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2025 SPRING CONVENTION

AUSTIN, TEXAS • APRIL 13 – 16, 2025

A Seemingly Improbable Crisis: The Perfect Storm at Oroville Dam

Presented by:
Jeremy Begley, PE
MAPEI Corporation

www.icri.org

INTRODUCTION

February 2017

https://www.newcivilengineer.com/archive/learning-from-failure-oroville-dam-spillway-14-11-2017/

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https://www.newcivilengineer.com/archive/learning-from-failure-oroville-dam-spillway-14112017/

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https://www.sparkpeople.com/resource/quotes_translation.asp?id=286

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ttps://www.scottgustafson.com/for-want-of-a-nail

Live Content Slide

When playing as a slideshow, this slide will display live content

Poll: How familiar are you with the Oroville Dam Spillway Incident of 2017?

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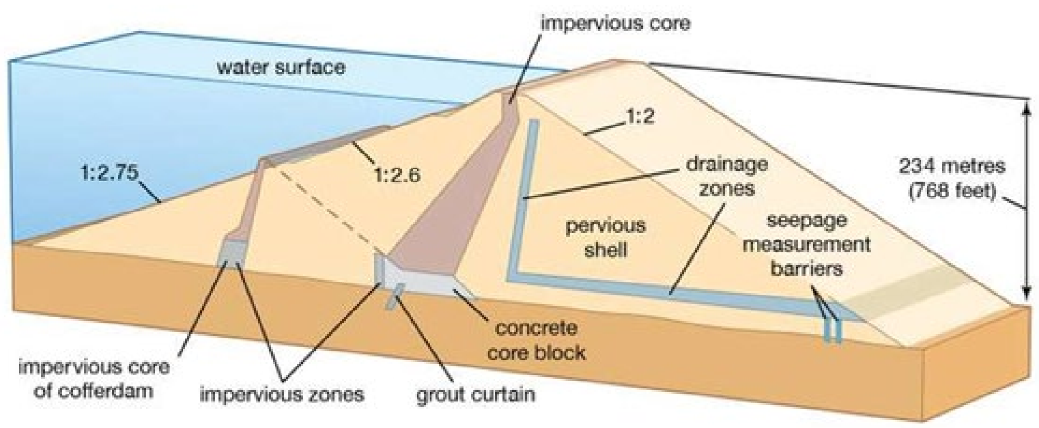
BACKGROUND

- **Location:** Oroville, CA (Feather River)
- **Construction Period:** 1961 – 1968 (7 years)
- **Opened:** May 4, 1968
- **Owner:** California Department of Water Resources (DWR)
- **Engineer:** California Department of Water Resources (DWR)
- **Height:** 770 feet (235 meters) – **Tallest dam in the U.S.**
- **Length:** 6,920 feet (2,109 meters)
- **Type:** Earthfill embankment dam (clay core)
- **Reservoir Capacity:** 3.5 million acre-feet (Lake Oroville)
- **Primary Purposes:**
  - Water supply: part of the California State Water Project (SWP)
  - Flood control
  - Hydropower generation
  - Recreation
  - Fish & wildlife protection
- **Main Spillway:** 3,000 feet (914 meters) long, 179 ft wide, RC chute
- **Emergency Spillway:** Concrete weir & unlined hillside (first use in 2017)
- **Power Generation:** Edward Hyatt Powerplant (645 MW capacity)

Oroville Dam, California, U.S.

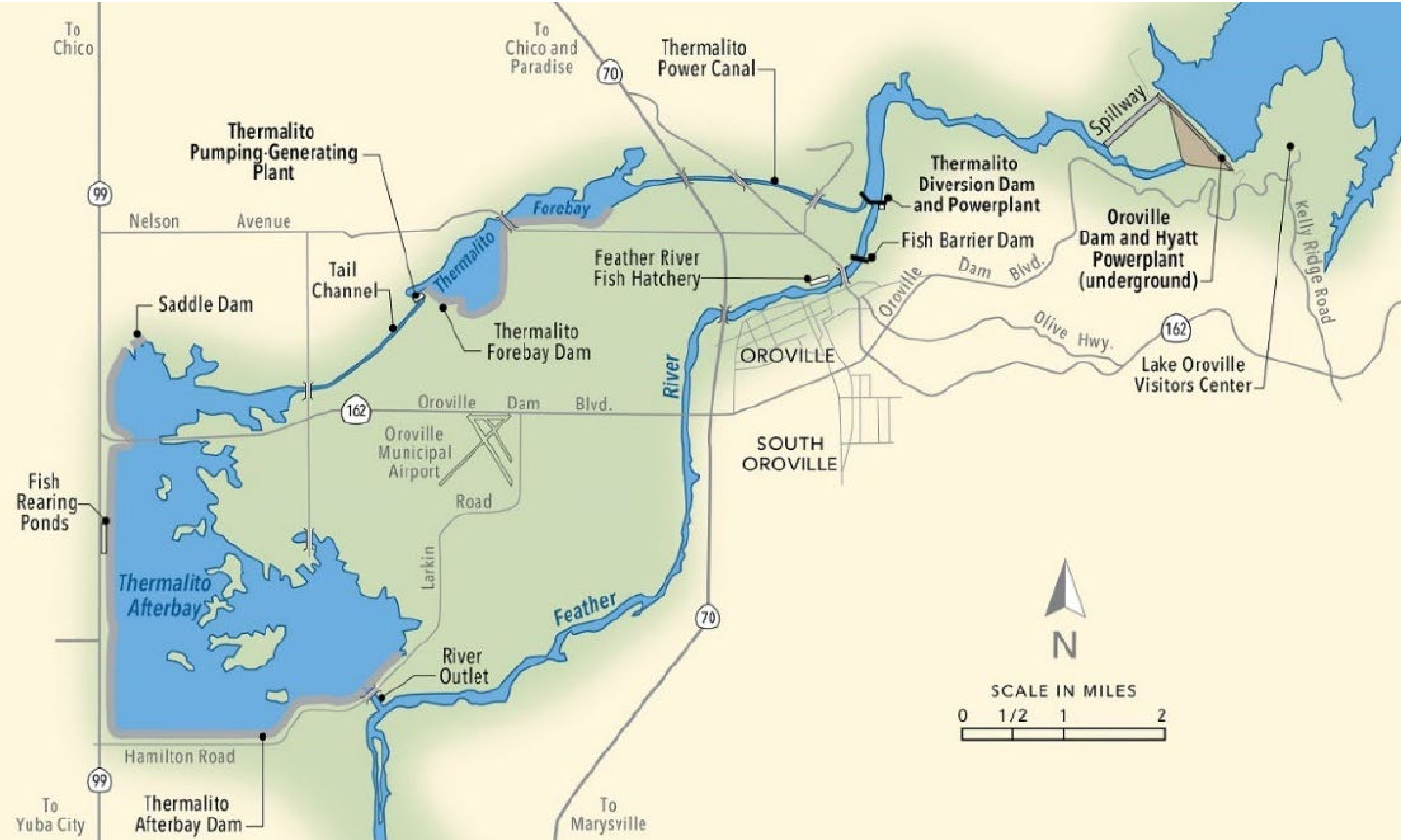


www.icri.org

https://water.ca.gov/-/media/DWR-Images/Maps/230726SWPPipelinesFacilitiesaav57.jpg

BACKGROUND

- **Oroville Dam Complex**
  - Dam & Reservoir
  - Forebay & Afterbay
  - Power Plants & Pumping Plants
  - Fish Hatchery



https://resources.ca.gov/-/media/CWC-Website/Files/Documents/2023/09_September/September2023_Items_7_8_Attach_1_OrovilleHandout.pdf

BACKGROUND

- **Overview of Oroville Dam Facility**
  - Prior to Feb 2017 Incident
  - Unlined emergency spillway

https://damsafety.org/sites/default/files/files/Independent%20Forensic%20Team%20Report%20Final%2001-05-18.pdf

BACKGROUND

- **Overview of Oroville Dam Facility**
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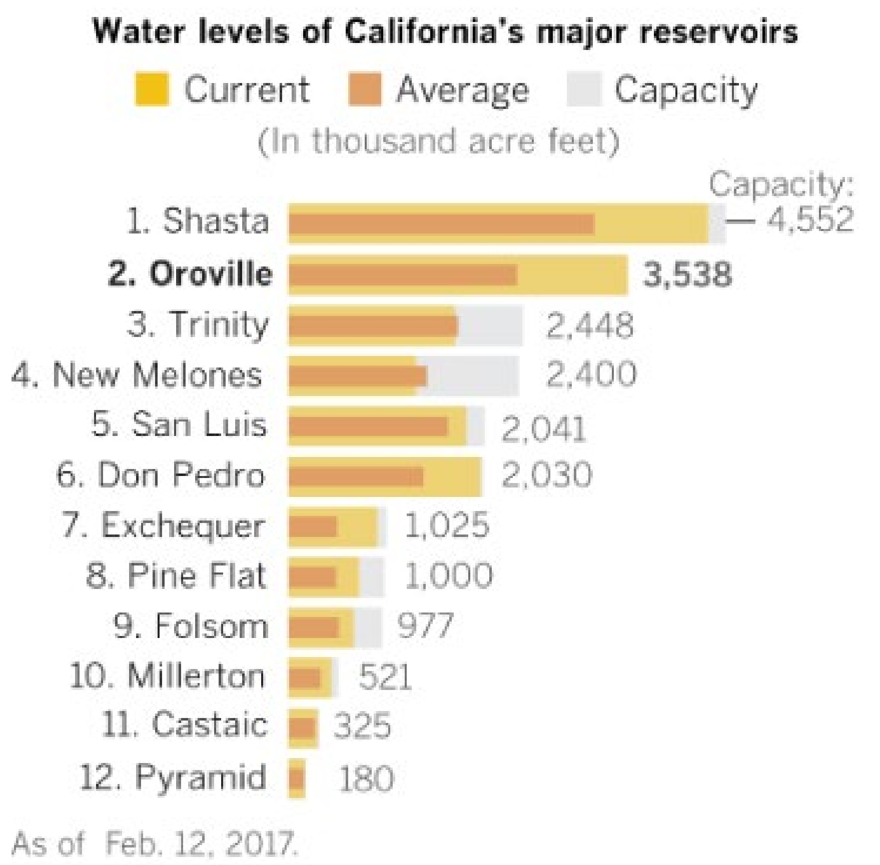
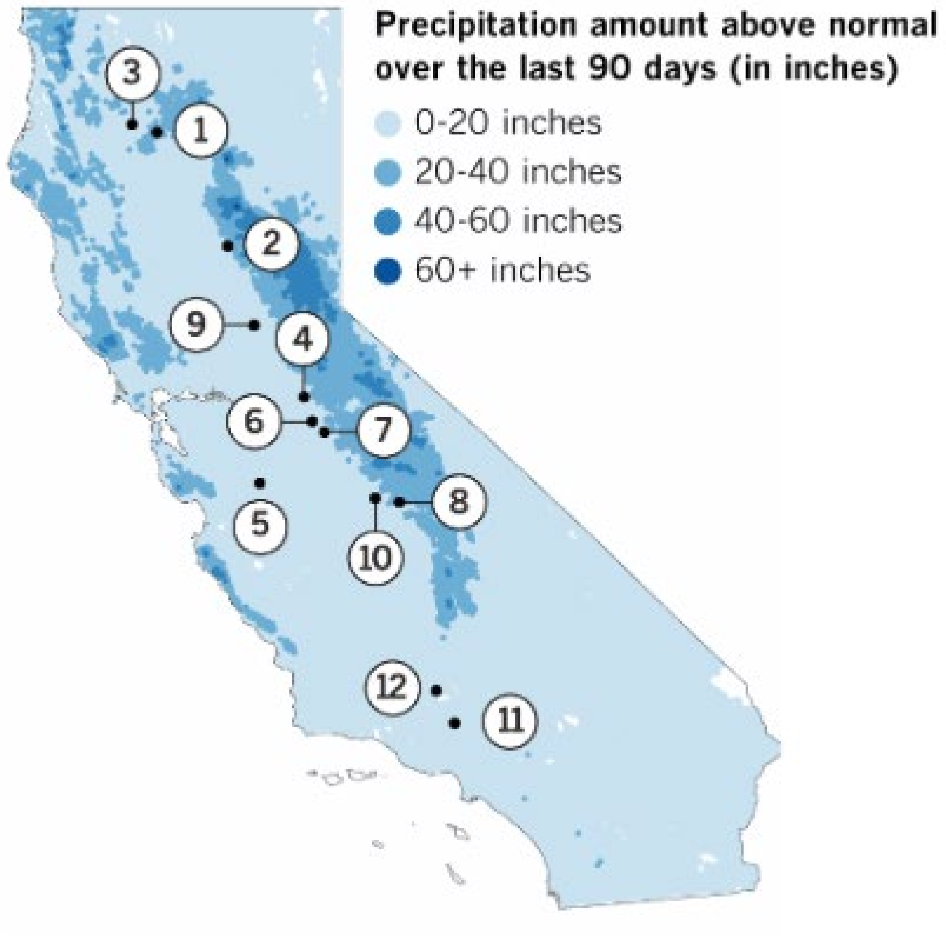
https://damsafety.org/sites/default/files/files/Independent%20Forensic%20Team%20Report%20Final%2001-05-18.pdf

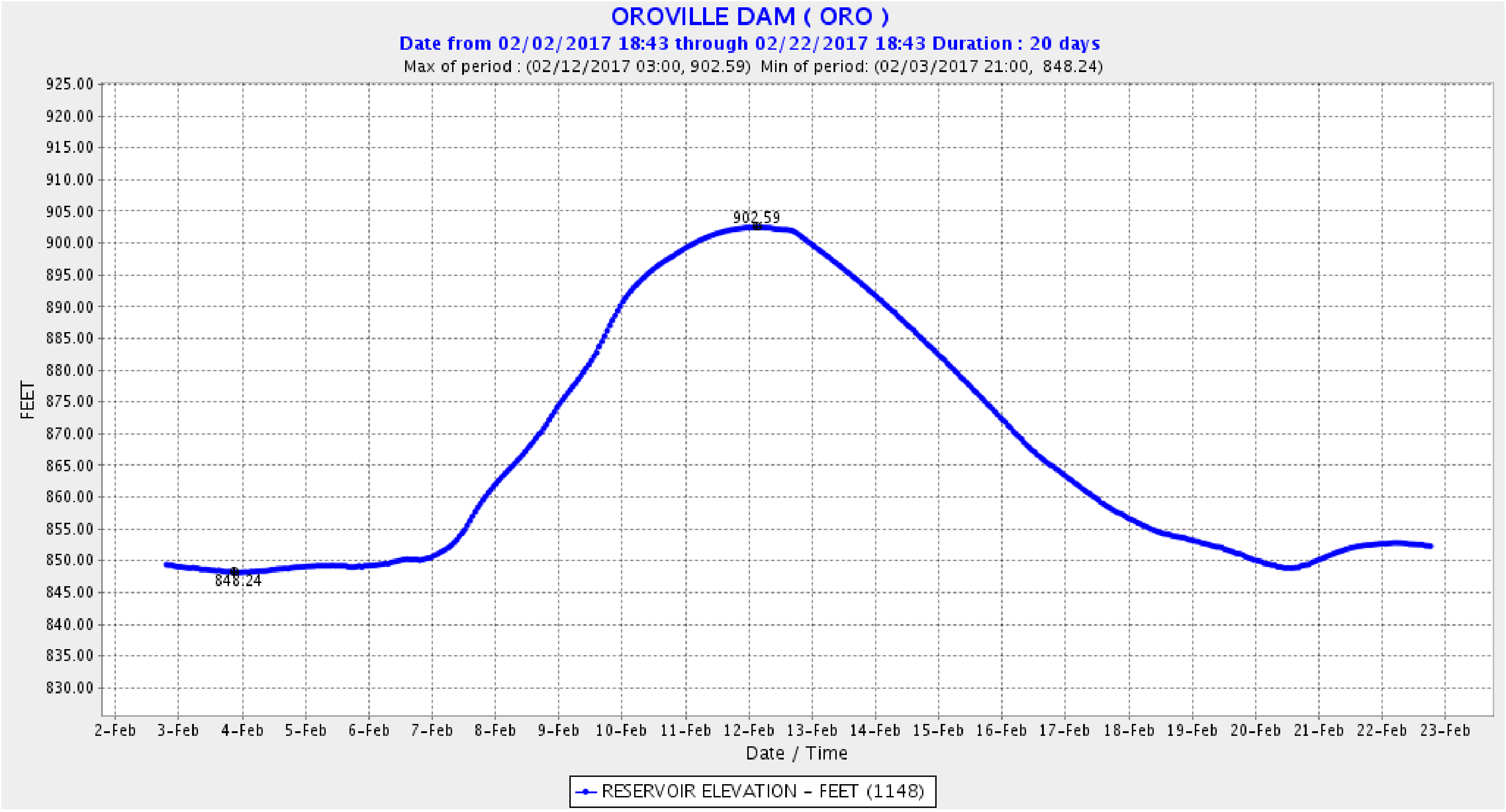
PRELUDE TO CRISIS

- **Heavy Rain in the Sierras**
  - Above-normal precipitation after years of drought
- **Feather River Basin**
  - Almost 13” (330 mm) between Feb. 6-10
  - Over 50 ft reservoir rise in 6 days





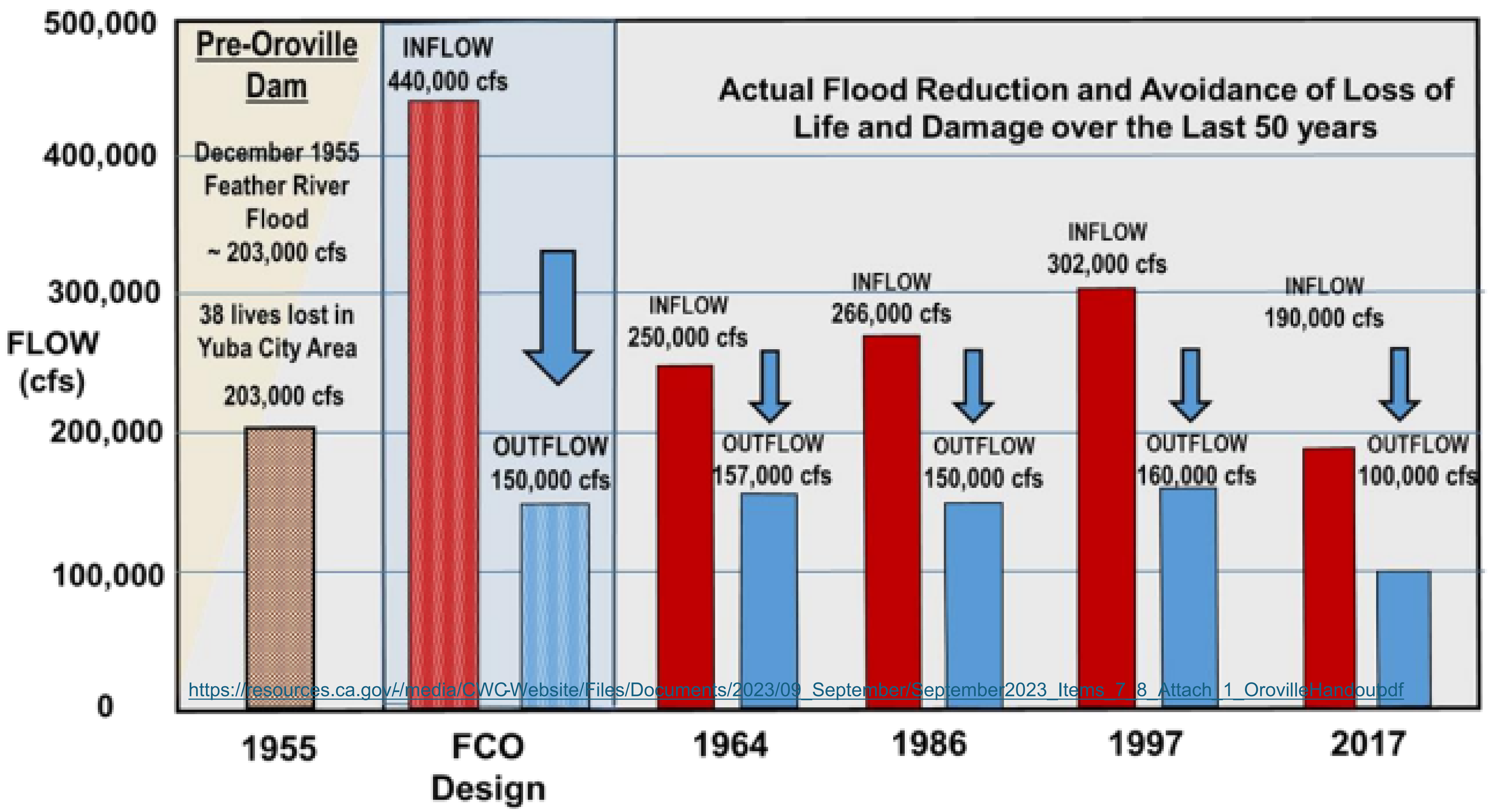
https://www.latimes.com/projects/la-me-oroville-flooding/



https://upload.wikimedia.org/wikipedia/commons/6/6c/Oroville_Lake_Elevation_Feb_2017.png

PRELUDE TO CRISIS

- **Flood Control**
- **Design for Flood Control Outlet (FCO)**
  - 440,000 cfs inflow
- **Larger Historical Flood Events:**
  - 1997 event (largest)
  - 300,000+ cfs inflow



INITIAL SIGNS OF TROUBLE

- February 7, 2017
- 52,500 cfs
- Flow disturbance noticed
- Damage discovery
  - Main spillway
- Immediate response & initial assessments

THE SITUATION ROOM

- **Incident Trigger** :
  - Chute slab failure and erosion
  - Closure of service spillway gates for damage assessment.
- **Risk Tradeoffs**:
  - Difficult choices
- **Key Dilemma**:
  - Further spillway damage
    - Potential damage to transmission tower
    - Debris buildup causing potential powerhouse flooding
  - Overtopping emergency spillway weir
    - Possible erosion
- **Strategic Response**:
  - “Sweet spot”
  - Controlled use of the service spillway with minimal discharges
  - Goal: prevent overtopping the emergency spillway weir
  - All hands on-deck to make the call

https://upload.wikimedia.org/wikipedia/commons/thumb/a/ac/Obama_and_Biden_await_updates_on_bin_Laden.jpg/400px-Obama_and_Biden_await_updates_on_bin_Laden.jpg

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ESCALATION OF INCIDENT

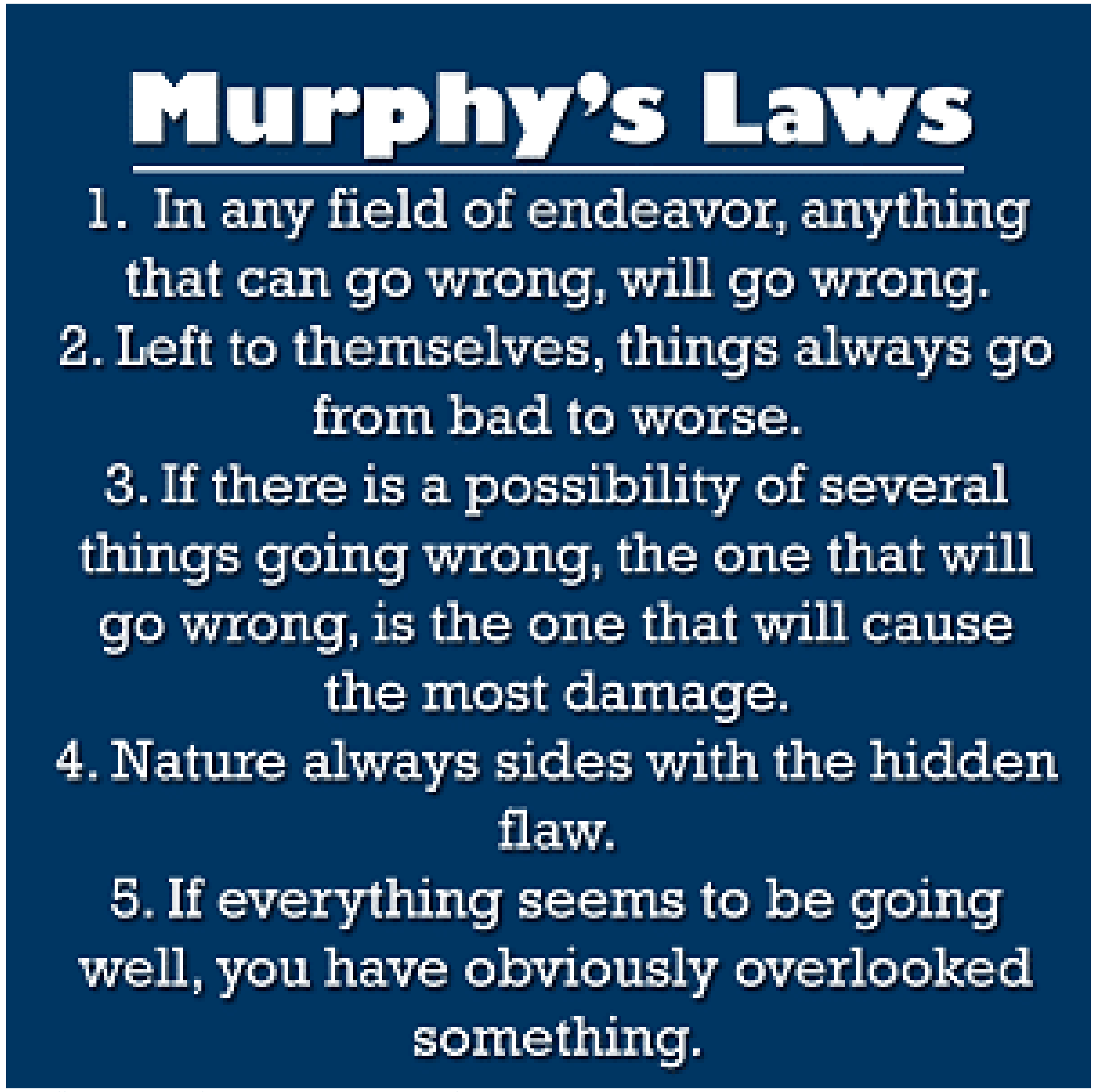
- **Tradeoffs & Decision Points**
  - Discharge limited
  - Best intentions
- **Risk Assessment**
  - Lower powerhouse flood risk
  - Limited discharge continuation
  - Rain keeps pouring

https://www.flickr.com/photos/nationalmuseumofamericanhistory/638348805 7


https://drgerrylewis.com/staging/wp-content/uploads/2014/07/when-it-rains_sandiegolawlibrary.org_.jpg

ESCALATION OF INCIDENT

- **Outcome**
  - Flow over emergency spillway weir
  - Sweet spot not achieved



https://www.eit.edu.au/the-truth-behind-murphys-law/

EMERGENCY SPILLWAY ISSUES

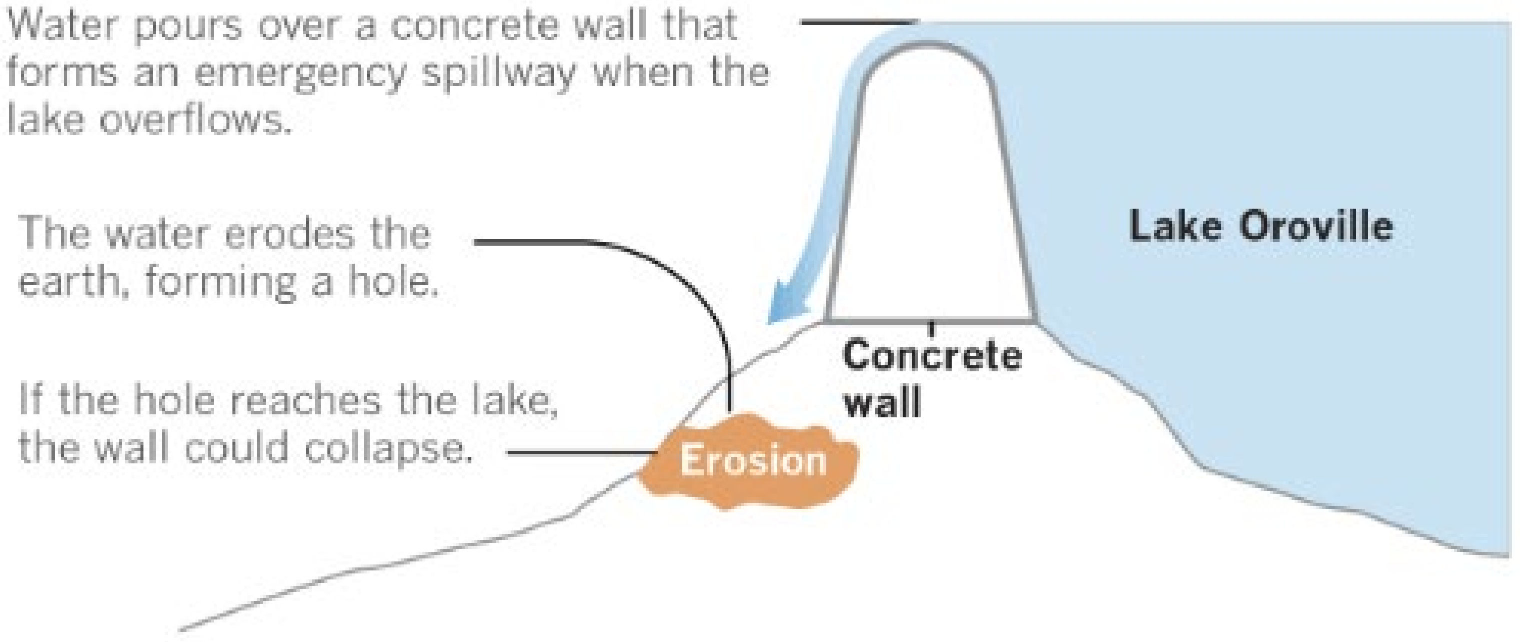
- **Activation of Emergency Spillway**
  - Untested
  - First-ever use of the emergency spillway
  - February 11, 2017
- **Erosion of Unlined Emergency Spillway**
  - More severe and rapid than expected
  - Geology assumed to competent
- **Weir Stability Concerns**
  - Headcutting
  - Undermining of toe

https://damsafety.org/sites/default/files/files/Independent%20Forensic%20Team%20Report%20Final%2001-05-18.pdf

https://www.youtube.com/watch?v=jxNM4DGBRMU

FAILURE MODES

- What is a Potential Failure Mode (PFM)?
- Use of PFMs
  - **Risk Identification**
    - How structure can potentially fail (e.g., overtopping)
  - **Design & Rehabilitation Guidance**
  - **Emergency Planning**
  - **Monitoring & Inspections**
  - **Training & Communication**
  - **Prioritization**
    - Determine issues with greatest risk and address first



Source: DWR. Graphics reporting by Rong-Gong Lin II, Chris Megerian
https://www.latimes.com/projects/la-me-oroville-flooding/

INITIATING EVENT → **PROGRESSION** → **FAILURE**

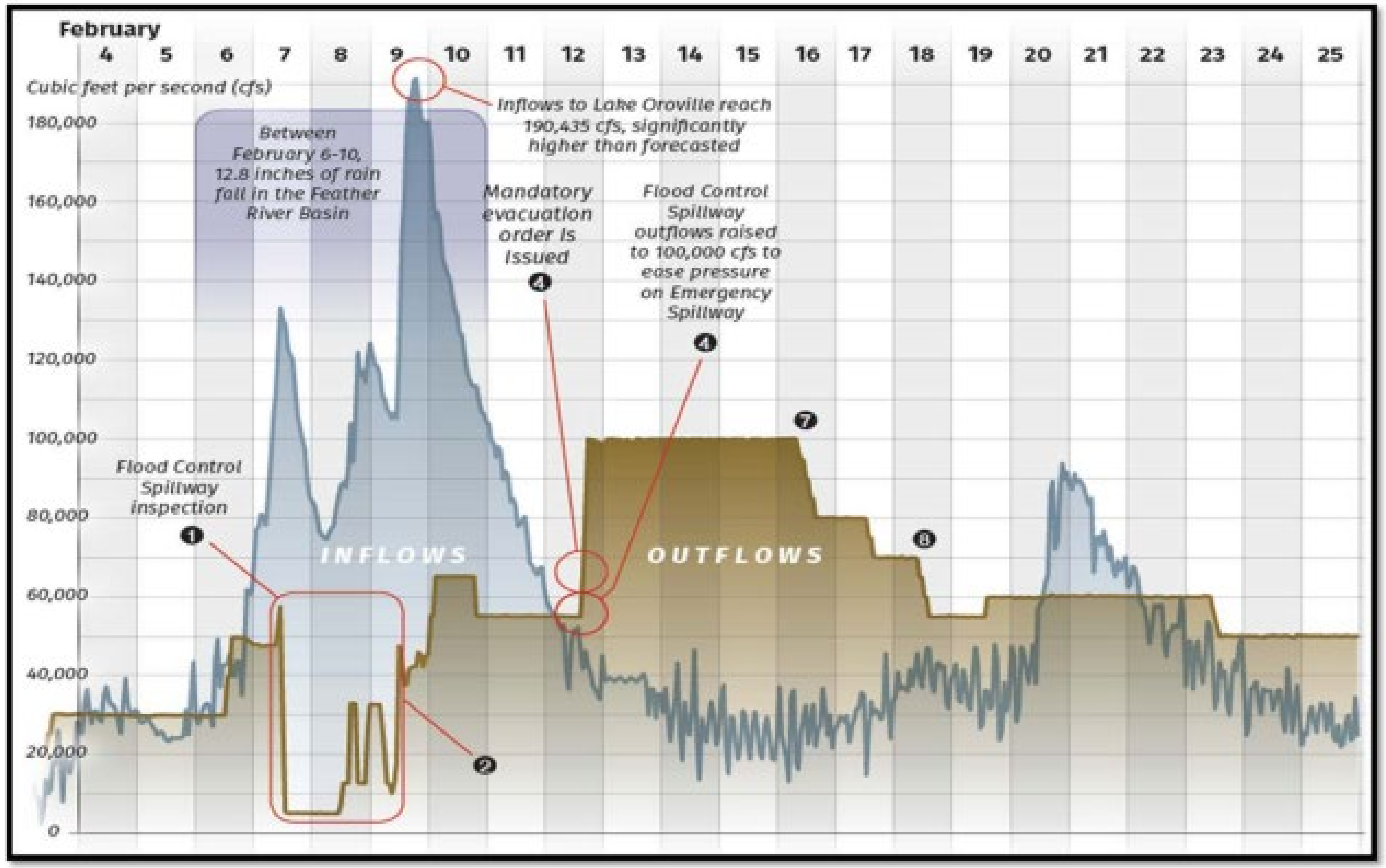
DAM OVERTOPPING

- Hydrologic event (flood) occurs.
- Inflows into the reservoir are greater than the outflow capacity causing an increase in the reservoir level.
- Higher reservoir level overtops crest of weir and overtopping jet impacts downstream foundation rock.
- Streampower from overtopping jet is greater than erodibility index of the rock, resulting in scour.
- Rock scour progresses beneath the weir, resulting in reduced sliding or overturning capacity.
- Driving force is greater than the capacity, and results in instability and uncontrolled release of the reservoir.

EVACUATION MEASURES

https://l450v.alamy.com/450v/f67arj/red-alert!-red-rubber-stamp-over-a-white-background-f67arj.jpg

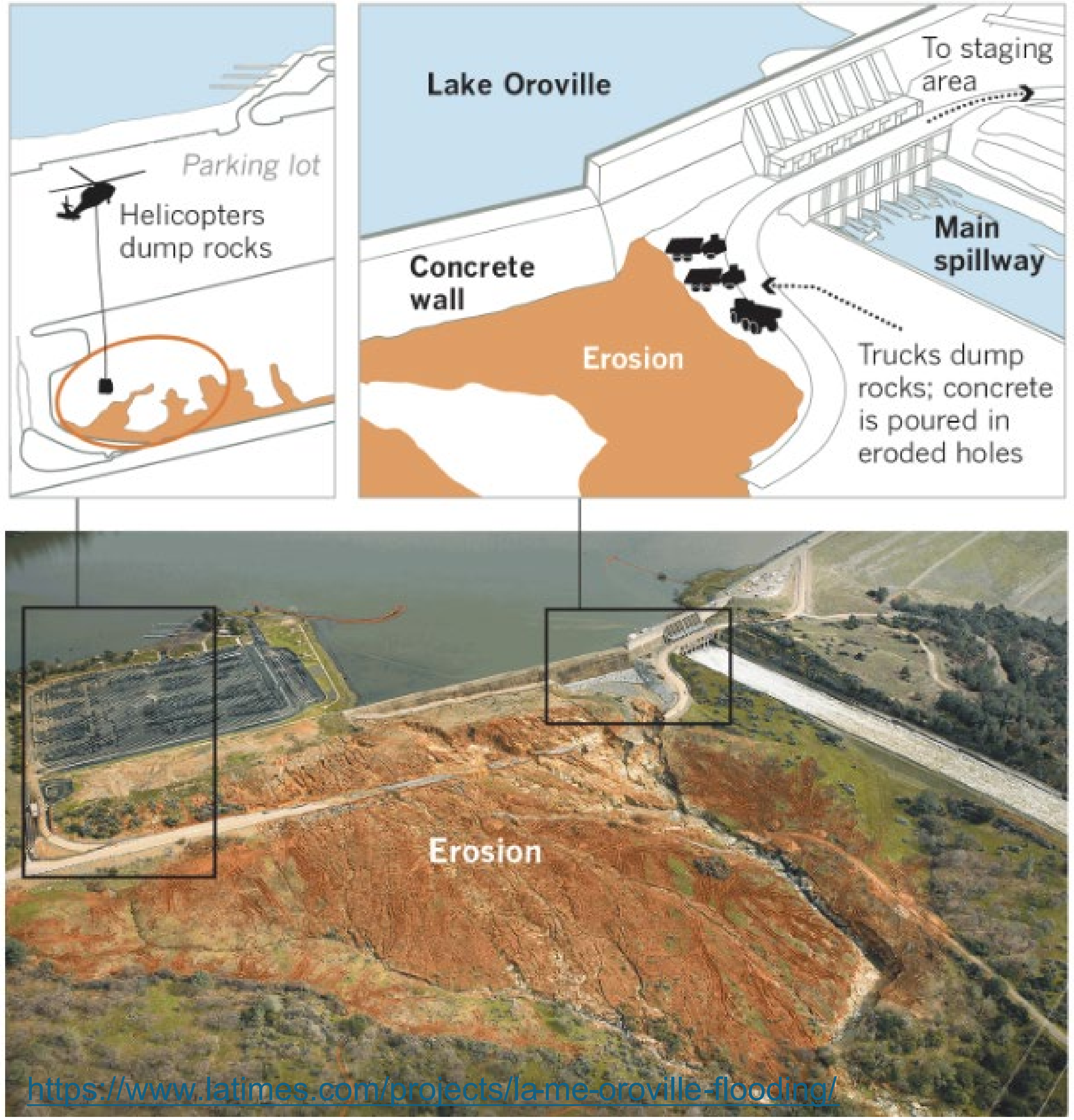
- **February 12: 3:44 PM**
  - Evacuation Order
  - Risks too great
  - Safety of lives downstream
  - 188,000 people evacuated
- **Feb 12: 7:00 PM**
  - FCO discharge increased to 100,000cfs
  - Maintained until Feb 16, 8:00 AM
- **Feb 14: 3:30 PM**
  - Downgrade to evacuation warning
- **Reservoir Management:**
  - Target level El. 850, 50 feet below full pool
  - Feb 20, 3:00 PM: Target reached and maintained
  - Feb 16–27: Discharges adjusted (80,000–50,000 cfs)
- **Feb 27: 7:00 AM**
  - Spillway gate closure began
  - Fully closed by 1:00 PM–investigations initiated



IMMEDIATE MITIGATION EFFORTS

- **Reduce reservoir levels to stop emergency spillway overflows**
  - FCO discharge increased to 100,000cfs
- **Emergency Repairs**
  - Boulders and concrete to fill voids

https://www.youtube.com/watch?v=jxNM4DGBRMU



https://www.latimes.com/projects/la-me-oroville-flooding/

TIMELINE OF CRISIS

7 Feb 2017: Main spillway fails

Craters appear in the main spillway. To avoid increasing the damage to the spillway, water releases are slowed allowing the lake to rise.

11 Feb 2017: Emergency spillway used

Water flows over the emergency spillway causing erosion and damage. This is by design and prevents water going over the top of the main dam. However the ground erodes faster than expected.

13 Feb 2017: Repairs made

Rocks and concrete (1) are placed under the emergency spillway weir to repair erosion damage (2). The release of water into the main spillway is increased, to lower the lake in preparation for more rain. This erodes the adjacent hillside considerably, generating a debris dam (3) that blocks the river and forces the closure of the hydroelectric plant.

Potential risks

While the main 770 ft (230 m) dam is not threatened, if the erosion on *either* spillway reaches the top, it would cause the weir or gate (respectively) to collapse, causing a large uncontrolled water release and life-threatening floods.

https://en.wikipedia.org/wiki/Oroville_Dam_crisis#:~:text=Between%20February%206%E2%80%9310%2C%202017,%2Fs)%20the%20following%20day.

AFTERMATH

- Assessing the damage


https://damsafety.org/sites/default/files/files/Independent%20Forensic%20Team%20Report%20Final%20005-18.pdf


https://www.youtube.com/watch?v=jxNM4DGBRMU

FORENSIC INVESTIGATION

- Independent Forensic Investigation
- Formation of Independent Forensic Team (IFT)
- Purpose and Objectives of IFT
- Findings and conclusions

To complete a thorough review of available information to develop findings and opinions on the chain of conditions, actions, and inactions that caused the damage to the service spillway and emergency spillway, and why opportunities for intervention in the chain of conditions, actions, or inactions may not have been realized. Evaluations of actions, inactions, and decisions for the various stages of the project (pre-design, design, construction, operations, and maintenance) will consider the states of practice applicable to the various time periods involved.

John W. France, PE, D.GE, D.WRE – Team Leader and Geotechnical Engineer

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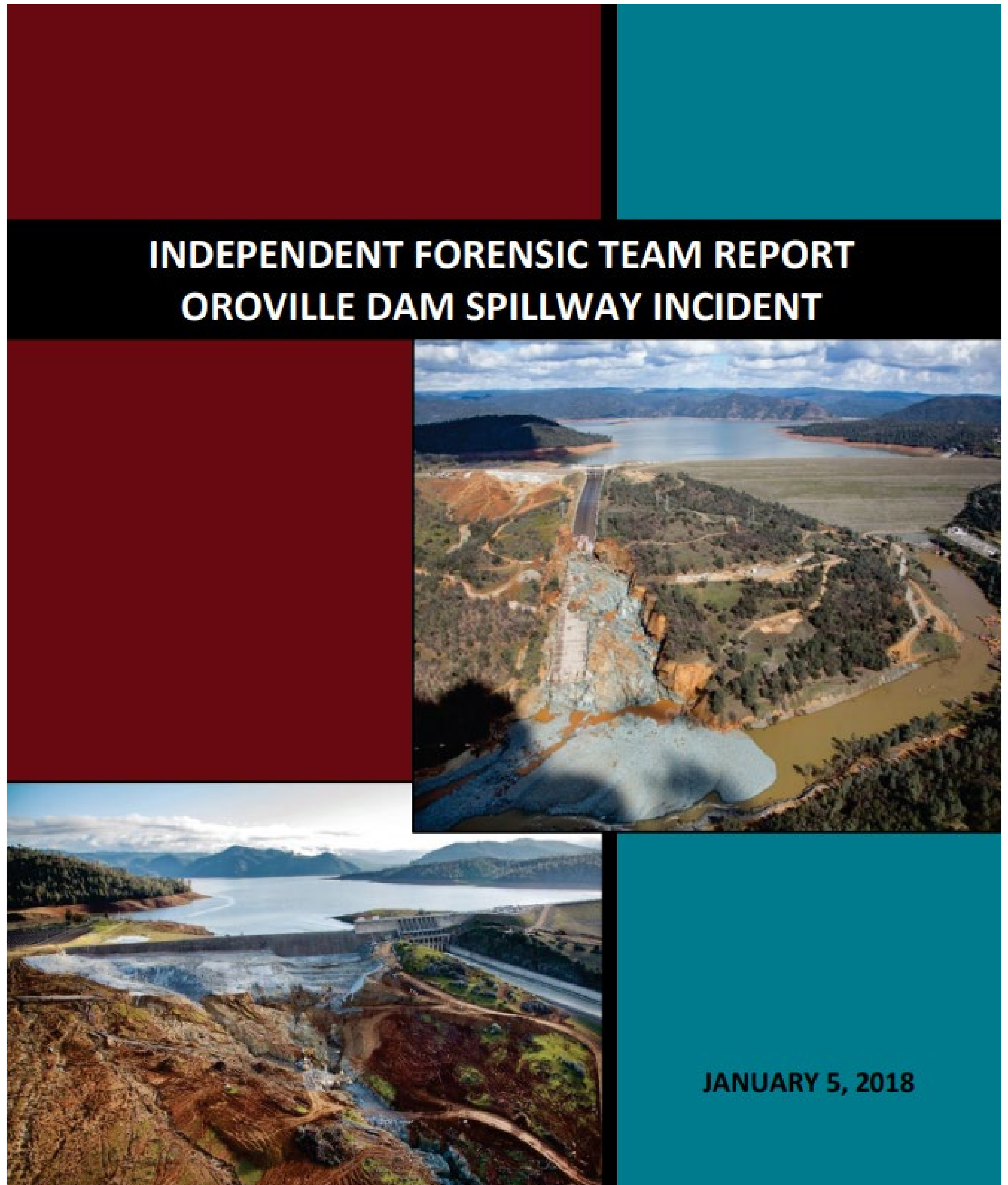
Peter A. Dickson, PhD, PG – Engineering Geologist

Henry T. Falvey, Dr.-Ing, Hon.D.WRE – Hydraulic Engineer

Stephen J. Rigbey – Director, Dam Safety at BC Hydro, and Geological Engineer

John Trojanowski, PE – Hydraulic Structures Engineer



https://damsafety.org/sites/default/files/files/Independent%20Forensic%20Team%20Report%20Final%200105-18.pdf

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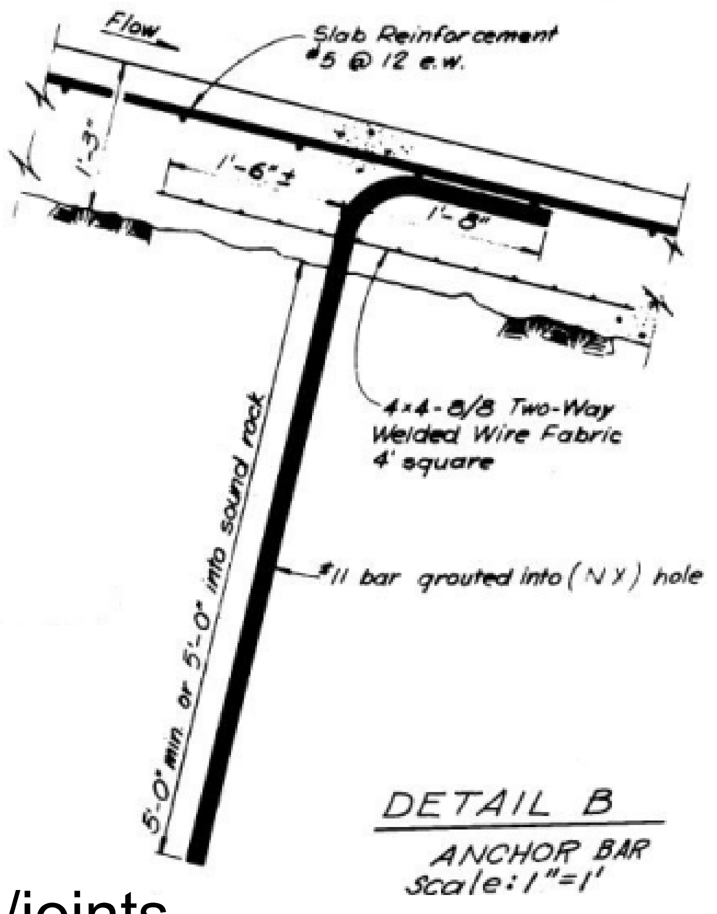
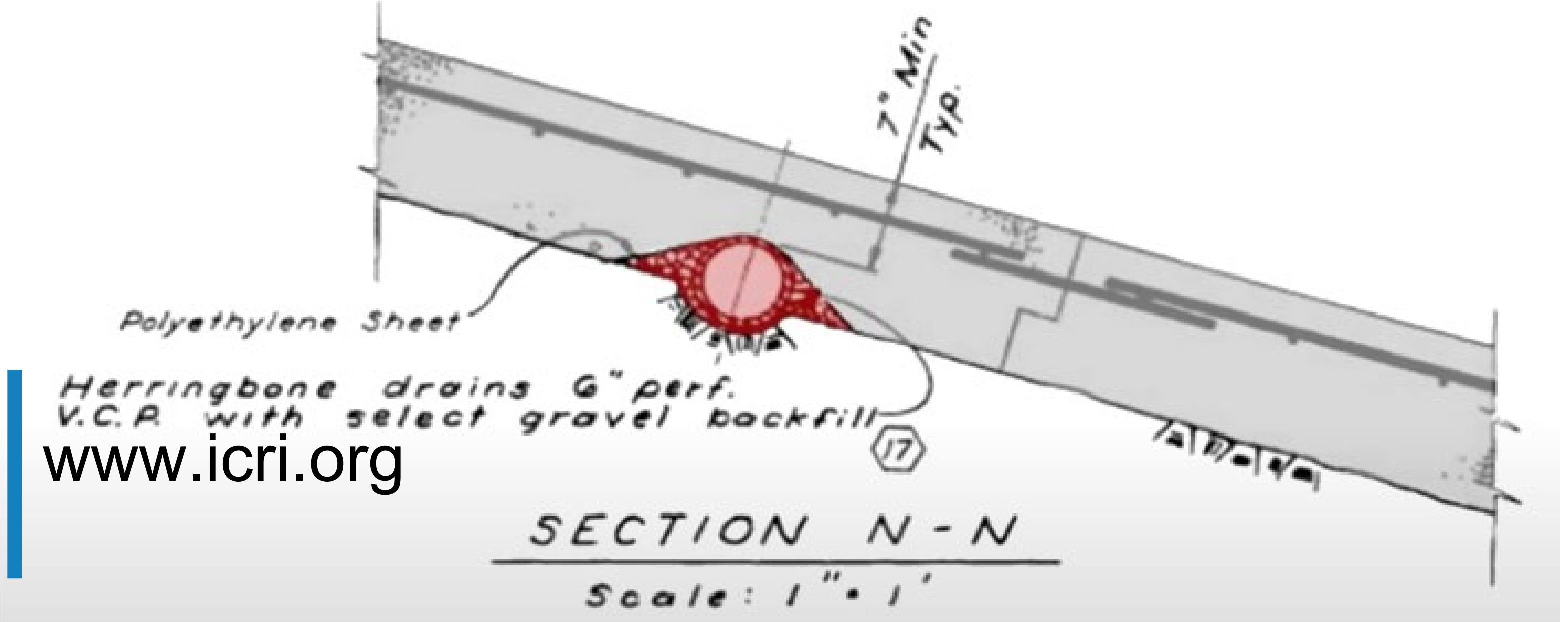
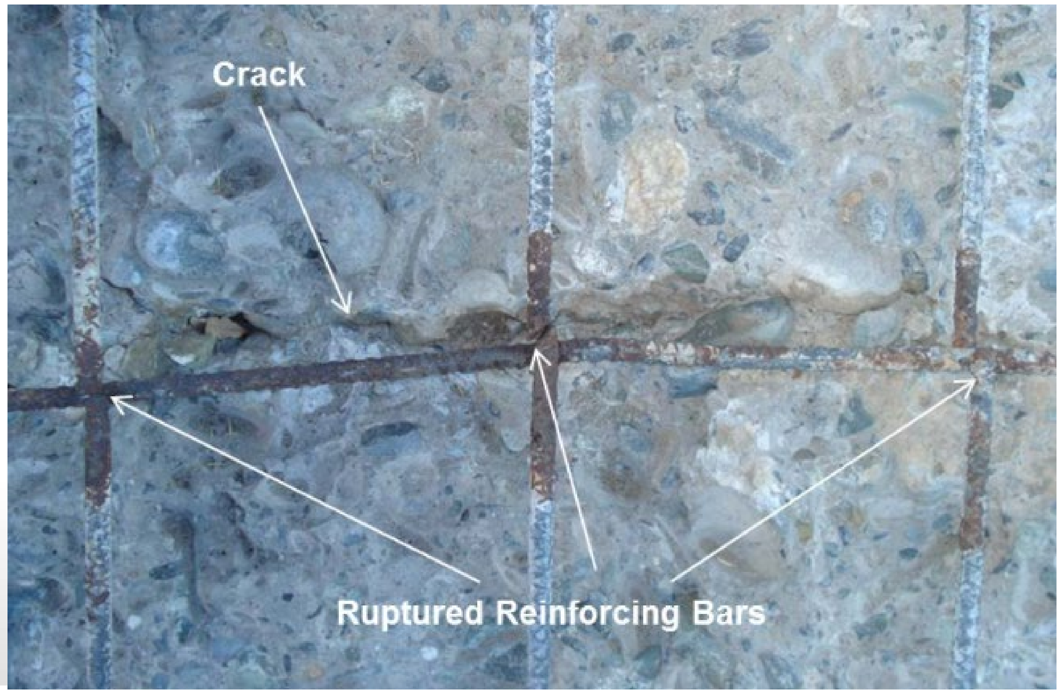
PHYSICAL FACTORS

- **Poor foundation and geologic conditions**
  - Erodible material and fractured rock
- **Design and as-constructed vulnerabilities**
  - Thin concrete slab
  - Drainage system issues
    - Blocked or poorly functioning
  - Anchor capacity reduction
    - Lack of proper anchorage in sound rock
  - Expansion of shallow void under slab
    - Erosion or clay shrinkage
  - Corrosion of steel reinforcement and dowels across cracks/joints
  - Ineffective repairs and progressive deterioration







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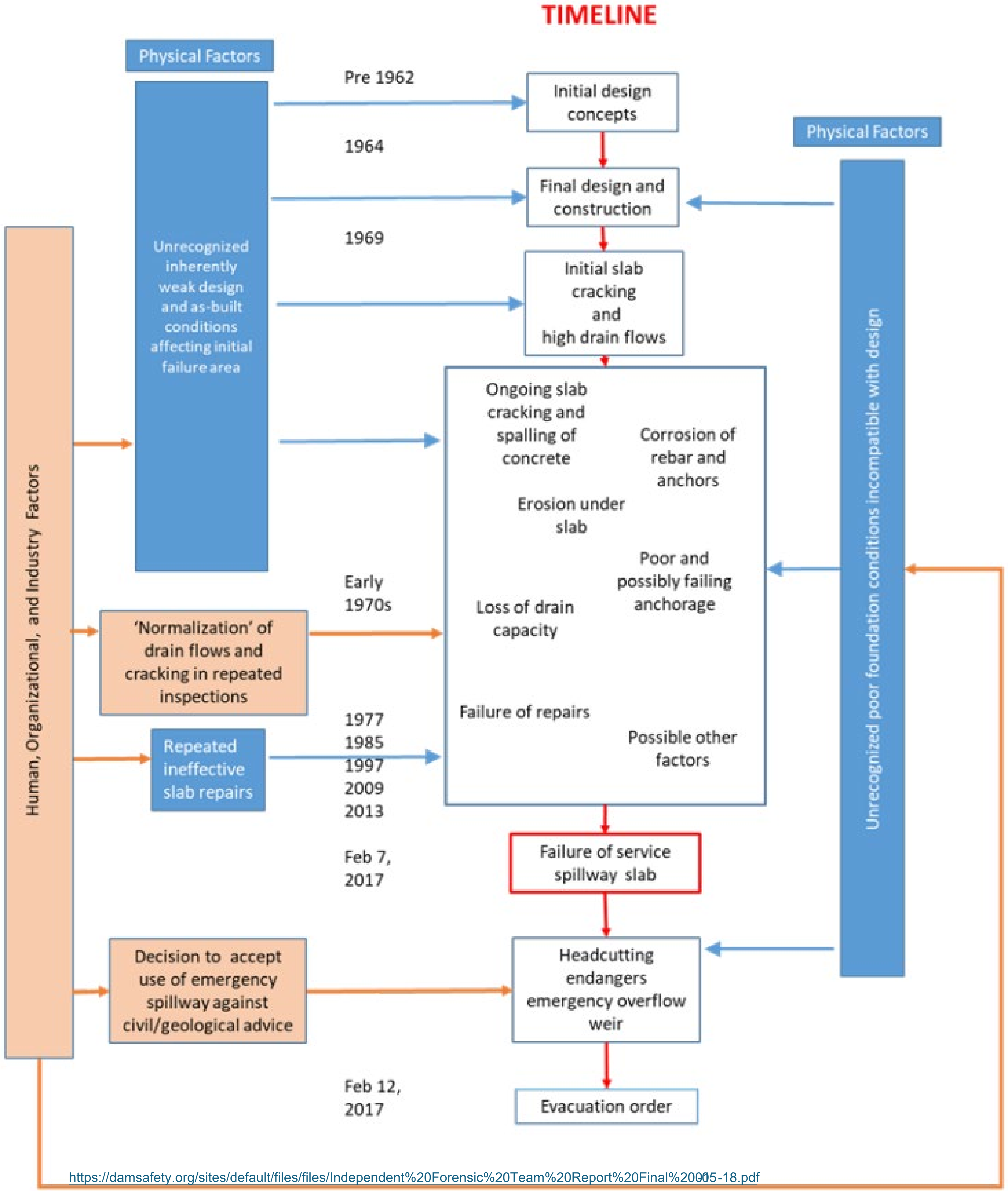
HUMAN FACTORS

- Normalization of unusual conditions
- Acceptance of past claims
- Overconfidence and complacency
- Poor decisions made during crisis

https://wizardofads.org/trust-but-verify-why-you-should-take-ronald-reagans-advice/

https://blog.prototypr.io/winning-the-telephone-game-5bf5457e16b4

- Failure Inevitable
- Yet Unexpected



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INSIGHTS AND IMPROVEMENTS

- IFTR Lessons Learned
  - Top-down safety culture for owners
  - More frequent inspection insufficient
  - Deep dive reviews into historical documents
  - Appurtenant structures must be considered
  - PFMA has limitations for complex systems
  - Regulatory compliance is not sufficient alone
- Policy and Regulatory Changes Post-Incident
  - Oversight shortcomings
  - Changes to process
    - Comprehensive and periodic assessments
    - Move to risk-based assessments
    - Role of independent consultants with dedicated specialties

Current Status of Oroville Dam
  - Responsible ongoing dam safety efforts
  - Community engagement and transparency initiatives

Although the practice of dam safety has certainly improved since the 1970s, the fact that this incident happened to the owner of the tallest dam in the United States, under regulation of a federal agency, with repeated evaluation by reputable outside consultants, in a state with a leading dam safety regulatory program, is a wake-up call for everyone involved in dam safety. Challenging current assumptions on what constitutes "best practice" in our industry is overdue.

2018 Independent Forensic Team Report (IFTR)
Summary Conclusion

TURNING LESSONS INTO ACTION

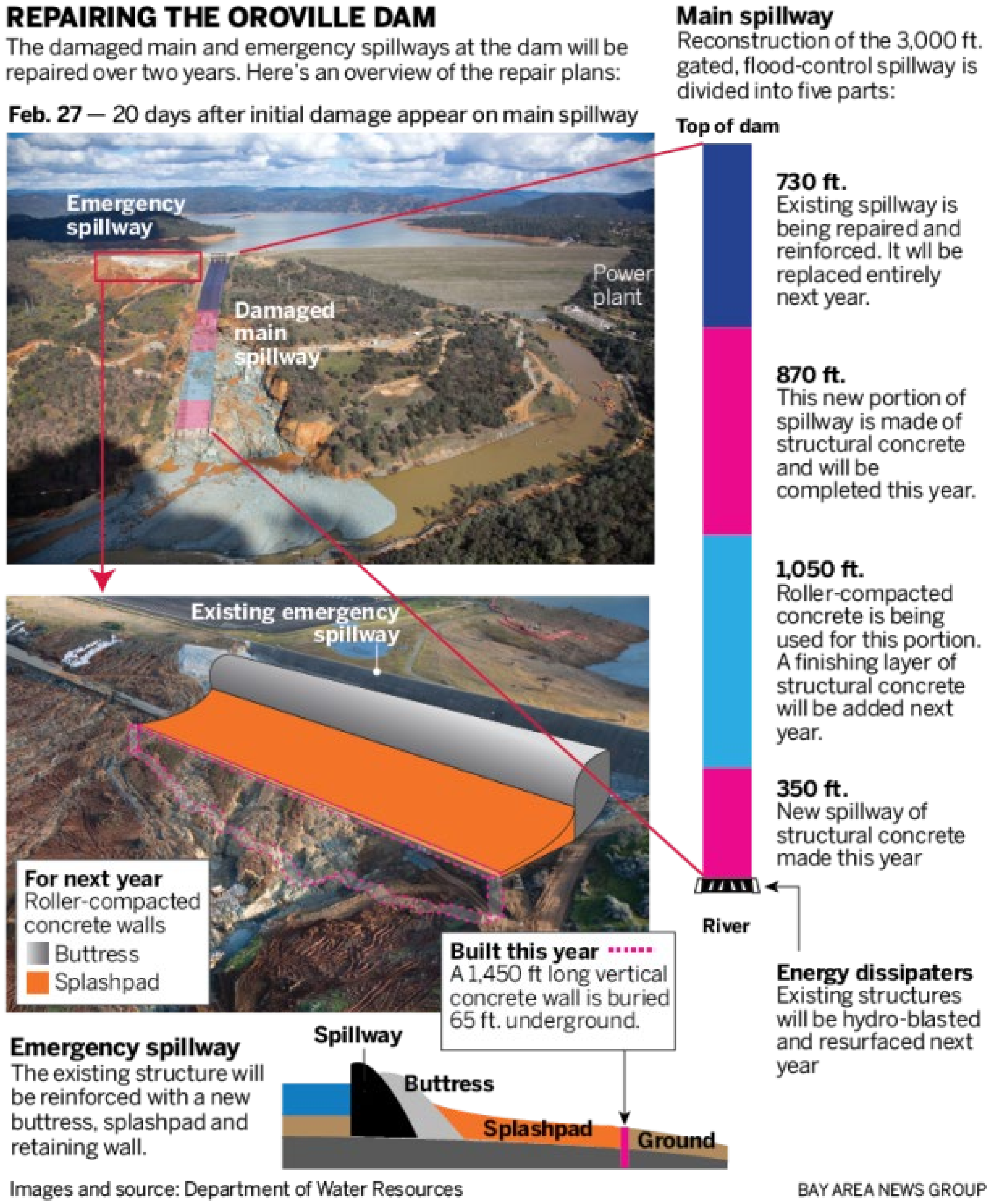
- Training and Preparedness
  - Emergency Action Planning
- Role of Emergency Management Agencies
- Technological Innovations for Monitoring

https://ih1.redbubble.net/image.5289942375.7295/bg,f8f8f8-flat,750x,075,f-pad,750x1000,f8f8f8.jpg

https://stock.adobe.com/search?k=pause+reflect+act

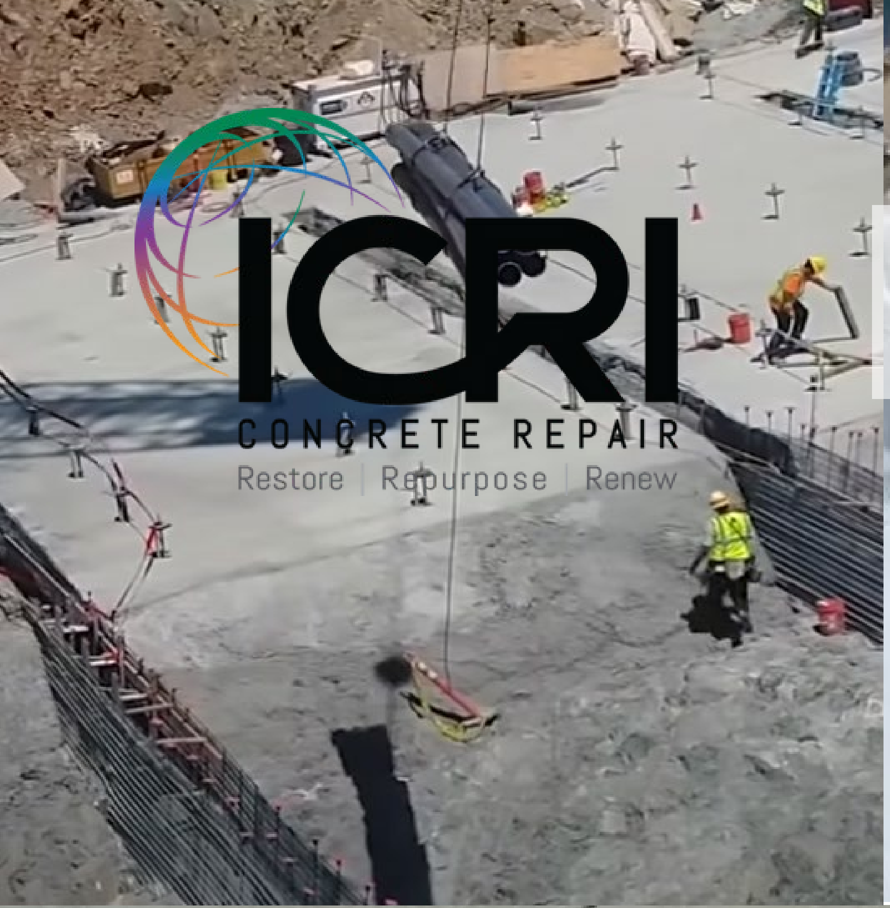
REPAIR AND RECONSTRUCTION

- Repair and Reconstruction Efforts
  - May 19, 2017: Service spillway closed for season, repairs begin
  - Design-build for efficiency
- Phased Construction: Two Main Seasons
  - 2017 Construction Season (Temporary Emergency Repairs)
    - Focus: Stabilize both spillways before 2018 rainy season
  - 2018 Construction Season (Final Reconstruction Started)
    - Main Spillway: entire chute reconstructed
    - Emergency Spillway: RCC apron to prevent erosion
- 2020 Completion: Ahead of schedule
  - Final Cost: $1.1 Billion
  - $400 Million under budget
  - National engineering awards
- Outcome
  - Spillways more robust and resilient, built to modern safety standards
  - Industry-wide reevaluation of spillway safety and dam inspection protocols



https://www.eastbaytimes.com/2017/10/19/cost-of-repairing-oroville-dams-spillway-nearly-doubles-in-price-to-500-million/

REPAIR AND RECONSTRUCTION



https://movies.disney.com/honey-i-shrunk-the-kids

https://www.youtube.com/watch?v=ekUROM87vTA

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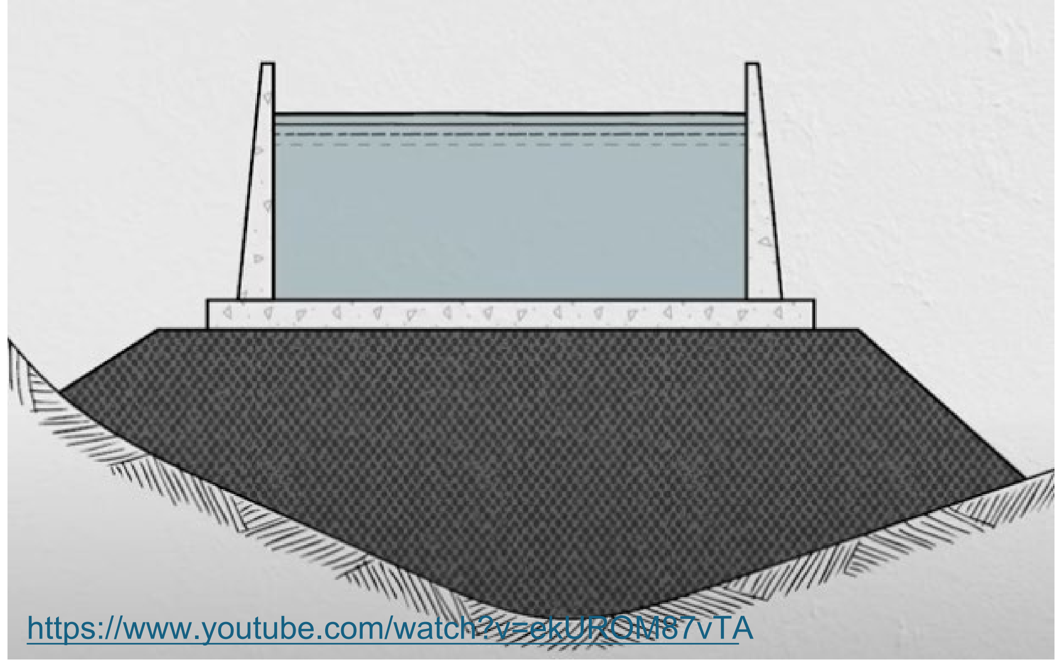
https://pixel-ca-dwr.photoshelter.com/galleries/C0000OxvlgXg3yfg/G0000aiQCyXvQI4Y/I00005W0jutvm8Ng/KG-oroville-49360-02-04-20-jpg

https://www.youtube.com/watch?v=ekUROM87vTA

TECHNOLOGIES & TECHNIQUES

- Advanced Technologies
  - LiDAR & Sonar
- State-of-the-art modeling techniques
  - 1:50 scale model at Utah State University
  - Computational Fluid Dynamics (CFD)
  - Building Information Modeling (BIM)



TECHNOLOGIES & TECHNIQUES

- Rapid large-scale placement methods
- Concrete technologies
  - RCC and conventional concrete
- Techniques for expedited construction
- Challenges and solutions

https://www.youtube.com/watch?v=ekUROM87vTA

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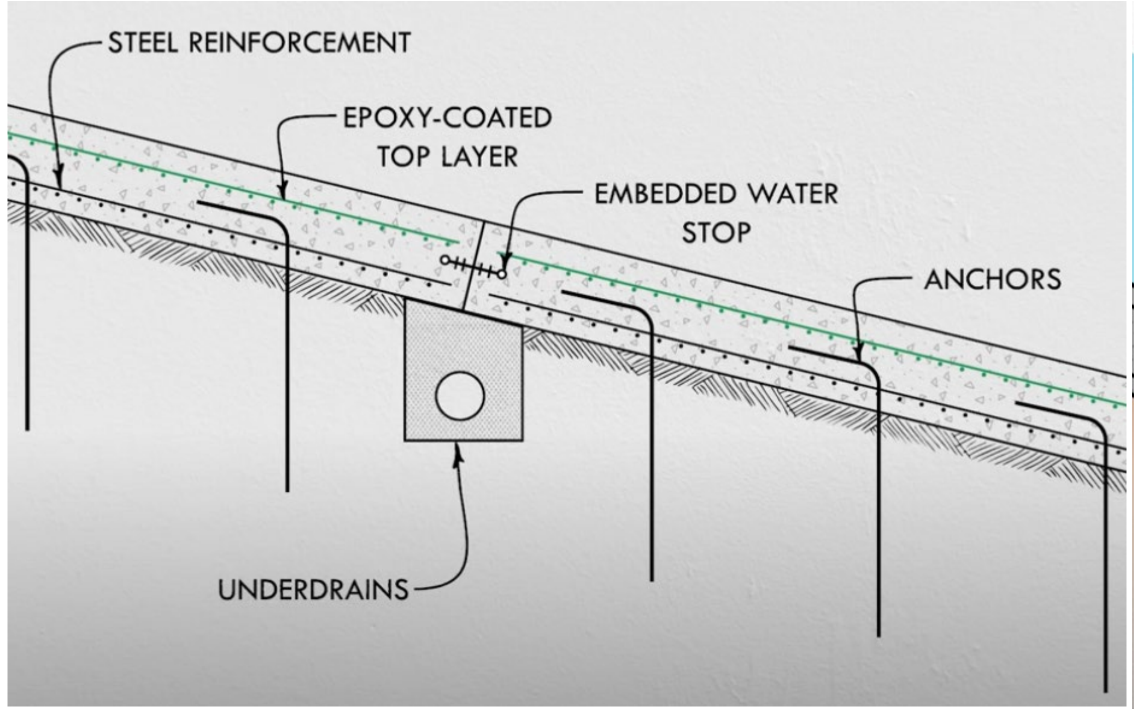
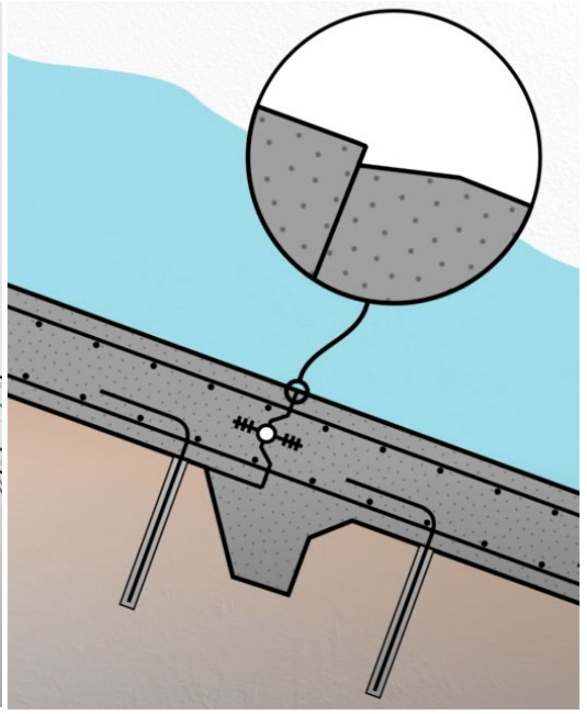
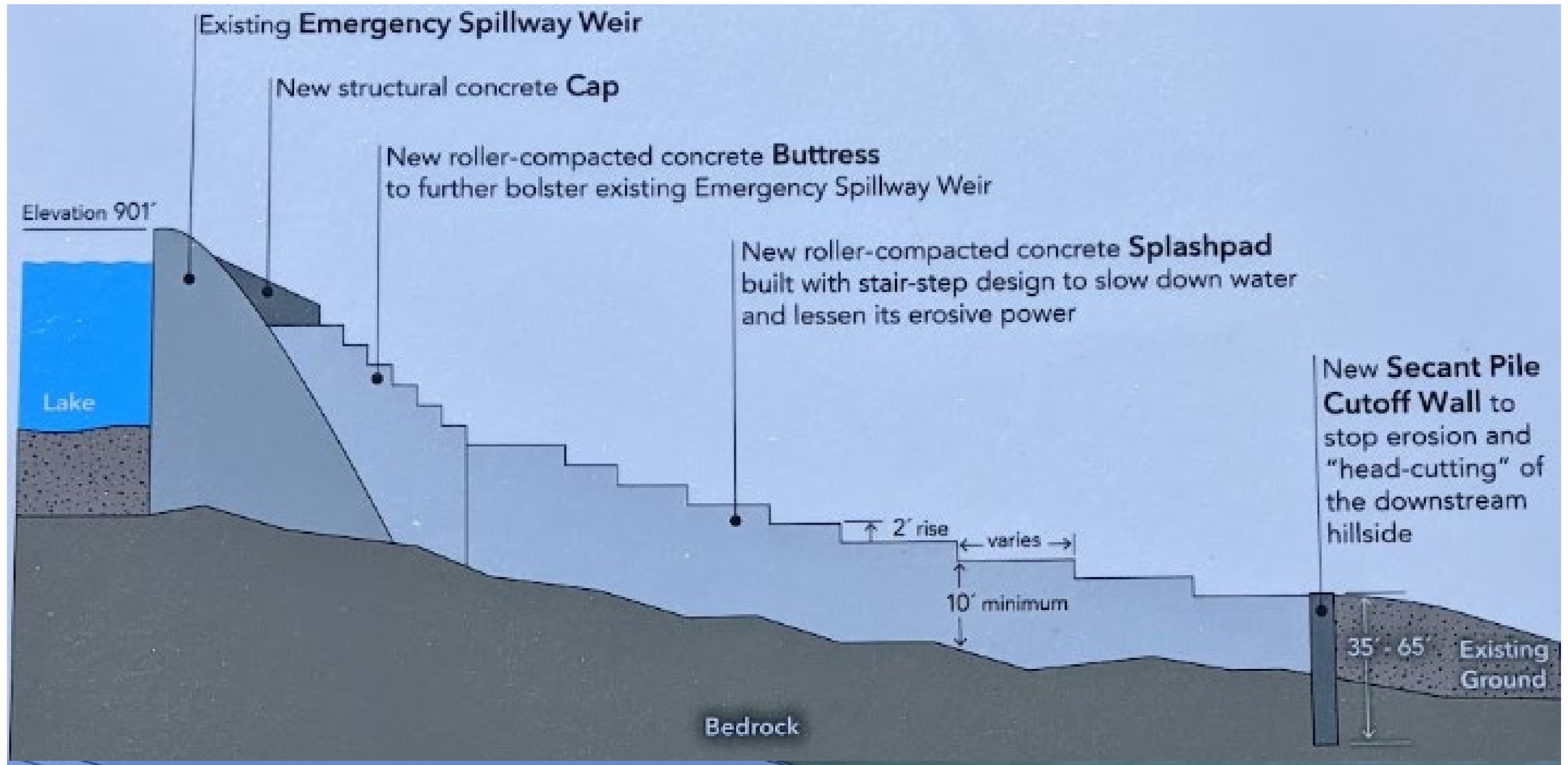
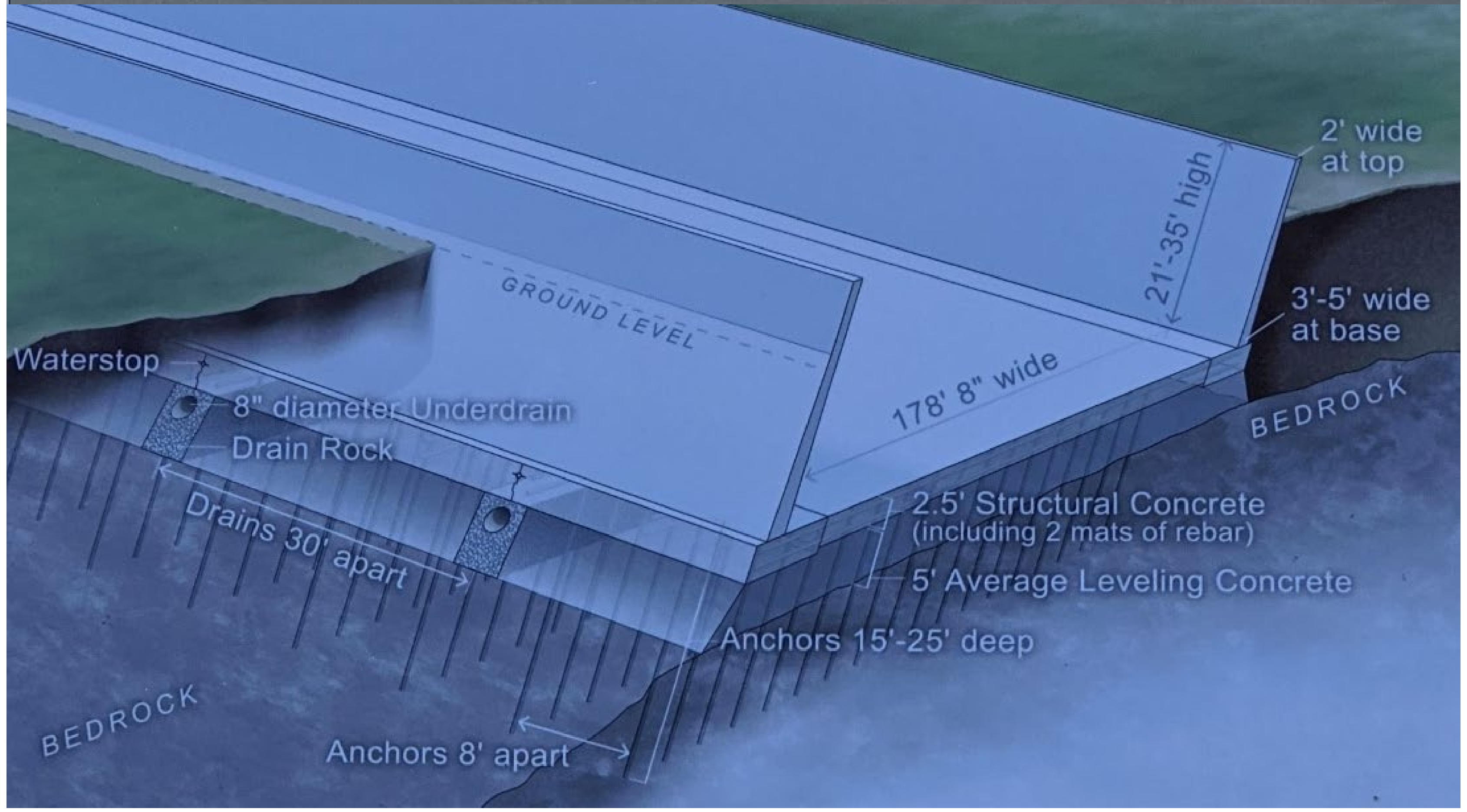
FAILURE MODE MITIGATION

- Stopping progression of failure modes
  - Main spillway
    - Thicker and more reinforced slab
    - Offset surface joints
    - Better drainage & waterstops
    - Solid foundation and anchorage
  - Emergency spillway
    - Buttress and structural concrete cap
    - RCC splashpad
    - Secant pile wall









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PROJECT COMPLETION

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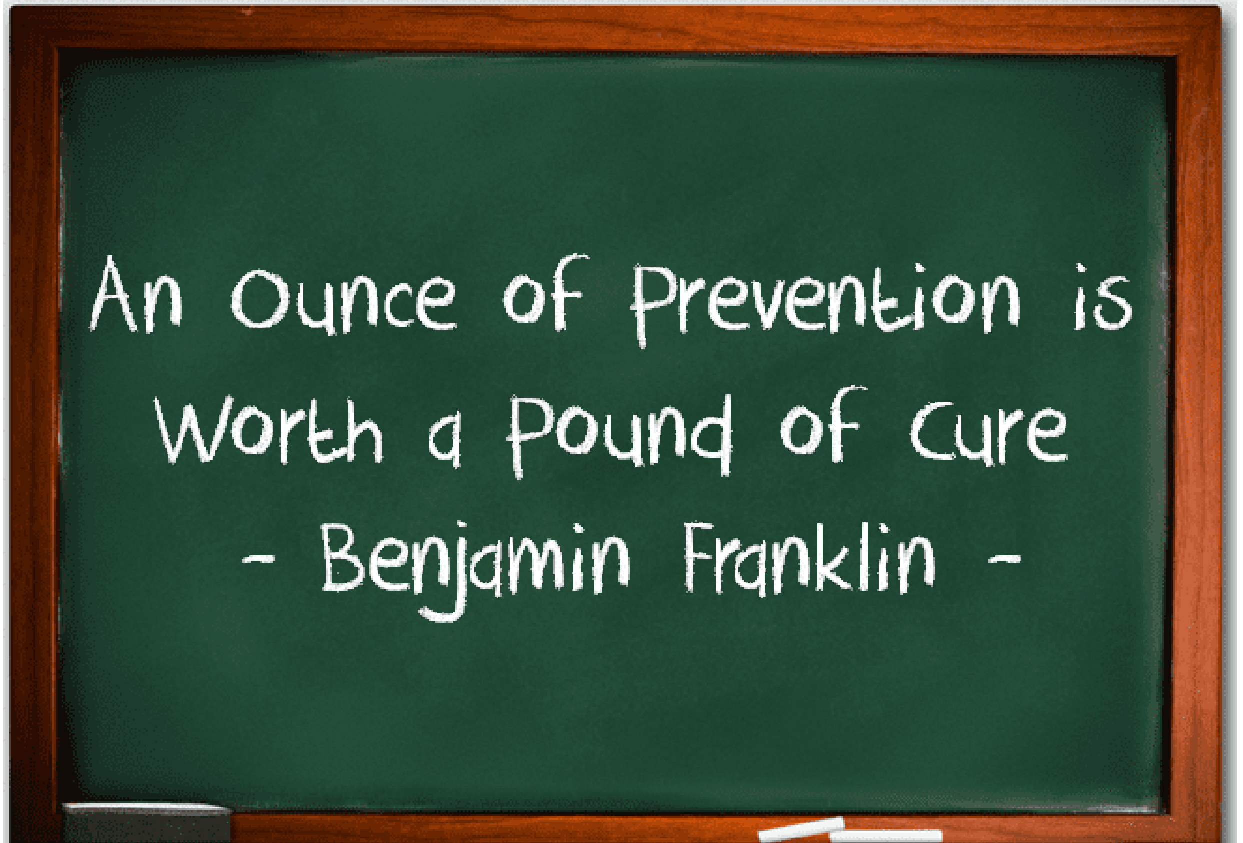
CONCLUSION

- Key Lessons
  - Think proactively: quality and maintenance matter
  - Longevity requires ongoing assessment and adaptation
  - Trust but verify: do due diligence
  - Be aware of normalization of deviations
  - Value of risk assessment for prioritization
  - Effectiveness of emergency preparedness
  - Learn from past failures: course correction
- Concrete Repair Industry
  - Cost-effective and sustainable solutions for aging structures



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- Photography
  - Most photographs provided from California Department of Water Resources public resources.
  - Links from online sources provided below photos
  - Practical Engineering Channel
  - MAPEI Corporation
  - Personal photos

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ANY QUESTIONS?

THANK YOU!

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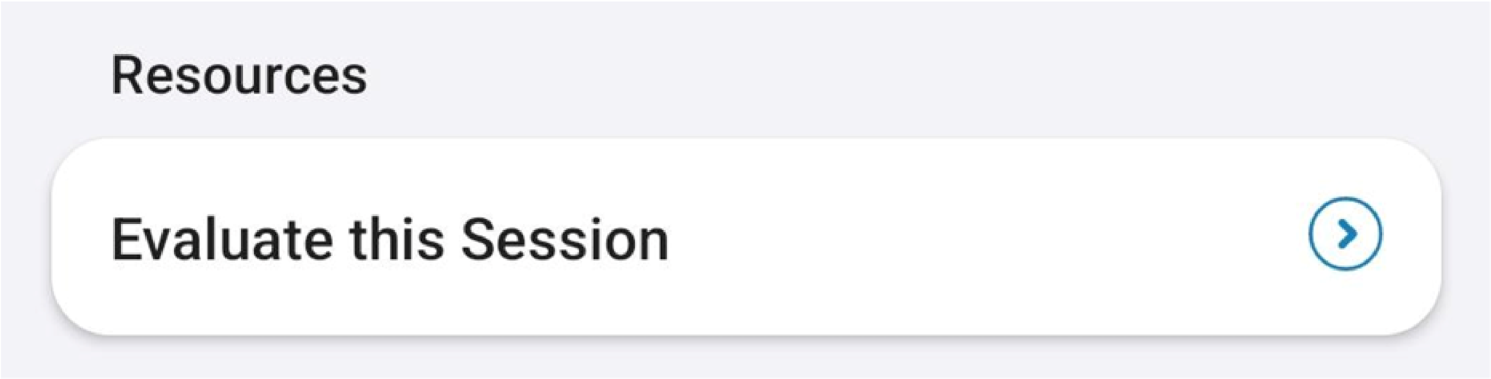
APRIL 13– 16, 2025

SESSION EVALUATION

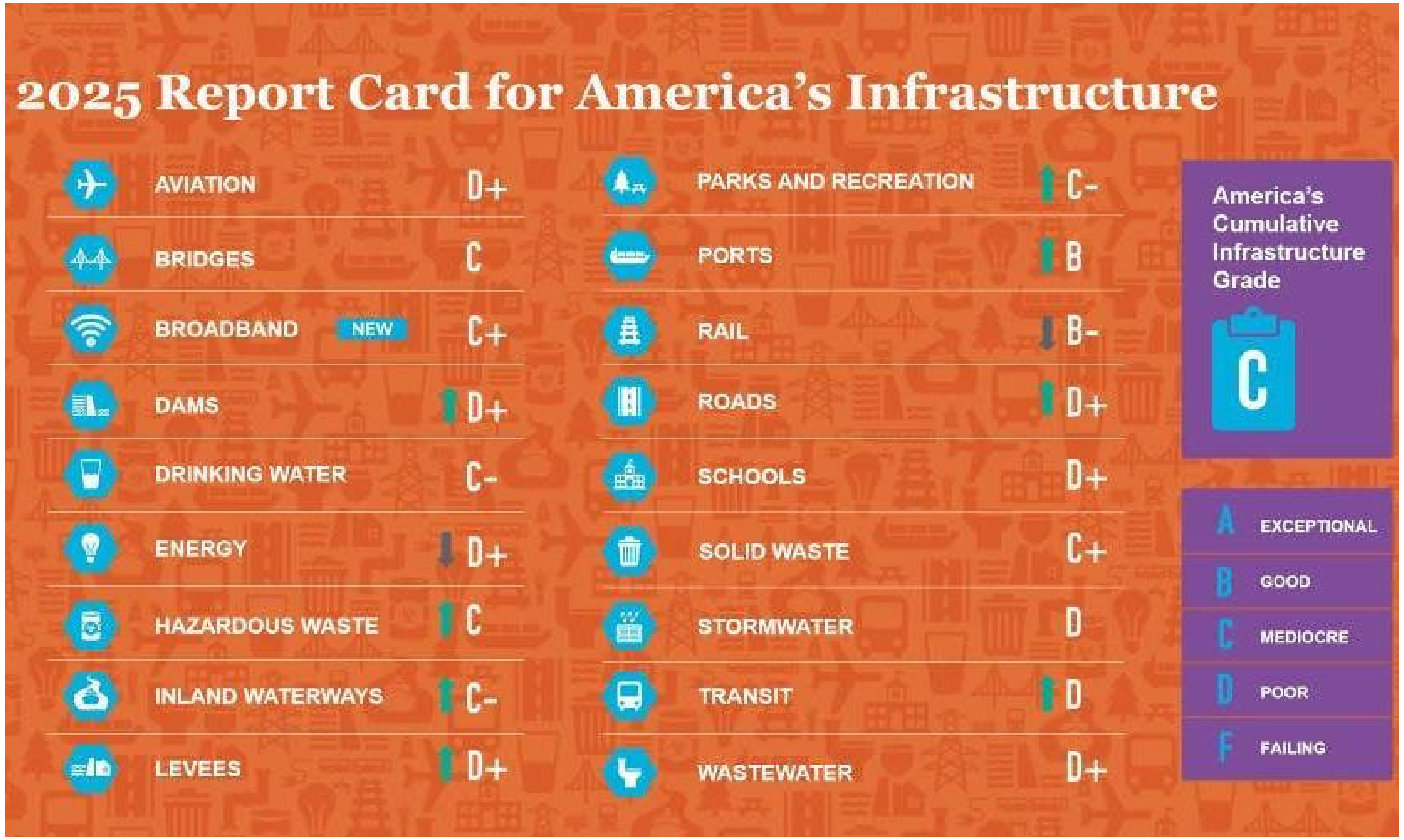


To complete the session evaluation, open the ICRI Convention App.

Under **Plan Your Event,** select Schedule, and then the Technical Session you are attending. Select the sub-session you are attending, scroll down to Resources, and select Evaluate this Session.

AGING INFRASTRUCTURE

https://infrastructurereportcard.org/wp-content/uploads/2025/03/Grades -One-Sheet-2025 -Natl-IRC.pdf



https://img.lightwaveonline.com/files/base/ebm/lw/image/2025/03/67e30df0c286064db671dd0a_-screenshot_189.png?auto=format,compress&fit=max&q=45

AGING INFRASTRUCTURE

Cumulative Investment Needs

BY INFRASTRUCTURE CATEGORY BASED ON MAINTAINING CURRENT FEDERAL INVESTMENT LEVELS ALL VALUES IN BILLIONS

Infrastructure System	Needs[1]	Funded, 2024-33[2]	Funding Gap, 2024-33
Aviation[3]	$310	$197	$113
Bridges[4]	$538	$165	$373
Broadband[5]	$61	$61	$0
Dams[6]	$185	$20	$166
Drinking Water[7]	$670	$361	$309
Energy[8]	$1,886	$1,308	$578
Hazardous & Solid Waste[9]	$162	$146	$16
Inland Waterways & Ports[10]	$45	$32	$13
Levees[11]	$97	$7	$91
Public Parks[12]	$106	$62	$44
Rail[13]	$145	$113	$32
Roads[14]	$2,233	$1,549	$684
Schools[15]	$1,100	$671	$429
Transit[16]	$618	$466	$152
Wastewater + Stormwater[17]	$983	$293	$690
TOTAL	**$9,139**	**$5,450**	**$3,689**

https://infrastructurereportcard.org/wp-content/uploads/2025/03/Full -Report-2025 -Natl-IRC-WEB.pdf

OUR ROLE & BENEFITS OF REPAIR

- Service Life Extension of Existing Infrastructure
  - Economic Savings
  - Historic Preservation & Societal Value
  - Environmental Impact
    - Reducing Waste & Resource Consumption (Sand, Water, Raw Materials)
    - Carbon savings

Center of Excellence for Preservation and Service Life Extension