The British Dam Society

River Roding Flood Storage Reservoir – CFD modelling and optimisation of a double baffle outlet to manage risk of tailwater

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The River Roding flood storage reservoir design has recently been completed and construction commenced in Spring 2024. The new 1.4Mm^3 flood detention reservoir will be retained by a 7m high and 570m long homogeneous earth embankment with a passive, 'double baffle' flow control structure. This structure will comprise six reinforced concrete bays each with a crump weir and double baffle arrangement. This will be the third double baffle flow control structure to be constructed in the UK, following Banbury and Chapelton reservoirs.

The double baffle structure is an alternative to more conventional vortex flow control devices, all of which are sensitive to downstream tailwater conditions; in this case due to a downstream road embankment. Double baffle structures are better suited for higher pass-forward flows and are less vulnerable to debris blockages than vortex devices.

Computational Fluid Dynamics (CFD) was first used to validate the modelling approach, based on the Banbury physical scale modelling to reduce the risk of the control structure not performing as designed. Following this an iterative approach between CFD and fluvial analysis was used to scale the design to achieve the optimum depth discharge characteristics. Due to the importance of tailwater depth, CFD simulations were run comparing how various upstream and downstream water depths affected the performance of the control structure.

A novel aspect is provision of a low flow bay with incorporation of a fish pass. Future adaptation has been incorporated into the design though the use of various bay widths and incorporating an additional spare bay.

INTRODUCTION

The River Roding in Essex has a long history of flooding. The river responds rapidly to rainfall events, particularly in the middle and lower reaches where there is less floodplain available for storage and a greater number of properties at risk of flooding. This was demonstrated in 2000, when fluvial and pluvial flooding caused damage to over 400 properties in Woodford, northeast London. Some protection from regular flooding is afforded by a manmade network of flood defences. However, once climate change is taken into account, a significant proportion of these areas remain within the Environment Agency (EA) designated Flood Zones 2 and 3. Therefore, the EA has deemed it necessary to carry out works to alleviate future flood impacts by creating a new Flood Storage Reservoir (FSR) to provide protection into the future.

Detailed design of the River Roding flood storage reservoir has recently been completed and construction of the scheme commenced in Spring 2024 with BAM as the Principal Contractor. The reservoir will have a storage volume of 1.4Mm^3 retained by a 7m high, 570m long homogeneous earth embankment. Flows are managed by means of a passive, reinforced concrete flow control structure in the form of a crump weir and double baffle arrangement. The structure is divided into six bays. This will be the third double baffle outlet to be utilised in the UK, following Banbury (Akers et al, 2004 & 2012) and Chapelton dams (Gowens etc al, 2010).

OBJECTIVES AND OPTIONS FOR FLOW CONTROL

As with any flood storage reservoir, a control structure is required to control flows through the dam. To optimise storage capacity, the ideal flow control structure would allow all flow to pass downstream until the capacity of the downstream channel (the 'pass-forward flow') is reached and would then discharge exactly the pass-forward flow for all stages above this. In reality, it is difficult to achieve such accurate control even with a fully automated gated system, but there are various forms of flow control which accomplish these objectives to a greater or lesser extent. Active flow controls systems, using moving gates, generally provide the most efficient form of control but were discounted at the options appraisal stage due to the client's preference for a passive system. This preference is due to the increased operational and maintenance requirements associated with moving gates and because with any form of active flow control they may be blamed (rightly or wrongly) for any residual flooding due to (perceived) maloperation. Other advantages and disadvantages of active versus passive flow control are discussed in Brown et al (2022).

Alternative passive options that were considered include vortex devices (i.e. Hydrobrake^{TM}) and gates controlled with a float mechanism (e.g. Hydro-Slide^{TM}) but due to the high pass-forward flow required (62m^3/s) these were not practical at this site.

The concept of a double baffle structure is explained in Akers (2004) along with references relating to the hydraulic design. Essentially the structure includes a crump weir with two concrete baffle walls downstream. As the reservoir fills and water levels rise, the hydraulic control switches from weir flow to orifice flow beneath the upstream baffle, and then to weir and orifice flow controlled by both the upstream and downstream baffles in turn (Figure 1). By optimising the geometry of the structure, the characteristics of the ideal rating curve can be achieved.

The double baffle control structure at Banbury has been in operation since 2012 and has performed well, although at 38m^3/s the pass forward flow is significantly less than that required for the River Roding scheme, and the tailwater conditions are different. There was a risk that these factors may severely affect the hydraulic performance of a similar structure on the River Roding and this risk needed to be assessed and managed.

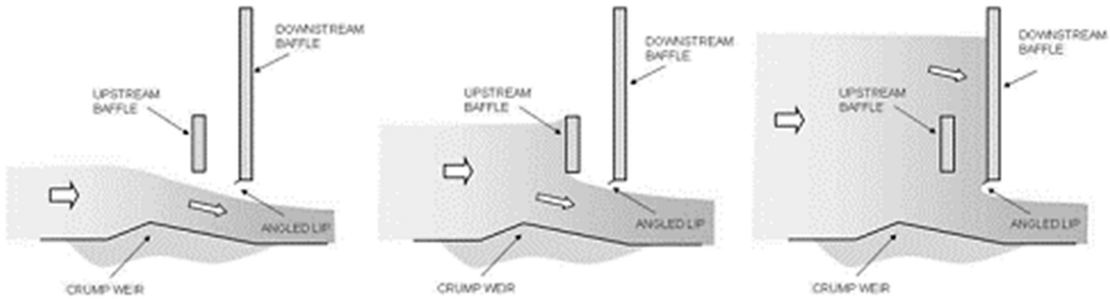

Figure 1. Three flow modes for double baffle flow control structure (Ackers et al, 2004)

DESIGN OF FLOW CONTROL STRUCTURE

Justification of options of physical model vs CFD

At the commencement of the detailed design process there were significant uncertainties regarding how the double baffle design would function when impacted by the elevated downstream water levels resulting from the nearby road bridge. Additionally, development of the detailing was envisaged to achieve acceptable outcomes in terms of low flow performance. To overcome these risks a high degree of flexibility and longevity (compared to physical models) was required from 3D modelling in order to support the overall design effort. This resulted in the selection of CFD modelling as the most appropriate and efficient tool to support the process, as it could be validated against the earlier designs of similar schemes and then optimised as needed, in parallel to design development and other modelling, including the key fluvial and hydrological inputs.

Previous data from Banbury: "theory from previous studies"

Earlier physical modelling data from the Banbury Flood Alleviation Storage scheme was utilised as the basis for modelling of the new structure. This provided geometry and performance data from physical modelling of a comparable scheme (albeit with different flow control characteristics). This enabled development for Roding to achieve the target pass-forward flow and depth-discharge performance.

CFD process

A multistage CFD modelling was employed to firstly validate the CFD approach against the Banbury physical model data (Figure 2), and then to utilise the validated modelling approach in conjunction with a 3D representation of the river and bridge to investigate and develop the performance of the larger Roding control structure.

The general CFD modelling processes were as illustrated in Figure 3. By utilising a digital model for the testing, significant changes to the geometry and scenarios were readily achievable throughout the process, providing numerous benefits to the design process including rapid integration with fluvial modelling and flexibility to trial different aspects without time consuming and costly modifications to a physical model.

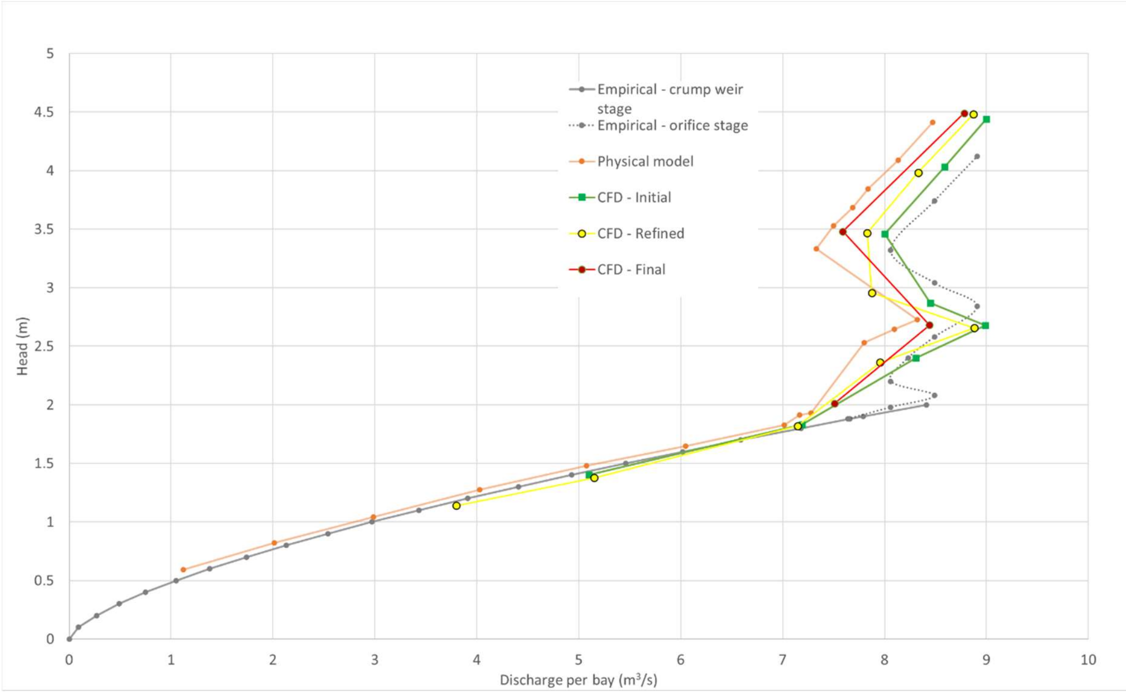

Figure 2. CFD depth-discharge validation against Banbury design data

Figure 3. Typical CFD modelling workflow

The flexibility of the modelling approach provided opportunities to implement the predicted depth-discharge performance from the CFD in the fluvial model (Flood Modeller), test performance and then evaluate performance of alternatives before undertaking further development without the need for retaining a large physical model within a laboratory during periods of 3D model downtime.

The phases of work were grouped as follows:

- Validation study – matching the geometry and flows from Banbury
- Initial design testing – analysis of a wider design with similar longitudinal section and a low flow channel to target suitable performance for the Roding scheme
- Development testing – modelling of alternative design concepts to obtain the required depth-discharge performance, mitigate backwater influence and to achieve acceptable low flow channel characteristics (see Figure 4 for an example output from the development tests)
- Additional review – review of modelling outputs to inform geomorphological and fish passage performance
- Final analysis – additional testing of refinement to the low flow channel geometry to promote fish passage under low flow conditions

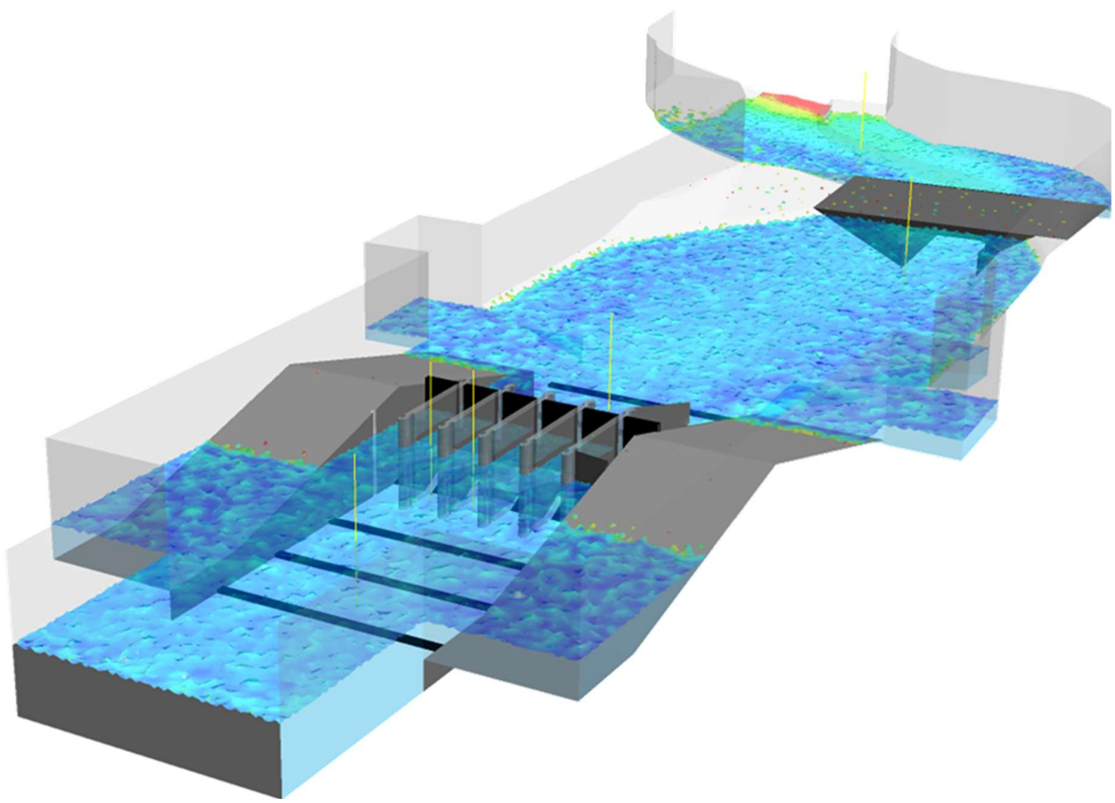

Figure 4. 3D Render of design development CFD model

Following the 3D modelling activities, a robust design was defined with site specific adaptations (raising of the crump weirs and baffles in the high flow bays, and lowering baffles and adding a short, notched crump weir in the low flow bay) to balance the opposing objectives of effective flow control for high flows and low flow performance. Modifications to the Banbury double baffle arrangement, aside from scaling the width of the structure, were found to be essential due to the significant backwater influence at the structure location – without these the structure was shown to produce an unsatisfactory depth-discharge relationship and would not have achieved the key objectives of the scheme (under baseline testing the hydraulic performance was found to be too linear, without the necessary inflections in the depth-discharge curve – see comparison in Figure 5). Through design amendments the primary risks of utilising a passive control structure, such as potential for blockage, were managed without compromise to provide effective impoundment performance for storage under high flows.

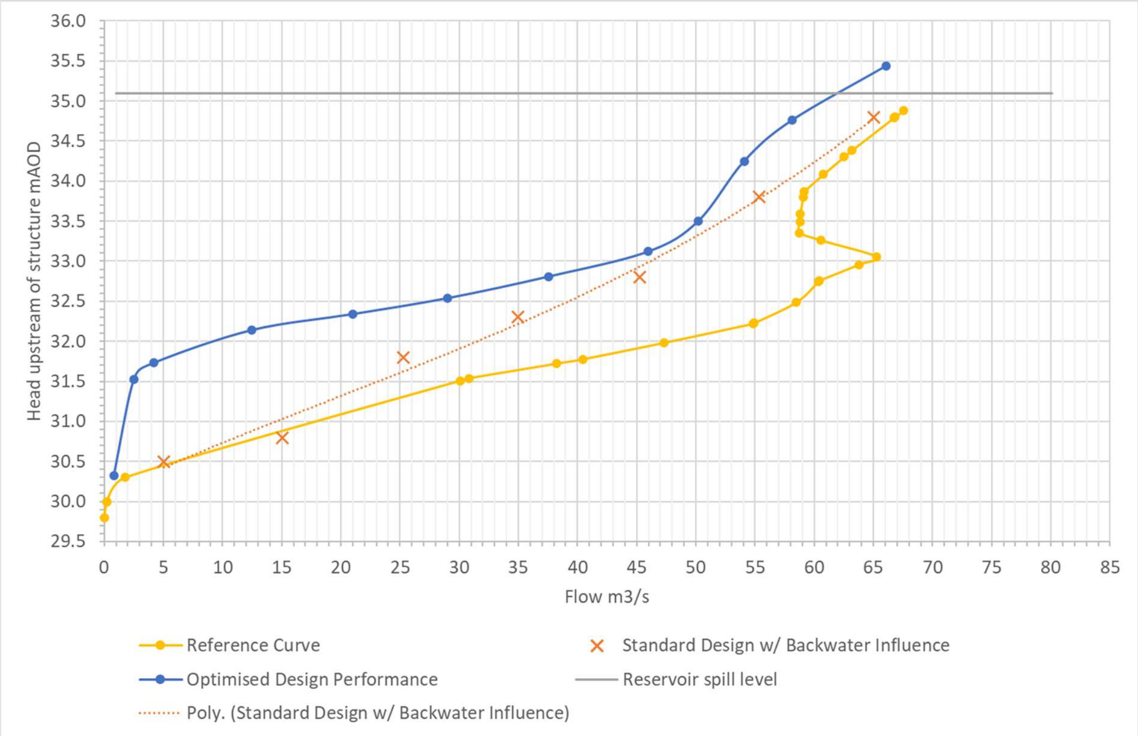

Figure 5. Comparison of depth-discharge performance predictions

Following design development using CFD, the specific depth-discharge curve was defined and then fed back to the fluvial model for retesting, thereby enabling confirmation of suitability and addressing the risks of the scheme not delivering the required flood risk management performance.

Future adaption and climate change

Future changes in climate and development introduce potential risks with utilising a passive flow control structure. However, enhanced operational flexibility was provided, as illustrated in Figure 5, by having two different size bay widths; the inclusion of an additional spare bay; and provision to close off any bay or combination of bays with stop logs. Through selecting which bays are isolated the pass forward flow and utilisation of storage can be managed during operation, providing a high level of flexibility despite the passive nature of the control structure.

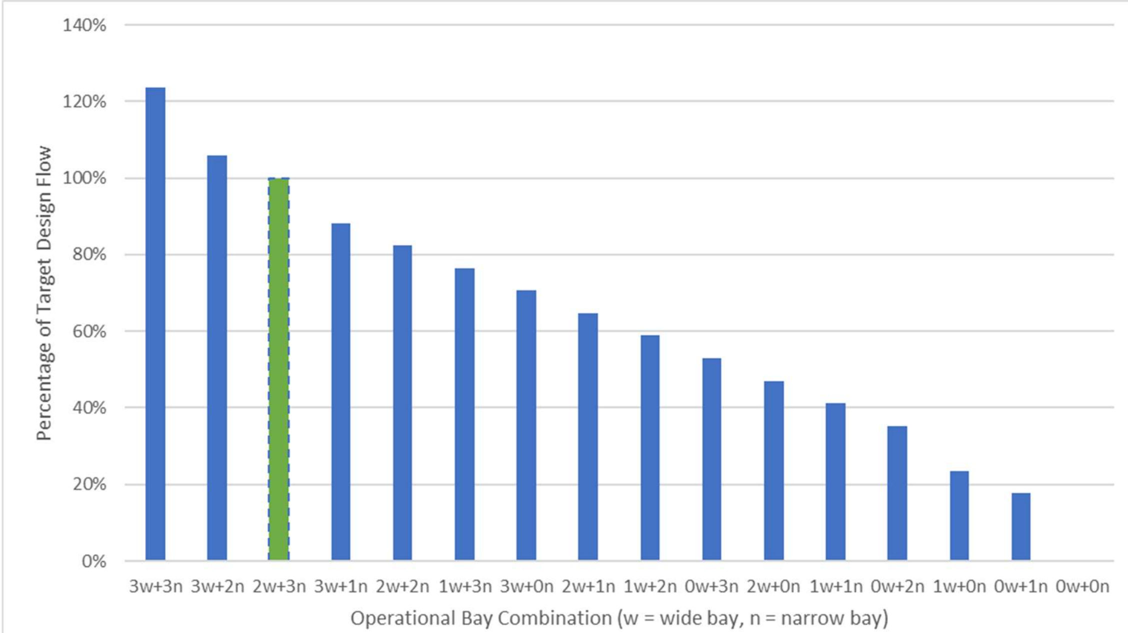

Figure 6. Illustration of operational flexibility through isolation of wide and narrow Bays

Managing floods during construction

The control structure will be completed prior to the embankment and spillway and it is therefore important that the control structure is able to pass flood flows during the construction period. This has been achieved by having two stages of construction. The majority of the structure will be built in the initial stage, including the whole of the low flow bay but excluding the weirs and baffles within the other five bays. The remaining weirs and baffles will only be built once the dam and spillway is safe to impound and the Preliminary Certificate has been issued under the Reservoirs Act.

This approach minimises the risk of flood damage during construction and avoids the need for working in water during the second stage of construction. The two-stage construction is facilitated using reinforcement couplers.

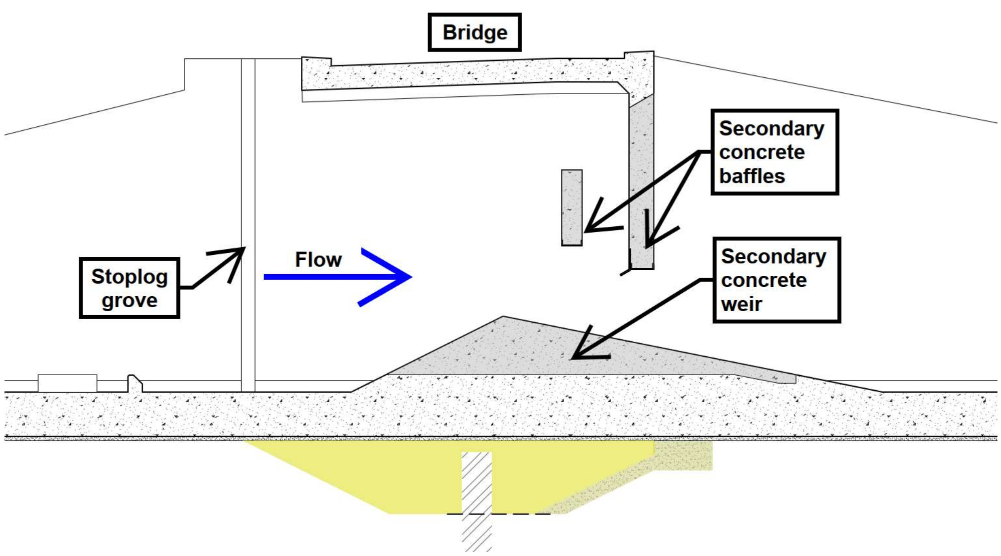

Figure 7. Staged construction of bays

Reducing environmental risk

Following development of the hydraulic design for passive flow control through the Roding double baffle structure, the CFD model was developed and tested to help inform environmental risks associated with constructing a control structure on the watercourse. During detailed design features were added to improve fish passage characteristics under low flow conditions. The key design amendments considered were to add notches in the cross walls and the crump weir of the low flow bay, and to incorporate stones cast into the base slab to promote near-bed low velocity regions. These features and an example of the corresponding model results are shown in Figure 8.

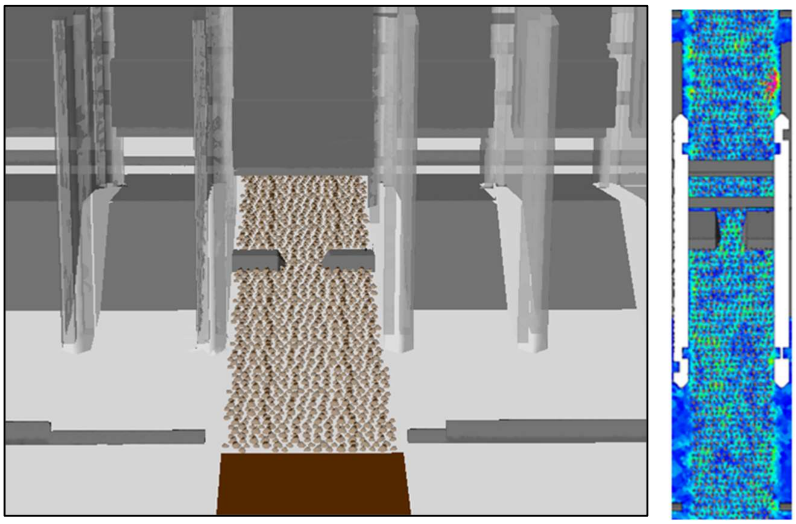

Figure 8. Model representation of low flow channel with cast-in stones (left)
CFD prediction of near-bed velocity under low flow (right)

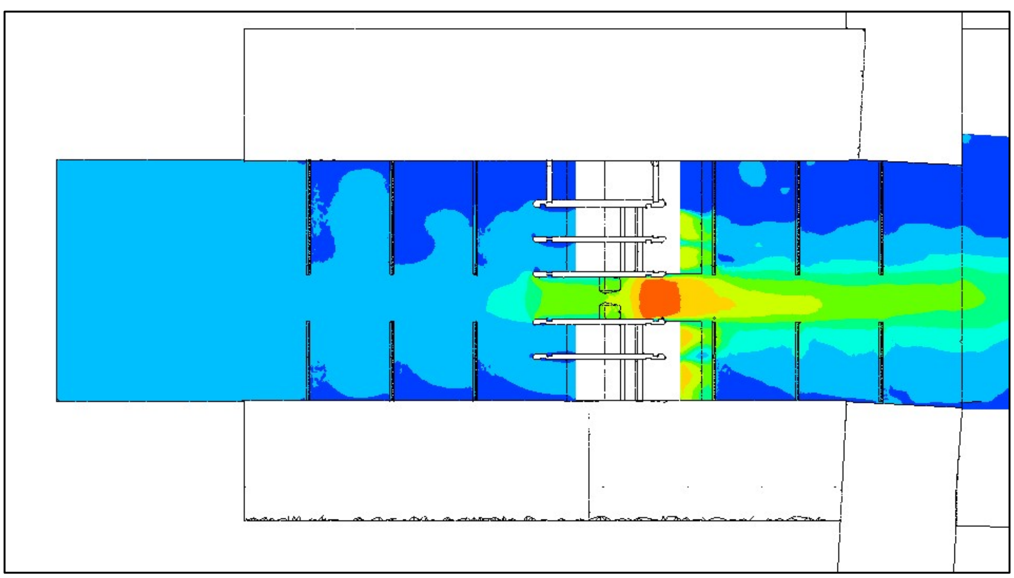

Figure 9. CFD predictions of near bed velocity

Extended analysis was also undertaken using the CFD model to investigate flow conditions over an expanded number of low to medium flows to inform sediment transport and geomorphological effects. This included assessment of near bed velocity (as illustrated in

Figure 9) and quantification of the shear stresses across the base slab. The CFD model results were also utilised to investigate the conditions beyond the new engineered structure to inform design of the transitions as the flow returns to the natural watercourse downstream.

The outputs from these supplementary analyses have been utilised through the detailed design process to provide detail on the impacts of the design refinements and reduce risk to ecology, natural river processes, and through ensuring that the fundamental flow control functionality is not affected.

SUMMARY OF KEY DIMENSIONS AND FEATURES OF CONTROL STRUCTURE

The key features and dimension of the control structure are summarised in Table 1.

Table 1. Summary of key features and dimensions

Feature	Units	Value / Description
Pass-forward flow	m^3/s	62
No. bays		Three @ 2.77m width; three @ 1.94m width (including one spare bay closed off)
Top water level	m AOD	35.1
Base slab level	m AOD	29.6
Low flow weir level	m AOD	29.8 (low flow notch 29.6)
Standard weir level	m AOD	30.9
Bed	-	Roughened concrete with embedded stones in low flow bay
Trash management	-	None. Any debris too large to pass through the flow control structure is likely to become lodged against the upstream piers where it can be later be removed when conditions allow by a Hiab or crane from the bridge deck or by accessing the upstream apron with suitable plant via the ramp on the west bank of the river.
Instrumentation		Water level sensors and CCTV

CONCLUSIONS

Flows through the River Roding flood storage reservoir will be controlled by a passive ‘double baffle’ flow control structure which is designed to optimise the reservoir operation by minimising premature impounding and capping peak flows more efficiently compared to a simple flume or orifice. Although the design concept has been proven at two similar structures in the UK there was a risk that high tailwater at this site and the need for a significantly higher pass-forward flow could prevent a double baffle structure from working effectively at this site.

Computational Fluid Dynamics (CFD) was used to assess this risk and optimise the hydraulic design of the structure. The CFD model was initially calibrated using the results of a physical hydraulic model which had previously been tested for the Banbury scheme. CFD allowed various design iterations to be tested and later enabled the design of measures to improve fish passage during low flows.

Operational flexibility, including climate change, was provided by having two different size bay widths, the inclusion of an additional spare bay, and provision to close off any bay or combination of bays with stop logs.

REFERENCES

Akers J, Hollinrake P and Harding R (2004). A passive flow-control device for the Banbury flood storage reservoir. In *Long-term Benefits and Performance of Dams - Proceedings of the 13th British Dam Society Conference* (Hewlett H (Ed)). Thomas Telford Publishing, London, UK pp 327-338

Akers J, Hopkins J, Caulfield P and Harding R (2012). The design and construction of Banbury flood storage reservoir. In *Dams: Engineering in a Social & Environmental Context - Proceedings of the 17th British Dam Society Conference* (Pepper A (Ed)). ICE Publishing, London, UK pp 457-473

Brown A, Courtnadge A and Gosden J (2022). Aspects of design detailing of flood detention reservoirs for resilience. *Dams and Reservoirs* 32(1) pp. 11-20

Gowans I, Moysy D and Winfield P (2010). Chapelton Flood Storage Reservoir. In *Managing Dams: Challenges in a Time of Change - Proceedings of the 16th British Dam Society Conference* (Pepper a (Ed)). Thomas Telford Publishing, London, UK pp 376-387