfer.
- A Flood Risk Assessment (FRA) will be required to support the Development Consent Order (DCO), in order to demonstrate that the scheme does not increase flood risk or any risks can be mitigated. The hydraulic model will be sufficient to assess this in most locations, however there may be some locations where additional fluvial modelling is recommended.
- The Minworth discharge structure at Atherstone, intermediate new pumping stations and by-passes, and the abstraction structure at Leighton Buzzard all have the potential to cause localised high velocities and complex flow patterns, which could locally impact navigation, fish, sediment suspension and scour. CFD modelling can be a useful tool for testing and refining the design of such hydraulic structures and should be considered at Gate 3.
- The new transfer pumping stations have been modelled as pumping directly from canal pounds, whereas in reality a new weir will spill water into the pumping station sump. This arrangement should initially be tested for one section of canal (with several pumps in sequence), and applied to the whole model if a stable set-up can be achieved.
- Overall, the Gate 2 modelling has identified that operational control, both within the model and in actual design, will be critical to avoiding issues of surge, hunting (frequent switching), water levels outside of the Normal Operating Zone. In addition, the scheme will aspire to be operable in ways which could reduce flood risk at specific locations, for example by drawing-down pounds ahead of forecast heavy rainfall, or where feasible pumping water away from areas at risk. Development of the control philosophy and the implementation and testing of this in the models should be a priority for Gate 3.
- LiDAR has been used to identify bank heights in locations where full cross-sections were not available. Consideration should be given, at Gate 3, to capturing more detailed topographic survey of bank heights (on both banks) to identify low points on any pounds where the transfer is predicted to increase water levels above the NOZ. This will improve confidence when assessing lengths of bank that require raising.

8.2.3 Water quality

- Work closely with Minworth process design team. If the conservative water Gate 2 modelling assumptions for Daventry and Leighton Buzzard (no dilution, degradation or speciation) are a key driver of treatment costs (capital and or operational) then consider more detailed water quality modelling of sensitive determinands.
- The impact assessment has focussed on a demand and discharge curve peaking at 115Ml/d. Further testing may be required to assess water quality impact for a peak discharge of 57.5Ml/d.
- The Aquator model may under-estimate feeder flows into the Atherstone top lock. Further collaborative work with The Trust should be undertaken to review the control curves at this location, although sensitivity testing suggests that the water quality assessment is not sensitive to changes in flow, because the proposed discharge flow is an order of magnitude greater than the background canal flow.
- Full testing was not possible for those determinands where an EQS has not been set. The Environment Agency has advised that it may be preferable to use the Probable No-Effect Concentration (PNEC) as a de-facto EQS in these cases. If the EA confirm this approach and provide a list of PNEC values these should be tested at Gate 3.
- The effluent concentrations required to meet the target EQS or to prevent deterioration are presented to assist the outline process design process and are not intended to represent possible future environmental permit limits.
- Where the treatment reduction of a determinand required to meet no-deterioration downstream at Daventry or Leighton Buzzard is greater than that required to prevent deterioration at Atherstone, it is recommended that for initial process design, the higher reduction values are considered.
- Ongoing consultation with the Environment Agency is recommended. This should cover, amongst other issues:
    - The emerging national approach to water quality and permitting of SROs,
    - The approach to assessing determinands which do not have an EQS,
    - Modelling the impacts of climate change, including lower summer flows and higher temperatures, in assessing water quality,
    - How to consider the risk of future deterioration of the effluent quality in permitting, and
    - Any local water body issues (in liaison with the Canal & River Trust).
- It is recommended that the water quality monitoring regime be continued at sites 1, 3, 5 and 6. Developing a longer time-series of water quality data at these sites will improve statistical confidence in the data and hence any further modelling, and will enable any trends or step-changes in the quality both of the Minworth effluent and of the Canal.

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