## Session 2

## LEGISLATION AND GUIDANCE – THERE IS A DIFFERENCE!

Amendments to Reservoir Act 1975 in Wales and Natural Resources Wales potential reservoirs project - M O'Brien and S Morris

Updating the English reservoir flood maps - A Brown and P Robinson

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

Guides and Guidance: A "luddite" view of guidance - C Scott

Discussion

# Amendments to the Reservoirs Act in Wales and NRW's associated reservoirs project


Natural Resources Wales

Matt O'Brien

Steve Morris


# Overview

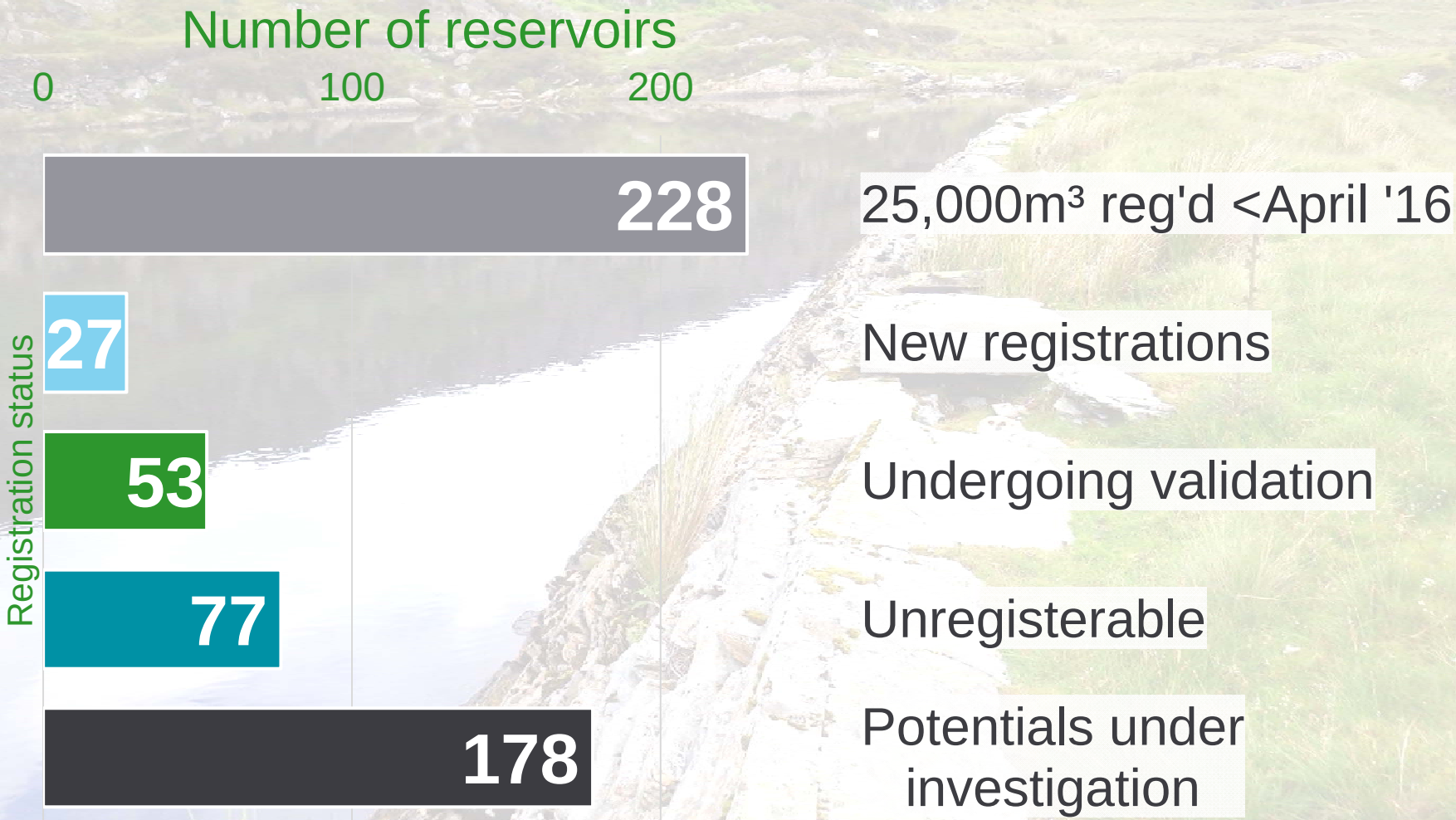
## Legislation – Matthew O'Brien

- Registration capacity => 10,000m³
- Risk designation
- Summary of other changes

## NRW reservoirs – Steven Morris

- Identifying reservoirs liable to new regulation
- Discovery, inspection and preparation
- Registration and compliance works

# Registration of reservoirs (Aug'16)



# Previously disputed capacity

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# Previously discontinued

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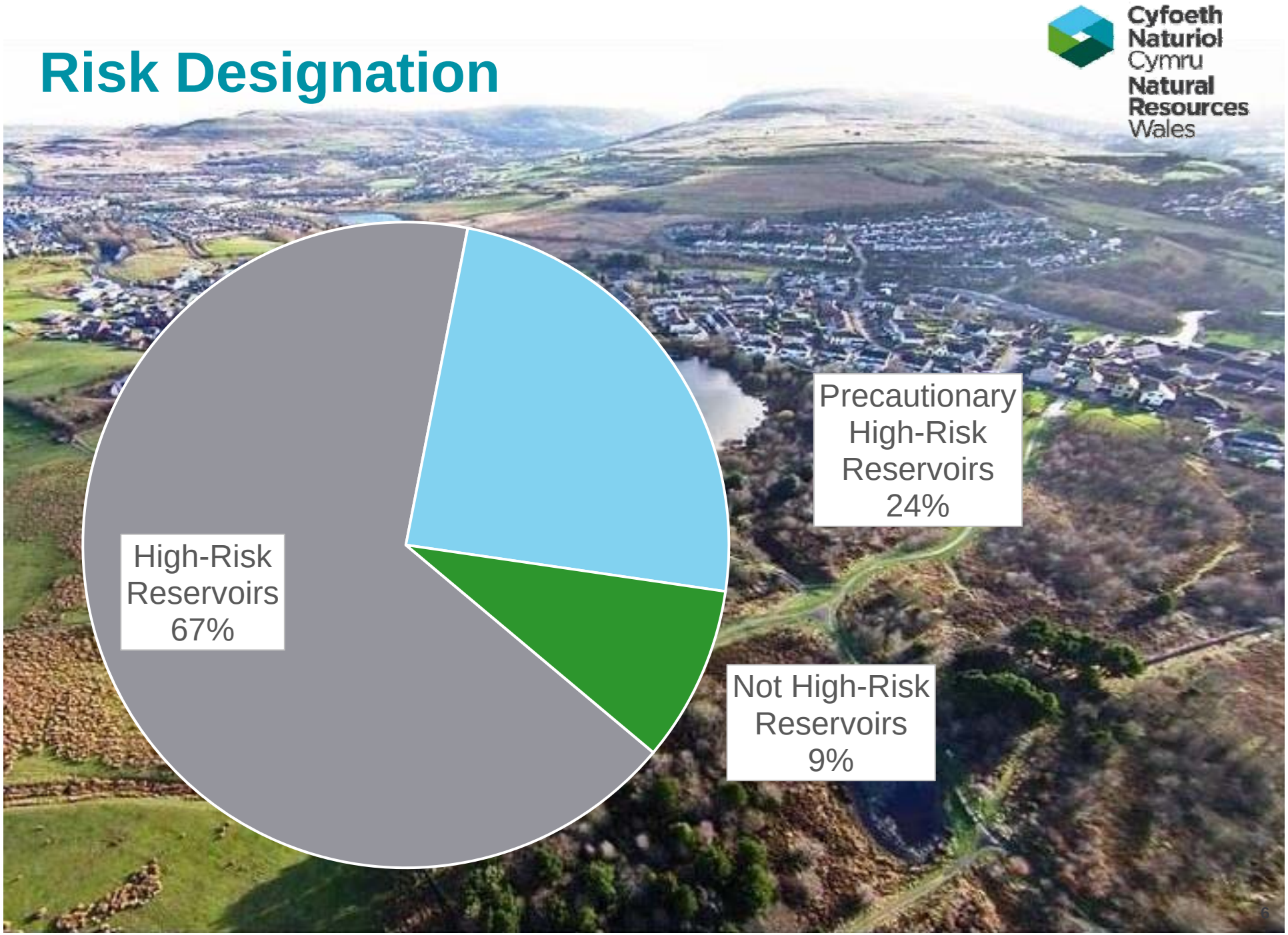
# Risk Designation



# Risk Designation

| Percentage of provisional risk designation by dam category | | | |
|---|---|---|---|
| Dam category | High-Risk | **Precautionary HR** | Not **HR** |
| **A** | **93%** | **7%** | **0%** |
| **B** | **77%** | **23%** | **0%** |
| **C** | **13%** | **63%** | **25%** |
| **D** | **4%** | **52%** | **43%** |

# Other changes

- Supervising Engineers: authority to direct undertakers to make visual inspections, and report on their findings
- Inspecting Engineers may include measures in the interests of maintenance
- S10 inspection reports sent to undertakers within 6 months
- S12 Annual Statements copied to us (not interims).
- Incidents must now be reported to us
- Proposed charging scheme April 2017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# Project Scope

## Potentials Project

- Identifying all reservoirs owned by NRW
- Establish which reservoirs would be liable to new regulation
- Site visit with ARPE
- ARPE opinion

# Information Gathering

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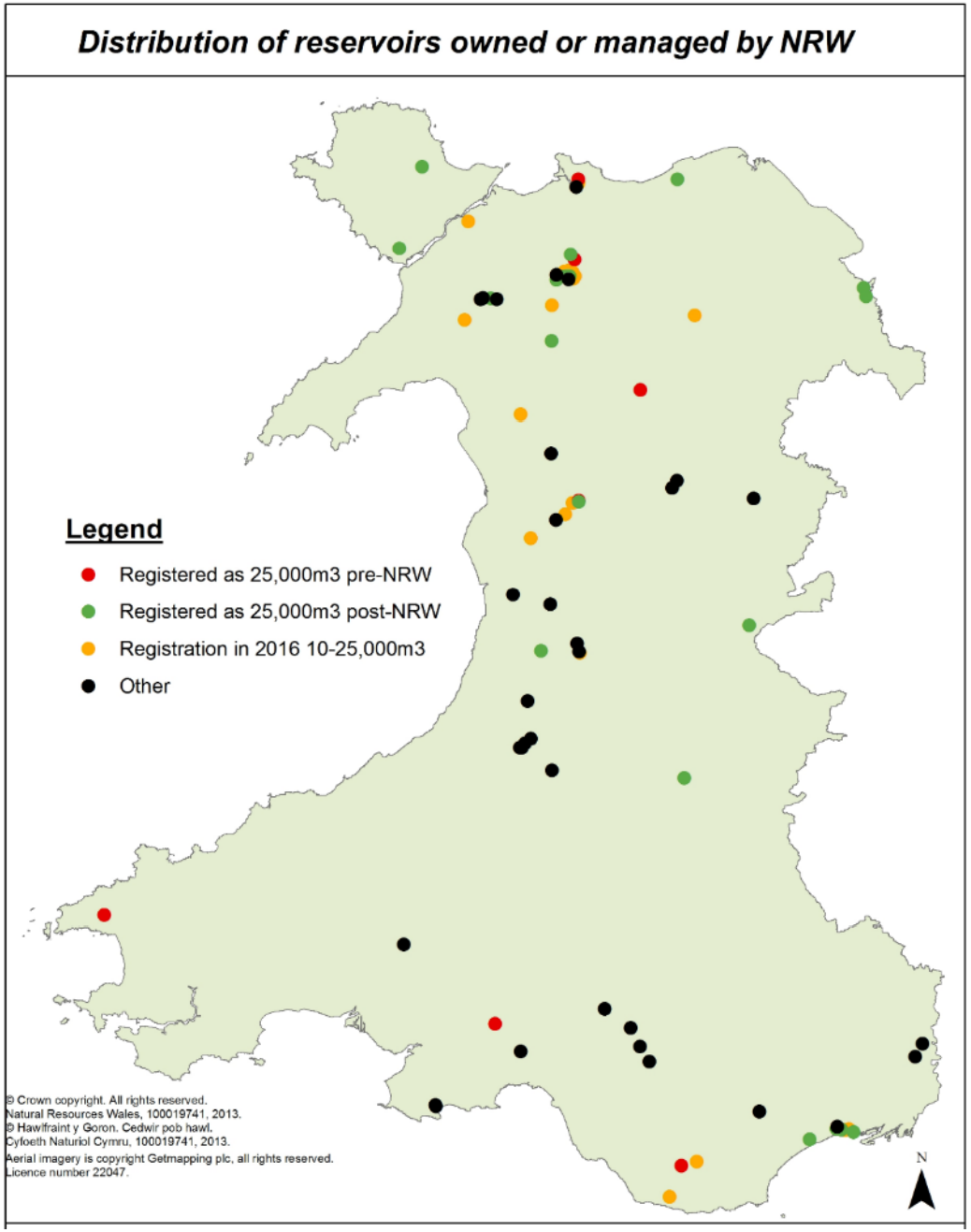
## Potentials Project

- Establish links with relevant staff to establish sites
- GIS scan of waterbodies
- Site visits

# ARPE Site Visits

The brief comprised the following:-

- Confirmation of whether the structure is a raised reservoir
- Assessment of the raised capacity
- Provisional risk category
- Identification of works required
- Summary of findings and recommendations.

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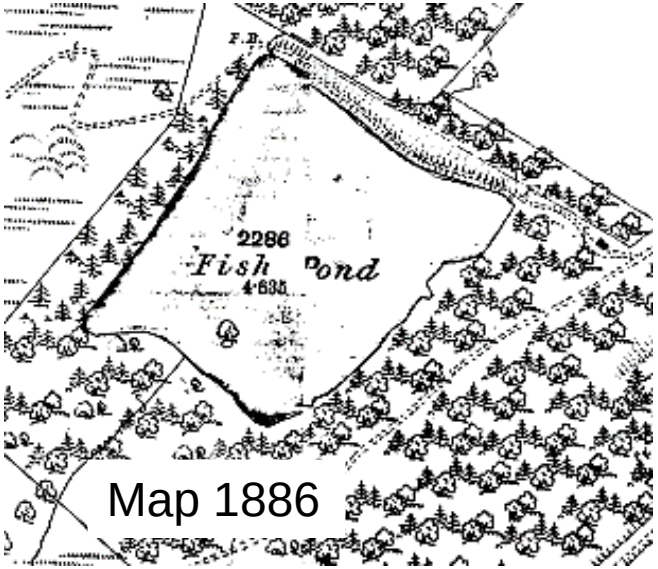
# Distribution of NRW reservoir sites

# Initial Outcomes

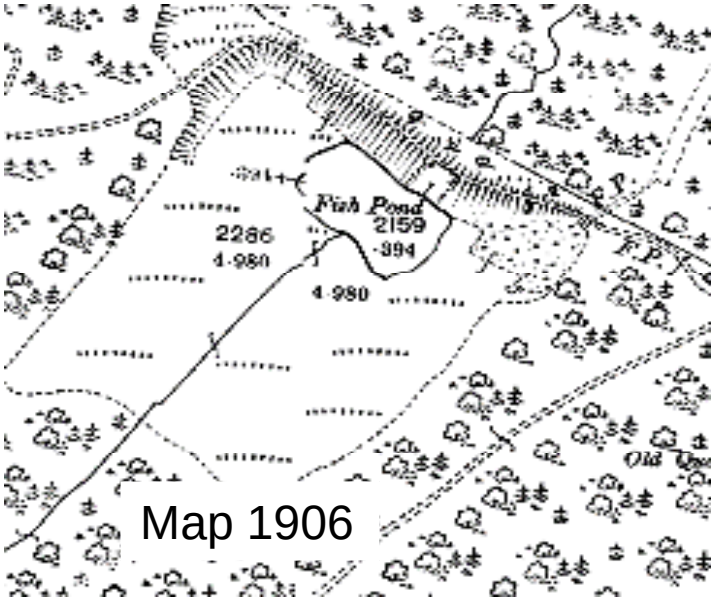
- **85 sites identified**
- **23 reservoirs identified as holding more than 25,000m³**
- **14 reservoirs identified as holding between 10,000m³ and 25,000m³**

# New Pool

# New Pool




Map 1886




Map 1906

# New Pool

upstream
Structure

Area believed to be bottom outlet in line with upstream structure at the downstream toe with temporary flow capture

# Llyn Fuches Las

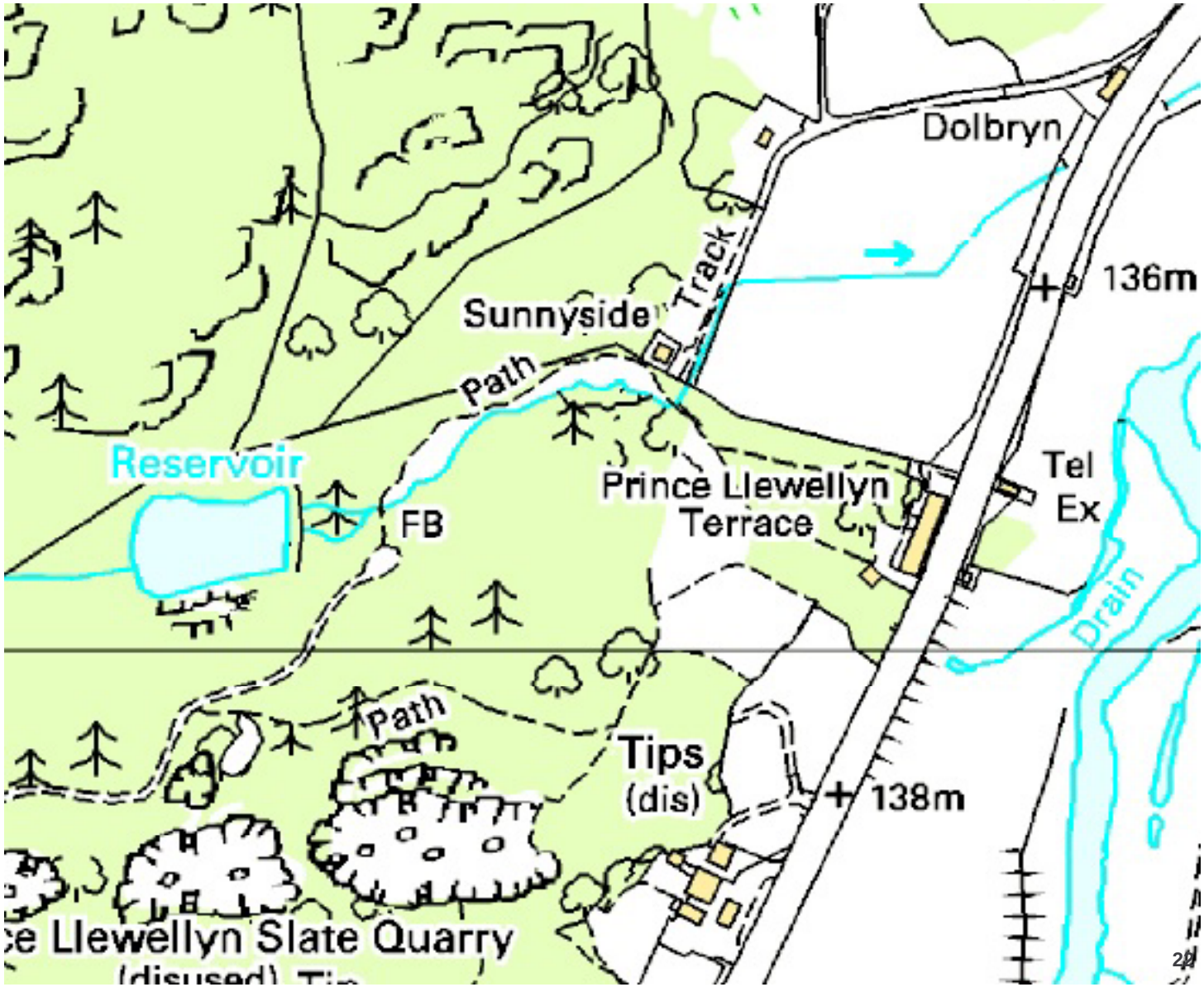
# Llyn Fuches Las

# Llyn Fuches Las

# Ty’n Twll

# Ty’n Twll

Concerns raised by area staff due to location above properties and significant leakage.



# Ty'n Twll

# Ty'n Twll

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# Conclusion

- From 11 LRRs in 2013 to 55 by the end of 2017
- 26 reservoir assets below the 10,000 threshold
- 161 MIOS to be completed by 2019
- Reviewing staffing requirements
- Additional annual funding from Welsh Government

# Diolch am wrando
# Thank you for listening

| | |
|---|---|
| WWW. | cyfoethnaturiol.cymru/DiogelwchCronfeydd<br>naturalresources.wales/ReservoirSafety |
| Ebost | cronfeydddwr@cyfoethnaturiolcymru.gov.uk |
| Email | reservoirs@naturalresourceswales.gov.uk |
| Ffôn<br>Phone | 03000 65 42 99 |

# Updating the specification for the English reservoir flood maps

**Tony Deakin, Project Executive, Environment Agency**
**Alan Brown, Technical Director, Stillwater Associates Ltd**
James Cheetham, Senior Analyst, JBA Consulting
Roger Lewis, Senior Advisor, Environment Agency
**Peter Robinson, Senior Analyst, JBA Consulting**
Jarek Zolnacz, Project Manager, Environment Agency

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Reservoir Safety & Water Consultancy

JBA consulting

Environment Agency

# Updating the English Reservoir Flood Maps - Contents

- Need for review and context
- Failure scenarios  and breach flow
- Reservoir data quality
- Downstream data quality
- Reservoir flood mapping outputs
- Summary and next steps



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JBA consulting

Environment Agency

# Need for review (and update) of 2009 specification / associated reservoir flood maps

- Flood Risk Regulations 2009 require review, and if appropriate update, every six years (next to be completed by 2019)
- Changing needs and uses since 2009
  - Emergency planning
  - Plus risk designation
  - Plus other uses
- Environment Agency commitment to *"continuous improvement in managing flood risk*"



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# Conceptual framework

- No unique extent of inundation in event of dam failure - depends on many factors, including conditions at dam and downstream valley at time of failure
- National flood mapping
  - balance between cost and bespoke mapping/ number of maps
  - Could be seen as equivalent to Tier 2 Risk assessment
- Degree of conservatism/Uncertainty
  - A “Best estimate” would under predict 50% of time
  - Cabinet Office requires “*reasonable worst case scenario*”
  - HSE R2P2 (2001) requires owners to demonstrate “*procedures for uncertainty are in line with the precautionary principle*”



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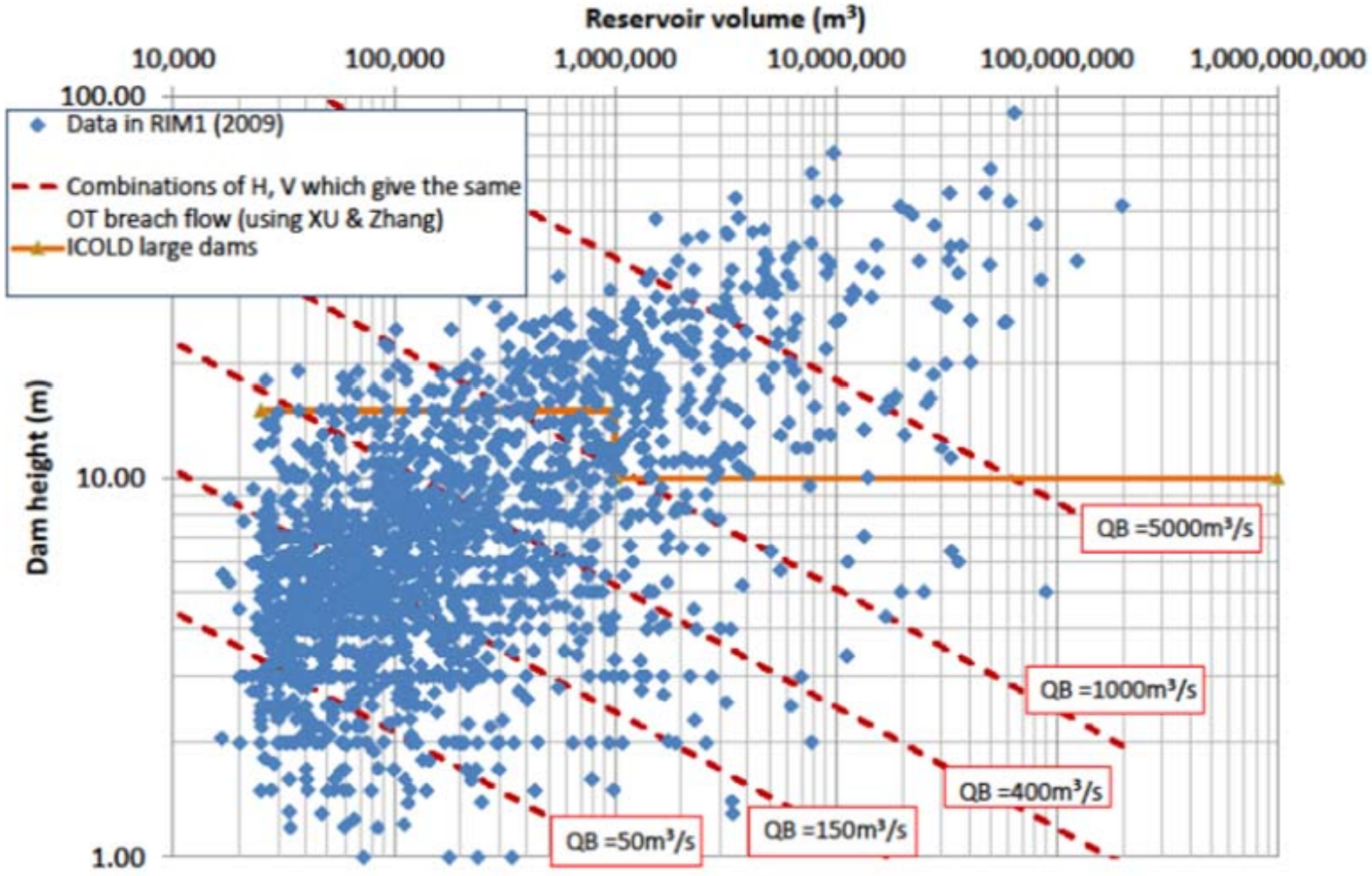
# Range of dam height / reservoir volume

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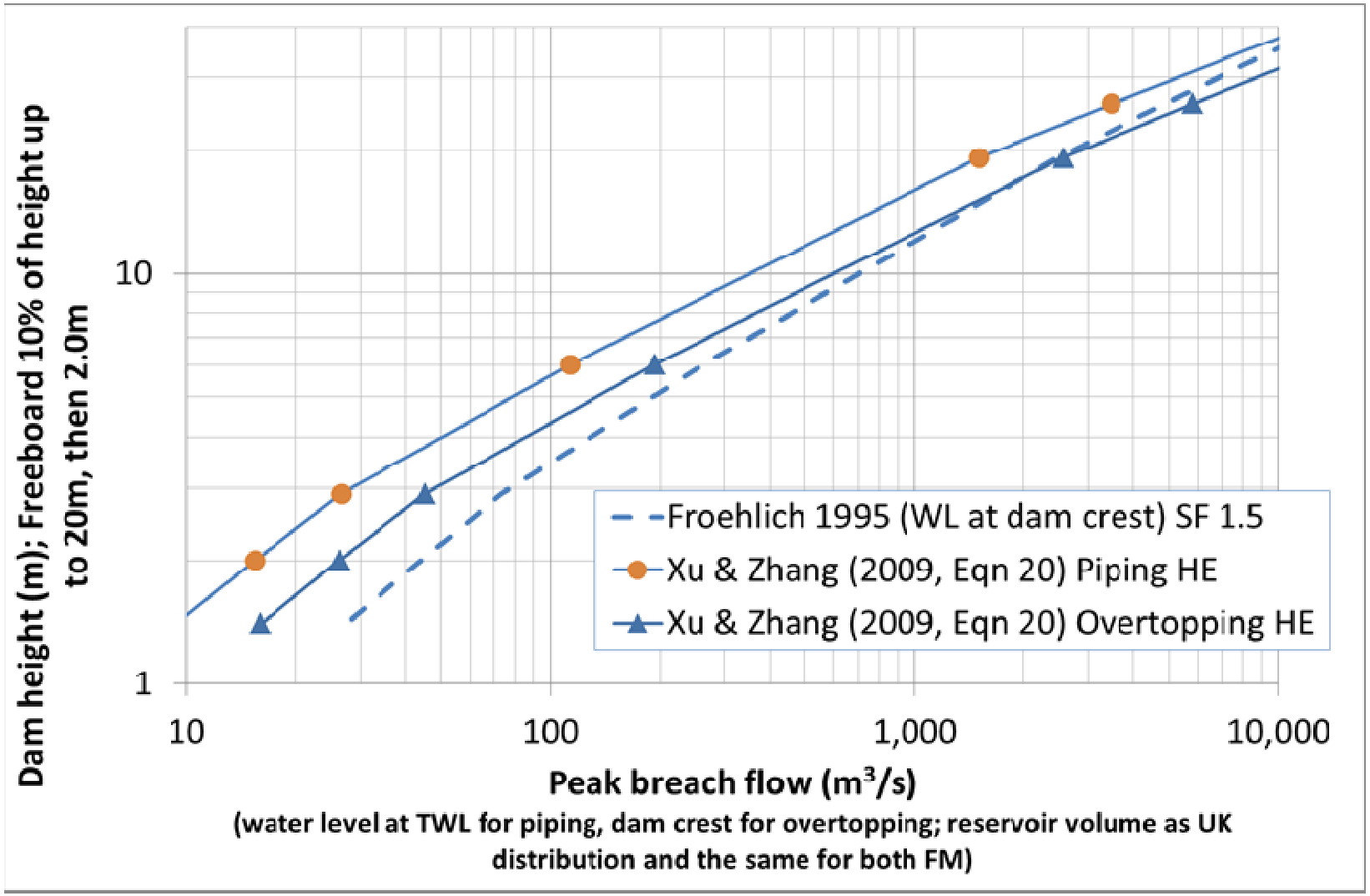
# Failure scenarios

| Condition | 2009 Spec | 2016 specification | |
|---|---|---|---|
| | | Dry Day | Wet Day |
| Reservoir level at time of failure | 0.5m above dam crest (to model downstream flooding) | At spillway crest (TWL) | Between TWL and 0.3m above dam crest, consistent with PMP event over reservoir catchment and blocked spillway. |
| Inflow hydrograph | None | None | Allowance made as above |
| Downstream flooding | None (modelled by 0.5m above crest) | None | Downstream flooding to replicate 1-in-1000 year fluvial flood extent (Flood Zone 2) |
| Embankment dam breach hydrograph | 1.5 times Froehlich peak flow | 1.0 times Xu & Zhang peak flow, HE, piping mode | As Dry Day, but equation for overtopping mode |
| Consequences of failure | Dam failure | Dam failure | Incremental effect of dam failure over fluvial flooding only |

# Peak Breach flow



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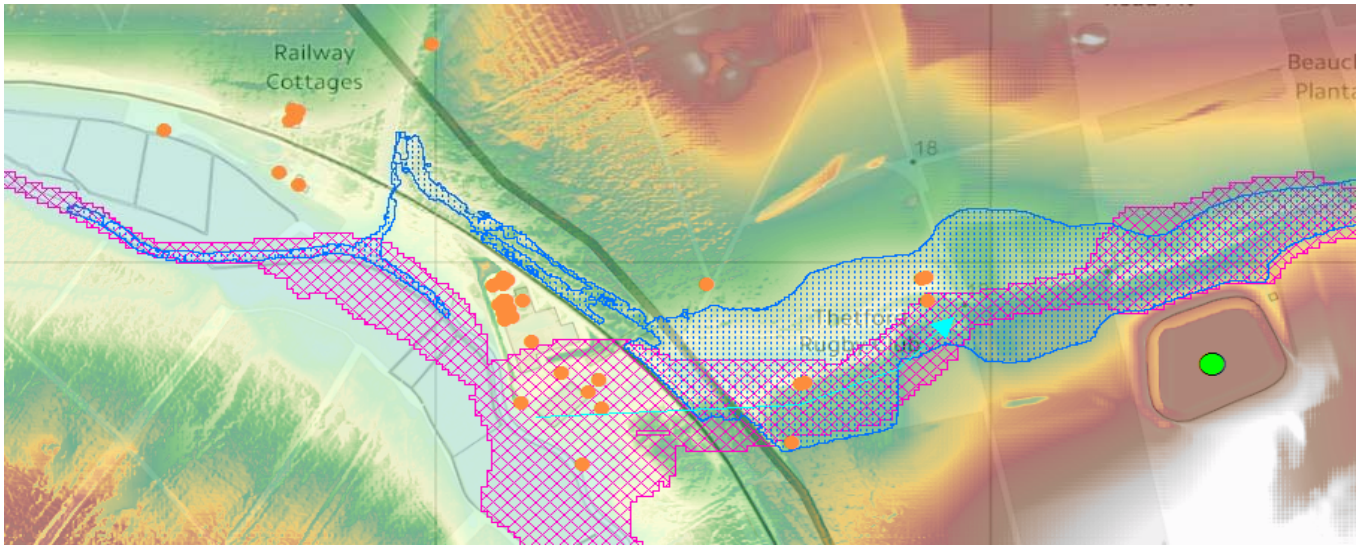
# Reservoir data quality

- NRIM exercise of 2009-2010 revealed many problems with reservoir data on public register
  - No explicit freeboard in many cases
  - Inconsistent dam heights/surface area/volume
- Change to legislation in 2013 (Reservoirs Act 1975 SI 1677) – additional requirement for TWL and crest level
- Data collection and review exercise started in August 2016
  - Contact all reservoir undertakers cc. supervising engineers
  - Review by reservoir engineer before entry to EA database

# Downstream Data Quality

## EA_IHM_2014 DTM @2m vs Next Map SAR @10m



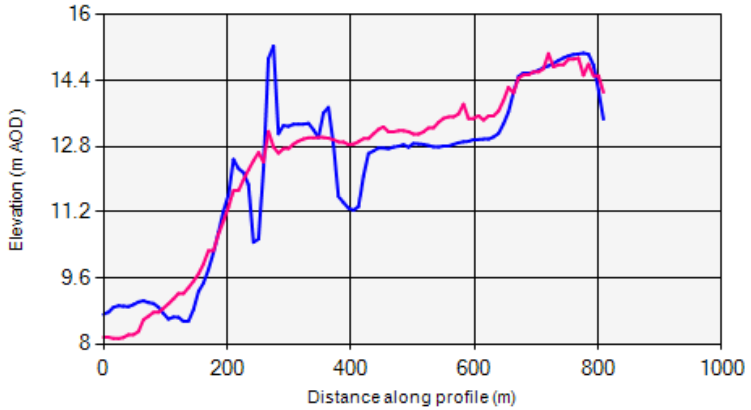

Reservoir location

NRD property point

flood extent 2m res

flood extent 10m res

2m profile 10m profile



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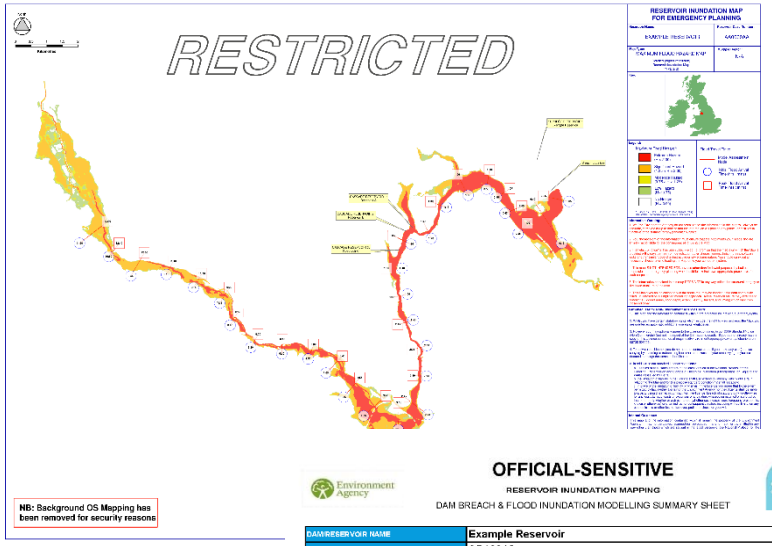
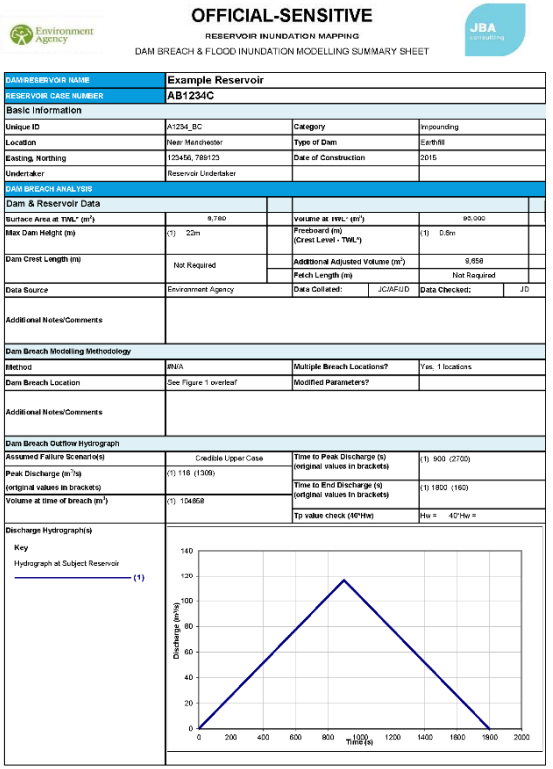
# RFM Outputs

- Maps for Wet & Dry Day
  - Max depth, velocity, hazard
  - Flood extent




- Flood modelling summary sheet
  - Records software used, QA info, cascade details, all modelling decisions
- Consequence Analysis
- All models (input data files)
- All GIS datasets



OFFICIAL-SENSITIVE

RESERVOIR INUNDATION MAPPING

DAM BREACH & FLOOD INUNDATION MODELLING SUMMARY SHEET

| | | | |
|---|---|---|---|
| DAM/RESERVOIR NAME | Example Reservoir | | |
| RESERVOIR CASE NUMBER | AB1234C | | |
| **Basic Information** | | | |
| Unique ID | A1234_BC | Category | Impounding |
| Location | Near Manchester | Type of Dam | Earthfill |
| Easting, Northing | 123456, 789123 | Date of Construction | 2015 |
| Undertaker | Reservoir Undertaker | | |
| **DAM BREACH ANALYSIS** | | | |
| Dam & Reservoir Data | | | |
| Surface Area at TWL* ($m^2$) | 9,780 | Volume at TWL* ($m^3$) | 95,000 |
| Max Dam Height (m) | (1) 22m | Freeboard (m) (Crest Level - TWL*) | (1) 0.6m |
| Dam Crest Length (m) | Not Required | Additional Adjusted Volume ($m^3$) | 9,658 |
| | | Fetch Length (m) | Not Required |
| Data Source | Environment Agency | Data Collated: JC/AF/JD | Data Checked: JD |
| Additional Notes/Comments | | | |
| **Dam Breach Modelling Methodology** | | | |
| Method | #N/A | Multiple Breach Locations? | Yes, 1 locations |
| Dam Breach Location | See Figure 1 overleaf | Modified Parameters? | |
| Additional Notes/Comments | | | |
| **Dam Breach Outflow Hydrograph** | | | |
| Assumed Failure Scenario(s) | Credible Upper Case | Time to Peak Discharge (s) (original values in brackets) | (1) 900 (2700) |
| Peak Discharge ($m^3/s$) (original values in brackets) | (1) 118 (1309) | Time to End Discharge (s) (original values in brackets) | (1) 1800 (162) |
| Volume at time of breach ($m^3$) | (1) 104858 | Tp value check (40*Hw) | Hw = 40*Hw = |
| Discharge Hydrograph(s) | Key: Hydrograph at Subject Reservoir (1) | | |



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# Summing up and next steps

- The 2009 reservoir flood maps have greatly improved public understanding of potential consequences of dam failure
- Second generation maps will build on this
- Updated specification has been completed
- Data collection & review exercise started
- Tender with WEM suppliers for national programme of RFM
  - First 400 reservoirs by March 2017
  - Remainder (1465 reservoirs) by March 2019



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

Dr Andy Hughes

Director of Dams & Reservoirs

# Operation

- Conflicting demands – operation/maintenance
- Legal responsibilities
- But how much is enough?

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# Historical change

- 1990’s cut backs
- Loss of staff - retirement / change
- Succession planning / Knowledge transfer ?

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# What does an Owner have to provide?

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- Supervision  (SE)
- Inspection
- Record Keeping
- Surveillance and Monitoring
- Maintenance

# What has this has led to ?

- 1990’s cut backs
- Led to enforcement of maintenance issues
- Loss of staff – people not coming into reservoirs
- Procurement changes - Frameworks

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# Where are we now ?

- Frameworks – good or bad ??????!!!!
- Ageing Engineers  - are we training properly?
- Encouraging – making it easy ? /  IE initiative !
- Status of the Engineer in Society
- Young Engineers ( YEF )
- Arkwright Scholarships

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# Judgement must prevail

- From Panel Engineers
- From Regulators
- Via documentation / guidance
- Must teach people to exercise pragmatism
- Mentoring

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# Surveillance

- ensure safety
- but it costs
- how many times do we go ?
- what do people do when they get there?

- via a workshop ( owner / SE / Panel Engineer)

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# Depends on ….

- types of dam
- complexity
- historical performance
- etc etc

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# An Approach ….might be

| Ref | Standard | Frequency |
|---|---|---|
| **'A'** | Take water level and do walk around consisting of walk over of crest (looking at upstream face), mitres, downstream face (where applicable) and toe. | Every visit |
| **'B'** | 'A' standard plus weekly readings of instruments and look/listen down shafts and up tunnels. | Every week |
| **'C'** | 'A' standard plus monthly readings, weekly readings and walk through tunnels and shafts. | Every month |

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# Other aspects might include…

- geographical area
- access
- transport
- lone working policies
- past history
- confined spaces
- etc etc

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# Resource plan

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Having done that you can progress to a resource plan:

- number of staff
- sickness/holiday cover/geographical cover
- training ES1 / ES15 / ES16
- but also WT30 (City and Guilds) for operators
- Emergency Planning  - this year

# Conclusion

Be sure you can ;

- Show logical approach
- Be able to defend it
- Follow best practice
- Challenge yourself
- Consider costs / training / outcomes

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# Thank you

Andy.hughes@atkinsglobal.com

BUILDING A WORLD OF DIFFERENCE

# Guides and Guidance: A Luddite view of guidance

A paper by Chris Scott, All Reservoirs Panel Engineer, Black & Veatch Ltd

Presented by Rachel Pether, Principal Engineer, Black & Veatch Ltd

BLACK & VEATCH
Building a world of difference:

**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.

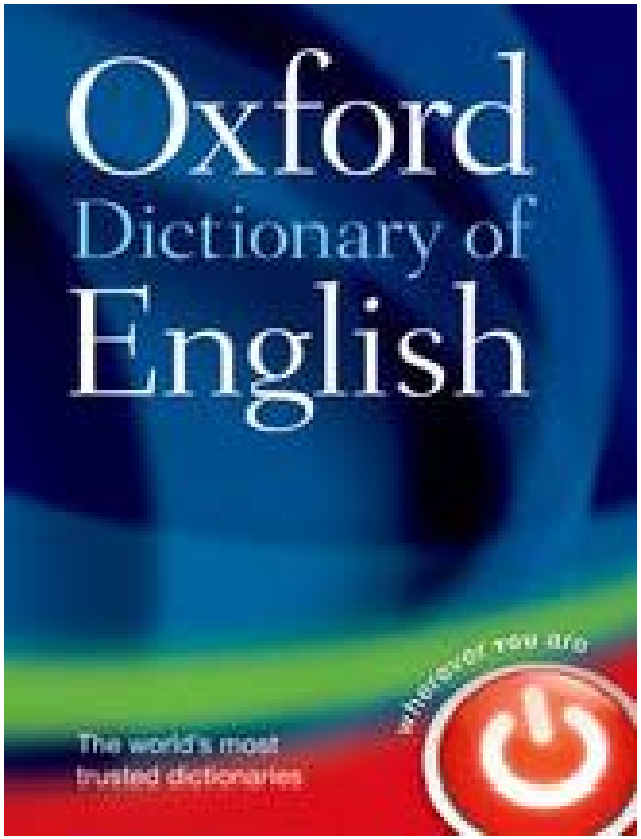
# Some definitions

**Guide** (noun)

- a book, document or display providing information on a subject

**Guidance** (noun)

- advice or information aimed at resolving a problem or difficulty



# What is the purpose of Guidance?

## Some evidence …

### Floods and Reservoir Safety (1978)

- "This guide is intended to assist those individuals who bear the personal responsibility that comes with being appointed to the statutory panels of engineers qualified to design and inspect impounding reservoirs."

### Wright, Coates & Charles (1992)

- "The research is designed to provide Panel Engineers with an appropriate and consistent background for carrying out their duties under the Act."

## An opinion

Guides are intended to assist panel engineers, undertakers and others with roles related to statutory reservoirs to the fulfil their roles and the purpose of reservoir safety legislation.

**Guides should provide background, context and tools, <u>not</u> mandate or instruct**

# delivering benefits through evidence


Guide to risk assessment for reservoir safety management

**Extract from Volume 1, Section 2.3.2, regarding Inspecting Engineer's Reports.**

"The report should state explicitly the significant failure modes identified through a potential failure mode identification process. … Although not a legal requirement, it is recommended that it should also include the equivalent of a Tier 1 qualitative risk assessment."

(auxiliary verb)
Used to express duty or obligation

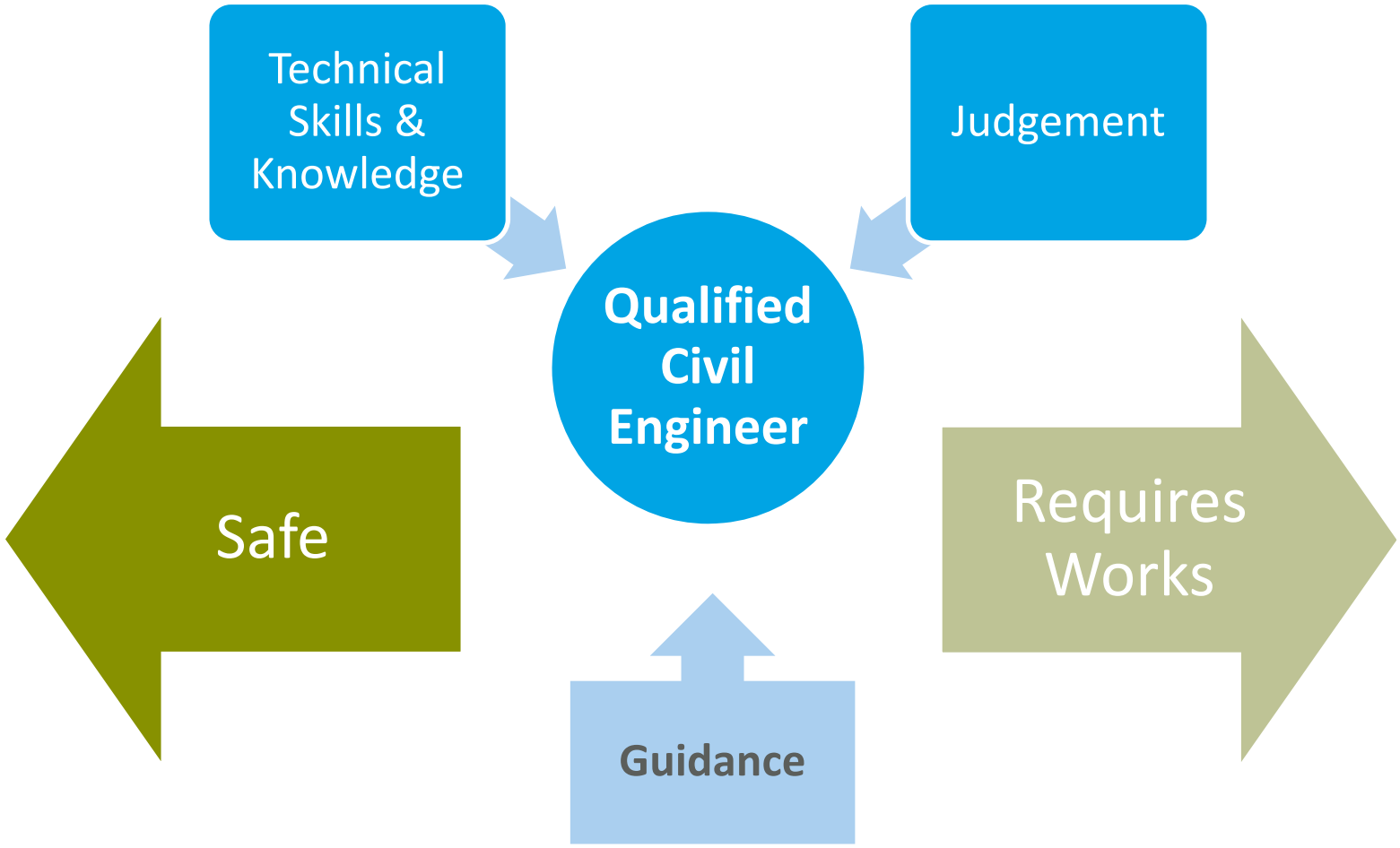
# What are the skills and capabilities needed for the reservoir engineers of the future?

The ability to assimilate and apply extensive prescriptive guidance in a manner that will pass external audit

**OR**

The ability to develop creative solutions that fulfil the needs of reservoir owners while maintaining public safety

# Guidance should support rather than dictate



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# Together

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**Session Chair: Richard Cox**
**Technical Reporter: Mark Acford**

## Amendments to the Reservoirs Act 1975 in Wales and Natural Resources Wales Potential Reservoirs Project (O'Brien and Morris, p3 of Proceedings)

**Question: Jim Claydon (J R Claydon Ltd)**
The project only refers to bathymetric surveys to top of silt for calculating reservoir capacity. How was allowance made for estimating the volume of silt that should be considered as part of the escapable contents?

**Answer: Dr Andy Hughes (Atkins Global)**
A bathymetric survey should attempt to identify the volume of silt. Sonar or GPS should be supplemented with the use of ranging rods pushed into the reservoir bed to estimate the accumulation of silt. This is especially true at the reservoir head where a panel engineer should then make a judgment on the volume of silt that may flow in the event of a dam failure.

**Question: Robin Hawley (Independent Consultant)**
Natural Resources Wales mentioned identifying 26 reservoirs between 10,000m³ and 25,000m³. How many of those are service reservoirs, or are service reservoirs not under consideration?

**Answer: Matt O'Brien (Natural Resources Wales)**
Service reservoirs are subject to registration under the amended legislation. There is service reservoirs among the existing registered reservoir and those soon to be registered.

**Question: Peter Kelham (Arup Group Limited)**
Could Natural Resources Wales please give a brief summary of any statutory instruments that have been issued to implement the Reservoirs Act in Wales?

**Answer: Matt O'Brien (Natural Resources Wales)**
Three Statutory Instruments came into force in April. The first of those is the Commencement Order which brings the Flood and Water Management Act changes to the primary legislation into force and introduces for example the requirement to make risk designations.

Two further Statutory Instruments prescribe records, inspections and exemptions etc:

- The Reservoirs Act 1975 (Capacity, Registration, Prescribed Forms, etc.) (Wales) Regulations 2016
- The Reservoirs Act 1975 (Exemptions, Appeals and Inspections) (Wales) Regulations 2016

The Statutory Instruments are available on the legislation.gov.uk website, a link to which can be found on the Natural Resources Wales website.

No further new Statutory Instruments are anticipated in the near future.

**Question: Ian Hope (Severn Trent Water)**
Could Natural Resources Wales please give further information on the introduction of charging for reservoir safety regulation? Is there a scale of charges, a single charge; is it annual and what is the likely cost?

A supplementary question to Tony Deakin of the Environment Agency, are there similar plans for regulatory charging in England?

**Answer: Matt O'Brien (Natural Resources Wales)**
Where a legal mechanism exists for a regulator to charge for its function the view of government is that it is unfair for costs to be borne by the public purse.

A public consultation on charging for reservoir safety regulation in Wales is due to be launched shortly.

The current proposal is for a registration fee of approximately £500 to apply to newly registered reservoirs. The registration fee will apply to reservoirs registered after the introduction of the charging scheme.

There will be an annual subsistence fee applicable to all registered reservoirs. This will be in the region of £250 for a high-risk reservoir and £150 for a not high-risk reservoir. The costs are subject to the results of the public consultation.

**Answer: Tony Deakin (Environment Agency)**
Defra is working to determine the appetite for charging and will be looking at work done by the Scottish and Welsh governments. Before the commencement of any charging scheme in England a public consultation would be undertaken.

**Question: Paul Monaghan (City of London)**
Are charges applied to reservoirs in public ownership?

*This question was unanswered.*

## Updating the English Reservoir Flood Maps (Deakin *et al,* p15 of the Proceedings)

**Question: Robert Mann (Aecom)**
The flood mapping exercise will produce very valuable data on the downstream effects of a dam breach, particularly the likely loss of life. This would be valuable for reservoir owners and their professional advisors. The data will be derived at public expense yet it is restricted by national security protocols. I urge that it be made available without undue hindrance or limitations, on a secure basis to owners and panel engineers to assist in the safe management of our reservoirs.

**Answer: Tony Deakin (Environment Agency)**
The Government in England has recently set the principles of open data where in principle any data we hold should be freely available to all. Exceptions to this are personal information, commercially sensitive information and security sensitive information. There is currently a data handling and security protocol applicable to reservoir flood maps which we are required to follow. We are in the process of working with colleagues in Wales and Scotland to determine whether the protocol can be amended within the principles of open data. It is hoped that towards the end of this year we will be in a better position to determine what data we can share.

**Question: Julian Welbank (Wessex Water)**
When the new flood mapping has been completed is it the intention to re-visit risk designations? Wessex Water has had the benefit of having three reservoirs designated not high-risk. I understand that these designations would only change as a result of development downstream. Is it the case that the risk designation might change in light of new information from the new flood maps?

**Answer: Tony Deakin (Environment Agency)**
If new information which allows us to make a better judgement on risk designations is available we will use it. If it highlights a potential downstream consequence that was previously not identified, the risk designation could be changed. The first of the new flood maps will be targeted at reservoirs where there is an unresolved challenge to a high-risk designation and where we are aware of an error in the current mapping. We do not propose to routinely review high-risk designations unless these designations are challenged.

**Question: Paul Monaghan (City of London)**
City of London has detailed flood maps for their reservoirs produced to a high specification. Concern that the fact the maps are being updated suggests that the previous maps are wrong and were a waste of money, and the change in specification and accuracy appears to confirm this.

**Answer: Tony Deakin (Environment Agency)**
In the 2007 Ulley Reservoir incident there were no flood maps to assist Gold Control in managing the consequences should the dam have failed. Emergency planners at the time had to resort to OS contour maps to try to determine what and who would be endangered by a dam failure. There was little good information on which to base the potential evacuation of up to 2000 people.

The 2009 Reservoir Inundation national mapping project was a response to the Pitt report and aimed to give a broad picture of the consequences of a dam failure. The maps are a useful tool in demonstrating the potential consequences of a dam failure.

The updated specification will build upon the existing mapping giving an improved picture of the potential consequences of a dam failure for a variety of users to benefit the people at risk.

## Operating Procedures For Ensuring Reservoir Safety – How Do You Do It – Too Much or Too Little? (Hughes, p 65 of the Proceedings)

**Question: Richard Cox (Environment Agency)**
Is there any support among the undertakers for the production of a best practice guide on the quantity of surveillance appropriate in different circumstances or is it just between the inspecting engineer and his client?

**Answer: Dr Andy Hughes (Atkins Global)**
Undertakers are looking for direction from panel engineers on what level of surveillance is appropriate. Historically reservoirs were visited every day of the week by the undertaker's staff but cutbacks have reduced the frequency of surveillance.

The level of surveillance which is appropriate is entirely dependent upon the type of dam, its construction type, history, potential failure modes and how quickly a failure might propagate. It is not possible to generalise as appropriate surveillance is site specific and can have significant resource repercussions for the undertaker.

**Guides and Guidance: A "luddite" view of guidance** (Scott, p57 of the Proceedings - presented by Rachel Pether)

**Comment: Robert Mann (Aecom)**

I fully agree with the implied criticism of the inclusion in the RARS guide for the requirement for a Tier 1 risk assessment in a Section 10 inspection. I don't include one unless it is necessary but the guide states the Inspecting Engineer has to give a good reason for not doing this. Panel engineers routinely give consideration to how a dam can fail and whether observed deficiencies could contribute to the possible failure. Risk assessment is inherent as part of the inspection process not necessarily requiring a Tier 1 written process.

*The following paper was not presented at the conference, but discussion was invited in this session.*

## Building on RARS: development of key themes (Peters *et al*, p 43 of the Proceedings)

**Question: Robert Mann (Aecom)**

I would like to congratulate the authors on an interesting and informative paper. The paper assigns an "Index Annual Probability of failure" related to the presence and capacity of low level outlets. It recognises that [lack of] provision of a low level outlet does not in itself create a risk of failure but it does affect the ability to avert failure. This is considered as a hypothetical failure mode, as a simplification from the rigorous approach of applying a conditional probability to those dam failure modes that might be averted by drawdown.

The assigned Index probability is a "notional" probability taken to range between upper and lower anchor points, selected notionally as near the upper and lower ends of the range of the ALARP zone on the standard F-N chart, and then adjusted according to the embankment speed of failure in Table 4. The result of this selection is that the upper and lower points (representing no draw-down provision and fully compliant provision respectively) represent failure probabilities 3 to 4 orders of magnitude apart. That is, fully compliant drawdown gives an assigned notional probability of failure of 1/1000 or 1/10,000 of that where no draw-down provision is available.

Unless I am mistaken, this difference between anchor points seems far too high as it is equivalent to assigning a 99.9% or 99.99% notional probability that fully compliant drawdown facilities will succeed in averting failure. This is clearly not the case, as drawdown has inevitable limitations: not all failure modes can be averted by drawdown, drawdown at compliant rate is only practicable when there is no flood or spate inflow taking place, and there is inevitably risk of human, communication, access or equipment failure on the day. I suggest that such limitations can and should be factored in to bring about a more credible range between the assigned notional anchor points. The 2004 Interim Guide treats [lack of] drawdown provision as a contributory factor affecting the Current Condition Score, and the draft Drawdown Guide states that the effect of having no drawdown capacity is "broadly equivalent to doubling the probability of failure". In view of the above limitations, I suggest this is a more valid assessment.

As it stands, the notional probability of failure assigned to [lack of] drawdown provision in the paper seems to fit reasonably well amongst the other actual failure modes assessed and presented in Figure 2, and might not cause me to take issue with it when used for comparative purposes only. However, the stated objective includes to "provide a business case for increasing the capacity" and therefore I think that in view of the limitations that I refer to above, the business case derived for increasing drawdown capacity appears to be very substantially over-stated.

Therefore I regard the index probabilities attributed to draw-down provision as not reliable for use in any ALARP study to determine a business case for substantial works to increase drawdown. I suggest that meantime any study used to establish a business or ALARP case for such works should use, or be verified by, a QRA study at Tier 2 or higher level that specifically considers [lack of] drawdown, together with the limitations that I refer to, as a conditional probability to apply to the relevant failure modes.

I would welcome the authors' comments.

**Response: Anthea Peters (Arup) & Alan Brown (Stillwater Associates)**

Firstly can we draw attention to a correction to the paper, in that on page 48 in text lines 5 and 6 from the bottom of the page the numbers 10 and 100 should be reversed, so that the text should read:

- Slow speed of embankment failure – ASLL ≥ 100.
- Medium of fast speed of embankment failure – ASLL ≥ 10

Robert raises a number of separate issues, namely:

a) The concept of index probability of failure due to insufficient drawdown capacity, suggesting that the anchor points cited in the paper are too far apart.

b) The index probability approach does not reflect the true incremental effect of drawdown capacity on likelihood of failure due, for example, to internal erosion.

c) Any study to establish a business case for substantial works to increase drawdown capacity should be verified by a QRA study at Tier 2 or higher.

The index probability approach is intended to be used as a screening risk assessment, to rank a substandard drawdown capacity with other threats to the dam, and thus identify for which features of the dam a more detailed RA would be worthwhile. We suggest that the concept is valid, and the values adopted reasonable, provided it is accepted that it is not intended as an absolute measure of likelihood of failure, but is a tool to rank absence of (or substandard) drawdown capacity with other threats to dam safety. It is particularly useful when applied as part of a portfolio risk assessment (which is the use described in the paper). We would also emphasise that risk assessment is an aid to judgment and should not be the sole arbiter on adequacy of the safety of a dam.

A possible refinement to the anchor points presented in the paper could be as follows:

| **Anchor point** | **Consideration** | **Suggested criteria** | **Comments** |
|---|---|---|---|
| Upper | When a dam has no fixed drawoff capacity, how should this be ranked against other threats? | Intolerable for average societal life loss (ASLL) of ten, which from the RARS FN chart is equivalent to likelihood of failure (LOF) 1 in 1000 | This is a given in the paper (although the paper suggests for slow failure, as defined in Box 8.2 of RARS, it may be more appropriate to use ASLL of 100 and LOF of 1 in 10,000) |
| Lower | When a dam has a drawoff capacity which fully meets current deterministic standards, what would be the equivalent Index probability? | Assign an index probability equivalent to having a spillway that can pass PMF as the safety check flood, say LOF of 1 in 400, 000 chance per year | It could be argued that this is more defendable than the 1 in 10 million value quoted in the paper<br><br>For very high consequence dams, these low LOF becomes questionable and instead the safety case suggested in Brown & Hewitt (2016) may be more appropriate |

We agree that before any works are carried out to increase drawdown capacity a more detailed risk assessment should be carried out, and suggest that the event tree approach in Section 8.3 of RARS may be helpful in considering the effect of drawdown capacity. However, for internal threats to embankments this is in effect a Tier 3 analysis, being equivalent to the Bureau of reclamation "Best Practices and Risk Methodology" chapter IV_4 Internal Erosion Risks for Embankments and Foundations (http://www.usbr.gov/ssle/damsafety/risk/methodology.html).

With this approach drawdown capacity is considered as part of Phase 7 "Unsuccessful detection and intervention", where Reclamation states "*Evaluating factors related to detection and physical intervention actions is very site-specific and requires judgment and subjective probability estimates (see Chapter I-6 Subjective Probability and Expert Elicitation)".* We note the forthcoming Environment Agency "Guide to drawdown capacity for reservoir safety and emergency planning", so compliance with this Guide would also be an important consideration in determining whether upgrading works to increase drawdown capacity needs to be considered.

We draw attention to one of the findings from the Environment Agency research contract "Guide to drawdown capacity for reservoir safety and emergency planning", that for some dams with highly erodible soils it is not physically practicable to provide drawdown capacity large enough to prevent failure once internal erosion has progressed to a concentrated leak through the dam. For these vulnerable dams filters and other control measures will need to be particularly robust. This supports the need for detailed site specific failure modes identification and risk assessment before embarking on physical works to increase drawdown capacity, as at some dams other control measures may be more appropriate.