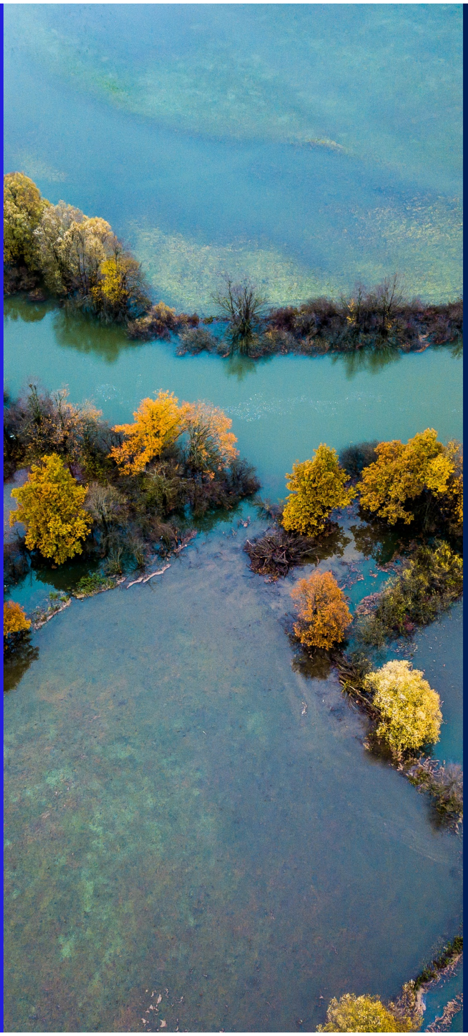
Jacobs Challenging today. Reinventing tomorrow.

Reservoirs Underpinning Civilization

Challenges and solutions in managing reservoir safety

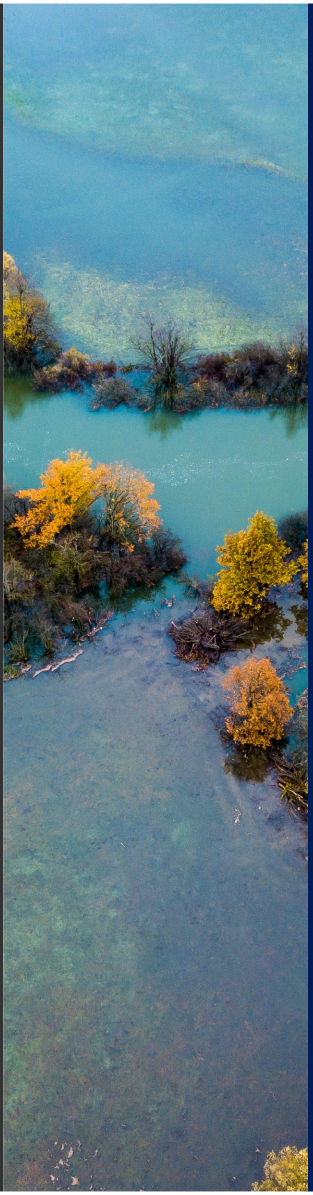
In the kNOW Webinar Series

Feb. 10, 2021



Agenda

- **Alan Brown,**
  Jacobs Global Technology Lead for Dams
- **Mark Zinniker, PE,**
  Generation Engineering Supervisor for the Eugene Water & Electric Board
- **Nason McCullough, PhD, PE, GE,**
  Jacobs US Regional Technology Leader for Dams
- **Stephen Naylor,**
  Reservoir Safety Manager for Environment Agency South East England
- **Andy Courtnadge,**
  Jacobs UK Discipline Lead for Dams

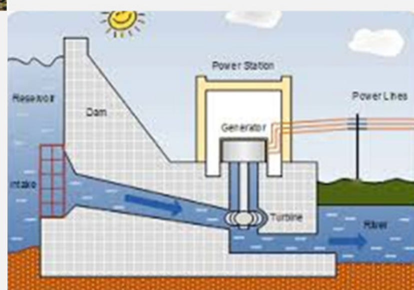


Reservoirs Fundamental to Civilization

Water supply
(upland reservoirs; service reservoirs)

Food
(store winter rains for summer Irrigation)

Electricity
(hydro-electricity)



Civilization:
Human society with comfortable living conditions

Flood risk management
Protection to houses in flood plain

Travel
(Pollution control lagoon - airport deicer)

Recreation
(Surf Snowdonia, sailing, fishing etc)

Challenges: Notable Dam Failures

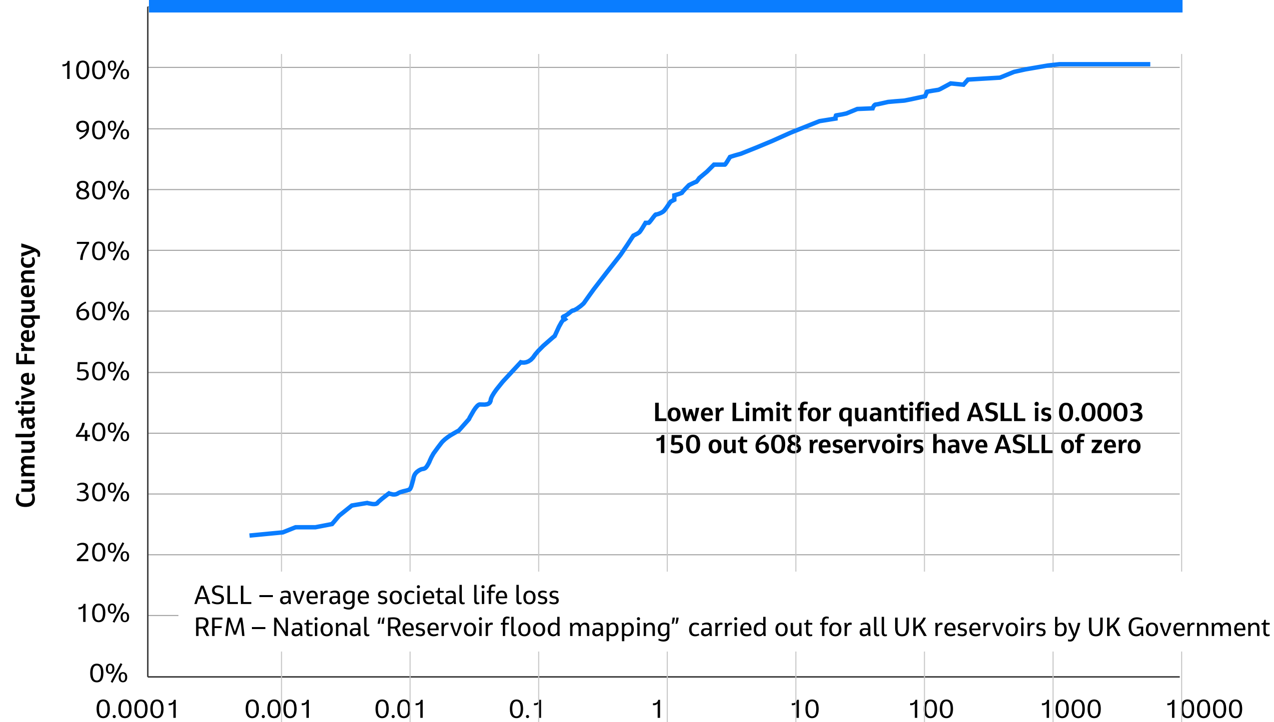
UK	US	
1864 Dale Dyke	**1889 South Fork, Pennsylvania**	**1976 Teton dam**
95 ft high dam failed releasing flood through the centre of Sheffield	Overflow of 72 ft dam in large flood	270 ft deep reservoir drained in less than 6 hours, travelled 155 miles downstream
250 dead, 5000 houses destroyed	2209 dead and $17Million (1889) damages	11 dead and $400million damages
Cause: Binnie, 1978: Hydraulic fracture in core on first filling, due to differential settlement of deep puddle clay cut-off trench With further failures in 1925 led to "Reservoirs (safety provisions) Act 1930"	Investigation by ASCE (American Society of Civil Engineers) in 1891 – alterations by non-technical owner	Rethink of design reviews; focus on internal erosion

Challenges: Understanding the Range of Potential Consequences of Failure

UK dams
– potential consequences of failure

- Vary by seven order of magnitude
- Range from over 1000 dead to
- 25% having less than 0.1 chance of one fatality
- And 25% have zero ASLL

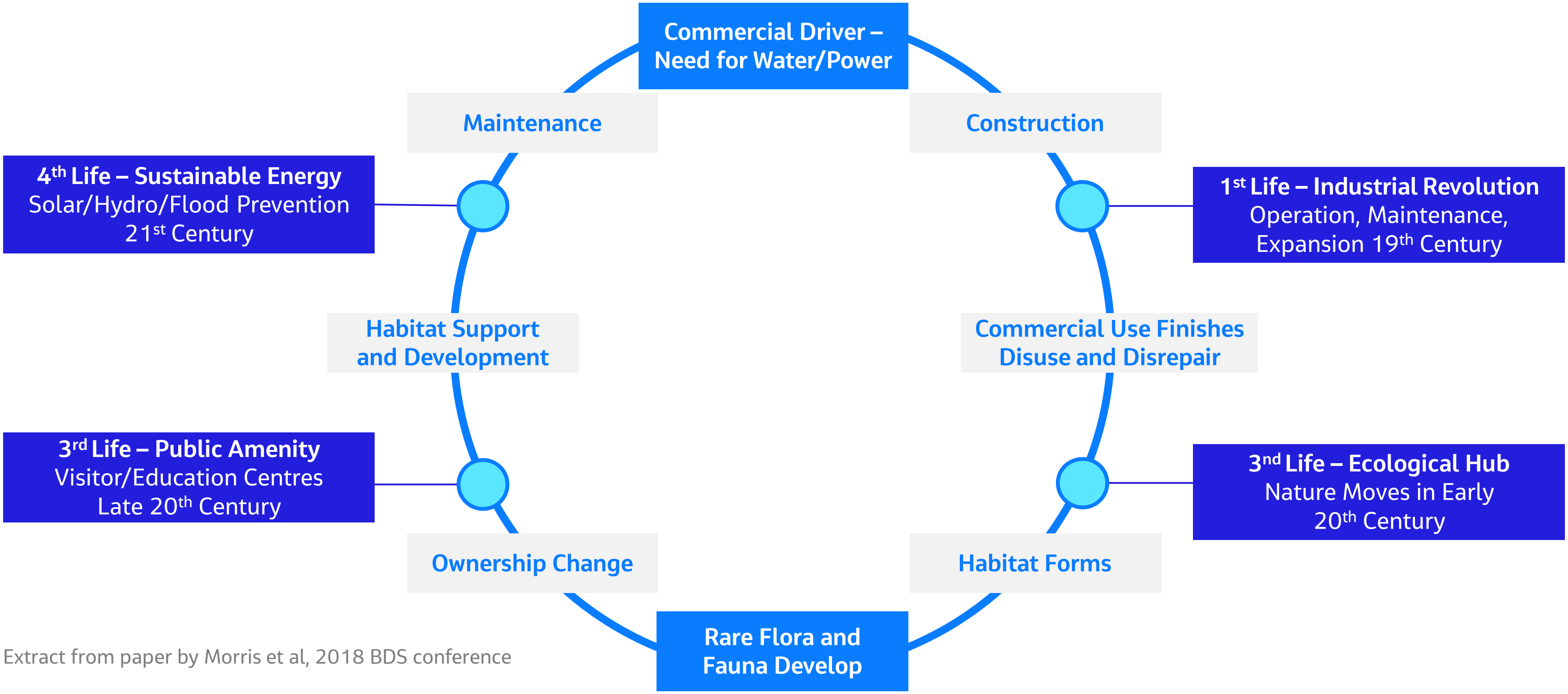
Figure 11: Cumulative frequency of ASLL based on RFM data



Source: Analysis by Mott MacDonald (2019) using RFM data provided by the EA (Environment Agency, 2019)

Extract from UK Defra research March 2020
FD2701 – Objective 3

Challenges: Environmental Aspects of Reservoirs Discontinuance? Or/ Repurposing? – Experience in Wales

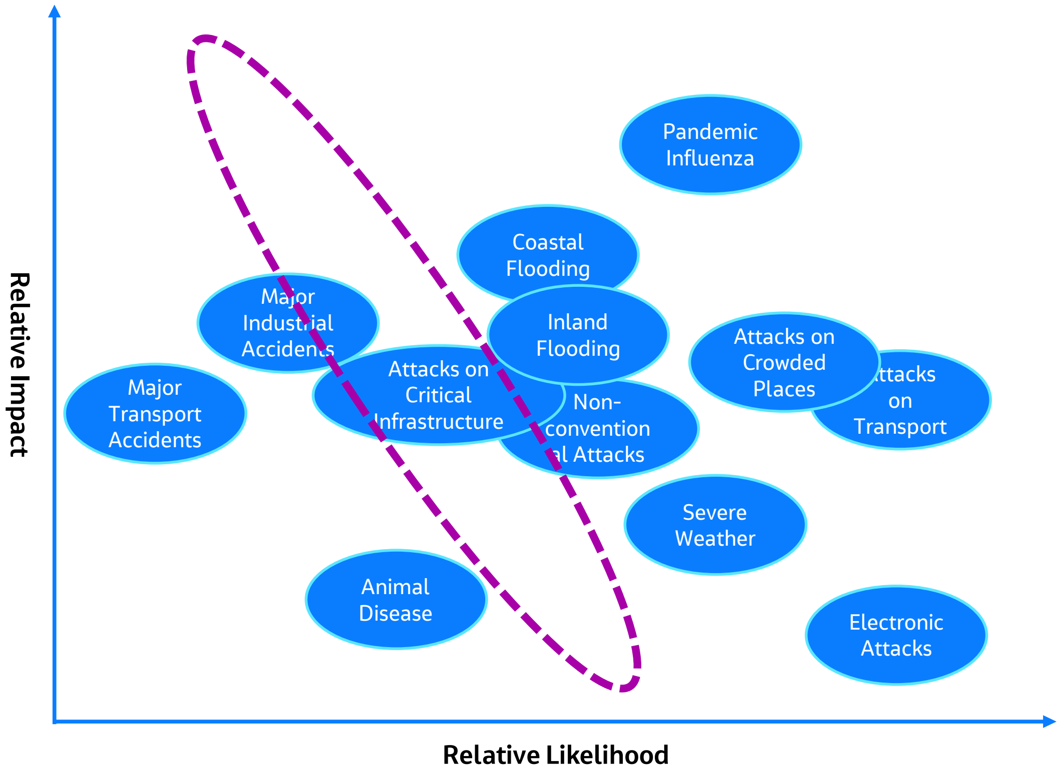


Extract from paper by Morris et al, 2018 BDS conference

Challenges: Comparing Reservoir Failure with Other Risks to Our Community

- National Risk Register is a report first released by the Cabinet Office in August 2008
- Updated every 2 - 3 years
- Using risk assessment as one of the tools to protect our community

Figure 1: An illustration of the high consequence risks facing the United Kingdom



https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/61934/national_risk_register.pdf

Solutions: Tools for Managing the Risk from Dams

Structural	Non-structural
Setting design standards	**Organizational awareness**
Enlarge spillways	Maintenance (drains, concrete joints, embankment etc)
Filters and drain to control internal erosion	Improve monitoring (instruments)
Cut-off walls through dam to cut–off foundation seepage	Surveillance
Drawdown capacity to lower reservoir in event of structural problem	Emergency planning
	Periodic risk assessment/ safety review

Challenges and Solutions in Managing Reservoir Safety:

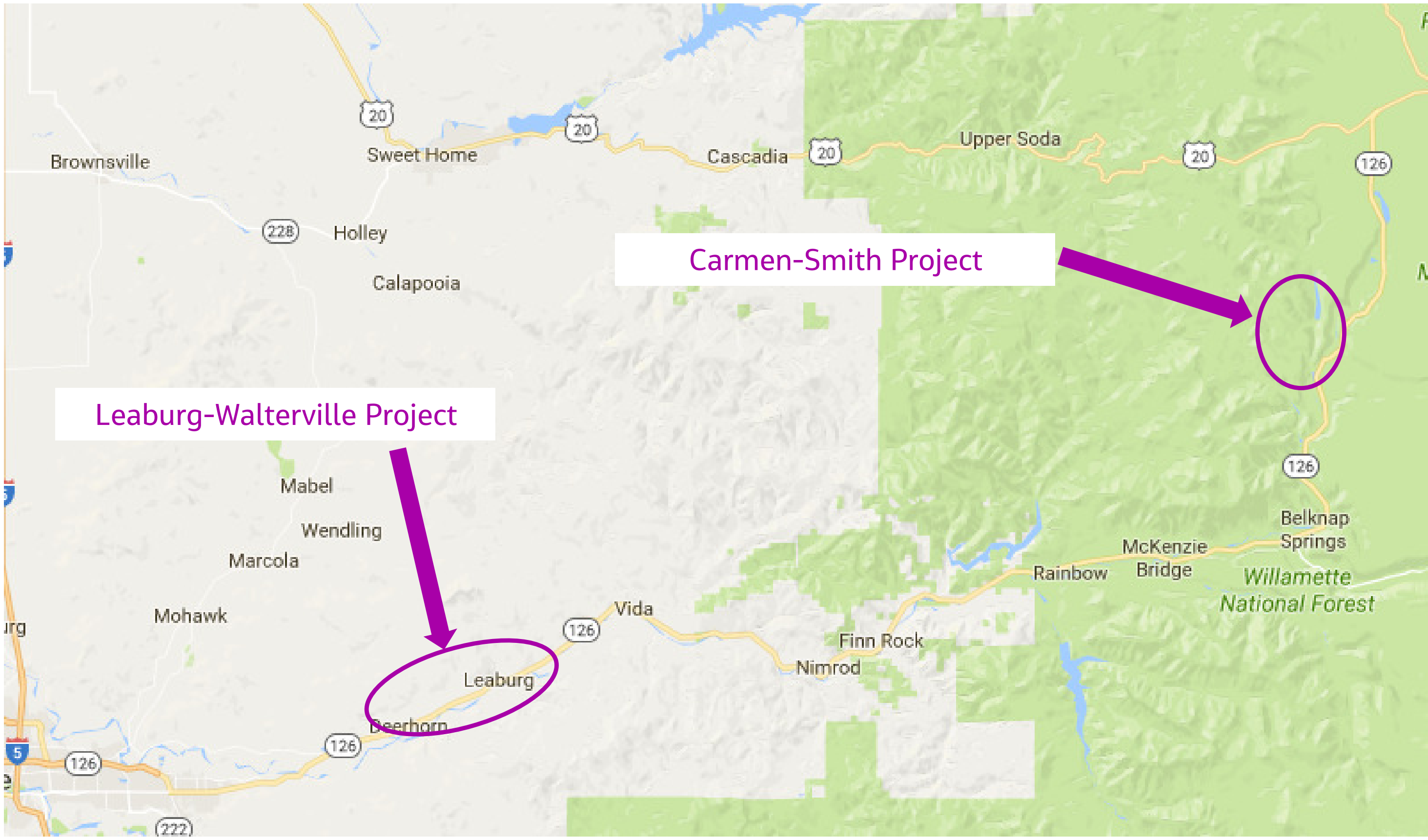
- Reservoirs underpin (facilitate) civilization – water supply, irrigation, hydropower etc.
- Challenges
  - Reservoirs vary in age – early Industrial Revolution through to modern dams
  - Potential for catastrophic failure of dam/ reservoir release
  - Climate change; improved understanding of natural hazards, aging
  - Human factors – operation/ maintenance etc
- Solutions - Engineers contributing to public safety
  - Understanding, quantifying and describing the risk
  - Engaging with society to define tolerable risk/ society's priorities
  - Devising and implementing risk reduction measures

Challenges in Hydroelectric Power Generation

Mark Zinniker, PE
EUGENE WATER & ELECTRIC BOARD

McKenzie River Hydroelectric Projects

- Four power plants, 145 MW nameplate
- Three embankment dams, two high hazard
- Two earthen high hazard power canals
- One concrete dam
- Two concrete forebay structures
- Regulated by the Federal Energy Regulatory Commission (FERC)



Regulatory Environment

FERC Licensing Process Settlement Parties

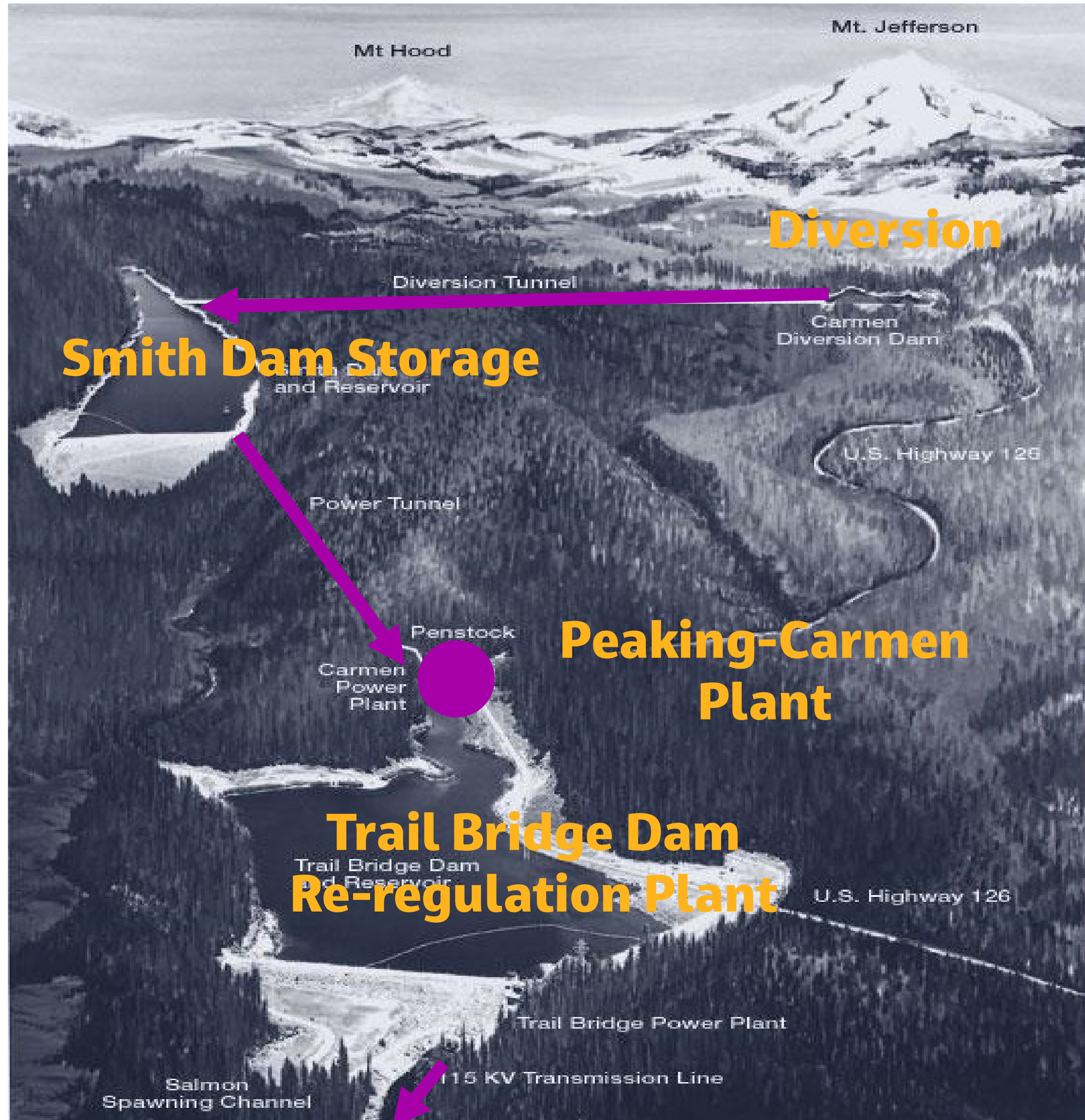
- National Marine Fisheries Service
- US Fish & Wildlife
- US Forest Service
- Oregon Department of Fish & Wildlife
- Oregon Department of Environment
- Oregon Parks and Recreation
- Confederated Tribes
- American Whitewater
- Cascadia Wildlands
- Oregon Hunters Association
- McKenzie Flyfishers
- Trout Unlimited
- Et cetera

Dam Safety Oversight

- Owner's Dam Safety Program
  - Daily, Weekly, Monthly, Quarterly, Annual
- FERC Inspections
  - Annual
- FERC Part 12 Safety Review
  - 5-year

Carmen-Smith Project

- Diversion Dam – 25 feet
- Diversion Tunnel – 2 miles
- Storage Dam – 235 feet
- Power Tunnel – 1.5 miles
- Peak Power Plant, 110 MW
- Re-Regulation Dam – 100 feet
- Re-Regulation Plant – 10 MW



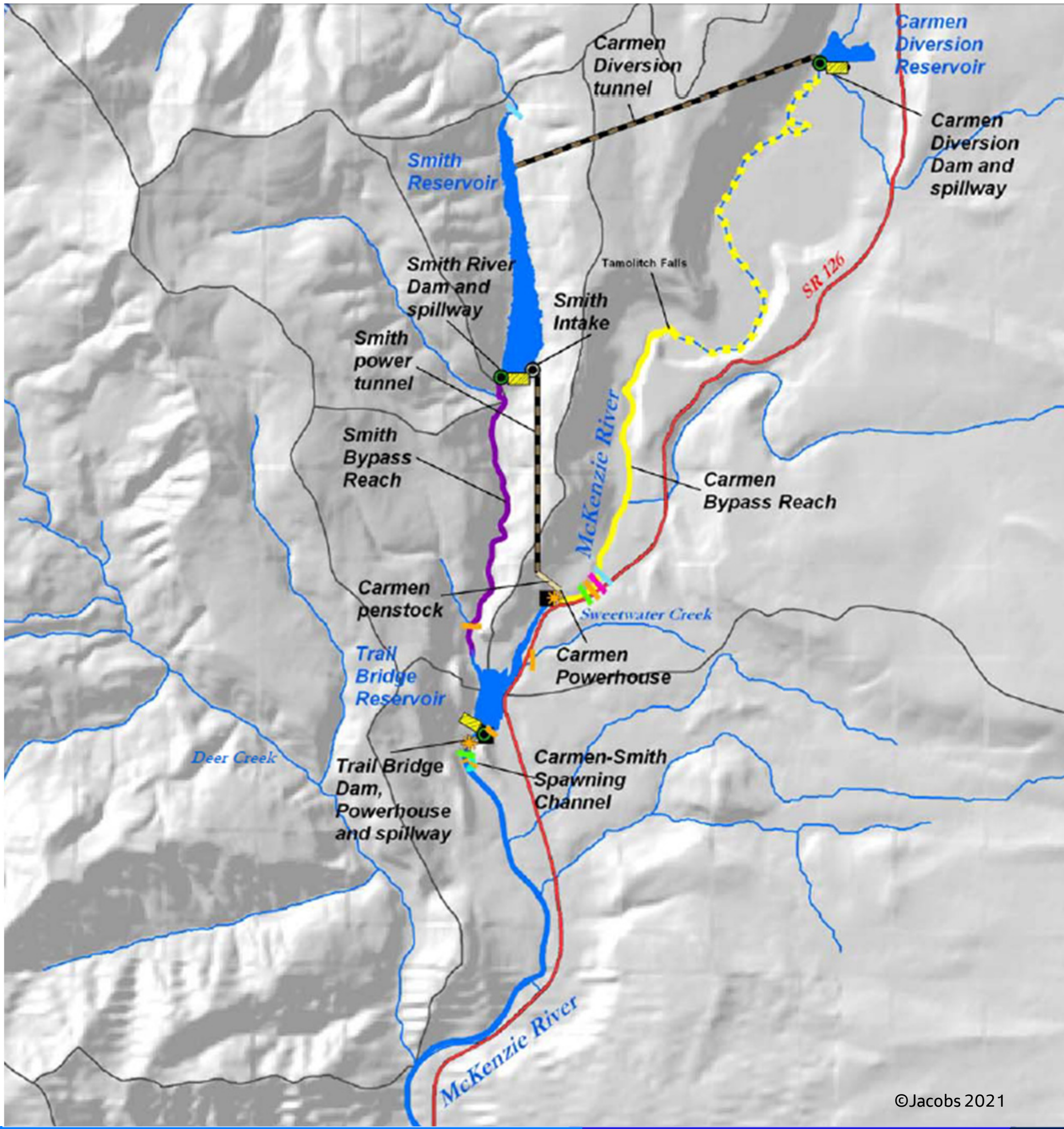
Improvement Obligations

FERC License Requirements

- Upstream/downstream fish passage at Trail Bridge
- Continuous flow release at Carmen Diversion
- Continuous flow release at Smith Dam
- Fish habitat
- Fish habitat protection

Dam Safety Needs

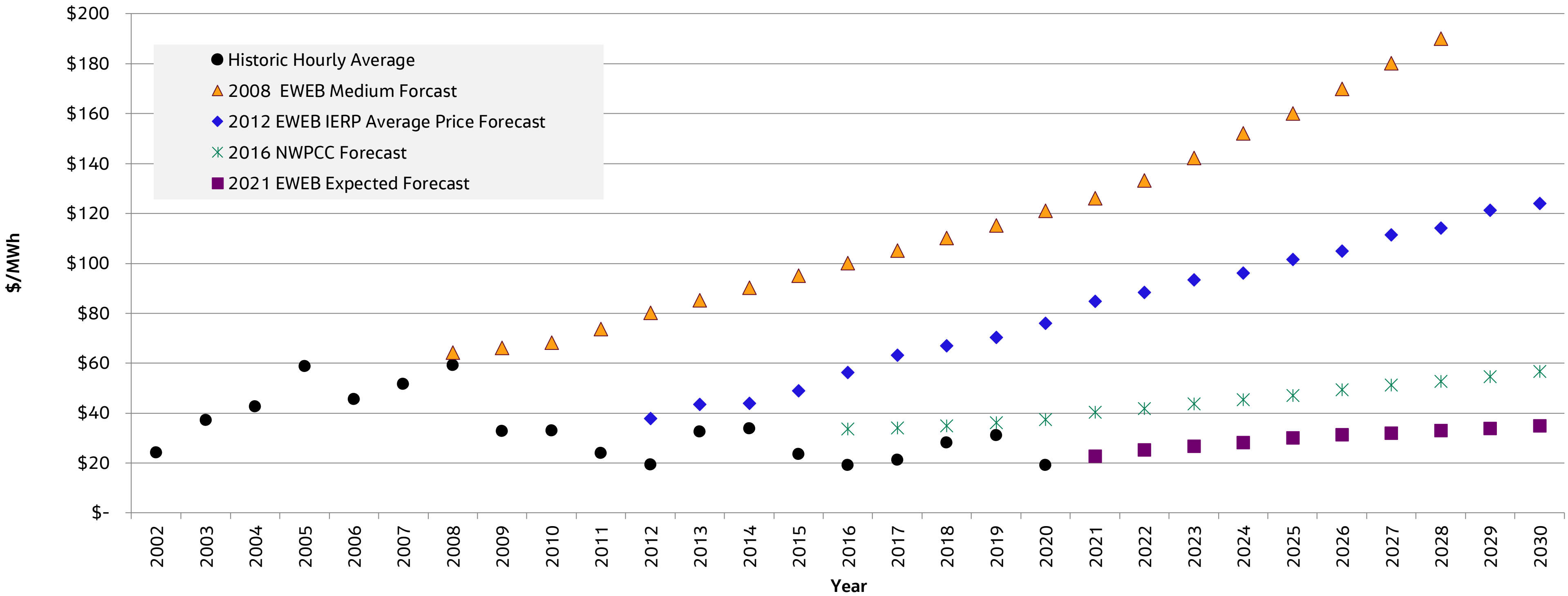
- Increased Probably Maximum Flood (PMF) tolerance
- Climate change
- Seismic design criteria
- Spillway stability
- Carmen Diversion sinkholes



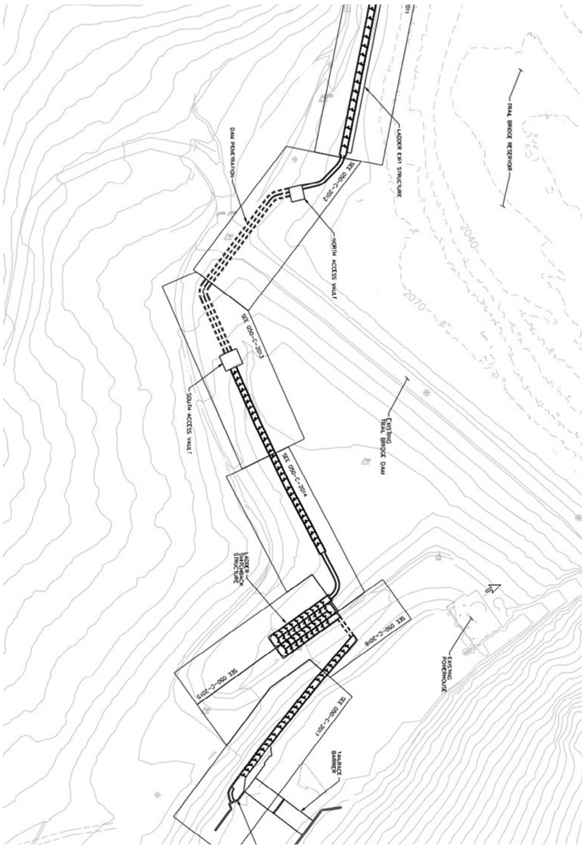
Power Market Dynamics

Impacts from plentiful natural gas

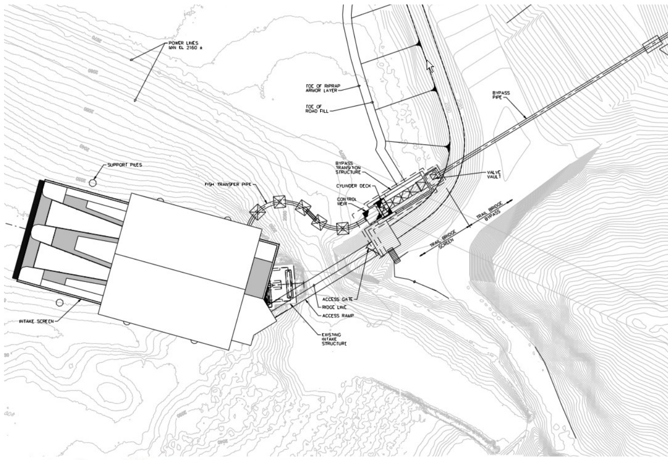
Market Price Forecasts and Historic Hourly Prices

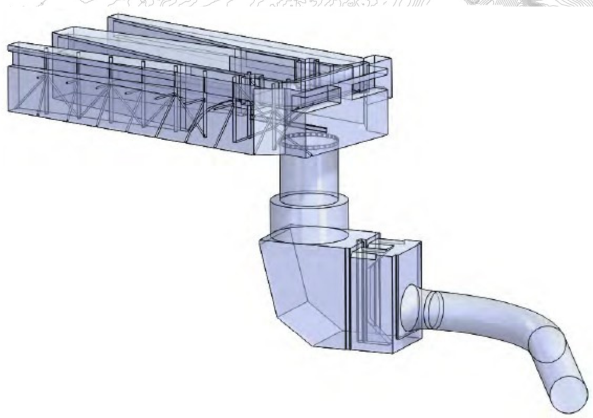


Change in Upstream Fish Passage Plans



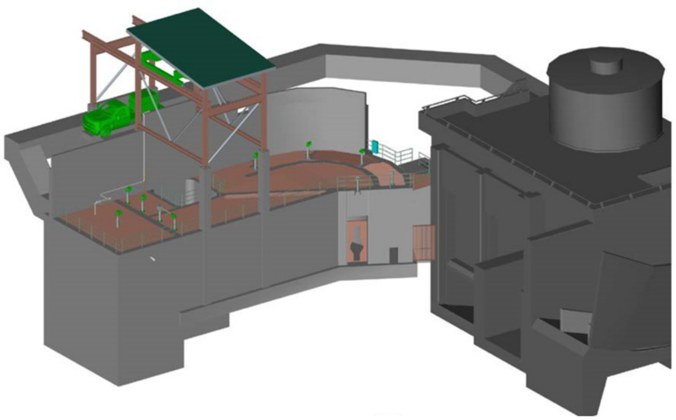
Change in Downstream Fish Passage Plans





Fish Passage Design Change

- Trap & Haul Facility
- Mothballed Power Plant



Spillway Modifications Dam Safety Issues

Probable Maximum Flood (PMF) Increase

- Raise spillway chute wall height
- Parapet wall at spillway entrance low area

Spillway Modifications – Dam Safety Issues

Chute Stability

- Post-Oroville focused spillway inspections
- Underdrain condition uncertainties

Spillway/Radial Gate Reliability

- Continuous vs. seasonal spillway operations
- Increased functional complexity and ramping rate compliance

Challenges in Engineering Existing Infrastructure

Nason McCullough, PhD, PE, GE

Effect of Relicensing on Trail Bridge Dam

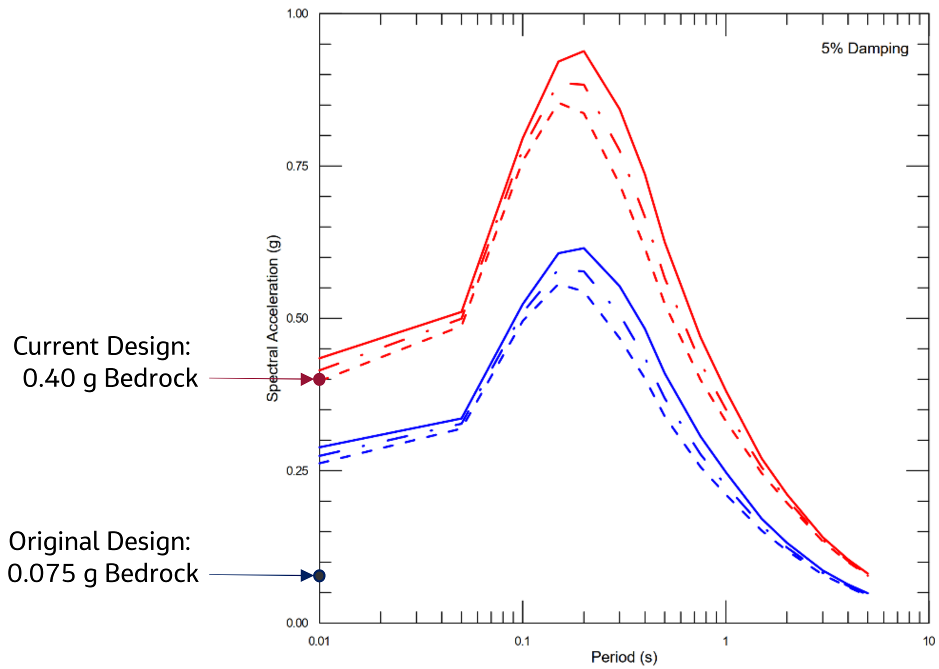
Relicensing resulted in changes to the dam operation to include:

- Upstream fish passage
- Downstream fish passage

Challenges:

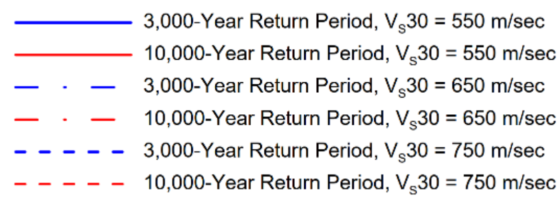
- Implementing these for an existing dam
- Maintaining dam safety
- Requires updating knowledge on hazard

Seismic Hazard – Increased Hazard Level



SEISMICITY

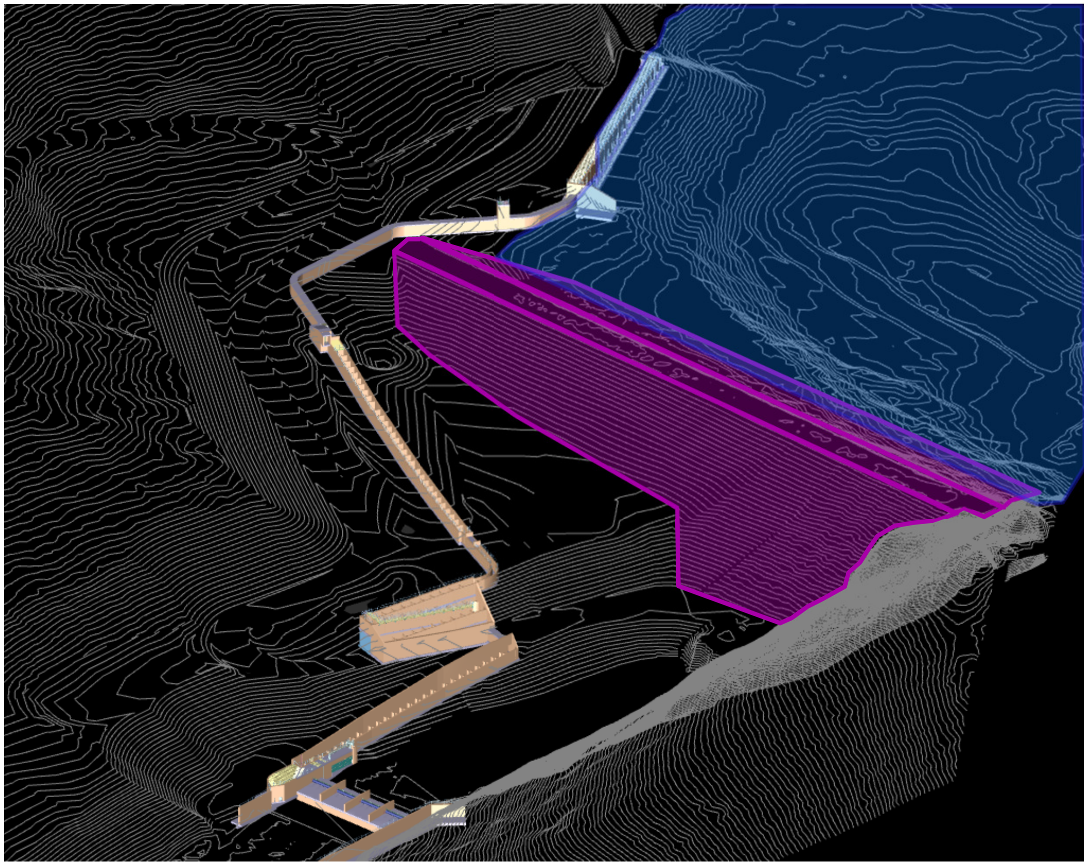
The general area of the Cascade Range where the Carmen-Smith project is located has been relatively quiet, seismically, during the 150-year historic period. According to the U.S. Army Corps of Engineers Seismic Zone Map, the project lies within Seismic Zone 2. Seismic Zone 2 is listed as a zone of moderate seismic probability for damage with an acceleration coefficient of 0.05, in the 1977 edition of the Seismic Zone Map, and a coefficient of 0.10 in the revised 1983 edition of the Map. The Carmen-Smith project design criteria was 0.075g for structures founded on rock and 0.10g for structures founded on overburden.



Upstream Fish Passage – Initial Concept

Fish Ladder:

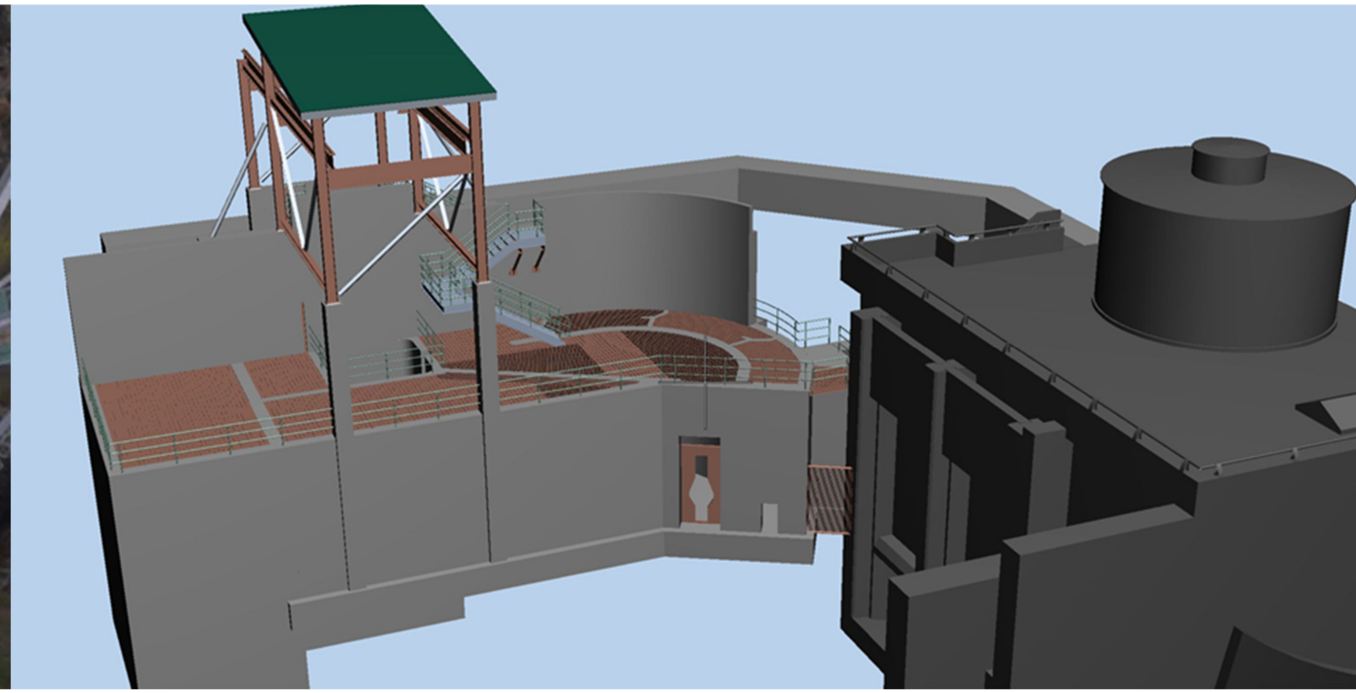
- Challenges:
  - Penetrate the right abutment of the dam, while preventing seepage along the structure
  - The upstream pool has a seepage blanket, do not want to disturb
  - Need to accommodate daily reservoir pool variations
- Costly structure with 100+ ladder pools and dam/abutment penetration



Upstream Fish Passage – Revised Concept

Trap and Haul Facility:

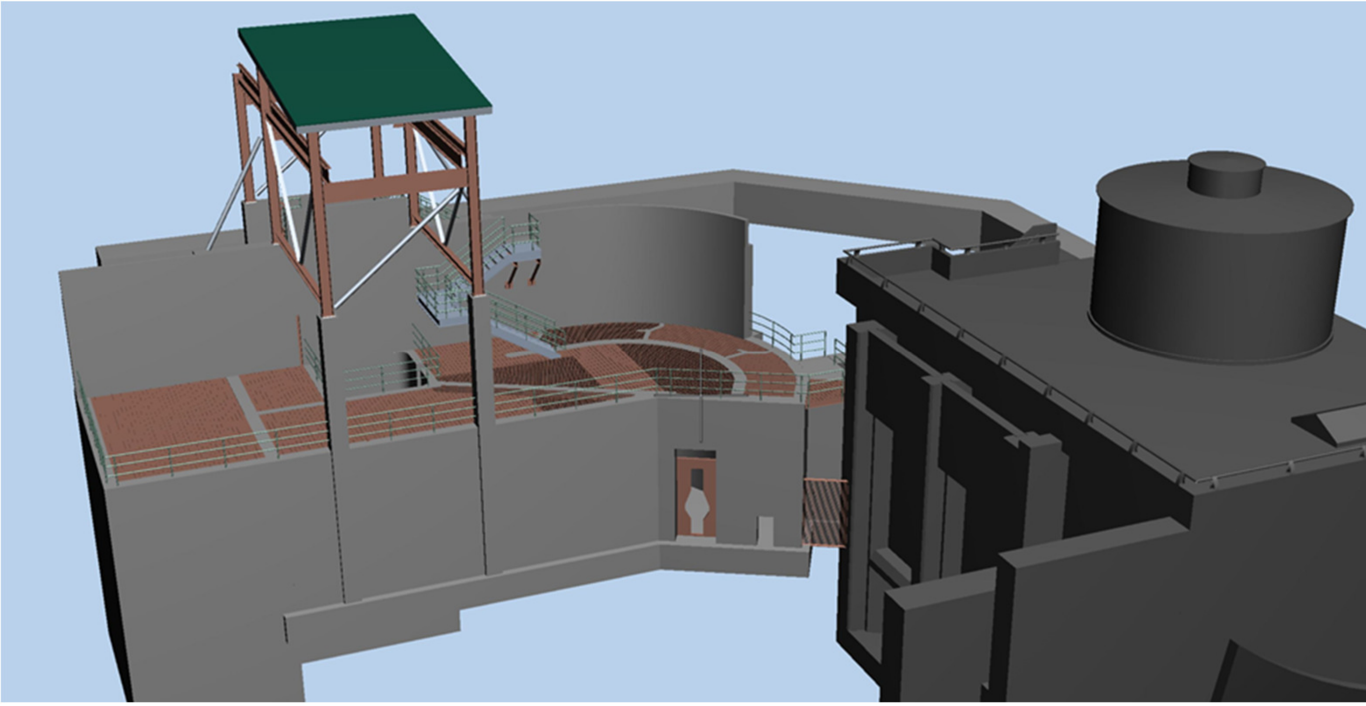
Instead of “passive” ladder option, a more “active” option involving trapping the fish and transporting them upstream around the dam



Upstream Fish Passage – Revised Concept

Trap and Haul Facility:

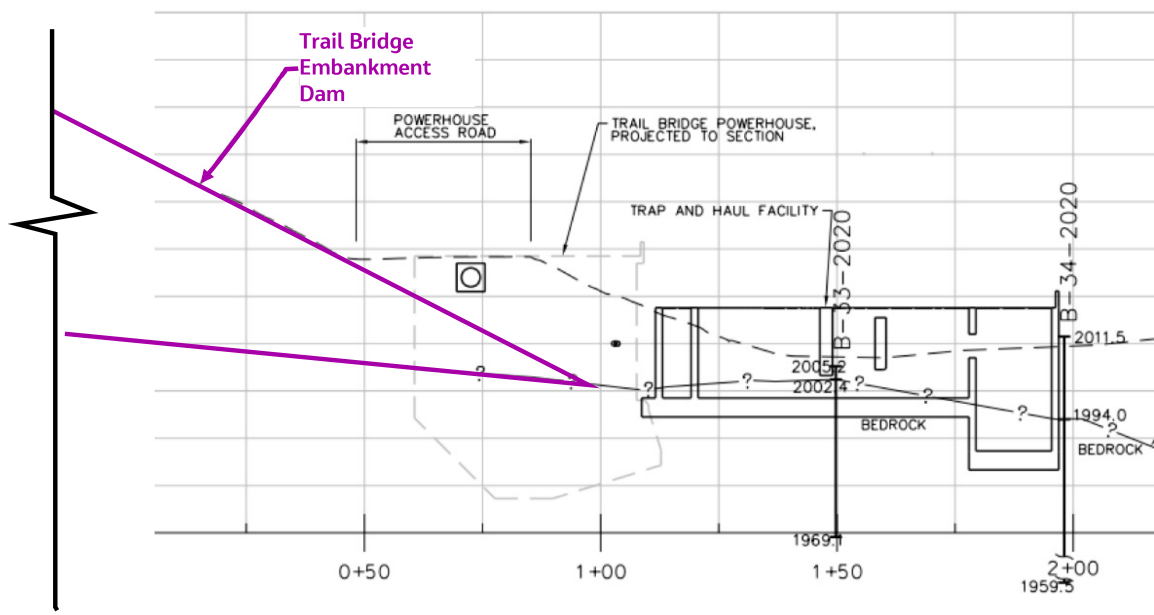
- **Significant structure**:
  88 feet long
  x 33 feet wide
  x 34 feet tall
- **Attraction water:**
  tap into the powerhouse penstock to provide continuous flow through the trap and haul facility to attract migrating fish
- **Transport:**
  Fish are collected and transported by truck upstream of the dam and released



Upstream Fish Passage – Excavation and Shoring Challenges

Construction Challenges:

- Deep excavation (up to 30 ft below grade) near the toe of the embankment dam
- Robust shoring needed to minimize impact to the dam
- Minimize changes to seepage and phreatic surface within the dam:
  - **lower phreatic surface** results in higher seepage gradients and potential for internal erosion
  - **high phreatic surface** results in lower embankment stability



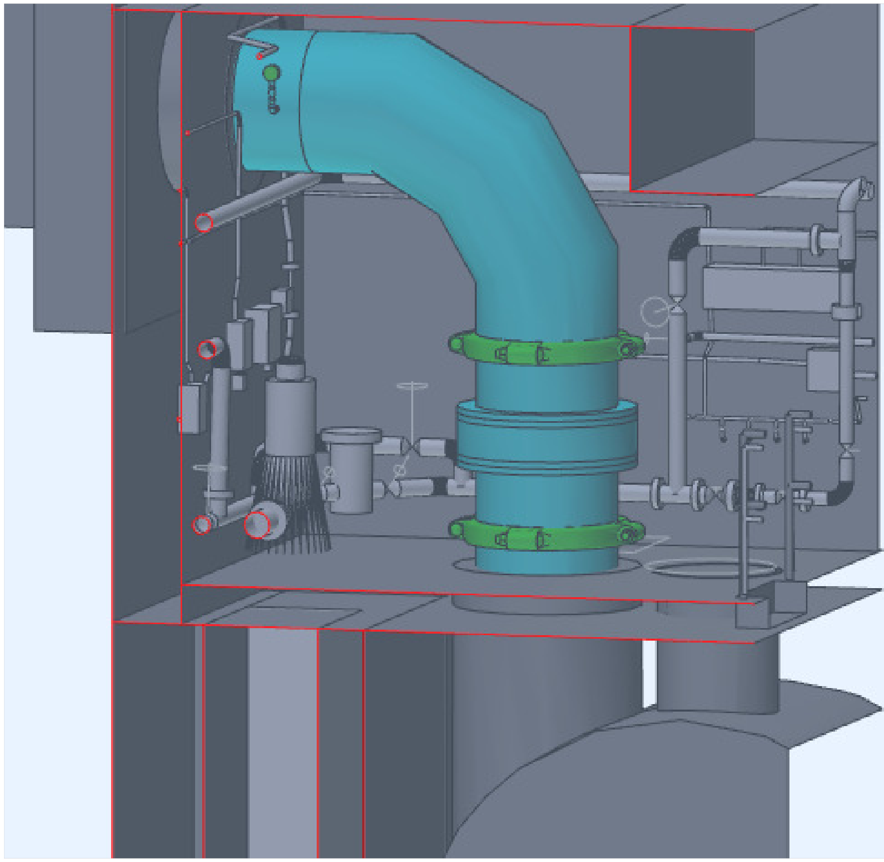
Upstream Fish Passage – Excavation and Shoring Challenges

Material for most of the excavation was uncontrolled "waste" fill from the dam construction:

- Gradation varies from sand/silt to cobbles/boulders
- Density variable, and difficult to confirm in the field
- Large boulders and voids are present, difficult excavation

Upstream Fish Passage – Requires Tapping Penstock

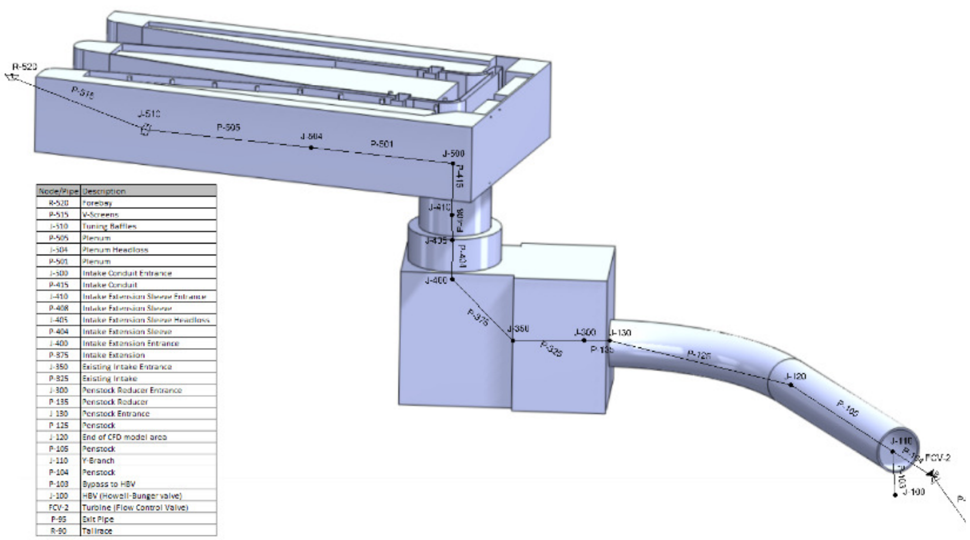
- In order to provide "attraction" water, requires tapping into the existing penstock within the powerhouse
- Challenges:
  - Pipe has full reservoir head, located at the toe of the dam, leaks in the pipe could erode the toe of the dam
  - Need to minimize damage during seismic event



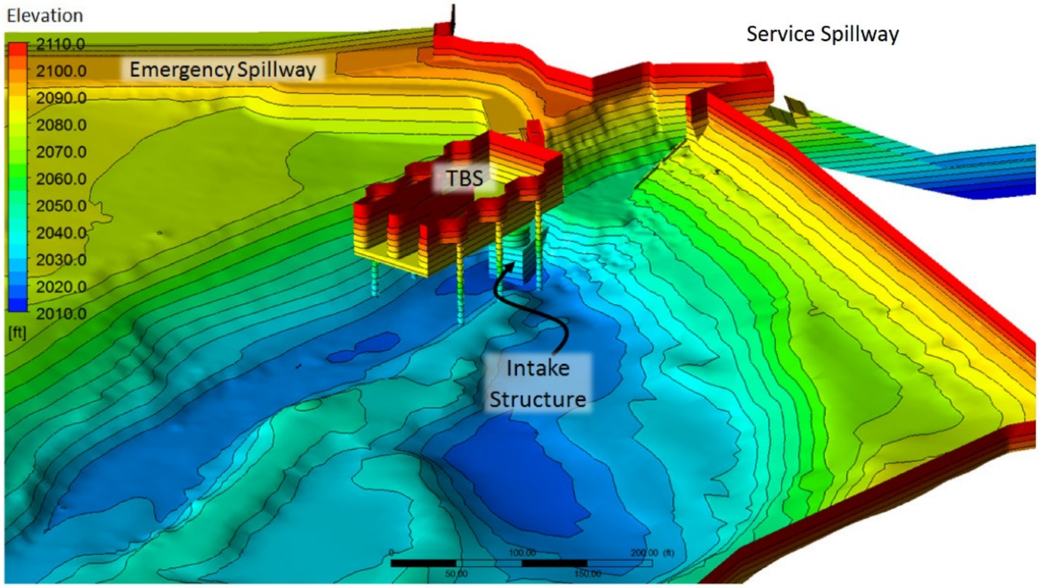
Downstream Fish Passage – Initial Concept

Floating Surface Fish Screen

- Collect fish near the surface
- Transport them in a pipeline “water slide” for about a mile
- Allowed intake/operation of the powerhouse with a telescoping vertical conduit



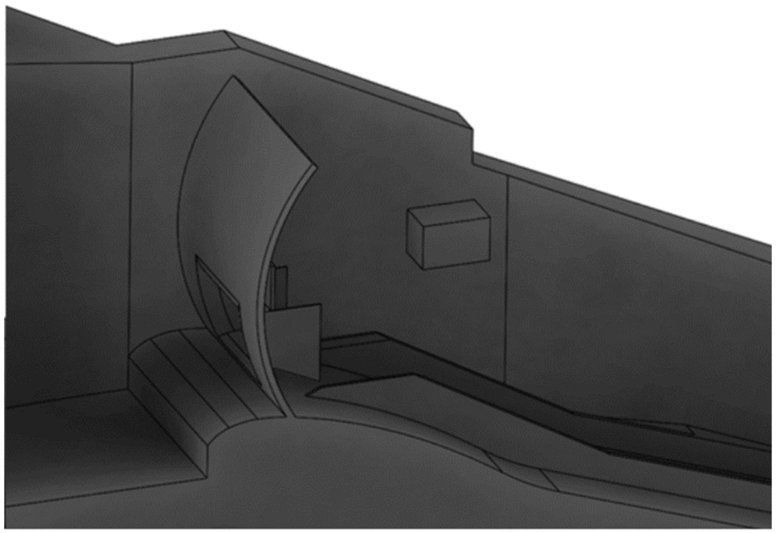
Node/Pipe	Description
R-520	Forebay
P-515	V-Screens
J-510	Tuning Baffles
P-505	Plenum
J-504	Plenum Headloss
P-501	Plenum
J-500	Intake Conduit Entrance
P-415	Intake Conduit
J-410	Intake Extension Sleeve Entrance
P-408	Intake Extension Sleeve
J-405	Intake Extension Sleeve Headloss
P-404	Intake Extension Sleeve
J-400	Intake Extension Entrance
P-375	Intake Extension
J-350	Existing Intake Entrance
P-325	Existing Intake
J-300	Penstock Reducer Entrance
P-135	Penstock Reducer
J-130	Penstock Entrance
P-125	Penstock
J-120	End of CFD model area
P-105	Penstock
J-110	Y-Branch
P-104	Penstock
P-103	Bypass to HBV
J-100	HBV (Howell-Bunger valve)
FCV-2	Turbine (Flow Control Valve)
P-95	Exit Pipe
R-90	Tailrace

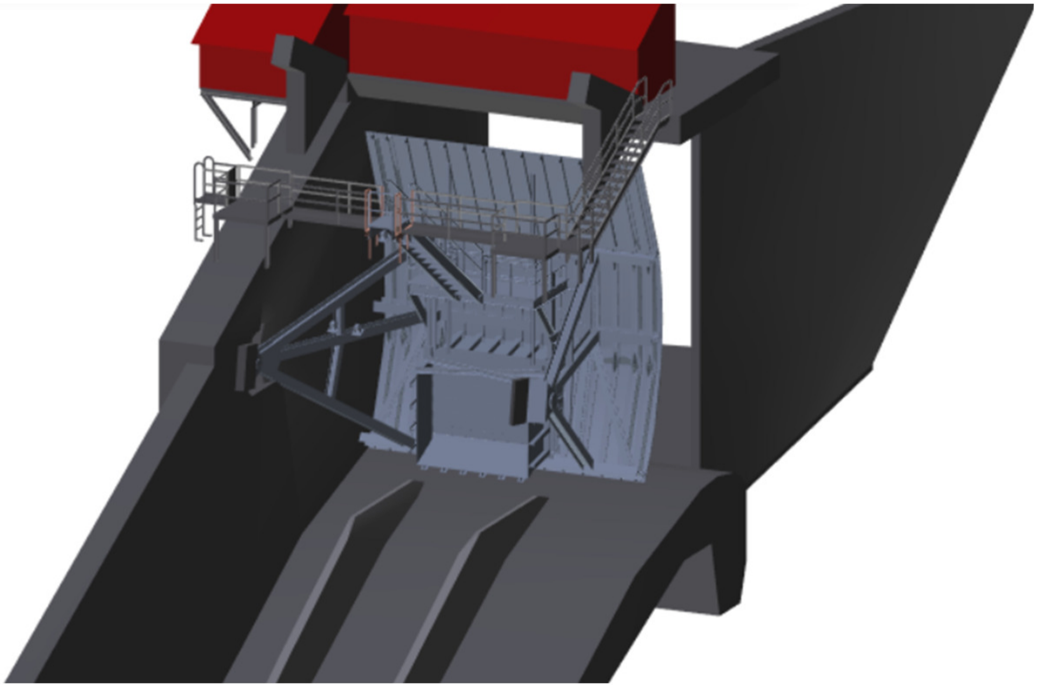


Downstream Fish Passage – Revised Concept

Gate within a gate

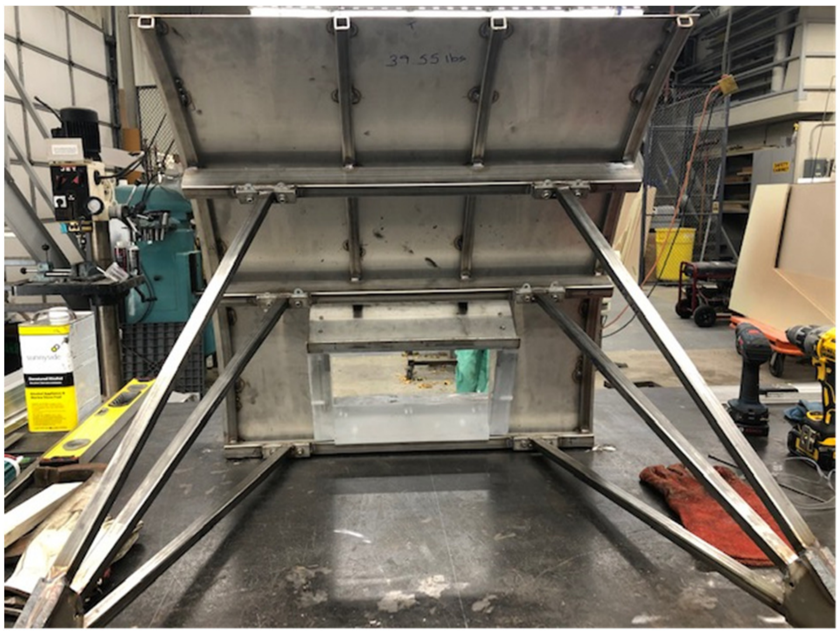
- Fish passage all the time (between the 95% and 5% exceedance river flows), flood passage when needed

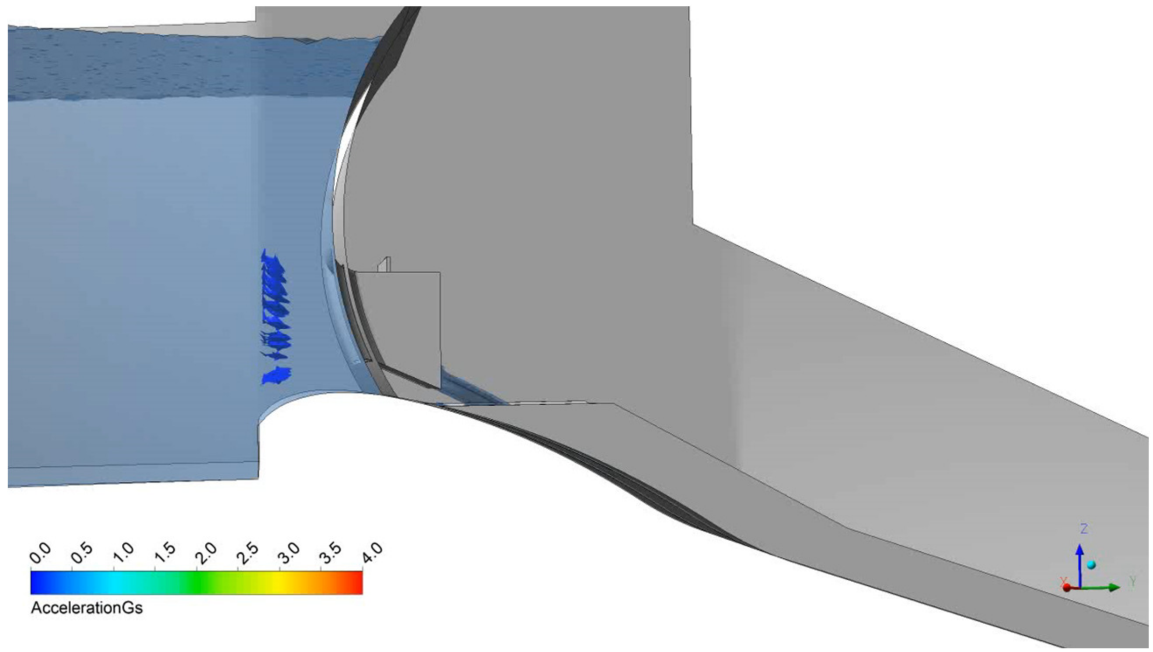




Downstream Fish Passage – Revised Concept

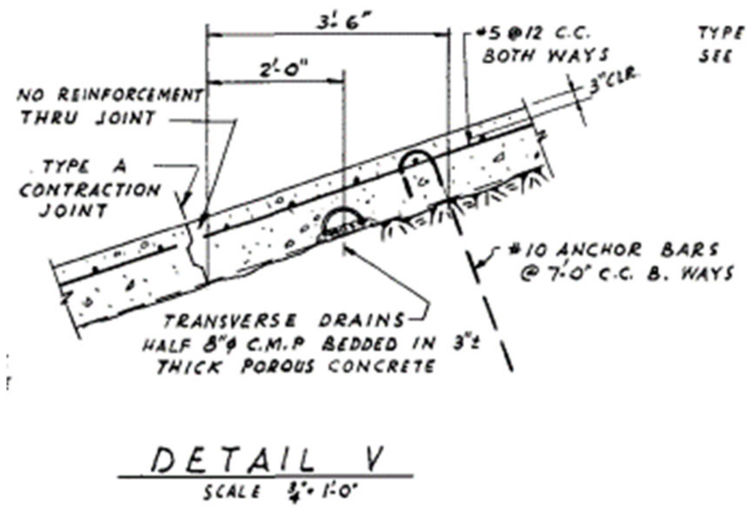
- Complex behavior: physical and numerical models used to validate
- Minimize injury and mortality of fish





Downstream Fish Passage – Spillway Chute

- Minimizing fish injury requires modification to spillway chute walls
- Raised concerns on spillway:
  - Underdrain efficiency/capacity
  - Effectiveness of grout curtain



Conclusions

- Relicensing often results in modification and modernization of existing dams
- Existing Dams are complex and challenging:
  - Original Design:
    - Original assumptions are often not known
    - New work was likely not anticipated, need to work within confines of existing structure(s)
  - Design Criteria may change over time (e.g., seismic, flood):
    - changing environmental conditions
    - refinement in the state of knowledge

Reservoir Safety – Managing Organizational Risk

Stephen Naylor
Environment Agency, UK

The Environment Agency

Environment Agency

Operations

- Flood Risk Management
- Asset Management
- **Reservoir Undertakers**
- Incident response

Regulation

- Major industry and waste
- Water quality and resources
- **Statutory Reservoirs**
- Fisheries, conservation and ecology
- Consultee on planning and development

Our Portfolio

- There are around 2200 statutory reservoirs in England – typically ornamental lakes, farm irrigation ponds, flood storage and public water supply reservoirs.
- The Environment Agency is the single largest reservoir Undertaker in England with around 220 statutory reservoirs.
- We have around 20 reservoirs under construction.
- Each one is unique, designed to reduce flood risk to communities.
- Our reservoirs range in size from the 9.0Mm3 to small local storage areas of just over 25,000m3.
- Most of our reservoirs are dry flood storage basins.

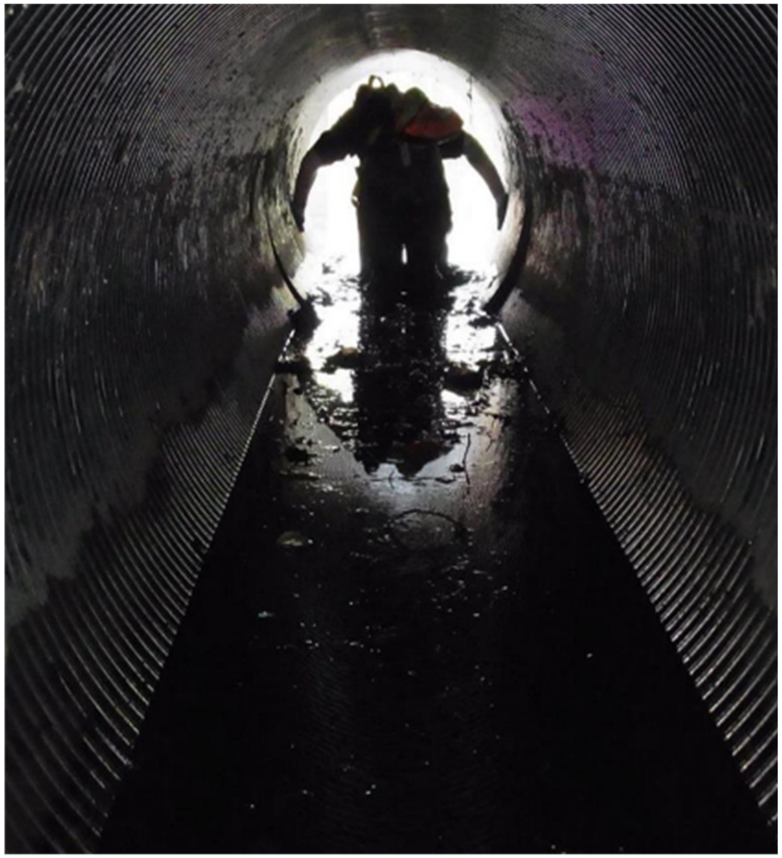
Public Safety

Public Safety Risk Assessments and Reservoirs

- The public are unpredictable
- Toddler test – if left unsupervised could they injure themselves?
- Safety of our staff links directly to that of the public
- Getting trapped in a flood storage area is low risk
- Escalation of control measures is often met by escalation of criminal damage
- There can be conflicts – such as fencing or security grilles for public safety that can affect operation of an asset
- Code of Practice developed to manage risk in projects

Managing Organizational Risk

- Consistent organizational structure – inconsistent delivery
- Responding to requests from Government or Head Office
- Recruitment and retention of civil engineers
- Data management and corporate memory
- Priorities and funding pressures
- National incident = funding



Consistency of Panel Engineers

- Highly skilled group
- Huge amount of experience
- Individuals have different and sometimes conflicting opinions
- Differences between accepted designs on schemes
- Difficulty in challenging decisions
- Changing Panel Engineer during scheme delivery can be a problem

Training and Competence

Training and Competence

- Legal compliance
- Assurance and Audit
- Support services
- Staff turn-over
- Training development and delivery
- Governance and risk
- Client role
- Design – learning from others
- In-house Supervising Engineers

Standard Designs and Details

Standard Designs and Details

- Why re-invent the wheel every time?
- Standard details for recurring design elements
- Minimum technical requirements issued to project teams
- Operation and maintenance requirements considered
- Shared learning from mistakes, failures and experience
- Embrace innovation and success

Maintenance Challenges

Consistency in Maintenance Delivery


Washlands FSA, 31/12/02, 09.35

Reservoir Safety, Staff Training, Succession Planning

Andy Courtnadge
Jacobs UK Discipline Lead for Dams

Agenda

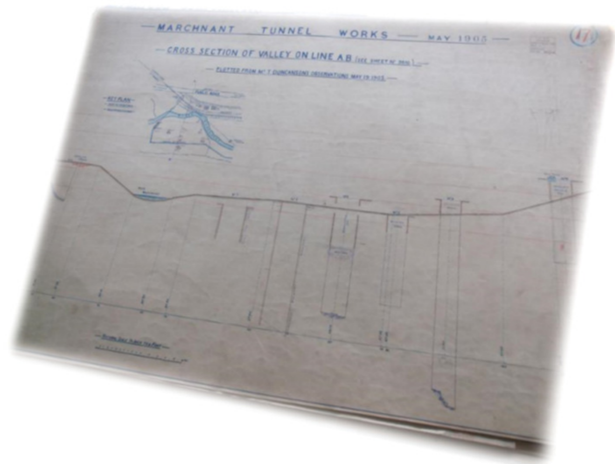
...the challenges from an engineering perspective

- Challenges faced by dam engineers
- Guidance, standards and legislation
- Moving towards a risk-based approach
- Succession planning
- Conclusions

Challenges Faced by Dam Engineers

…explaining why panel engineers may be inconsistent

- Decisions affecting dam safety are difficult
  - Very rarely "black & white" but "Shades of grey"
  - Requires judgement
- Lack of data, or conflicting data
  - Median age of dams is >120 years in UK, ~60 years in USA
  - Construction records often lost or illegible
  - Modifications not always recorded
- Confidence in quality of operation and maintenance
  - What condition will dam be in when design flood occurs
  - Will owner follow the agreed operating procedures, e.g., opening gates etc. as required



Examples of Difficult Decisions

...inspecting existing dams

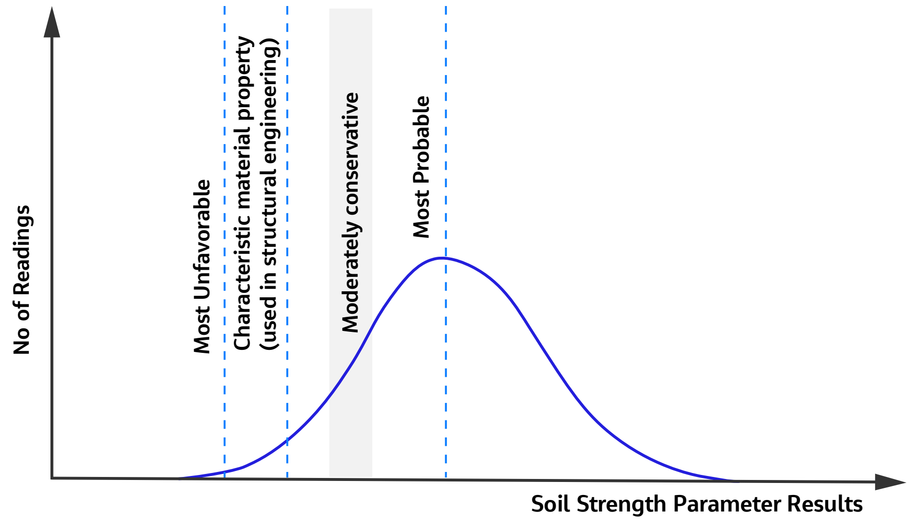
- Judging quality of grass cover to resist flood flows
  - Should I require the owner to upgrade the spillway?
  - 80% of UK dams are embankments, often with grass spillways
  - Guidance categorizes 'good', 'average' & 'poor' – significant difference in erodibility
  - Grass reinforcement buried so cannot be inspected.
  - Grass quality will vary seasonally and depending on maintenance
  - It only takes one defect to trigger scour damage which could unravel whole spillway
- Internal erosion due to seepage
  - Should I require the owner to install filters and drains?
  - Accounts for 43% of reported incidents (CIRIA SP167)
  - Risk depends on construction details & fill properties (often limited information)
- Flood estimation
  - Should I require the owner to increase spillway capacity?
  - Methodology constantly evolving
  - Climate change

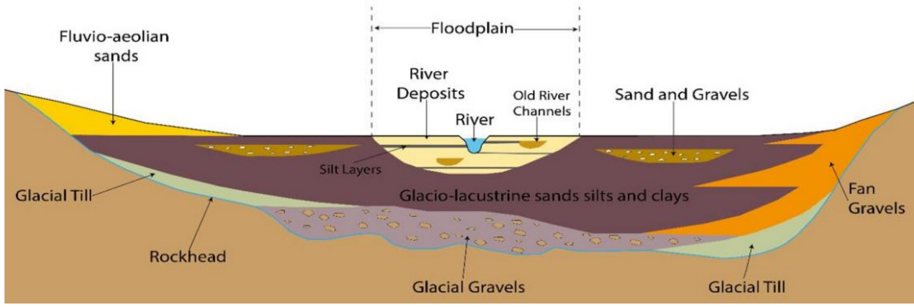
Examples of Difficult Decisions

...design of new dams

- Design value for geotechnical parameters
  - Affects slope angle required, predicted seepage and settlement allowance
  - Codes normally recommend taking 'a low cautious average' (say 1 in 20 chance of being below the design value)
  - Statistically inconsistent with other aspects of dam design (PMF = 1 in 400,000yr)
  - Logically need to select a more conservative design line → judgement!
- Ground model / soil parameters of dam foundation
  - Do we need a positive cut-off barrier to prevent internal erosion
  - Majority of new dams are for flood storage within river valleys
  - Foundation material is variable (alluvium and terrace deposits)
  - Difficult to assess permeability/erodibility and quantify risk of internal erosion
  - Cost of foundation cut-off barrier could make scheme economically unviable
- Allowance for climate change
  - How big does the spillway need to be?

Figure 3. Type of soil strength parameters, Nicholson (1999)





Climate Change

...allowances for extreme floods?
How big does the spillway need to be?

https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

Table I: peak river flow allowance by rivier basin district (based on a 1961 to 1990 baseline				
River basin district	**Allowance category**	**Total potential change anticipated for the '2020s' (2015 to 2020)**	**Total potential change anticipated for the '2050s' (2040 to 2069)**	**Total potential change anticipated for the '2080s' (2070 to 2115)**
South east	H++	30%	60%	120%
	Upper end	25%	50%	105%
	Higher central	15%	30%	45%
	Central	10%	20%	35%

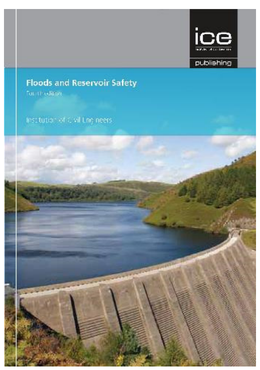
US Climate Assessment Report:

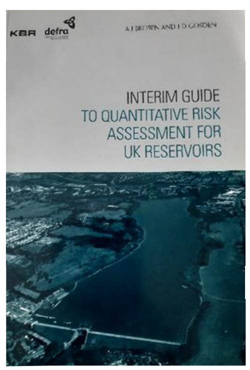
bottom). For 2070–2099 relative to 1986–2015, precipitation increases of up to 20% are projected in winter and spring for the north central United States and more than 30% in Alaska, while precipitation is projected to decrease by 20% or more in the Southwest in spring. In summer, a slight decrease is projected across the Great Plains, with little to no net change in fall.

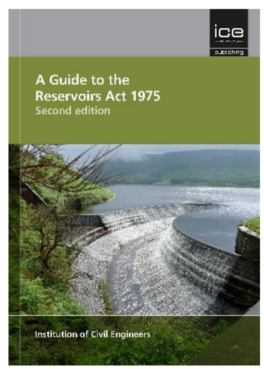
Guidance, Standards and Legislation

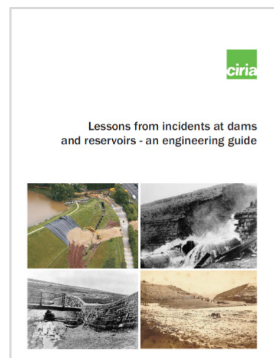
…tools to improve consistency and dam safety

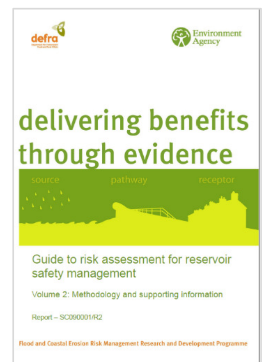
Guidance/standards developed at request of the profession	Non-prescriptive	Regular changes / updates	Part funded by industry	Part funded by industry
▪ In response to incidents ▪ In response to new science/research				

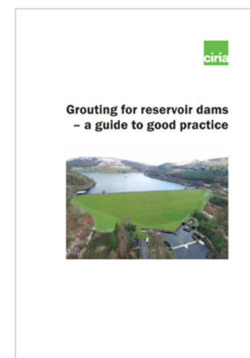










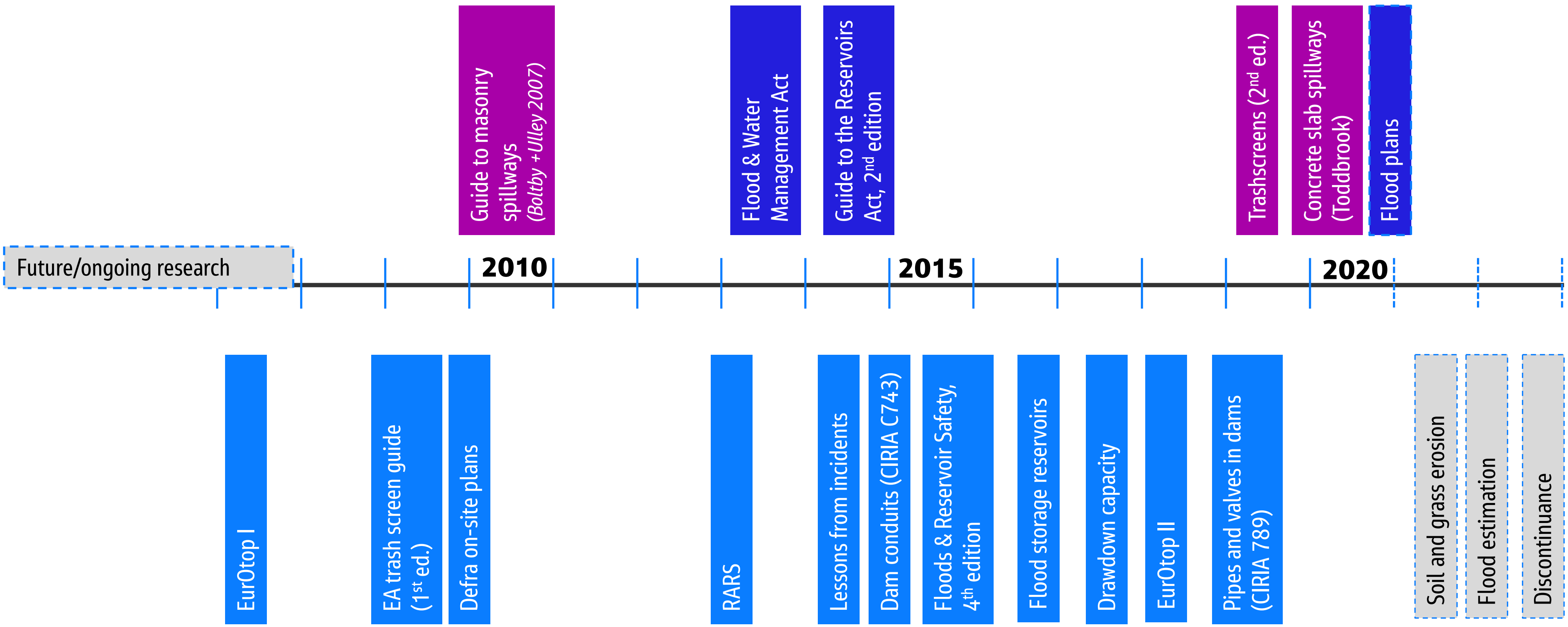


Guidance, Standards and Legislation

...timeline of recent key UK publications

KEY

- Produced in response to incidents
- New science/ research/ advice
- New legislation
- Future / ongoing research



Moving Towards a Risk-Based Approach

Date	UK developments	International developments
1990	Cullen - DOE research (QRA not yet appropriate for dams)	
1992	Binnie DOE research - *Estimation of flood damage following potential dam failure: guidelines.*	
2000	HSE - Reducing risk, protecting people (R2P2)	
	CIRA - Risk Management for UK Reservoirs	
2002	Defra Research contract - can we compare risk from floods with risk to Internal Erosion?	
2004	**Interim guide to quantitative risk assessment**	ANCOLD Guidelines on Risk Assessment
2005	UK Treasury - Managing risks to the public: appraisal guidance	ICOLD Bulletin 130
2008		Seepage & Piping Toolbox
2009	First national specification for "reservoir inundation mapping"	
2010	Flood & Water Management Act added risk designations	**Bureau of Reclamation, Dam Safety Risk Analysis Best Practices Training Manual (1st ed.)**
2011		USACE Safety of Dams – Policy and Procedures regulation
2012	Concrete dams and service reservoirs	
2013	**Guide to risk assessment for reservoir safety management (RARS)**	
2014		USACE Safety of Dams – Policy and Procedures update
2015	Floods & Reservoir Safety (4^{th} ed.) advocates risk based approach	
2016	National specification for reservoir flood mapping changed to separate: ▪ Dry day failure; ▪ Wet day – Incremental effect of dam failure on 1 in 1,000 fluvial flooding	FERC guidelines on Risk-Informed Decision Making
2019		**Bureau of Reclamation, Dam Safety Risk Analysis Best Practices Training Manual (6th ed.)**

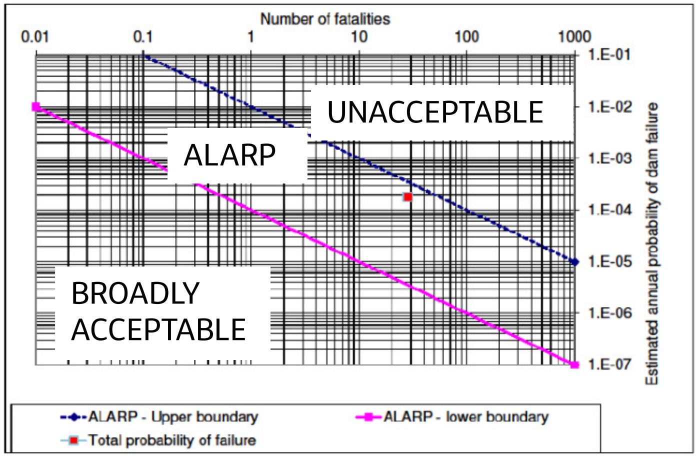
Who Decides When Risk is Tolerable?

…Concept in HSE “Reducing risk protecting people” (2000)

124 The zone between the unacceptable and broadly acceptable regions is the tolerable region. Risks in that region are typical of the risks from activities that people are prepared to tolerate in order to secure benefits, in the expectation that:

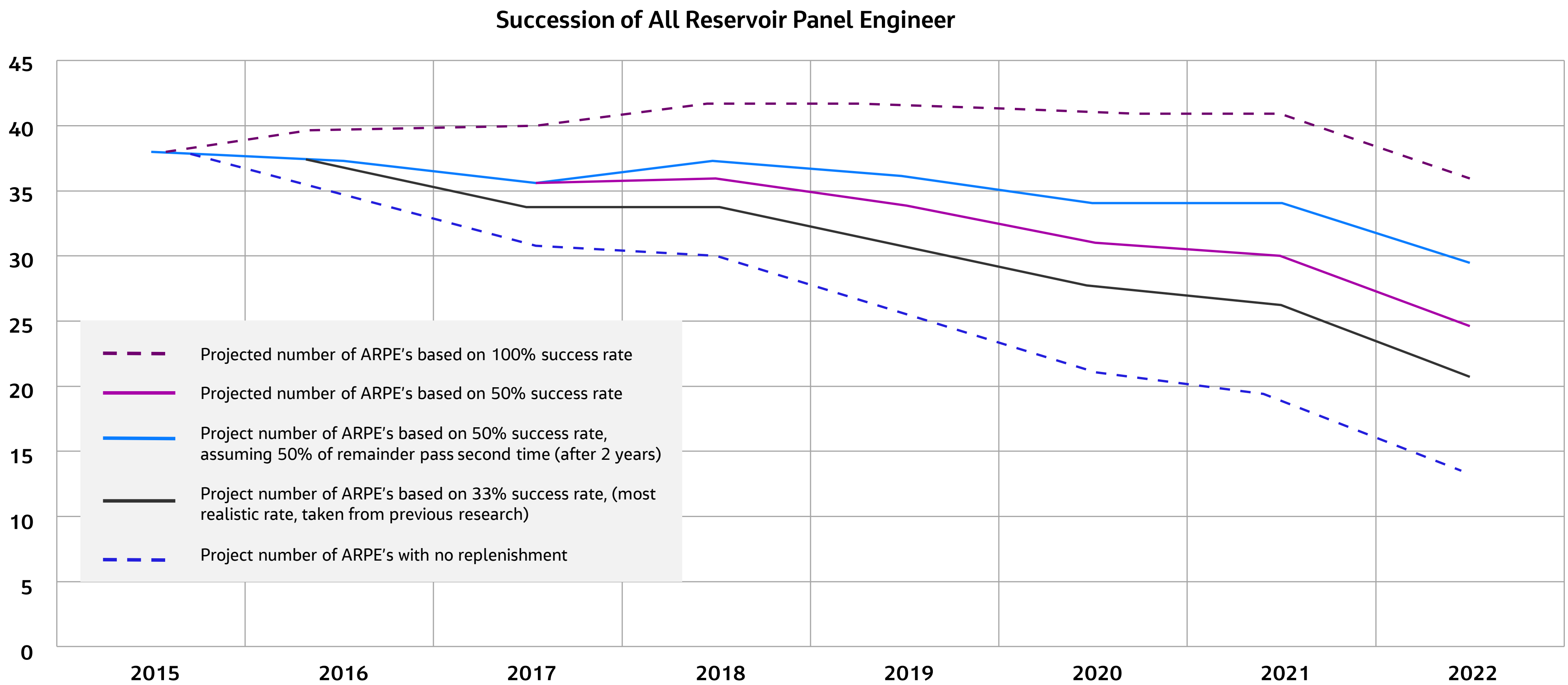
- the nature and level of the risks are properly assessed and the results used properly to determine control measures. The assessment of the risks needs to be based on the best available scientific evidence and, where evidence is lacking, on the best available scientific advice;
- the residual risks are not unduly high and kept as low as reasonably practicable (the ALARP principle – see Appendix 3); and
- the risks are periodically reviewed to ensure that they still meet the ALARP criteria, for example, by ascertaining whether further or new control measures need to be introduced to take into account changes over time, such as new knowledge about the risk or the availability of new techniques for reducing or eliminating risks.

125 Benefits for which people generally tolerate risks typically include employment, lower cost of production, personal convenience or the maintenance of general social infrastructure such as the production of electricity or the maintenance of food or water supplies.



- Risks are tolerable if:
  - Associated benefits to society
  - Assessed based on best available scientific advice
  - Periodically reviewed
  - Control measures in place
  - As Low as Reasonably Practicable (ALARP)
- **Society needs to decide what is tolerable**
- **Engineers need to**
  - Accurately quantify risks
  - Describe in ways that society can understand and make decisions on tolerability

Succession Planning



Conclusions

- Reservoirs are hugely valuable to civilization
- Often above centers of population
  - devastating consequences if dams fail
- Managing dam safety is challenging
  - Difficult engineering judgements, often with limited information
  - How robust should designs be?
  - Too robust and projects become unviable?
  - Balancing the benefits to society of reservoirs versus the risk
- Tools for dam safety management
  - Technical knowledge is continuously being improved
  - Moving towards risk-based approaches
  - Still uncertainty, hence ongoing incidents
- Moving forwards dam engineering will continue to work for reservoirs to benefit society / enable civilization




Questions and Answers

Thank You!