FRED BURR DAM FEASIBILITY STUDY
Fred Burr Dam Feasibility Study

- **Purpose:** Develop pre-feasibility risk reduction alternatives and recommendations for short-term operations and long-term rehabilitation.
- **Tasks:**
  - Topographic Survey
  - Hazard Analysis/Breach Mapping
  - Simplified PFMA/Risk Assessment
  - Geotechnical Investigation
  - Develop alternative with cost estimates and recommendations
Dam Information

- Owner: MT Department of Natural Resources & Conservation
- Operator: Fred Burr Water Users Association
- Dam Type: Zoned earth fill
- Height: 50 ft; Length: 325 ft
- Storage: 403 acre-ft @ Spillway Crest; 523 acre-ft @ Top of Spillway Gate; 688 acre-ft @ Dam Crest
- Spillway: 20-ft wide concrete chute with 4.3-ft high radial gate
- Outlet Works: 196-ft long, 48-inch RCP with slide gate in wet well
- Originally Constructed 1946-1948
- Failed during first filling in 1948
- Reconstructed 1948-1950
1948-1949 Drawings
Photos – Upstream and Spillway

- Upstream slope
- Downstream Chute
- Radial Gate at Spillway Crest
Photos – Crest/Full Reservoir

Dam Crest

Spillway

Reservoir
Photos – Downstream Slope
Photos – Outlet Works

- Intake
- Outlet Discharge
- Gate Tower On Dam Crest
Dam failed on May 27th, 1948 during first filling.

- Construction of Embankment and Outlet Works Complete, Spillway not finished
- Reservoir 4 feet below spillway crest at 12:30 pm on May 26th, control gate fully open. Slight seepage near toe of right abutment and wet area near toe of left abutment.
- May 27th at 2:00 am resident near Fred Burr Creek heard “rumbling” from water coming down creek. Flood wave reached Highway 93 about 4:00 am.
Dam Failure

- Section of dam between gate tower and spillway washed out to 5’-10’ below outlet conduit. Ends of outlet conduit exposed.
- Flow depth of approximately 1 foot over spillway weir.
- No evidence of dam overtopping.
- Springs through natural ground at right abutment. Substantial seepage was evident emerging from breach slope below spillway; and reports of “wet spots” on left side before breach.
- Damage to downstream irrigation ditches, crops, fences, dam access road and county road. Stream channel eroded up to 20’. Evidence of flow depths between 10’ and 30’ in Fred Burr Creek.
Historic Photos of Breach Repair

- Breach Area
- Rebuilt Spillway
- Gate Tower
Historic Photos of Breach Repair
Past & Current Deficiencies

- Identified Issues/Deficiencies since 1950 reconstruction:
  - Void in upstream side of left side of abutment identified in late 50’s and repaired in 1958.
  - Left spillway joint offset approximately 1-inch at flip bucket; no recent changes.
  - Left spillway wall seepage – Joint above flip bucket, worsened around 2009.
  - Upstream conduit damage – Identified in 2012, two large, 1’ diameter holes through pipe approx. 9’ downstream of inlet. No grout remaining in most joints. Joints near tower open approx. 2” at invert and tight at crown.
Deficiencies Cont.

- Identified Issues since 1950 reconstruction:
  - Void adjacent to left spillway wall downstream of dam crest.
  - Depressed area downstream of crest near right side – Identified in 2009, Pin #2 settled 0.2' in 2013.
  - Downstream depressed area above outlet – Not recent, located near toe along outlet alignment.
  - **Void at gate tower – Identified 2011 after record reservoir level. Test pit exploration inconclusive.**
  - Upstream left embankment void – Identified 2012, 1’x2’ area at high water level; excavated and filled to repair.
1950 “Sinkhole” Repair – Upstream left abutment
Recent Actions

- Pool Level Restriction – In place since 2011, spillway gate to remain full open.
- Transducers installed for reservoir and monitor wells in May 2014.
Fred Burr Dam Feasibility Study

- Topographic Survey
- Hazard Analysis/Breach Mapping
- Simplified PFMA/Risk Assessment
- Geotechnical Investigation
- Develop alternative with cost estimates and recommendations
Site map and DEM developed using LiDAR, IfSAR and GPS ground survey.
Three dam breach scenarios modeled with 2-dimensional software (FLO-2D).
Breach Modeling

<table>
<thead>
<tr>
<th>Dam Breach Scenario</th>
<th>Total 2013 PAR</th>
<th>Graham (1999) Fatality Rates for Loss of Life (Flood Severity Based on Depth)</th>
<th>Graham (1999) Fatality Rates for Loss of Life (Flood Severity Based on Local (Depth*Velocity))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunny Day Failure</td>
<td>49</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Modified Sunny Day Failure</td>
<td>67</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Hydrologic Failure</td>
<td>102</td>
<td>0.3</td>
<td>0.4</td>
</tr>
</tbody>
</table>

IDF = min. 500-year flood (1,080 cfs)
Montana DNRC commissioned this risk assessment to evaluate continued operation of Fred Burr Dam after discovery in 2011 of a sink hole and void adjacent to the outlet works gate tower.

Purpose of risk assessment was to provide basis for:
- short-term recommendations for continued operation of the dam, and
- pre-feasibility level rehabilitation alternatives and cost estimates for long-term rehabilitation or decommissioning of the dam.
RISK ASSESSMENT

- **Focused PFMA:**
  - limited range of credible PFMs associated with *seepage and internal erosion* mechanisms, only;
  - normal operating pool conditions, consistent with the currently imposed spillway open-gate restriction; other PFMs for extreme flood and earthquake load conditions were not considered.

- **Perform Semi-quantitative Risk Assessment:**
  - Likelihood probabilities were estimated using procedures generally consistent with USBR/USCOE Best Practices guidance documents
  - Consequences were estimated initially based on descriptive categories; later updated with quantitative loss of life estimates
POTENTIAL FAILURE MODES IDENTIFICATION

- Preliminary PFMs were provided by facilitator prior to workshop based on review of background information
- During the PFMA workshop the preliminary PFMs were reviewed and a final list of PFMs was developed based on background information review, site inspection, and review of additional information provided at the workshop

### PRELIMINARY PFMs

<table>
<thead>
<tr>
<th>PFM</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PFM’s Involving Erosion of Embankment and Foundation Materials:</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Internal erosion exiting into the left abutment foundation talus and downstream rock fill materials.</td>
</tr>
<tr>
<td>2</td>
<td>Internal erosion exiting into coarse-grained fill foundation materials beneath the spillway in the right abutment.</td>
</tr>
<tr>
<td><strong>PFM’s Involving Erosion of Embankment Only:</strong></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Erosion and scour along transverse cracks formed in closure fill placed following the 1948 breach.</td>
</tr>
<tr>
<td><strong>PFM’s Involving Outlet Conduit:</strong></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Internal erosion exiting into cracks, open joints, or voids in the concrete outlet pipe.</td>
</tr>
<tr>
<td>5</td>
<td>Internal erosion/scour along the outside perimeter of the concrete outlet pipe.</td>
</tr>
<tr>
<td><strong>PFM’s Involving Spillway:</strong></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Internal erosion exiting into open cracks in the left spillway sidewall.</td>
</tr>
<tr>
<td>7</td>
<td>Internal erosion/scour along the interface with the left spillway sidewall.</td>
</tr>
</tbody>
</table>
PFM PROCESS

- Identify, Describe, and Discuss Candidate Potential Failure Modes
- Candidate potential failure mode (PFM) solicited from team members and a full description was developed in detail including initiation and sequence to failure.
- Group listed adverse factors that make the failure mode more likely and positive factors that make the failure mode less likely to initiate and progress.
- Assigned PFM Screening Category

### Screening Categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Brief Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Highlighted</td>
<td>Those PFMs of greatest significance considering need for awareness, potential for occurrence, magnitude of consequence and likelihood of adverse response. Carried forward into a risk analysis. May require short-term action.</td>
</tr>
<tr>
<td>II</td>
<td>Considered, but not Highlighted</td>
<td>Physically possible, but are not highlighted for one or more reasons. Carried forward into a risk analysis, but do not appear to require immediate (short-term) action.</td>
</tr>
<tr>
<td>III</td>
<td>Insufficient Information</td>
<td>A dam safety investigative action or analyses can be recommended. There is insufficient information to make a judgment on whether these PFMs should be carried forward for risk analysis.</td>
</tr>
<tr>
<td>IV</td>
<td>Ruled Out</td>
<td>Do not need to be carried forward for risk estimates.</td>
</tr>
</tbody>
</table>
### FINAL PFM

<table>
<thead>
<tr>
<th>PFM</th>
<th>Description</th>
<th>Screening Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>Internal erosion (piping) of core materials exiting into the left abutment foundation talus and downstream rock fill.</td>
<td>III → II</td>
</tr>
<tr>
<td>2</td>
<td>Internal erosion scour at right abutment contact exiting into coarse-grained shell materials beneath right abutment.</td>
<td>II</td>
</tr>
<tr>
<td>3</td>
<td>Internal erosion along hydro-fractures or other built-in flaws at &quot;closure&quot; section of embankment.</td>
<td>II</td>
</tr>
<tr>
<td>4A</td>
<td>Internal erosion exiting under steady seepage into existing cracks, open joints, or voids in the concrete outlet pipe.</td>
<td>II</td>
</tr>
<tr>
<td>4B</td>
<td>Internal erosion into newly formed void in downstream concrete outlet pipe.</td>
<td>II</td>
</tr>
<tr>
<td>5</td>
<td>Internal erosion along outside of conduit, similar to PFM-3 but also involving outlet works.</td>
<td>II</td>
</tr>
<tr>
<td>9</td>
<td>Internal erosion in area of gate tower exiting downward into dam foundation (embankment-foundation).</td>
<td>II</td>
</tr>
</tbody>
</table>
For each significant PFM identified, a failure event tree was developed, nodal probabilities estimated, and annual probability of failure ($f$) computed as sum of load probability ($P_L$) $\times$ probability of failure under the load ($P_F$)

$$f = P_L \times P_F$$


- Subsequent nodal probabilities were subjective, and considered proposed values assigned to verbal descriptors as summarized in USBR: [http://www.usbr.gov/ssl/damsafety/Risk/BestPractices/13-SubjectiveProbability20121116.pdf](http://www.usbr.gov/ssl/damsafety/Risk/BestPractices/13-SubjectiveProbability20121116.pdf)
### Examples Result for Calculation of “f”

**PFM-9: Internal Erosion of Fine-Grained Embankment Core Materials in Area of Gate Tower Exiting Downward into Dam Foundation (Screening Category II)**

<table>
<thead>
<tr>
<th>Node Description</th>
<th>Comments</th>
<th>Probability Descriptor</th>
<th>Probability Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir Filled to Normal Pool at Spillway Crest Elev (Spillway Gate Open)</td>
<td></td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>Initiation - Erosion Starts (includes possible re-initiation)</td>
<td>Sinkhole is strong evidence that some erosional process has initiated</td>
<td>Use higher range of values than USBR best estimates</td>
<td>$1 \times 10^{-3}$ to $1 \times 10^{-2}$</td>
</tr>
<tr>
<td>Continuation - unfiltered exit</td>
<td>No filter zones, although limited aperture area for exit of fines (into foundation crack)</td>
<td>Neutral to Likely</td>
<td>0.75</td>
</tr>
<tr>
<td>Progression - roof forms</td>
<td>Note: this node is eliminated because the vertical stoping (chimney) mechanism does not require this condition for progression of this PFM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Progression - upstream zone fails to fill in pipe</td>
<td></td>
<td>Likely to Very Likely</td>
<td>0.9 to 0.99</td>
</tr>
<tr>
<td>Progression - constriction or upstream zone fails to limit flows</td>
<td>Foundation aperture opening will limit flow to some degree</td>
<td>Neutral</td>
<td>0.5</td>
</tr>
<tr>
<td>Intervention fails</td>
<td>Although site is remote; process would develop more slowly with sinkhole evidence as clue and there would be more time to react</td>
<td>Unlikely to Neutral</td>
<td>0.1 to 0.5</td>
</tr>
<tr>
<td>Dam Breaches</td>
<td>Sufficient progression of the PFM would lead to dam overtopping and rapid breach development</td>
<td>Very Likely</td>
<td>0.99</td>
</tr>
</tbody>
</table>

**Estimated Probability of Failure (f)**

$3.3 \times 10^{-5}$ to $1.8 \times 10^{-3}$
ESTIMATION OF CONSEQUENCES

At time of the PFMA workshop, inundation mapping for various dam breach scenarios was in progress and loss of life estimates were not available. The workshop participants elected to use a broad consequence category descriptors.
Subsequent to the workshop, dam breach and inundation mapping was performed and loss of life estimates were determined to be low (<0.5).

CONSEQUENCE CATEGORIES

**Level 0** – No significant impacts to the downstream population other than temporary minor flooding of roads or land adjacent to the river.
**Level 1** – Downstream discharge results in minor property and environmental damage. Damage is likely to recreation areas, roads, and bridges in low-lying areas. Direct loss of life is unlikely.
**Level 2** – Downstream discharge results in moderate property and environmental damage. Damage to permanently occupied structures, recreation areas, roadways, and bridges in low-lying areas is possible. The potential exists for some direct loss of life, related primarily to difficulties in warning and evacuating recreationists/travelers and small population centers.
**Level 3** – Downstream discharge results in extensive damage to permanently occupied structures, roadways and bridges throughout the inundation zone. Direct loss of life is likely, related primarily to difficulties in warning and evacuating recreationists/travelers and smaller population centers, or difficulties evacuating large population centers with significant warning time.
**Level 4** – Downstream discharge results in extensive damage to permanently occupied structures, roadways and bridges throughout the inundation zone. Direct loss of life could be high due to limited warning for large population centers and/or limited evacuation routes.
### RISK ESTIMATES AND EVALUATION

<table>
<thead>
<tr>
<th>PFM</th>
<th>Description</th>
<th>f</th>
<th>N</th>
<th>LOL Risk (annual)</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>Internal erosion exiting into left abutment foundation talus and downstream rock fill.</td>
<td>$1.4 \times 10^{-5}$</td>
<td>0.4</td>
<td>$5.6 \times 10^{-6}$</td>
<td>No - monitor</td>
</tr>
<tr>
<td>2</td>
<td>Internal erosion / scour at right abutment contact exiting into coarse-grained shell materials.</td>
<td>$4.5 \times 10^{-4}$</td>
<td>0.4</td>
<td>$1.8 \times 10^{-4}$</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>Internal erosion along hydro-fractures or other built-in flaws at &quot;closure&quot; section of embankment.</td>
<td>$4 \times 10^{-5}$</td>
<td>0.4</td>
<td>$1.6 \times 10^{-5}$</td>
<td>No - monitor</td>
</tr>
<tr>
<td>4A</td>
<td>Internal erosion exiting into existing cracks, open joints, or voids in the concrete outlet pipe.</td>
<td>$2.5 \times 10^{-7}$</td>
<td>0.4</td>
<td>$1 \times 10^{-7}$</td>
<td>No - monitor</td>
</tr>
<tr>
<td>4B</td>
<td>Internal erosion exiting into newly formed void in downstream concrete outlet pipe.</td>
<td>$3.3 \times 10^{-4}$</td>
<td>0.4</td>
<td>$1.3 \times 10^{-4}$</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>Internal erosion along outside of conduit, similar to PFM-3 but also involving outlet works.</td>
<td>$3 \times 10^{-1}$</td>
<td>0.4</td>
<td>$1.2 \times 10^{-2}$</td>
<td>Yes - Expedite</td>
</tr>
<tr>
<td>9</td>
<td>Internal erosion in area of gate tower exiting downward into dam foundation.</td>
<td>$1.8 \times 10^{-3}$</td>
<td>0.4</td>
<td>$7.2 \times 10^{-4}$</td>
<td>Yes - Expedite</td>
</tr>
</tbody>
</table>
RISK ESTIMATES – FROM PFMA WORKSHOP

Descriptive Consequence Level

f, Annualized Failure Probability (AFP)

N, Estimated Life Loss

PFM-1A
PFM-2
PFM-3
PFM-4A
PFM-4B
PFM-5
PFM-9

Annualized Life Loss < 1 x 10^-7
Annualized Life Loss 1 x 10^-7
Annualized Life Loss > 1 x 10^-7
RISK ESTIMATES – ADJUSTED FOR DOWNSTREAM HAZARD

Descriptive Consequence Level

Annualized Life Loss 1 x 10^{-3}

Annualized Life Loss 1 x 10^{-2}

Annualized Life Loss 1 x 10^{-1}

Loss of Life Range
Estimate for Fred Burr Dam based on Downstream Flood Hazard Mapping
Two PFMs were found to be in the highest risk category (descriptive consequence basis), justifying expedited action:
  o PFM 5 – Internal Erosion along Outside of Conduit
  o PFM 9 - Internal erosion of embankment core near gate tower exiting downward into dam foundation

Two PFMs were found to be in the risk category that justifies action to reduce risk but not needing expedited action:
  o PFM-2 - Internal erosion of embankment due to scour at right abutment contact)
  o PFM-4B - Internal erosion of embankment into void in downstream outlet pipe
POST-PFMA INVESTIGATIONS

- Geotechnical investigations and additional testing to evaluate condition of outlet pipe were completed in October 2013 to address unknowns identified in PFMA.
  - Five borings with monitor wells
  - Four test pits in embankment and nine around reservoir
  - Ten concrete cores from outlet conduit

- **Outlet conduit coring:** Concrete in core samples of conduit appeared in good condition with no signs of corrosion on the reinforcing steel. No evidence of voids in the embankment adjacent to the outlet conduit were observed.

- **Geotechnical:**
  - Core materials are comprised of silty sand and sandy silt with gravel
  - Alluvial foundation materials are gravels with sand and silt, up to 38 feet thick above granite bedrock near max. section
  - Test pits in toe area observed intact matrix of soil around oversize cobbles and boulders; no evidence of voids or erosion of fines from matrix
- From test pit observations of intact, well compacted embankment matrix in toe area in vicinity of outlet:
  Probability for initiation of internal erosion for Expedited Action PFM-5 (erosion along outside of conduit) was reduced from “highly likely” value = 0.99; to 3 times the upper end of range of statistical probabilities for internal erosion involving conduits $3 \times 10^{-3}$; this significantly reduced “f” from 0.3 to $9 \times 10^{-4}$
RISK REDUCTION ALTERNATIVES

- Three alternatives were developed that addressed items requiring expedited action (PFMs 5 and 9) and items with justified action to reduce risk, but not considered to need expedited action (PFMs 2 and 4B)

- Rehabilitation
  - Outlet works: remove and replace terminal structure and lower portion of pipe; slip-line remaining length of pipe
  - Install filter-protected toe drain
  - Replace the spillway

- Replacement: Complete removal of dam, outlet works, and spillway; replace dam with bentonite-amended core and cutoff (including foundation grouting, if feasible) to reduce seepage, chimney filter and drain zones; new outlet works and spillway

- Removal: Decommission dam by removal of embankment and re-establishing Fred Burr Creek
RISK REDUCTION ALTERNATIVES

- Risk model considered only internal erosion PFM; none related to spillway, so re-evaluation considered only elements of alternatives that were relevant to those PFM.
- Four PFM were re-evaluated against the alternatives based on the risk-based need to take action.

### FAILURE PROBABILITIES

<table>
<thead>
<tr>
<th>PFM</th>
<th>PFMA</th>
<th>Post-Geotech Investigation</th>
<th>Slipline Outlet</th>
<th>Replace Outlet</th>
<th>Reconstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4.5 X 10^{-4}</td>
<td>4.5 X 10^{-4}</td>
<td>4.5 X 10^{-4}</td>
<td>4.5 X 10^{-4}</td>
<td>9.9 X 10^{-6}</td>
</tr>
<tr>
<td>4B</td>
<td>3.3 X 10^{-4}</td>
<td>1.3 X 10^{-4}</td>
<td>3.3 X 10^{-4}</td>
<td>1.3 X 10^{-5}</td>
<td>1.3 X 10^{-5}</td>
</tr>
<tr>
<td>5</td>
<td>3 X 10^{-1}</td>
<td>8.9 X 10^{-4}</td>
<td>2.2 X 10^{-6}</td>
<td>8.8 X 10^{-7}</td>
<td>8.8 X 10^{-7}</td>
</tr>
<tr>
<td>9</td>
<td>1.8 X 10^{-3}</td>
<td>1.8 X 10^{-3}</td>
<td>3.3 X 10^{-5}</td>
<td>1.8 X 10^{-6}</td>
<td>9.9 X 10^{-8}</td>
</tr>
</tbody>
</table>
RECOMMENDATIONS

- Short-term Operation:
  - Install instrumentation to monitor water levels in new wells (installed Oct 2013) and reservoir levels
  - Review and evaluate monitoring well data in 2014 season,
  - Consider temporarily closing the spillway gate to allow reservoir level to rise and closely monitor water levels in the wells and performance of the dam, especially in the previous sinkhole areas
FRED BURR DAM

Monitoring Data

May – September 2014
RESERVOIR TRANSDUCER 1
May 20, 2014
Closed Radial Arm Gate on July 7, 2014

Spilling began over gate July 8, 2014
BH-1 IS FINISHED IN FOUNDATION

BH-2 IS FINISHED IN EMBANKMENT
Long-term risk reduction:
- Re-evaluation of PFMs based on downstream flood hazards and geotechnical data reduced urgency for needed actions to reduce risk
- Although expedited action may not be required, four PFMs are generally above established risk guidelines for action to reduce risk
- Only the Reconstruction Alternative adequately addresses PFM-2 associated with internal erosion at the right abutment; the Outlet Replacement Alternative could be modified
LESSONS LEARNED

- Semi-quantitative risk assessment was a valuable decision tool for assessing and evaluating the existing conditions and need for action at Fred Burr Dam to address specific dam safety concerns that came to light following recent (2011-2012) inspections.

- It is appropriate and necessary to continually update a risk assessment as new information becomes available; in this case the post-PFMA workshop analyses for downstream flood hazards and geotechnical investigations both had substantial impacts on the calculations of risk.
FRED BURR DAM
FEASIBILITY STUDY

Questions?