BC Dam Safety Pocketbook

A QUICK REFERENCE GUIDE

BRITISH COLUMBIA

Contents

Introduction

The BC Dam Safety Pocketbook was developed for dam owners, representatives, and staff as a reference guide when providing surveillance and maintenance inspections. If further detail is required for a deficiency assessment, please refer to the Inspection and Maintenance of Dams Guideline Manual provided on the Dam Safety Website. You may also contact your Dam Safety Officer responsible for the dam or region.

Funding for this project has been provided in part by the Governments of Canada and British Columbia under the Canadian Agricultural Partnership, a federal-provincial-territorial initiative. Opinions expressed in this document are those of the author and not necessarily those of the Government of Canada. The Government of Canada and its directors, agents, employees, or contractors will not be liable for any claims, damages, or losses of any kind whatsoever arising out of the use of, or reliance upon, this information.

Roles and Responsibilities

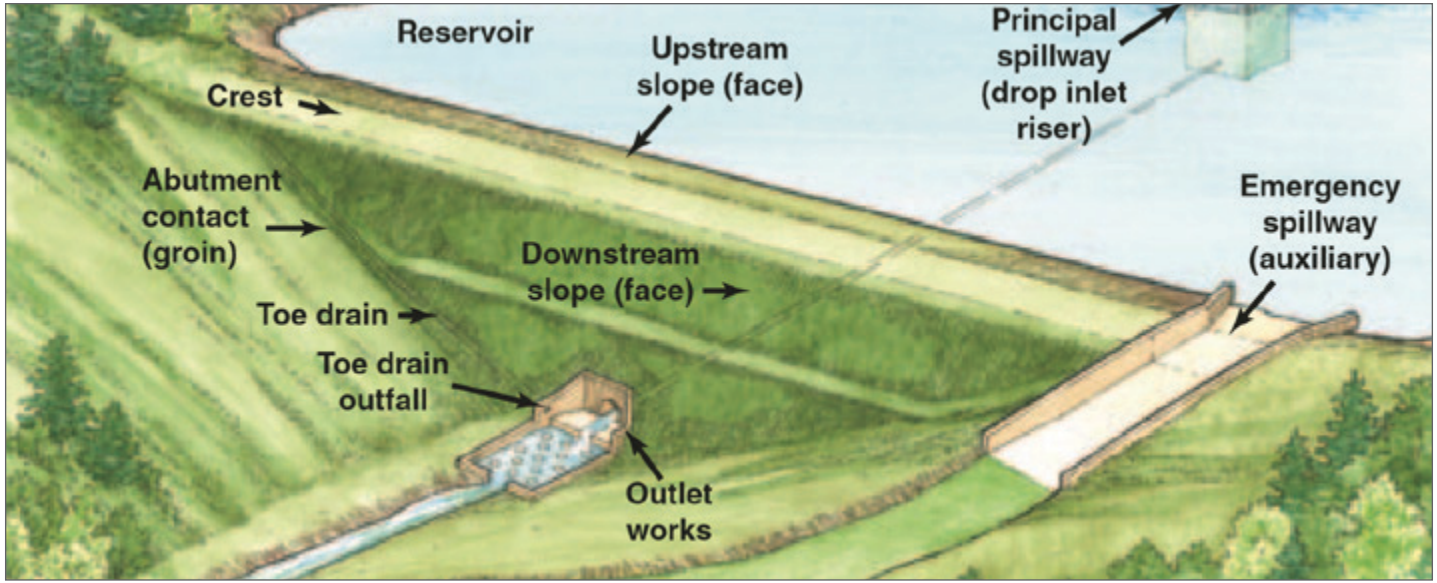
As stated in the Dam Safety Regulation, the owner of the dam is responsible for the operation and maintenance of a dam. This includes maintaining safety as a key aspect. By managing a proper and thorough dam safety system, the dam owner will prevent failures and limit potential liability held upon the owner in the event of a dam failure.

Owners may be held liable for any failure of a dam and all damages resulting from its failure. Any uncontrolled release of the reservoir from a dam failure may have a devastating impact on the individuals and property downstream.

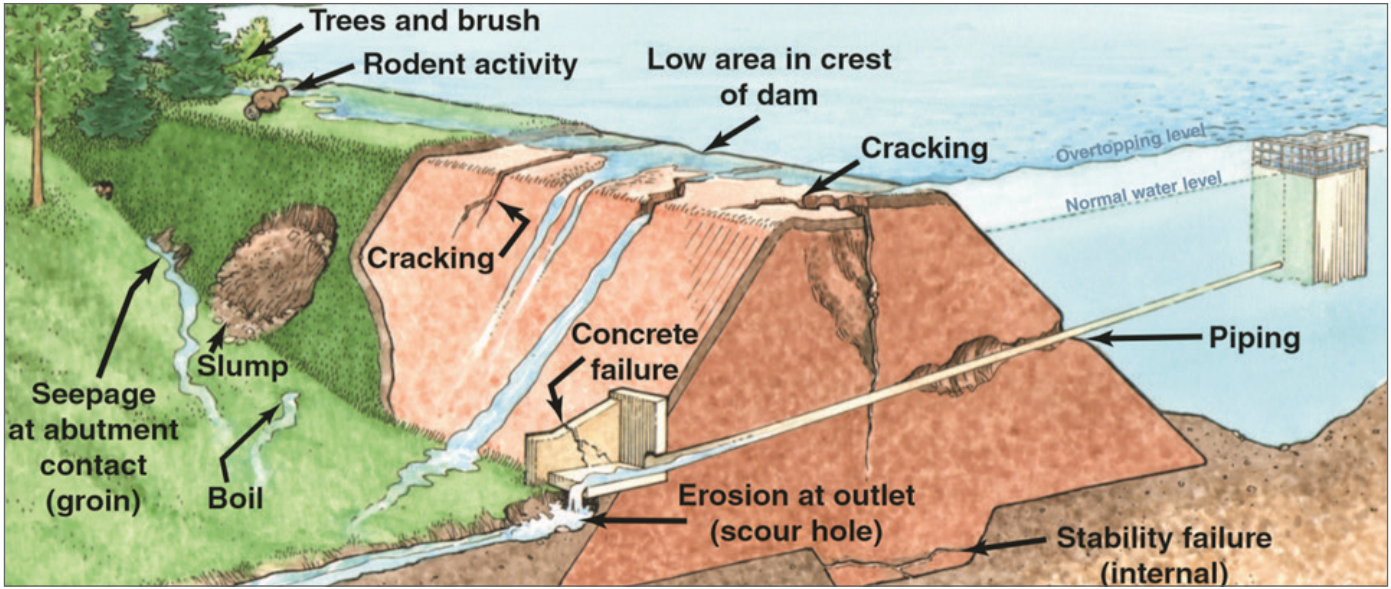
This guide is designed for a broad audience. The recommended actions taken by individuals will be determined by their expertise in dam safety. Inexperienced individuals should report any issues to the owner responsible for the dam or to the appropriate local emergency authority.

The content provided in this guide such as diagrams and descriptions, are inspired and influenced by the work from the USDA Forest Service Technology and Development Center, and the Association of State Dam Safety Officials.

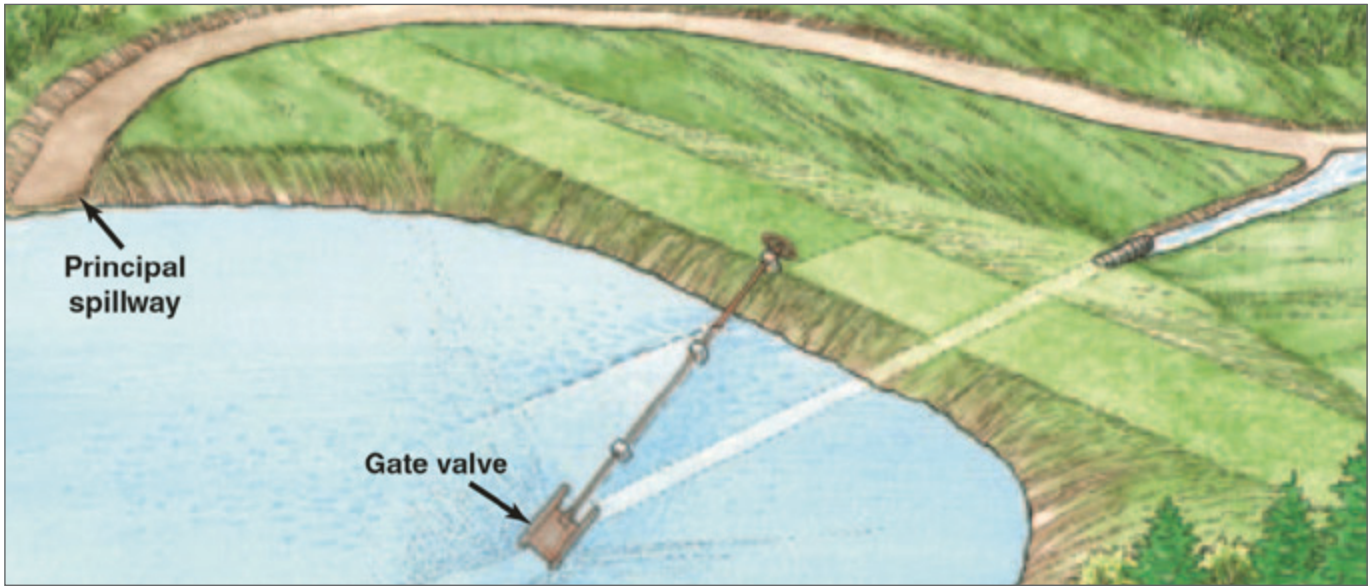
DAM DIAGRAM: *Typical Dam Diagram Showing Common Terminology*



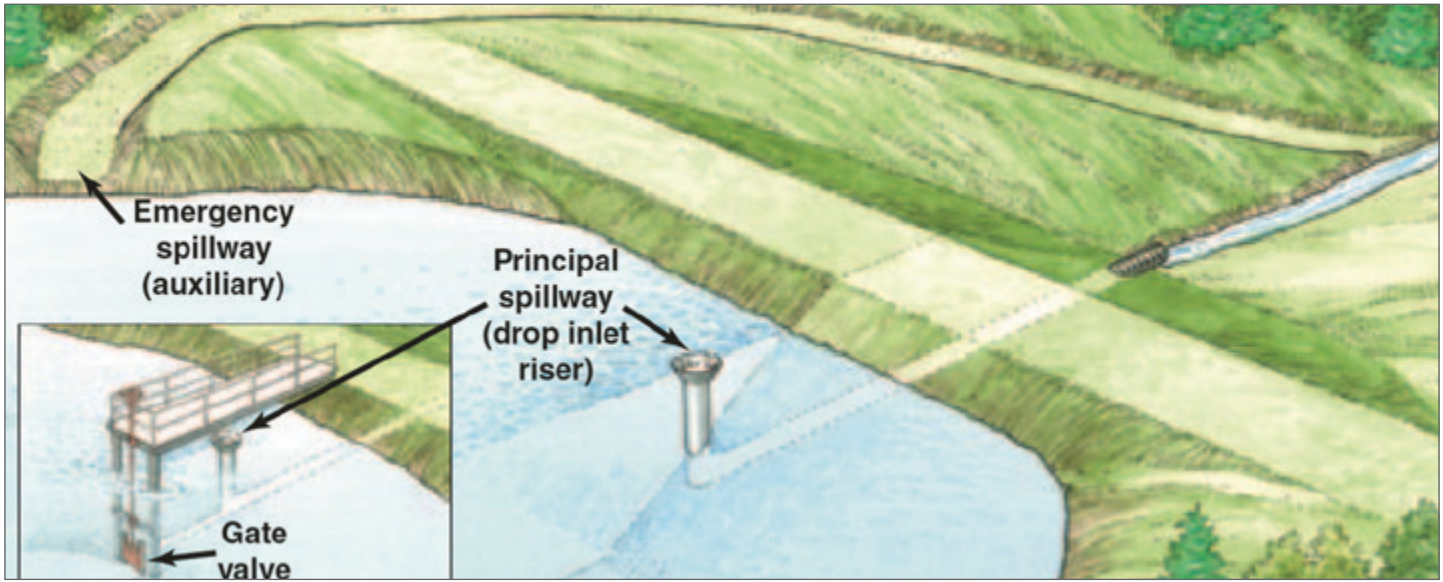
TYPICAL DAM FAILURES: *Various Causes of Dam Failures*



OUTLET STRUCTURES – GATE VALVE: *Typical Gate Valve Used with Spillway to Control Water Level*



DROP INLET RISER: *Typical Drop Inlet Riser Serving as a Spillway to Control Water Level*



Dam Deficiencies – Sinkholes

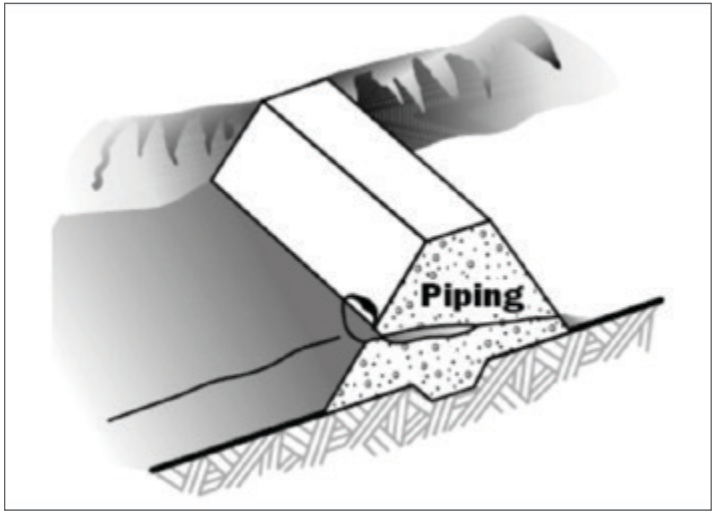
CAUSES AND CONSEQUENCES

- Internal erosion of the embankment materials or the piping can cause a sinkhole.
- An eroded cavern can result in a sinkhole.
- Water with sediment at the exit indicates erosion of the dam.
- Piping can empty a reservoir through a small hole in the wall. This can lead to dam failure as soil pipes develop and erode through the foundation or another part of the dam.

RECOMMENDED ACTION

- ***Report the suspected issue to dam owner or local authority immediately.***
- Inspect other parts of the dam which may be the cause of the seepage or sinkholes.
- Check seepage and leakage flow for dirty or muddy water.
- Have a qualified engineer inspect conditions, identify the probable cause of sinkholes, and recommend follow-up actions.
- Depending on the location of the sinkhole, have the reservoir drawn down as required.

Sinkholes



Whirlpools Indicate Advanced Piping Issue

Dam Deficiencies – Slides and Slumps

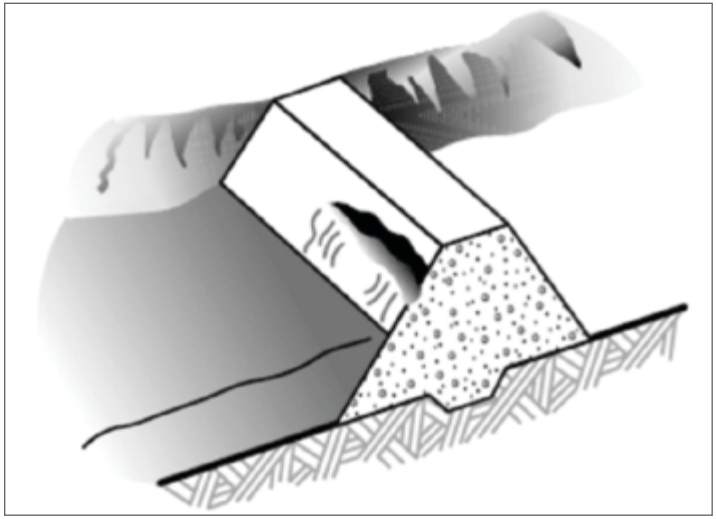
CAUSES AND CONSEQUENCES

- Foundation movement or a steep slope can cause earth and rocks to move along a plane, which can lead to a slump of the embankment.
- Slide movements in the reservoir basin can lead to inlet obstruction or a dam failure.

RECOMMENDED ACTION

- ***Report the suspected issue to dam owner or local authority immediately.***
- Evaluate the extent of the slide.
- Monitor the slide.
- Draw down the reservoir level if the safety of the dam is at risk.
- Have a qualified engineer inspect the conditions and recommend further actions if necessary.

Typical Slide or Slump



Slumping on the Downstream Face

Dam Deficiencies – Broken or Missing Riprap

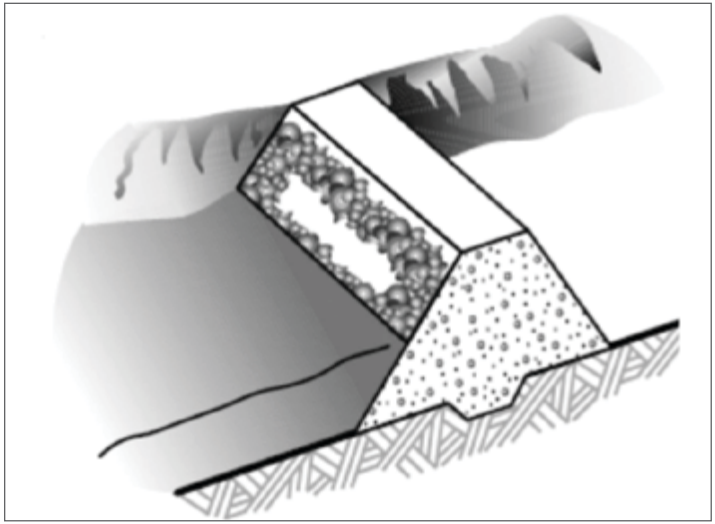
CAUSES AND CONSEQUENCES

- Poor quality of riprap deteriorates and does not protect the slope as intended.
- Wave or ice action can displace riprap which furthers erosion of the bank.
- Similar sized rocks may roll downhill and expose the slope.
- Wave action against unprotected areas can decrease the embankment width.

RECOMMENDED ACTION

- ***Report the suspected issue to dam owner or local authority immediately.***
- Re-establish the normal slope as required.
- Place bedding material and properly sized riprap to protect against wave or ice action.

Broken or Missing Riprap



Wave Erosion on an Unprotected Face of a Dam

Dam Deficiencies – Erosion

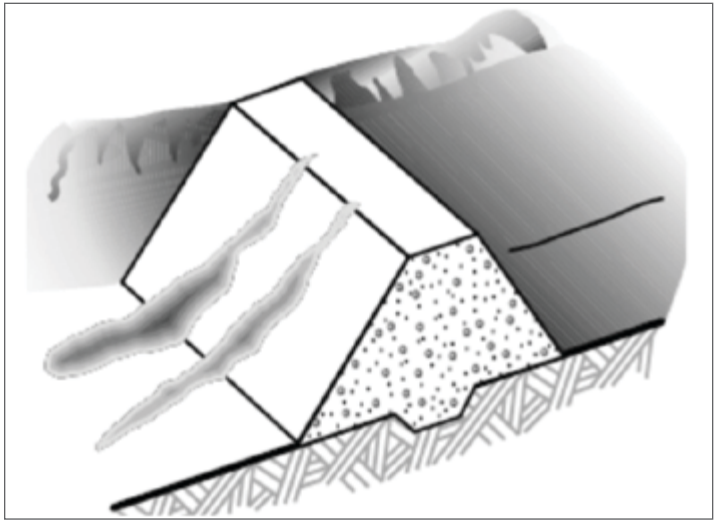
CAUSES AND CONSEQUENCES

- Water from intense rainstorms or snowmelt carries surface materials down the slope, which results in continuous troughs that can be hazardous to the dam if allowed to continue.
- Erosion can lead to deterioration of the downstream slope and failure of the dam.

RECOMMENDED ACTION

- ***Report the suspected issue to dam owner or local authority immediately.***
- If erosion is detected early, add protective grasses which may resolve the issue.
- Protect eroded areas by adding rock or riprap which is the typical solution.

Erosion



Erosion on the Downstream Face of the Dam

Dam Deficiencies – Trees and Vegetation

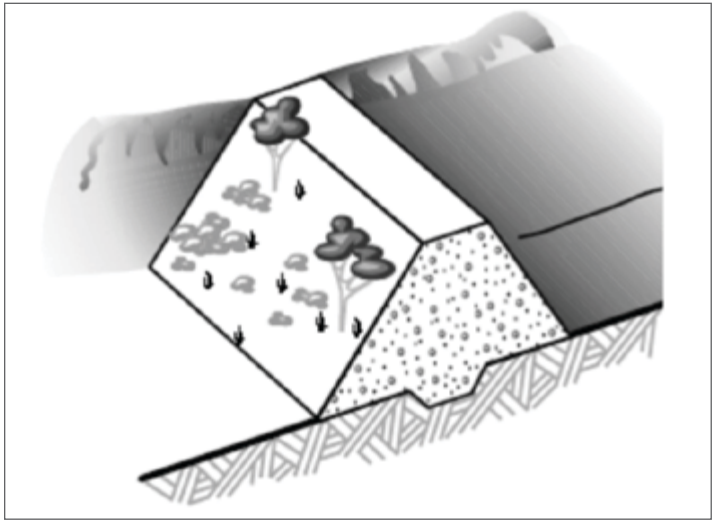
CAUSES AND CONSEQUENCES

- Natural vegetation such as bushes and weeds will obscure visual inspection and harbor rodents.
- Large tree roots can create seepage paths in and through the dam.
- Large trees can blow over during a storm and damage the dam, which may result in a breach.

RECOMMENDED ACTION

- Control vegetation that obscures any visual inspection of the embankment.
- Remove all large and deep-rooted trees / shrubs on or near the embankment.
- Backfill voids properly.
- Remove trees at the toe of the dam to provide a 25-foot buffer.

Trees and Obscuring Vegetation



Trees Growing on the Crest and Faces of the Dam

Dam Deficiencies – Rodent Activity and Animal Infestation

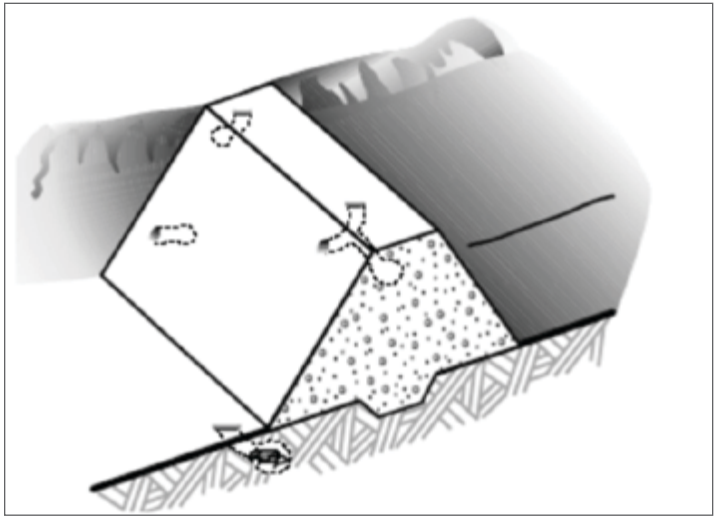
CAUSES AND CONSEQUENCES

- Cattail-filled areas and locations where trees are close to the reservoir provide ideal habitats and foraging areas for animals.
- An overabundance of rodents increases the chance of animal burrowing, which creates holes, tunnels, and caverns.
- These tunnels may reduce the required length of the seepage path, which may cause piping issues.
- Tunnels can lead to the collapse of the dam crest and may cause a dam failure.

RECOMMENDED ACTION

- Start a rodent control program and reduce the population to prevent future damage to the dam.
- Determine the exact location and extent of tunneling issues.
- Backfill existing rodent holes with suitable compacted material to repair any existing damages.

Rodent Activity



Rodent Holes on the Face of the Dam

Dam Deficiencies – Livestock and Cattle Traffic

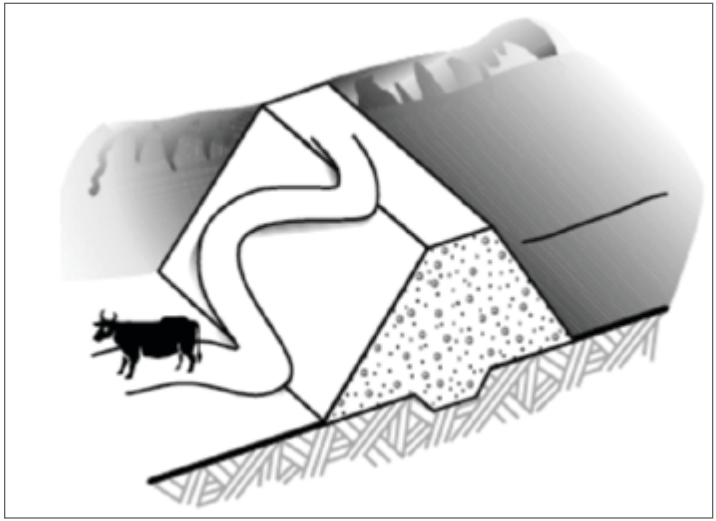
CAUSES AND CONSEQUENCES

- Livestock paths and activities on the crest or downstream dam face can damage surfaces, slopes, and other deficiencies – especially when wet.
- Livestock activities may reduce erosion protection and cause erosion channels.
- Bare areas may allow water to stand and be susceptible to drying cracks.

RECOMMENDED ACTION

- Fence the embankment areas to keep livestock from entering.
- Repair erosion protection by re-establishing grasses, material, or replacing riprap.

Livestock and Cattle Traffic



Livestock Paths and Erosion on a Face of a Dam

Dam Deficiencies – Transverse Cracking

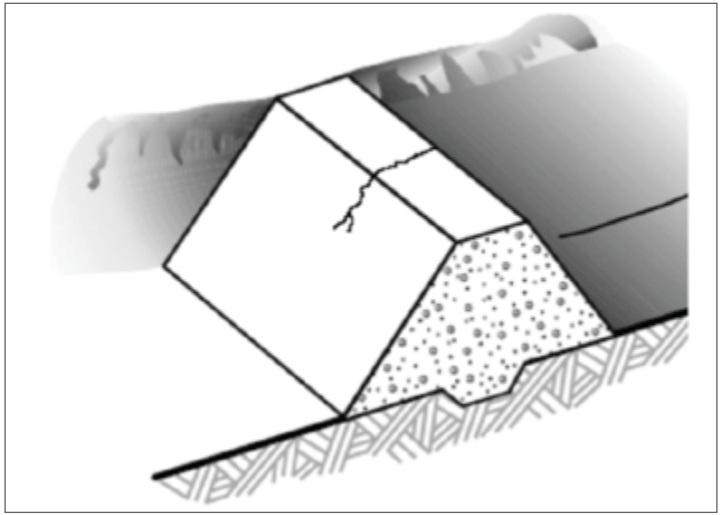
CAUSES AND CONSEQUENCES

- Uneven movement between adjacent segments of the embankment may cause transverse cracking.
- Deformation caused by structural stress or instability may provide a path for seepage.
- If unmanaged, cracking creates areas of low strength within embankment that may lead to structural movement, deformation, or failure.
- Cracks create a point for water to enter embankment.

RECOMMENDED ACTION

- ***Report the suspected issue to dam owner or local authority immediately.***
- Inspect the crack and record its location, measurements, and physical features.
- Stake out crack limits and monitor changes.
- Have a qualified engineer determine the cause of cracking and supervise all necessary steps to reduce danger and correct the dam condition.
- Excavate along the crack to a point below the bottom of the crack. Backfill using suitable material and correct construction techniques. This seals the cracks at the crest surface to prevent water infiltration.

Transverse Cracking



Transverse Cracks Indicate Dam Instability

Dam Deficiencies – Longitudinal Cracking

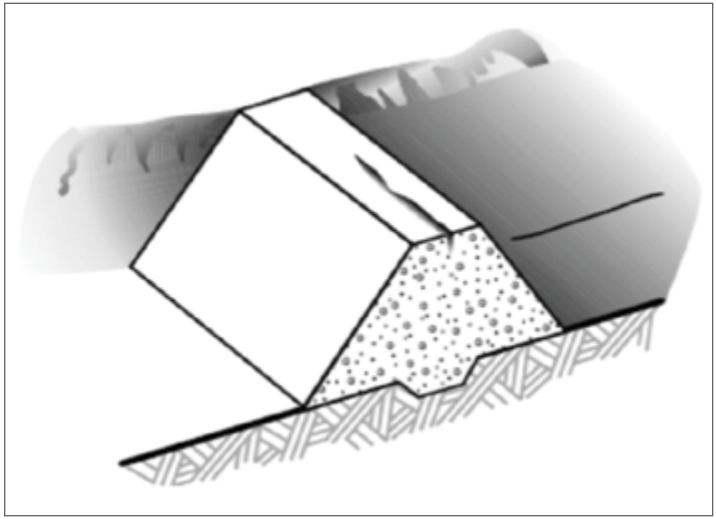
CAUSES AND CONSEQUENCES

- Uneven settlement between adjacent sections within the embankment may cause longitudinal cracking.
- Foundation failure causes loss of embankment support that may result in an embankment slide.
- Settlement creates an area of low strength which may cause structural movement, deformation, or failure.
- Cracks create a point for water to enter embankment.

RECOMMENDED ACTION

- ***Report the suspected issue to dam owner or local authority immediately.***
- Inspect the crack and record the location, measurements, and other physical features.
- Stake out crack limits and monitor frequently.
- Have a qualified engineer determine the cause of cracking and supervise the necessary steps to reduce danger of the dam and correct the condition.
- Seal all cracks at crest surface to prevent water infiltration.
- Monitor crest routinely for further cracking.

Longitudinal Cracking



Longitudinal Cracks Indicate Dam Instability

Dam Deficiencies – Low Area in the Crest of Dam

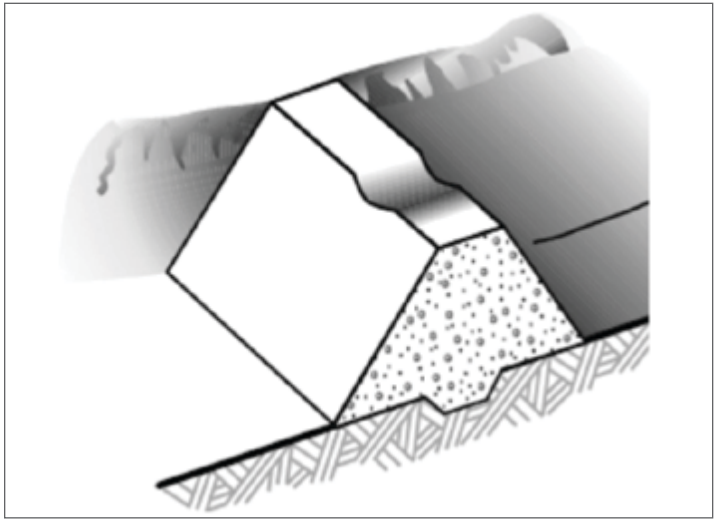
CAUSES AND CONSEQUENCES

- Excessive settlement of the embankment or internal erosion of embankment material may cause a depression at the crest.
- Foundation spreading upstream and/or downstream, prolonged wind erosion, or improper final grading following construction may cause a low area on crest.
- Low areas can reduce the freeboard available to pass flood flows safely through the spillway.

RECOMMENDED ACTION

- ***Report the suspected issue to dam owner or local authority immediately.***
- Establish survey monuments along the length of the crest to determine measurements, location, and extent.
- Have a qualified engineer determine the cause of low area, supervise necessary steps to reduce dam failure risk, and to correct the condition.
- Use proper construction techniques to fill low area and re-establish a uniform elevation over the crest.
- Routinely monitor survey monuments to detect any settlement across crest.

Low Area on the Crest



Low Areas in Crest Will Reduce Freeboard

Dam Deficiencies – Excessive Quantity and/or Muddy Water Exiting from a Point

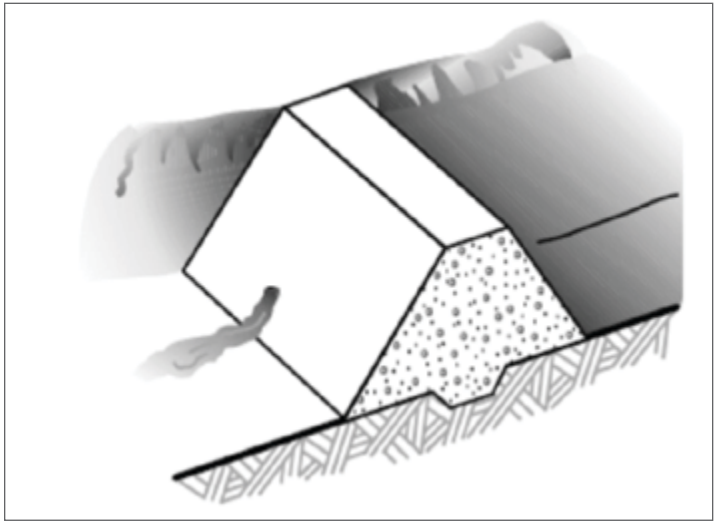
CAUSES AND CONSEQUENCES

- Water has created an open pathway through dam and may be eroding or carrying embankment material.
- Surface agitation of water and embankment may cause muddy water.
- Rodents, frost action, or poor construction may allow water to open pathway.
- Continued flows can saturate parts of embankment and lead to slides.
- Continued flows can cause further erosion.

RECOMMENDED ACTION

- ***Report the suspected issue to dam owner or local authority immediately.***
- Begin measuring outflow quantity to determine if water is getting muddier, staying constant, or clearing up.
- Have a qualified engineer inspect the condition and recommend further actions.
- If the quantity of flow is increasing, lower the water level in the reservoir until the flow stabilizes or stops completely.
- Search for an opening on the upstream side of the dam and plug it if possible.

Diagram of Water Exiting from a Point



Water Piping Through Toe of Embankment

Dam Deficiencies – Seepage Water Exiting as a Boil in the Foundation

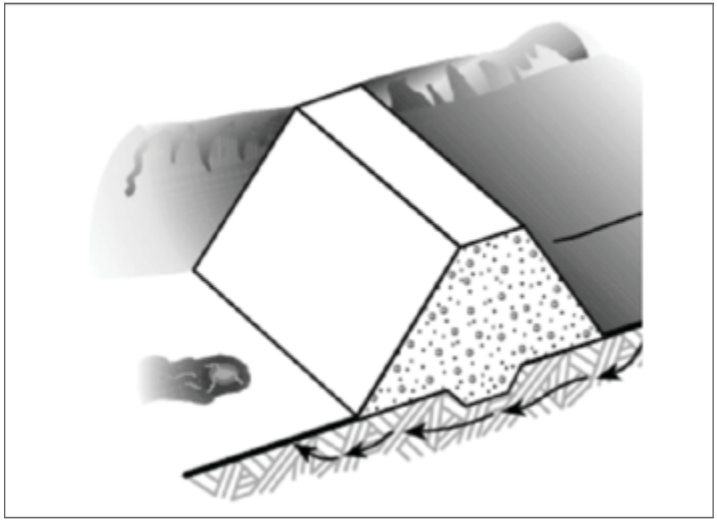
CAUSES AND CONSEQUENCES

- Some part of the foundation material is supplying a pathway of water flow.
- This could be caused by a sand or gravel layer within the foundation.
- Increased flows can lead to erosion of the foundation, and eventually a dam failure.

RECOMMENDED ACTION

- ***Report the suspected issue to dam owner or local authority immediately.***
- Examine the boil to see if foundation materials are being transported.
- Have a qualified engineer inspect the condition and recommend further actions.
- If soil particles are moving downstream, use sandbags or earth to create a dike around it.
- The pressures created by the water level may control velocities and temporarily prevent further erosion.
- If erosion increases, lower the reservoir level as required.

Seepage Water Exiting as a Boil in Foundation



Sandbags Surrounding a Boil on Downstream

Dam Deficiencies – Seepage Water Exiting Abutment Contact

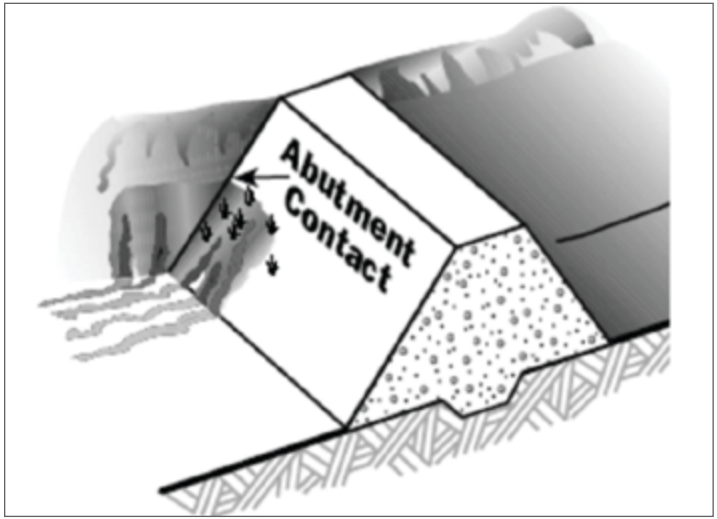
CAUSES AND CONSEQUENCES

- Water flowing through pathways in the abutment or through the embankment can cause seepage.
- Seepage can lead to erosion of the embankment material, which may result in a dam failure.

RECOMMENDED ACTION

- ***Report the suspected issue to dam owner or local authority immediately.***
- Study the leakage area to determine the quantity of flow and extent of saturation.
- Inspect daily for the possible development of slides.
- Have a qualified engineer inspect the condition and recommend further actions.
- To ensure embankment safety, the water level in the reservoir may need to be lowered and adjusted accordingly.

Seepage Exiting at the Abutment Contact



Abutment Seepage May Lead to a Dam Failure

Dam Deficiencies – Seepage Water Exiting from a Point Adjacent to Outlet Pipe

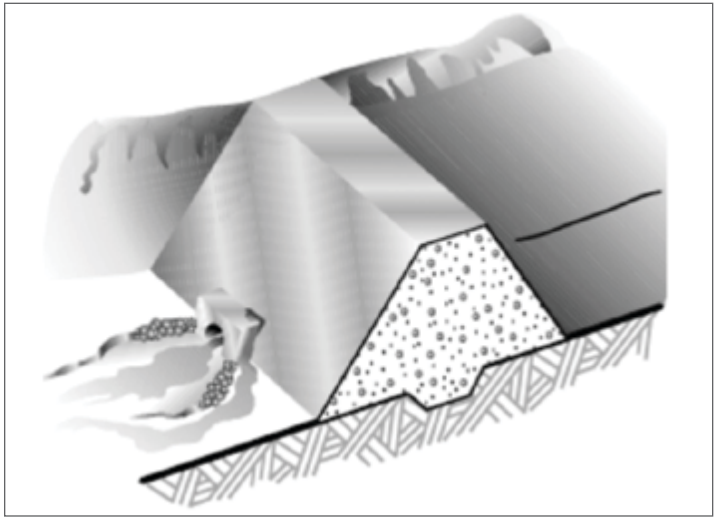
CAUSES AND CONSEQUENCES

- A break or a hole in the outlet pipe, or poor compaction around the pipe allows water to flow through and create a pathway along the outside of the outlet pipe.
- The continued flow can lead to embankment material erosion and a dam failure in the future.

RECOMMENDED ACTION

- ***Report the suspected issue to dam owner or local authority immediately.***
- Investigate the area by probing and/or shoveling to determine cause.
- Determine if seepage carries soil (muddy).
- Determine quantity of the flow.
- Have a qualified engineer inspect the condition and recommend further actions.
- If flow increases or is carrying embankment material, lower reservoir level until leakage stops.
- Investigate the embankment along the alignment of the spillway pipe for signs of settlement or sinkholes.

Seepage Water Exiting Adjacent to Outlet Pipe



Piping of Water Alongside an Outlet Pipe

Dam Deficiencies – Failure of Concrete or Rock Outfall Structures

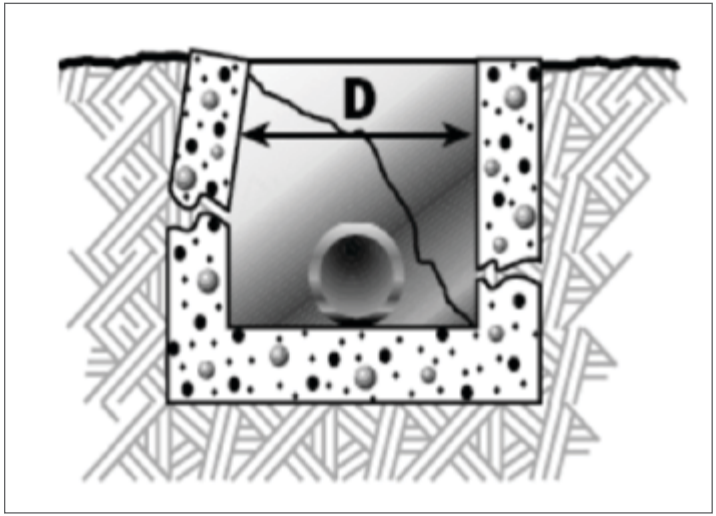
CAUSES AND CONSEQUENCES

- Excessive side pressure on a nonreinforced concrete structure or poor concrete quality can cause failure of the outfall structure.
- A slope that is too steep can cause rocks to roll down the hill and partially block the outlet.
- The embankment may be exposed to erosion by outlet releases due to the loss of an outfall structure.

RECOMMENDED ACTION

- Monitor a typical dimension (such as dimension "D" in the next figure) to check for any progressive failures.
- Repair the deficiency by patching crack and supplying drainage around the concrete structure.
- The entire outfall structure may need to be replaced.
- Repair the sloped and place riprap to stabilize it.

Failure of Concrete Outfall Structure



Rock Failure Around an Outlet Pipe

Dam Deficiencies – Outlet Releases Eroding the Toe of the Dam

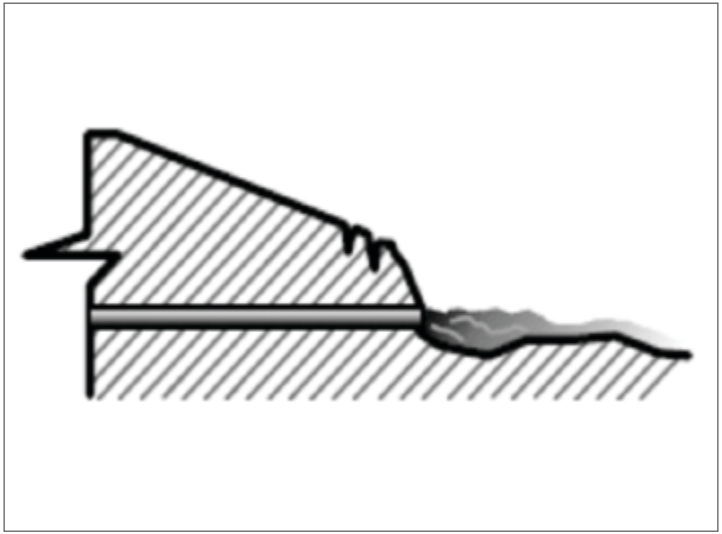
CAUSES AND CONSEQUENCES

- The outlet pipe may be too short and cause a scour hole.
- No energy-dissipating pool or structure at the downstream end of the conduit can cause a scour hole.
- Erosion of the toe of the dam makes the downstream slope too steep and causes progressive sloughing.

RECOMMENDED ACTION

- Extend the outlet pipe beyond the toe (using the same size of pipe and material).
- Form a watertight connection to the existing conduit.
- Stabilize the slope.
- Use riprap over suitable bedding to properly protect the embankment.

Outlet Releases Erode the Toe of the Dam.



A Scour Hole at an Outlet Erodes Toe of Slope.

Dam Deficiencies – Excessive Vegetation or Debris in the Spillway, or Around the Inlet

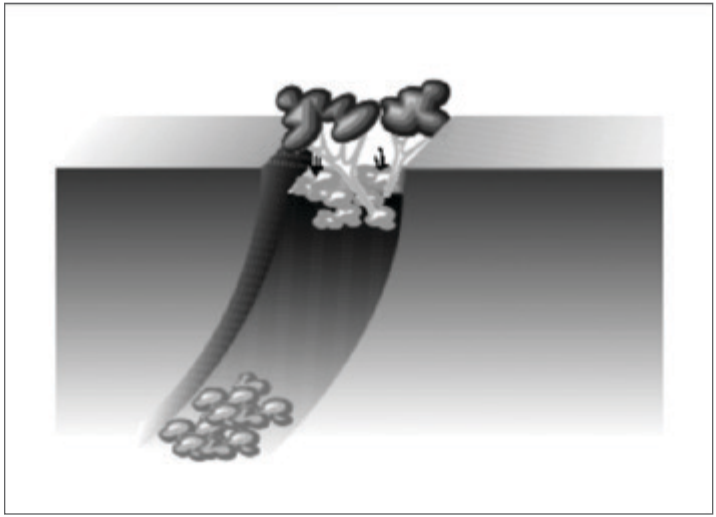
CAUSES AND CONSEQUENCES

- An accumulation of slide materials, dead trees, excessive vegetation growth, and more deficiencies in the spillway channel can reduce waterway capacity.
- Reduced discharge capacity may cause the spillway to overflow and the dam to overtop.
- Prolonged overtopping can cause dam failure.

RECOMMENDED ACTION

- Clean out debris periodically and control vegetative growth in the spillway channel.
- Install a log boom in front of the spillway entrance to intercept debris.

Vegetation or Debris in Spillway Channel



Blocked Spillway Channel of a Dam

Dam Deficiencies – Erosion of Spillway Channels

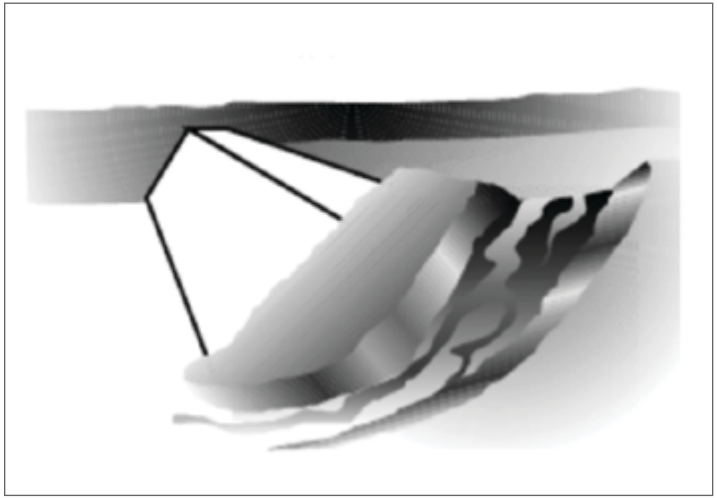
CAUSES AND CONSEQUENCES

- Surface runoff from intense rainstorms or flow from the spillway carries surface material down the spillway causing continuous troughs.
- Livestock traffic create gullies where runoff flow can concentrate.
- Unabated erosion can lead to slides and slumps which can result in reduced spillway capacity.
- Inadequate spillway capacity can lead to overtopping and result in a dam failure.

RECOMMENDED ACTION

- Photograph the condition and bring it to the attention of a qualified engineer.
- Replace the eroded material with compacted fill to repair damaged areas.
- Revegetate the areas if appropriate.
- Install suitable rock riprap to protect against future erosions.

Erosion Channels



Erosion of Spillway May Lead to Slumps/Slides

Resources and Websites

- BC Dam Safety Website
  https://www2.gov.bc.ca/damsafety
- Dam Safety Regulation
  http://www.bclaws.ca/civix/document/id/complete/statreg/40_2016
- Water Sustainability Act
  www.bclaws.ca/civix/document/id/complete/statreg/14015
- Contact the BC Dam Safety Program
  dam.safety@gov.bc.ca
- Canadian Dam Association
  https://www.cda.ca/
- Association of State Dam Safety Officials
  https://damsafety.org/

Terminology

ABUTMENT: The part of the valley side against which the dam is constructed. An artificial abutment is sometimes constructed, as a concrete gravity section, to take the thrust of an arch dam where there is no suitable natural abutment. The left and right abutments of dams are defined with the observer viewing the dam looking in the downstream direction, unless otherwise indicated.

APPURTENANT STRUCTURE: Ancillary features of a dam, such as outlets, spillways, powerplants, tunnels, etc.

BERM: A nearly horizontal step in the sloping profile of an embankment dam. Also, a step in a rock or earth cut.

BREACH: An opening through a dam that allows the uncontrolled draining of a reservoir. A controlled breach is a constructed opening. An uncontrolled breach is an unintentional opening caused by discharge from the reservoir. A breach is generally associated with the partial or total failure of the dam.

CHANNEL: A general term for any natural or artificial facility for conveying water.

CONDUIT: A closed channel to convey water through, around, or under a dam.

CORE WALL: A wall built of relatively impervious material, usually of concrete or asphaltic concrete, in the body of an embankment dam to prevent seepage.

CREST LENGTH: The measured length of the dam along the crest or top of dam.

CREST OF DAM: See "Top of dam."

CROSS SECTION: An elevation view of a dam formed by passing a plane through the dam perpendicular to the axis.

CUT-OFF WALL: A wall of impervious material usually of concrete, asphaltic concrete, or steel sheet piling constructed in the foundation and abutments to reduce seepage beneath and adjacent to the dam.

DAM: Any artificial barrier, including appurtenant works, that impounds or diverts water either temporarily or long term.

DAM FAILURE: Catastrophic type of failure characterized by the sudden, rapid, and uncontrolled release of impounded water or the likelihood of uncontrolled release. It is recognized that there are lesser degrees of failure and that any malfunction or abnormality outside the design assumptions and parameters that adversely affect a dam's primary function of impounding water is properly considered a failure. These lesser degrees of failure can progressively lead to or heighten the risk of a catastrophic failure. They are, however, normally amenable to corrective action.

DRAIN, TOE: A system of pipe and/or pervious material along the downstream toe of a dam used to collect seepage from the foundation and embankment and convey it to a free outlet.

DRAINAGE AREA: The area that drains to a point on a river or stream.

EMBANKMENT DAM: Any dam constructed of excavated natural materials, such as both earth fill and rockfill dams, or of industrial waste materials, such as a tailings dam.

FACE: The external surface of a structure (e.g., the surface of a wall of a dam).

FILTER (FILTER ZONE): One or more layers of granular material graded (either naturally or by selection) to allow seepage through or within the layers while preventing the migration of material from adjacent zones.

FLASHBOARDS: Structural members of timber, concrete, or steel placed in channels or on the crest of a spillway to raise the reservoir water level but intended to be quickly removed, tripped, or fail in the event of a flood.

FLOOD: A temporary rise in water surface elevation resulting in inundation of areas not normally covered by water. Hypothetical floods may be expressed in terms of average probability of exceedance per year, such as one-percent-chance-flood, or expressed as a fraction of the probable maximum flood or other reference flood.

FOUNDATION: The portion of the valley floor that underlies and supports the dam structure.

FREEBOARD: Vertical distance between a specified still water (or other) reservoir surface elevation and the top of dam, without camber.

GATE: A movable water barrier for the control of water.

CREST GATE (SPILLWAY GATE): A gate on the crest of a spillway to control the discharge or reservoir water level.

OUTLET GATE: A gate controlling the flow of water through a reservoir outlet.

HEIGHT, HYDRAULIC: The vertical difference between the maximum design water level and the lowest point in the original streambed.

HEIGHT, STRUCTURAL: The vertical distance between the lowest point of the excavated foundation to the top of the dam.

INTAKE: Placed at the beginning of an outlet-works waterway (power conduit, water supply conduit), the intake establishes the ultimate drawdown level of the reservoir by the position and size of its opening(s) to the outlet works. The intake may be vertical or inclined towers; drop inlets; or submerged, box-shaped structures. Intake elevations are determined by the head needed for discharge capacity, storage reservation to allow for siltation, the required amount and rate of withdrawal, and the desired extreme drawdown level.

LEAKAGE: Uncontrolled loss of water by flow through a hole or crack.

LENGTH OF DAM: The length along the top of the dam. This also includes the spillway, powerplant, navigation lock, fish pass, etc., where these form part of the length of the dam. If detached from the dam, these structures should not be included.

OUTLET: An opening through which water can be freely discharged from a reservoir to the river for a purpose.

PHREATIC SURFACE: The free surface of water seeping at atmospheric pressure through soil or rock.

PIPING: The progressive development of internal erosion by seepage.

RESERVOIR: A body of water impounded by a dam and in which water can be stored.

RESERVOIR SURFACE AREA: The area covered by a reservoir when filled to a specified level.

RIPRAP: A layer of large stone, precast blocks, bags of concrete, or other suitable material, generally placed on the slope of an embankment or along a watercourse as protection against wave action, erosion, or scour. Riprap is usually placed by dumping or other mechanical methods, and in some cases is hand placed. It consists of pieces of relatively large size, as distinguished from a gravel blanket.

SEEPAGE: The internal movement of water that may take place through the dam, the foundation, or the abutments.

SLOPE: Inclination from the horizontal. Sometimes referred to as batter when measured from vertical.

SLOPE PROTECTION: The protection of a slope against wave action or erosion. See "Riprap."

SPILLWAY: A structure over or through which flow is discharged from a reservoir. If the rate of flow is controlled by mechanical means, such as gates, it is considered a controlled spillway. If the geometry of the spillway is the only control, it is considered an uncontrolled spillway

SPILLWAY CHANNEL: An open channel or closed conduit conveying water from the spillway inlet downstream.

SPILLWAY CHUTE: A steeply sloping spillway channel that conveys discharges at super-critical velocities.

SPILLWAY CREST: The lowest level at which water can flow over or through the spillway.

STORAGE: The retention of water or delay of runoff either by planned operation, as in a reservoir, or by temporary filling of overflow areas, as in the progression of a flood wave through a natural stream channel.

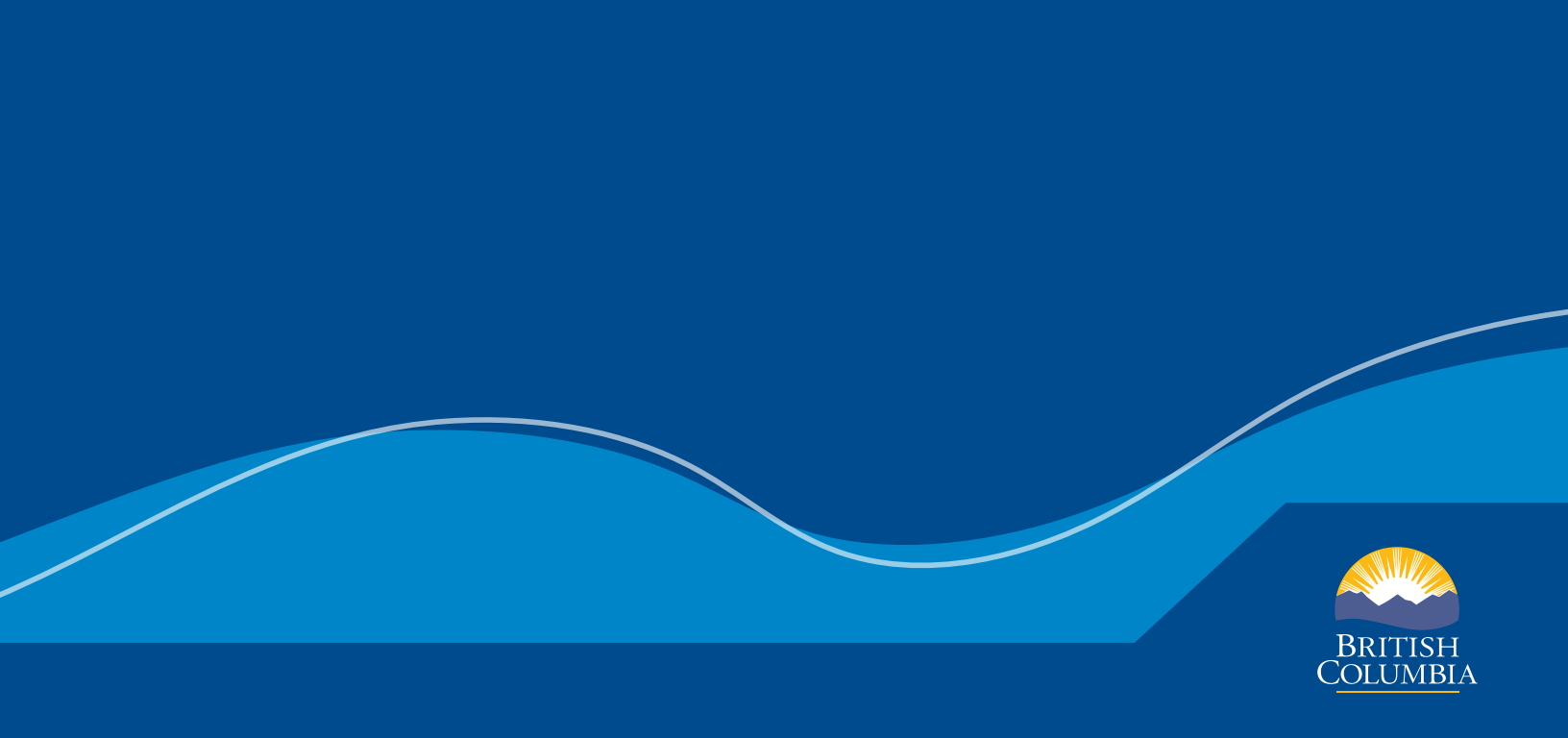
TOE OF THE DAM: The junction of the downstream slope or face of a dam with the ground surface; also referred to as the downstream toe. The junction of the upstream slope with ground surface is called the heal or the upstream toe.

TOP OF DAM: The elevation of the uppermost surface of a dam, usually a road or walkway, excluding any parapet wall, railings, etc.

TRASH RACK: A device located at an intake to prevent floating or submerged debris from entering the intake.

VALVE: A device fitted to a pipeline or orifice in which the closure member is either rotated or moved transversely or longitudinally in the waterway to control or stop the flow.

Notes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