Intelligent water level management within the Somerset Levels and Moors

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INTELLIGENT WATER LEVEL MANAGEMENT WITHIN THE SOMERSET LEVELS AND MOORS

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KEY WORDS

Model predictive control, river flooding, water level management

ABSTRACT

The Somerset Levels and Moors cover approximately 60,000 Ha of low lying land between Bridgwater, Taunton and Yeovil. This area is drained predominantly by the rivers Parrett, Tone, Cary and Sowy, and also King's Sedgemoor Drain. The Somerset Levels and Moors are an area of significant environmental designation, and are also prone to flooding due to the embanked river system and low-lying land. Water level management on the Somerset Levels and Moors is critical in promoting the favourable condition of this environmentally designated site. As part of the reconstruction of the Oath Lock and Greylake Sluices on the River Parrett and King Sedgemoor Drain, the opportunity was taken to develop a unique control system that predicts water level changes and automatically controls the sluice gates to manage water levels. The system draws on real-time data from a regional telemetry network, interpretation of extensive numerical modelling, and complex programming to enable a powerful, user-friendly system. In addition to having an environmental and water level management function, the control system effectively acts to manage flooding during extreme fluvial and/or tidal events. The control system has been implemented on site since summer 2007.

The control systems are defined as 'model predictive', in that the dynamics of the river system in response to tidal and fluvial inputs, and hydraulic structure operation can be predicted. In addition to this, the capability to predict river system dynamics by up to 12 hours defines the control system as a 'receding horizon' type. The river system is defined within the control system by empirical and hydraulic equations drawn from a detailed ISIS model.

The control systems can operate in a number of overall modes, dependent on hydraulic control structure discharge capacity. These modes include manual override, back up operation due to telemetry failure, and low to high flow conditions. These different modes operate the hydraulic control structures in the most efficient manner, for example using tilting weirs for fine water level control during low to mid flow conditions, and vertical lift gates for more responsive water level control during high flows.

Algorithms were developed to find the most efficient method of controlling water levels. These consist of local telemetry at Greylake, using volumetric deviation from the target as a main factor to operate the tilting weirs, and remote telemetry at Oath Lock to pro-actively discharge predicted excess flow to minimise the effect of peak flows during high flow events.

Testing of the control system on site has also highlighted further improvements to be made in the future as field data is collected. These include fine tuning of hydraulic structure discharge coefficients over a wider range of conditions, and improved definition of time lag and flow attenuation coefficients throughout the river system.

INTRODUCTION

The Somerset Levels and Moors cover approximately 60,000 Ha of low lying land between Bridgwater, Taunton and Yeovil. This area is drained predominantly by the rivers Parrett, Tone, Cary and Sowy, and also King's Sedgemoor Drain (KSD). The Somerset Levels and Moors are an area of significant environmental designation, and are also prone to flooding due to the embanked river system and low-lying land (see Figure 1). Due to this, previous studies have been carried out to manage flood risk (Atkins, 2003) and also maintain favourable condition of the moor system (Atkins, 2007). The source of flooding is predominantly tidal up to Oath Lock, whilst further upstream extreme fluvial events become dominant.

A number of hydraulic control structures are manually operated to minimise flood risk and also to avoid damage to the environmentally designated areas. Significant structures in the river system (shown in Figure 1) include:

- Monk Leaze Clyse, a vertical lift gate controlling flow between the rivers Parrett and Sowy.
- Oath Lock Sluice, improved recently to comprise of two vertical lift gates with a bypass channel and tilting weir, controlling flow down the River Parrett, and controlling tidal incursion.
- Greylake Sluice, improved recently to comprise two tilting weirs, controlling flow down the River Cary/KSD.
- Dunball Sluice, a vertical lift gate controlling flow between the KSD and River Parrett and controlling tidal incursion.

Further to this, the regional Environment Agency telemetry system (SWANTEL) collects data from the various gauges in the river system to enable monitoring of flood risk.

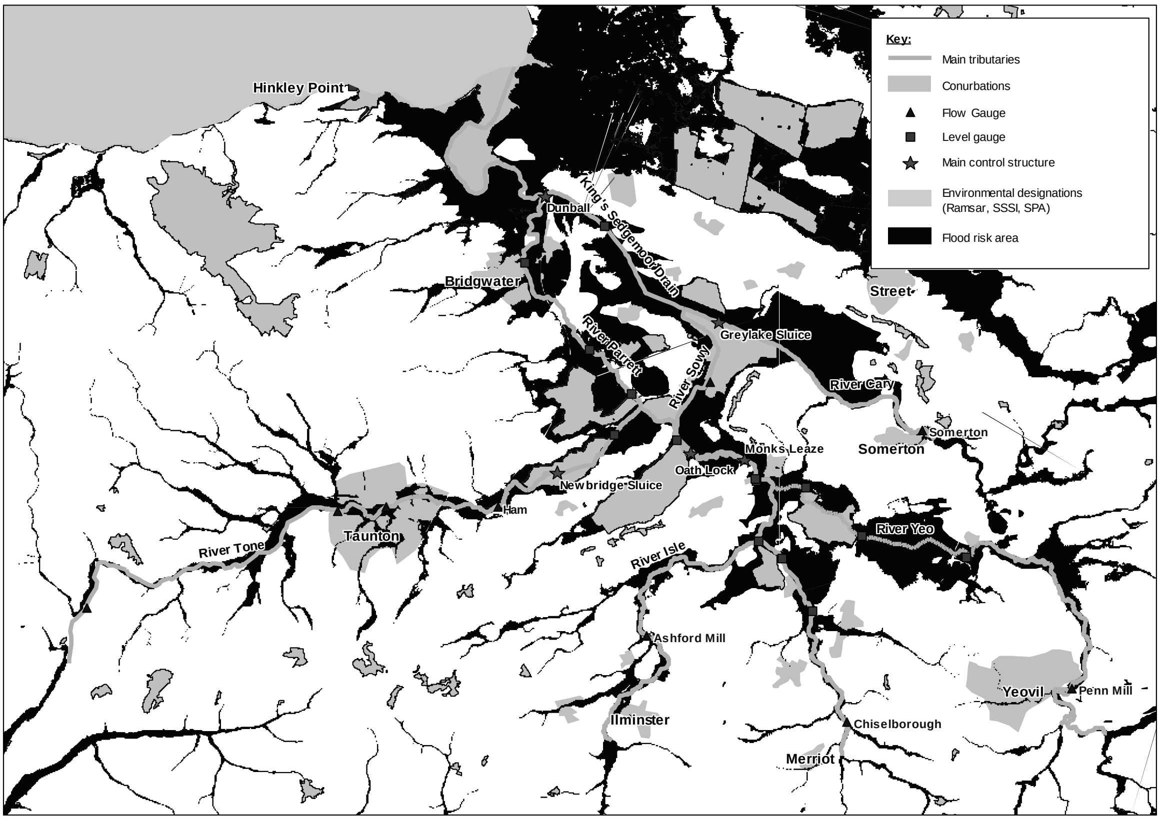


Figure 1. Somerset Levels and Moors.

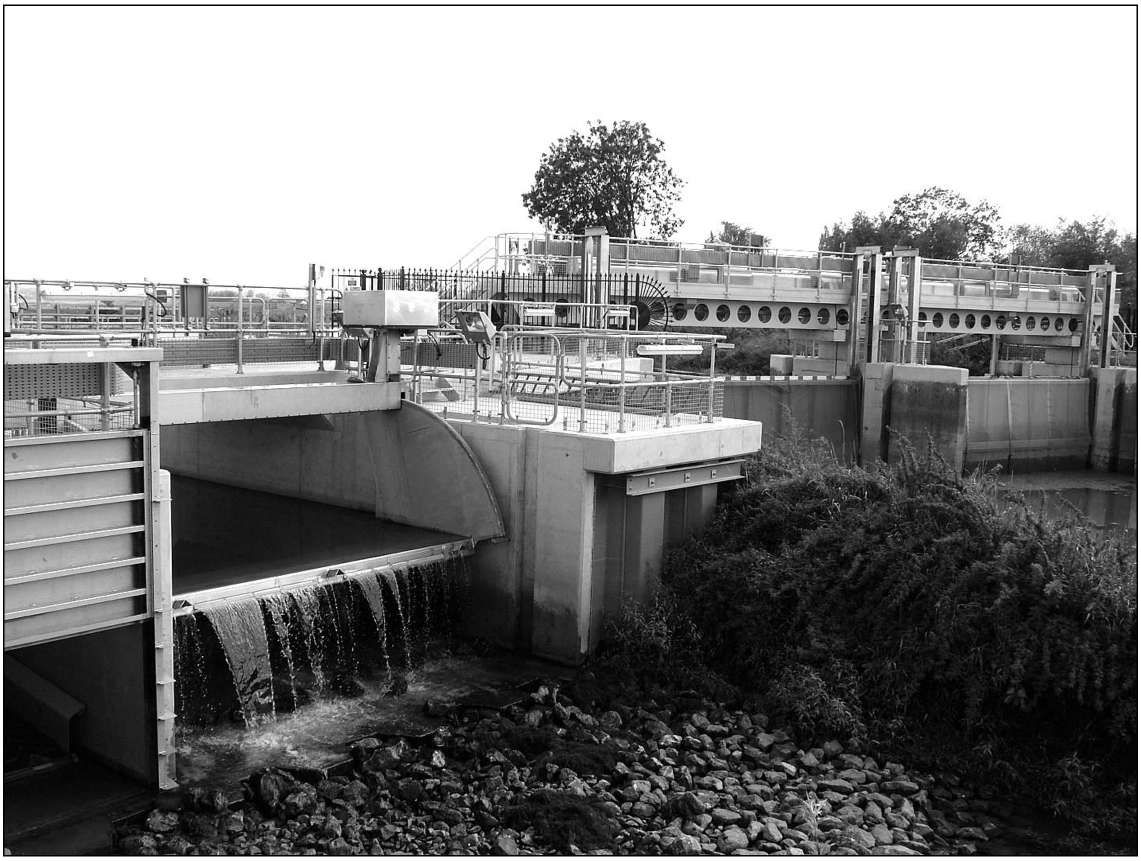
OATH LOCK AND GREYLAKE SLUICE STRUCTURES

Structure Refurbishment

Oath Lock and Greylake Sluice are two of the major hydraulic control structures on the Somerset Levels, directly controlling water levels in the River Parrett and King's Sedgemoor Drain respectively. Structural condition inspections carried out as part of the project concluded that Oath Lock and Greylake Sluices were coming to the end of their design life, and as such Atkins were commissioned to re-design the structures. The original Oath Lock Sluice consisted of two vertical lift gates operated manually, whilst Greylake Sluice consisted of one vertical lift gate operated manually.

The re-designed Oath Lock structure consists of two vertical lift gates, with a bypass channel and tilting weir, and Larinier fish pass, whilst the Greylake structure consists of two tilting weirs with a facility for elver passage. Photographs of these two structures, before and after reconstruction are given in Figure 2.

a) Oath Lock Sluice prior to refurbishment



b) Oath Lock subsequent to refurbishment

c) Greylake Sluice prior to refurbishment

d) Greylake subsequent to refurbishment

Figure 2. Hydraulic control structure refurbishment.

Original Control Philosophy
The conventional control of the structures aimed at:

- Providing summer penning.
- Allowing flood conveyance.
- Winter penning over dry periods.
- Transfer of water using Monks Leaze Clyce.

Summer penning was provided by the fixed weir in the bypass channel with the vertical lift gates closed or slightly open, operated locally. Levels are monitored at the Incident Control Room (ICR) through the SWANTEL system. The vertical lift gates were manually opened to control the release of summer high flow events, and subsequently closed to recover the summer penning levels. During the winter there were no control requirements for the Oath Lock Sluice vertical lift gates which were normally fully opened. During prolonged periods of low winter flow the gates could be lowered in preparation for the build up of the summer penning level. Greylake Sluice was used in a similar way to provide summer penning by manually lowering the gate and installing penning boards. High flows were passed during the winter by manually raising the gate. The gate at Monks Leaze Clyse closes during low flows. During normal flows MLC is manually partially opened to divert a proportion of the flow upstream of Oath Lock Sluice to the KSD via the Sowy River. The MLC gate is also closed while certain pumping stations are operating or Beazley spillway is active.

In conjunction with the reconstruction of the Oath Lock and Greylake structures, the opportunity was taken to improve water level management by developing an automated control system.

CONTROL SYSTEMS
Control systems can vary widely in complexity, from the application of simple logic switches through to artificial intelligence applications. Control systems have been common within the chemical engineering industry since the 1980s, and are sometimes applied on irrigation, canal or reservoir schemes, but their application to river systems is extremely limited. A recent example related to managing river flooding is on the Demer river in Belgium (Blanco et al, 2008).

A diagram showing the range of control systems is given in Figure 3, with the Oath Lock and Greylake control systems developed within the Somerset Levels and Moors highlighted. The control system at Oath Lock was implemented as a non-linear model predictive system with the ability to use remote telemetry from throughout the river system, due to its significance in controlling water levels throughout the Somerset Levels and Moors. At Greylake the control system was implemented as a non-linear predictive model system using local telemetry. The control system developed for Oath Lock is focussed on herein as it is more extensive and complex.

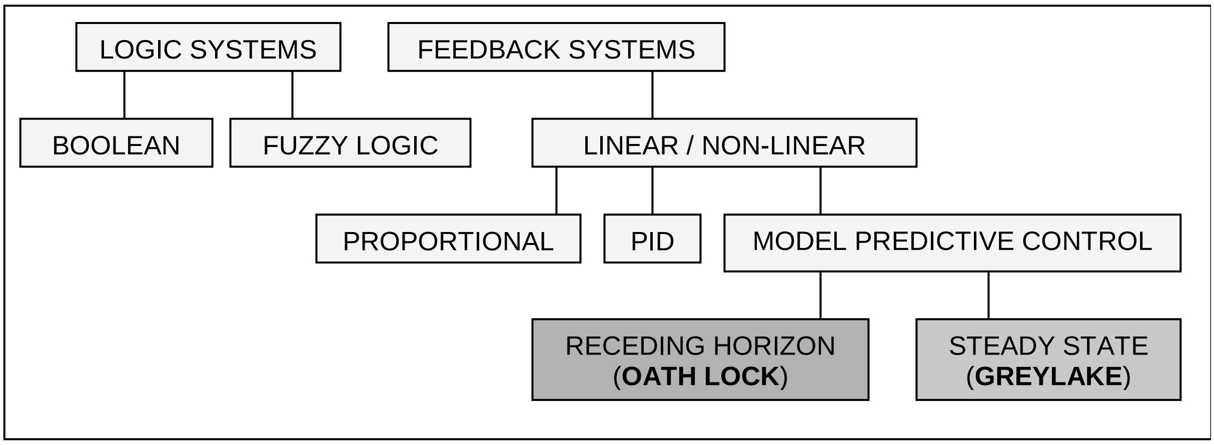


Figure 3. Control system heirarchy.

OATH LOCK CONTROL SYSTEM
Philosophy
The Oath Lock control system aims were to:

- provide automated upstream penning level control
- automate control of gates in flood conditions in response to remote level and flow measurement upstream and downstream in the catchment

- automate control of gates during ‘summer flooding’ to re-establish upstream penning rapidly
- provide automated control of rate of rise/fall of upstream level
- provide tidal exclusion

The control system comprises two main modules: predictive model and optimal solver. In addition to this, five modes of operation were defined to most effectively use the vertical lift gate and tilting weir hydraulic characteristics, as well as covering other maintenance/reduced telemetry scenarios.

Mode 0 was designed as a ‘back-up’ mode for when historic telemetry was not available. This would occur when the control system is started up, either for first operation or due to the system being taken offline, and also if remote telemetry fails for greater than 3 hours. In this mode control is carried out using local water level gauging at Oath Lock.

Mode 1 was designed to control water levels during low flows. This mode uses the tilting weir, with incoming flow within the discharge capacity of the tilting weir for the required upstream and predicted downstream water levels. This provides fine control of water levels.

Modes 2 and 3 were designed for intermediate and high flows respectively. Under these conditions, incoming flow exceeds the discharge capacity of the tilting weir, requiring the vertical lift gates to be operated as well. In addition to the tilting weirs being held completely open, the vertical lift sluices are operated to achieve the required upstream and predicted downstream water levels. Mode 3 is a special case where the combined discharge capacity of the tilting weir and vertical lift gates is exceeded. Under these conditions an alarm is raised, and current/predicted spillway and out of bank flows are recorded.

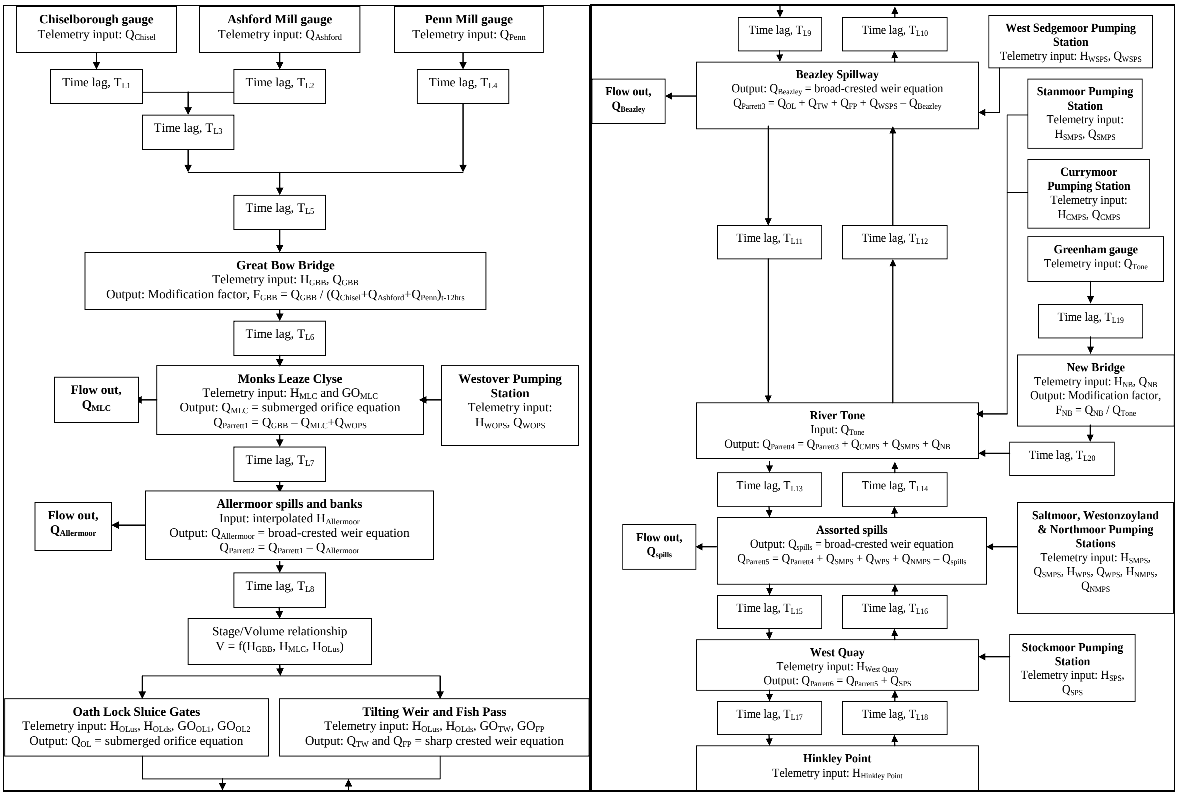
Mode 4 was designed for manual gate operation when required. Gate positions are able to be programmed manually to control upstream water level. This mode enables any gate to be shut down for maintenance and shall continue to control the site with the remaining operational gate and tilting weir.

Predictive Model

Telemetry data was available for flow gauges at Chiselborough, Penn Mill and Ashford Mill, ranging from 20 to 30km upstream of Oath Lock Sluice. Experience of Environment Agency operatives in the catchment estimated that the representative time lag for flows from these three upstream sites to reach Oath Lock was of the order of 12 hours. This allowed river system parameters (water levels and flow) locally and downstream of Oath Lock to be defined 12 hours in advance, enabling the predictive capability of the control system.

A conceptual representation of the river system was developed (shown in Figure 4), comprising of:

- telemetry inputs from SWANTEL.
- time lags and attenuation coefficients between telemetry input/output locations in the river system.
- head-discharge performance of formal (weirs and sluices) and informal structures (banks and spillways).



a) Upstream of Oath Lock b) Downstream of Oath Lock

Figure 4. Conceptual river system.

Runs of the Lower Parrett and Tone ISIS model for MHWS to 1% Annual Exceedance Probability (AEP) tide levels, combinations of weir and sluice positions, and base to 1% AEP fluvial flows were used to provide data to generate parametric relationships defining time lags and attenuation coefficients for the river system. Analysis of the model results confirmed that the boundary conditions (incoming flow and tide level) dominated these relationships, with limited influence from Monks Leaze Clyse gate opening. Time lag and flow attenuation equations of this form were applied throughout the river system model.

Head-discharge performance of formal structures was defined based on analysis of telemetered data and field calibration tests, defining discharge coefficients to be applied within standard under/overflow gate equations and weir equations. However, the flow over spillways and river banks was simplified to parametric equations, based solely on local water level conditions. These equations were used to define flow over Allermoor banks, Beazeley Spillway, Currymoor banks, and extensive bank lengths downstream of Oath Lock.

Optimal Solver

The optimal solver was designed to have two main capabilities:

- Enable tracking of the target water level as closely as possible, based on proportional-integral-derivative (PID) control.
- Assess if maximum discharge capacity at any point during the next 12 hours is exceeded (resulting in uncontrolled water levels), and actively manage hydraulic structure positions so that deviations from the target water level are minimised: ‘volumetric balancing’.

A representation of how the target water level tracking works is given in Figure 5. This shows that this methodology works well during conditions where the maximum achievable discharge is not exceeded. When the maximum achievable discharge is exceeded (the red hatched areas), movement away from the target water level is not controllable.

In ‘volumetric balancing’ mode, shown in Figure 6, the predictive capability of the control system allows the exceedance volume to be calculated. The time available prior to the maximum discharge being exceeded is then utilised to reduce water levels before water levels become temporarily uncontrolled. The mathematical representation of this consisted of:

$$V_e = \sum_{t=t_1}^{t_2} \left[Q_{in} - Q_{\max} \right]_t \text{ and } Q_{out_t} = Q_{in_t} + \left(\frac{V_e}{t_1 - t_0} \right)$$

where t_0, t, t_1 and t_2 are the time at origin, the time of interest, beginning and end of the exceedance zone respectively, Q_{in} and Q_{out} are the predicted incoming and outgoing flows, and Q_{max} is the maximum discharge. At each timestep telemetry inputs are collected, hydraulic behaviour of the river system is calculated, and the optimal solver is re-run with the revised predicted outputs.

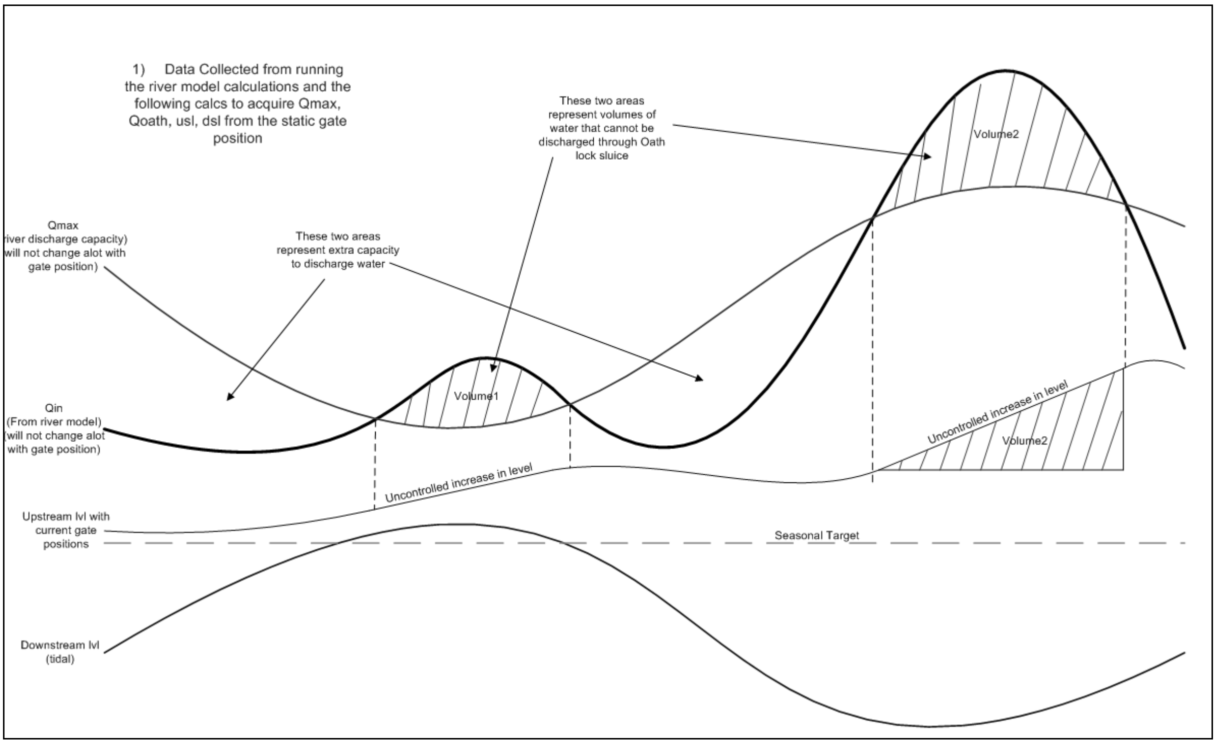


Figure 5. Water level control without active volumetric balancing.

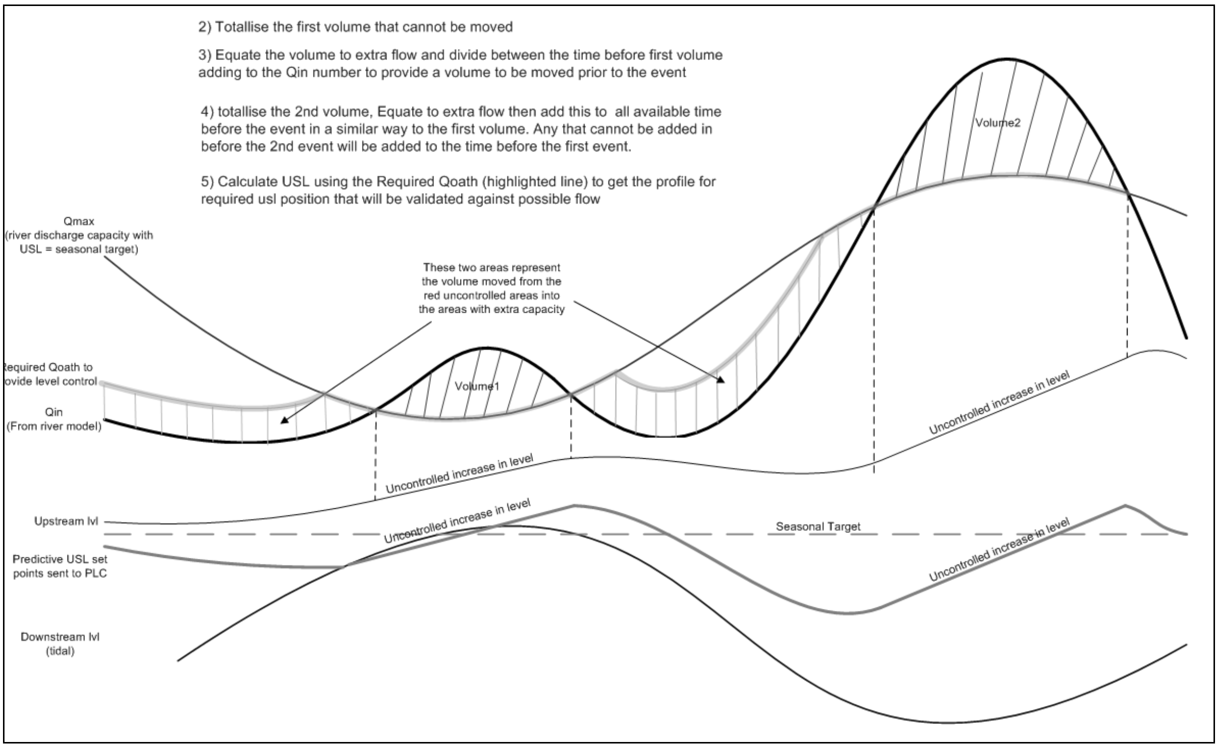


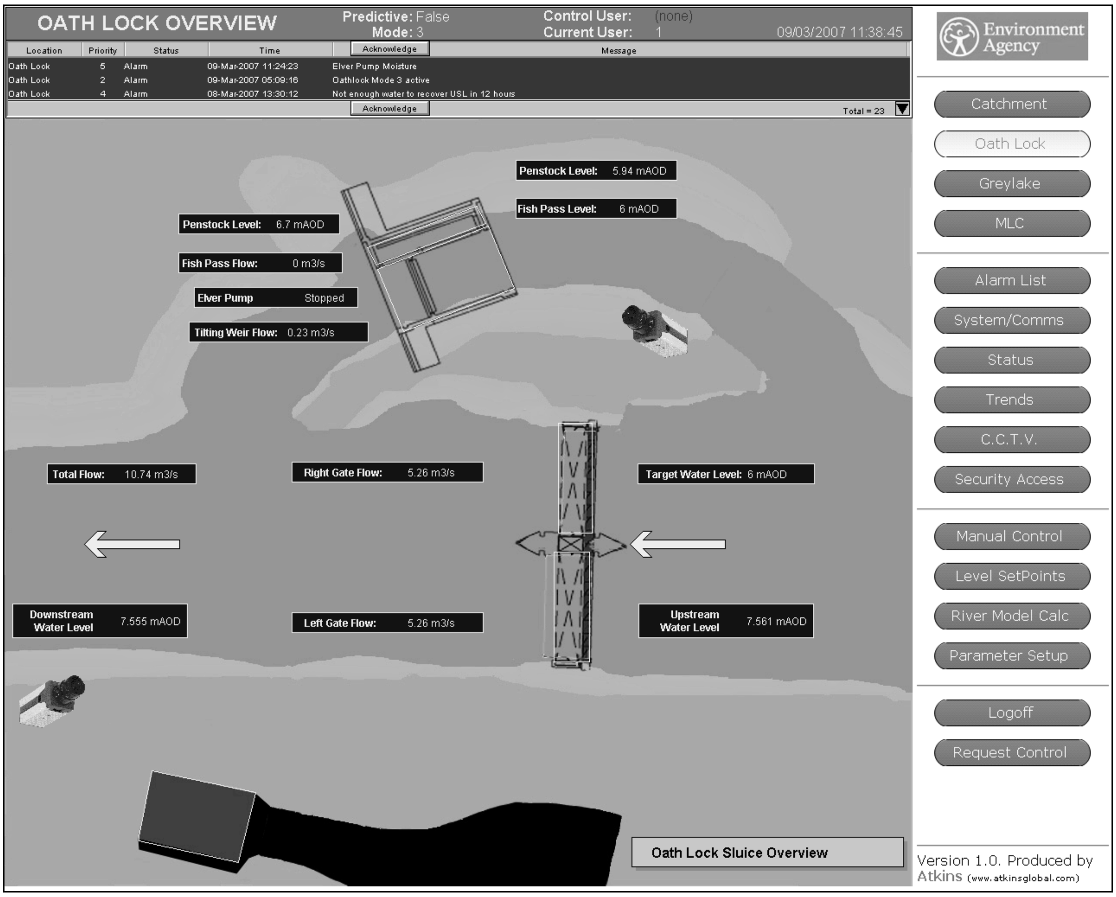
Figure 6. Water level control with active volumetric balancing.

IMPLEMENTATION ON SITE

The implementation of the control systems on site included the provision of a large number of more detailed methods of control. These included:

- Ability to amend system variables when necessary.
- Use of a ‘dead band’ of 100mm to avoid un-necessary gate movements near the target water level.
- Maximum limits on the rate of movement of the vertical lift gates and tilting weirs.
- Limits on stepped weir and sluice movements to avoid mechanical fatigue.
- Swapping of control between weirs and sluices to reduce mechanical fatigue.
- Various levels of user access dependent on security clearance.
- Logic control of the elver pass pump operation based the upstream and down stream water level, with an over-ride function during droughts.
- Warnings (both aural and visual) for situations where the difference between actual and target water levels exceed absolute limits.

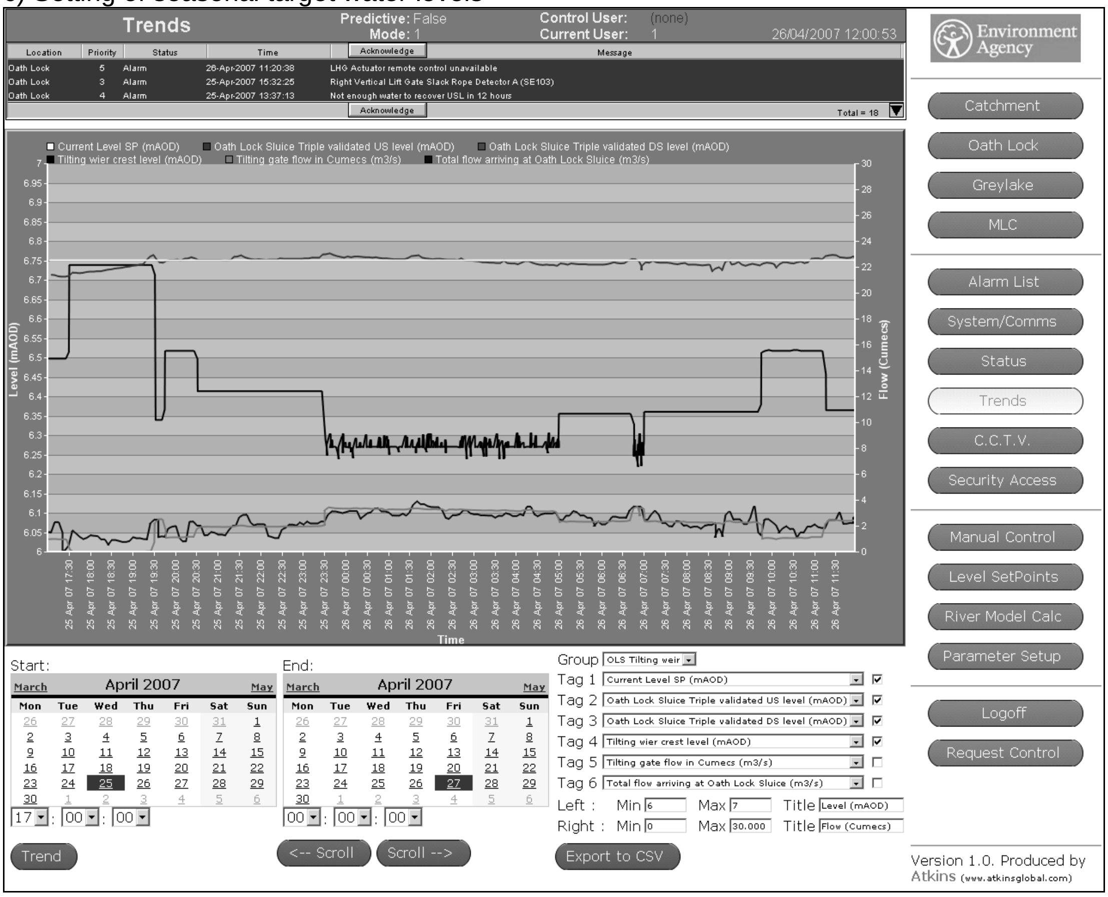
The control system software included the development of a graphic user interface (GUI), to allow commands to be entered, show current system operation and variable values, historical trends in key parameters, predicted river system behaviour. Examples from the GUI are given in Figure 7.



a) Oath Lock overview

b) Vertical lift gate operation

c) Setting of seasonal target water levels



d) Gate movements/water levels during field testing

Figure 7. Examples from Oath Lock control system GUI.

The Oath Lock and Greylake control systems were implemented on site in summer 2007, and are being tested for effectiveness. Two critical aspects of the control systems will be improved over time:

- Time lags and flow attenuation throughout the river system, particularly between the upstream flow gauges (Ashford Mill, Chiselborough and Penn Mill) and the upstream boundary of the ISIS model (Great Bow Bridge).
- Tuning of the discharge coefficients for the hydraulic control structures. Limited field data and testing allowed discharge coefficients to be derived under a relatively narrow band of conditions, due to practical and operational limitations. Collection and analysis of further field data over time will enable relevant coefficients to be defined over a wider range of conditions.

CONCLUSION

Non-linear predictive control systems have been developed and implemented at Oath Lock and Greylake to provide automated control of hydraulic structures and consequently water levels within the Somerset Levels and Moors. These control systems aim to ensure that favourable condition and flood risks within the Somerset Levels and Moors are managed efficiently.

The control systems can operate in a number of overall modes, dependent on hydraulic control structure discharge capacity. These modes include manual override, back up operation due to telemetry failure, and low to high flow conditions. These different modes operate the hydraulic control structures in the most efficient manner to maintain proximity to target water levels, for example using tilting weirs for fine water level control during low to mid flow conditions, and vertical lift gates for more responsive water level control during high flows. Now implemented on site, further opportunities to improve the control systems include fine tuning of time lag, flow attenuation, and discharge coefficients under a wide range of conditions.

ACKNOWLEDGEMENTS

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