# Operation & Maintenance of Dams and Spillways

David Trujillo, PE, CFM

# Agenda

- Importance of Dam Maintenance in Texas
- Operation and Maintenance (O&M) Guidelines
  - O&M Guidelines: Inspections
  - O&M Guidelines: Instrumentation and Monitoring
  - O&M Guidelines: Maintenance Guidelines
- Owner Responsibilities
- Q&A

# Importance of Dam Maintenance in Texas

- Over 7,000 dams in Texas
- Aging infrastructure concerns
- Prevents loss of life and property
- Supports water supply, flood control
- Potential risks of dam failure

# Deterioration of Dams

- Piping/seepage
- Concrete deterioration
- Settlement
- Gate deterioration
- Geotextile deterioration

# Dam Failures - causes

- 34% - overtopping
- 30% - foundation defects
  slope instability
- 20% - piping or seepage

*ASDSO*

# Dam Failures Fatalities

- 86% fatalities from dams 20 to 49 feet high
- 47% of fatalities from dams with DA less than 2 sq. mi.
- 75% of fatalities from dams with DA less than 10 sq. mi.
  (this would include 80% of all dams)
- 7 dams had less than 300 ac-ft of water released.

# Basic Legal Premise

- The primary goal of modern tort law is to provide compensation for injuries caused by wrongful acts, with the aim of restoring the injured party to their pre-injury state.

- Perception can mean more than facts.

- Highest standard of care.

# Basic Legal Premise

- Lawsuits will claim extensive liability on the part of everyone involved in the dam failure incident.
- We live in a litigious society – there will likely be an attempt to sue any/all of the following:
  - Owners
  - Operators
  - Engineers
  - Designers
  - Contractors
  - Inspectors
  - Employees
  - Regulators

# Dam Owner per 30 TAC §299.2

- Holds legal possession or ownership;
- Is the fee simple owner;
- Is a sponsoring local organization for an NRCS Watershed dam; or
- Has a lease or easement.

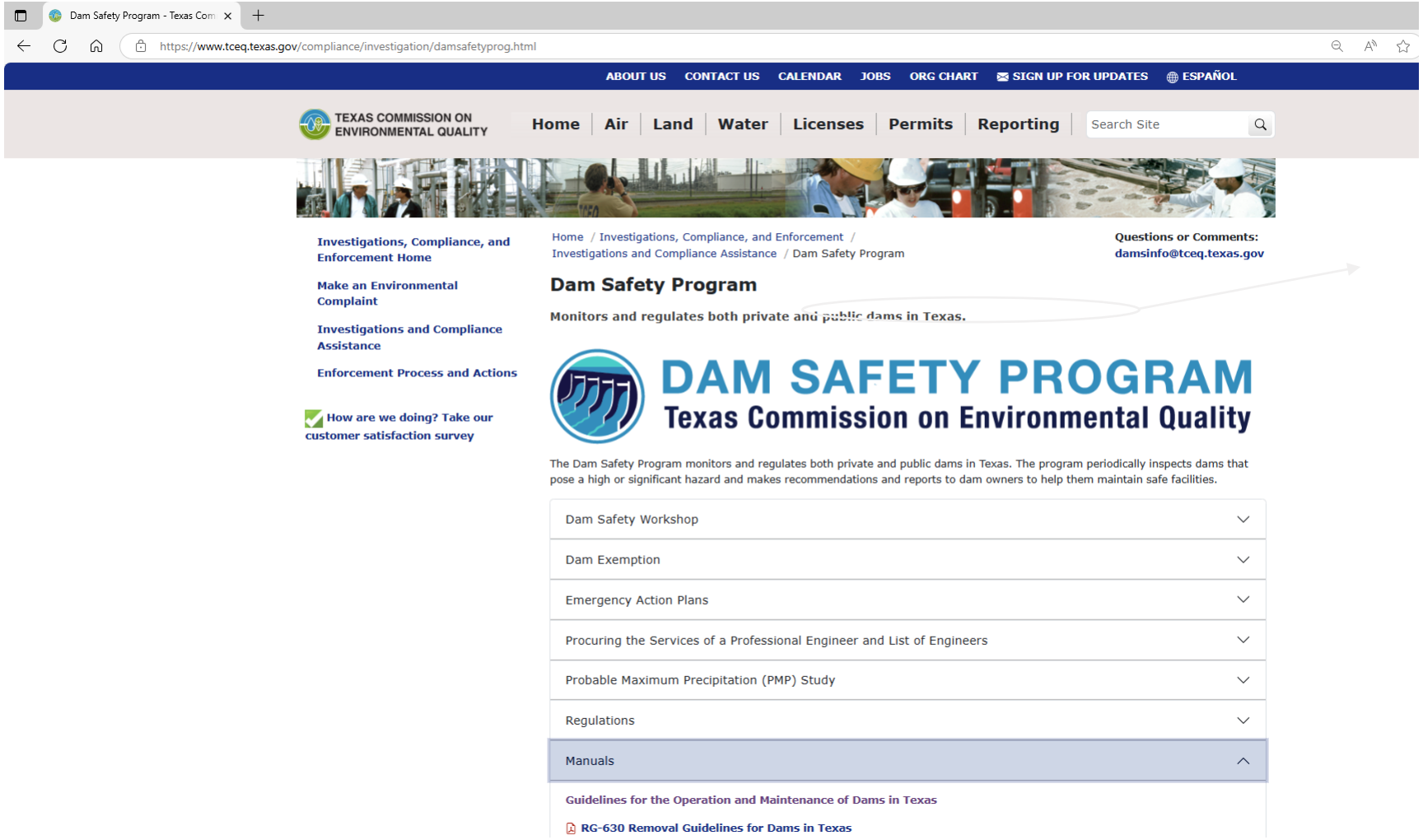
# Dam Owner Responsibilities

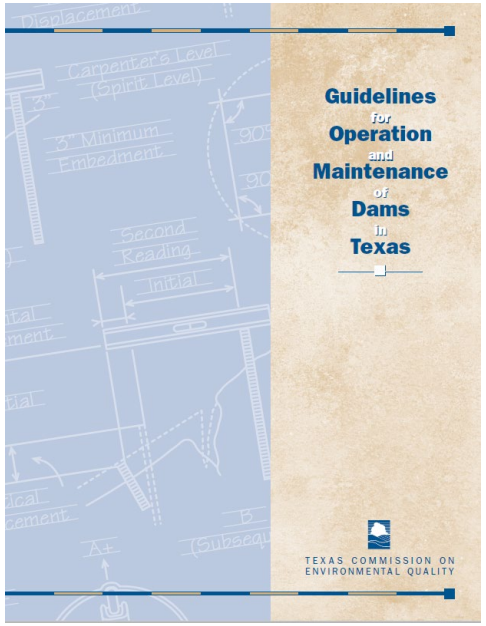
- Owner is responsible for operating and maintaining the dam and spillways in a safe manner regardless if the TCEQ has inspected the dam.
- Owner is responsible for addressing all maintenance and safety concerns identified during any inspection.
- Owner must ensure that necessary maintenance, repairs, or alterations are started and completed in a timely manner.
- “Owners, not the state, are responsible for the safety of the dam including making any additional dam safety evaluations and repairs.” Spencer Dam Failure Investigation Report

# Texas Administrative Code §299.43

- (a) The owners of all dams shall develop and implement an operation and maintenance plan. The owner may use the most current version, at the time of the plan development, of the agency's Guidelines for Operation and Maintenance of Dams in Texas, a manual, a checklist, or some other procedure to demonstrate implementation of the program.

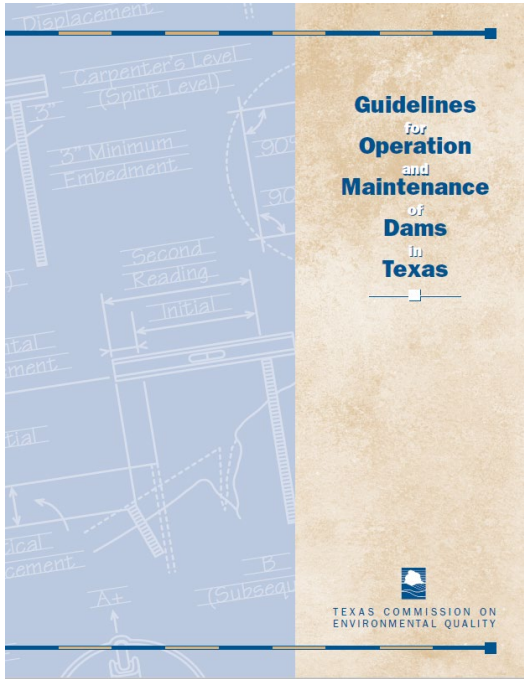
# O&M Guidelines



# O&M Guidelines

- **Chapter 5** – *Inspection Guidelines*
- **Chapter 6** – *Instrumentation & Monitoring Guidelines*
- **Chapter 7** – *Maintenance Guidelines*
- **Chapter 9** – *Guidelines for Operations*



# Chapter 5 – Inspection Guidelines

- Types of Inspections
  - Technical
  - Maintenance
  - Informal

- When to Inspect
  - Routine
  - Before/after storms

# Inspections (Rule §299.42)

- Owner shall inspect the dam and spillways on a regular basis, following significant rainfall events, and during emergency events.
- Owner shall notify TCEQ Dam Safety in writing within 5 working days after becoming aware of any problems or damage that pose a significant threat to the dam.
- Owner shall submit a copy of all engineering inspection reports prepared by the owner's professional engineer to TCEQ Dam Safety for review

# Inspection Frequency

- Owner should conduct a walking inspection of the dam at least once per year.
- TCEQ aims to conduct engineering inspections of dams once every 5 years.
- Owner can have engineering inspections done more frequently.

# Pre-Storm Inspections

- If weather forecasts predict significant rainfall, a pre-storm inspection may be warranted:
  - Inspect spillway inlet at outlet, make sure there are no obstructions, debris, beaver dens, etc. that would interfere with spillway operation.
  - Ensure there are no structural issues (cracks, slides) that would suggest lowering the reservoir before rainfall begins.

# Post-Storm Inspection

- Assure that spillways remain unobstructed, remove debris that may have accumulated
- New slides, seepage, sand boils, or changes to existing issues that may have developed because of high water levels at the dam
- New areas of erosion, or advancement of any existing headcutting erosion.

# Chapter 5 – Inspection Guidelines


- What to Inspect
  - Entire Embankment
  - Spillways
  - Downstream areas
- What to document
  - Location of any problems
  - Extent or Area
  - Details

# Longitudinal Cracks / Vertical Displacement

- Possible Causes
  - Uneven settlement between sections or zones of the embankment
  - Failure of the foundation

- Possible Consequences
  - Local area of low strength
  - Leads to structural instability or failure
  - Creates entrance point for runoff into embankment

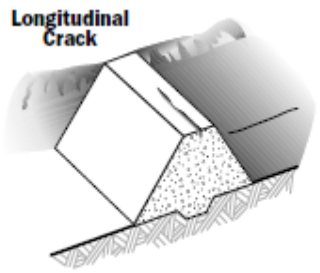


Figure 5.3a

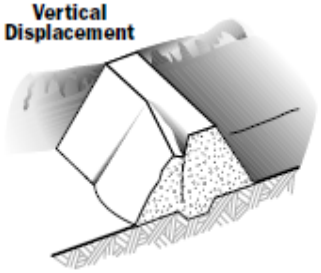


Figure 5.3b

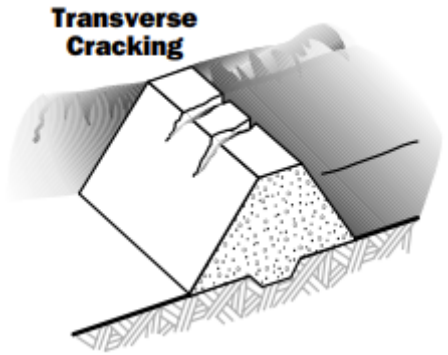
# Longitudinal Cracks

# Vertical Displacement

# Vertical Displacement

# Transverse Cracking

- Possible Causes
  - Uneven movement between adjacent segments of the embankment
  - Deformation caused by structural stress or instability




- Possible Consequences
  - Can provide a path for seepage through the embankment cross-section
  - Local area of low strength. Future structural movement/deformation
  - Entrance point for surface runoff

# Cave-in on Crest

- Possible Causes
  - Rodent activity
  - Hole in outlet conduit causing erosion
  - Internal erosion/piping
  - Breakdown of dispersive clays

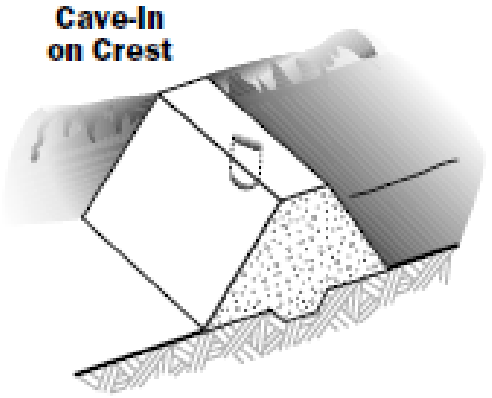


Figure 5.3c

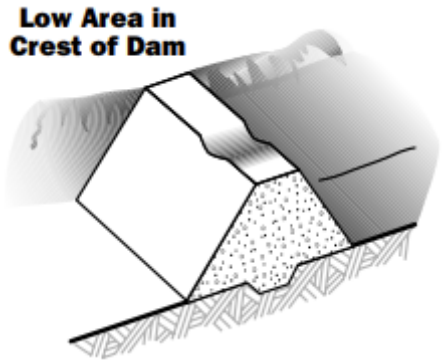
- Possible Consequences
  - Void within dam could cause localized caving, sloughing, instability
  - Entrance point for runoff

# Cave-in on Crest

# Cave-in on Crest

# Low Area on Crest

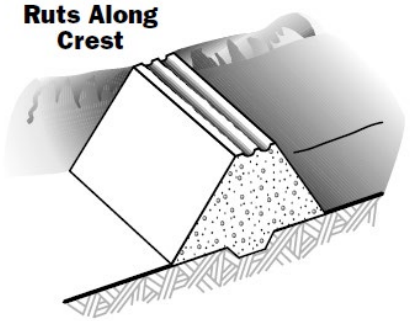
- Possible Causes
  - Excessive settlement in the embankment or foundation
  - Internal erosion of embankment material
  - Improper final grading following construction



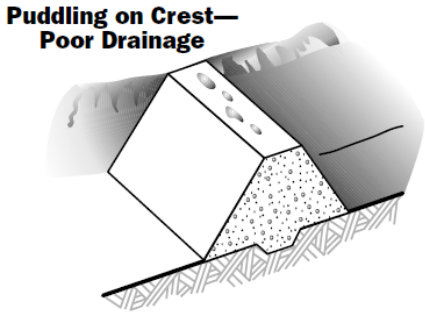

- Possible Consequences
  - Reduces freeboard available to pass flood flows safely through spillway

# Ruts & Puddling

- Possible Causes
  - Heavy vehicle traffic
  - Poor grading and improper drainage of crest
  - Localized settlement




- Possible Consequences
  - Inhibits easy access
  - Allows continued development of rutting
  - Allows standing water to collect and saturate the dam



# Ruts and Ponding


# Obscuring Vegetation

- Possible Causes
  - Neglect of dam
  - Lack of proper maintenance

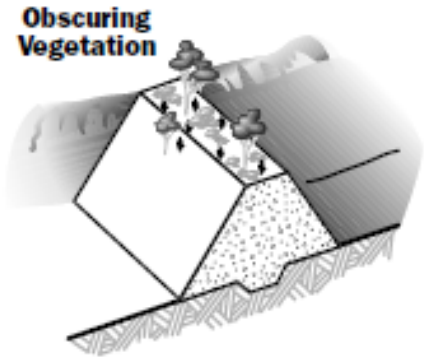



Figure 5.3g

- Possible Consequences
  - May obscure other problems
  - Root systems develop
  - Prevents access to the dam
  - Provides habitat for rodents
  - Large trees can blow over during storms

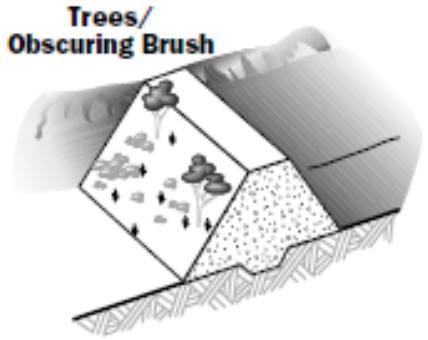



Figure 5.2g

# Obscuring Vegetation

# Root System on Embankment

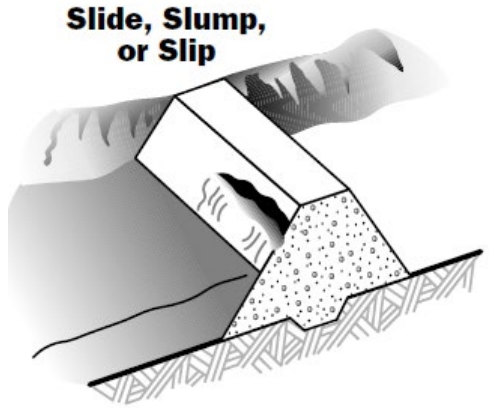
# Trees Blown Over

# Before & After


# Before & After

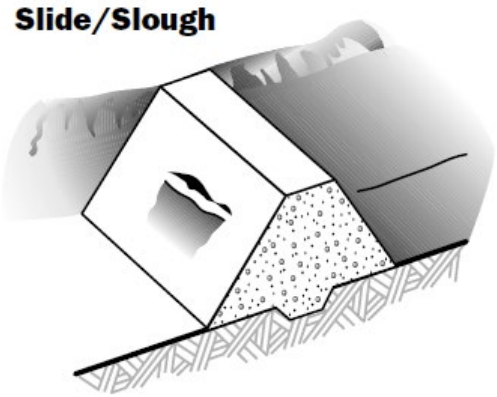

# Controlled Burn

# Slide/Slough

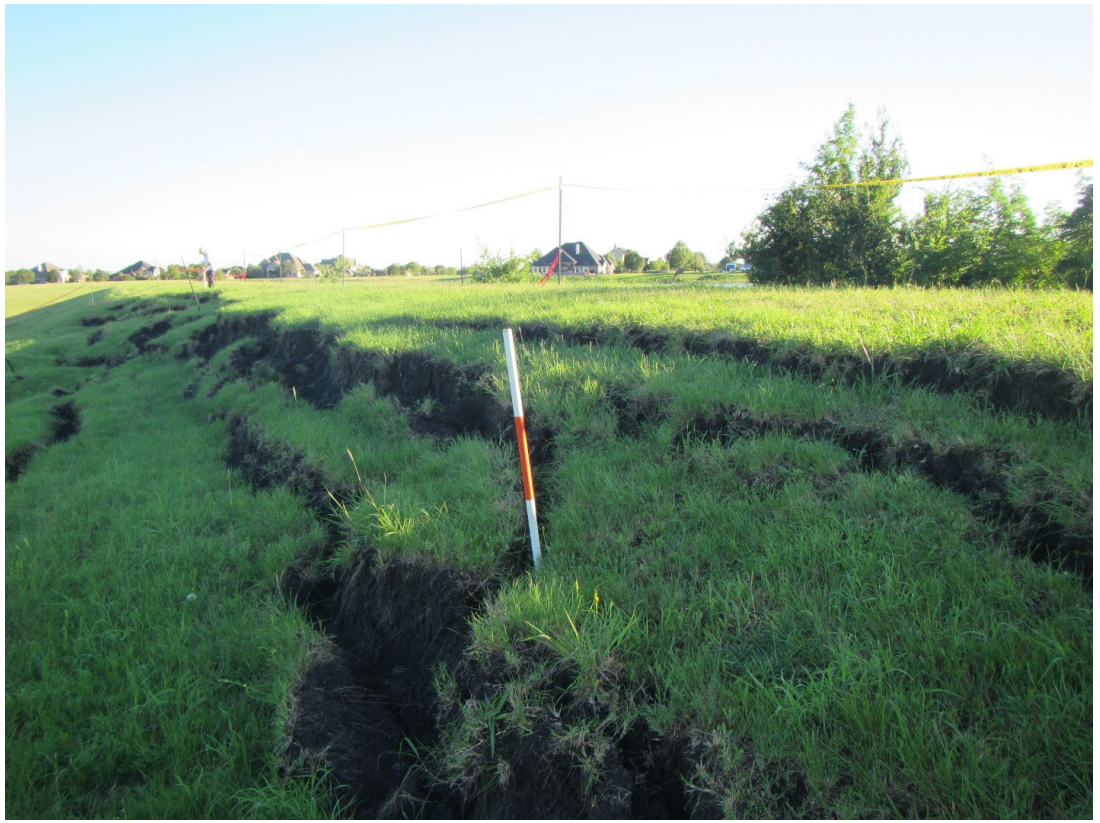



- Possible causes
  - Loss of strength in embankment material
  - Infiltration of water into embankment
  - Loss of support by the foundation, foundation movement
  - Earth/rocks move down the slope because of a steep slope

- Possible Consequences
  - Reduces freeboard and cross-section
  - Structural collapse or overtopping
  - Can lead to obstruction of the inlet



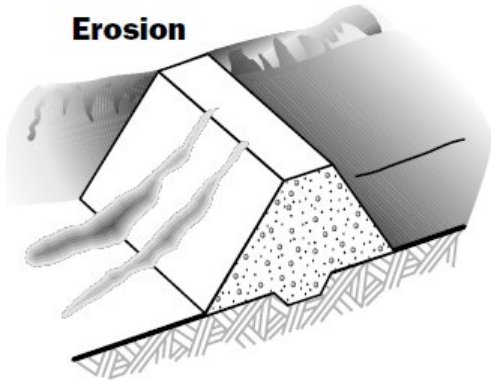
# Slide



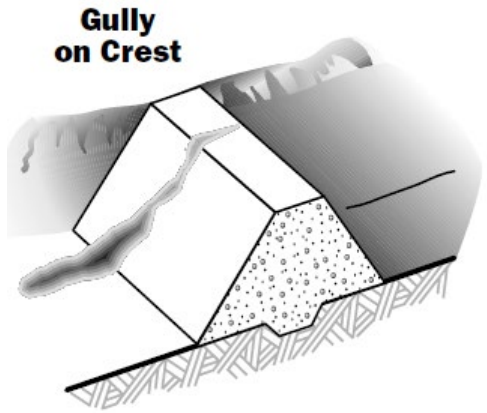
# Slide


# Erosion Gullies

- Possible Causes
  - Poor grading and improper drainage
  - Inadequate spillway capacity causing overtopping
  - Run-off from storms carries material down the slope
  - Animal trails




- Possible Consequences
  - Deterioration of the slope
  - Failure of the structure
  - Reduces cross-sectional area of dam
  - Can reduce freeboard



# Erosion Gullies

# Erosion Gullies

# Erosion Gullies

# Scarps, Benches, Oversteep Areas

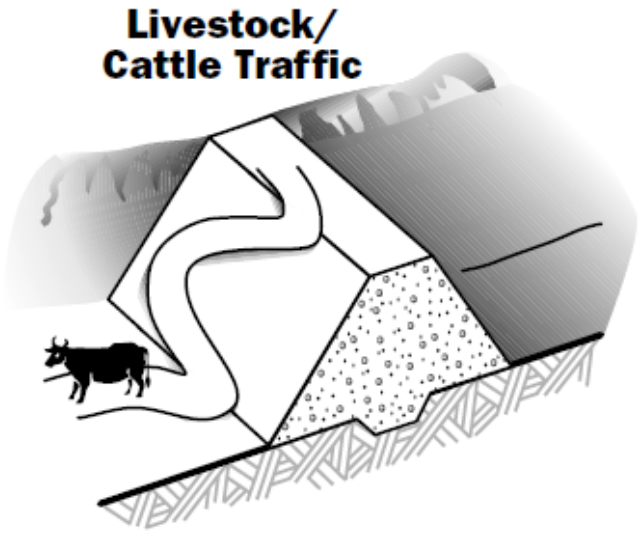
- Possible Causes
  - Wave action
  - Local settlement
- Possible Consequences
  - Erosion lessons the width and possible height of embankment
  - Could lead to seepage or overtopping

# Bench

# Bench

# Livestock/Cattle Traffic

- Possible Causes
  - Excessive travel by livestock
- Possible Consequences
  - Creates bare areas
  - Causes erosion channels
  - Allows water to stand

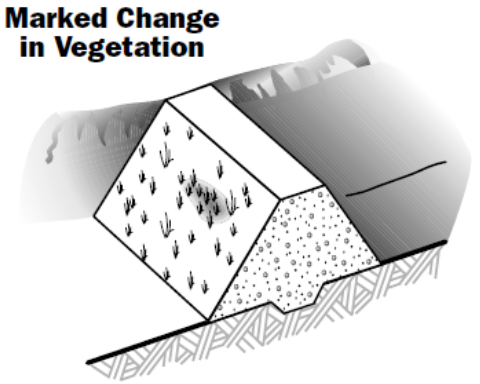


# Erosion from cattle

# Holes and burrows

# Seepage – Change in Vegetation

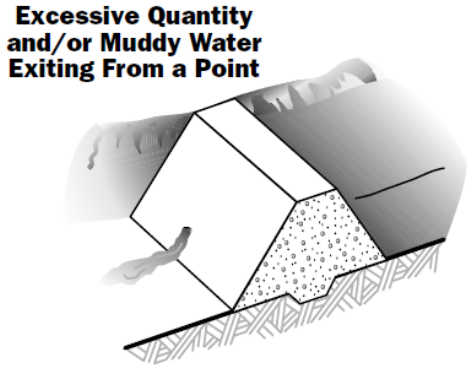
- Possible Causes
  - Embankment materials supplying flow paths
- Possible Consequences
  - Saturated area

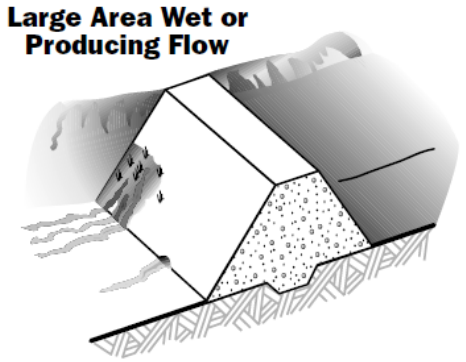


# Change in Vegetation

# Seepage

- Possible Causes
  - Water has created a pathway through the dam
  - Water has accumulated in the downstream slope
  - Rodents, frost action, or poor construction
- Possible Consequences
  - Saturation of embankment which could cause slides
  - Erosion of the embankment
  - Failure of the dam



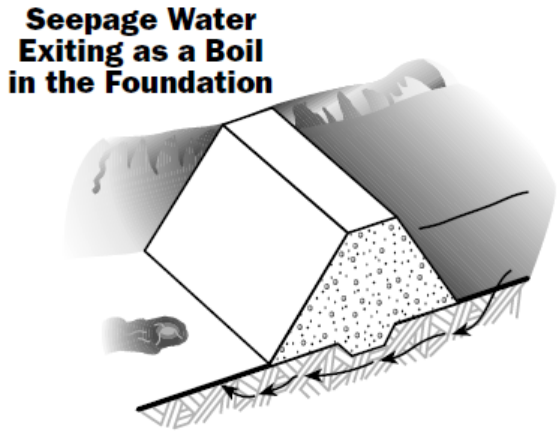



# Seepage exiting from a point

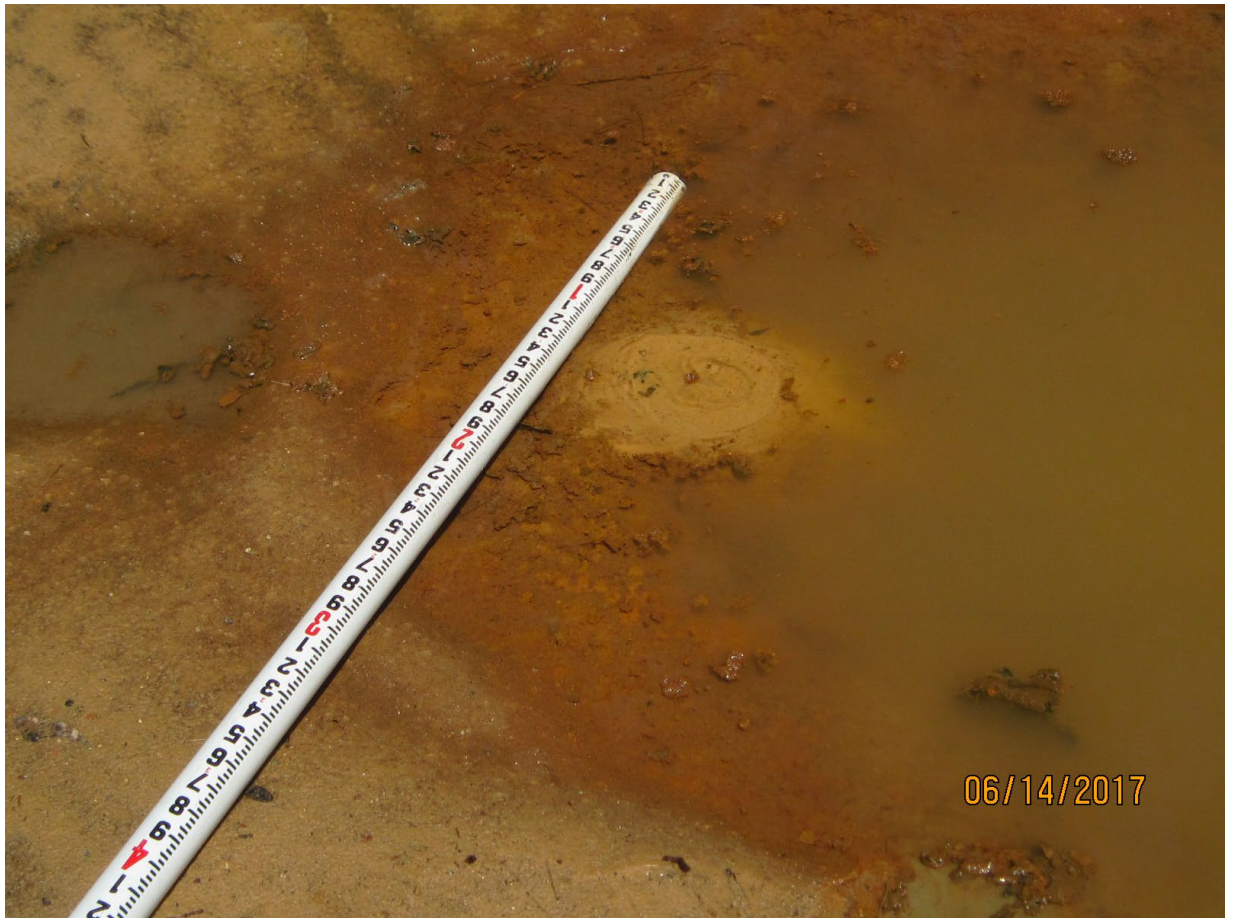
# Large Wet Area

# Seepage

- Possible Causes
  - Part of foundation is supplying a flow path
- Possible Consequences
  - Erosion of the foundation
  - Failure of the dam



# Boil

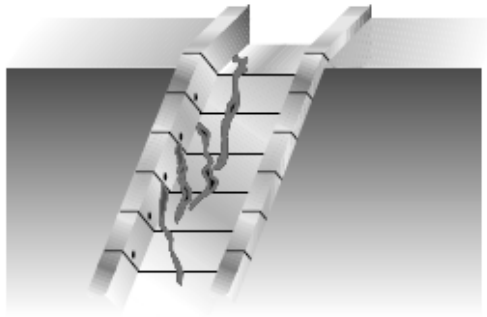


# Boil

# Seepage

- Possible Causes
  - Water collecting behind structure because of inefficient drainage
- Possible Consequences
  - Can cause wall to tip in/over
  - Concrete deterioration from weathering
  - Failure of the dam

**Seepage From a Construction Joint or Crack in Concrete Structure**

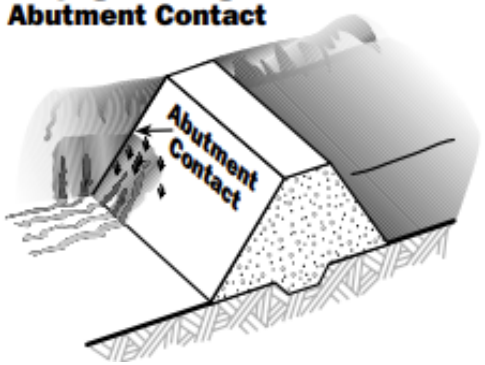


# Seepage from joints/cracks

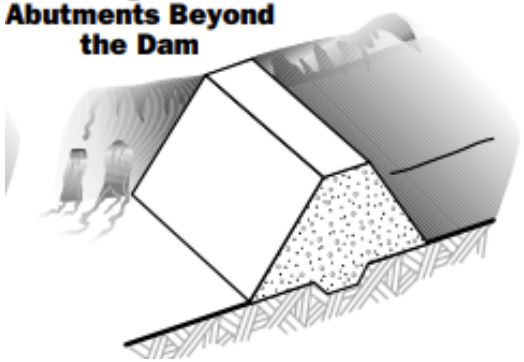
# Seepage from joints/cracks

# Seepage

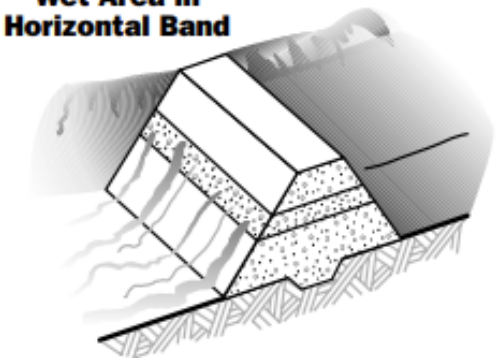
Seepage Exiting at Abutment Contact



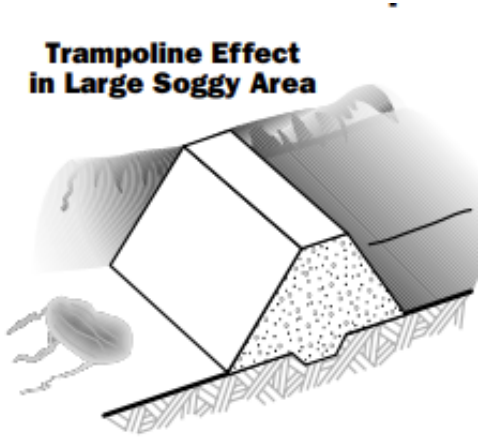

Leakage From Abutments Beyond the Dam



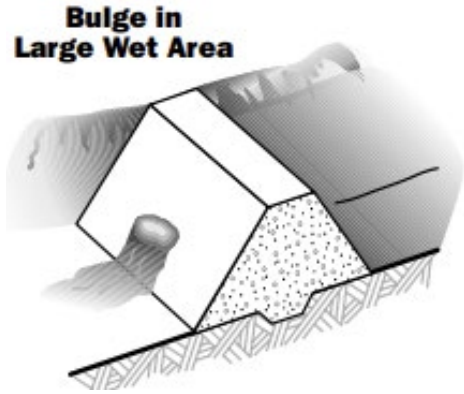
Wet Area in Horizontal Band



Trampoline Effect in Large Soggy Area

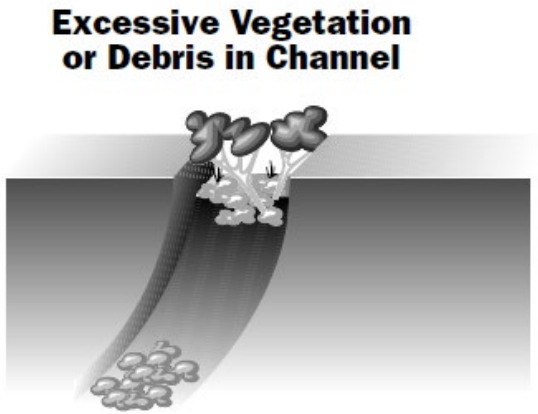


Bulge in Large Wet Area



# Vegetation or Debris in Spillway

- Possible Causes
  - Accumulation of slide materials
  - Dead trees
  - Excessive vegetative growth
- Possible Consequences
  - Reduced discharge capacity
  - Overflow of spillway
  - Overtopping of dam



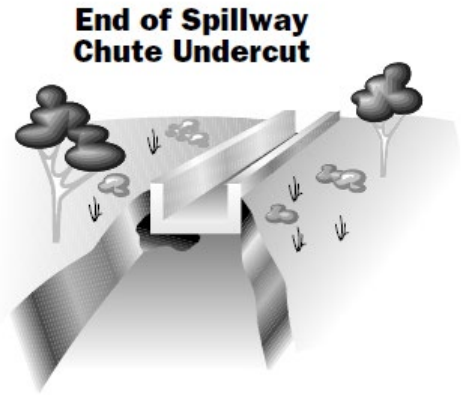
# Excessive Vegetation

# Excessive Debris

# End of Spillway Chute Undercut

- Possible Causes
  - Poor configuration of stilling basin
  - Highly erodible materials
  - Absence of cut-off wall at end of chute

- Possible Consequences
  - Structural damage to spillway
  - Collapse of slab



# End of Spillway Chute Undercut

# End of Spillway Chute Undercut

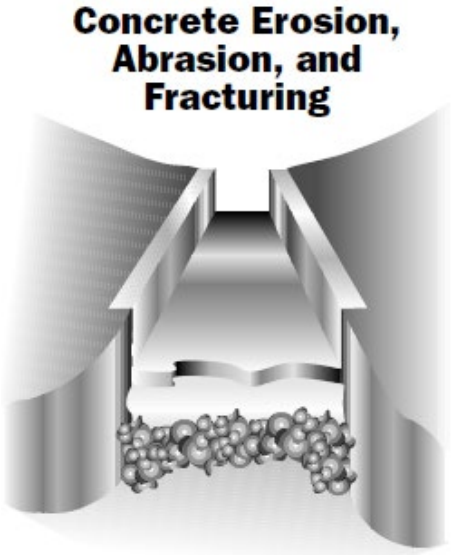
# Spillway undermining

# End of Spillway Chute Undercut

# Concrete Erosion, Abrasion, & Fracturing

- Possible Causes
  - Flow velocity too high
  - Rolling of gravel and rocks
  - Cavity behind or below the slab

- Possible consequences
  - Pockmarks and spalling may worsen
  - Undermining of foundation
  - Failure of structure



# Fracturing

# Fracturing

# Spillway Repair

# Spillway Repair

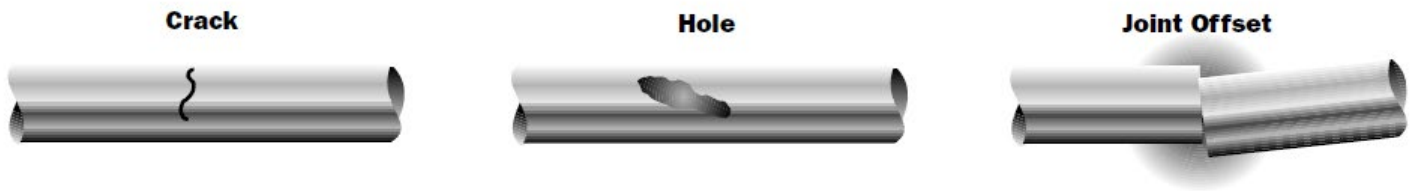

# Spillway Repair


# Spillway Repair (before/after)

# Outlet Pipes

- Possible Causes
  - Settlement, Impact
  - Rust, erosion, cavitation
  - Poor construction

- Possible Consequences
  - Excessive seepage, internal erosion
  - Provides passageway for water to exit or enter pipe



# Joint Offset

# Damaged Spillway

# Holes in Outlet Pipe

# Clogged outlet pipe

# Inspect inside Outlet Pipes

# Gates

- Areas to inspect
  - Main framing members
  - Lifting & supporting assemblies
  - Lifting connections, chains, cables
  - Fractures, cracks, welds
  - Normal waterline, abrasion areas, crevices
  - Trunnions
  - Seal plates

# Gates

# Gates

# Gates

# Gates

# Gates

# Gates

# Toe Drains

# Toe Drains

# Drains


# Toe Drains


# Low Flow Outlet

# Low Flow Outlet

# Chapter 6- Instrumentation & Monitoring

- Why do we have instrumentation
  - Warning of a problem
  - Analyzing or defining a problem
  - Shows that dam is performing as expected
  - Evaluate a remedial action

# Chapter 6- Instrumentation & Monitoring

- Concrete movement
  - Inclinometer, extensometer, tilt meter, plumb lines, GPS
- Pore pressure/Uplift
  - Piezometer, open well, pressure meters
- Water level and flow
  - Weirs, flumes, flow metes

# Piezometer

# Weirs


# Chapter 7 - Maintenance Guidelines

- Most components of a dam are susceptible to deterioration
- Good maintenance program protects a dam against deterioration
- Maintenance costs are small compared to major repairs

# Maintenance Priorities

- Immediate
- As soon as possible
- Continuing

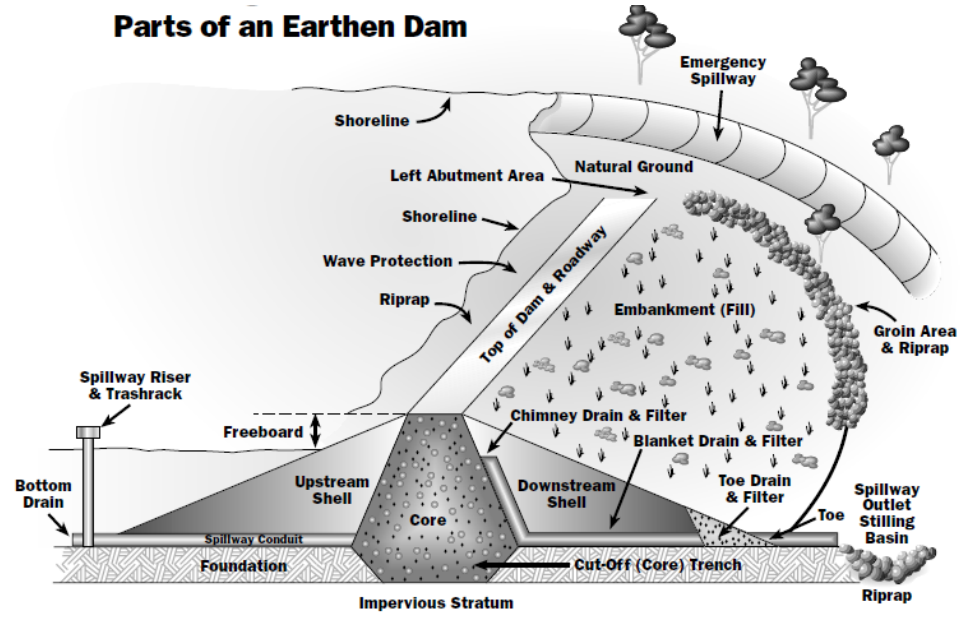
# Chapter 9 - Guidelines for Operation

- Proper operation procedures are important for maintaining a safe structure

- Special operational guidelines should be posted

# Background Data

- Vital dam statistics
- Description of appurtenances



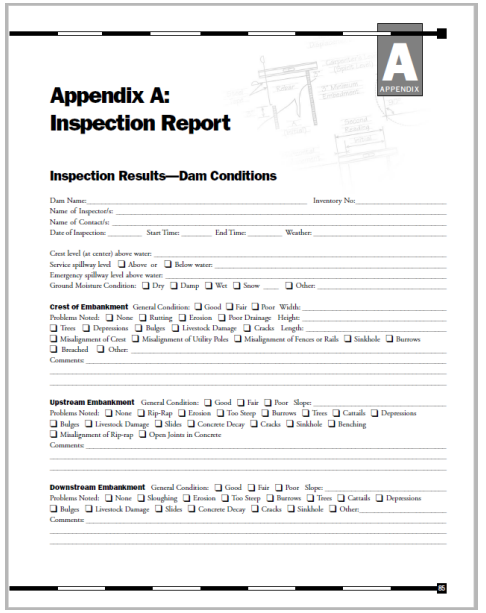
# Operable Mechanisms

- Step-by-step instructions for all mechanisms
- Gate usage during low or high flows
- Any known operating problems
- General operation of the reservoir
- Method for periodic drainage for inspection

# Inspection

- Step-by-step instructions for a comprehensive inspection of the dam and surroundings

- Inspection Report form



Appendix A:
Inspection Report

Inspection Results—Dam Conditions

Dam Name:_____ Inventory No:_____
Name of Inspector/s:_____
Name of Contact/s:_____
Date of Inspection:_____ Start Time:_____ End Time:_____ Weather:_____

Crest level (at center) above water:_____
Service spillway level ❑ Above or ❑ Below water:_____
Emergency spillway level above water:_____
Ground Moisture Condition: ❑ Dry ❑ Damp ❑ Wet ❑ Snow ____ ❑ Other:_____

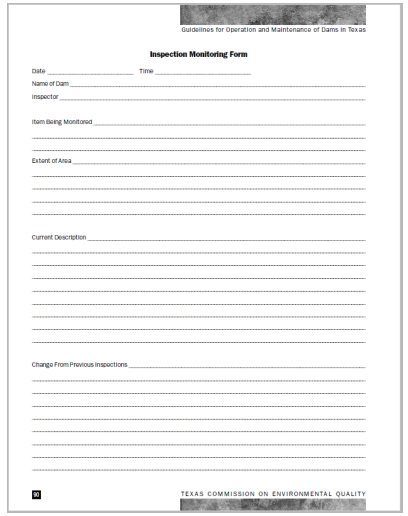
**Crest of Embankment** General Condition: ❑ Good ❑ Fair ❑ Poor Width:_____
Problems Noted: ❑ None ❑ Rutting ❑ Erosion ❑ Poor Drainage Height:_____
❑ Trees ❑ Depressions ❑ Bulges ❑ Livestock Damage ❑ Cracks Length:_____
❑ Misalignment of Crest ❑ Misalignment of Utility Poles ❑ Misalignment of Fences or Rails ❑ Sinkhole ❑ Burrows
❑ Breached ❑ Other:_____
Comments:_____

**Upstream Embankment** General Condition: ❑ Good ❑ Fair ❑ Poor Slope:_____
Problems Noted: ❑ None ❑ Rip-Rap ❑ Erosion ❑ Too Steep ❑ Burrows ❑ Trees ❑ Cattails ❑ Depressions
❑ Bulges ❑ Livestock Damage ❑ Slides ❑ Concrete Decay ❑ Cracks ❑ Sinkhole ❑ Benching
❑ Misalignment of Rip-rap ❑ Open Joints in Concrete
Comments:_____

**Downstream Embankment** General Condition: ❑ Good ❑ Fair ❑ Poor Slope:_____
Problems Noted: ❑ None ❑ Sloughing ❑ Erosion ❑ Too Steep ❑ Burrows ❑ Trees ❑ Cattails ❑ Depressions
❑ Bulges ❑ Livestock Damage ❑ Slides ❑ Concrete Decay ❑ Cracks ❑ Sinkhole ❑ Other:_____
Comments:_____

# Monitoring

- Clear instructions on using monitoring instruments and collecting data
- Map of instrument and monitoring locations
- Keep monitored areas clear of vegetation
- Plot/Chart readings as necessary


Guidelines for Operation and Maintenance of Dams in Texas

Inspection Monitoring Form

Date _____ Time _____

Name of Dam _____

Inspector _____

Item Being Monitored _____

Extent of Area _____

Current Description _____

Change From Previous Inspections _____

99 TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

# Maintenance

- The plan should include instructions for periodic maintenance in detail
- Include items listed in 299.43(a)(3)
- Include any additional items from inspections

# Bibliography and Telephone List

- Document title and location of reference materials
- Keep an up-to-date listing of important contact info

# Record Keeping

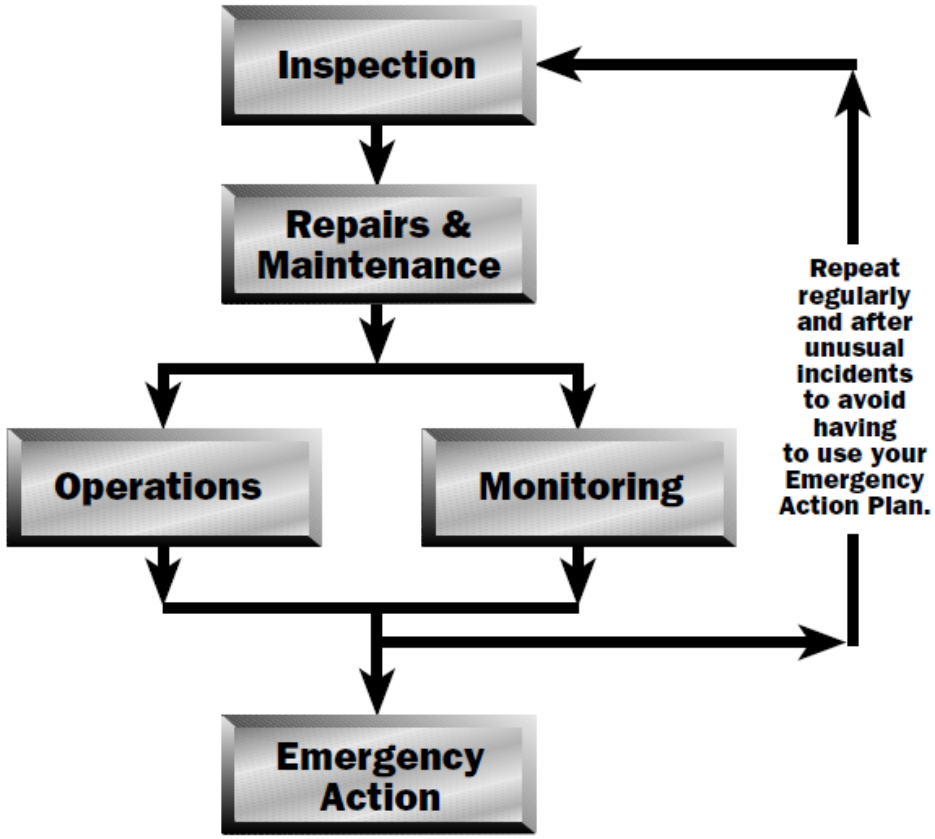
- Observations
- Maintenance
- Rainfall & Water Levels
- Drawdown
- Other Procedures

# Operations Plan

**Table 9.1**
**Operation Plan—Schedule of Routine Tasks**
***Hazard Classifications***

| Frequency (minimum) | CATEGORY 1 High Hazard *(many lives lost excessive damage)* | CATEGORY 2 Significant Hazard *(few lives lost appreciable damage)* | CATEGORY 3 Low Hazard *(no lives lost minimal damage)* |
|---|---|---|---|
| Daily | Surveillance. | — | — |
| Weekly | Monitor seepage. | Surveillance. | — |
| Monthly | Collect & examine observation well or other data. | Collect & examine observation well data. | Surveillance. Monitor seepage. Collect & examine observation well data. |
| Quarterly | Inspect visually. | Inspect visually. | — |
| Bi Annually | Test outlet & spillway components. | — | — |
| Annually | Inspection by engineer. Check alignments & movements. | Inspection by engineer. Test outlet & spillway components. Check alignments & movements. | Visual inspection. Test outlet. |
| As Required | Routine maintenance & additional inspections. | Routine maintenance & additional inspections. | Routine maintenance & additional inspections. Check alignments & movements. |
| Immediately After Floods & Earthquakes | Additional inspections. | Additional inspections. | Additional inspections. |

# Operations Flowchart



# Owner Responsibilities- TCEQ Dam Safety Enforcement

- TCEQ will not require the dam owner to breach the dam or drain the lake simply for not meeting requirements.

- TCEQ will enforce if the dam presents an unacceptable threat to public safety and owner is not working to reduce risk (Failure to Act)

- Best way to avoid enforcement is being proactive.
  - Conduct routine O&M so dams are not ‘too far gone’

# Owner Responsibilities

- Emergency repairs (per §299.45):
  - Undertaken under supervision of a P.E.
  - May start without TCEQ approval.
  - Notify TCEQ within 12 hours after emergency discovered and evaluated.
  - P.E. prepared plans for permanent repairs after emergency.  Must be approved.

# Owner Responsibilities

- Consider Dam Removal if dam can’t be maintained
  - New Dam Removal Guidelines
  - ‘Hydraulically Adequate Breach’ will not ultimately remove from TCEQ Dam Safety oversight
  - Remove the entire dam to its natural channel; or,

# Recap - Q&A

- Inspect regularly
- Maintain thoroughly
- Document everything
- Questions?