The British Dam Society

Multiple Types of Spillway Installation/Refurbishment in Wales (Ten years of experience)

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SYNOPSIS Over the last decade Natural Resources Wales (NRW) has undertaken design and construction of a number of new spillways (and drawdown facilities) as well as refurbishment of numerous existing structures. This has included works at several new and existing flood storage reservoirs, but also a large number of historic reservoirs brought within the Reservoirs Act 1975 by the changes in registration capacity implemented within Wales from 2016.

With a portfolio of newly registered reservoirs, a full programme of investigation works, studies and evaluations was undertaken to determine the risks associated with the different dam structures and subsequent mitigation works required. The range of spillways has included conventional concrete spillways, Armorloc, Armorflex, Dycel, Grasscrete, Reno mattress/gabion, overtopping crest design and a labyrinth weir.

This paper will discuss the design and construction of these different spillway types and their relative merits for the specific locations; design factors affecting the choice of spillways; and issues and difficulties encountered (and overcome) during construction. It also considers the lessons learnt during the process, subsequent operational performance and a commentary on the appropriateness of selecting and implementing various spillway types for a range of sites.

INTRODUCTION & HISTORY

On the 1st April 2016 in Wales, the Minister for Natural Resources approved amendments to the Reservoirs Act 1975 (HMG, 1975) and its regulations, enacted from the recommendations made by Sir Michael Pitt following extensive flooding in 2007, updating Schedule 4 of the Flood and Water Management Act 2010 (HMG, 2010). This brought the inclusion of reservoirs >10,000m^3 capacity into the Act, from the previous capacity of >25,000m^3. The steps taken by Welsh Government to amend the regulations are a reaffirmation that reservoirs hold a public safety risk which justifies its own primary legislation.

From its inception in 2013, with one eye on the impending amendments, NRW had identified 74 potential reservoirs in its ownership or management. Following the assessment of these bodies of water, 45 sites were confirmed as reservoir with a capacity greater than 10,000m³, and in fact 19 sites had a capacity over 25,000m³ and had to be registered immediately.

As part of this assessment and planning work for the 2016 capacity changes, reservoir inspections at the sites highlighted that many of the historic reservoir structures were in a dilapidated state. Many were historic mining reservoirs and had been devoid of any maintenance since their abandonment in the early 20thC (Shaw et al, 2021). Their existing spillway structures were either badly eroded with insufficient capacity, or entirely failed, with water flowing through unprotected breaches. Immediate intervention, under QCE guidance, was therefore often necessary to safeguard the reservoir and prevent further damage to the spillway structure.

The most effective and efficient method of temporarily protecting the existing spillways from further erosion damage was often utilising a combination of heavy duty plastic sheeting and sandbags or concrete filled bags. The spillway channel (or breached locations) would be cleared of any obstructions or sharp objects, with the plastic sheeting then laid within the channel and sides. Rows of sandbags or concrete filled bags would then be placed on the sides of the spillway channel, to weigh down and secure the plastic sheets as well providing further erosion protection to the sides of the spillways (Figures 1 and 2). Often sandbags were also employed on the crest of these dams to afford the required freeboard.

These temporary arrangements would be frequently checked by NRW's Reservoir Keepers, as well as the Supervising Engineers during their 6-monthly visits, with any damage or deterioration immediately reported to NRW's in-house Operations Teams, whereby prompt remedial works were undertaken. Many of these temporary arrangements were in place for several years whilst the permanent MIOS works were being planned and designed. They generally proved very effective in safeguarding the reservoir and prolonging the life of the existing spillways until new, robust and permanent spillways were provided.

Figure 1. Temporary repairs at Tynymynydd.

Figure 2. Temporary repairs at Pandora.

Following a risk-based approach NRW has implemented a program of work over the past 11 years to undertake essential safety works generally under Measures in the Interests of safety (MIOS) to address these issues.

TYPES OF RESERVOIRS

The NRW reservoir stock is varied in terms of purpose (Morris et al, 2018) and includes:

- Flood storage – Legacy Environment Agency Wales Reservoirs
- Conservation, habitat creation & water level management – Legacy Countryside Council for Wales

- General amenity – Legacy Forestry Commission Wales*
- Historical and heritage structures – Legacy Forestry Commission Wales*
- Water supply – Legacy Forestry Commission Wales*

* Reservoirs on the FCW estate are mostly structures left over from the mining industry (mainly lead) which operated between 1830 - 1905 with the exception of some sites which reprocessed tailings up to 1960. It is also worth noting that these sites, with little intervention over the last century, have become important habitat and are generally designated.

MIOS DEADLINES

The primary driver on NRW reservoirs requiring work over the last ten years has been MIOS requirements. The large number of reservoirs registered at one time (2014/15/16), increasing the portfolio from 11 to 41, led to the requirement for numerous Section 10 inspections (or Section 8 inspections if constructed after 1930 with no final certificate issued) within 12 months of the Final Risk Designation.

Predominately, MIOS from this initial round of inspections included the completion of topographic and bathymetric surveys, vegetation clearance, flood studies and inundation mapping. These studies subsequently established the correct category of the reservoirs and established the spillway capacity requirements, which were generally inadequate for the reservoirs not previously registered – indicating their original designs do not meet modern standards.

Table 1 provides a summary of NRW reservoirs. Each site has differences in terms of existing features present (such as spillways and outlet structures), the condition of embankments and the environmental/ location factors specific to the sites. It should be noted that these all are impounding with the exception of Pen y Gwaith, which is spring fed.

Table 1. Key details and spillway types of Natural Resources Wales' statutory reservoirs

Dam	Cat[a]	Purpose	Type	Date	H[b] (m)	Capacity (m^3)	Existing Spillway	New/Refurb Spillway
Afon Wydden	A	FSR	HD	1995	5	29,000	Reno Mat.	Refurb
Bwlch Nant yr Arian	A	Rec.	HD	1995	3	28,530	Armco Pipe	RC inc. Drawoff
Cowbridge	A	FSR	HD	2006	4.4	989,000	Sleepers/ Armorloc	Refurb
Cyfty	B	Mg/WS	MY	19C	6	13,600	Masonry	Concrete + rip rap
Goddionduon	C	WS	HD	1900	1.5	60,000	Masonry	Labyrinth inc. Drawoff
Llaeron	NA	Mg	Pen.	19C	20	450,000	Breached	N/A
Llyn Lleywelyn	B	Folly	MY	1850	4	14,200	Concrete	RC Multistage
Llyn yr Wyth Eidion	NA	Habitat	HD	1994	1.2	36,000	Reno Mat.	Refurb / Fishpass

Dam	Cat[a]	Purpose	Type	Date	H[b] (m)	Capacity (m^3)	Existing Spillway	New/Refurb Spillway
Llyn Fuches Las	B	Mg/FSR	HD	19C	3-4	11,110	Masonry	TBC
Llyn y Parc	A	Mg	CG	19C	3-4	49,445	Breach	Concrete
Lower Hendre Ddu	NA	Mg	RF	19C	5	39,000	Masonry Culvert	Gabion Basket
New Pool	A	Rec	HD	19C	14	44,500	Breached	TBC
Pandora	B	Mg	MY	19C	3	10,000	Breached	RC
Pen y Gwaith	B	Mg/WS	MY	19C	3	12,500	Rock	RC
Pont y Cerbyd	A	FSR	HD	1990	1.7	30,500	Armorloc	Armorflex
Pontarddulais[c]	A	FSR	HD	2014	9.3	170,000	N/A	Grasscrete
Prince Llewelyn	NA	Mg	MY	19C	6	4,500	Masonry	Masonry
Pysgodlyn	B	WS/Rec	CG	1870	1.7	17,630	Concrete	Refurb / Armorloc
Ratcoed	NA	Mg	HD	19C	8	90,000	Breached	N/A
Rhiw Bach Quarry	NA	Mg	RF	1930	3	26,000	Breached	N/A
Tynymynydd	B	Mg/WS	HD	19C	1.5	46,000	Breached	Concrete / Dycel
Llyn Tegid	A	FSR	HD	17C/ 20C	3-4	21.8Mm^3	Concrete Weir	Overflow / Grass

[a]Category (ICE, 2015); [b]Height (of dam); [c]Still under Construction Engineer.

Purpose: FSR – flood storage Reservoir, Rec. – Recreational, Mg – Mining, WS – Water Supply.

Type: CG – concrete/masonry gravity, CB – concrete buttress, ME – modern embankment, PE– Pennine embankment, HD –homogeneous dam, RF – rockfill dam, SR – service reservoir, MY – Masonry with peat core.

FUNDING

Funding was a major issue for the projects. NRW funding is limited and has to be prioritised accordingly. The number of reservoir sites and the significant MIOS requirements coming from the S10 inspections led to more than 150 MIOS deadlines within a three-year period. Some of these related to studies, but increasingly these then led to substantial works, such as the requirement for new or upsized spillways, drawdown facilities or freeboard generation.

The schemes that have been delivered have cost £25m+, ranging from £150k (simple, formal discontinuance) up to £7m for large overtopping sites (Llyn Tegid) (Figure 8), although those with new spillways and associated works such as new berms, have typically cost £0.5m-£1.5m. Timelapse videos of some of the construction can be found here:

- https://naturalresources.wales/about-us/what-we-do/our-projects/reservoir-safety-projects/gwydir-reservoirs/?lang=en

- https://naturalresources.wales/about-us/what-we-do/our-projects/reservoir-safety-projects/llyn-tegid-gwynedd/?lang=en

DESIGN

In terms of the design works undertaken at the sites there have been three primary focuses:

1. clarification of the dam category via inundation modelling,
2. the provision of a spillway capable of meeting the design flood conditions, as set out in *Floods and Reservoirs 4th Edition* (ICE, 2015), relative to the dam category,
3. ensuring suitable drawdown arrangements are in place to meet the Guide to drawdown capacity for reservoir safety and emergency planning, (EA, 2017).

These have formed the crux of safety works but NRW has also undertaken other significant improvement works at some of the sites, including improved public and operational access, H&S improvements, leakage reduction, improved drainage, dam raising, stability berms, gravity shoulders and wave protection.

Hydraulics

The reservoirs within the NRW portfolio range from Category A to Category D (ICE, 2015). Those which have had work completed within the last 10 years are typically Category A (primarily flood storage reservoirs) or Category B. Typically smaller historic mining dams have a Category B designation due to the limited numbers of properties present downstream and the smaller capacities of the reservoirs. These typically required new or formalised spillways, such as at Pen y Gwaith and Pandora (both Category B). The spillway selection was driven by a number of factors:

- Calculation of the flows and associated velocities, for which CIRIA Report 116 (CIRIA, 1987) was used (Figure 3), and freeboard requirements, for which Floods and Reservoir Safety 4th edition (ICE, 2015) was used.
- Sensitivity analysis was also used to determine whether it was appropriate to reduce dam raising (conventional weir vs labyrinth weir).
- Space available for the weir(s)
- Ground conditions and other mitigating factors such as environmental aspects.

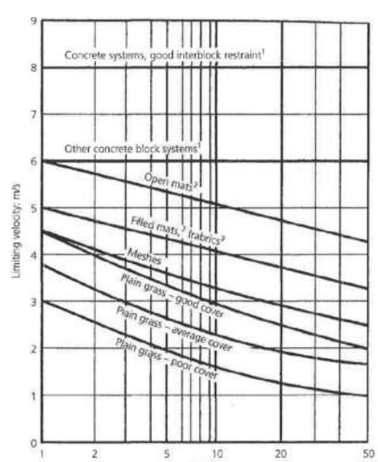

Figure 3. Recommended limited values for erosion resistance. Chart from CIRIA (1987).

Managing Risks for Dams and Reservoirs

The spillway types selected can be broken down into the following basic types:

- Small reinforced concrete broad crested weirs – used at Pen y Gwaith and Pandora.
- Overtopping – used flood storage reservoirs such at Pont y Cerbyd, where the majority of the embankment acts as the spillway.
- Labyrinth weirs (reinforced concrete) – Goddionduon water supply reservoir (Figure 4).
- Multistage – Llyn Llewelyn (Figure 5), and locations where auxiliary weirs have been designed to cater for lower flows, make best use of space, or for fisheries purposes.

Figure 4. Llyn Goddionduon RC Labyrinth weir incorporating drawoff.

Figure 5. Llyn Llewelyn RC multistage weir, incorporating drawoff.

Examples*: Pen y Gwaith (Figure 6) and Pandora (Figure 7) reservoirs, both Category B. Design requirement for the spillways of 1 in 1000yr, safety check flood of 1 in 10,000yr. Similar events with 2.5hr duration, 122mm rainfall for Pen y Gwaith and 3.5hr, 116mm for Pandora. Peak flows vary with Pen y Gwaith 1.3m^3/s for the safety check flood but Pandora 5.6m^3/s. Both have spillways designed as broad crested weirs as using $Q=Cd\sqrt{g}\, b\, H^{1.5}$, with the coefficient of discharge, $Cd = 0.544$.*

Figures 6 & 7. Pen y Gwaith & Pandora RC broad crested weirs.

Figure 8. Llyn Tegid Overtopping embankment using reinforced grass.

Geotechnical Factors

Wherever possible, with the exception of flood storage, spillways have been located on the mitres of the dam, and therefore usually within competent rock. This has a number of distinct advantages, as the rock can be used to form part of the spillway, and less material is required for the spillway structure, reducing the amount of concrete required, associated transport, costs and knock on reduced carbon benefits.

***Example**: Cyfty (Category B) – the spillway was located on the right-hand mitre in rock, with a concrete beam forming the spillweir and additional rip rap in channel downstream*.

Space

The available space for any new spillway or drawoff works has been a key factor in terms of the design. With the flood storage reservoirs, it is typically the whole length of the dam that has acts as the spillway for design events. This reduces the depth and velocity over the spillway and hence allows a lower specification selection of erosion resistance. These can provide a better aesthetic, looking more like a natural bank due to the grass cover. Where space is at a premium, or the embankment itself is short in length, the driving factor may be to generate sufficient freeboard. In this instance labyrinth weirs can be considered, generating a lower water level compared to a broad crested dam, due to the additional weir length generated. These can also be seen as quite attractive structures, more interesting than a standard weir.

Example: *Llyn Goddionduon (Category C) where the dam was very short in length due to the fact it was a raised natural lake and achieving a suitable freeboard to meet the 1 in 1000 yr design event was the primary driver. The labyrinth weir at the site (Figure 4) allows this to be achieved, with a total weir length of 7m, but an overall spillway width of just 4.88m.*

Heritage and Aesthetics

Wherever possible, the selection of spillways has tried to take account of the surrounding environment and associated aesthetics. In addition, many sites are historic and have heritage value.

***Example:** At Prince Llewelyn masonry was used (Figure 12), in keeping with the historic structure.*

Environmental SSSI impacts, approvals and licences

All required licencing and approvals was undertaken, with enhancements made wherever possible. As most sites were designated, it was imperative not to cause any unnecessary disturbance during the works.

***Example:** Prince Llewelyn – non-native fish were rescued and relocated in a pond on Anglesey.*

SMNR/Wellbeing Wales

We had to comply with The Well-being of Future Generations Act (Wales) 2015 (HMG, 2015) on all schemes. Therefore, consideration is given to all users, for example by incorporating improved access.

Drawdown – incorporation of facilities

One interesting aspect on the historical mining sites was that they typically lacked any form of usable outlet. It was clear that historically they had had outlets to leats or downstream streams but that these had ceased to operate long ago, although in some cases indications were still visible (e.g. timber posts sticking up out of the water). Therefore new drawdown facilities had to be provided. Factors that affected the design of the drawdowns were:

- Location – the point at which the drawoff would be most effective, ideally the lowest point in the reservoir.

- Whether a new spillway was also required and its location – could the drawoff be incorporated to save space and construction costs.
- Access for operational staff to allow them to operate the penstock.
- Upstream control was preferred.

At several sites which incorporated drawdown facilities into the spillway structure, sustainably sourced oak footbridges, supplied by a local company based in Llanrwst, North Wales, were installed. These provide safe access to operate the drawdown facility, as well as enhancing the aesthetics of the structures and ensuring continuation of the dam crest footpaths.

Spillway Materials

The following materials have been used on spillways across the NRW portfolio:

- Reinforced concrete – insitu construction
- Grasscrete – insitu construction (Figure 9)
- Armorloc – precast units brought to site and assembled.
- Armorflex / Dycell – precast units brought to site and assembled (Figures 10 and 13)
- Reno mattress/gabion – assembled on site (Figure 11).
- Overtopping crest design – using some form of reinforced grass.

SPILLWAYS INSTALLED

Figure 9. Pontarddulais, Grasscrete.

Figure 10. Pont y Cerbyd, Armorflex.

Figure 11. Afon Wydden, Reno Mattress

Figure 12. Prince Llewelyn, Masonry.

Dam	Cat	New Weir Construction	Drawoff incorporated	Cut offs	Design	Details	Construction Issues
Bwlch Nant y Arian	A	RC Concrete and rip rap downstream	A low level 400w x 600h penstock, incorporated into main spillway design via low level channel.	Base slab cast onto concrete blinding/rock, small cutoff/toe upstream (300mm). Sloped RC concrete side wall (300mm wide).	Peak inflow 5.5m3/s (winter PMF), peak outflow 1.98m3/s. Velocity 2.1m/s to 5.4m/s along the spillway channel. Q=Cd √g b H1.5, Cd= 1.7.	2.5m long weir, 1.87m high,14.3m wide channel. 10.5m long rock mattresses at the end of the spillway channel providing protection from hydraulic jump. RC 300mm thick, sloped side walls.	Poor access, retarder used in concrete, coffer dam installed, good rock. Existing spillway/outlet (Armco pipe) remained flowing during the works before it was removed and infilled accordingly.
Goddionduon	C	RC Concrete and rip rap downstream	A low level 450w x 350h penstock, incorporated into main spillway design.	500mm deep 300mm wide RC cut off in base slab. Sloped RC concrete side wall on sides to spillway.	Peak inflow 4.89m3/s (1 in 10000), peak outflow 3.72m3/s.	Total length of Labyrinth weir 7m long, overall spillway width 4.88m, channel 8m. Rip rap protection extending 8m downstream and 500mm thick.	Steep and narrow access within forest, original contractor going into administration – 6 month delay.
Llyn Llewelyn	B	Concrete - multistage weir	A low level 400w x 400h penstock, incorporated into main spillway design.	Sloped cut off wall on sides to spillway. 300mm RC cut off in base concrete into mass concrete plug under spillway (2m).	14.49m3/s (10,000yr safety check), velocity 1.8m/s, Q=Cd L H1.5, Cd= 1.7. 1D Flood Modeller Pro up to 1 in 1000.	7.8m long weirs (high level 4m and low level 3.8m) and 11.7m channel (with rip rap on both upstream and Downstream).	Extreme weather – heavy rainfall events (difficultly drawing down the reservoir and controlling flows) followed by high temperatures (concrete pours/surface).
Llyn Tegid	A	Overflow Weir/ Reinforced Grass	Separate - Existing river gates	N/A	Embankment overtops in design events discharge 0.26m3/s / m up to 0.6m3/s /m. Velocity 2.2-3.4m/s (10,000yr), 3-3.9m/s (PMF).	Rip rap on upstream face, asphalt footpath crest, downstream slope (1500m) protection with 3D geotextile membrane (C350 Vmax). Protection extend over berms, or otherwise ~ 2m beyond existing embankment toe line.	Removal of trees from existing embankment. Reuse of existing riprap. Keeping rabbits under control while the fresh grass established.
Pandora	B	Concrete - broad crested (sensitivity analysis for labyrinth weir to check dam raising).	A low level 300w x 300h penstock, incorporated into main spillway design.	Sloping outside side walls to spillway. Mass concrete base onto rock.	5.6m3/s (10,000yr), velocity 1.12m/s, Q=Cd √g b H1.5, Cd= 0.544 (value for streamlined broad crested)	Simplistic 3.5m long RC weir, 2.3m high, 12.1m channel, positioned next to road for access purposes. Masonry chute 10m long downstream of spillway.	Greater depth of silt than anticipated, piled coffer dam for lower section. Concrete infill to the rockhead below the new spillway. Spillway central location.
Pont y Cerbyd	A	Armorflex	Separate 1.5m x 1.2m culvert through embankment (left hand side of new spillway).	N/A Crest beam with Armorflex.	125.8m3/s inflow (PMF), velocity 7.5m/s, Cd = 1.5.	51m long RC crest beam (0.7mx0.4m), 20 wide spillway channel, 1.8m high redi-rock wing walls. Armorflex laid panels downstream, extended beyond toe of embankment. Downstream slope 1V:5.5H.	Winter working – reservoir impoundments and spillway operating during construction, with only 50% of spillway crest available whilst other 50% was being worked on.
Pontarddulais	A	Grasscrete, stilling basin downstream.	1.52m x 2,25m culvert under spillway (discharging into stilling basin).	Foundation down to formation level clay.	111.78m3/s (Summer PMF) spillway discharge (assuming culvert blocked), velocity 7.88m/s.	50m long grasscrete , ~60m wide (crest far side of stilling basin) with 1.86m high wing walls at highest point on crest. 1V:4.5H downstream slope and stilling basin.	Some issues around placement of clay and installation of grasscrete.
Tynymynydd	A	Concrete weir and Dycel sides, rip rap downstream.	N/A	2 RC concrete walls with Dycel in between, with compacted clay underneath.	17.79m3/s inflow (Summer PMF), velovity 7.5m/s, Cd = 1.7.	RC crest beam in spillway channel (length 10m, width 3.8m), flanked by Dycel access ramps on both sides leading to rip-rap lined downstream channel	Dam with peat core. 2020 Covid Pandemic – contactor demob during first lockdown.

Figure 13. Tynymynydd, Concrete/Dycel.

Figure 14. Bwlch, reinforced concrete spillway including drawoff.

CONSTRUCTION ISSUES

Access

One of the most significant problems on NRW sites has been access. Many locations are remote and within Sites of Special Scientific Interest (SSSIs) or other designated areas; it has therefore taken time to obtain permissions/licences to improve access.

Example: *Rhiw Bach Quarry discontinuance - no access available to the site other than through bogs, a forestry coup with no access or historically important heritage site. This reservoir was discontinued with helicopters used to bring materials to site and the new outlet channel constructed by creating a notch in the embankment and leaving it to naturalise.*

Ground Conditions

Ground investigation works can only ever give an indication of anticipated ground conditions. It is not uncommon to find different, challenging, foundation conditions that have to be allowed for on site.

Example: *At Pandora reservoir (Figure 15) there was greater depth of silt than anticipated. This resulted in concrete infill to rockhead below the new spillway. In addition, it had been anticipated that the rock would be weathered and fractured, therefore permeable, in the location of the berm. More intact rock was encountered, with no such fracturing, suggesting low permeability. A slope stability indicated this could give rise to excess water pressures within the clay, leading to failures at the toe of the slope. Therefore a zone of higher permeability material (crushed slate) was installed, connecting to the toe drain.*

Concrete setting times

With some of the other remote sites extended concrete batching to placement times were also an issue.

Example: *Bwlch Nant yr Arian (Figure 14) - Concrete for the spillway had to be offloaded from delivery wagons and then transported in smaller vehicles down a hillside for subsequent installation. A retardant was used to ensure the concrete did not go off before it was placed.*

Inundation

The time at which a new spillway is at highest risk of failure is during construction and initial operation, therefore careful consideration was always given to emergency planning and temporary protection.

Example: *At Cyfty reservoir (Figure 16) even though 80% of the inflow was diverted and the reservoir was drawn down, significant rainfall events led to inundation of the works.*

Figure 15. Pandora rock foundation.

Figure 16. Cyfty spillway inundation.

Aesthetics

Wherever possible the selection of spillways has been designed to take account of the surrounding environment and associated aesthetics but sometimes there are issues with delivering the desired result.

Example: *Pen y Gwaith - Exposed aggregate finish was hampered due to hot weather at the time of pour, adversely impacting the effectiveness of the surface retarder product. Scabbling and some hydro-demolition was needed achieve the desired finish.*

Fish spawning

The fish spawning season can significantly impact construction programmes and restrict working periods.

Example*: Llyn yr Wyth Eidion – Spawning meant that works associated with a fishpass could not be completed in one season, with the contractor having to pull off site and come back to undertake spillway/embankment gabion basked repair works 6 months later.*

Temporary Works

Reservoir drawdowns, flow diversion, siphons and coffer dams were required to assist in the construction of the various spillways. Access routes, cost and constructability were all considered during the selection design.

OPERATIONAL PERFORMANCE

As spillways continue to be improved or replaced NRW has the opportunity to evaluate the success of the installations. To date the structures have performed well, but some operational consequences have been identified which will be taken into account for subsequent projects:

1. Where open mat concrete systems have been installed and spillways have operated before grass has established, material has been lost with subsequent reinstatements required, or even more significant action such concrete infilling.

Managing Risks for Dams and Reservoirs

2. In recent years, the frequency of spillways operating has increased, due to more frequent and higher intensity storms, resulting in more operational time/cost.
3. On flood storage reservoirs where embankments have been lowered to provide an uncontrolled washland incorporating a barrier bank, reinforced turf has been used. Although this met the specification in terms of flow/velocity and inundation time, little consideration was given to land use. Livestock was introduced to some embankments, leading to damage over a short space of time and exacerbated during a flood event. Consideration to different products is needed for a spillway is subject to other uses.
4. Operations and maintenance – NRW has instigated a regular (monthly) Reservoir Keepers' forum to spread experience across the portfolio of reservoirs. This has been crucial in discussing issues such as seepage, monitoring equipment being installed (V notches, crest pins, CCTV, telemetry), and also maintenance equipment such various grass cutting machinery. It has fed back into design in terms of preferences of different of slopes, access methods (steps vs pathways), valve/penstocks, handle arrangements and operational effectiveness of spillway types (during floods). As an example, ropes are being incorporated into some spillway designs to facilitate S12 inspections.

LESSONS LEARNT

The programme of reservoir works undertaken since 2014 is a continuous process, with priorities set by risk level. This has allowed lessons learnt to be applied across design, construction and operations and simplified procurement routes. The first capital scheme from new registrations was Cyfty reservoir, which took six years, finishing in 2021. Therefore it has now been operational for three years. Some lessons learnt across the portfolio include:

- Procurement – during the 11-year period of works, NRW consultancy and contractor frameworks changed from a mini competition to direct award with two designers and four contractors. The benefits of this have been a continuity in design and construction teams, moving from one reservoir project to the next, with lessons from one applied to another.
- Early Contractor and Designer Engagement with QCE – A decision was made to allow the designer and contractor who undertake the scheme to attend S10 inspections. This allowed them to understand likely MIOS requirements, and afforded the opportunity for them to discuss solutions and any potential issues (access, plant, locations).
- Annual Lessons Learnt Workshops – A two-day annual lessons learnt workshop was held with designers, contractors, site supervisors, as well as Project Managers, Project Executives and commercial teams. Within this workshops, overviews of schemes would be presented, lessons shared or issues highlighted and discussed, with common themes identified, potential improvement listed and actions with timescales allocated to implement them across the portfolio.
- Enabling Works – A decision was made early on in some projects, that to assist the main construction works, it was beneficial to undertake enabling works to improve access. Due to work within SSSIs and other designations, approvals could take a significant amount of time. As such, separating the access works from the main contract whilst design of the main works was being undertaken saved significant time relative to the MIOS deadlines.

- Legacy Dams – Due to the extensive number of legacy dams encountered, unusual conditions have been found throughout (peat cores, old outlets, unusual foundations) and had to be resolved on site. Frequently old maps from 1880 indicated a sluice present, but none were visible or found by divers. Upon draining the reservoirs, old buried cast iron outlet pipes of unusual size or wooden culverts were found. These had to be removed/grouted or sealed in some way. These typically linked to seepage locations previously observed.
- Designations – The majority of sites received a provisional High Risk designation from the Enforcement Authority; in some instances this was challenged and studies undertaken to provide greater detail with respect to reservoir details and downstream implications should they fail. By undertaking various studies and detailed inundation modelling it was possible to provide sufficient information to a QCE to advise that a Not High Risk designation was applicable. This evidence was presented to the Enforcement Authority and subsequently, following review, several sites were amended to Not High Risk.
- Aesthetics – Many structures had significant aesthetic and historical legacy. New designs had to try to preserve as much as possible whilst not affecting stability. For example, masonry faces were retained with new filter drains/ berms installed downstream.

CONCLUSIONS

There are many different types of spillway that have been designed and installed on NRW reservoir sites over the last ten years. Their selection, design and construction have been influenced by flow requirements, relevant industry guidance (ICE, 2015; CIRIA, 19787), their location, available space, suitable foundations, aesthetics and the specific duration and scale of design storms. Each spillway has distinct benefits, but also potential issues. The final selection is a balance of all of these, whilst meeting the key driver to safely transfer flow from the reservoir to downstream without jeopardising the integrity of the dam.

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