The British Dam Society

Overflow and outlet screens

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SYNOPSIS Overflow/outlet screens are often fitted to reservoirs to prevent human exposure to hazards, to catch large debris, or to prevent fish and mammals being washed downstream.

Whatever its primary purpose, a screen will collect debris and block temporarily. This blockage can lead to an increase in reservoir water level and could alter the stage-discharge relationship of the overflow or outlet. Furthermore, blocked screens will reduce the available freeboard and overflow capacity. Their impact must therefore be considered in reservoir flood studies and the design of outlet structures. This is particularly important for flood storage reservoirs (FSRs) that operate infrequently and rely on maintaining the design stage-discharge relationship to achieve the required flood attenuation.

Case studies are presented concerning two FSRs fitted with self-activating flow-control devices on their outlets that failed to operate as anticipated on first filling. In both cases the unexpected operation was attributed to downstream screens fitted to mitigate perceived hazards. A third case study concerns the impact of a 'fish' screen placed in the overflow spillway of an amenity lake.

This paper summarises research on the impact of screen size on fish and mammal passage, and on debris movement, in particular the relationship between debris volume and bar spacing. It looks at some alternative screen design and management measures to reduce the impact on reservoir water level and overflow capacity.

INTRODUCTION

Screens can fulfil several purposes on a reservoir, the main ones being:

- Trapping of debris which would otherwise present an unacceptable risk of blockage to an overflow, gate or outlet ('debris screens') (Figure 1),
- Reduction of exposure to hazards and hence harm from accidental or intentional entry ('security screens') (Figure 2),
- Prevention of fish / bird / mammal 'wash-out' into an overflow or outlet ('fish or mammal screens') (Figures 3 and 4).

Figure 1. Multi-stage inlet screen to a FSR outlet

Figure 2. Single stage inlet security screen to a reservoir overflow culvert

Figure 3. Fish screen on a reservoir overflow spillway inlet

Figure 4. Mammal screen on inlet channel to an amenity lake

Screens normally consist of vertical or inclined metal bars and may consist of a single or multiple stages.

The screen bars form a permanent blockage to flow resulting in increased headlosses and a 'backwater' effect. In *extremis* they can reduce the pass-forward flow.

Regardless of its purpose, a screen within a reservoir or water carrying conduit will collect debris. Therefore even if its primary purpose is not to trap debris, the impacts of debris causing temporary blockage to the screen must be considered in design. This involves a three-stage process:

(1) Estimate the amount of blockage (either directly as a proportion of screen area, or by first estimating debris load and converting this to an equivalent blocked area),

(2) Estimate the new upstream water level for the required flows, either by:

  a. assuming the blockage is impermeable and acts as a temporary weir (generally most representative for inlet screens), or

  b. assuming the blockage is permeable and the remaining clear area of the screen acts as an orifice (generally most suitable for outlet screens).

(3) If the temporary blockage is substantial (i.e. where the remaining clear area of the screen is less than the opening area of the downstream structure), a check should also be made for potential choking of the flow.

Information on the hydraulic analysis of blockage is available in Benn *et.*(2019), Pavlov (2022) and ICOLD Bulletin 176 (2021). The latter two documents cover the mechanisms of blockage of spillways by large floating debris while the former is more focussed on culvert screens. The available methods to predict potential debris volume fall into one of three categories:

i. Empirical methods based on existing data on flood debris transport;

ii. Evaluation of the upstream catchment for debris sources; and

iii. Evaluation of debris transport in past flood events.

All provide estimates with considerable amounts of uncertainty.

While there has been international research on debris generation and how it accumulates on screens at reservoirs (e.g. USBR, 2016), there has been limited UK research on this topic. The international research focusses mainly on large woody debris under conditions that are likely to apply only to reservoirs with the largest catchments in the UK.

UK-specific research concerns culvert screens in rivers rather than in overflows and conduits at reservoirs. Debris loads are typically dominated by smaller floating debris such as leaves and twigs (typically 60% - 90% of total load by volume). While small debris load generally increases with flow and wind speed, it has a weak correlation with flood return period. A more significant factor is the period of time that has elapsed since the last elevated water levels in the reservoir or contributing watercourses. This suggests that it is the slow accumulation of debris on channel and reservoir margins which is more important than flood magnitude in determining debris sources.

In the context of screens on reservoir outlets and smaller overflows such as seen on flood storage and amenity reservoirs, operational experience tells us that it only requires small debris such as leaves, twigs and litter to result in a temporarily blockage. This is especially so where the clear bar spacing is less than 260mm. Wallerstein and Arthur (2012) showed that a reduction in clear bar spacing from 260 mm to 160mm on a culvert inlet screen led to a threefold increase in trapped debris – nearly all being small floating debris.

All screens require a monitoring and maintenance regime. Without one, their effectiveness, especially for preventing significant blockage, is significantly reduced. However, even the best surveillance and maintenance regimes will not be able to keep a screen completely free of accumulated debris, especially during a flood event.

DEVIL'S BRIDGE POND, SHEFFIELD

This is a privately-owned impounding reservoir constructed in 2010 on Blackburn Brook upstream of the Thorncliffe Business Park in Chapeltown, Sheffield (Figure 5).

It consists of a 7m high, 112m long earth embankment dam along the reservoir's southern edge. Its purpose is to store water during high flow events and hence to provide flood protection to a business park located immediately downstream. It was designed to provide a 150-year return period standard of protection.

Managing Risks for Dams and Reservoirs

The reservoir has a storage capacity of 32,600m^3 when full to the point of spilling (which is a level of 100.6m AOD). Twin Type 1098C Hydro-Brake™ vortex flow control units located in a reinforced concrete chamber (Figure 6) are designed to limit the 'pass forward' flow out of the reservoir via two low-level 1.5m diameter concrete pipe outlets to 5.7m^3/s when the reservoir is full to the point of spilling. The flow of 5.7m^3/s is estimated to be the maximum capacity of the Newton Bank Road culvert which carries the Blackburn Brook beneath the Business Park downstream of the reservoir.

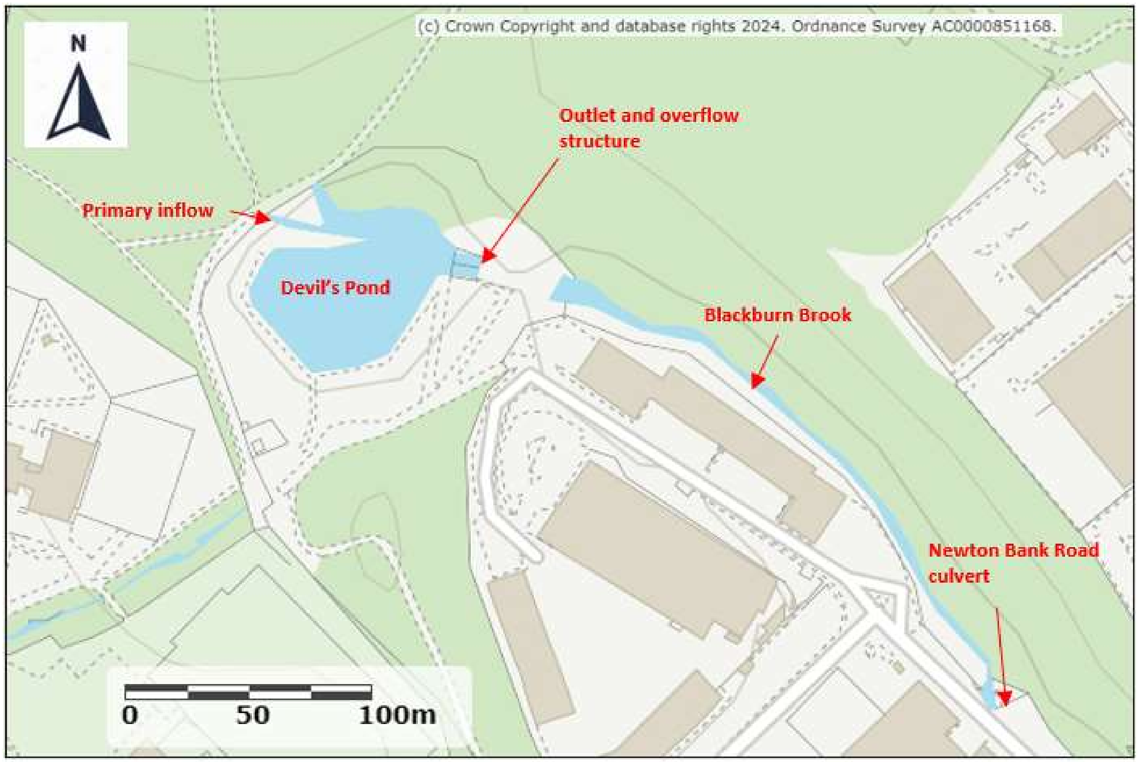

Figure 5. Devil's Bridge Pond

Twin 3.2m high, 200mm clear spacing vertical bar debris screens cover the entry to the twin Hydro-brakes™ (Figure 7). The net effective area (i.e. the area between the bars below the overflow level) is 15 times larger than the inlet area of the Hydro-brakes™. The control structure is also designed to allow easy removal of large debris by means of a concrete invert slab and access ramp.

The original design risk assessment concluded that the hazard to people presented by the twin pipe culverts was low and that it could be mitigated by the security fence around the reservoir perimeter and the site security measures which included CCTV. However a post-construction site-wide public safety audit recommended the addition of 200mm x 180mm 'mesh' security screens to the outlet which were subsequently installed against the Supervising Engineer's advice (Figure 8).

Figure 6. Devil's Bridge Pond – aerial view of the Hydro-brake™ chamber and dam. Note the access ramp leading down to the screen.

Figure 7. Devil's Bridge Pond – debris screens on inlet of the Hydro-brake™ chamber. Note the concrete invert to aid cleaning of the screen.

Figure 8. Devil's Bridge Pond – outlet culverts with security screens open

Figure 9. Devil's Bridge Pond – outlet culverts with security screens closed

Following heavy rain during the 7th and 8th November 2019 the reservoir filled for the first time and the overflow spillway started to operate, discharging the excess flow that could not be passed through the Hydro-Brakes™ and the low-level outlet. The outlet security screens were closed during the event, and because of the high water levels in Blackburn Brook they could not be safely opened (Figure 9).

Following the event the screens, culverts and overflow spillway were inspected. While the inlet debris screens had minimal debris accumulation, the outlet security screens had accumulated small debris (mainly grass) representing a 25% loss of area between the screen bars.

Using the observed rainfall and a hydrological model, the peak inflow to Devil's Bridge Pond was estimated to be 3.5 m^3/s. This had an estimated return period of between 5 and 30 years. This was substantially less than the design 150-year inflow of around 11 m^3/s for the reservoir to fill completely. The modelling shows that if the Hydro-Brakes™ had operated in accordance with the manufacturers rating curve the reservoir level should have peaked at 98.77 mAOD – well below spill level of 100.6 mAOD.

Further analysis using hydraulic modelling showed that the tailwater effect from the partially blocked outlet screens had prevented the Hydro-brakes™ priming fully and they therefore acted as simple fixed orifices. This reduced the average pass forward flow through them by 62% (Figure 10).

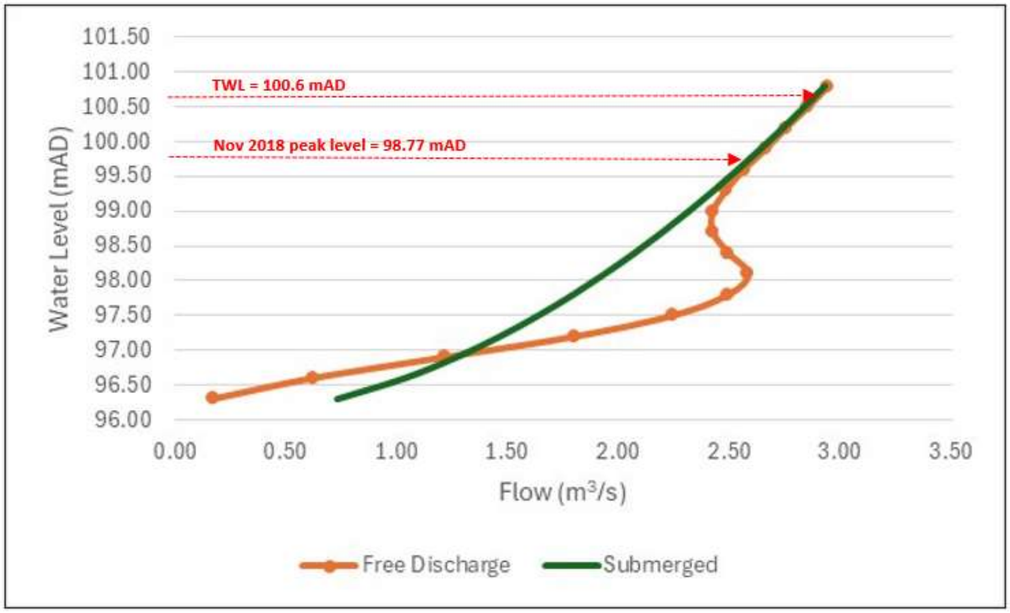

Figure 10. Comparison of Devil's Bridge Pond Hydro-brake™ rating curves under free and submerged outlet conditions (for a single 1098C Hydro-brake™ unit)

Had the design flood event occurred in October 2019 with the security screen closed, the reservoir would not have provided the standard of protection expected, with potentially severe consequences both for public safety and property damage as the flow capacity of the Newton Bank Road Culvert would have been exceeded and the business park would have flooded. The presence of the security screens, even though they are normally open, presents a hazard to the safe operation of the reservoir. This hazard must be balanced against the consequences of unauthorised access to the outlet culverts.

Since the November 2019 event, the outlet screens are now normally left open (or they are opened as soon as the reservoir starts to fill). A further high flow event in October 2023 - which is estimated to have been greater than that seen in 2019 (4.0 m^3/s) - saw the reservoir fill and reach a level of 99.9 mAOD. The reservoir did not spill. The outlet screens were open before and during the event.

POCFAS RESERVOIR, YORKSHIRE

The Pocklington Flood Alleviation Scheme (POCFAS) protects the town of Pocklington in the East Riding of Yorkshire. The main component of the scheme is an 87,000m^3 capacity on-line flood storage reservoir. The reservoir outlet consists of a 1800mm x 1800mm box culvert with an upstream inlet comprising a 1000mm diameter orifice controlled by a self-activating 'Hydroslide®' scissor gate (Figure 11). There is a debris screen just upstream of the scissor gate with 140 mm spacing between the bars. The net effective area of the debris screen is 14 times the orifice area. A security screen was installed at the downstream end of the culvert to prevent unauthorised access. The security screen has a spacing of 100 mm between the bars (Figure 12). The net effective area of the security screen is 0.9 times the culvert area.

The upstream debris screen is designed to be easily cleared using rakes from the access steps and platforms provided. In contrast, the security screen includes no provision for cleaning, although in an emergency the whole gate can be dropped to the horizontal using an emergency release. Once the emergency release is operated there is no easy way to lift the screen back into position.

Figure 11. POCFAS – scissor gate at the 1000mm diameter inlet to the FSR control structure (photo taken from inside the debris screen)

Figure 12. POCFAS – outlet security screen in November 2023

The FSR was completed in 2019 and had its first substantial filling in November 2023. During this event it was noted there was temporary blockage of the inlet and outlet screens from small floating debris of 20% and 40% of the effective area respectively. The resulting headlosses resulted in the impounded water level being 500mm higher than would have occurred if the screens had been completely clear of debris. This represents approximately 12% of the live storage volume. Following the 2023 event the removal of the outlet security screen is being considered based on a risk assessment using the CIRIA C786 manual.

PRIVATE RESERVOIR, NORTHUMBERLAND

This fishing lake is in Northumberland. It is impounded by a 3.5m high homogenous embankment dam. Its catchment area is approximately 6.8km^2 mainly comprising woodland and open moor of moderate gradient. It lies immediately downstream of a much larger reservoir.

Its overflow consists of a 5m wide inlet weir leading into a stepped masonry channel running down the right hand mitre.

Due to concern about the loss of fish and ducklings from the lake, an inclined 15mm clear spacing bar screen was placed by the owner on the inlet extending to the full height of the overflow wing walls (Figure 13).

Figure 13. Fishing Lake in Northumberland - Fish screen on the inlet to the spillway

Figure 14. Fishing Lake in Northumberland – flows during Storm Babet, October 2023

Visual monitoring of the screen over a period of four years has shown that the fish screen is easily blocked with small floating debris and requires regular cleaning with a rake. While raking is possible when the lake is not spilling it becomes more problematic when water levels are higher due to the lack of a safe access platform. It was concluded for flood study purposes that the effective starting reservoir water level should be the top of the fish screen. This showed there was minimal freeboard and even a modest flood rise would result in flow over the dam crest. In October 2023, following heavy rain, the screen did indeed block and acted as a weir. The dam crest was overtopped for most of its length (Figure 14).

Following consultation with a fish and bird ecologist and the Supervising Engineer, a replacement screen has been designed which is half the height of the current one and with a wider 25mm spacing between the bars. This is a compromise between fish and duckling protection and flood risk. To discourage fish movement towards the screen an apron of gravel has been placed in front of the screen.

MAMMAL PASSAGE

In some situations it is important to allow for mammal passage through a screen. Benn *et. al.* (2019) suggests that a 150 mm high gap is left at the base of screens for fish and eel passage (Figure 17).

For aquatic birds, eels and mammals, consideration should be given to the provision of ramps to allow weirs and steep drops to be negotiated (see examples in Figures 15 and 16). They can also replace the need for a ‘fish’ screen in some circumstances. These are best as simple wooden ‘plank’ structures and do not need to be able to withstand floods.

More recent work by the Environment Agency in England (Environment Agency, 2024) has looked at providing for beaver and other mammal passage through screens. The advice from this research is to:

i. Provide a rectangular (letterbox-shaped) opening of any orientation to allow the beaver to flatten out sideways and squeeze through.

ii. Provide an opening size of 200mm by at least 250mm for the comfortable passage of adult beavers.

iii. Avoid square openings unless oversized.

iv. Avoid sharp edges that could cause injury. Exposed bar ends or edges should be rounded.

v. For a screen with 150mm centre-to-centre bar spacing, opening size should be 140mm by at least 300mm - this is the minimum requirement. The screen must have a gap between the toe of the bars and the stream bed, which should be at least 150mm high, larger if this can be achieved without compromising the security function of the screen (e.g. part of the opening is permanently below water).

vi. Any horizontal bar at the toe of the screen must have one or more breaks in (see Figure 18).

Figure 15. 'Duck' ramp installed on an overflow weir as an alternative to a screen

Figure 16. Eel pass installed on a reservoir spillway

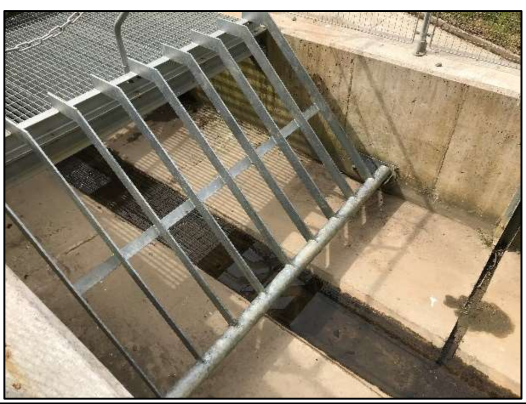

Figure 17. Example detail to allow for mammal, fish and eel passage through a screen

Figure 18. Example detail to allow for beaver through a screen

Beavers of course can cause serious damage to dams and also block overflows through their activities (Brown, 2012).

CONCLUSIONS

Screens have a role to play in reservoir safety, environmental management, and public safety. Drawing on the case studies above and the authors' experience, the following screen 'rules' for reservoirs are suggested to complement the guidance given in CIRIA C786 (Benn *et.al*., 2019), Pavlov (2022) and ICOLD Bulletin 176 (2021):

1. Use of security screens to prevent human entry can lead to enhanced risk of blockage from debris. Other management measures should be used wherever possible.
2. Inlet debris screens should have clear spacing between the bars appropriate to the debris size that could lead to a significant blockage.
3. For any overflow inlet screen with bars of less than 260mm clear spacing an allowance should be made to the design top water level to allow for temporary blockage of the screen. This should typically extend to the equivalent of two-thirds the height of the screen but for screens of less than 0.5 m height this should be the full height of the screen.
4. Screens with clear bar spacing of less than 260mm are very prone to temporary blockage even from small debris such as leaves. If the screen is on the inlet to an overflow, then explicit consideration should be made for this temporary blockage on the stage-discharge relationship.
5. The net effective screen area of an inlet screen on an overflow should be at least seven times the design flood flow area. The screen opening area required will ultimately depend on the consequences of screen blockage and could be higher.
6. Consideration should be given to 'tree pole' primary screens upstream of inlet screens to trap larger floating debris.
7. Inlet screens on overflow / outlet culverts should have a by-pass.
8. Outlet screens are not advised on outlets with vortex control devices. If a screen is used, a check should be made on the impact on hydraulic performance from temporary screen blockage. Any outlet screen should have a means of opening it in anticipation of high flows or if it starts to block with debris.
9. If a security outlet screen is required to an overflow or outlet works, then an inlet screen should also be provided.
10. The clear gap spacing between bars on outlet screens should be no smaller than the bar spacing on inlet screens on the same structure.
11. Design of security screens should consider how the screens will be cleared and maintained under both normal and flood conditions.
12. Fish screens designed to prevent fish/animal 'wash-out' from a reservoir should be no higher than 200mm above normal water level and should be at least 600 mm lower than overflow side walls.
13. Consider 'duck ramps' as an alternative to a screen to prevent bird/mammal injury.

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