Dams: Benefits and Disbenefits; Assets or Liabilities?

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Amendments to Reservoir Act 1975 in Wales and Natural Resources Wales potential reservoirs project

M O'BRIEN, Natural Resources Wales
S MORRIS, Natural Resources Wales
A R DAVIES, Natural Resources Wales

SYNOPSIS This paper provides an update on the implementation of the amendments to the Reservoirs Act 1975 (HMSO, 1975) in Wales and summarises the principal changes brought in with the amendments. In addition, the paper describes the project that Natural Resources Wales (NRW), as a reservoir undertaker, embarked on to identify and register its reservoirs.

Updating the English reservoir flood maps

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A J BROWN, Stillwater Associates, Redhill, UK
J L CHEETHAM, JBA Consulting, Warrington, UK
R I LEWIS, Environment Agency, Exeter, UK
P J ROBINSON, JBA Consulting, Warrington, UK
J ZOLNACZ, Environment Agency, Bristol, UK

SYNOPSIS The 2009 specification that was used to produce the English reservoir flood maps is being updated to take account of changing circumstances and technical advances. The scope of the review includes digital terrain modelling, dam breach hydrograph and initial conditions at time of failure, both at the reservoir site itself and in the upstream and downstream catchments.

Managing the safety of very high consequence dams – is the UK doing enough?

A J BROWN, Stillwater Associates, Redhill
M HEWITT, Mott MacDonald, Glasgow

SYNOPSIS This paper explores key issues in relation to the management of the safety of very high consequence dams, where the very high consequences make it almost impossible to reduce the risk out of the Unacceptable zone without rebuilding the dam.

The issues arising include guidance to evaluate when risk has been reduced as low as reasonably practicable, the weighting that should be attached to deterministic and risk based approaches, the role for non-structural measures such as enhanced monitoring and surveillance, and the effort and detail that should be involved in periodic dam safety reviews

The paper concludes by identifying some potential improvements to current UK practice.

Building on RARS: development of key themes

A PETERS, Arup
T DOYLE, Arup
I CARTER, MWH
R COOMBS, MWH
A J BROWN, Stillwater Associates

SYNOPSIS In 2015 the authors undertook a portfolio risk assessment (PRA) across the full range of dams owned by a large water company, including earth embankment dams, concrete and service reservoirs. The PRA was based on a Tier 2 assessment as set out in the Guide to Risk Assessment for Reservoir Safety Management (Environment Agency, 2013).

This technical paper details the work undertaken to refine and extend the RARS Tier 2 assessment, ensuring a more comprehensive understanding of the safety of an asset and improved tool to manage the safety of a portfolio of dams.

Guides and Guidance: A “luddite” view of guidance

C W SCOTT, Black & Veatch, UK

SYNOPSIS

Luddite (noun) - *a member of any of various bands of workers in England (1811–16) organized to destroy manufacturing machinery, under the belief that its use diminished employment.* (OUP, 2010)

Are guidance documents an unalloyed boon to reservoir engineers? This paper will consider whether the reservoir community’s current addiction to guidance is helpful or not. Does guidance improve public safety? Does working within an ever widening network of guidance make reservoir engineering an attractive choice for talented young engineers?

Provoke (verb) - *make angry; arouse action; produce a reaction or effect* (OUP, 2010)

Operating procedures for ensuring Reservoir Safety - How do you do it – too much or too little?

Dr A K HUGHES, Atkins, Epsom, United Kingdom

SYNOPSIS This paper will describe the process carried out with one large water company to decide the level of resourcing to try to ensure reservoir safety.

This study not only looked at the impact of different types of structure; but the likely modes of failure, access problems, geographical constraints, the frequency of visits, what is carried out on each visit, how information is obtained and recorded, how quality is controlled, how information is analysed.

The paper will also open up the debate on valve operations, scour discharges, the frequency of reading instruments, the designation of confined space, and lone working procedures.

Reservoir Panel Membership: Is the end nigh?

P KELHAM, Arup, UK
I SCHOLEFIELD, United Utilities, UK
C W SCOTT, Black & Veatch, UK
A L WARREN, Mott MacDonald, UK

SYNOPSIS Concerns have been raised over a number of years about the falling number of engineers on the various panels operated under the auspices of the Reservoirs Act 1975. Numbers have undoubtedly fallen over the 30 years since the Act came into force. But is there a 'crisis'? Why have numbers diminished?

This paper examines the current situation, seeking to quantify the challenge, identifies the factors affecting the reduction in numbers and considers what steps could be taken to address those factors. The authors will draw on work completed under the auspices of the Institution of Civil Engineers (ICE) Reservoirs Committee and other work.

The purpose of the paper is to engender some discussion and debate within the reservoir community.

Reservoir Flood Estimation: Time for a Re-think

D FAULKNER, JBA Consulting
J BENN, JBA Consulting

SYNOPSIS Design floods for reservoirs in the UK and Ireland are currently estimated using a method that in many respects has not changed since the Flood Studies Report of 1975. Although estimates of design rainfall for reservoirs in the UK have recently been updated, other aspects of the design method and the estimation of probable maximum precipitation (PMP) are dated. Methods for river flood estimation have moved on since the 1970s and there are new and longer-term sources of hydro-meteorological data. Research has shown instances of both PMP and probable maximum flood estimates being exceeded.

This paper gives an overview of aspects of the design flood estimation procedure that are in need of an update. Discrepancies are identified between the different methods used to calculate percentage runoff and time to peak for the 10,000-year flood and the probable maximum flood. The pros and cons of adopting the newer Revitalised Flood Hydrograph rainfall-runoff method for reservoir safety work are discussed and suggestions offered for development of an up-to-date method for reservoir flood estimation that builds on existing methods, with the aim of improving understanding of the liabilities associated with dams and reducing the risk of dam failures.

Floods and Reservoir Safety 3rd and 4th Edition Flood Freeboard Estimates Compared

D A BRUGGEMANN, Atkins Ltd
J A RIBEIRO CORREIA, Atkins Ltd

SYNOPSIS The paper provides a short summary of some of the changes introduced in the 4th Edition such as the introduction of the Safety Check Flood in conjunction with the Design Flood and the move away from wave freeboard to a permissible wave overtopping discharge. The freeboard estimate in both editions is based on the significant wave height and the paper outlines the differences in approach after the significant wave height has been determined.

The variation of the flood freeboard estimates derived from both editions as a function of fetch and other parameters will be examined. Examples of the application of the two approaches to existing dams in the UK are provided.

Prevention of Internal Erosion in Homogeneous Dams - A Case Study

N BENNETT, Mott MacDonald Ltd, UK
Dr M EDMONDSON, Mott MacDonald Ltd, UK
Dr P BENNETT, Mott MacDonald Ltd, UK
A WOOD, Mott MacDonald Ltd, UK
P RIGBY, United Utilities, UK

SYNOPSIS Under the 1975 Reservoirs Act, United Utilities (UU) is the statutory undertaker for 140 impounding reservoirs (IRs) retained by earth-fill embankment dams.

Many of the dams were constructed around the turn of the 19th century, before the phase associated with the 'Pennine' style clay core. Therefore, owing to their early construction, the dams are substantially homogeneous, comprising locally available materials, including a mixture of peat, sand, gravel and clay.

UU has utilised a 'Portfolio Risk Assessment' (PRA) method, in combination with the seepage 'Toolbox' (Rigby *et al,* 2014*),* to provide quantification and ranking of various potential failure mechanisms in order to allow a targeted approach to risk reduction.

To provide the highest risk reduction possible and remove three such dams (Blackstone Edge, Whiteholme and Springs IRs) from the 'intolerable' zone, Mott MacDonald Bentley (MMB) was appointed to address the potential risk of internal erosion via a poorly compacted or high permeability zone, either within the embankment or surrounding an existing conduit.

This paper presents case studies of remedial works which have been undertaken at these sites to reduce the risk of failure to an acceptable level. The schemes comprised a variety of methods, including a granular filter combined with partial sheet pile cut-off wall and permeation grouting by both 'Tube-à-Manchette' (TaM) and end-of-case techniques. Grouting operations have included the innovative addition of dyed grouts to allow permeation to be traced.

An investigation and assessment of embankment stability at Daer Reservoir

R MORRIN, Scottish Water
M SULLIVAN, Jacobs UK Limited
A MACDONALD, Jacobs UK Limited
C HOLT, Jacobs UK Limited

SYNOPSIS Daer Reservoir, constructed in the 1950s, is one of the largest earth embankment dams in Scotland at approximately 40m high with capacity of around 25.5Mm³. The dam has an articulated concrete core with bitumen seals provided for the movement of joints. It is classified a Category A dam as defined by Floods and Reservoirs Safety, 3rd Edition (ICE, 1996).

On Friday 13th December 2013 a slip was observed on the downstream face of the dam during heavy rainfall. The paper describes the short term actions taken to address stability, and the subsequent ground investigations and failure analysis, including assessing if other areas of the embankment were at risk.

Slurry trench cut-off wall and permeation grouting of Chapel House Embankment Dam, Cumbria.

C F PAILING, United Utilities, Warrington, UK
D E JONES, United Utilities, Warrington, UK
S WORTHINGTON, Keller Geotechnique, UK

SYNOPSIS United Utilities Chapel House embankment dam is located 1.5km southeast of Uldale, Cumbria and was a significant early construction project for the firm John Laing in 1902 for the Aspatria and Silloth Joint Water Board.

In 2008 improvements were required, to reduce the probability of dam failure associated with internal erosion. The Portfolio Risk Assessment (PRA) had already assessed overall failure of the dam but the United Utilities seepage "Toolbox" workshops identified the main risks of failure associated with internal erosion. An impermeable cut-off through the embankment, around the spillway and into the rock was identified as the appropriate technique to control the risk. United Utilities design, developed with Keller Geotechnique, comprised a slurry trench cut-off wall along the length of the embankment into the underlying foundation soils along with permeation grouting adjacent to the spillway, conduits and below the slurry trench into the rock. This paper details the design, construction and monitoring of the ground engineering with considerations including stability of the slurry trench; the interface of the permeation grouting to the slurry trench; and, crucially, demonstrable benefit in terms of reduced seepage and risk of internal erosion.

Some particular issues in the application of Eurocode 7 to embankment dams

M W HUGHES, Atkins

SYNOPSIS Eurocode 7 (BSI, 1997a) sets out the “principles and requirements for safety and serviceability” and “sets out the basis of design” to be applied to the geotechnical aspects of buildings and civil engineering works.

Whilst there are several guidance documents and text books which discuss the application of Eurocodes to infrastructure embankments, there is very little guidance on how to deal with the assessment of embankment dams.

Using British Research Establishment Report BR 363 (Johnston *et al*, 1999) as a benchmark, and making particular reference to flood attenuation embankments, this paper summarises available guidance on the subject of limit state (GEO) design of the embankments (excluding rapid drawdown). It uses worked examples to test the use of partial factor modifiers to increase the level of safety for embankment dams and includes various approaches for dealing with variable water levels/pressures.

Retrofit of Fibre Optics for Permanent Monitoring of Leakage and Detection of Internal Erosion

J DORNSTÄDTER, GTC Kappelmeyer, Karlsruhe, Germany
D DUTTON, GTC Kappelmeyer, Watford, UK

SYNOPSIS The experience of the last 20 years has shown the great advantage of the use of fibre optics for the efficient monitoring of dams. More than 100 large dams have been equipped during construction or major refurbishment. But old existing dams have been excluded until now from the use of this valuable technique.

In 2014 GTC developed a new fibre optic cable with optimized fibres which could be inserted into small diameter tubes. The fibres in these cables form an internal loop, allowing light to travel in both directions in the same cable. The well-established GTC's temperature sounding method is used to install high grade steel probes into the earth fill dam along its axis, and down into the foundation if required. The new cables are inserted and connecting cables form a "light pass" from one end of the dam to the other. Thereby a two-dimensional view of the temperature distribution within the dam is obtained which can be monitored remotely and in real time.

In 2015 three dams were equipped with this new technique, two in England and one in France; all three are monitored permanently. The cables have been installed to a maximum depth of 30m and a crest length of 430m. At one site the recorded data shows the successful sealing of a leak in the dam by a new slurry trench cut-off wall.

The new technique is described, the installation process is shown and results from permanent monitoring are demonstrated.

Haweswater Reservoir: an environmental asset or an environmental liability?

P J RIGBY, United Utilities, Warrington, UK
A THOMPSON, United Utilities, Warrington, UK
J BUTCHER, United Utilities, Warrington, UK
D E JONES, United Utilities, Warrington, UK

SYNOPSIS Haweswater Reservoir, owned and operated by United Utilities (UU), is the third largest reservoir within England behind Kielder Water and Rutland Water. Constructed in 1940 it holds approximately 85,000 million litres of water and supplies Manchester via 72 miles of aqueduct.

The dam itself was considered to be a major feat of engineering at the time and is a rare example of a buttress concrete dam. The reservoir location is viewed as one the most beautiful parts of the Lake District and is a vital for the local economy, tourism and diverse flora and fauna. But this was not always the case. At the time of its design and construction there was huge opposition to its construction from the local community. Marland, a village at the heart of the valley, was flooded and villagers were relocated, losing their homes and livelihood. The impact on the local flora and fauna in the short term was also significant.

This paper will look at the social and environmental impacts resulting from the construction of the reservoir through to its present day operation. It will also discuss the impacts associated with returning such reservoirs back to their natural environmental as part of discontinuance works and the challenges faced.

Environmental Benefits of Reservoir Discontinuance – Hurst Reservoir Case Study

H J BEEDEN, United Utilities
C D PARKS, United Utilities

SYNOPSIS Hurst Impounding Reservoir was situated east of Glossop, in Derbyshire, but after decommissioning of Hurst water treatment works, the 167Ml reservoir supplied only compensation flow to Hurst Brook. The design was a homogeneous embankment with an upstream puddle clay blanket. Investigations identified defects in the embankment and several options were considered to address these.

United Utilities' (UU) sustainable long-term solution was achieved through complete removal of the dam and restoring Hurst Brook to a natural watercourse. The project reused all excavated materials with the ambitious intention of zero waste removed off-site; an achievement fundamental to the project subsequently winning the Sustainability Category of the Ground Engineering Awards in 2015.

Ecological benefits of the project included extension of acidic grassland and moorland habitats within the Peak District National Park (PDNP), the creation of bird breeding areas and new aquatic habitats. A short construction programme ensured only one "game & native bird" nesting season was disrupted, alleviating stakeholder concerns.

Environmental Impact Assessment (EIA) (Halcrow, 2012) conclusions were incorporated in the planning consent. The project promoted good stewardship of the land in the Dark Peak and managed the operational risks whilst also achieving excellent consultation and stakeholder management.

The Discontinuance of Sunnyhurst Hey and Improvements to Earnsdale Reservoirs, Darwen, Lancashire

S TENNANT, GHD Livigunn
Dr C D PARKS, United Utilities

SYNOPSIS Sunnyhurst Hey and Earnsdale Reservoirs are adjacent reservoirs situated on the north-western edge of Darwen Moor, some 1.5km west of Darwen town centre. Earnsdale Reservoir was constructed in 1863 and impounds 433Ml with a 300m long, 24m high embankment. A history of seepage and settlement and a more recent stability assessment, that indicated an insufficient factor of safety (FoS) on global stability, required mitigation measures. As a result a unique solution was formulated that incorporated a geogrid reinforced earth berm with a basket/rock facing, constructed on a geogrid reinforced load transfer platform that spanned between a number of deep soil mixed foundation cells and a filter that covers the downstream face of the dam. These were substantially completed in 2015 and form the main focus of the paper.

Sunnyhurst Hey reservoir was constructed in 1875 and formerly impounded 436Ml. The embankment, of 855m in length, suffered from a history of seepage, damp areas and soft ground at the toe. During investigations in 2008 the embankment was found to have no “core” and no “cut-off”, contrary to historical information. Given the extent of the mitigation measures that would be required to bring the reservoir to an acceptable safety standard it was decided to permanently discontinue the reservoir.

Insights into the composition of Pennine type dams – experiences from two reservoir discontinuances

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V KING, Mott MacDonald, Sheffield, United Kingdom
D REBOLLO, Mott MacDonald, Leeds, United Kingdom
A JACKSON, Mott MacDonald, Leeds, United Kingdom

SYNOPSIS In recent years there has been an increased demand for a better understanding of the composition of our portfolio of 19th century embankment dams, with work being carried out to safeguard these structures and the communities who live around them. During works to discontinue two of these dams, investigations were undertaken to better understand the composition of the dams and gain an increased understanding of the potential risk of internal erosion, particularly associated with conduits through the foundation and other defects that may be present. A comparison has been made against the model of a typical 19th century Pennine type embankment dam.

Discontinuance of Small Reservoirs in Scotland

L J DUNNE, Atkins Limited
R MORRIN, Scottish Water

SYNOPSIS Much attention has been given to the discontinuance of small reservoirs in Scotland recently, for two main reasons:

- The phased implementation of the *Reservoirs (Scotland) Act 2011* (TSO, 2011a)
- The practical need for Reservoir Managers (referred to as "*Undertakers*" in the *Reservoirs Act 1975* (HMSO, 1975)) to reduce risk, and manage their long term financial and resource commitments associated with operating and maintaining small reservoirs.

This paper examines the processes involved in discontinuing small reservoirs and highlights some of the key challenges encountered on recent discontinuance projects.

Case studies are presented which relate to the discontinuance of five small reservoirs that are no longer used for their original purpose of water supply and, following assessment, each reservoir has been considered to represent a "liability" rather than an "asset". Discontinuance has been identified as providing the most appropriate long term solution for these reservoirs.

Many small reservoirs provide a degree of flood attenuation which protects downstream communities. Conversely, they can also represent a significant risk to downstream communities in the event of an uncontrolled release of water. Therefore, discontinuance of small reservoirs requires careful planning, consultation and investigation. The process can be lengthy and relatively expensive.

Recent Experiences in Design and Construction of Siphons to Supplement Reservoir Drawdown Capacity

N R KEMPTON, Mott MacDonald, United Kingdom
P BENNETT, Mott MacDonald Bentley, United Kingdom
J WILSON, Mott MacDonald Bentley, United Kingdom
A HOBSON, Yorkshire Water Services, United Kingdom
I SCHOLEFIELD, United Utilities Group PLC, United Kingdom

SYNOPSIS Recently there has been increasing focus on the ability of UK reservoirs to be adequately drawn-down in an emergency situation. This emergency planning has led to a growing demand for drawdown capacity assessments, consideration of the acceptable drawdown rate and, where existing facilities do not provide an acceptable drawdown, the design and construction of supplementary capacity.

It is not uncommon for the installed drawdown capacity at UK reservoirs to fail to meet the varying targets. With the reliability and adequacy of temporary solutions under question, permanent solutions are regularly preferred. As a result, the requirement for permanent improvement works such as the construction of siphon drawdown pipes is becoming prolific.

This paper shares some recent experiences in the design and construction of siphon pipes to supplement the drawdown capacity in order to achieve an acceptable drawdown rate. It presents four case studies of improvement works undertaken, including a variety of siphon options, a range of pipe diameters, pumped and suction priming systems and the use of various types of valves.

The experience presented is that of Mott MacDonald and the Mott MacDonald Bentley joint venture ‘the Principal Designer’ gained while delivering schemes for Yorkshire Water Services (YWS) and United Utilities Group PLC (UU) ’the Clients’ assets under the AMP 5 and AMP 6 frameworks.

Delivery of Drawdown Improvements at Anglian Water Reservoirs

R PETHER, Black & Veatch Ltd
I KIRKPATRICK, Anglian Water

SYNOPSIS In 2005 Anglian Water commissioned a study into emergency draw-down rates at all of its larger reservoirs. As a result of the findings, between 2010 and 2014 Anglian Water successfully constructed and commissioned schemes to increase drawdown rates at four reservoirs assessed as having insufficient capacity. A further significant improvement scheme is planned for a fifth reservoir.

In this paper the process through which these reservoirs were selected for improvement is described. We will go on to describe the options that were considered for increasing the drawdown capacity at each of the reservoirs and the preferred option in each case. Each scheme had its own challenges which will be discussed, some of which were unique whilst others are common to many reservoirs. The paper draws conclusions and describes lessons learnt for consideration on future schemes, either by Anglian Water or other undertakers considering drawdown improvements, perhaps as a result of the forthcoming guidance document setting out recommended drawdown rates for large reservoirs.

Scour Releases for UK Reservoirs – A Case study

A PEPPER, Mott MacDonald Ltd, Cambridge, UK

SYNOPSIS As part of the inspections carried out under Section 10 of the Reservoirs Act 1975 (HMSO, 1975), the Inspecting Engineer is required to assess the efficiency of the reservoir drawdown capacity and proper function (SI 2013-1677, Schedule 5, viii (HMSO, 2013)). However, within the UK there are a number of large raised reservoirs which do not have their scour (drawdown) valves regularly tested under full head conditions. One reason that many undertakers in England do not regularly open these valves is due to concerns that the Environment Agency (EA) may have regarding the environmental impact resulting from the release of water from a reservoir.

This paper outlines a case study in 2015 where the EA granted permission for a single release of water from a scour valve on a statutory reservoir, and the lessons learnt. During the test the scour valve did not close as anticipated, highlighting the need to regularly exercise reservoir scour valves under full head conditions.

Managing the Environmental Risk from Reservoir Draw Down

D ARMOUR, Mott MacDonald Ltd.
M HEWITT, Mott MacDonald Ltd.
J MALIA, Scottish Water
R MURRAY, Mott MacDonald Ltd.

SYNOPSIS Pollution incidents caused by uncontrolled discharges of sediment rich water from reservoirs can impact on an owners' reputation and performance measures. Such incidents can also affect programme and have significant cost implications.

Scottish Water is developing a Reservoir Operation and Maintenance Strategy (ROMS) comprising work procedures and instructions, similar to those that it has implemented to control activities on its water distribution network. This paper describes the development of processes to identify the risks and manage the controlled drawdown of reservoirs for the purposes of maintenance and capital works, ranging from nominal water level lowering over a period of a few weeks for minor repairs to complete reservoir emptying for the purposes of dam breaching. It includes lessons learned from previous incidents, an outline of the approach to identifying the threats within the reservoir and the receptors in the downstream environment and hence the level of risk that the drawdown may pose. It describes the suggested minimum mitigation and monitoring measures to be incorporated in the drawdown plan dependant on that level of risk.

Spillway and Dam Gate Reliability – Harmonising the Approach to Mechanical and Electrical Systems?

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R DIGBY, KGAL Consulting Engineers, Poole, UK
P JONES, KGAL Consulting Engineers, Wakefield, UK
B IMISSON, KGAL Consulting Engineers, Wakefield, UK

SYNOPSIS There is much innovative work going on around the world in respect of risk-based approaches to dam safety. Whilst these techniques are being used widely in the civil engineering aspects of dam design and inspection, there is no single, accepted, best-practice approach for the mechanical and electrical aspects of protection gates.

In 2014 the main ICOLD commission set up a hydromechanical sub-committee to specifically consider these issues. The lead author sits on this committee as the UK representative and is heavily involved in the writing of a "Best Practice Approach to Protection Gate Reliability" which is expected to be launched in 2016.

The purpose of this paper is to set out the various approaches being used elsewhere and to show the direction of travel being adopted by ICOLD and which will likely become accepted practice in the near future. In so doing the paper addresses the following questions:

- What is an acceptable risk to individuals and society?
- Does this vary if:
  - Equipment is old or new?
  - Equipment is in the developed or third world?
- How does hydromechanical equipment reliability relate to dam reliability overall?
- How will this be translated into contract specifications?
- What are the implications for Inspecting and Supervising engineers?

Incident management and repair of a ruptured scour main at Talybont dam caused by a pressure wave

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A L WARREN, Mott MacDonald, Bristol, UK

SYNOPSIS Talybont reservoir is impounded by a 30m high earthfill embankment dam. A 760mm diameter water supply main and 635mm diameter scour main are located in a tunnel that passes beneath the dam. A branch off the scour main supplies a hydropower turbine.

When the power to the turbine pump failed one evening, a pressure shock wave in the scour main caused a section of the pipe to rupture catastrophically. The incident was detected when the reservoir level dropped by an unusual amount overnight. The repair was undertaken in difficult conditions due to the confined space environment of the tunnel and manual handling issues of heavy pipe sections; the inability to isolate the main due to the guard valve being jammed in a partially open; the supply-critical main having some corrosion and weakened pipe joints near the section of scour main that was to be repaired; and the unknown condition of the remainder of the scour pipework and valve, which had been subjected to the pressure wave.

This paper describes how the incident was managed; it presents the options considered to undertake the emergency repair and the post-incident analysis and lessons learnt.

Bosley Reservoir, outlet improvements

D H BROWN, Canal & River Trust

SYNOPSIS Works were carried out at Bosley Reservoir in Cheshire during 2015/16 to increase the dam freeboard, to understand better the risks associated with downstream control of the outlet and to improve the drawdown capacity.

These works, which included the design and construction of two siphons and the investigation of the original draw-off system, are discussed in this paper.

Slaithwaite Reservoir Improvement Works

M COOMBS, Arcadis
N POVEY, Canal & River Trust (seconded from Arcadis)

SYNOPSIS David Brown (CRT Principal Reservoir Engineer) identified the need for the drawoff pipe at Slaithwaite reservoir to be lined in 2009 (Brown, 2009). In addition the drawoff valve itself, located at the head of a tunnel approximately 40m long, was proving increasingly difficult to operate and was located within a confined space. In order to address these issues a project was undertaken to extend the existing drawoff pipework, replace the valve, provide a guard valve and investigate the upstream inlet arrangements.

The opportunity was undertaken to include further improvement works, identified in the 2011 Section 10 inspection and by the Supervising Engineer, during the project. This included replacement of a bellmouth penstock to allow safe operation remotely from the reservoir bank, repairs to the spillway, grouting of a downstream culvert and refurbishment of a pedestrian footbridge. This paper outlines the works undertaken, the difficulties encountered and the solutions subsequently developed.

Butterley Spillway Improvement Works

R WOODS, Mott MacDonald Bentley
C MORRISON, Mott MacDonald

SYNOPSIS Following on from a partial spillway failure in 2002 during a flow event significantly below Probable Maximum Flood (PMF), and a lengthy planning process, works have now started on site for the much-needed spillway improvement works at Butterley Impounding Reservoir. This paper will describe the project journey, the challenges faced by the project team and the design details.

The existing spillway is Grade II listed and an iconic structure within the local landscape. The solution that has currently been awarded planning permission has been reached through compromise between the Client, the All Reservoirs Panel Engineer (the Inspecting Engineer), The Project Team and Local Planning Authority.

The upper two-thirds of the spillway will be refurbished including replacement of the existing masonry invert and raising of the right hand side spillway wall. The lower third of the spillway will be completely rebuilt to provide a more consistent gradient. A number of existing features are to be retained and incorporated into the new spillway including masonry piers, copings and curved wing walls to help preserve the character of the original spillway.

The Hampstead Heath Ponds Project – achieving dam safety in a highly sensitive area

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B C JONES, Atkins, Epsom, United Kingdom
T E CREED, City of London Corporation, London, UK

SYNOPSIS This paper will describe the works currently being undertaken on Hampstead Heath. There are three 'statutory reservoirs' on Hampstead Heath but two chains of more than 12 reservoirs. This paper will describe the process followed which identified a significant deficiency in spillway capacity down the two chains, the way in which the flood study calculations were carried out, the risk assessments made, and the design decisions made.

The works include a new embankment and a raised dam to provide additional flood storage capacity. The paper will describe the significant amount of consultation undertaken and the concerns voiced by the stakeholders.

Challenges of design and construction for reservoir safety improvements within an historic estate

D E NEEVE, Arup, Leeds, UK
M JENKINS, Arup, Leeds, UK
S PORTER, Chatsworth House Trust, Chatsworth House, UK
T KILBANE, Fox (Owmby) Limited, Lincoln, UK
P KELHAM, Arup, Leeds, UK

SYNOPSIS Detailed design and construction of any reservoir safety and improvement works can be challenging. The team successfully overcame the constraints of three historic dams with protected ecology all set within a National Park and a Grade 1 listed parkland with a remote moorland access.

The chosen solution provides compliance for the two high risk dams and peace of mind for the third within a limited budget for the charitable owner. The works included new top water level and auxiliary weirs with associated spillways to three reservoirs and crest raising on two high risk (Category A) dams.

Waun Pond - New Overflow

K M H BARR, Fairhurst
M HAYWARD, Fairhurst
V FORD, Fairhurst

SYNOPSIS Following a periodical inspection of Waun Pond, Blaenau Gwent County Borough Council appointed Fairhurst to address safety recommendations. The overflow capacity was found to be grossly inadequate. The solution involved design of a new overflow which accounted for significant physical constraints including services laid along the crest of the dam below a public road and conflicting stakeholder interests in terms of amenity and flood risk downstream.

The adopted solution was a box-type overflow, with the potential for flow to enter on all four sides, discharging through culverts formed by tunnelling below the crest of the dam using pipe jacking, into a downstream stilling basin and channel. The paper covers the flood study, design and construction aspects of the new overflow.

Castle Irwell Flood Detention Reservoir - Design and Construction

A COURTNADGE, Jacobs
J GOSDEN Jacobs
T AMBLER, Jacobs
R LEWIS, Jacobs
E ADALI, Jacobs
A RADLEY, Axis P.E.D. Ltd

SYNOPSIS Castle Irwell Flood Detention Reservoir is a new offline flood storage reservoir, located in Salford, approximately 2km upstream of Manchester city centre. The reservoir sits in the lower reaches of the River Irwell catchment on the former site of Manchester Racecourse. The project client is the Environment Agency. The reservoir is fully bunded within a meander on the River Irwell by a 2.3km long, 3m high, zoned earth embankment. Inflows into the reservoir are controlled by a grass reinforced inlet weir at the upstream end and outflows are controlled through twin, automatically actuated, 1.5m square penstocks. Construction commenced in February 2015 and is due to be completed in 2016.

Design and Construction of Mitford Flood Storage Reservoir

J G PENMAN, CH2M
A D MYATT, Environment Agency
A B CARR, CH2M
V S COVERDALE, CH2M
D M LATHAM, JBA (formerly CH2M)
I G EDMONDS, CH2M

SYNOPSIS Following severe flooding from the River Wansbeck in 2008 a flood alleviation scheme for Morpeth, Northumberland, UK was designed and constructed which includes one of the largest flood storage reservoirs the Environment Agency has commissioned in England.

The dam comprises an earth embankment 14m high with a crest length of 370m, a spillway capacity of 760m³/s and a storage capacity of 1.4Mm³.

Construction of the scheme was completed in 2015. The paper will describe the design of the dam, the construction work and the implementation of the environmental mitigation measures.

Ageing Service Reservoirs - an increasing burden or scope for innovation?

I HOPE, Severn Trent Water

SYNOPSIS Whilst the structural integrity of service reservoirs (SRs) is the key focus for Panel Engineers, other regulatory regimes can designate a failure of these vital structures. Root cause analysis of incidents for bacteriological failures has revealed causes ranging from physical deterioration of assets through to complexities arising from loss of knowledge of the way in which the asset should be operated.

This vital asset base is aging, with some structures dating back to Victorian times originally comprising brick-built open structures. Over the years SRs have been significantly modified and repaired. The current replacement rate for these tanks that house food-grade water could be up to 200 years. Individual component parts such as water bars, roof membranes and joint sealants have a limited life.

Engineers are challenged to become more engaged by overseeing construction quality and seeking opportunities for innovation, for example by challenging the convention to backfill against SR walls.

Asset or liability: stabilising an historic dam

A PETERS, Arup
N WALDING, Arup
D CROOK, Arup
M COOPER, Arup
P KELHAM, Arup
B COTTER, Dŵr Cymru Welsh Water

SYNOPSIS This paper describes the investigations and studies carried out to confirm the construction details of a Grade 2* listed dam, the leakage issues, causes of lateral displacements, and potential for instability. The conclusions of this work are summarised in relation to the requirements to achieve a safe asset, and the approach taken to achieve this. A description is provided of the remedial works designed and constructed to ensure the future stability.

Bollinhurst Impounding Reservoir – Spillway Apron Leakage Remedial Works

D R C HUGHES, J and D Geotechnical Services Ltd
K HARVEY, United Utilities
P J RIGBY, United Utilities

SYNOPSIS An overflow study undertaken in 2004 identified that the spillway of Bollinhurst Impounding Reservoir (IR) had insufficient capacity to pass the Probable Maximum Flood. An overflow model test was commissioned by the owner, United Utilities, which confirmed that additional overflow capacity was required. A replacement spillway was constructed between 2010 and 2011 which incorporated the original spill weir and adjacent wing walls. During refilling of the reservoir in 2012, leakage into the new overflow tumble bay under drainage system was identified. The leakage commenced at approximately 0.5m below overflow level and the flow, via the 160mm diameter connecting outlet pipe, into the connecting chamber was full bore.

Works were commissioned to investigate and remediate the observed leakage following a meeting in September 2012 which included AR Panel Engineer Dr Peter Mason, subsequently appointed as QCE for the remedial works.

This paper describes the history of the reservoir, investigation of the leakage source, and the determination of possible remedial options. It also discusses the observations made during the construction works and the design of the solution to fix the leakage.

Investigation of Voids under a Spillway using GPR and its Resolution

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B DOOLEY, Mott MacDonald Bentley
R ROBSON, Mott MacDonald Bentley
A HOBSON, Yorkshire Water Services

SYNOPSIS This paper describes the findings of a project to refurbish an existing spillway on a Category A dam, in particular focusing on the investigation methodology used to identify voids beneath the spillway. The paper presents a summary of the investigation findings and the remediation works completed.

The paper explains how Ground Penetrating Radar (GPR) was used to investigate the presence of voids beneath the spillway. This was used together with more conventional ground investigation as verification. The paper reviews the benefits and limitations of using GPR in identifying void potential beneath spillways. The paper concludes by providing details of how the voiding issue was remediated, outlining the measures employed.

Control of moss on reservoir dam embankments

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T M YOUNG, STRI Ltd
R L MANN, STRI Ltd
M DIXON, United Utilities Water Plc
B TOLLITT, United Utilities Water Plc

SYNOPSIS Earth dam embankments need to maintain a year round high grass content sward to achieve a constant surface and ensure slope stability. Moss in the sward is considered to reduce potential stability, increase vulnerability to erosion and increase the risk of slips and trips. United Utilities and STRI have undertaken trials at Mitchell's House Reservoirs. The research objectives were to assess the degree of moss invasion, evaluate the optimum approach for controlling moss in sustainable ways, to identify optimum strategies of increasing grass dominance and to define practical safe and environmentally benign methods for delivery through basic grounds maintenance capabilities.

Moss control using several environmentally sensitive moss control products, physical removal by scarification and improving soil fertility to boost grass growth to outcompete moss, have all been successful strategies, with each treatment on its own significantly reducing moss content in treated plots. There was no advantage in combining the treatments. In terms of turf recovery, application of low levels of organic fertilisers and nitrogen were successful at speeding up the recovery of turf after moss removal, by scarification, resulting in almost full grass cover over all treated plots.