The British Dam Society

Re-establishing and Improving Scour Capacity at Daer Reservoir

R McHUGH, Mott MacDonald
M HEWITT, Mott MacDonald
K MURRAY, Scottish Water

SYNOPSIS Daer Reservoir was formed in the 1950s by the construction of a 43m high, 790m long earthfill embankment dam with a concrete corewall.

During the winter of 2021/22 monitoring showed that the water levels in the vertical drains on the downstream side of the corewall were significantly higher than previously recorded and there was increased wetness from the downstream face. A review of the monitoring data found that drainage flows increased significantly once the reservoir was within 2m of the full supply level. Attempts to lower the reservoir using the scour (bottom outlet) pipe found it to be restricted by debris from the valve house that had collapsed in 2005. Following works in 2022 to clear rubble from within the scour pipe, it was found that the 24" needle valve which controls the scour discharge was in poor condition and uneconomical to refurbish.

While the scour was being cleared, a notch was cut in the spillweir to aid control of the reservoir level. During this time, a 24" diameter washout off the supply main was used to control the reservoir level. Due to this frequent operation, the washout valve became damaged. Repair of the valve would have required shutdown of flow to the works.

This paper will briefly outline the investigations and cause of the wet areas and the difficulties and measures taken to control reservoir levels, and the works undertaken to re-establish and improve drawdown capacity. These include replacing (upsizing) the scour needle valve, installing permanent penstock gates within the notch formed in the spillweir, and replacement of the 24" diameter washout off the supply main without interrupting flow to the works.

INTRODUCTION

Introduction

Daer Reservoir is impounded by a 43m high, 790m long earthfill embankment dam with a concrete corewall. It was formed in the 1950s to provide drinking water and currently supplies a population of around 200,000. Construction drawings show that the corewall was formed using 6ft high tongue and groove precast concrete panels as permanent formwork with an in-situ concrete infill. The wall was formed in 24ft wide panels with a central 4" diameter plug of poured bitumen. The corewall is described in more detail in a paper by McHugh et al (2023).

The outlet (Figure 1) comprises a 42" supply main with three draw-offs connecting to a 42" diameter stack pipe in a dry valve tower. The supply main passes through a culvert below the dam before turning and rising over the spillway channel on its way to the adjacent Water Treatment Works (WTW).

There are two washouts off the supply main; a 12" washout at the head of the tunnel controlled by a 24" butterfly and a 12" fixed cone discharge valve, and a 24" washout at the left-hand end of the spillway bridge controlled by a gate valve. There is also a disused 900mm diameter bypass on the right-hand side of the spillway bridge with a 600mm diameter branch at the toe of the dam. This bypass had not been operated in some time and there were few records of this available.

The scour comprises a 36" pipe which is encased in the concrete floor of the culvert with a branch off to a compensation turbine and a branch off to a spill turbine, both located within the turbine building at the downstream end. The compensation flow at the reservoir is discharged through the compensation turbine and, when the reservoir is (or close to) spilling, the spill turbine operates to generate energy from what would have otherwise been wasted water. The scour discharges through a 24" diameter needle valve, the body of which is encased within the concrete foundation of the turbine building.

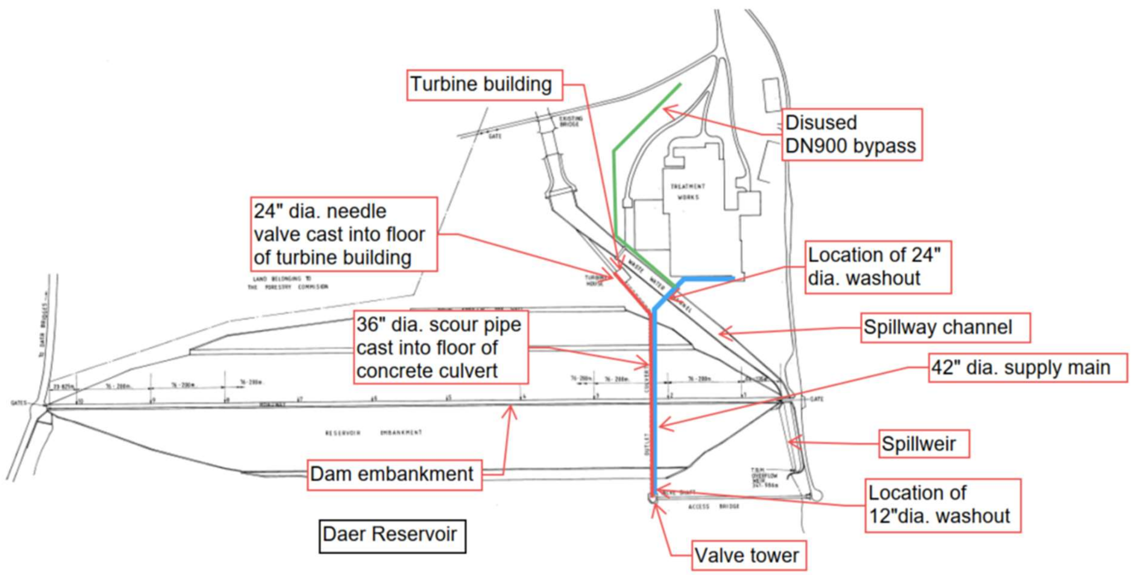

Figure 1. Outlet Pipework at Daer Reservoir

The reservoir has a side channel overflow (Figure 2) which is formed of precast concrete crest blocks on an in-situ base, discharging into a concrete channel down the left-hand mitre of the dam.

Figure 2. Overflow Weir

In the winter of 2021/2022, wet areas were identified on the downstream face of the dam. Given the previous slip at the site, described in a paper by Morrin et al (2016), there was a concern that further slips could occur. The Supervising Engineer monitored the wet areas and observed that, while they did not appear to be getting larger, there was an audible 'popping' sound at them which could indicate flowing water beneath the ground. As a precautionary measure, the water level in the reservoir was lowered until the cause of the wet areas could be investigated. When lowering the water level, the scour ran at full flow for around 24 hours before a sudden and substantial reduction in flow occurred. Subsequent investigations into the reduced scour flow, which included inserting an endoscope from the downstream end of the needle valve, found the upstream end to be restricted by concrete blocks. These were presumed to be from the valve house that had suddenly and catastrophically collapsed in 2005 (Figure 3). Consequently, in order to maintain control of the water level in the reservoir during this time, the Qualified Civil Engineer (QCE) instructed that a notch (approximately 4m wide x 1.5m high) be cut into the overflow weir. Given the catchment area of 47km^2, this was seen as the only viable way of attempting to keep water levels below the level at which there was a noted change in performance, whilst the scour was cleared. Forming a notch also had the benefit of offering the ability to enhance drawdown in the future by the inclusion of penstock gates.

During the time that the scour was non-operational, 24" diameter washout off the supply main was used to control the water level in the reservoir. This more frequent operation resulted in damage to the valve which eventually became inoperable, fortunately after the scour had been cleared.

The attempts to improve core wall drainage and the rehabilitation of the scour pipe was discussed in a paper by McHugh et al (2023) and an update on these items will be provided in this paper, along with a discussion on further drawdown reinstatement works and the installation of remote monitoring devices to provide real time information on the behaviour of the dam.

Figure 3. Valve Tower House Collapse

UPDATE ON REMEDIATION OF WET AREAS

In the winter of 2021/22, Mott MacDonald was instructed by Scottish Water to assist in identifying the cause of the wet areas, and the reduction in scour capacity, and devising a solution. It was concluded that the increased wetness and drain levels that had been observed were largely due to the ever-diminishing capacity of the corewall drains due to infilling by fines, resulting in increased flow of water from the corewall to the downstream face via horizontal pathways to the downstream face. Concentrated flow from a few of the joints were observed, by CCTV survey, at high water levels. It was decided to attempt to restore drainage capacity in the first instance, rather than attempt to stem the leakage from the joints, for example by reaming out and regrouting the bitumen joints, as overall leakage rates were low.

The drain clearance works commenced in May 2022 using a vacuum evacuator with a 3" hose to suck out infill from the drains. For the first few drains, the removed material was sampled, and particle size distribution testing was undertaken. This showed that the infill to the drains was likely to have come from the embankment (most likely the downstream). While using a CCTV unit to undertake the works, the precast concrete half-pipe drains were found to have large gaps in the joints. While probably not part of the original design, this assists drainage from the embankment into the drain but also allows migration of material from the embankment into the drain. Fibreglass patches were installed into the drains which were found to be in very poor condition and were at risk of collapse. The patches were only over a short vertical distance so would not have had a material impact on infiltration rates.

During the clearing works, some larger obstructions were encountered which could not be cleared using the 3" diameter hose of the vacuum evacuator. Some of the drains had the concrete cap from the drain lodged in them at a shallow depth (around 2m) and others had bricks / blocks at greater depths (up to 30m). For the drain covers lodged at shallow depths, the embankment was locally excavated to remove the obstruction by hand. For deeper obstructions, a drilling rig was setup on the crest to break up the obstruction which could then be removed by vacuum excavator.

At the time of writing, all (approx. 100) drains have been worked on and a further five drains remain to be cleared using the drilling rig method. The impact of clearing deeper obstructions in the drains on the water level in drain 23, which is located within the wet area, is shown in Figure 4.

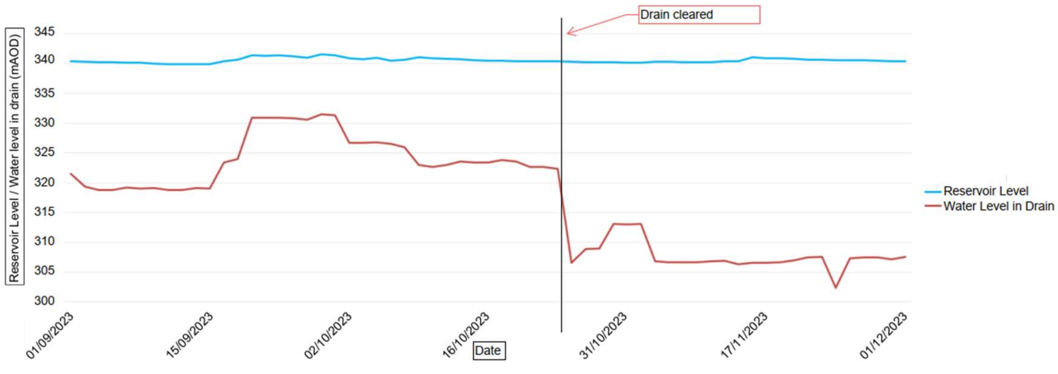

Figure 4. Impact of drain clearing on water level within drain

To avoid the risk of larger obstructions being dropped, or falling, into the drains, new drain covers were installed on all the drains.

After clearing the drains, a clear reduction in the water level in the drains was observed which indicates the works have been successful in restoring drainage capacity. Due to the inoperable scours at the site, the water level in the reservoir has been held in a range of between TWL-1.25m and TWL-1.5m since the drain clearing works were started. The impact of the drain clearing works when the reservoir is at TWL is therefore not yet fully known and will be monitored when the scours are rehabilitated and the reservoir level allowed to return to TWL. A longitudinal section is plotted in Figure 5 showing: the depth to the base of the drain before any clearing works, the depth to the base of the drain after clearing works, and the as-built depth measured from record drawings. This shows the extent of the infilling and the beneficial impact of the drain clearing. The plot was produced ahead of the final stage of drilling works to tackle drains 20, 21, 35, 50, and 70 which is ongoing at the time of writing.

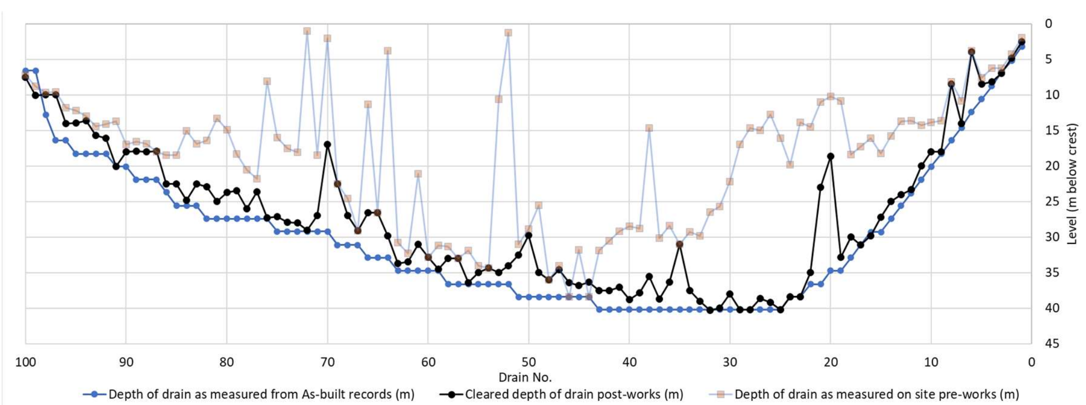

Figure 5. Longitudinal section through dam showing original depth vs cleared depth with as-built depth of drains

SCOUR REHABILITATION

The reduced scour capacity was found to be due to rubble which had fallen into the pipe when the valve tower house suddenly and catastrophically collapsed in 2005 (Figure 3). As discussed in the paper by McHugh et al (2023), the initiating event of the collapse was unidentified; however, poor bed jointing between the pre-cast corbels which resulted in long term over stressing and cracking, coupled with ongoing deterioration due to water ingress and freezing, was attributed as the primary cause of failure.

The rubble was cleared from within the scour pipe in 2023 and, while the pipe was empty, the opportunity was taken to partially dismantle the needle valve and replace seals and re-grease. During the strip down, cracks were noted on the valve internals as well as extensive cavitation damage to the valve body (Figure 6 and 7). The crack is thought to have been caused by rubble impact and the cavitation damage is thought to have been caused by mis-operation with the valve never fully closed, instead remaining at 1% open, outwith the operational range for the valve. There was a risk that this damage could have caused the valve to seize open, which would have prevented the turbines from operating and resulted in issues with providing compensation flows, or seize closed, which would render the scour unusable for drawdown capacity. As the valve is built into the concrete foundation of the turbine building, with restricted access, and is encased in concrete it is unable to be removed and in-situ repairs were not possible (the needle valve in operation is shown in Figure 8). A decision was therefore made to remove and replace the needle valve.

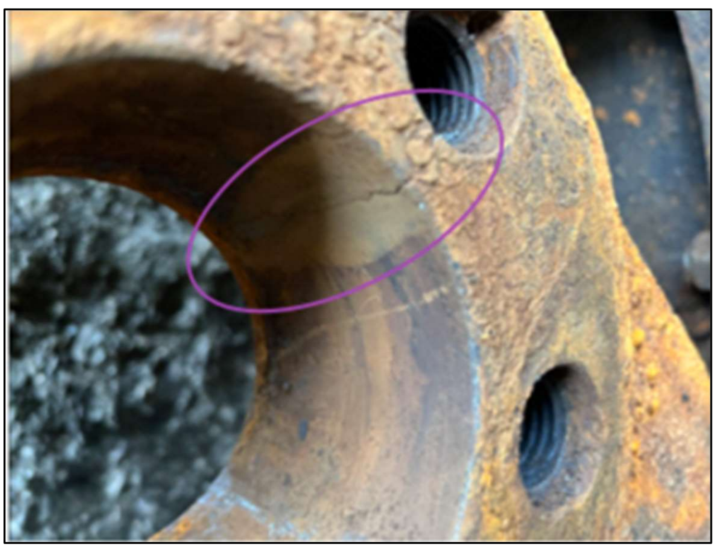

Figure 6. Cracking to valve internals

Figure 7. Cavitation to valve body

Figure 8. Needle Valve in operation in foundation of turbine building

DRAWDOWN ENHANCEMENTS

Drawdown capacity

Prior to undertaking any works, the existing drawdown capacity at Daer Reservoir comprised:

- 36” diameter scour pipe, tapering to 24” dia. needle valve: 4.8m^3/s at TWL
- 12” washout off the supply main: 1.1m^3/s at TWL
- 24” dia. washout off the supply main: 3.4m^3/s at TWL

This provides a total capacity of 9.3m^3/s which, over a reservoir surface area of 2km^2, results in a drawdown rate of 402mm/day. According to Table 6.2 of the Drawdown Guide (EA, 2021), the recommended minimum rate for a Category A earthfill embankment dam greater than 20m height is 1m/day. This is for a reference dam of earthfill embankment with clay core; however, the dam at Daer Reservoir has a concrete corewall which would likely be less susceptible to internal erosion than the reference dam, so a lower drawdown rate was judged as being acceptable. However, due to the size of the reservoir and catchment and known leakage issues, it was considered would be prudent to maximise the drawdown capacity at the site. The solutions to maximise drawdown capacity at the site are discussed in the following sections.

Scour Pipe Upsizing

As the 24” diameter needle valve at the downstream end of the 36” diameter scour line was to be replaced, the possibility of upsizing the valve was investigated. The headloss across the needle valve is relatively high so upsizing the valve has a substantial increase in the capacity of the pipe. The civil works required in replacing the valve are largely the same whether remaining with 24” or upsizing to 36” so the only major increase in cost is for the valve itself. From supplier estimates, the budget price for a 36” valve is around double the price of a 24” valve but this increase in price is relatively low when compared to the overall project budget.

The existing and proposed arrangement of the pipework at the turbine house is shown in Figure 9. The existing 36” scour passes through the back wall of a sump under the floor of the building before tapering to a 900mm diameter spool pipe with two offtakes for the turbines. The existing spool pipe has an integral taper (to 24”) welded as part of the second offtake and connects to the original scour line downstream which discharges through the needle valve cast into the foundation of the turbine building.

In order to upsize the needle valve to 900mm diameter, all in-line pipework on the scour line within the turbine house is to be replaced. From discussions with the turbine installer, the spool pipe was installed ahead of the turbines, and it is not clear if it is able to be removed through the doors of the building with the turbines still in place. The proposed pipework is therefore in two sections to for ease of installation / removal. Even with this increased flexibility, it will be difficult to fully fabricate the pipe offsite to match the angle, length, and orientation of the offtakes. It is, therefore, proposed to offer the pipe up and tack weld the offtakes in-situ before taking the pipe away for final fabrication.

Compensation flow at the site is normally provided through the compensation turbine (fed by the scour line) but when the turbine trips or is offline for maintenance, compensation is currently maintained through the needle valve opening a small amount. To reduce the risk of further cavitation damage to the new fixed cone valve, a DN300 tee off the scour branch for compensation flows is included. This is controlled by a DN300 gate valve (guard) and a DN200 fixed cone valve with hood (duty) with the duty valve automatically opening to a set percentage (to be calibrated onsite) when the turbine trips before tapering back depending on the flows read from a downstream flow meter.

The existing needle valve is to be replaced with a fixed cone valve with hood which directs the discharge flows to within the downstream channel. The new valve is to be installed within the channel downstream of the building to make future maintenance easier. To facilitate this, a new concrete plinth was installed within the channel to provide a support for the valve and act as a working area for the valve removal works.

At the time of writing, the replacement works for the needle valve are due to commence in June 2024.

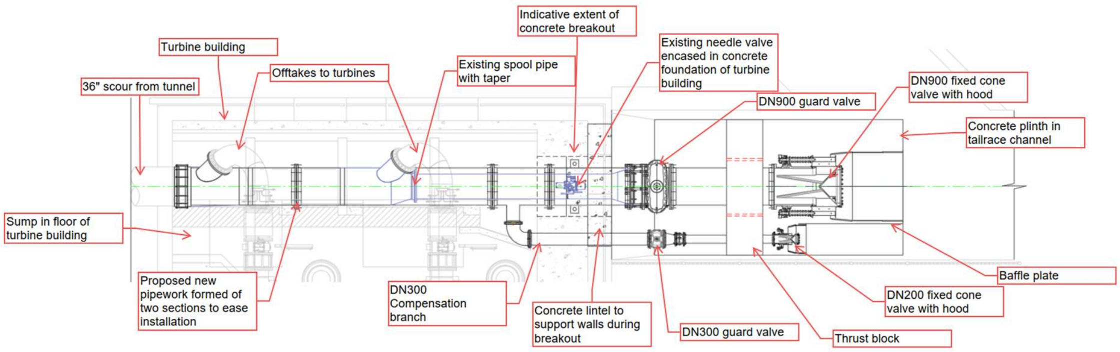

Figure 9. Scour upsizing works

Weir Notch Reinstatement

When the reservoir level is plotted against recorded leakage, there is a step change in the relationship at around TWL-1.5m to TWL-2.0m. Figure 10 shows the leakage measured at the two measuring chambers at the toe (rainfall effects have been removed by only considering data points for which the total rainfall for the previous three days was less than 1mm). This shows a step change in behaviour at around TWL-2.0m. This change is shown at different levels at other monitoring points, hence the range provided. The top 2m of drawdown is therefore key in reducing the leakage through the dam and the installation of penstock gates would be beneficial in reducing the water level in the reservoir to this 2m threshold, or as close to it as possible.

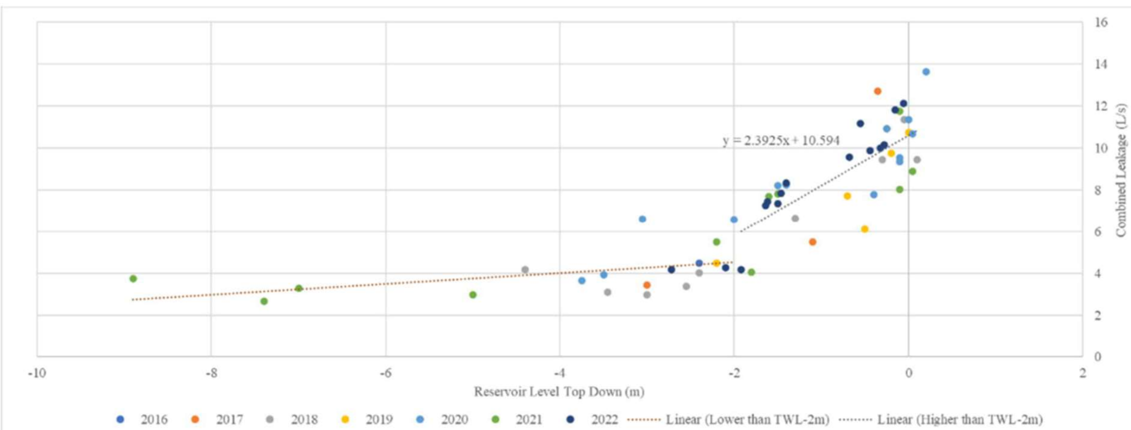

Figure 10. Leakage vs Reservoir Level

In order to maximise the size of the opening and utilise an existing concrete baffle wall to support an access gantry, a new concrete structure was formed upstream of the notch formed in the weir. The penstock gates are to be fixed to the downstream side of the wall with stoplogs (to allow maintenance on the penstocks) installed at the upstream side. There is a removable section of floor at the gantry and a lifting beam to allow the stoplogs to be lowered into position. The gantry is also covered by open mesh fencing to allow operations staff to safely access the gantry during adverse weather, with a section left uncovered to allow the stoplogs to be lifted onto the gantry from the adjacent roadway. Under normal conditions, the penstocks will be operated from a control panel within a new kiosk adjacent to the spillway channel. The supply to this kiosk is backed up by a site generator in the event of a mains power failure and if the onsite generator also fails, the penstocks can be operated by hand from the gantry. The penstock design is shown in Figure 11. At the time of writing, the penstock installation works are due to commence in June 2024.

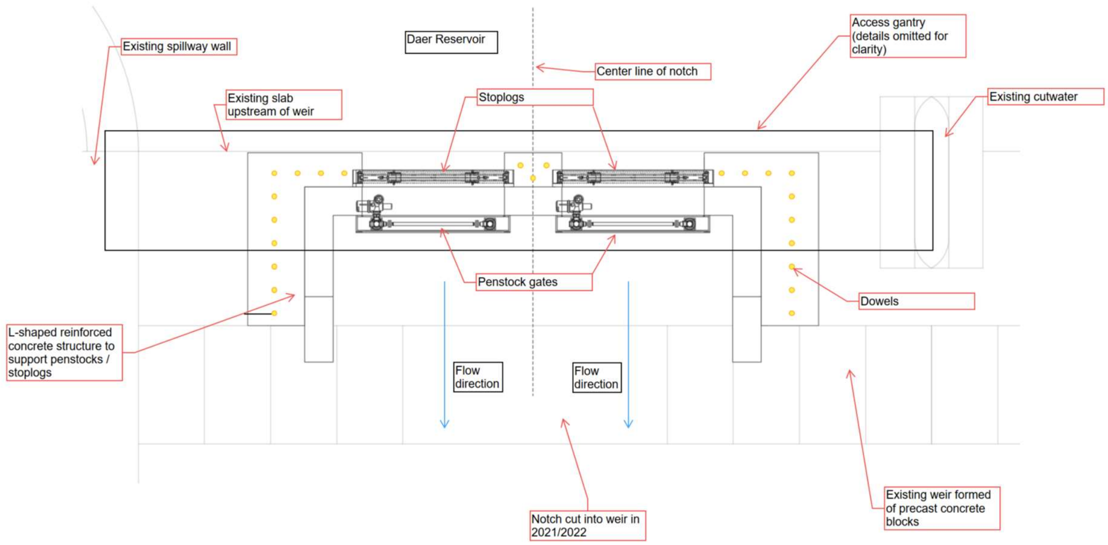

Figure 11. Penstock Design

Washouts off Supply Main

The 24" washout at the spillway channel is controlled by a gate valve which has seized closed and is inoperable but repairable. There is no guard on the 24" washout, so in order to repair the 24" gate valve (and replace the 12" butterfly), the supply main would have to be emptied which would have an impact to the works.

There are two options for the works while emptying the supply main; shutdown the works for the duration of the repair / replace or provide flows by other means (including hot tapping off the supply main). Initially, a shutdown of the works was planned but when the works were detailed it became clear that a number of shutdowns would be required (up to 6 No.) and there were concerns over whether there would be silt / sediment issues when starting up the works again, resulting in water quality issues. This option was therefore discounted in favour of providing flow by alternative means (temporary siphons). Due to the required length of the siphons and the need for contingency in case of breaking down of the siphon priming pumps, they were deemed to be prohibitively expensive.

Around this time, the disused bypass was identified, and investigations were undertaken to ascertain the route of this pipe and its functionality. The pipe was found to be in good condition and the valves on the pipe were found to be operational; therefore it was feasible to use this pipe. A decision was made to modify the bypass to provide additional drawdown at the site which would make up for the loss of the two existing washouts by upsizing the washout at the toe from 600mm diameter to 900mm diameter. At the time of writing, the design of the bypass extension is being developed but is likely to comprise around 50m of DN900 pipework discharging into the spillway channel via an impact style discharge basin.

Summary of Drawdown Enhancement

The proposed alteration works would provide (at TWL):

- 36" diameter scour pipe, discharging through a 900mm diameter needle valve: 5.9m^3/s

- 4m wide x 1.2m deep notch in weir: 9.7m^3/s
- 900mm diameter bypass extension: 5.2m^3/s

The proposed works will increase the drawdown capacity at TWL to 20.7m^3/s (890mm/day). This is an increase in drawdown capacity of 11.4m^3/s (123% increase). The most likely failure scenario is likely to be leakage through the corewall joints overwhelming drainage capacity, saturating the downstream face leading to slope instability and loss of support to the concrete corewall. A critical level in mitigating against this failure mode is TWL-2.0m as this is the level at which leakage through the dam substantially decreases. The installation of the penstock gates provides a high initial discharge, helping to mitigate against this failure mode, with the upsized scours available below this level. Automated remote monitoring would be expected to detect increased drainage rates and levels enabling drawdown.

DRAIN CLEARANCE UPDATE AND REMOTE MONITORING

Remote Monitoring Install

Currently, the monitoring at the site comprises twice weekly (increasing to daily during higher reservoir levels) recording of the water level at 14 of the core drains, recording leakage flow rate in the headwalls at the berm and the left-hand mitre, and recording flow rate in the two chambers at the toe of the dam which collect all leakage and rainfall at the dam. This recording regime places an onerous requirement on operations staff, as well as potential health and safety issues gathering readings in poor weather conditions, so it was decided to install remote monitoring devices at the site to ease this pressure. The remote monitoring devices also send the readings to a web-based platform to allow real time data to be taken at a frequency as desired by Scottish Water, currently 15-minute intervals.

Pressure transducers were installed at 20 of the core drains, selected as those which show a clear link to changes in reservoir level. For measurement of leakage flows, V-notch boxes and ultrasonic sensors were installed at three of the headwalls and at the measuring chambers at the toe. Pressure transducers were also installed at piezometers 17 and 19 which are in the line of the 2013 slip and close to the wet areas previously identified. A raingauge will also be installed with the aim of being able to remove the effects of rainfall on the leakage monitoring model; currently radar rainfall records are used. At the time of writing, the readings from the remote sensors are currently being calibrated against manual reads to ensure continuity. Having the remote sensors in place during the refill will provide real time information on the behaviour of the dam. The output from the sensors is included in Figure 12 and shows the response in the drain to the changes in reservoir level when the reservoir reaches around TWL-1.7m.

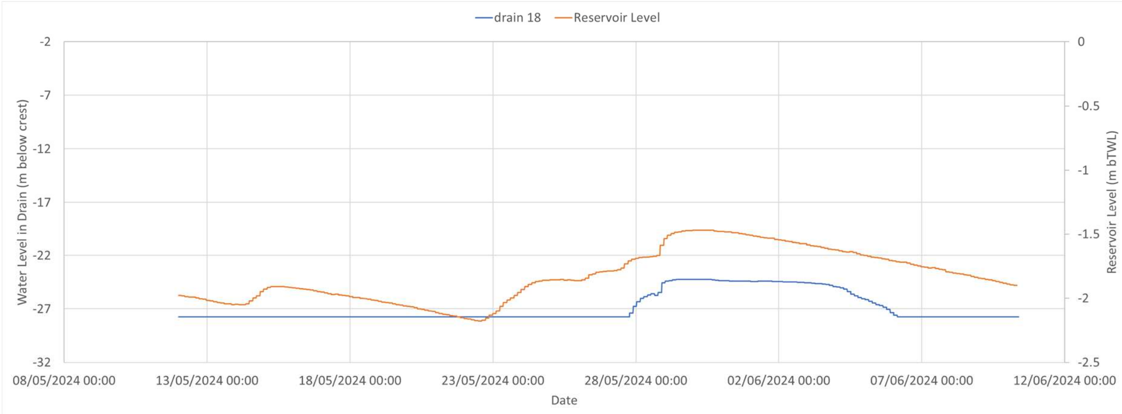

Figure 12. Example Monitoring Plot

DISCUSSION AND FUTURE WORKS

To date, the clearing of the core drains appears to have been successful in reducing the water level in the drains, but the true test will be when the reservoir is returned to a normal operating state (at TWL) over the winter of 2024/2025. Allowing the reservoir to return to the normal operating levels is contingent on the completion of the works to enhance the drawdown capacity at the site.

Having remote monitoring installations in place for the refill and return to normal operation will provide early indications of the dam's behaviour to allow the reservoir to be drawn down again to TWL-1.5m. If leakage rates at TWL are overwhelming the drainage capacity, then works to reduce leakage rates through the corewall may be required. Such works might include investigating those vertical joints that have been seen to be leaking, reaming out the bitumen plug and stemming the leakage by grouting, for example with an acrylic grout. If required, such works will be challenging and likely costly to safeguard water supply quality. Periodic drain clearance will be required unless a means of preventing ingress of fines can be found.

REFERENCES

McHugh R, Hewitt T M and Murray K (2023). Daer Reservoir, UK - Investigation of leakage and works to re-establish drain and scour capacity at a concrete corewall dam. In *Proceedings of the symposium on "Management for Safe Dams" - 91st Annual ICOLD Meeting – Gothenburg.* Swedish Commission on Large Dams, Östersund, Sweden.

EA (2021). *Guide to drawdown capacity for reservoir safety and emergency planning.* Environment Agency, Bristol, UK. Available at: https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/guide-to-drawdown-capacity-for-reservoir-safety-and-emergency-planning (Accessed 6 July 2024)

Morrin R, Sullivan M, MacDonald A and Holt C (2016). An Investigation and Assessment of Embankment Stability at Daer Reservoir. In *Dams – Benefits and Disbenefits; Assets or Liabilities. Proceedings of the 19th British Dam Society Conference* (Pepper A (Ed.)). ICE Publishing, London, UK pp 125-137