

# Dam Safety- Fact Sheet

Montana Watercourse and Montana Department of Natural Resources and Conservation  
Water Resources Division



## Basic Dam Layout and Nomenclature

Fact Sheet: 1

**Abutment** - That part of the valley side against which the dam is constructed. An artificial abutment is sometimes constructed where there is no suitable natural abutment. Right and left abutments are those on respective sides of an observer when viewed looking downstream.

**Appurtenances**- Structures associated with dams such as spillways, gates, outlet works, ramps, docks, etc. that allow proper operation of dams

**Auxiliary Spillway**- A secondary spillway also called an emergency spillway, designed to operate only during exceptionally large floods.

**Boil**- Typically a circular feature created by the upward movement of soil particles by seepage flowing under a pressure slightly greater than the submerged unit weight of the soil through which seepage is occurring.

**Breach**- A break, gap, or opening in a dam that allows an uncontrolled release of impounded water.

**Dam Crest**- The top of the dam embankment.

**Embankment Dam** - Any dam constructed of excavated natural materials, usually earth or rock, placed with sloping sides.

**Freeboard** - The vertical distance between a stated water level and the top of a dam.

**Groin** – The area along the intersection of the upstream or downstream face of the dam with the abutment.

**Height of Dam**- The vertical distance as measured from the downstream toe of the dam at its lowest point to the elevation of the top of the dam.

**Intake** - Any structure in a reservoir, dam or river through which water can be drawn into an aqueduct.

**Riprap** - A layer of large uncoursed stones, broken rock or precast blocks placed in random fashion on the slope of an embankment dam, a reservoir shore, or the sides of a channel to prevent erosion by wave and ice action.

**Plunge Pool (Plunge Basin)** - A natural or artificial pool that dissipates energy of free-falling water from an outlet pipe or spillway. The basin is located at a safe distance downstream of the structure from which the water is being released.

**Normal Water Level (Normal Pool)** - The lowest level of a dam's fixed overflow spillway crest.

**Outlet** - An opening through which water can be freely discharged for a particular purpose from a reservoir.

**Scarp** - The nearly vertical, exposed earth surface remaining at the upper edge of a slide on an embankment slope.

**Spillway** - A structure over or through which flood flows are discharged. If the flow is controlled by gates, it is called a controlled spillway; if the elevation of the spillway crest is the only control, it is called an uncontrolled

spillway.

**Spillway Crest** – The overflow elevation or location intended to spill.

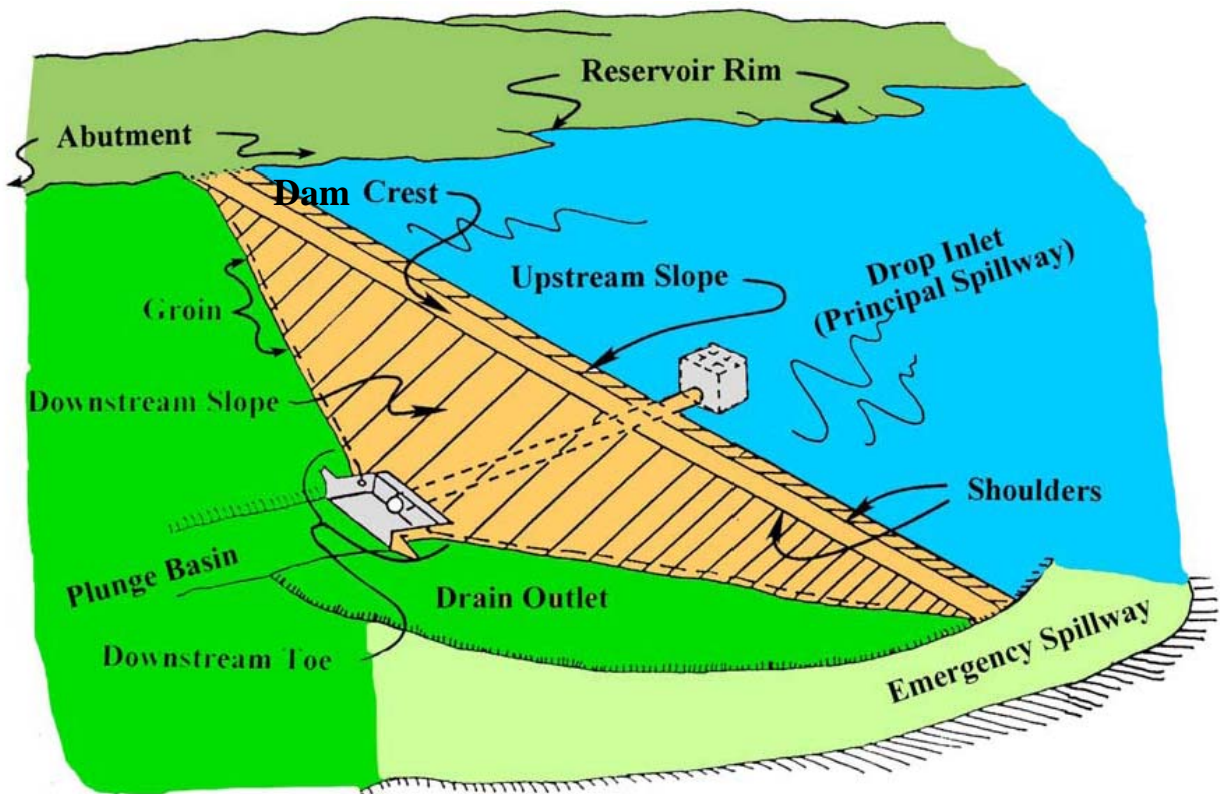
**Principal Spillway** - The principal or first used spillway during flood flows.

**Toe of Dam**- The junction of the face of a dam with the ground surface. An embankment dam has an “upstream” toe and a “downstream” toe.

**Seepage** - The movement of water through the dam, its foundations or its abutments.

**Stilling Basin**- A basin constructed to dissipate the energy of fast-flowing water, e.g., from a spillway or bottom outlet, and to protect the riverbed from erosion.

**Weir** - A structure built across a stream or channel to measure flow, sometimes called a measuring weir or gauging weir. A low dam or wall built across a stream to raise the upstream water level. Types of weirs include broadcrested, sharp-crested, ogee and V-notch weirs.



For more questions, comments, additional fact sheets, and area specific information you can contact DNRC or Montana Watercourse at the addresses below or on the web.

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## Earthen Dam Inspection

Fact Sheet: 2

Regardless of a dam's hazard classification, a detailed inspection is an important part of operation and maintenance of any size dam. Performing a detailed inspection can save the owner money by identifying problems early and by protecting downstream structures and inhabitants. Below is a list of key things to inspect and record observations of when performing an inspection.

### General Inspection Methodology

**Crest:** Walk across the crest from abutment to abutment.

**Upstream/Downstream Slope:** Walk across the slope in an up and down or zigzag pattern from abutment to abutment.

**Embankment-Abutment Contacts:** Walk the entire length of the embankment-abutment contacts (groin).

**Outlet Conduit:** Observe all accessible features of the outlet conduit. An outlet conduit can be either the low level drain or the principal spillway See Fact Sheet #16 and #17.

**Spillway:** Visually observe the entire length of the spillway or spillways, and all other visible features.

**Downstream Channel:** Travel the route of the stream below the dam to maintain familiarity with locations of residences and property that can be affected by dam failure. Dam owners should be aware of new downstream development and how this may impact the hazard class of their dam. Go far

enough downstream to cover the area that could be affected by a dam failure.

**Downstream Toe:** Walk the entire length of the downstream toe.

**Reservoir Slopes:** Scout the reservoir perimeter in an effort to develop an overall familiarity with its conditions.

Blank inspection forms are available on the DNRC's website at: [http://dnrc.mt.gov/wrd/water\\_op/dam\\_safety/dam\\_owners.asp](http://dnrc.mt.gov/wrd/water_op/dam_safety/dam_owners.asp).

### Inspection Kit Checklist:

Camera  
Measuring Tape  
Inspection Forms, Clipboard, Pens, Pencils  
Previous Inspection Report to Compare  
Buckets  
Stopwatch  
Ziploc Bags  
Flashlight  
Hammer

### What to Look For During Inspection:

- Settlement
- Turbid Discharge
- Structural Cracking
- Foundation Movement
- Erosion
- Sinkholes
- Vandalism
- Animal Burrows
- Boils
- Depressions
- Voids
- Debris in Gates and Spillways
- Wave Erosion
- Excessive Vegetation

- Seeps
- Soil Displacement on Slopes (Sloughing)



Seepage has severely damaged this embankment.

### Record Keeping

To properly maintain a dam from year to year an owner needs to keep all records throughout the life of the dam.

### Engineer Inspection

Periodically, dams should be inspected by a licensed dam engineer. A licensed dam engineer will be able to evaluate seepage and structural problems and help develop a plan for repair if necessary.

#### Important Items to Keep:

Annual Inspection Forms  
 Field Sketches  
 Ground Photos  
     Dated and Position Recorded  
 Monitoring Data  
     Record Seepage Rates, Settlement,  
     Crack Width, Reservoir Level,  
     Piezometer Elevation Readings



The area around the metal conduit has been eroded away by seepage along the pipe.



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## Dam Owner Resources

Fact Sheet: 3

### Montana Resources

Montana Association of Dam and Canal Systems (MADCS)

- [www.madcs.org](http://www.madcs.org)

Montana Association of Conservation Districts (MACD)

- Links to other Conservation Districts websites
- [www.macdnet.org](http://www.macdnet.org)

Montana Department of Natural Resources and Conservation – Water Resources Division

- Dam owner specific information
- Permitting, inspection, repair, emergency planning, technical references
- [www.dnrc.mt.gov/wrd/water\\_op/dam\\_safety](http://www.dnrc.mt.gov/wrd/water_op/dam_safety)

Montana Watershed Coordination Council

- Comprehensive list of Watershed Councils and Conservation Districts in the State
- [www.mtwatersheds.org](http://www.mtwatersheds.org)

Montana Watercourse

- Educational activities and support, workshops, guides
- Montana landowner specific resources
- [www.mtwatercourse.org](http://www.mtwatercourse.org)

### National Resources

National Resource Conservation Service

- Archival information on dam case studies, dam breach software
- [www.nrcs.usda.gov](http://www.nrcs.usda.gov)

FEMA Dam Safety Publications and Resources

- Many helpful technical manuals, guides, and resources.
- Manuals for dam owners on the impacts of animals and plants on earthen dams.
- [www.fema.gov/plan/prevent/damfailure/ndsp.shtm](http://www.fema.gov/plan/prevent/damfailure/ndsp.shtm)

Association of State Dam Safety Officials

- Links to many useful resources
- [www.damsafety.org](http://www.damsafety.org)

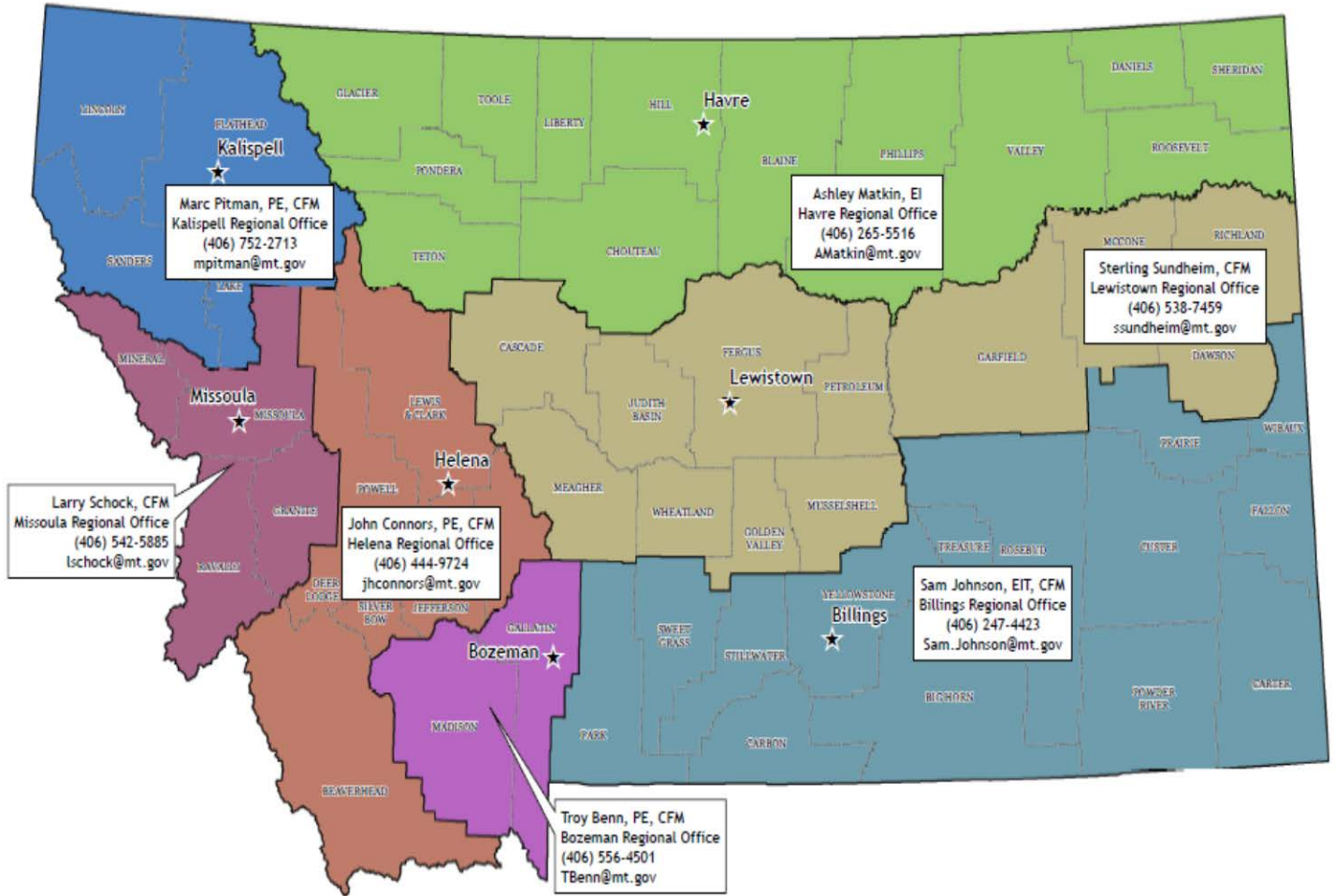
Army Corp of Engineers Dam Safety Program

- Engineering Design References
- Dam Regulations
- [www.usace.army.mil/damsafety/Pages/DamSafetyProgramOverview.aspx](http://www.usace.army.mil/damsafety/Pages/DamSafetyProgramOverview.aspx)

U.S Department of the Interior - Bureau of Reclamation

- Technical Publications on dam issues and materials
- [www.usbr.gov/ssle/damsafety](http://www.usbr.gov/ssle/damsafety)

## DNRC FLOODPLAIN PROGRAM Regional Engineering Specialist Boundary Map



Map Revised: Apr 2015

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## Animal and Rodent Control

Fact Sheet: 4

Rodents such as the northern pocket gopher, vole, prairie dogs, muskrat, and beaver are attracted to dams and reservoirs, and can be quite dangerous to the structural integrity and proper performance of the embankment and spillway. Rodent burrows weaken the embankment and can serve as pathways for seepage. Beavers may plug the spillway and raise the pool level. Rodent control is essential in preserving a well maintained dam.

In Montana the most likely aquatic mammals are beaver and muskrat. These rodents burrow into the upstream face of dam usually under the water line. Other burrowing mammals include: northern pocket gopher, badger, vole, black-tailed prairie dogs, and ground squirrels. These animals burrow into the downstream face of the dam for nesting and hunting.

### Muskrat

Muskrats are semi-aquatic rodents with brownish black fur. They range in size from 10-14 inches long with an 8-11 inch tail that is vertically flattened for swimming. They dig fairly large burrows and will continue to dig upwards as the phreatic surface (water level) rises. Their burrows are typically 6 to 18 inches below the water surface on the upstream face.



### Beaver

The Beaver is the largest rodent in Montana with body length of 25-30 inches and a weight of 45-60 pounds. They are easily distinguished by their large flat tails used for swimming. Beavers burrow into the bank of the upstream face just below the dam crest. A beaver den entrance can be 1-4 feet below the water surface. Often the outlet and intake structures are blocked by excess cutting. Beaver dams may be constructed across spillways.

### Badger

The North American Badger is easily distinguished by the white stripe down the middle of the head. A badger ranges in weight from 19 to 30 pounds. Badgers typically enlarge existing burrows looking for their prey: prairie dog, pocket gopher, ground squirrel. They are primarily nocturnal but can be seen during the day.

### Pocket Gopher

The Northern Pocket Gopher is a medium sized rodent with a body length of 5-14 inches. Fur color may be highly variable with ranges from black to almost white. Pocket gophers may have small burrow but can damage buried utilities and increase the likelihood of badgers.

### Vole

These small rodents can be a threat to dam safety if in large numbers due to their extensive network of tunnels and runways. They are active year round and create a hazard by attracting other burrowing predators such a coyotes, foxes, and badgers.

### Other Impacts

In addition to burrowing rodents and animals a dam embankment is at risk of erosion and vegetative cover loss from livestock and Canada geese. As livestock roam over an earthen dam they can remove stabilizing vegetation through grazing, trampling, and rooting. If livestock are drinking from the reservoir they can create ruts and paths that erode the bank and dam crest.

### Control

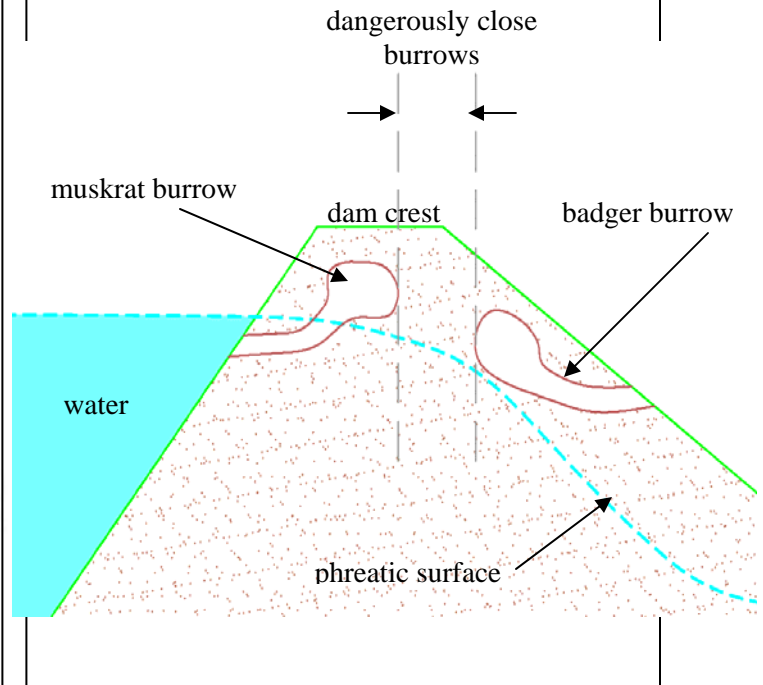
The most effective deterrent for burrowing animals is riprap or concrete facing with a filter layer. The armoring must extend above and under the water level for proper protection. As a rodent tries to burrow into the upstream face the filter sand and gravel will cave in, discouraging den making. Also maintaining proper vegetative cover along the bank eliminates habitat for rodents to forage and live in. Proper cover includes removing brush and trees and keeping grass mowed.

### Eliminating a Burrow

The recommended method of backfilling a burrow in an embankment is mud-packing. This simple, inexpensive method can be accomplished by placing one or two lengths of metal stove or vent pipe in a vertical position over the entrance of the den. Making sure that the pipe connection to the den does not leak, the mud-pack mixture is then poured into the pipe until the burrow and pipe are filled with the earth-water mixture. The pipe is removed and dry earth is tamped into the entrance. The mud-pack is made by adding water to a 90 percent earth and 10 percent cement mixture until a slurry or thin cement consistency is attained. All entrances should be plugged with well compacted earth and vegetation re-established. Dens should be eliminated without delay because damage from just one hole can lead to failure of a dam or levee.

Also, a fluctuating water level will deter aquatic burrows.

Before trapping or hunting any rodents or animals on your property, consult Montana Fish, Wildlife & Parks for current rules and regulations.



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## Trees and Brush

Fact Sheet: 5

The establishment and control of proper vegetation is an important part of dam maintenance. Properly maintained vegetation can help prevent erosion of embankment and earth channel surfaces, and aid in the control of rodents. The uncontrolled growth of vegetation can damage embankments and concrete structures and make close inspection difficult.

### Trees and Brush

Trees and brush should not be permitted on embankment surfaces or in vegetated earth spillways. Extensive root systems can provide seepage paths for water. Trees that blow down or fall over can leave large holes in the embankment surface that will weaken the embankment and can lead to increased erosion. Brush obscures the surface, limiting visual inspection, provides a haven for burrowing animals, and retards growth of grass vegetation. Tree and brush growth adjacent to concrete walls and structures may eventually cause damage to the concrete and should be removed.

### Tree Removal

Stumps of cut trees should be removed, and cavities should be filled and covered with a short grass that can be easily maintained and mowed. Stumps can be removed either by pulling or with equipment that will grind them down. All woody material should be removed to about six inches below the ground surface. Stumps of trees in rip-rap cannot usually be pulled or ground down, but can be chemically treated prevent them from continually forming new sprouts.

### Upstream Embankment

Remove all trees, stumps, rootballs, and root systems; clean rootball cavity; and backfill with properly placed and compacted soil. Install rip-rap for wave erosion protection on the upstream slope from about four feet below normal pool elevation to about three feet above normal pool elevation.

### Dam Crest

Cut trees having stump diameters of twelve inches or less flush with the ground and treat the stump with a waterproof sealant to delay stump decay. Completely remove trees having stump diameters of about twelve inches and greater, and backfill rootball cavity with properly compacted backfill soil.

### Downstream Embankment

Cut trees having stump diameters of about six inches and less level with the ground and treat the stump with a waterproof sealant to delay stump and rootball decay. Completely remove all trees having stump diameters greater than about eight inches and backfill the cleaned rootball cavity with compacted backfill soil.

### Lower Portion of Embankment and Toe of Dam

Cut all trees having stump diameters of about four inches and smaller flush with the ground and treat the stump to delay stump and rootball decay. Install a toe drain or subdrain system to lower the subsurface water level. The drain filter system will collect and discharge the seepage. Incorporate major subdrain with tree rootball and stump removal where possible. Remove all trees located up to 30 feet beyond the toe of the downstream slope having stump diameters greater than

about four inches. Install sand filters and drain systems in rootball cavities where seepage boiling and soil piping are likely to occur.

### **Tree Removal Tips**

When cutting trees for removal, at least one to two feet of the stump should be left above the ground, leaving a well-defined stump that can be used in the stump removal process. The stump and rootball should then be removed by pulling the stump upward with a track-mounted backhoe (or similar equipment) after loosening the rootball by pulling on the stump from different directions. The rootball cavity should be cleaned to remove loose soil and the remaining roots in the cavity using a backhoe. The side slopes of the hole are to be no steeper than 1:1. Compacted soil should be a cohesive material, compacted in lifts no greater than 8-inches loose lift thickness on top of a flat bottom.

### **Embankment Maintenance**

Embankments, groins, areas adjacent to spillway structures, vegetated channels, and other areas associated with a dam require continual maintenance of the vegetative cover. Grass mowing, brush cutting, and removal of woody vegetation (including trees) are necessary for the proper maintenance of a dam, dike, or levee. All embankment slopes and vegetated earth spillways should be mowed at least twice per year. Trees and brush should be removed in all areas within 30 feet of the embankment.

Well tended grasses improve aesthetics, simplify inspections, create a non-erodible surface, and discourage burrowing animal habitation. Chemical spraying and burning for the purpose of regular maintenance are no longer acceptable methods of vegetation control near a water body. More acceptable methods include the use of weed whips or power brush-cutters and mowers. If chemical

spraying is used, utmost care should be taken to protect the local environment. To protect the integrity of the embankment, mowing with heavy equipment when wet should be avoided. Only proper equipment designed specifically for the type of slope and vegetation should be utilized following the manufacturer's recommended safe operation procedures.



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## Dam Failure Modes

Fact Sheet: 6

Owners of dams as well as operating and maintenance personnel must be knowledgeable of the potential problems which can lead to failure of a dam. These people regularly view the structure and, therefore, need to be able to recognize potential problems so that failure can be avoided. If a problem is noted early enough, an engineer experienced in dam design, construction, and inspection can be contacted to recommend corrective measures, and such measures can be implemented.

**IF THERE IS ANY QUESTION AS TO THE SERIOUSNESS OF AN OBSERVATION, AN ENGINEER EXPERIENCED WITH DAMS SHOULD BE CONTACTED.**

Acting promptly may avoid possible dam failure and the resulting catastrophic effect on downstream areas. Engineers from the Dam Safety Program of the Montana Department of Natural Resources and Conservation are available at any time to inspect a dam if a serious problem is detected or if failure may be imminent.

Since only superficial inspections of a dam can usually be made, it is imperative that owners and maintenance personnel be aware of the prominent types of failure and their telltale signs. Earth dam failures can be grouped into three general categories: overtopping failures, seepage failures, and structural failures. A brief discussion of each type follows.

### **Overtopping Failures**

Overtopping failures result from the erosive action of water on the embankment. Erosion

from overtopping is due to uncontrolled flow of water over, around, and adjacent to the dam.



Earth embankments are not designed to be overtopped and therefore are particularly susceptible to erosion. Once erosion has begun during overtopping, it is almost impossible to stop. A well vegetated earth embankment may withstand limited overtopping if its crest is level and water flows over the crest and down the face as an evenly distributed sheet without becoming concentrated. The owner should closely monitor the reservoir pool level during severe storms. The primary defense against overtopping is properly designed and maintained spillways.

### **Seepage Failures**

All earth dams have seepage resulting from water permeating slowly through the dam and its foundation. Seepage must be controlled in both velocity and quantity. If uncontrolled, it can progressively erode soil from the embankment or its foundation, resulting in rapid failure of the dam. Erosion of the soil begins at the downstream side of the

embankment, either in the dam proper or the foundation, progressively works toward the reservoir, and eventually develops a direct connection to the reservoir. This phenomenon is known as "piping." Piping action can be recognized by an increased seepage flow rate, the discharge of muddy or discolored water, sinkholes on or near the embankment, or a whirlpool in the reservoir. Once a whirlpool (eddy) is observed on the reservoir surface, complete failure of the dam will probably follow in a matter of minutes. As with overtopping, fully developed piping is virtually impossible to control and will likely cause failure. Seepage can cause slope failure by creating high pressures in the soil pores or by saturating the slope. The pressure of seepage within an embankment is difficult to determine without proper instrumentation. A slope which becomes saturated and develops slides may be showing signs of excessive seepage pressure. Embankments are most vulnerable to seepage during high water conditions.

### **Structural Failures**

Structural failures can occur in either the embankment or the appurtenances. Structural failure of a spillway, lake drain, or other appurtenance may lead to failure of the embankment. Cracking, settlement, and slides are the more common signs of structural failure of embankments. Large cracks in an appurtenance or the embankment, major settlement, and major slides will require emergency measures to ensure safety, especially if these problems occur suddenly. If this type of situation occurs, the lake level should be lowered, the appropriate state and local authorities notified, and professional advice sought.

If the observer is uncertain as to the seriousness of the problem, a licensed engineer should be contacted immediately. The DNRC Water Resource Division has engineers located through out the state that you can also call for assistance.

The three types of failure previously described are often interrelated in a complex manner. For example, uncontrolled seepage may weaken the soil and lead to a structural failure. A structural failure may shorten the seepage path and lead to a piping failure. Minor defects such as cracks in the embankment may be the first visual sign of a major problem which could lead to failure of the structure. The seriousness of all deficiencies should be evaluated by someone experienced in dam design and construction. A qualified professional engineer can recommend appropriate permanent remedial measures.



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## Earthen Dam Seepage

Fact Sheet: 7

Contrary to popular opinion, wet areas downstream from dams are not usually natural springs, but seepage areas. Even if natural springs exist, they should be treated with suspicion and carefully observed. Flows from ground-water springs in existence prior to the reservoir would probably increase due to the pressure caused by the pool of water behind the dam. All dams have some seepage as the impounded water seeks paths of least resistance through the dam and its foundation. Seepage must, however, be controlled to prevent erosion of the embankment or foundation or damage to concrete structures.



### Detection

Seepage can emerge anywhere on the downstream face, beyond the toe, or on the downstream abutments at elevations below normal pool. Seepage may vary in appearance from a "soft," wet area to a flowing "spring." It may show up first as an area where the vegetation is lush and darker green. Cattails, reeds, mosses, and other marsh vegetation often become established in a seepage area. Another indication of seepage is the presence of rust-colored iron bacteria. Due to their nature, the bacteria are found more often where water is discharging from the ground than in surface water. Seepage can make

inspection and maintenance difficult. It can also saturate and weaken portions of the embankment and foundation, making the embankment susceptible to earth slides. If the seepage forces are large enough, soil will be eroded from the seepage path and be deposited in the shape of a cone around the outlet of the seepage. If these "boils" appear, professional advice should be sought immediately. Seepage flow which is muddy and carrying sediment (soil particles) is evidence of "piping," and will cause failure of the dam. Piping can occur along a spillway and other conduits through the embankment, and these areas should be closely inspected. Sinkholes may develop on the surface of the embankment as internal erosion takes place. A whirlpool in the lake surface may follow and then likely a rapid and complete failure of the dam. Emergency procedures, including downstream evacuation, should be implemented if this condition is noted (See Dam Fact Sheet #6). Seepage can also develop behind or beneath concrete structures such as chute spillways or headwalls. If the concrete structure does not have a means such as weep holes or relief drains to relieve the water pressure, the concrete structure may heave, rotate, or crack. The effects of the freezing and thawing can amplify these problems. It should be noted that the water pressure behind or beneath structures may also be due to infiltration of surface water or spillway discharge. A continuous or sudden drop in the normal lake level is another indication that seepage is occurring. In this case, one or more locations of flowing water are usually noted downstream from the dam. This condition, in itself, may not be a serious problem, but will require frequent and close

monitoring and professional assistance.

### **Control**

The need for seepage control will depend on the quantity, content, and location of the seepage. Reducing the quantity of seepage that occurs after construction is difficult and expensive. It is not usually attempted unless the seepage has lowered the pool level or is endangering the embankment or appurtenant structures. Typical methods used to control the quantity of seepage are grouting or installation of an upstream blanket. Of these methods, grouting is probably the least effective and is most applicable to leakage zones in bedrock, abutments, and foundations. These methods must be designed and constructed under the supervision of a professional engineer experienced with dams.

Preventing seepage flow from eroding soil particles is extremely important. Modern design practice incorporates this control into the embankment through the use of cutoffs, internal filters, and adequate drainage provisions. Control at points of seepage exit can be accomplished after construction by installation of toe drains, relief wells, or inverted filters. Weep holes and relief drains can be installed to relieve water pressure or drain seepage from behind or beneath concrete structures. These systems must be designed to prevent migration of soil particles but still allow the seepage to drain freely. The owner must retain a professional engineer to design toe drains, relief wells, inverted filters, weep holes, or relief holes.

### **Monitoring**

Regular monitoring is essential to detect seepage and prevent dam failure. Knowledge of the dam's history is important to determine whether the seepage condition is in a steady or changing state. It is important to keep written records of points of seepage exit,

quantity and content of flow, size of wet area, and type of vegetation for later comparison. Photographs provide invaluable records of seepage. All records should be kept in the operation, maintenance, and inspection manual for the dam. The inspector should always look for increases in flow and evidence of flow carrying soil particles, which would indicate that a more serious problem is developing. Instrumentation can also be used to monitor seepage. V-notch weirs can be used to measure flow rates, and piezometers may be used to determine the saturation level (phreatic surface) within the embankment. Regular surveillance and maintenance of internal embankment and foundation drainage outlets is also required. The rate and content of flow from each pipe outlet for toe drains, relief wells, weep holes, and relief drains should be monitored and documented regularly. Normal maintenance consists of removing all obstructions from the pipe to allow for free drainage of water from the pipe. Typical obstructions include debris, gravel, sediment, and rodent nests. Water should not be permitted to submerge the pipe outlets for extended periods of time. This will inhibit inspection and maintenance of the drains and may cause them to clog.

For more questions, comments, additional fact sheets, and area specific information you can contact DNRC or Montana Watercourse at the addresses below or on the web.

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# Dam Safety- Fact Sheet

Montana Watercourse and Montana Department of Natural Resources and Conservation  
Water Resources Division



## Earthquakes

Fact Sheet: 8

Montana is a seismically active state with large areas near faults and active zones. A dam owner should be aware of active faults and historical seismic activity in their area. Online maps are available from the Montana Bureau of Mines and Geology (MBMG) and the United States Geological Survey (USGS).

For maps and additional information visit the USGS Earthquake Hazards Program and the MBMG Earthquake Studies Office.

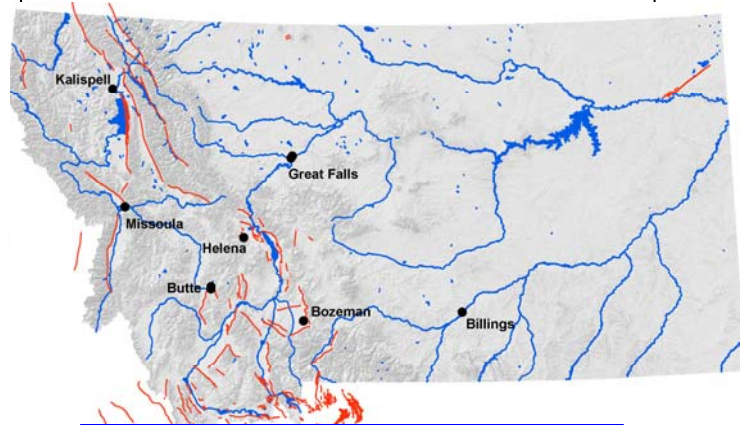
<http://earthquake.usgs.gov/>

<http://mbmgquake.mtech.edu/>

The Northwestern and Southwestern parts of the state have the highest probability of seismic activity. While an earthquake can happen anywhere, an owner should be aware of historical earthquakes in their area and mapped fault lines. Information on earthquakes and seismic zones is readily available on the internet by the agencies shown above.



As with any other event, the dam should be inspected after any noticeable earthquake (See Dam Fact Sheet #2). Look for movement, cracking, sloughing or displacement of the dam. Also check that outlet works are functioning properly and in the correct alignment. If a large event occurs (greater than magnitude 5.5) you should hire an engineer to inspect your dam for damage. Not all damage will be obvious.



Known Active Faults in Montana

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# Dam Safety- Fact Sheet

Montana Watercourse and Montana Department of Natural Resources and Conservation  
Water Resources Division



## Upstream Slope Protection

Fact Sheet: 9

Slope protection is usually needed to protect the upstream slope against erosion due to wave action. Without proper slope protection, a serious erosion problem known as “beaching” can develop on the upstream slope.

The rate of erosion is dependent on:

- predominant wind direction
- orientation of the dam
- steepness of the slope
- water level fluctuations
- boating activities
- animal activities
- vegetative cover

Further erosion can lead to cracking and sloughing of the slope which can extend into the crest, reducing its width. When erosion occurs and beaching develops on the upstream slope of a dam, repairs should be made as soon as possible. However, an erosion scarp less than one foot high may be stable and not require repair.

The upstream face of a dam is commonly protected against wave erosion by placement of a layer of rock riprap over a layer of bedding and a filter material. Other materials such as concrete facing, soil-cement, fabric-form bags, slush grouted rocks, steel sheet piling, chain link fencing over rock and articulated concrete blocks can also be used. Vegetative protection combined with a berm on the upstream slope can also be effective.

### Rock Riprap

Rock riprap consists of an assortment of irregular shaped rocks placed over gravel bedding and a sand filter or geotextile fabric.

The smaller rocks help to fill the spaces between the larger pieces forming an interlocking mass. The filter prevents soil particles on the embankment surface from being washed out through the spaces (or voids) between the rocks. The maximum rock size and weight must be large enough to break up the energy of the maximum anticipated wave action and hold the smaller stones in place. If the rock size is too small, it will eventually be displaced and washed away by wave action. If the riprap is sparse or if the filter or bedding material is too small, the filter material will wash out easily, allowing the embankment material to erode. Once the erosion has started, beaching will develop if remedial measures are not taken.

Technical Release No. 69 developed by the USDA, Natural Resources Conservation Service can be used to help design engineers develop a preliminary or detailed design for riprap slope protection.

The dam owner should expect some deterioration (weathering) of riprap. Freezing and thawing, wetting and drying, abrasive wave action, and other natural processes will eventually break down the riprap. Its useful life varies with the characteristics of the stone used. Stone for riprap should be rock that is dense and well cemented. In Montana, glacial cobbles or boulders, most limestone, basalt, and a few types of sandstone are acceptable for riprap. Most sandstones and shales found in Montana do not provide long-term protection. Due to the high initial cost of rock riprap, its durability should be determined by appropriate testing procedures prior to installation. Vegetative growth



within the slope protection is undesirable because it can displace stone and disturb the filter material. Heavy undergrowth prevents an adequate inspection of the upstream slope and may hide potential problems. For additional information, see the “Trees and Brush” fact sheet.

### **Vegetated Wave Berm**

Vegetated wave berms dissipate wave energy and protect the slope from erosion. Berms are constructed on the upstream slope at the normal pool level and should be no less than 20 feet wide. This method of slope protection will not work well where the water surface fluctuates regularly from normal pool. If improper or sparse vegetation is present, the wave berm may not adequately dissipate the wave energy, allowing erosion and beaching to develop on the upstream slope.

Technical Release No. 56 developed by the USDA, Natural Resources Conservation Service provides design and layout information for vegetated wave berms.

The vegetation on the wave berm should be monitored regularly to verify adequate growth. Sufficient funds should be allocated for the regular maintenance of the vegetation. Severe erosion or reoccurring problems may require a registered professional engineer to design a more effective slope protection.

### **Concrete Facing**

Concrete facing can be used if severe wave action is anticipated, however, settlement of the embankment must be insignificant to insure adequate support for the concrete facing. A properly designed and constructed concrete facing can be expensive. This slope protection should extend several feet above and below the normal pool level. It should terminate on a berm or against a concrete curb or header. Granular filter or filter fabric (geotextile) is required under the concrete

facing to help reduce the risk of undermining. As with any type of slope protection, problems will develop if the concrete facing has not been properly designed or installed. Concrete facing often fails because the wave action washes soil particles from beneath the slabs through joints and cracks. This process is known as undermining, which will continue until large voids are created. Detection of voids is difficult because the voids are hidden. Failure of the concrete facing may be sudden and extensive. Concrete facing should be monitored for cracks and open joints. Open joints should be sealed with plastic fillers, and cracks should be grouted and sealed (See Dam Fact Sheet #12).

### **Inspection and Monitoring**

Regular inspection and monitoring of the upstream slope protection is essential to detect any problems. It is important to keep written records of the location and extent of any erosion, undermining, or deterioration of the riprap, wave berm or other slope protection. Photographs provide invaluable records of changing conditions. A rapidly changing condition may indicate a very serious problem, and the Dam Safety Program should be contacted immediately.

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# Dam Safety- Fact Sheet

Montana Watercourse and Montana Department of Natural Resources and Conservation  
Water Resources Division



## Groundcover

Fact Sheet: 10

The establishment and control of proper vegetation are an important part of dam maintenance. Properly maintained vegetation can help prevent erosion of embankment and earth channel surfaces, and aid in the control of burrowing rodents.

Grass vegetation is an effective and inexpensive way to prevent erosion of embankment surfaces. If properly maintained, it also enhances the appearance of the dam and provides a surface that can be easily inspected. Roots and stems tend to trap fine sand and soil particles, forming an erosion-resistant layer once the plants are well established. Grass vegetation may not be effective in areas of concentrated runoff, such as at the contact of the embankment and abutments, or in areas subjected to wave action.

### **Suggested Native Montana Grassland Seeding Mixtures (Provided by the Natural Resources Conservation Service)**

#### Mountain/Foothills

- Bluebunch Wheatgrass - 4 lbs. per acre
- Idaho Fescue - 2 lbs. per acre
- Big Bluegrass - 1 lb. per acre
- Mountain Brome - 9 lbs. per acre

#### Tallgrass Prairie

- Big Bluestem - 4 lbs. per acre
- Little Bluestem - 3 lbs. per acre
- Switchgrass - 2 lbs. per acre
- Sideoats Grama - 3 lbs. per acre

#### Mixed Prairie (upland)

- Bluebunch Wheatgrass - 4 lbs. per acre
- Sandberg Bluegrass - 1 lb. per acre
- Needle & Thread - 3 lbs. per acre
- Indian Ricegrass - 3 lbs. per acre

#### Mixed Prairie (lowland)

- Western Wheatgrass - 4 lbs. per acre
- Green Needlegrass - 3 lbs. per acre
- Thickspike Wheatgrass - 3 lbs. per acre
- Blue Grama - 1 lb. per acre

### **Erosion**

Embankment slopes are normally designed and constructed so that the surface drainage/runoff will be spread out in a thin layer as "sheet flow" over the grass cover. When the sod is in poor condition or flow is concentrated at one or more locations, the resulting erosion will leave rills and gullies in the embankment slope. The erosion will cause loss of material and make maintenance of the embankment difficult. Prompt repair of the erosion is required to prevent more serious damage to the embankment. If erosion gullies are extensive, a registered professional engineer may be required to design a more extensive repair such as riprap or concrete or various synthetic or natural erosion control products. Minor rills and gullies can be repaired by filling them with compacted cohesive material. Topsoil should be a minimum of 4 inches deep. The area should then be seeded and mulched. Not only should the eroded areas be repaired, but the cause of the erosion should be addressed to prevent a continued maintenance problem.

### **Footpaths**

Paths from animal and pedestrian traffic are problems common to many embankments. If a path has become established, vegetation in this area will not provide adequate protection and a more durable cover will be required unless the traffic is eliminated. Gravel, asphalt, and concrete have been used effectively to cover footpaths. Embedding

railroad ties or other treated wood beams into an embankment slope to form steps is one of the most successful and inexpensive methods used to provide a protected pathway.

### Vehicle Ruts

Vehicle ruts can also be a problem on the embankment. Vehicular traffic on the dam should be discouraged especially during wet conditions except when necessary. Water collected in ruts may cause localized saturation, thereby weakening the embankment. Vehicles can also severely damage the vegetation on embankments. Worn areas could lead to erosion and more serious problems. Ruts that develop in the crest should be repaired by grading to direct all surface drainage into the impoundment. Bare and eroded areas should be repaired using the methods mentioned in the above sections. Constructed barriers such as fences and gates are effective ways to limit access of vehicles.

### Unwanted Vegetation

While groundcover by short grasses and plants is essential to maintaining an earthen dam, other vegetation can be detrimental (See Fact Sheet #5). Large bushes or high brush make dam inspection and maintenance difficult. They also provide habitat for wildlife that can create burrows and erosion.

### Maintenance

Embankments, areas adjacent to spillway structures, vegetated channels, and other areas associated with a dam require continual maintenance of the vegetal cover. Removal of improper vegetation is necessary for the proper maintenance of a dam, dike or levee. All embankment slopes and vegetated earth spillways should be mowed at least twice a year.

Reasons for proper maintenance of the

vegetal cover include:

- unobstructed viewing during inspection
- maintenance of a non erodible surface
- discouragement of burrowing animal habitation
- aesthetics

Common methods for control of vegetation include the use of weed trimmers or power brush-cutters and mowers. Chemical spraying to kill small trees and brush is acceptable if precautions are taken to protect the local environment. Some chemical spraying may require proper training prior to application.



Common Name:  
Bluebunch Wheatgrass

Scientific Name:  
*Pseudoroegneria  
spicata*

Native Grazing Grass

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# Dam Safety- Fact Sheet

Montana Watercourse and Montana Department of Natural Resources and Conservation  
Water Resources Division



## Problems with Concrete Materials

Fact Sheet: 11

Concrete materials in a dam can deteriorate due to poor installation, disintegration, scaling, cracking, efflorescence, acid attack, erosion, spalling and popouts.

### Construction Errors

Errors made during construction such as adding improper amounts of water to the concrete mix, inadequate consolidation, and improper curing can cause distress and deterioration of the concrete. Proper mix design, placement, and curing of the concrete, as well as an experienced contractor are essential to prevent construction errors from occurring. Construction errors can lead to some of the problems discussed later in this fact sheet such as scaling and cracking.

Honeycombing can be recognized by exposed coarse aggregate on the surface without any mortar covering or surrounding the aggregate particles. The honeycombing may extend deep into the concrete. Honeycombing can be caused by a poorly graded concrete mix, by too large of a coarse aggregate or by insufficient vibration at the time of placement. Honeycombing will result in further deterioration of the concrete due to freeze-thaw because moisture can easily work its way into the honeycombed areas. Severe honeycombing should be repaired to prevent further deterioration of the concrete surface.

### Disintegration and Scaling

Disintegration can be described as the deterioration of the concrete into small fragments and individual aggregates. Scaling is a milder form of disintegration where the surface mortar flakes off. Large areas of crumbling (rotten) concrete, areas of

deterioration which are more than about 3 to 4 inches deep (depending on the wall/slab thickness), and exposed rebar indicate serious concrete deterioration. If not repaired, this type of concrete deterioration may lead to structural instability of the concrete structure.

Disintegration can be a result of many causes such as freezing and thawing, chemical attack, and poor construction practices. In Montana the freeze thaw cycle is a large contributor to degradation of concrete. All exposed concrete is subject to freeze-thaw, but the concrete's resistance to weathering is determined by the concrete mix and the age of the concrete. Concrete with the proper amounts of air, water, and cement, and a properly sized aggregate, will be much more durable. In addition, proper drainage is essential in preventing freeze-thaw damage. When critically saturated concrete (when 90% of the pore space in the concrete is filled with water) is exposed to freezing temperatures, the water in the pore spaces within the concrete freezes and expands, damaging the concrete. Repeated cycles of freezing and thawing will result in surface scaling and can lead to disintegration of the concrete. Hydraulic structures are especially susceptible to freeze-thaw damage since they are more likely to be critically saturated. Older structures are also more susceptible to freeze-thaw damage since the concrete may not be air entrained. Air entrainment is done by adding an add mixture to the mix to create tiny air bubbles in the mixture. These "pockets" allow the concrete to expand and contract during the freeze thaw cycle.

Other forms of disintegration come from acidic substances in the surrounding soil and water. These can cause disintegration of the concrete surface due to a reaction between the acid and the hydrated cement. Three ways are available to improve the ability of concrete to resist acids: decrease the porosity of the concrete, coat the surface, or remove aggressive soils surrounding the concrete.

### **Cracks**

Cracks in the concrete may be structural or surface cracks. Surface cracks are generally less than a few millimeters wide and deep. These are often called hairline cracks. A small number of surface or shrinkage cracks is common and does not usually cause any problems. Surface cracks can be caused by freezing and thawing, poor construction practices, and alkali-aggregate reactivity. Alkali-aggregate reactivity occurs when the aggregate reacts with the cement causing crazing or map cracks. Crazing is a network of cracks that form on the surface of the concrete due to uneven curing of the top layer of concrete that are rarely a structural issue. The placement of new concrete over old may cause surface cracks to develop. This occurs because the new concrete will shrink as it cures. Surface cracks in the spillway should be monitored and will need to be repaired if they deteriorate further. Structural cracks in the concrete are usually larger than 0.25 inch in width. They extend deeper into the concrete and may extend all the way through a wall, slab, or other structural member. Structural cracks are often caused by settlement of the fill material supporting the concrete structure, or by loss of the fill support due to erosion. The structural cracks may worsen in severity due to the forces of weathering. A registered professional engineer knowledgeable about dam safety must investigate the cause of structural cracks and prepare plans and specifications for repair

of any structural cracks.

### **Efflorescence**

A white, crystallized substance, known as efflorescence, may sometimes be noted on concrete surfaces, especially spillway sidewalls. It is usually noted near hairline or thin cracks. Efflorescence is formed by water seeping through the pores or thin cracks in the concrete. When the water evaporates, it usually leaves behind a thin white film. This film is the minerals that have been leached from the soil, fill, or concrete as water passes through them. Efflorescence is typically not a structural problem unless it contains sulphates or other salts that can deteriorate concrete.



Efflorescence on a concrete face of a dam.

Efflorescence should be monitored because it can indicate the amount of seepage finding its way through thin cracks in the concrete and can signal areas where problems (i.e. inadequate drainage behind the wall or deterioration of concrete) could develop.

Also, water seeping through thin cracks in the wall will make the concrete more susceptible to deterioration due to freezing and thawing of the water.

### Spalling and Popouts

Spalling is the loss of larger pieces or flakes of concrete. It is typically caused by sudden impact of something dropped on the concrete or stress in the concrete that exceeded the design. Spalling may occur on a smaller scale, creating popouts. Popouts are formed as the water in saturated coarse aggregate particles near the surface freezes, expands, and pushes off the top of the aggregate and surrounding mortar to create a shallow conical depression. Popouts are typically not a structural problem.

### Erosion

Erosion due to abrasion is caused by the rubbing and grinding of aggregate or other debris on the concrete surface of a spillway channel or stilling basin. Minor erosion is not a problem but severe erosion can jeopardize the structural integrity of the concrete. A registered professional engineer must prepare plans and specifications for repair of this type of erosion if it is severe. Erosion due to cavitation results in a rough, pitted concrete surface. Cavitation is a process in which subatmospheric pressures, turbulent flow and impact energy are created and will damage the concrete.



Popouts are caused by the freeze thaw cycle.

### Inspection and Monitoring

Regular inspection and monitoring is essential to detect problems with concrete materials. Concrete structures should be inspected a minimum of once per year. Proper ventilation

and confined space precautions must be considered when entering a conduit. It is important to keep written records of the dimensions and extent of scaling, disintegration, efflorescence, honeycombing, erosion, spalling, popouts, and the length and width of cracks. Structural cracks should be monitored more frequently and repaired if they are a threat to the stability of the structure or dam. Photographs provide invaluable records of changing conditions. A rapidly changing condition may indicate a very serious problem, and the Dam Safety Program should be contacted immediately. All records should be kept in the operation, maintenance, and inspection manual for the dam.



Spalling exposes metal reinforcement to corrosion.

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# Dam Safety- Fact Sheet

Montana Watercourse and Montana Department of Natural Resources and Conservation  
Water Resources Division



## Concrete Repair

Fact Sheet: 12

Concrete is a durable, strong and basic building material often used in dams for core walls, spillways, stilling basins, control towers, and slope protection. However, poor workmanship, construction procedures, and construction materials may cause imperfections that later require repair. Any long-term deterioration or damage to concrete structures caused by flowing water, ice, or other natural forces must be corrected.

Neglecting to perform periodic maintenance and repairs to concrete structures as they occur could result in failure of the structure from either a structural or hydraulic standpoint. This in turn may threaten the continued safe operation and use of the dam.

### Considerations

Floor or wall movement, extensive cracking, improper alignments, settlement, joint displacement, and extensive undermining are signs of major structural problems. In situations where concrete replacement solutions are required to repair deteriorated concrete, it is recommended that a registered professional engineer be retained to perform an inspection to assess the concrete's overall condition, and determine the extent of any structural damage and necessary remedial measures. Typically, it is found that drainage systems are needed to relieve excessive water pressures under floors and behind walls. In addition, reinforcing steel must also be properly designed to handle tension zones and shear and bending forces in structural concrete produced by any external loading (including the weight of the structure). Therefore, the finished product in any concrete repair procedure should consist of a structure that is durable and able to withstand

the effects of service conditions such as weathering, chemical action, and wear. Because of their complex nature, major structural repairs that require professional advice are not addressed here.

### Repair Methods

Before any type of concrete repair is attempted, it is essential that all factors governing the deterioration or failure of the concrete structure are identified. This is required so that the appropriate remedial measures can be undertaken in the repair design to help correct the problem and prevent it from occurring in the future. The following techniques require expert and experienced assistance for the best results. The particular method of repair will depend on the size of the job and the type of repair required.

1. The Dry-Pack Method: The dry-pack method can be used on small holes in new concrete which have a depth equal to or greater than the surface diameter. Preparation of a dry-pack mix typically consists of about 1 part portland cement and 2 1/2 parts sand to be mixed with water. You then add enough water to produce a mortar that will stick together. Once the desired consistency is reached, the mortar is ready to be packed into the hole using thin layers.
2. Concrete Replacement: Concrete replacement is required when one-half to one square foot areas or larger extend entirely through the concrete sections or where the depth of damaged concrete exceeds 6 inches. When this occurs, normal concrete placement methods should be used. Repair will be more

effective if tied in with existing reinforcing steel (rebar). This type of repair will require the assistance of a professional engineer experienced in concrete construction.

3. Replacement of Unformed Concrete: The replacement of damaged or deteriorated areas in horizontal slabs involves no special procedures other than those used in good construction practices for placement of new slabs. Repair work can be bonded to old concrete by use of a bond coat made of equal amounts of sand and cement. It should have the consistency of whipped cream and should be applied immediately ahead of concrete placement so that it will not set or dry out. Latex emulsions with portland cement and epoxy resins are also used as bonding coats.

4. Preplaced Aggregate Concrete: This special commercial technique has been used for massive repairs, particularly for underwater repairs of piers and abutments. The process consists of the following procedures: 1) Removing the deteriorated concrete, 2) forming the sections to be repaired, 3) prepacking the repair area with coarse aggregate, and 4) pressure grouting the voids between the aggregate particles with a cement or sand-cement mortar.

5. Synthetic Patches: One of the most recent developments in concrete repair has been the use of synthetic materials for bonding and patching. Epoxy-resin compounds are used extensively because of their high bonding properties and great strength. In applying epoxy-resin patching mortars, a bonding coat of the epoxy resin is thoroughly brushed onto the base of the old concrete. The mortar is then immediately applied and troweled to the elevation of the surrounding material.

6. Crack Repair: Two main objectives when repairing cracks are structural bonding and

stopping water flow. Epoxy can be injected into non active cracks to form a structural bond. To seal active cracks from moisture a urethane sealant can be used, but does not form a structural bond. A minimum of ¼ inch opening to the crack is recommended to effectively fill a crack with sealant or an epoxy.

Before attempting to repair a deteriorated concrete surface, all unsound concrete should be removed by sawing or chipping and the patch area thoroughly cleaned. A sawed edge is superior to a chipped edge, and sawing is generally less costly than mechanical chipping. Before concrete is ordered for placing, adequate inspection should be performed to ensure that (1) foundations are properly prepared and ready to receive the concrete, (2) construction joints are clean and free from defective concrete, (3) forms are grout-tight, amply strong, and set to their true alignment and grade, (4) all reinforcement steel and embedded parts are clean, in their correct position, and securely held in place, (5) adequate concrete delivery equipment and facilities are on the job, ready to go, and (6) any cold weather precautions have been taken and planned for to prevent concrete freezing.

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# Dam Safety- Fact Sheet

Montana Watercourse and Montana Department of Natural Resources and Conservation  
Water Resources Division



## Problems with Metal Materials

Fact Sheet: 13

Some examples of metal materials used in dams include: ductile iron, smooth steel, and corrugated metal. Corrugated metal pipe is not recommended for use in dams since the service life for corrugated metal is only 25 to 30 years, whereas the life expectancy for dams is much longer.

Corrosion is a common problem for spillway conduits and other metal appurtenances. Corrosion is the deterioration or breakdown of metal because of a reaction with its environment. Exposure to moisture, acidic soils, or salt will accelerate the corrosion process. Soils that are typically associated with increased corrosion are clays, silts, or other poorly draining materials.

In areas with aggressive water such as, acid runoff from a strip-mined area, rapid corrosion of metal conduits can occur. In these areas, conduits made of less corrodible materials such as concrete or plastic should be used. Due to these destructive effects on corrugated metal conduits, they typically need to be repaired or replaced early in the dam's design life, which can be very expensive.

Conduit coating is an effective way of controlling corrosion of metal conduits if used properly. It is relatively inexpensive and extends the life of the conduit. Some examples of coatings include cement-mortar, epoxy, aluminum, or polyethylene film. Asphalt (bituminous) coatings are not recommended since their service life is usually only one or two years. Coatings must be applied to the conduit prior to installation and protected to ensure that the coating is not scratched off. Coatings applied to conduits in

service are generally not very effective because of the difficulty in establishing an adequate bond.



Severely damaged corrugated metal pipe, due to corrosion.

Corrosion can also be controlled or arrested by installing cathodic protection. A metallic anode such as magnesium (or zinc) is buried in the soil and is connected to the metal conduit by wire. Natural voltage current flowing from the magnesium (anode) to the conduit (cathode) will cause the magnesium to corrode and not the conduit. However, sufficient maintenance funds should be allocated for the regular inspection of this active system.

If corrosion is allowed to continue, metal conduits will rust out. The spillway must be repaired before water flows through the rusted out portion of the conduit and erodes the fill material of the embankment. Continued erosion can lead to failure of the dam. Sliplining can be an economical and effective method of permanently restoring

deteriorated spillways. During sliplining, a smaller diameter pipe is inserted into the old spillway conduit and then grout is used to fill in the void between the two pipes. If sliplining the spillway is not feasible, the reservoir may need to be drained and a new spillway must be installed. A registered professional engineer must be retained to develop and submit plans and specifications for any major modifications such as spillway sliplining or replacement.

Corrosion of the metal parts of the operating mechanisms such as lake drain, valves and sluice gates can be effectively treated by keeping these parts lubricated and/or painted. If the device has not been operated in several years, a qualified person (i.e. manufacturer's representative or registered professional engineer) should inspect it to determine its operability. Caution must be used to prevent the mechanism from breaking. A registered professional engineer may be needed to prepare plans and specifications for repair if the device is determined to be inoperable.

Regular inspection and monitoring is essential to detect any problems with metal materials. Coatings on metal pipes should be inspected for scratched and worn areas. The inspector should also look for corrosion inside the spillway conduit. Proper ventilation and confined space precautions must be considered when entering the spillway conduit system. If using cathodic protection, regular inspections are required to verify that the system is working properly. It is important to keep written records of the amount of surface rust, pitting, and corrosion on any metal surface. Areas of thin metal should be monitored more frequently and repaired or replaced if they rust out. Photographs provide invaluable records of changing conditions. A rapidly changing condition may indicate a very serious

problem, and the Dam Safety Engineering Program should be contacted immediately. All records should be kept in the operation, maintenance, and inspection manual for the dam.



Aging metal culvert, with bulging seams and some corrosion on the bottom of the pipe.



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# Dam Safety- Fact Sheet

Montana Watercourse and Montana Department of Natural Resources and Conservation  
Water Resources Division



## Trashracks

Fact Sheet: 14

Keeping the principal spillway clear and function properly is an important part of maintaining the overall safety of the dam. Pipe and riser, drop inlet, and slant pipe spillways are susceptible to obstruction and damage by floating debris such as leaves, branches, and logs. One device used to ensure that these spillways operate correctly is a trashrack. Trashracks are designed to keep trash and other debris from entering the spillway and causing damage.

### Common Problems

Trashracks usually become plugged because the openings are too small or the head loss at the inlet causes material and sediment to settle out and accumulate. Small openings will cause debris such as twigs and leaves to accumulate on the trashrack bars. This buildup will cause progressively larger debris to accumulate against the trashrack bars. Ultimately, this will result in the complete blockage of the spillway inlet. Pipe and riser spillways can also become blocked by a build up of debris in the spillway. This type of blockage occurs when no trashrack is in place, or if the openings are too large. In many spillway systems, the size of the outlet conduit is smaller than the size of the inlet. Therefore, it is incorrect to assume that debris which passes through the inlet will not obstruct the flow through the outlet. Large debris, such as logs and tree limbs, can become lodged in the transitions in the spillway. This reduces the capacity of the spillway and could cause damage. An obstructed outlet pipe can be a major problem because removal of large debris from inside the spillway can be very difficult. A partially blocked spillway reduces the capacity of the

spillway and may also create a higher than normal pool level. The combination of these two factors can dramatically reduce the discharge/storage capacity of the dam. A reduction in the discharge/storage capacity of a dam increases the likelihood that the dam will be overtopped during a severe storm event. Overtopping for even a short period of time can cause damage to the embankment and possible failure of the dam. If the dam has an emergency spillway, a blocked principal spillway will cause more frequent flows in the emergency spillway. Since emergency spillways are usually grass lined channels designed for infrequent flows of short duration, serious damage is likely to result.

### Trashrack Design

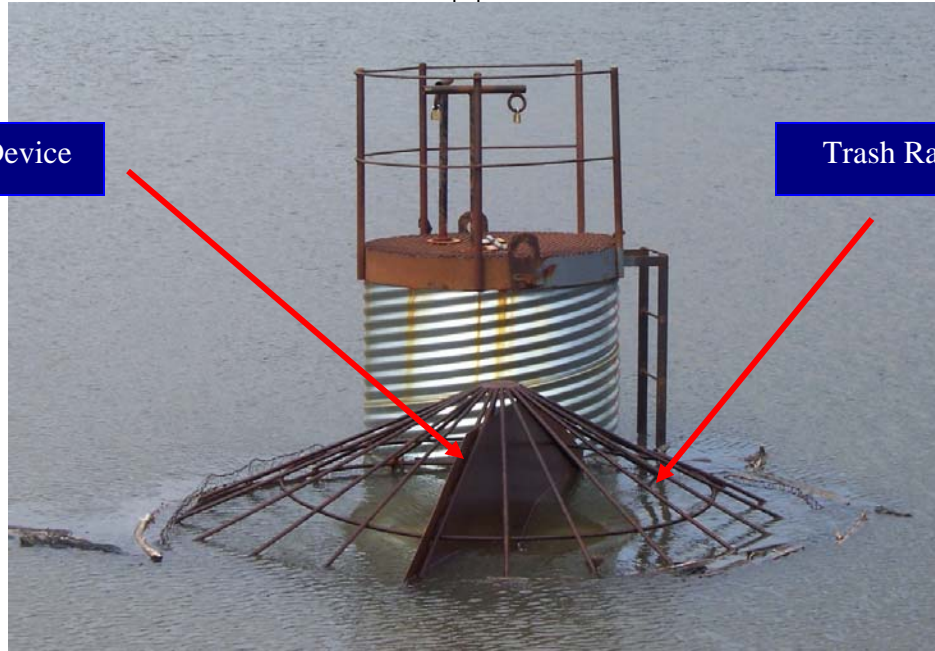
A well-designed trashrack will stop large debris that could plug the conduit but allow unrestricted passage of water and smaller debris. The larger the outlet conduit, the larger the trashrack opening should be. In the design of a trashrack the openings should be sized so that they measure one-half the nominal dimension of the outlet conduit. For example, if the outlet pipe is 18 inches in diameter, the trashrack openings should be the effective equivalent of 9 inches by 9 inches. This rule applies up to a maximum trashrack opening of two feet by two feet. For an outlet conduit with a nominal dimension of 12 inches or less, the trashrack openings should be at least 6 inches by 6 inches. This prevents large debris from passing through the inlet and blocking the outlet conduit while allowing smaller debris (leaves, sticks, etc.) to flush through the spillway system. Another important design criteria is that the trashrack

should be securely fastened to the inlet. The connection must be strong enough to withstand the hydrostatic and dynamic forces exerted on the trashrack during periods of high flow.

### Anti-vortex devices

An anti-vortex device can easily be incorporated into most trashrack designs. A common anti-vortex device is a flat metal plate which is placed on edge and attached to the inlet of the spillway.

Anti-vortex Device



Trash Rack

### Fish Protection

Many owners are concerned about losing fish through trashracks that have large openings. If this is a concern, a metal plate surrounding the riser or drop inlet which extends above and below the normal pool level should be installed. On the bottom of the plate, a metal screen should be attached and connected to the riser pipe. The solid plate at the water level will prevent the fish and floating debris from passing over the crest of the riser. The underwater screen will keep the fish from moving under the metal plate and through the spillway. The underwater screen will not become blocked because most of the debris floats on the water surface. If this design is used, the area between the inside of the cylinder and the outside of the riser must be equal to or greater than the area inside the riser.

The capacity of the spillway will be increased by equipping the trashrack with an anti-vortex plate. The anti-vortex plate increases capacity by preventing the formation of a flow-inhibiting vortex during periods of high flow.

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# Dam Safety- Fact Sheet

Montana Watercourse and Montana Department of Natural Resources and Conservation  
Water Resources Division



## Inspection of Structures

Fact Sheet: 15

Routine inspection and maintenance are important to keep a dam functioning safely. The owner should inspect a dam and its structures at least annually. This fact sheet is intended to give the owner advice on how to better inspect all dam structures and to better address any problems that may be observed.

Before starting any inspection a detailed checklist of all the spillways and/or outlet works of the dam should be created. A consistent checklist will help establish a picture of how the structures are behaving over time. A rapidly changing situation may indicate a serious problem. See Dam Fact Sheet # 2 for what to bring on an inspection.

The regional DNRC dam safety engineer should be contacted if there are any questions of the seriousness of the observation.

### Concrete Structures

#### What to Look For:

- Cracking
- Rust stains
- Seepage under concrete or through joints and cracks
- Efflorescence
- Function of weep holes and under drains
- Displacement of concrete slabs
- Sedimentation or blockage of conduits and basins

#### What to Record:

In the inspection of concrete structures the inspector should note all structural cracks. The width of large cracks should be recorded and scheduled for repair. Any seepage from

cracks or joints in concrete should be noted along with the cloudiness of water. Cloudy water could indicate erosion of the bedding or fill around and under the concrete spillways or conduits.



Using a hammer to tap the concrete will indicate any voids behind a slab that have occurred. If the soil surrounding a concrete structure is eroding away through seepage or improper drainage then the slabs may shift. Any displacement that this causes should be measured and closely watched to prevent major failure and costly repairs (See Dam Fact Sheet # 11).

### Metal Structures

#### What to Look For:

- Corrosion
- Operation of valves and sluice gates
- Condition of coatings
- Operation of cathodic protection
- Deformation
- Proper alignment
- Structural integrity of joints or seams
- Seepage.

What to Record:

Metal structures such as corrugated metal pipe typically have a service life of 25 years and are sensitive to deterioration due to moisture, acidic conditions, and salt. When inspecting metal structures any rusting or damaged coatings should be noted and photographed. Note any operation of valves or other moving parts in the dam, to establish if it is working properly. Inspect any cathodic protection system to guarantee the active system is still functioning. See Fact Sheet #13 for more descriptions of problems with metal materials.

Proper ventilation and confined space precautions must be considered when entering any spillway conduit system.



**Plastic Outlets**

What to Look For:

- Proper alignment
- Deformation
- Blockages
- Ultraviolet damage

What to Record:

When inspecting plastic outlets the inspector should be aware of any deformation or displacement of the pipe from its original position and shape. Also inspect the plastic pipe for any cracking or clogging on the inside of the pipe. Verify that all joints are still aligned and waterproof. Leaking joints will undermine the bedding of a plastic pipe. This may severely damage the pipe since structural integrity of the pipe is highly dependent on even bedding. Also record any seepage around the pipe.



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# Dam Safety- Fact Sheet

Montana Watercourse and Montana Department of Natural Resources and Conservation  
Water Resources Division



## Lake Drains/Low Level Outlets

Fact Sheet: 16

A lake drain or low level outlet is a mechanism to lower the water level of the reservoir below the normal water level. This has advantages to operating and maintaining a dam.

### Types of Drains

Common types of drains include the following:

- A valve located in the spillway riser
- A conduit through the dam with a valve at either the upstream or downstream end of the conduit
- A siphon system (often used to retrofit existing dams)
- A gate, valve or stoplogs located in a drain control tower

### Uses of Drains

The following situations make up the primary uses of lake drains:

Emergencies: Should serious problems ever occur to threaten the immediate safety of the dam, drains may be used to lower the lake level to reduce the likelihood of dam failure. Examples of such emergencies are as follows: clogging of the principal spillway which may lead to high lake levels and eventual dam overtopping, development of slides or cracks in the dam, severe seepage through the dam which may lead to a piping failure of the dam, and partial or total collapse of the spillway system.

Maintenance: Some repair items around the lake and dam can only be completed or are much easier to perform with a lower than normal lake level. Some examples are: slope protection repair, spillway repairs, repair

and/or installation of docks and other structures along the shoreline, and dredging the lake.

Winter Drawdown: Some dam owners prefer to lower the lake level during the winter months to reduce ice damage to structures along the shoreline and to provide additional flood storage for upcoming spring rains. Several repair items are often performed during this winter drawdown period. Periodic fluctuations in the lake level also discourage muskrat and beaver habitation along the shoreline (See Dam Fact Sheet #4).

### Common Maintenance Problems

Common problems often associated with the maintenance and operation of lake drains includes the following:

- Deteriorated and bent control stems and stem guides
- Deteriorated and separated conduit joints
- Leaky and rusted control valves and sluice gates
- Deteriorated ladders in control towers
- Deteriorated control towers
- Clogging of the drain conduit inlet with sediment and debris
- Inaccessibility of the control mechanism to operate the drain
- Seepage along the drain conduit
- Erosion and undermining of the conduit discharge area because the conduit outlets are significantly above the elevation of the streambed
- Vandalism
- Development of slides along the upstream slope of the dam and the shoreline caused by lowering the lake level too quickly

### **Operation and Maintenance Tips**

A. All gates, valves, stems and other mechanisms should be lubricated according to the manufacturer's specifications. A local valve distributor may also be able to provide assistance with valve care.

B. The lake drain should be operated at least twice a year to prevent the inlet from clogging with sediment and debris, and to keep all movable parts working easily.

Most manufacturers recommend that gates and valves be operated at least four times per year. Frequent operation will help to ensure that the drain will be operable when it is needed. All valves and gates should be fully opened and closed at least twice to help flush out debris and to obtain a proper seal. If the gate gets stuck in a partially opened position, gradually work the gate in each direction until it becomes fully operational. Do not apply excessive torque as this could bend or break the control stem, or damage the valve or gate seat. With the drain fully open, inspect the outlet area for flow amounts, leaks, erosion and anything unusual.

C. All visible portions of the lake drain system should be inspected at least annually, preferably during the periodic operation of the drain. Look for and make note of any cracks, rusted and deteriorated parts, leaks, bent control stems, separated conduit joints or unusual observations.

D. A properly designed lake drain should include a headwall near the outlet of the drain conduit to prevent undermining of the conduit during periods of flow. A headwall can be easily retro-fitted to an existing conduit if undermining is a problem at an existing dam. A properly designed layer of rock riprap or other slope protection will help reduce erosion in the lake drain outlet area.

E. Drain control valves and gates should always be placed upstream of the centerline of the dam. This allows the drain conduit to remain depressurized except during use, therefore reducing the likelihood of seepage through the conduit joints and saturation of the surrounding earth fill.

F. For accessibility ease, the drain control platform should be located on shore or be provided with a bridge or other structure. This becomes very important during emergency situations if high pool levels exist.

G. Vandalism can be a problem at any dam. If a lake drain is operated by a crank, wheel or other similar mechanism, locking with a chain or other device, or removing the mechanism for off-site storage may be beneficial. Fences or other such installations may also help to ward off vandals.

H. The recommended rate of lake drawdown is one foot or less per week, except in emergencies. Fast drawdown causes a build-up of hydrostatic pressures in the upstream slope of the dam which can lead to slope failure. Lowering the water level slowly allows these pressures to dissipate.

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# Dam Safety- Fact Sheet

Montana Watercourse and Montana Department of Natural Resources and Conservation  
Water Resources Division

## Outlet Erosion Control

Fact Sheet: 17



Erosion caused by the outlet of fast moving water can become a big problem without a proper guard against erosion. Failure to properly design, install, or maintain a stilling basin could lead to problems such as undermining of the spillway and erosion of the outlet channel and/or embankment material. These problems can lead to failure of the spillway and ultimately the dam. A stilling basin provides a means to absorb or dissipate the energy from the spillway discharge and protects the spillway area from erosion and undermining. An outlet erosion control structure such as a headwall/endwall, impact basin, United States Department of the Interior, Bureau of Reclamation Type II or Type III basin, baffled chute, or plunge pool is considered an energy dissipating device. The performance of these structures can be affected by the tailwater elevation. The tailwater elevation is the elevation of the water that is flowing through the natural stream channel downstream during various flow conditions. A headwall/endwall, impact basin, Type II or Type III basin, and baffled chute are all constructed of concrete. Concrete structures can develop surface and structural defects that can threaten the function of the control structure (See Fact Sheet # 11).



Concrete Headwall

### Headwall/Endwall

A headwall/endwall located at or close to the end of the discharge conduit will provide support and reduce the potential for undermining. A headwall/endwall is typically constructed of concrete, and it should be founded on bedrock or have an adequate foundation footing to provide support for stability. A headwall/endwall can become displaced if it is not adequately designed and is subject to undermining. Displacement of the headwall/endwall can lead to separation of the spillway conduit at the joints which could affect the integrity of the spillway conduit. If a concrete structure develops the structural defects, or if the discharge spillway conduit does not have a headwall/endwall, then a registered professional engineer should be contacted to evaluate the stability of the outlet.



Impact Basin

### Impact Basin

A concrete impact basin is an energy dissipating device located at the outlet of the spillway in which flow from the discharge conduit strikes a vertical hanging baffle. Discharge is directed upstream in vertical eddies by the horizontal portion of the baffle and by the floor before flowing over the endsill. Energy dissipation occurs as the discharge strikes the baffle, thus, performance

is not dependent on tailwater.

**U.S. Department of Interior, Bureau of Reclamation Type II and Type III Basins.**

Type II and Type III basins reduce the energy of the flow discharging from the outlet of a spillway, and allow the water to exit into the outlet channel at a reduced velocity. Type II energy dissipators contain chute blocks at the upstream end of the basin and a dentated (tooth-like) endsill. Baffle piers are not used in a Type II basin because of the high velocity water entering the basin.



Baffled Chute

**Baffled Chute**

Baffled chutes require no initial tailwater to be effective and are located downstream of the control section. Multiple rows of baffle piers on the chute prevent excessive acceleration of the flow and prevent the damage that occurs from a high discharge velocity. A portion of the baffled chute usually extends below the streambed elevation to prevent undermining of the chute. If any of the severe problems associated with concrete that are referenced in the opening paragraphs are observed, a registered professional engineer should be contacted to evaluate the stability of the outlet.

**Plunge Pool**

A plunge pool dissipates energy as the discharge flows into the plunge pool. Plunge pools are commonly lined with rock riprap or other material to prevent excessive erosion of the pool area. Discharge from the plunge pool should be at the natural streambed elevation. Typical problems may include movement of the riprap, loss of fines from the bedding material and scour beyond the riprap and lining. If scour beneath the outlet conduit develops, the conduit will be left unsupported and separation of the conduit joints and undermining may occur. Separation of the conduit joints and undermining may lead to failure of the spillway and ultimately the dam. A registered professional engineer should be contacted to ensure that the plunge pool is designed properly.



Plunge Basin

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# Dam Safety- Fact Sheet

Montana Watercourse and Montana Department of Natural Resources and Conservation  
Water Resources Division



## Concrete Spillways

Fact Sheet: 18

Concrete chutes and weirs are used for principal spillways and emergency spillways. The principal spillway is used to pass normal flows, and the emergency spillway provides additional flow capacity during large flood events. If the principal spillway for a dam is a concrete weir and/or chute, the flow capacity may be large enough that an emergency spillway is not needed. Unlike grass-lined channel spillways that should always be located on natural ground, a concrete weir or chute may be located on the dam, but must be properly designed so that the integrity of the dam is not endangered.

The main components of a concrete chute spillway are the inlet structure, control section, discharge channel, and outlet erosion control structure. The inlet structure conveys water to the control section. The control section is the highest point in the channel and regulates the outflow from the reservoir. It is usually located on or near the crest of the dam. The control section may consist of a concrete weir or may simply be the most elevated slab in the floor of the chute. The discharge channel is located downstream of the control section and conveys flow to the outlet erosion control structure. This structure is designed to dissipate most of the erosive energy of the flow before it enters the downstream channel.

### Overall Design and Safety Consideration

#### Alignment

For good hydraulic performance, abrupt changes should be avoided. This applies to sudden changes in vertical elevation of the chute floor, abrupt widening or narrowing of

the chute, and sharp turns in the chute. Anything that will abruptly disrupt or change the direction of the flow in the chute will reduce flow capacity and will place more stress on the concrete. The best performance is obtained when the distribution of flow is even across the channel.

#### Settlement and Movement

Abnormal settlement, heaving, deflections, and lateral movement of the sidewalls or floor slabs of the spillway can occur. Movements are usually caused by a loss of underlying material, excessive settlement of the fill, or the buildup of water pressure behind or under the structure. Any abnormal settlement, heaving, deflections or lateral movement in the concrete spillway should be immediately investigated by a registered professional engineer knowledgeable about dam safety. As necessary, plans and specifications for repair to the spillway should also be promptly developed and implemented by a registered professional engineer. The concrete sidewalls and floor of the chute must have enough strength to withstand water loads, soil/fill loads, uplift forces, weathering, and abrasion. The forces of weathering, movement of abrasive materials by water flowing in the spillway, or cavitation may cause surface defects or more serious concrete deterioration. The freeze thaw cycle is the most damaging weathering force acting on exposed concrete. The concrete's durability and resistance to weathering and deterioration will be determined by the concrete mix, age of the concrete, and proper sealing of the joints (See Fact Sheet # 11).

### **Cutoff Wall and Endwall**

A cutoff wall should be placed at the entrance to the concrete chute to prevent the flow approaching and entering the chute from flowing beneath and undermining the floor slabs. Undermining of the chute can cause cracking and collapse of the slabs as the underlying material is eroded away. In addition, a cutoff wall is necessary at the downstream end of the chute in order to prevent undermining by flows exiting the chute and entering the downstream channel. The cutoff wall or endwall should be founded on bedrock or have adequate support to provide stability and prevent undermining of the wall itself. Refer to Outlet Erosion Control Fact Sheet #18 for further discussion on erosion control.

### **Underdrainage and Weep Holes**

Weep holes, relief drains and underdrains must be included with the concrete chute to relieve excessive water pressure or infiltration from behind the walls and floor. The drainage system for the chute should consist of correctly placed and sized drainage holes, perforated pipes, and filter and bedding materials, such as sand and gravel. Seepage can occur through the dam, along the contact between the embankment and the concrete chute, or through open joints and cracks. Uncontrolled seepage flow along the structure can erode the underlying fill material (undermining) which may cause cracking or buckling of the slabs. Excessive pressure behind the walls and floor of the chute can cause cracking and heaving of the concrete. The freeze-thaw cycle can increase the amount of stress and strain on the concrete and can also cause heaving, cracking and additional serious damage to the structure. Weep holes, relief drains, and underdrainage for a concrete chute spillway should be designed by a registered professional engineer.



Concrete spillway on embankment of dam.

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# Dam Safety- Fact Sheet

Montana Watercourse and Montana Department of Natural Resources and Conservation  
Water Resources Division



## Earthen Spillways

Fact Sheet: 19

Open channels are often used as the emergency spillway and sometimes as the principal spillway for dams. A principal spillway is used to pass normal inflows, and an emergency spillway is designed to operate only during large flood events, usually after the capacity of the principal spillway has been exceeded. For dams with pipe conduit principal spillways, an open channel emergency spillway is almost always required as a backup in case the pipe becomes clogged. Open channels are usually located in natural ground adjacent to the dam and can be vegetated, rocklined, or cut in rock. The low cost and ease of construction make the earthen spillway the most common type of spillway for small dams.

### Design

Flow through an emergency spillway does not indicate a problem with the dam, but high velocity flows can cause severe erosion and result in a permanently lowered lake level if not repaired. Proper design of an open channel spillway will include provisions for minimizing any potential erosion. One way to minimize erosion is to design a flatter channel slope to reduce the velocity of the flow. Earthen channels can be protected by a good grass cover, an appropriately designed rock cover, concrete or various types of erosion control matting or rock grade control structures. Rock-lined channels must have adequately sized riprap to resist displacement and contain an appropriate geotextile fabric or granular filter beneath the rock. Guide berms are often required to divert flow through open channels away from the dam to prevent erosion of the embankment fill. If an open channel is used for a principal spillway, it

must be rock-lined or cut in rock due to more frequent or constant flows. All dams should have an emergency spillway that will pass high flows without damage to the dam structure. Sizing of the spillway should be done by a professional engineer.

### Maintenance

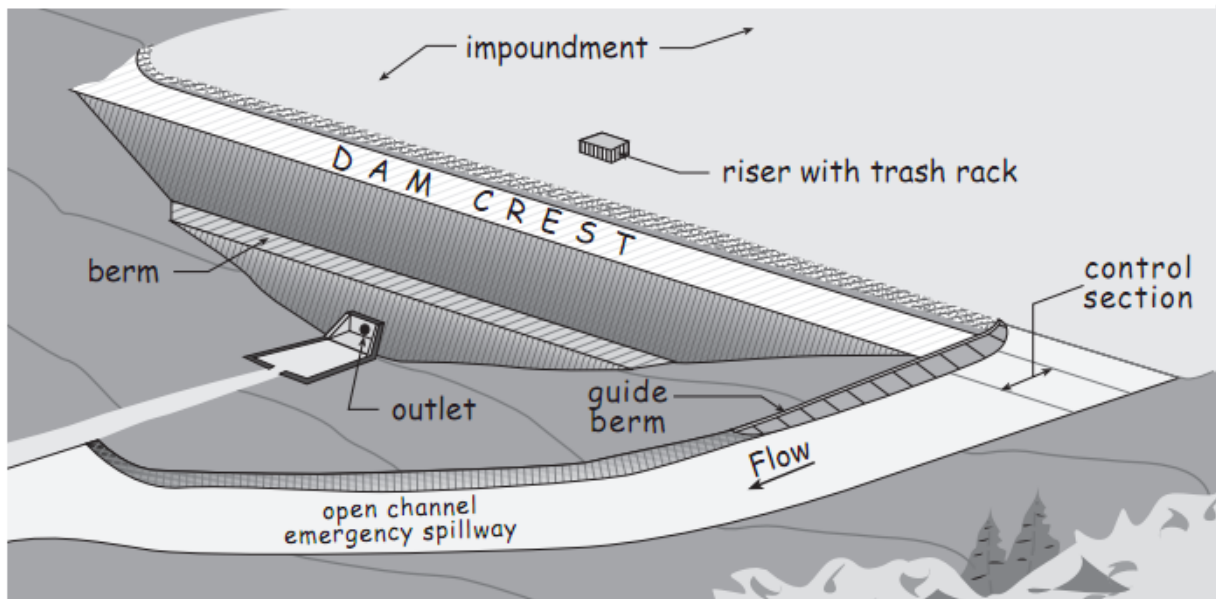
Maintenance should include, but not be limited to, the following items:

Grass-covered channels should be mowed at least twice per year to maintain a good grass cover and to prevent trees, brush and weeds from becoming established. Poor vegetal cover can result in extensive and rapid erosion when the spillway flows. Repairs can be costly. Reseeding and fertilization may be necessary to maintain a vigorous growth of grass (See Dam Fact Sheet #10).

Trees and brush must be removed from the control section of the spillway since they can reduce the discharge capacity of the spillway channel. This increases the lake level during large storm events which can lead to overtopping and failure of the dam. Trees and woody vegetation may be acceptable and enhance erosion protection in sections of the channel that are off the dam embankment and do not limit spillway capacity.

Erosion in the channel must be repaired quickly after it occurs. Erosion can be expected in the spillway channel during high flows, and can also occur as a result of rainfall and runoff, especially in areas of poor grass cover. Terraces or drainage channels may be necessary in large spillway channels where large amounts of rainfall and runoff

## Overview of an Open Channel Spillway



may concentrate and have high velocities.

Erosion of the side slopes may deposit material in the spillway channel, especially where the side slopes meet the channel bottom. In small spillways, this can significantly reduce the discharge capacity. This condition often occurs immediately after construction before vegetation becomes established. In these cases, it may be necessary to reshape the channel to provide the necessary capacity.

All obstructions should be kept out of the channel. Open channel spillways often are used for purposes other than passage of flood flows. Among these uses are reservoir access, parking lots, boat ramps, boat storage, pasture and cropland. Permanent structures (buildings, fences, etc.) should not be constructed in these spillways. If fences, bridges or other such structures are absolutely necessary, they should cross the spillway far enough upstream or downstream from the control section so that they do not interfere with the flow. The control sections geometry is what determines the amount of water that can flow through the spillway. Altering this geometry will most likely decrease the capacity of the spillway.

### Monitoring

Open channel spillways should be monitored for erosion, poor vegetal cover, growth of trees and brush, obstructions, and weathering and displacement of rock. Monitoring should take place on a regular basis and after large flood events. It is important to keep written records of observations. Photographs provide invaluable records of changing conditions. All records should be kept in the operation, maintenance, and inspection manual for the dam.

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