Colorado Division of Water Resources

COLORADO DAM SAFETY BRANCH

2012 Irrigationist Symposium

Dam Safety and Maintenance

Loveland, CO

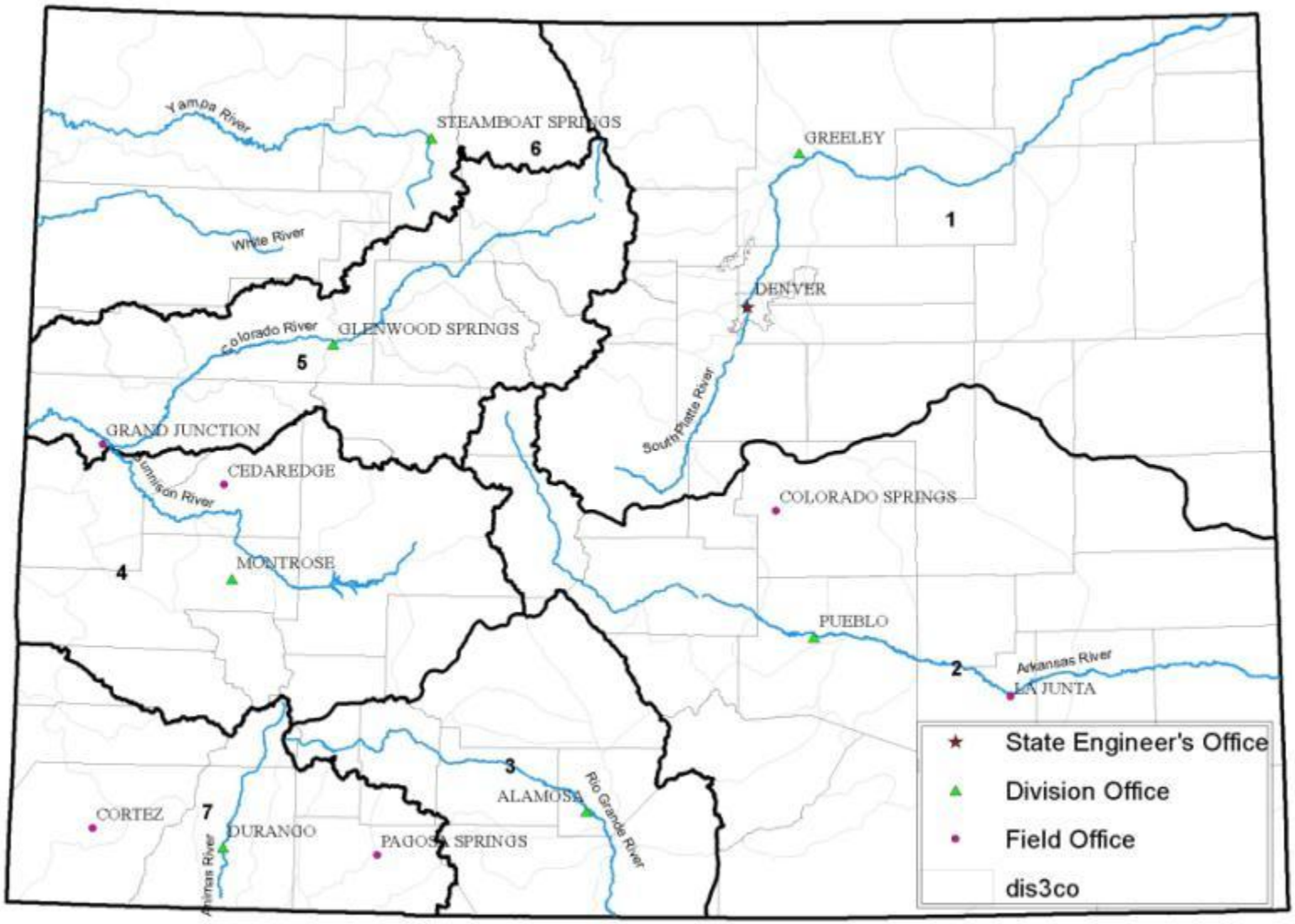
March 15, 2012

Presentation Outline

- Fundamentals of Dams
- Importance of Dam Safety
- Dam Inspections

Colorado Division of Water Resources

Colorado's Water Divisions



Colorado Dam Safety Program

Fundamentals of Dams

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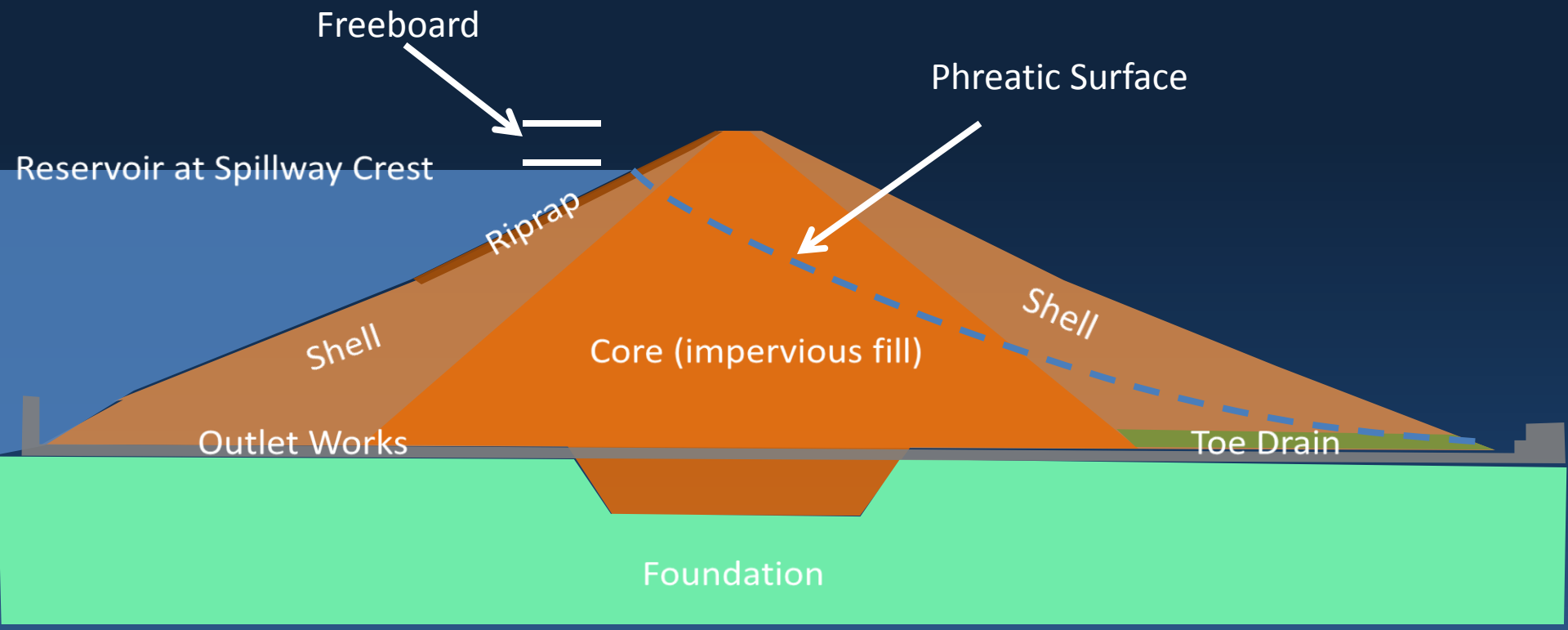
Types of Dams

- **Embankment Dams**
  - Built of locally available soil and/or rock materials as a compacted mass
  - Variable engineering properties
- **Concrete Dams**
  - Constructed of concrete, a rigid man-made structural material
  - Controlled engineering properties

Typical Dam Section



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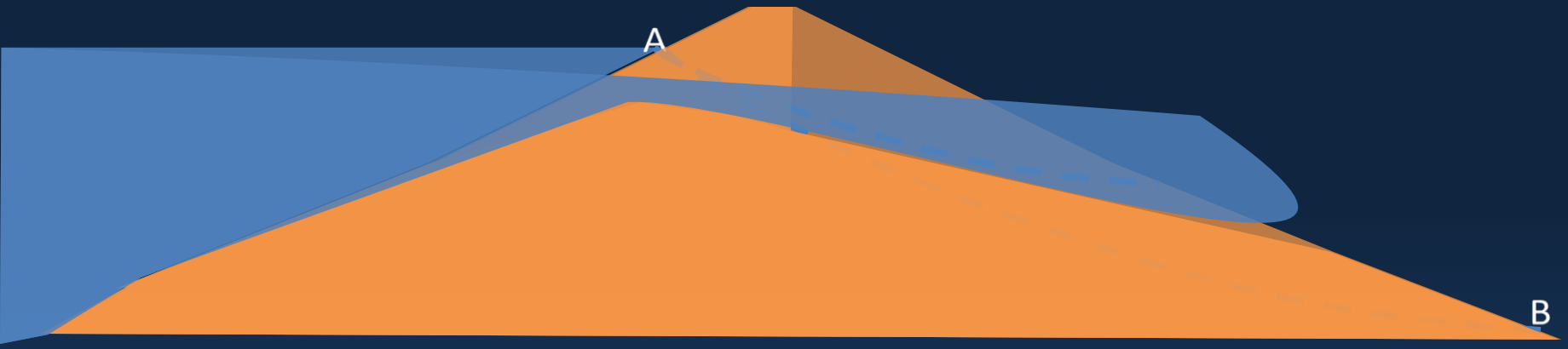
Embankment Dams: Understanding Seepage



- All Dams Leak
- Seepage is controlled by grain size and compaction.
  - Large grains (gravels, sands) = low resistance to flow
  - Fine grains (clays) = high resistance to flow
  - Flow path must be increased/controlled to dissipate reservoir head pressure (Pt. A) at seepage point exit downstream (Pt. B)
- Do NOT want uncontrolled seepage on D/S face of dam
  - Seepage can move soil with it, causing the soil to lose strength **(boggy, bulging, sloughing)** and causing movement of material from inside the embankment or foundation**.**
  - **Homogeneous Vs. Zoned Dams.**

Embankment Dam Examples: Homogeneous with Upstream Barrier

South Catamount

Riverside Reservoir

Embankmant Dam Example Pictures: Granular Shell w/ Finer Grained Core

Loveland Water Storage Reservoir

Joe Wright Reservoir

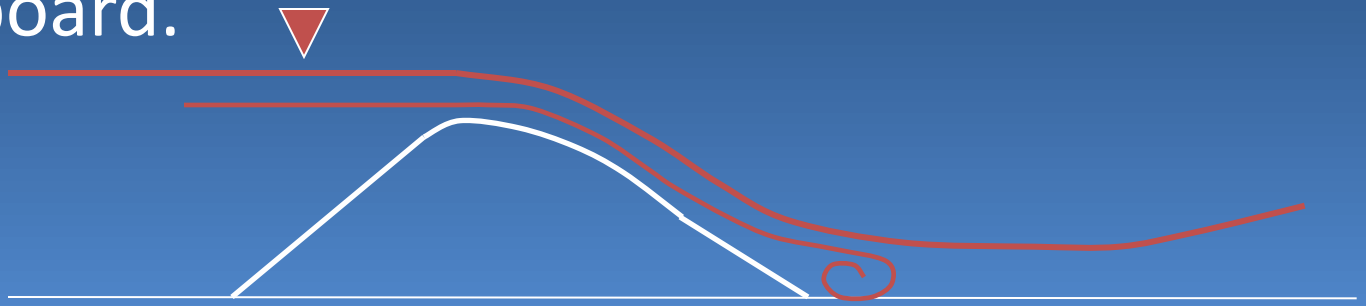
Dam Failure Mechanisms – Earth Dams

- Overtopping
- Piping

Overtopping

Accounts for roughly ~1/2 of all dam failures

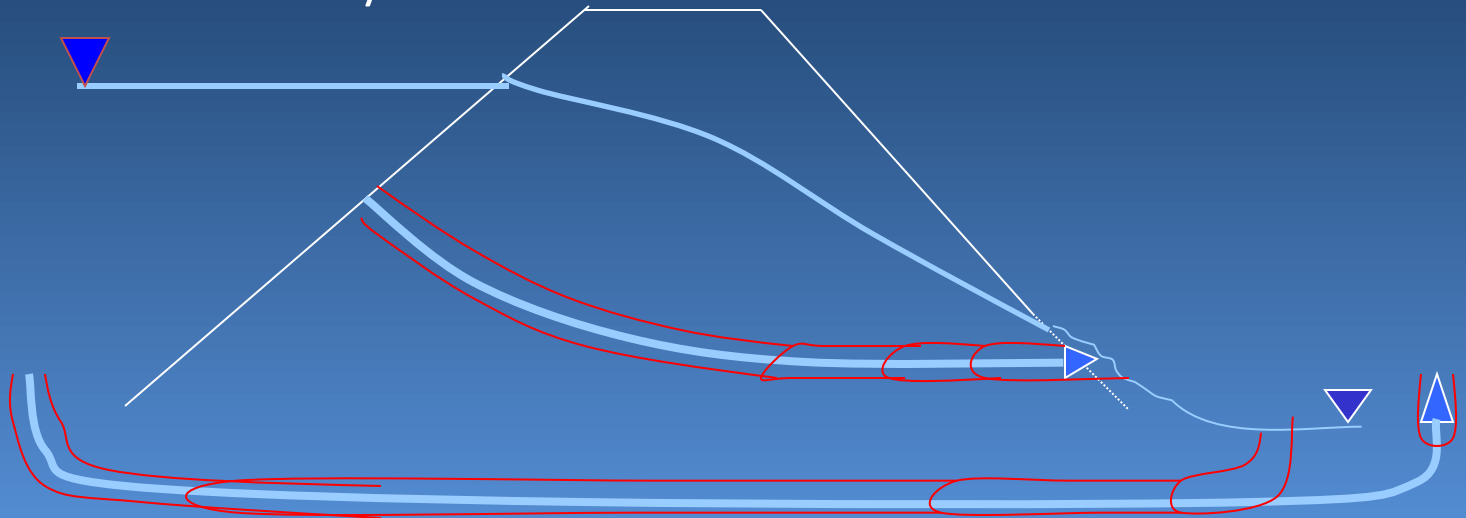
- Definition
  - Uncontrolled flow of water over crest causes backward head cutting.
- Common Causes
  - Obstructed or inadequately designed emergency spillway
  - Inoperable or inadequate outlet
  - Settlement of crest causing loss of freeboard.



Seepage Piping/Internal Erosion

Accounts for roughly ~1/2 of all dam failures

- Definition
  - Uncontrolled movement of soil particles caused by flowing water and development of internal erosion by seepage
- Common Causes
  - Seepage along penetrations through the dam (ie: Conduit, rodent holes, cracks, etc.)
  - Uncontrolled seepage through embankment and/or foundation



Concrete Dams

less than 3% of CO Dams

Multiple arch –
Strontia Springs

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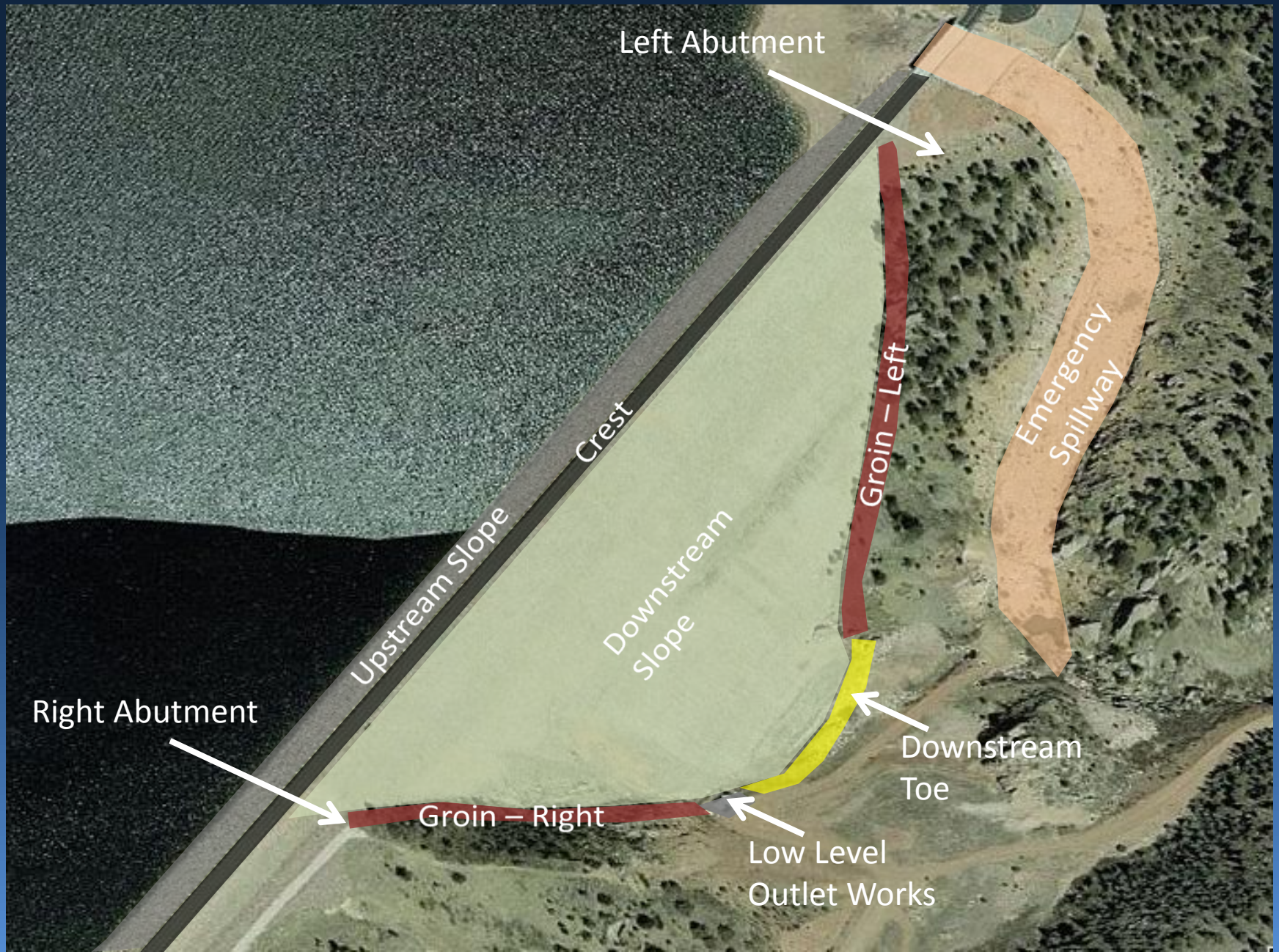
Water Resources

Dam Failure Mechanisms – Concrete Dams

- Overtopping
  - Leading to structural failure of dam, abutments or foundation
- Drainage System Failure
  - Leading to uplift and sliding
- Foundation/Abutment Settlement
  - Leading to loss of support and excess deformation

Typical Dam – Key Features/Nomenclature



Notable US Dam Failures, 1874 - 2005

Dam Name	State	Date Completed	Date Failed	Dam Size/Type	Storage	Failure Mode	Lives Lost
Mill River	NH	1865	**1874**	43′ Earth	307	Piping	**138**
South Fork	PA	1853	**1889**	72′ Earth	11,500	Overtopping	**2209**
Austin Dam	PA	1909	**1911**	43′ Concrete	675	Foundation	**78**
St. Francis	CA	1926	**1928**	188′ Concrete	38,000	Foundation	**420**
Swift Dam	MT	1915	**1964**	157′ Rockfill	34,300	Overtopping	**19**
Teton	ID	1976	**1976**	305′ Earth	250,000	Piping	**11**
Lawn Lake	CO	1903	**1982**	26′ Earth	674	Piping	**3**
Pergeron Pond	NH	1992	**1996**	35′ Earth	282	Piping	**1**
Hadlock Pond	NY	1897 Rebuilt 2005	**2005**	20′ Earth	2200	Piping	**0**
Taum Sauk	MO	1963	**2005**	100′ Earth	4350	Overtopping (Overpumping)	**0**

Teton Dam, ID – 1976

- Dam Characteristics:
  - Dam type: Zoned Earthfill
  - Dam height: 305 feet
  - Dam length: 3,100 feet
  - Reservoir volume: 288, 250 acre-feet

Piping/Internal Erosion

Muddy Water - early morning

Flow Increasing, Dozers Sent to Fill Hole on dam, about 10:45 am

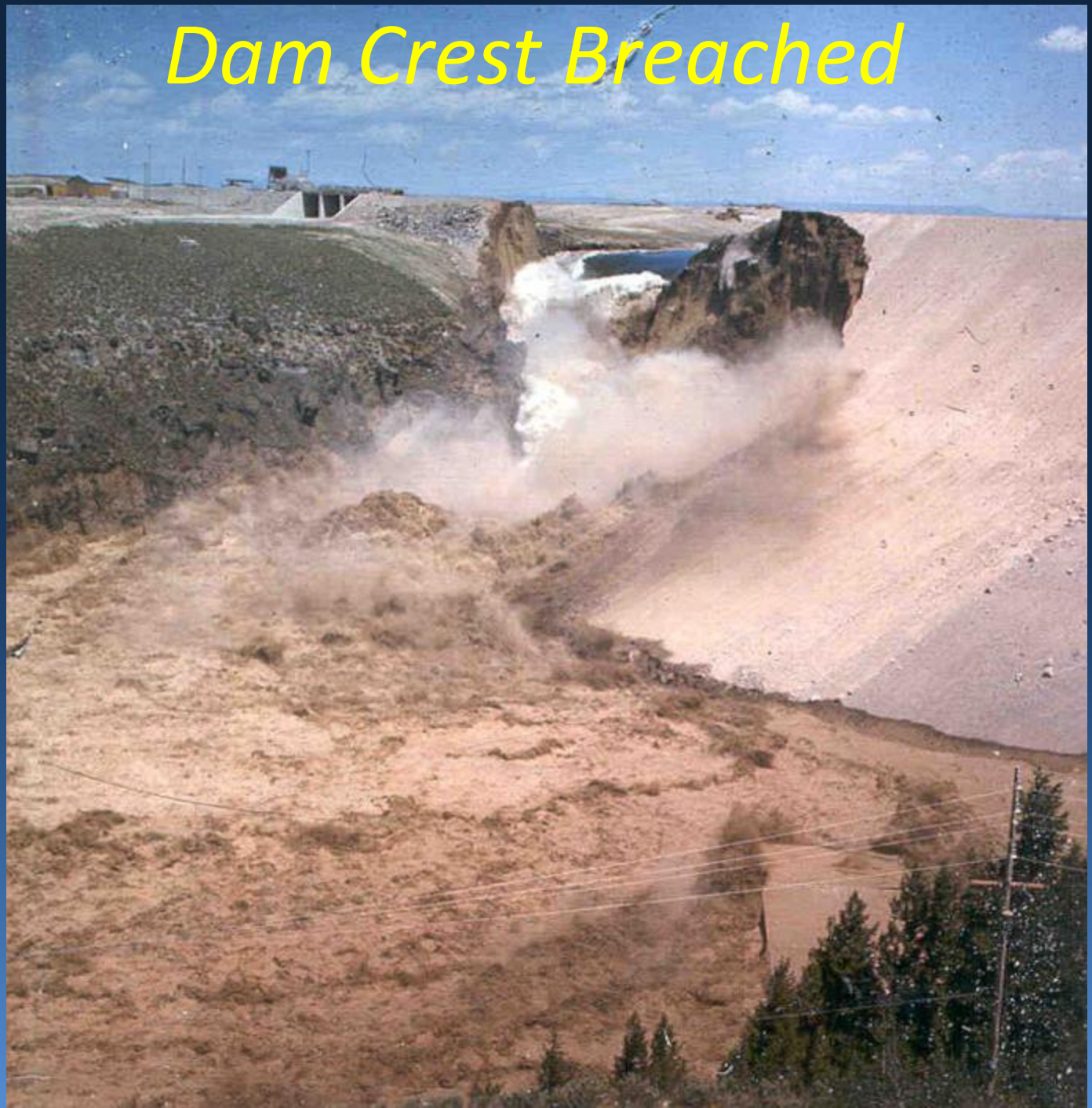
Time for Heroic Efforts – Dozers Lost


About 11:30 AM
B-14

Second Hole in Dam, about 11:32AM

Dam Crest Breaching, 11:55 AM

Dam Crest Breached



Lawn Lake Dam, CO – July 15, 1982

- Dam Characteristics:
  - Dam type: Earthfill
  - Dam height: 24 feet
  - Dam length: 560 feet
  - Reservoir volume: 674 acre-feet

Rocky Mountain News

Friday

Dam bursts near Estes; 1 feared dead, 2 lost

PAGE 6

INSIDE: THE ESTES PARK FLOOD

On Page 7 ■ Residents cope with havoc caused by massive flooding

■ Campers heard mighty roar like thunder or a landing jet

On Page 10 ■ Resort motels bear brunt of rampaging flood water

■ Homes, offices in flood-ravaged area ineligible for state disaster aid

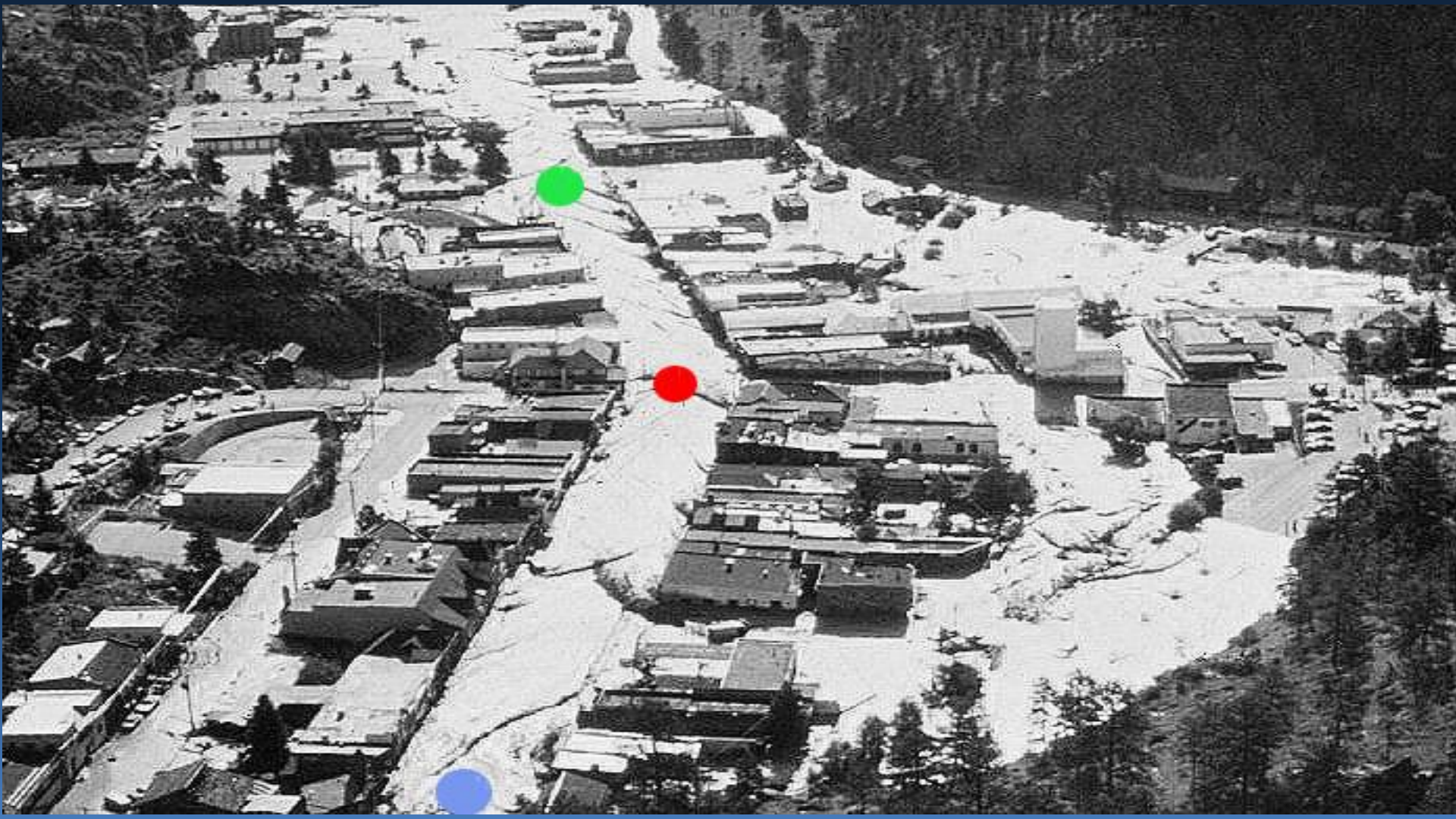
On Page 12 ■ Residents recall tragic 1976 Big Thompson flood

■ Steel and concrete Olympus Dam at Estes Lake prevented repeat of 1976 flood

On Page 8 ■ Lawn Lake Reservoir dam was cited for seepage

On Page 9 ■ Flood of 1864 almost wiped out Denver

Estes Park –Dam Break Flooding



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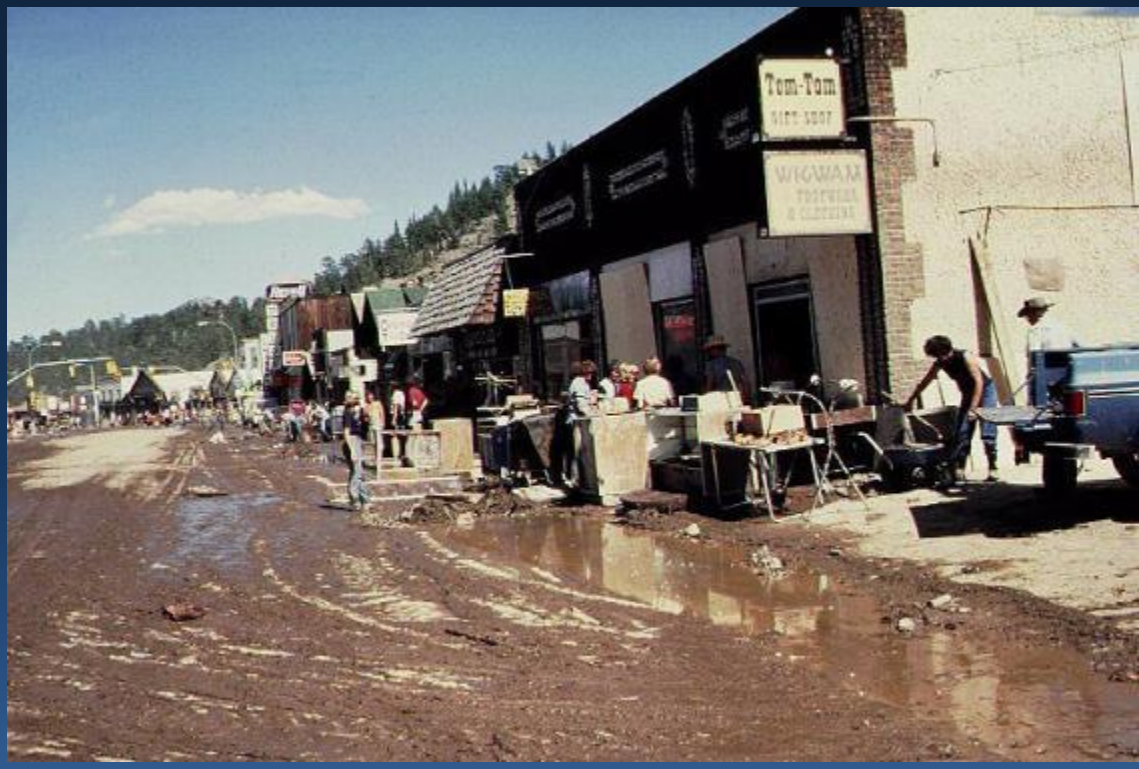
Lawn Lake Dam

- Incident:
  - Deterioration of lead caulking between upstream outlet works pipe and valve housing.
  - Seepage around outlet pipe leading to piping and catastrophic failure.
  - ***3 people killed.***



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Lawn Lake Dam

- Lessons learned:
  - Significant damage from relatively small dam
  - Importance of seepage control
  - Dormant, unseen problem

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Colorado Dam Safety Program

Importance of Dam Safety

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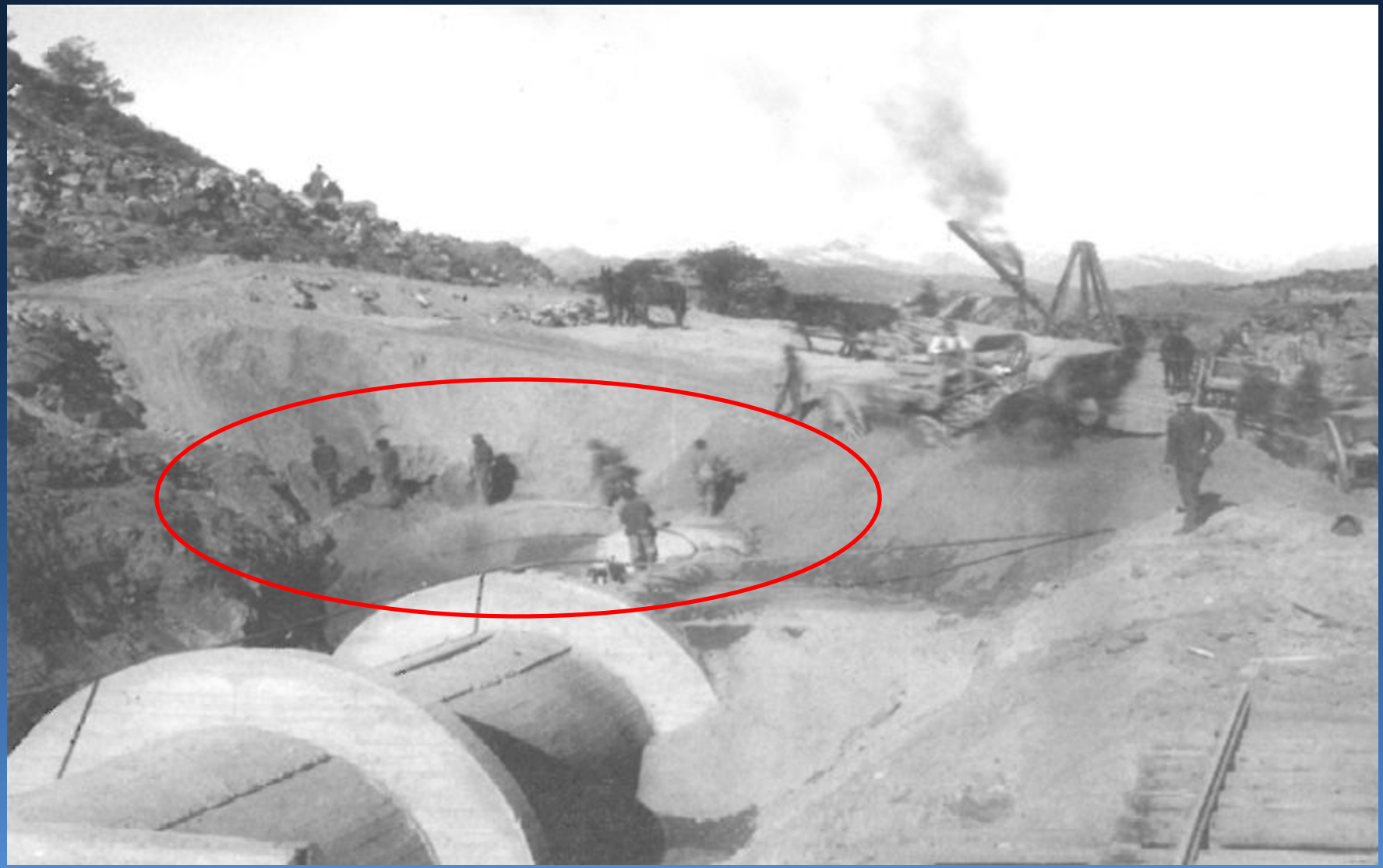
Why focus on Dam Safety?

- As shown, dams can and do fail, need to protect public safety.
- Minimize risk to public and owners.
- Original Engineering/construction practices may be outdated.
- Dams don’t improve with age.

Historic Construction Practices

- Heavy Compaction equipment! Size 12 boots. San Luis Valley, 1910.



More…

- Heavier Compaction equipment! Horses, puddle core. South Park Area, 1908.

More…

- Corrugated Metal Pipe (CMP) + Cutoff Collars! Many, (most?), small dams built before 1980's.

Dams Don't Improve with Age

- Typical economic design is service life of 50 to 75 years, but we don't typically don't replace at end of design life.
- Oldest dam in the U.S.
  - Mill Pond Dam in Newington, CT, built in 1677, still in service
- Many dams in CO are over 100 years old

Benefits of a Dam Safety Program Partnership= State + Dam Owner

- Extended life of the structure
- Reduce likelihood of costly repairs
- Full use of available storage
- Prevent failure of the dam & protect downstream public

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How do we Achieve a Safe Dam?

- Inspections
- Maintenance
- Monitoring
- Emergency Planning
- Rehabilitation Design & Construction

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Colorado Dam Safety Program

Dam Inspections

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Routine Vs. Comprehensive

- Routine:
  - Owners and Caretakers perform surveillance and reporting regularly.
  - SEO performs between comprehensive inspections, as necessary.
- Comprehensive:
  - SEO performs on standard frequency with more in-depth dam adequacy analysis.

Comprehensive Inspection Frequency - SEO

Hazard Classification	***Minimum Frequency***
High	Every Year
Significant	Every 2 Years
Low	Every 6 years
NPH	No Public Hazard dams; not normally inspected unless requested by owner, or a complaint

SEO Comprehensive Inspections

- File Review
  - Design Plans & Specs
  - Dam History
  - Monitoring
- Potential Failure Modes
  - Hydrology - Can spillway pass design storm?
  - Geotechnical - Seepage vs. Filter compatibility?
  - Outlets - Design life, encasement, filtered?
- Full Visual Inspection
  - Walk entire structure
  - Inspect & operate outlet works
  - Spot check monitoring devices

SEO Comprehensive Inspections

- Issue Engineer's Inspection Report (EIR):
  - *General conditions*
  - *Concerns*
  - *Actions & Timeline* required to address concerns
  - *Safe Storage Level*.

Dam Inspections

ENGINEER'S INSPECTION REPORT

OFFICE OF THE STATE ENGINEER - DIVISION OF WATER RESOURCES - DAM SAFETY BRANCH 1313 SHERMAN STREET, ROOM 818, DENVER, CO 80203, (303) 866-3581

INSPECTOR: JEH

DAM NAME: RAMPART T: 12S R: 65W S: 21 COUNTY: EL PASO DATE OF INSPECTION: 2/7/2011

UPSTREAM SLOPE

PROBLEMS NOTED: ☐ (0)NONE ☐ (1)RIPRAP - MISSING, SPARSE, DISPLACED, WEATHERED ☐ (2) WAVE EROSION - WITH SCARPS

☐ (3) CRACKS WITH DISPLACEMENT ☐ (4) SINKHOLE ☐ (5) APPEARS TOO STEEP ☐ (6) DEPRESSIONS OR BULGES ☐ (7) SLIDES

☐ (8) CONCRETE FACING - HOLES, CRACKS, D

COND

Upstream Slope Solutions

Dam Inspections

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OFFICE OF THE STATE ENGINEER - DIVISION OF WATER RESOURCES - DAM SAFETY BRANCH 1313 SHERMAN STREET, ROOM 818, DENVER, CO 80203, (303) 866-3581

INSPECTOR: JEH

DAM NAME: RAMPART T: 12S R: 068W S: 26 COUNTY: EL PASO DATE OF INSPECTION: 2/7/2011

CREST

PROBLEMS NOTED: ☐ (10) NONE ☐ (11) RUTS OR PUDDLES ☐ (12) EROSION ☐ (13) CRACKS - WITH DISPLACEMENT ☐ (14) SINKHOLES

☐ (15) NOT WIDE ENOUGH ☐ (16) LOW AREA ☐ (17) MISALIGNMENT ☐ (18) IMPROPER SURFACE DRAINAGE ☐ (19) OTHER

CONDITIONS OBSERVED: ☐ Good ☐ Acceptable ☐ Poor

OBSERVED GROUND MOISTURE CONDITION: ☐ DRY ☐ WET ☐ SNOWCOVER OTHER

DIRECTIONS: MARK AN X FOR CONDITIONS FOUND AND UNDERLINE WORDS THAT APPLY

Crest Repair Solutions

Dam Inspections

ENGINEER'S INSPECTION REPORT

OFFICE OF THE STATE ENGINEER - DIVISION OF WATER RESOURCES - DAM SAFETY BRANCH

INSPECTOR: JEH

1313 SHERMAN STREET, ROOM 818, DENVER, CO 80203, (303) 866-3581

DOWNSTREAM SLOPE

PROBLEMS NOTED: ☐ (20) NONE ☐ (21) LIVESTOCK DAMAGE ☐ (22) EROSION OR GULLIES ☐ (23) CRACKS - WITH DISPLACEMENT ☐ (24) SINKHOLE

☐ (25) APPEARS TOO STEEP ☐ (26) DEPRESSIONS OR BULGES ☐ (27) SLIDE ☐ (28) SOFT AREAS ☐ (29) OTHER

CONDITIONS OBSERVED: ☐ Good ☐ Acceptable ☐ Poor

FIELD CONDITIONS OBSERVED

WATER LEVEL: BEL

GROUND MOISTURE CO

Downstream Slope Solution

Dam Inspections

SEEPAGE

PROBLEMS NOTED: ☐ (30) NONE ☐ (31) SATURATED EMBANKMENT AREA ☐ (32) SEEPAGE EXITS ON EMBANKMENT

☐ (33) SEEPAGE EXITS AT POINT SOURCE ☐ (34) SEEPAGE AREA AT TOE ☐ (35) FLOW ADJACENT TO OUTLET ☐ (36) SEEPAGE INCREASED / MUDDY

DRAIN OUTFALLS SEEN ☐ No ☐ Yes Show location of drains on sketch and indicate amount and quality of discharge. ☐ (37) FLOW INCREASED / MUDDY ☐ (38) DRAIN DRY / OBSTRUCTED

☐ (39) OTHER

CONDITIONS OBSERVED: ☐ Good ☐ Acceptable ☐ Poor

OBSERVED | GROUND MOISTURE CONDITION: ☐ DRY ☐ WET ☐ SNOW COVER OTHER

DIRECTIONS: MARK AN X FOR CONDITIONS FOUND AND UNDERLINE WORDS THAT APPLY

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☐ (3) CRACKS WITH DISPLACEMENT ☐ (4) SINKHOLE ☐ (5) APPEARS TOO STEEP ☐ (6) DEPRESSIONS OR BULGES ☐ (7) SLIDES

☐ (8) CONCRETE FACING - HOLES, CRACKS, DISPLACED, UNDERMINED ☐ (9) OTHER

CONDITIONS OBSERVED: ☐ Good ☐ Acceptable ☐ Poor

CREST

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☐ (39) OTHER

CONDITIONS OBSERVED: ☐ Good ☐ Acceptable ☐ Poor

OUTLET

PROBLEMS NOTED: ☐ (40) NONE ☐ (41) NO OUTLET FOUND ☐ (42) POOR OPERATING ACCESS ☐ (43) INOPERABLE

☐ (44) UPSTREAM OR DOWNSTREAM STRUCTURE DETERIORATED (45) OUTLET OPERATED DURING INSPECTION ☐ YES ☐ NO

INTERIOR INSPECTED ☐ (120) NO ☐ (121) YES ☐ (46) CONDUIT DETERIORATED OR COLLAPSED ☐ (47) JOINTS DISPLACED ☐ (48) VALVE LEAKAGE

☐ (49) OTHER

CONDITIONS OBSERVED: ☐ Good ☐ Acceptable ☐ Poor

Seepage Solutions

Dam Inspections

ENGINEER'S INSPECTION REPORT INSPECTOR: JEH

OUTLET

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☐ (49) OTHER

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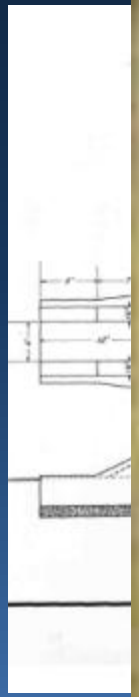
Outlet Repairs



Dam Inspections, cont.

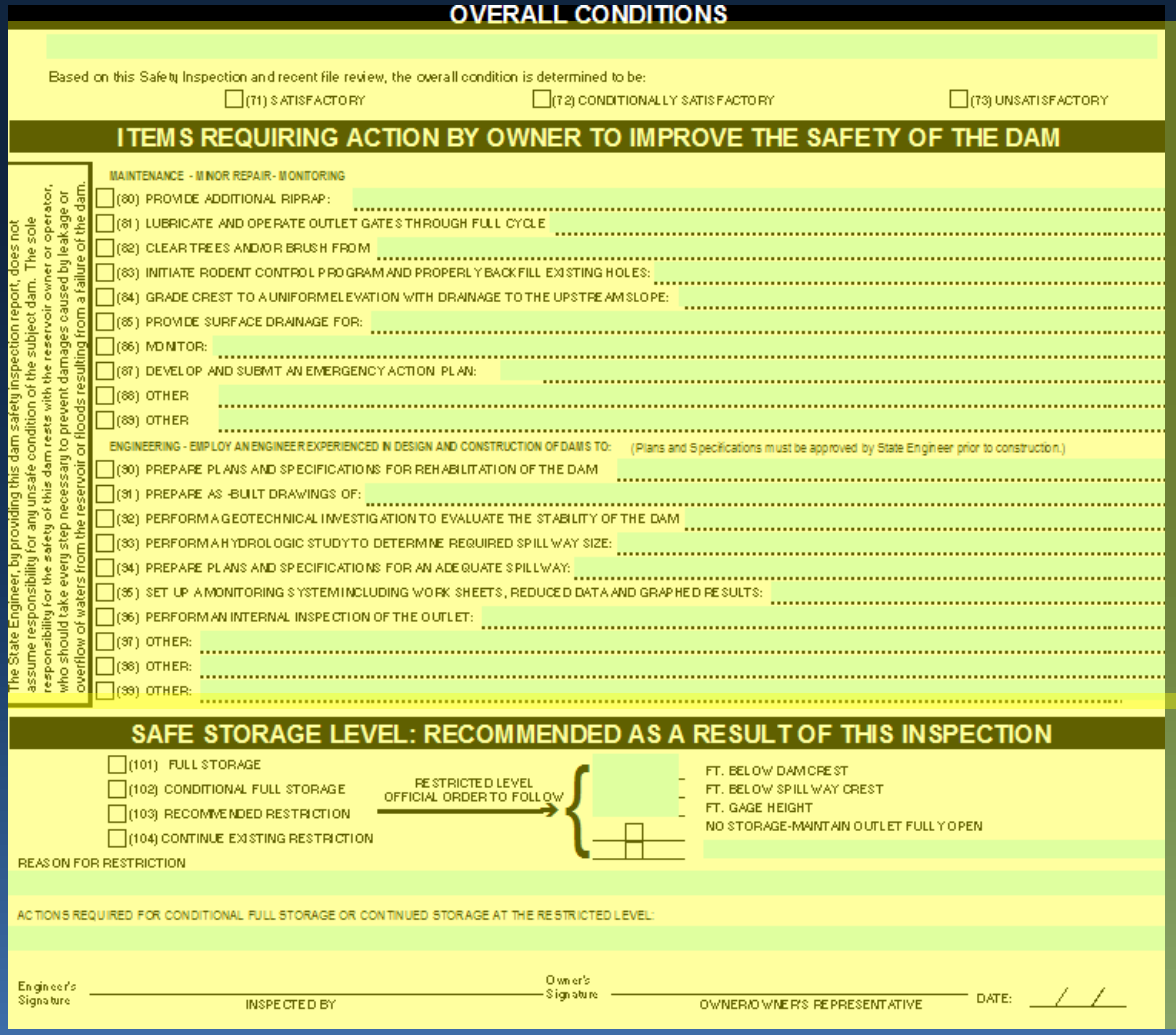
SPILLWAY

PROBLEMS NOTED ☐ (50) NONE ☐ (51) NO EMERGENCY SPILLWAY FOUND ☐ (52) EROSION WITH BACKCUTTING ☐ (53) CRACK - WITH DISPLACEMENT

☐ (54) INADEQUATE FREEBOARD ☐ (57) FLOW OBSTRUCTED

Dam Inspections, cont.

- Overall Conditions
- Action Items
- Safe Storage Level



OVERALL CONDITIONS

Based on this Safety Inspection and recent file review, the overall condition is determined to be:

☐ (71) SATISFACTORY ☐ (72) CONDITIONALLY SATISFACTORY ☐ (73) UNSATISFACTORY

ITEMS REQUIRING ACTION BY OWNER TO IMPROVE THE SAFETY OF THE DAM

The State Engineer, by providing this dam safety inspection report, does not assume responsibility for any unsafe condition of the subject dam. The sole responsibility for the safety of this dam rests with the reservoir owner or operator, who should take every step necessary to prevent damages caused by leakage or overflow of waters from the reservoir or floods resulting from a failure of the dam.

MAINTENANCE - MINOR REPAIR - MONITORING

☐ (80) PROVIDE ADDITIONAL RIPRAP:
☐ (81) LUBRICATE AND OPERATE OUTLET GATES THROUGH FULL CYCLE
☐ (82) CLEAR TREES AND/OR BRUSH FROM
☐ (83) INITIATE RODENT CONTROL PROGRAM AND PROPERLY BACKFILL EXISTING HOLES:
☐ (84) GRADE CREST TO A UNIFORM ELEVATION WITH DRAINAGE TO THE UPSTREAM SLOPE:
☐ (85) PROVIDE SURFACE DRAINAGE FOR:
☐ (86) MONITOR:
☐ (87) DEVELOP AND SUBMIT AN EMERGENCY ACTION PLAN:
☐ (88) OTHER
☐ (89) OTHER

ENGINEERING - EMPLOY AN ENGINEER EXPERIENCED IN DESIGN AND CONSTRUCTION OF DAMS TO: (Plans and Specifications must be approved by State Engineer prior to construction.)

☐ (90) PREPARE PLANS AND SPECIFICATIONS FOR REHABILITATION OF THE DAM
☐ (91) PREPARE AS-BUILT DRAWINGS OF:
☐ (92) PERFORM A GEOTECHNICAL INVESTIGATION TO EVALUATE THE STABILITY OF THE DAM
☐ (93) PERFORM A HYDROLOGIC STUDY TO DETERMINE REQUIRED SPILLWAY SIZE:
☐ (94) PREPARE PLANS AND SPECIFICATIONS FOR AN ADEQUATE SPILLWAY:
☐ (95) SET UP A MONITORING SYSTEM INCLUDING WORK SHEETS, REDUCED DATA AND GRAPHED RESULTS:
☐ (96) PERFORM AN INTERNAL INSPECTION OF THE OUTLET:
☐ (97) OTHER:
☐ (98) OTHER:
☐ (99) OTHER:

SAFE STORAGE LEVEL: RECOMMENDED AS A RESULT OF THIS INSPECTION

☐ (101) FULL STORAGE
☐ (102) CONDITIONAL FULL STORAGE
☐ (103) RECOMMENDED RESTRICTION
☐ (104) CONTINUE EXISTING RESTRICTION

RESTRICTED LEVEL OFFICIAL ORDER TO FOLLOW →

FT. BELOW DAM CREST
FT. BELOW SPILLWAY CREST
FT. GAGE HEIGHT
NO STORAGE-MAINTAIN OUTLET FULLY OPEN

REASON FOR RESTRICTION

ACTIONS REQUIRED FOR CONDITIONAL FULL STORAGE OR CONTINUED STORAGE AT THE RESTRICTED LEVEL:

Engineer's Signature _____ INSPECTED BY

Owner's Signature _____ OWNER/OWNER'S REPRESENTATIVE

DATE: / /

Owner Dam Inspections: Major Elements to Look For?

- Anything unusual, however minor
- Uncontrolled seepage (cloudy, deltas, etc.)
- Movement of the embankment or structures
- Potential problems (conditions which should not be allowed to develop further)

Critical Inspection Times

- Prior to heavy runoff
- During severe rainstorms
- During/ After windstorms
- After an Earthquake
- First filling (re-filling) of reservoir, Rapid Filling, Rapid Drawdown.
- During periods of high storage

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Emergency Remedial Actions

- Embankment Overtopping:
  - Open outlet
  - Sand bags on crest
  - Cover weakened areas of crest and downstream slope with:
    - riprap,
    - plastic sheeting, etc
    - to provide erosion resistance.

Emergency Remedial Actions

- Upstream Sinkhole (whirlpool):
  - Open outlet
  - If accessible, attempt to reduce flow by plugging entrance with
    - Hay bales,
    - Bentonite,
    - Soil or rock fill, or
    - Plastic sheeting

Emergency Remedial Actions

- Downstream Seepage/Sinkhole:
  - (
  - k :

Photograph 6-5 - Filter material

Emergency Remedial Actions

- Downstream Seepage/Sinkhole:
  - What if seepage pushes filter sand away?
    - Add gravel or riprap first to spread out flow and then continue building filter as described.
    - Build a berm or cofferdam to create a pond of water at the exit point to put hydraulic back pressure on the seepage

Emergency Remedial Actions

- Embankment Movement
  - Open outlet
  - Repair any settled areas of crest to restore freeboard
  - Add soil or rock buttress on toe area of downstream slope slides

Emergency Remedial Actions

- Planning:
  - EAP Current?
  - Knowledge of dam behavior and weather forecast?
  - Is outlet accessible and operable during emergency?
  - Is heavy equipment readily available?
  - Light plants if at night?
  - Materials stockpiled?
    - ASTM C-33 Filter Sand?
    - 2 to 3 inch minus drain gravel?
    - 8 to 12 inch graded riprap?
    - Sand bags, plastic sheeting?

Questions ?

Thanks for Coming

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