Flood Protection Works Inspection Guide

Public Safety Section

Water Management Branch

Province of British Columbia

Ministry of Environment Lands and Parks

March 2000

Canadian Cataloguing in Publication Data
Main entry under title:
Flood protection works inspection guide
Includes bibliographical references: p.44

ISBN 0-7726-4183-8

1. Dikes (Engineering) - Inspection - British Columbia. I.
British Columbia. Water Management Branch. Public Safety Section.

TC337.F56 2000 627'.42'0288 C00-960101-5

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Inspecting a Floodbox

1. Introduction

The purpose of this guide is to assist in the inspection of dikes and related flood control structures. A regular program of dike inspection can identify potentially critical conditions and facilitate maintenance in advance of high water periods. Routine observations, recording and reporting, followed by repairs will ensure that flood protection structures operate effectively and safely.

This guide focuses on field identification of conditions that might jeopardize the safety of the dike. It also provides information on scheduling inspections, inspection methods and tips, and record keeping methods that assist with ongoing monitoring of changing conditions and with maintenance scheduling and tracking. Depending on the nature of the problem, it may be necessary to initiate regular maintenance and repairs, monitoring, immediate interim measures or additional investigation. While there are a number of possible actions outlined in Appendix 2 that could be considered to remedy critical conditions, the focus is to help inspectors identify and record visual indicators of potential problems as opposed to providing diagnoses or specific solutions. In many cases, expert advice may be required to fully assess the condition and recommend the appropriate action.

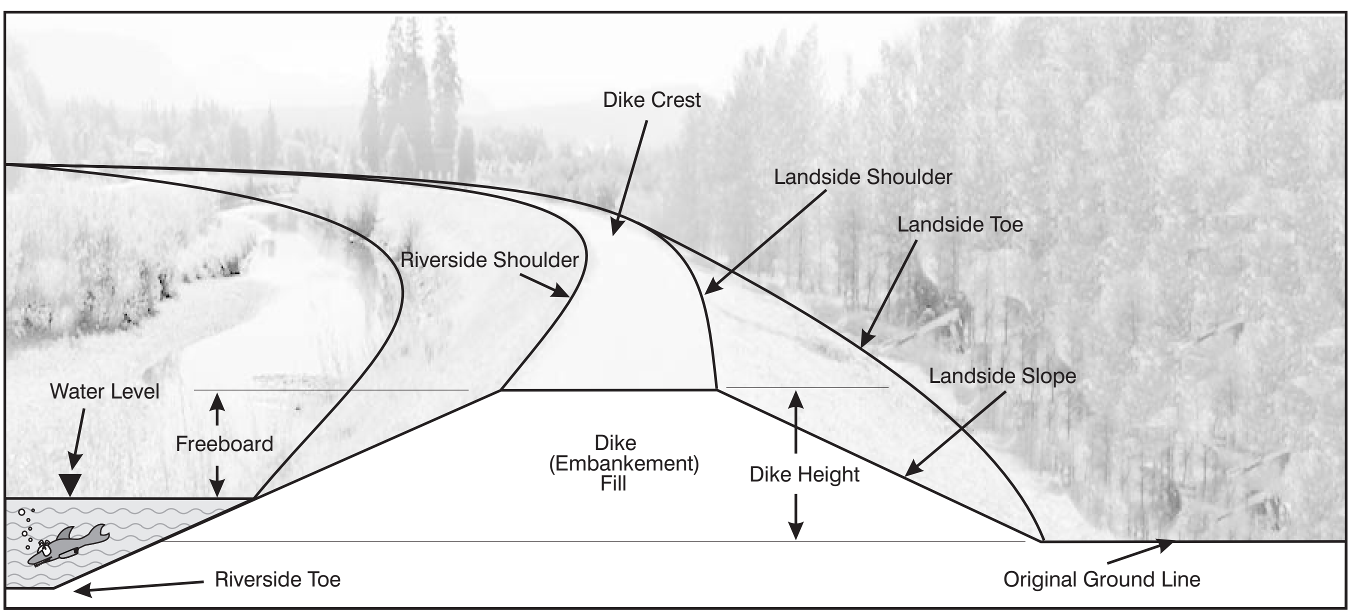
The Guide is organized according to the following format:

Inspection Scheduling and Methods

Field Guides and Report Forms

Contact and Reference Information

Appendix 2 provides a more detailed discussion of typical dike issues.



1.1 Historical Dike Failures in British Columbia

Dike inspections are aimed at identifying developing problems in advance allowing time for appropriate action. Examining conditions that contributed to past dike failures can help inspectors identify potential future problems. The table below lists reasons for dike failure in British Columbia from as early as 1894. As can be inferred from looking at the causes, many failures could have been prevented; routine inspections and accompanying maintenance programs are a key component in prevention. Typical dike issues are discussed further in Appendix 2.

Date	Stream	Place	Cause
1894	Fraser	numerous	overtopping, erosion, seepage
1935	Sumas		Nooksack ice jam
1935	Nicomekl/ Serpentine		ice storm
May 28, 1948	Fraser	Nicomen Island	seepage (tree?)
June 3, 1948	Fraser	Hatzic	seepage
1948	Fraser	Sumas	seepage
1948	Alouette	Pitt Meadows	bank beaver
1948	Alouette	Pitt Meadows	bank beaver
1948	Pitt	Pitt Meadows	bank beaver
1948	Fraser	Matsqui	bridge collapse, erosion
1948	Fraser	Chilliwack	trees, lack of access
1948		Sumas Prairie	tree collapse
June 7, 1948	Kootenay R.	Reclamation DD	unknown
June 7, 1948	Kootenay R.	Creston DD	collapse
Winter, 1948	Fraser	Westham Island	high tides, winds
1955	Coquitlam	Colony Farm east	overtopping, erosion
1960	Fraser	Kent	floodbox washed out
1968	Bella Coola	Airport	dike breach
1972	N. Thompson	Oak Hills	piping
Nov. 21, 1972	Nicomekl	nr. Crescent Beach	animal holes/piping?
Dec. 1973	Koksilah	Dinsdale Farm	overtopping
Dec. 1975?	Vedder	Yarrow	overtopping
1980	Stawamus	Squamish	unknown
March 19, 1980	Pitt R.	Coquitlam DD	collapse/pipe seepage
Dec. 16, 1982	Serpentine		surge/tide overtopping
Dec. 16, 1982	Mud Bay		surge/tide overtopping
Dec. 16, 1982	Georgia Strait	Westham Island	surge/tide overtopping
Dec. 16, 1982	Boundary Bay	Crescent Beach	surge/tide overtopping
1984	Lillooet/ Miller	Pemberton	overtopping
Nov. 1990	Sumas		overflows from Nooksack
Nov. 1990	Vedder	Railway	collapse: overflow structure
Aug. 1991	Green	Pemberton	erosion/slumping
Aug. 1991	Cheakamus	Outdoor School	overtopping
June 1995	Coal	Fernie	erosion, tree/debris battering
June 1995	Michel	Sparwood	erosion, bridge collapse
Dec. 1995	Tulameen	Princeton	overtopping
Dec. 1995	Mission	Kelowna	ice-jam overtopping

2. Scheduling Inspections

Inspections are critical for identifying problems and planning corrective actions. A dike is an active structure, constructed of materials that are subject to various stresses that may lead to deterioration and risk of failure. An inspection program to observe, record and report on the flood protection system should start during construction and continue on a regular basis throughout its operation. Effective management of a dike system involves inspections at several times of the year, coinciding with water events. The program is usually described in the Operation and Maintenance Manual for the flood protection works. Inspection scheduling, methods, preparation, and record keeping are discussed below.

2.1 Regular Inspections

2.1.1 Annual Inspections

At least once a year the entire diking system should be inspected in detail by the Diking Authority for routine maintenance purposes. This inspection should be scheduled prior to the high flow season, and early enough to allow adequate time for any required work to be completed prior to possible flood events. In some northern interior regions, this inspection may have to be carried out in the previous summer or fall as snow conditions in spring may make it impossible to inspect the system just prior to the flood period. The inspection should note and record any conditions that might affect the performance of the flood protection system.

2.1.2 Low Water Inspections

This inspection should be undertaken each year when the river water levels or ocean tides reach their lowest annual levels. During this period, areas of the dike fill, bank protection and some of the appurtenant structures (pump intake chambers, floodboxes, gates, conduit interiors, etc.) that are normally under water, are exposed making inspection much easier.

2.2 Special Inspections

Special inspections may be needed at other times of the year to monitor and react to particular situations such as storms, ice jamming, reports of vandalism, or construction activity on or near the dike. Construction activity should be observed to confirm that accepted engineering practices are being followed (compaction, placement of cut-off walls, etc.). A record should be kept of what was done, by whom, and the cost. This information may be needed to provide evidence should structural failures occur in the future.

2.2.1 High Water Patrol Inspections

Patrol inspections should be carried out during high water events to monitor the performance of the flood control works and emphasize early detection of problems resulting from increased hydraulic pressure (seepage, boils, etc.), increased potential for erosion of materials, and increased chance of reduced freeboard (observed from gauge readings). During high water events, local water level gauges should be monitored regularly and the readings recorded to assess changing conditions and for future reference. Dike patrol frequency should increase as flow and/or water levels approach critical conditions, and should be continuous while the level is within about 1.0 m of the dike crest. The patrol crews are to observe, mark, record and submit reports similar to the High Water Patrol Log in Section 6.7 (to the Diking Authority) for any conditions or occurrences that could signal a weakening or malfunction of any component of the flood control system. Refer to the Operation and Maintenance Manual and the Flood Planning and Response Guide for BC for further information.

2.2.2 Post-Flood Inspections and Evaluations

Inspection of the protective works should be undertaken after flood events. A complete high water profile along the dike should be obtained after significant flow events to assess the dike crest level and the amount of freeboard. Changes in the river channel should be noted not only for the reach adjacent to the flood protection works but for areas both upstream and downstream such as any new locations of log jams, streambed aggradation (gravel accumulation) and degradation (gravel scour) areas, weakened or damaged areas, and the condition of all appurtenant works.

2.2.3 Post-Earthquake Inspections

This type of inspection should be integrated with local emergency plans. A rapid initial overall assessment of the entire flood protection system should be undertaken to determine what level of protection it still offers and if there is an immediate danger of secondary damage (i.e. next high tide could overtop, causing widespread flooding). When the immediate threat is determined and addressed, a detailed inspection should be undertaken of the entire dike, erosion protection and appurtenant works. The functionality of individual structures should be checked in detail as follow up. A detailed inspection and evaluation of the system by a suitably qualified professional engineer may be advisable because damage may not be readily visible. Identification of areas prone to earthquake damage in advance will aid assessment after an event.

3. Inspection Methods

Inspections should emphasize complete examination of all aspects of the works.

A flood protection system is only as good as its weakest link.

3.1 Inspection of the Dike Fill

The usual method of inspecting the dike fill is to walk along both crest edges (shoulders) and the landside toe, in order to see the entire surface area clearly. Details can usually be seen for a distance of 3 to 10 metres depending on the roughness of the surface, vegetation, or other surface conditions. The riverside toe is inspected in the same manner as the landside toe for set-back dikes, however for riverside dikes without erosion protection, walking along the slope just above the current water level can prove challenging and may be more efficiently done from a boat.

3.2 Erosion Protection Works

The structure of most types of erosion protection works makes walking over them difficult and somewhat hazardous. It may be easier to identify problems from across the river using binoculars or from a boat when closer observations are necessary.

3.3 Appurtenant Structures

Since many appurtenant works are mechanical in nature, they usually require hands-on inspection. Checking that locks work, pumps run properly, floodbox gates open fully and easily are a few examples of this aspect of inspection. Structures such as pumpstation chambers and floodbox conduits should be viewed internally for defects and deterioration.

Look for gradual deterioration as well as recent damages. One method of noting the location of a deficiency is to bring a reduced set of the as-built drawings and mark the exact location of the deficiency on the drawings. Another way is to use a Ground Positioning System (GPS) if the as-built plan is digitized and has a corresponding grid reference.

Photographs are recommended as they provide visual proof that is often needed to obtain repair funds. If photos are taken from the same place over time they can show changes that may be too gradual to detect during inspections.

Note: All references to left or right banks of the river are described viewing in a downstream direction.

Flow			Flow		
Left	⬆	Right	Right	⬇	left

4. Pre-Inspection Activities

Depending on the size of the flood protection works, some preparation for the inspection may be necessary. This involves planning, equipment preparation and personal safety considerations.

4.1 Planning

A review of notes from previous inspections, photographs and "as-constructed" drawings, if available, should precede the actual field inspection. This allows comparison of the present condition to the "as-constructed", and also at the time of the previous inspection.

Pre-arranging meeting times with key land owners if access is required may save time, and these contacts can prove to be a valuable source of information.

4.2 Equipment

Equipment requirements vary depending on the type of inspection and conditions expected on site. Equipment requirements may include the following:

Type	Purpose
Hand level	Checking elevations and heights (approximate)
Inclinometer	Measuring the degree of slope
Measuring tapes	Measuring dimensions of features or abnormalities
Hip chain	Measuring longer distances
Rock Hammer	Sounding concrete or rock to check quality and checking for pipe corrosion
Shovel	Minor clearing, taking soil samples
Lights (flashlights)	Looking into floodboxes or other darkened areas
Probe (steel rod)	Probing wet, soft areas, sinkholes, and voids
Bucket and timer	Measuring seepage and other flow rates
Machete or sandvick	Minor brush clearing
Sounding lines or tapes	Measuring water depths
Binoculars	Cross river inspection of erosion protection
Camera	Making photographic records
Water sample containers	Obtaining water samples
Sample bags	Obtaining soil or rock samples
Level, rod and tripod	Obtaining accurate elevations and heights
Clipboard and record keeping material	Recording inspection observations
G.P.S.	Measuring position of the object

4.3 Personal safety

For safety reasons it is always a good idea to inform appropriate co-workers, prior to departure, of the basic five "**W**'s"

Who is going and with whom are they meeting?

What is going to be inspected?

When is the departure, arrival and estimated time of return?

Where is the location of the inspection?

Why is the inspection being carried out - reported problems or routine inspection?

A personal safety plan should be in place for all personnel inspecting any or all components of a flood protection system. This plan should include:

- Supplying and using all personal safety equipment required by the Workers' Compensation Board of British Columbia.
- Providing appropriate communication devices
- Ensuring that a check-in procedure is in place and is being used
- Supplying and updating all necessary vehicle safety equipment

Ideally, inspection personnel should work in teams of two when in the field, particularly when doing high water or post-earthquake inspections, or at night in severe weather conditions. All safety requirements must be organized according to the applicable requirements of the Occupational, Health and Safety Regulations (WCB).

5. Record Keeping

All inspections are carried out by or for the Diking Authority and inspection reports should be retained for future reference or examination under the *Dike Maintenance Act*. Examples of inspection forms are provided in Section 6, and more dike information is available on the internet at: **www.elp.gov.ca/wat/flood/floodmgt.html**.

Major repairs and some maintenance work will require written approval from the regional Deputy Inspector of Dikes (DIOD), and may also require the approval of other agencies. Activities around dikes are regulated under the *Dike Maintenance Act* which requires written approval for works in and about flood protection dikes including:

- Anything that may lower or decrease the size and/or integrity of the cross-section of a dike;
- Installations of floodboxes, culverts, pipes or any structure within or under the dike fill;
- Construction of works over or on a dike right of way; and
- Alterations to the foreshore adjacent to a dike.

For further information, refer to the Guidelines for Management of Flood Protection Works in British Columbia.

Use the **SMPL** (pronounced Simple) rule for all inspection reporting:

S Sketch the deficiency and note its important characteristics

M Measure the deficiency

P Photograph the deficiency or describe its characteristics in writing

L Locate the deficiency relative to some standard point

The Flood Protection Works Basic Inspection Checklist in Section 6.1 provides a guide to conducting most inspections.

5.1 Flood Protection Inspection Report

A written report on the results of the annual inspection should be prepared on a copy of the Flood Protection Inspection Report, see Section 6.6. Field notes may be prepared using the form or one similar which clearly identifies the three main failure groups (Dike, Erosion Protection Works and Appurtenant Structures), their condition and the work required to correct any noted deficiencies.

5.2 High Water Patrol Log

During flooding events, frequent dike patrols are essential for the early observation and correction of deficiencies which could, if left undetected, lead to dike failures. High Water Patrol Logs should be used by the Diking Authority to record all such inspections and actions taken, and also to serve as part of the performance records for floodboxes, pumps and other appurtenant works. A sample of the High Water Patrol Log form is provided in Section 6.7. For more information refer to the Operation and Maintenance Manual for the dike and the Flood Planning and Response Guide for BC.

For a complete list of all the records that should be kept by the Diking Authority please refer to the publication entitled Guidelines for Management of Flood Protection Works in British Columbia, available from the regional DIOD.

Inspecting the Landside Toe

6. Field Guides for Inspection and Reporting

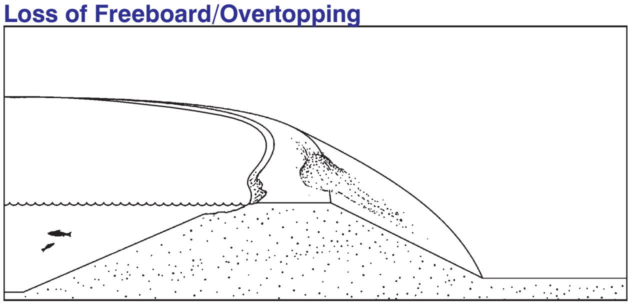
6.1 Flood Protection Works Basic Inspection Checklist

Item❑	Yes	No
A) Pre-inspection activities		
1. Review all safety requirements	❑	❑
2. Ensure all necessary safety equipment is in place for the inspection	❑	❑
3. Ensure safety check-in procedures are in place	❑	❑
4. Review pertinent office materials such as plans, reports, previous inspections etc.	❑	❑
5. Inform all necessary contacts (e.g. adjacent landowners) about when the inspection will take place and to ensure access	❑	❑
B) Inspection of the dike		
Walk along both shoulders of the crest and record details and mark location of any of the following deficiencies:		
1. Check for loss of freeboard, recent high water marks and their relationship to the crest elevation	❑	❑
2. Check for signs of settlement/depressions/sinkholes	❑	❑
3. Check for signs of seepage/piping/boils	❑	❑
4. Check for cracking	❑	❑
5. Check for slides, sloughs, scarps and bulges	❑	❑
6. Check for surface erosion (rutting, scars, tracks, water pools)	❑	❑
7. Check for signs of unauthorized activity (construction, excavation, vandalism)	❑	❑
8. Check for areas where vegetation hampers inspection	❑	❑
9. Check for signs of rodent/beaver activity	❑	❑
Walk along the landside toe and where possible the riverside toe and record details and mark location of any of the following deficiencies:		
11. Check for changes in the river flow pattern, existence of log jams, gravel build up or scour holes	❑	❑
12. Check for signs of seepage/ piping / boils	❑	❑
13. Check for signs of toe bulges	❑	❑

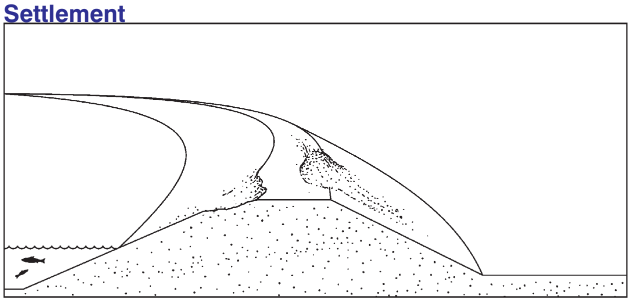
Item	Yes	No
C) Inspection of erosion protection works		
Choose the most efficient and safe method of inspection, i.e. vantage points, boat or from across the river using binoculars		
1. Look for evidence of toe scour	❑	❑
2. Check for signs of weakness in the protective cover, i.e. riprap loss, unusually steep slopes, beaching, scarping	❑	❑
3. Check for riprap material degrading (weathering)	❑	❑
4. Check for bed degradation (e.g. riprap perched on a ledge)	❑	❑
5. Check for indications of outflanking at the upstream end of the erosion protection works	❑	❑
6. Check for changes in river flow patterns (log jams, gravel bars, and imminent problems etc.)	❑	❑
7. Check for rock displacement due to ice, logs etc.	❑	❑
8. Check for areas of reduced overbank - unprotected bank erosion	❑	❑
9. Check for areas where vegetation hampers inspection	❑	❑
10. Check for signs of rodent / beaver activity	❑	❑
D) Inspection of appurtenant works		
1. Check condition of access roads	❑	❑
2. Check water level gauges for damage, elevation change, readability	❑	❑
3. Check condition of floodboxes, operation of control gates, intakes and outlets	❑	❑
4. Check for seepage at all interfaces between structures and dike fills	❑	❑
5. Check pump station building for signs of deterioration, settlement, or vandalism.	❑	❑
6. Check maintenance records of pumps	❑	❑
7. Check condition of pump intake and outlets areas including trash racks for debris buildup, etc.	❑	❑
8. Check condition of pump power source (fuel tanks, electrical transmission lines, etc.)	❑	❑
9. Run pump(s) - check for excessive vibration, etc.	❑	❑
10. Check condition of relief wells	❑	❑
11. Check all concrete structures for signs of deterioration and/or settlement	❑	❑
12. Check for areas where vegetation hampers inspection	❑	❑
13. Check for signs of beaver activity at intakes to floodboxes and pump station	❑	❑
14. Test switching	❑	❑
15. Check alignment of floats and sensors	❑	❑
16. Test operation of gates	❑	❑

6.2 Guide for Identifying Problems in Dike Fill

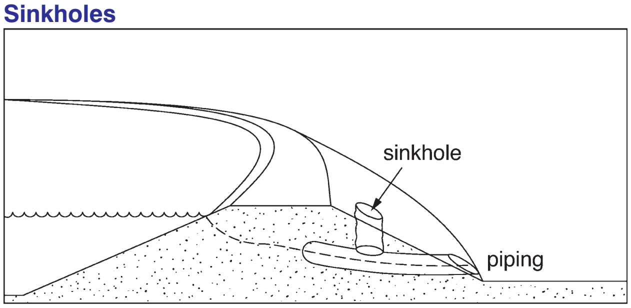
Loss of Freeboard/Overtopping



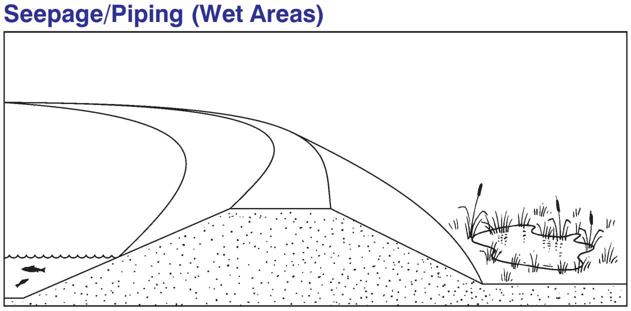
Settlement



Sinkholes



Seepage/Piping (Wet Areas)



Loss of Freeboard/Overtopping

Observation:
- High water surface profile is within the freeboard allowance
- Evidence of slumps, sinkholes, slides

Causes:
- Aggradation of the channel bed
- Channel blockages; logs, ice, etc.
- Settlement of dike

Concerns:
- Reduced freeboard creating a potential for overtopping

Settlement

Observation:
- Uneven surface of the crest or slopes
- Depressions with gently sloping bowl-like sides

Causes:
- Internal erosion of the embankment material
- Prolonged erosion from wind or water
- Poor construction practices, poorly compacted fill, organic material in fill
- Foundation consolidation

Concerns:
- Creates areas of structural weakness
- Loss of freeboard from settling can create the potential for overtopping

Sinkholes

Observation:
- Hole in the dike surface
- Depression with steep bucket-like sides

Causes:
- Animal burrows
- Internal erosion from seepage piping or a hole in a floodbox conduit
- Foundation problems such as rotting stumps or other wood debris

Concerns:
- Weakens the dike fill by decreasing the length of the seepage path
- Provides an entrance point for surface water
- Can pose a danger to vehicular and pedestrian traffic
- May signal collapse and/or instability

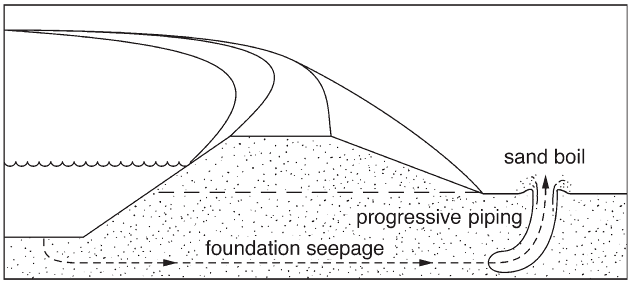
Seepage/Piping (Wet Areas)

Observation:
- Turbid (dirty) or cloudy seepage water
- Water or wet areas near the toe or on dike slope
- Localized or lush vegetation on dike slopes or adjacent to the dike
- Increase in seepage flow rates different from past patterns

Causes:
- Excessive flow of water through the dike fill or through the foundation material
- Surface water entering through cracks, sinkholes, animal burrows, along the outside surface of conduits

Concerns:
- May cause slope instability which can lead to failure
- Turbid (dirty) seepage water is an indication that piping may be occurring and may result in a piping failure of the foundation and ultimately the embankment

Boils

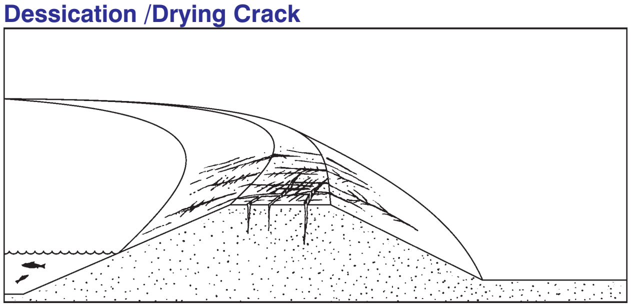


Observation:
- Water upwelling on landside of dike, near toe or further away
- Upwelling may form cone-shaped 'volcanoes'

Causes:
- A weak layer of sand or gravel in the foundation material is being charged by hydraulic pressure produced during high water conditions
- A concentrated seepage path or pipe has developed through the foundation

Concern:
- May be an early sign of piping

Dessication/Drying Crack

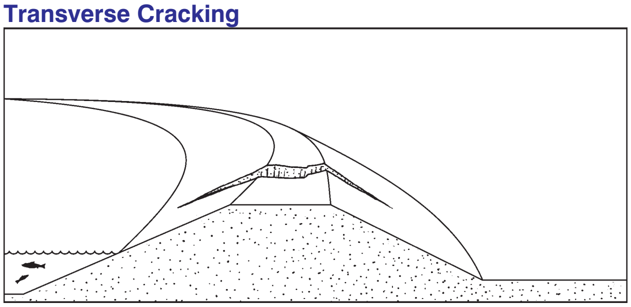


Observation:
- Random, honeycomb pattern of cracks along the embankment

Causes:
- Embankment material expands and contracts with alternating wet and dry weather
- Embankment fill with high fines content and/or inadequate compaction

Concerns:
- Provides an entrance point for surface water which can saturate the crest material
- May affect durability of the crest in wet weather

Transverse Cracking

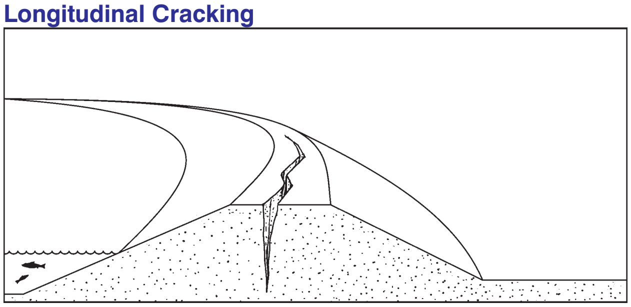


Observation:
- Cracks extend across the crest perpendicular to the dike length

Causes:
- Uneven movement between two adjacent segments of the embankment
- Instability of the embankment or foundation material
- Differential settlement

Concerns:
- Provides an entry point for surface water
- Creates an area of structural weakness which could result in further movements or failure
- May create a seepage path and/or a potential piping failure

Longitudinal Cracking

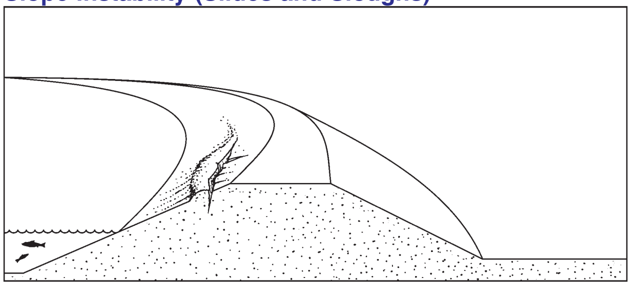


Observation:
- Cracks extend roughly parallel to the length of dike

Causes:
- Uneven settlement within the foundation or embankment
- Initial stage of a slope failure or embankment slide

Concerns:
- Possible instability
- Can lead to future movements or failure (breach)
- Provides an entry point for surface water which can promote movement
- Often reduces the effective crest width

Slope Instability (Slides and Sloughs)



Slope Instability (Slides and Sloughs)

Observation:

- Displaced material on dike slope
- Bulges along the embankment slope or toe
- Area above the bulge shows cracking or scarps
- Excessive moisture or softness upon probing the bulge
- Arc-shaped crack (beginning of a slide)
- Evidence of settlement
- Slides (shallow or deep-seated)

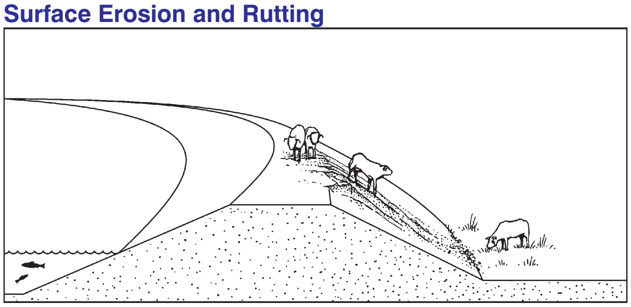
Causes:

- Ice action and wave erosion creating vertical slopes
- Steep slopes left unsupported by erosion
- Embankment fill becomes saturated during high water followed by a rapid drop in water levels
- Slope too steep for type of embankment material to allow free draining

Concerns:

- Direct threat to the integrity of the dike - possible breaching
- Provides an entry point for surface water which can promote movement
- Often reduces the effective crest width

Surface Erosion and Rutting



Surface Erosion and Rutting

Observation:

- Evidence of material loss from dike surface
- Wheel tracks, animal tracks
- Scarring of dike surface
- Pooling of water on crest

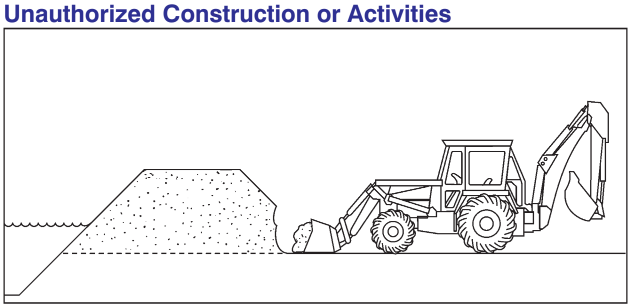
Causes:

- Livestock or human traffic
- Surface runoff over erodible material

Concerns:

- Encourages further erosion
- Can decrease cross-sectional width and weaken the embankment

Unauthorized Construction or Activities



Unauthorized Construction or Activities

Observation:

- Embankment material disturbed or removed
- New ponds, holes or foundations dug close to the dike

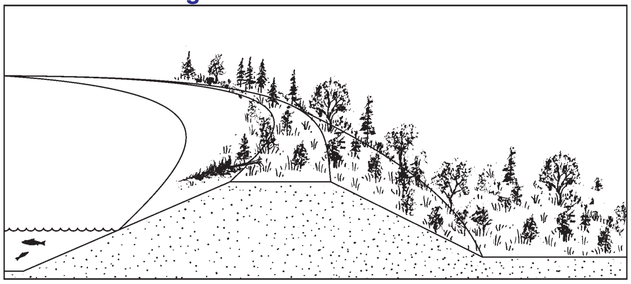
Cause:

- Uninformed or illegal construction practices

Concerns:

- Otherwise competent system can be compromised by a single unauthorized action
- Can block or hamper access
- Often hides defects such as poorly compacted fill around a newly placed or repaired conduit increasing the chance of seepage
- Can encourage boils or slumping and reduce top width
- Can encourage boils and failure from piping

Uncontrolled Vegetative Growth



Uncontrolled Vegetative Growth

Observation:

- Vegetation obscures ability to detect cracks, seepage or other problems

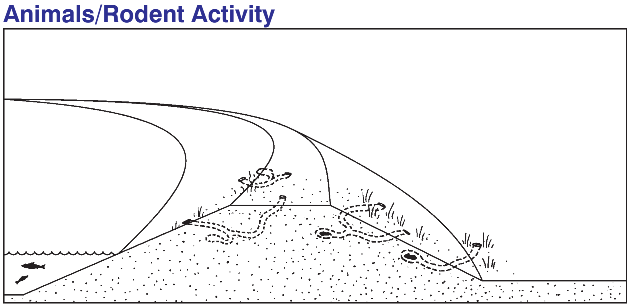
Causes:

- Lack of maintenance

Concerns:

- Root systems can provide seepage conduits
- Rotting root systems weaken the embankment
- May prevent emergency access
- Provides a habitat for unwanted burrowing animals
- Windthrow or uprooting of trees can create holes and weakness

Animals/Rodent Activity



Animals/Rodent Activity

Observation:

- Rodent holes, burrows and tunnels
- Animal trails
- Fallen trees (beaver activity)

Causes:

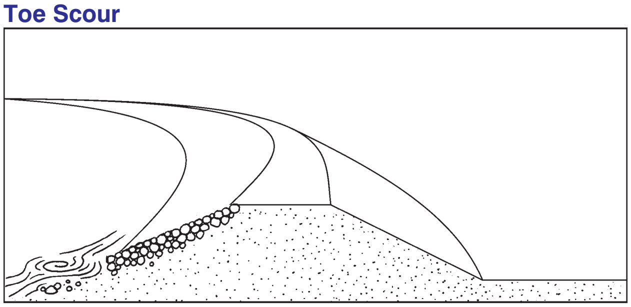
- Burrowing animals including bank beavers

Concerns:

- Can weaken the embankment - cause sinkholes and piping
- Potential vehicle access restrictions if unchecked

6.3 Guide for Identifying Problems in Erosion Protection Works

Toe Scour



Toe Scour

Observation:

- Loss of riprap from dike slope
- Loss of riprap starting at the toe
- Undermining of the dike slope
- Eddying at the dike toe

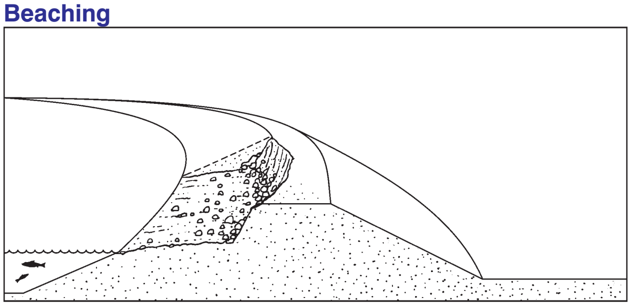
Causes:

- Inadequate riprap toe design/material size
- Shift in flow impact angle due to formation of log jams, ice jams, shifting river bed materials or man made obstacles

Concern:

- Loss of erosion protection material leaving the embankment materials vulnerable to erosion and possible breaching

Beaching



Beaching

Observation:

- Riprap on dike slope slumping and forming a horizontal beach near the water level

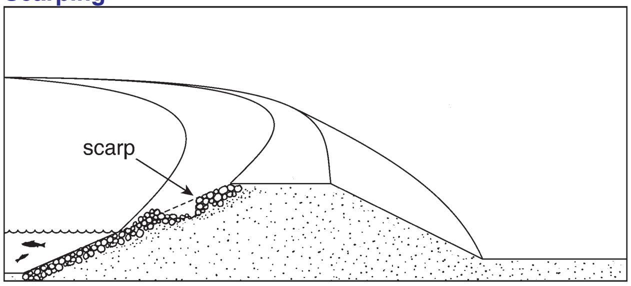
Cause:

- Wave action removing a portion of the riprap slope and depositing it further down the slope
- Insufficient riprap rock size

Concern:

- Loss of erosion protection material leaving the embankment materials vulnerable to erosion and possible breaching

Scarping



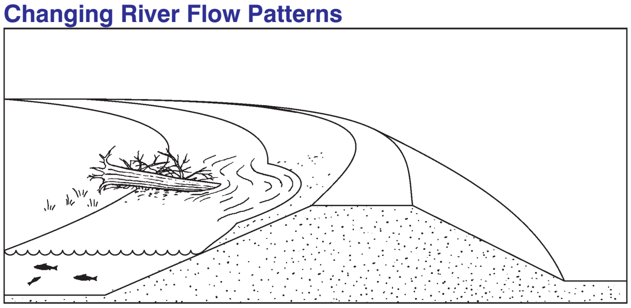
Scarping

Observation:
- Riprap undermined and sliding down the slope
- Cracking, spalling of riprap material
- Oversteepened riprap slope

Cause:
- The removal of bedding material (filter material) from beneath riprap due to ice, wave action, internal erosion or local settlement

Concern:
- Riprap slides to lower part of the slope causing scarps to form which could reduce the cross-sectional width of the dike

Changing River Flow Patterns



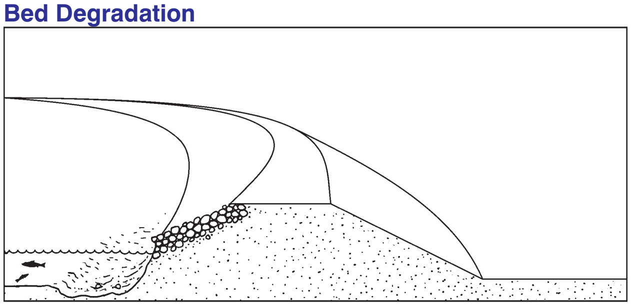
Changing River Flow Patterns

Observation:
- Dramatically altered flow pattern of the river
- Areas of impingement on the dike altered
- Channel obstructions in the vicinity

Cause:
- Landslides
- Ice and log jams
- Gravel accumulations
- Man made obstructions
- Natural meander progression and/or formation of cutoffs

Concern:
- Additional erosive forces applied against existing bank protection works increasing the chance of its failure
- Direct flow against sections of the flood protection system not previously subjected to erosion . If not already armoured, could lead to rapid loss of embankment fill
- Outflanking of existing works at upstream end

Bed Degradation



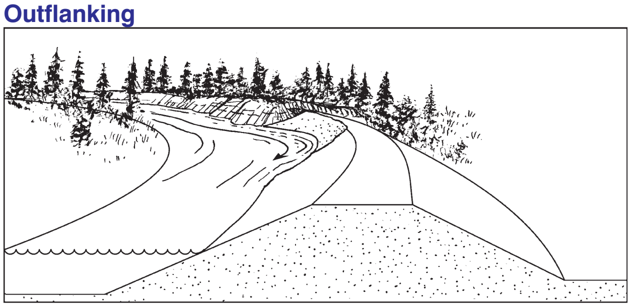
Bed Degradation

Observation:
- River channel scouring adjacent and roughly parallel to the erosion protection
- Riprap perched on a ledge

Cause:
- Changing river currents and high water levels
- Deepening of the riverbed in the reach near the dike
- Insufficient toe protection design or construction

Concern:
- The erosion protection material is vulnerable to undermining and collapse exposing the bank

Outflanking



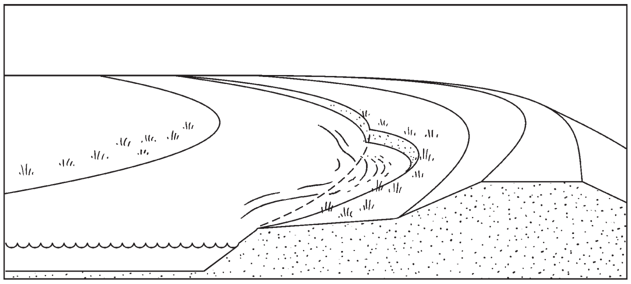
Outflanking

Observation:
- River erosion upstream of hardpoint or key trench

Cause:
- Erosion protection not extending far enough upstream
- Erosion protection not extended to a hardpoint at the upstream end
- Weak upstream key (poor design)
- Sudden change in river flow pattern

Concerns:
- Rapid loss of erosion protection material leaving the embankment fill vulnerable to erosion
- Exposure of unprotected fill to erosive forces

Overbank Erosion



Overbank Erosion

Observation:

- Reduced riverbank area
- Progressive erosion

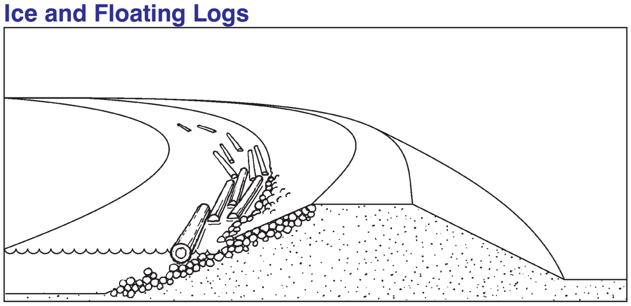
Cause:

- Reduced distance from the dike fill to the river channel due to changing river currents
- Natural meander progression
- Lack of erosion protection on set-back area

Concerns:

- Threat to embankment stability
- Undermining of embankment

Ice and Floating Logs



Ice and Floating Logs

Observation:

- Dislodged riprap pieces on riverside slope, holes in riprap
- Riprap damaged
- Impingement on dike of uprooted trees

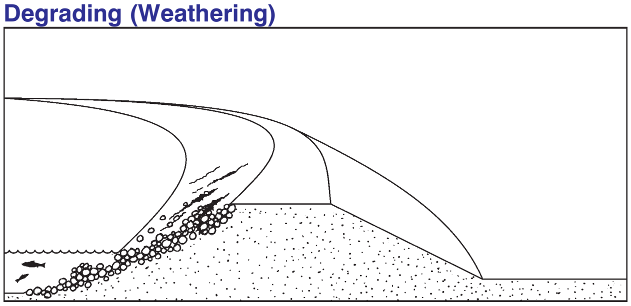
Cause:

- Loss of erosion protection due to forces exerted by flowing ice and floating logs (trees)
- Moving ice grinding or displacing riprap

Concern:

- Weakening or complete loss of erosion protection material

Degrading (Weathering)



Degrading (Weathering)

Observation:

- Disintegration of riprap material
- Cracks, spalling, crumbling of riprap material
- Hollow sound on rock hammer testing

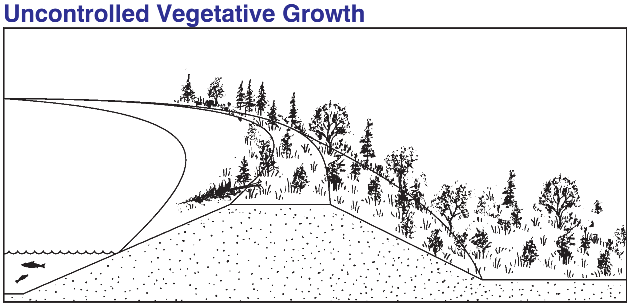
Cause:

- Chemical or mechanical deterioration of the erosion protection material often accelerated by wave action and ice flows and freeze and thaw cycle

Concern:

- Widespread weakening of erosion protection material leaving the embankment fill more susceptible to erosion

Uncontrolled Vegetative Growth



Uncontrolled Vegetative Growth

Observation:

- Vegetation obscuring inspection
- Large vegetation and trees on fill
- Tree uprooting on riprap
- Tree blowdown across dike

Cause:

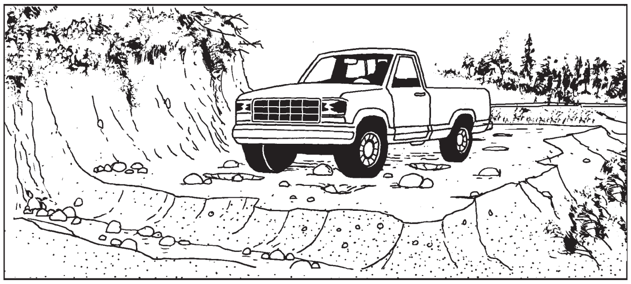
- Lack of regular vegetation management
- Poor maintenance procedures

Concerns:

- Can obscure serious problems which may exist
- Tall trees with large root systems can displace large amounts of erosion protection material when forced over by wind, ice flows or high water
- Provides a habitat for unwanted burrowing animals

6.4 Guide for Identifying Problems in Appurtenant Works

Access Roads



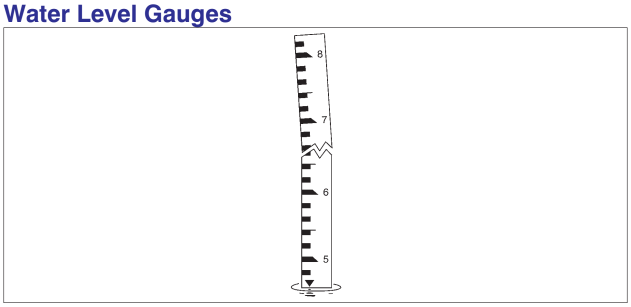
Access Roads

Observation:
- Poor road conditions
- Blocked access

Causes:
- Lack of proper gates and controlled access
- Poor construction practices
- Poor maintenance
- Jurisdictional problems regarding access and maintenance of access

Concerns:
- Blocked access during emergencies
- Unnecessary delays

Water Level Gauges



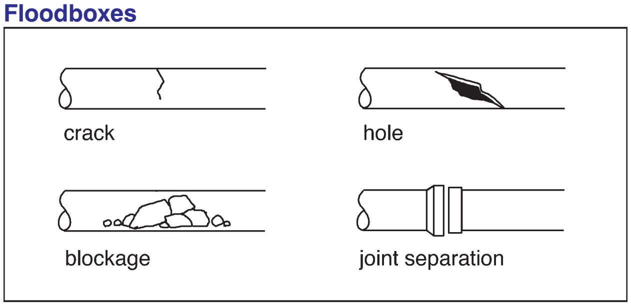
Water Level Gauges

Observation:
- Gauge is broken, bent or missing
- Gauge is unreadable (paint gone)
- Gauge is obscured from view

Causes:
- Ice, high water, floating debris, vegetation growth
- Poor installation
- Vandalism
- Deterioration due to weathering

Concerns:
- Loss of a vital information tool for operation, maintenance and flood fighting activities
- Unnoticed elevation change resulting in incorrect reading

Floodboxes



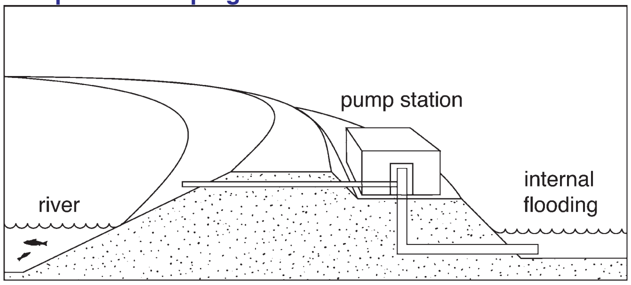
Floodboxes

Observation:
- Cracks/holes/joint separation
- Concrete deterioration
- Gates not opening easily
- Gates blocked (woody debris, slumping, siltation)
- Evidence of rusting at culvert joints

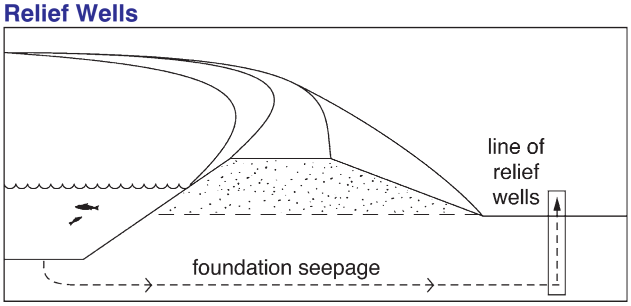
Causes:
- Poor construction practices
- Internal settlement, separation
- Corrosion
- Lack of maintenance
- Beaver activity
- Damage from ice, floating debris, etc. to the gate and its supports (guides)
- Vandalism

Concerns:
- Internal flooding from debris blockage or improperly or partially closed gates
- Seepage along outside of conduit resulting in piping and ultimately embankment failure

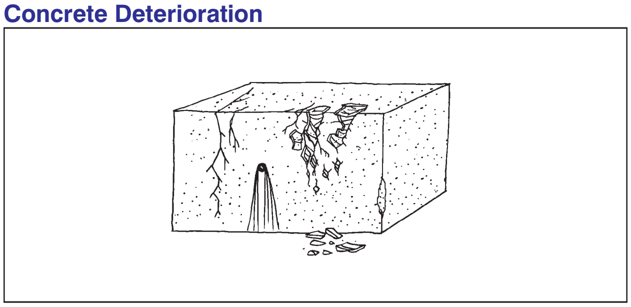
Pumps and Pumping Station



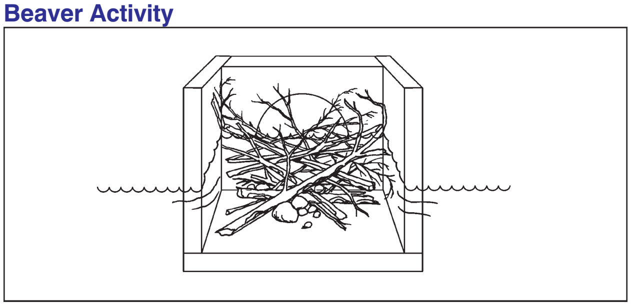
Relief Wells



Concrete Deterioration



Beaver Activity



Pumps and Pumping Stations

Observation:

- Pumps not working to specifications
- Rust on pipes or pumps
- Power source not operative
- Switching devices not working to specifications
- Walls, doors, gates, etc. out of alignment
- Scouring or undermining near the footing or foundation of the structure

Causes:

- Lack of a proper maintenance schedule
- Power outages
- Vandalism

Concern:

- Failure causing internal flooding

Relief Wells

Observation:

- Turbid water in wells
- Concrete deterioration

Causes:

- Piping of foundation materials

Concerns:

- Piping leading to weakening of embankment

Concrete Deterioration

Observation:

- Cracking, spalling, disintegration
- Evidence of rust
- Hollow sound on rock hammer test

Causes:

- Poor construction practices
- Corrosion of reinforced steel from salt content
- Forces of erosion and weathering

Concern:

- Loss of ability to carry out the designed functions of the appurtenant works

Beaver Activity

Observation:

- Beaver dam and/or wood debris blocking intakes

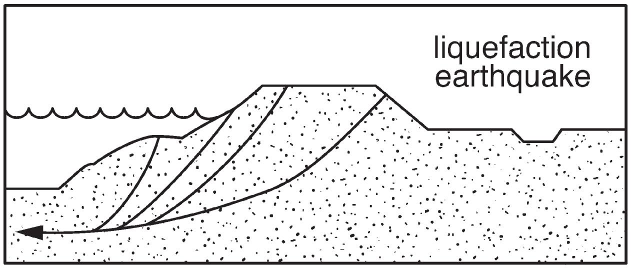
Cause:

- A favourable habitat

Concern:

- Beaver activity may block intakes to floodboxes and pump stations causing internal flooding

6.5 Post-Earthquake Problems



Observation:
- Slumping of the fill
- Bulges at lower elevations on the dike
- Liquefaction of ground
- Collapse of fills
- Cracking in the embankment
- Damage to appurtenant works

Cause:
- Seismic activity

Concerns:
- Widespread damage to the flood protection system is possible
- If widespread, complete repair might not be possible before high water conditions
- Areas affected by tides are of special concern
- Functionality of pumps, gates and structures
- Damages may not be visible immediately

Inspections by Boat

Sheet No. __________
File No. __________

6.6 Flood Protection Inspection Report

Dike Length: __________

DIKE: ____

REACH: ____

DATE INSPECTED: ____________________________ Signed: ______________________________________

The condition of the flood protection works is as reported below:

1. DIKES: (access, gates, locks, vegetation growth, gravel surface, height, slopes, erosion, animal burrows, seepage, trash, berms, relief wells)

____
____
____
____
____
____
____

2. BANK PROTECTION: (loss of rock, settlement, slumping)

____
____
____
____
____
____
____

3. FLOODBOXES/PUMP STATIONS: (inlet and outlet channels, gate operation, trash racks, debris, erosion, corrosion, structure, discharge structure, electrical and mechanical components)

____
____
____
____
____
____

4. WORK REQUIRED:

____

____

____

____

____

____

____

____

5. ADDITIONAL INFORMATION (see below) (sketch, photos, etc.)

6. WORK COMPLETED: Date: ____________________ Signed: __________________________________

6.7 High Water Patrol Log

Date: ______________________________ Inspector: ______________________________

Time Commenced: ______________________ Time Completed: ______________________

1. **Gauges Height**	**Design WL**	**Time**	**Water Level**
Gauge ________	__________	__________	__________
Gauge ________	__________	__________	__________

2. **Landside Seepage**			**Comments/Location**
Boils	Yes ❑	No ❑	**Clear:**__________**Dirty:**__________**Piping:**__________
Ponding	Yes ❑	No ❑	______________________________
			______________________________
3. **Landside Slope**			
Cracking	Yes ❑	No ❑	______________________________
Sloughing	Yes ❑	No ❑	______________________________
Seepage	Yes ❑	No ❑	______________________________
			______________________________
			______________________________
4. **Dike Crest**			
Accessible	Yes ❑	No ❑	______________________________
Cracking	Yes ❑	No ❑	______________________________
Settlement	Yes ❑	No ❑	**Sinkholes:**______________________________
Freeboard	Yes ❑	No ❑	______________________________
5. **Riverside Slope**			
Erosion	Yes ❑	No ❑	**Dike Fill:**______________**Riprap:**______________
Instability	Yes ❑	No ❑	______________________________
Underwater	Yes ❑	No ❑	______________________________
6. **Floodboxes**			
Gates	Yes ❑	No ❑	**Leakage:**______________**Flow Estimate:**______________
7. **Pumps**			
Inlet/Outlet			**Open:**______________**Obstructed:**______________
Operating	Yes ❑	No ❑	**Flow Estimate:**______________________________

8. **Required Action:** ______________________________

Notification:______________________________**To Whom:** Time:______

Refer to System Operation & Maintenance Manual

7. Further Information

7.1 Contacts - Regional Deputy Inspectors of Dikes

In the following regional offices:

Vancouver Island Region
2080 Labieux Road,
Nanaimo BC V9T 6E9
Phone (250) 751-3100
Fax (250) 751-3103

Okanagan Region
201 - 3547 Skaha Lake Rd.,
Penticton, BC V2A 7K2
Phone (250) 490-8200
Fax (250) 492-1314

Kootenay Region
401-333 Victoria Street,
Nelson BC V1L 4K3
Phone (250) 354-6333
Fax (250) 354-6332

Omineca / Peace Region
3rd Floor 1011 Fourth Avenue,
Prince George BC V2L3H9
Phone (250) 565-6135
Fax (250) 565-6629

Southern Interior Region
1259 Dalhousie Drive,
Kamloops BC V2C 5Z5
Phone (250) 371-6200
Fax (250) 828-4000

Inspector of Dikes Office
10470 - 152 Street,
Surrey BC V3R 0R3
Phone (604) 582-5200
Fax (604) 930-7119

Lower Mainland Region
10470 - 152 Street,
Surrey BC V3R 0R3
Phone (604) 582-5200
Fax (604) 930-7119

Skeena Region
Bag 5000, 3726 Alfred Avenue,
Smithers BC V0J 2N0
Phone (250) 847-7260
Fax (250) 847-7591

MELP WEB SITE (FOR DIKES) http://wlapwww.gov.bc/wat/flood/structural.html

EMERGENCIES

In emergencies contact the local office of the Provincial Emergency Program and/or the Provincial Emergency Program Emergency Reporting at:

1-800-663-3456

7.2 References

The following publications are referred to in this Guide and can be obtained by contacting the regional Deputy Inspector of Dikes:

- Environmental Guidelines for Vegetation Management on Flood Protection Works to Protect Public Safety and the Environment. BC Ministry of Environment Lands and Parks and the Department of Fisheries and Oceans Canada. March 1999.
- Guidelines for Management of Flood Protection Works in British Columbia. Public Safety Section, Water Management Branch, Ministry of Environment Lands and Parks. March 1999.

Additional references:

- Flood Planning and Response Guide for British Columbia. Public Safety Section, Water Management Branch, Ministry of Environment Lands and Parks and the Provincial Emergency Program, Ministry of Attorney General. March 1999.
- Riprap Design and Construction Guide. Public Safety Section, Water Management Branch, Ministry of Environment, Lands and Parks. March 2000.

Barrowtown Pump Station

Appendices

Appendix 1: Terminology

Aggradation	the long-term hydraulic process by which streambeds and floodplains are raised in elevation by the deposition of materials such as sand and gravel. It is the opposite of degradation.
Appurtenant Structures	structures and equipment other than the embankment and the erosion protection works that contribute to the overall function of the flood protection works
Bank failure	the collapse of a mass of bank material into a stream channel
Bank protection or Erosion Protection	treatment of slopes of dikes and banks of streams, lakes and other water bodies by placement of riprap (an engineered layer of graded broken rock pieces) or other forms of protection to prevent erosion by surface runoff, stream flows and/or wave action
Boil	a disturbance in the surface layer of soil caused by water escaping under pressure from behind a water-retaining dike structure. The boil may be accompanied by deposition of soil particles in the form of a conical-shaped mound (miniature “volcano”) around the area where the water escapes.
Caving	the collapse of a streambank by undercutting due to wearing away of the toe or an erodible soil layer above the toe
Channel	a natural waterway that periodically or continuously contains moving water. It has a definite bed and banks that confine the water.
Channel scour and fill	erosion and sedimentation that occurs during relatively short periods of time. Degradation and aggradation apply to similar processes that occur over a longer period of time.
Channel stability	a relative measure of the resistance of a stream or river to erosion. Stable reaches do not change markedly in appearance year to year.
Clay	an extremely fine grained sediment. Individual particles are not visible to the unaided eye. If moist, clay can be molded into a ball that will not crumble.
Cross Section	(1) a section of a stream channel or structure that provides a side view, (2) a transect taken at right angles to the flow direction
Culvert	one or more pipes, pipe arches, or other conduit structures designed to transfer water through an embankment
Current	the flow of water moving in a particular direction. See also velocity.
Cut bank	the steep or overhanging slope on the outside of a meander curve, typically produced by lateral erosion of the stream

Cut off collar	a vertical barrier surrounding a culvert designed to increase the length of the seepage path
Degradation	the long-term hydraulic process by which stream and river beds lower in elevation, through removal of material such as sand and gravel
Deposition	the settlement of material out of the water column and onto the streambed or floodplain. Occurs when the flowing water is unable to transport the sediment load.
Deputy Inspector of Dikes	(DIOD) - an official of the Ministry of Environment, Lands and Parks as defined under the *Dike Maintenance Act* of British Columbia. See Inspector of Dikes.
Dike	an embankment, berm, wall, piling or fill constructed to control flooding of land. For the purposes of this manual, the term "dike" usually refers to an embankment fill.
Dike crest	elevation of the uppermost surface of a dike proper, not taking into account any camber allowed for settlement, curbs, guard rails or other structures that are not part of the main body of the flood protection structure
Dike height	the vertical distance from the dike crest level to natural ground as measured at the landside toe of a dike
Dike shoulder	the point of intersection of the dike crest and the side slope of the dike
Dike toe	the point at the bottom of a dike slope where it intersects the original ground
Diking Authority	(1) the commissioners of a district to which Part 2 of the *Drainage, Ditch and Dike Act* applies, (2) a person owning or controlling a dike other than a private dike, (3) a public authority designated by the minister as having any responsibility for maintenance of a dike other than a private dike, or (4) a regional district, a municipality or an improvement district
Embankment dike	any dike constructed of natural excavated materials placed without addition of binding materials other than those inherent in the natural material
Erosion	means the wearing away, by water, of the banks or of the bed of a stream or of the materials used in any flood protection works
Filter layer	layer of fabric, sand, gravel, or graded rock placed between the erosion protection material (usually riprap) and the underlying soils. Its purpose is to prevent the soil from being removed by the action of water. Also called filter blanket.
Flood protection works	all works needed to prevent or control floods

Floodbox	a culvert through the dike that allows the normal passage of water (by gravity) from internal drainage systems to the river/ocean. It has a valve or gate that can close during highwater conditions preventing backflow from the river/ocean to the land protected by the dike.
Freeboard	(1) a vertical distance added to the designed flood water level to allow for hydraulic uncertainty, wave run-up, surges, ice jams, debris accumulations, obstructions of bridge openings and floodways, the effects of urbanization on the hydrology of the watershed, loss of flood storage acres due to development and the aggradation of a river or streambed and other open water conditions, as a factor of safety, (2) also at a given time, the vertical distance between the design water level and the top of the structure
Freshet	a seasonal rise, usually in spring, in river discharge and level caused by heavy rains or melting snow
Gabion	a galvanized wire basket with a hinged top, intended to be filled with stones and used to stabilize banks or channel beds, to control erosion, and to prevent bed materials from shifting
Gravel	sediment particles larger than sand and ranging up to 8 cm (3 inches) in diameter
Hardpoint	a river erosion resistant feature such as exposed bedrock by which the upstream end of erosion protection works connects to prevent outflanking
High water mark (HWM)	a trace of any kind left by a flood on the banks, obstacles or floodplain. It may be used to determine the highest level attained by the water surface during a particular flood.
Inspector of Dikes	an official of the Ministry of the Environment, Lands and Parks as defined under the *Dike Maintenance Act of British Columbia*. See Deputy Inspector of Dikes (DIOD).
Landside slope	slope of the embankment from the shoulder to the toe located on the land side
Left bank	the river or stream bank that is on the left hand side when looking downstream
Natural streambank	the bank of the stream, formed naturally and not part of the dike fill, located below the dike height on the river side
Overbank	the area of land between the waterside toe of a setback dike and the top of the natural streambank
Overbank flow	water flowing over the top of the natural streambank
Permeability	means the capacity or property of material such as rocks and soil to allow the passage of water or other fluids
Piping	flow of water through subsurface conduits transporting fine materials

Private dike	a dike built on private property without public funds to protect only the property of the person owning the private dike
Pumping station	a structure housing pumping machinery used to reduce internal water levels by transporting this water from the land side of a dike to the river
Reach	a length of stream that has generally similar physical characteristics and defined starting and ending points
Riprap	a layer, facing, or protective mound, generally of quarried rock, placed to prevent erosion, scour, or sloughing of a structure or embankment
Right bank	the river or stream bank that is on the right hand side when looking downstream
Riverside dike	a dike located adjacent to a stream (i.e. directly on a streambank). Riverside dikes may be with or without bank protection.
Riverside slope	slope from the riverside shoulder of the embankment to the toe
Setback dike	a dike that is set back from the ordinary high water mark of a river creating an overbank strip of natural ground between the dike fill and the streambank
Silt	slightly cohesive to noncohesive soil composed of particles that are finer than sand but coarser than clay. Silt will crumble when rolled into a ball
Sliding or Sloughing	the downward slipping of a mass of soil, moving as a unit usually with backward rotation, down a bank into the channel. Also called sloughing off or slumping.
Trashracks	a grid usually constructed of wood or metal that helps to prevent large floating debris from entering culverts, floodboxes or pumping chambers. It also has the advantage of preventing unauthorized human access to these structures.
Tsunami	a rise in water level caused by tectonic or volcanic activity
Upstream key	a constructed hardpoint, often a riprap filled trench extending inland from the river bank at roughly a 45 degree angle to the river bank
Water level gauges	a measuring device to obtain water level and/or discharge records
Weathering	physical disintegration or chemical decomposition of a substance (such as riprap) or a structure due to wind, rain, heat, freezing, thawing or chemical reaction

Inspection observations may result in the need for immediate emergency actions on an interim basis, further investigation, monitoring, or scheduled repairs. A general list of possible actions is as follows:

- Refer to the Operation and Maintenance Manual
- Undertake further investigation
- Monitor and compare records for evidence of changing patterns
- Initiate emergency response as required in the interim
- Undertake routine maintenance
- In many cases, consultation with a suitably qualified Professional Engineer will be advisable

The following provides a brief description of typical dike issues that might be encountered, visual indicators, and some possible actions that may be undertaken in addition to those listed above.

Loss of Freeboard/Overtopping

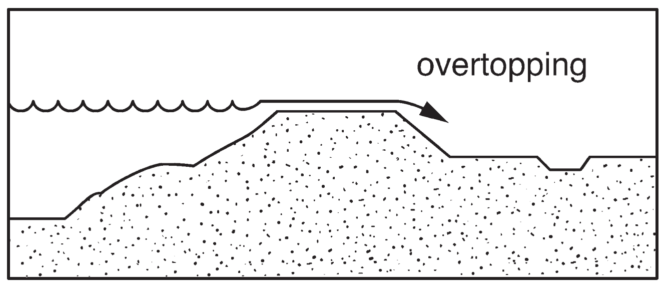
Overtopping is a form of dike failure where water flows over the crest of the dike due to the erosive action of waves or uncontrolled flow of water. Once erosion has begun during overtopping, it is almost impossible to stop as equipment and materials can not be transported along the crest of the dike. It is extremely hazardous for both equipment and operators to be in this location during overtopping. Overtopping of a dike can be caused by:

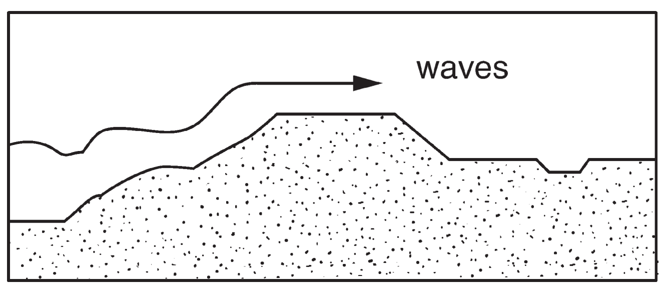
- design parameters exceeded
- extreme flood flows that exceed the embankment design
- loss of design freeboard (due to settlement, erosion, constant vehicle traffic on the embankment or grading)
- sudden flood flow disruptions such as ice and or log jams
- tsunamis in coastal areas
- wave action during high water conditions
- shifts in the position and amount of stream bed materials
- surges, floodwaves caused by temporary stream blockages

Dike fills are usually not designed to withstand overtopping and therefore are particularly susceptible to erosion when it occurs.

Possible Actions

- If loss of freeboard seems to be occurring, a verification survey of the crest elevation should be conducted.
- If changes in the crest elevation are identified corrective action must be completed well in advance of the next potential flood season.





Settlement/Depressions

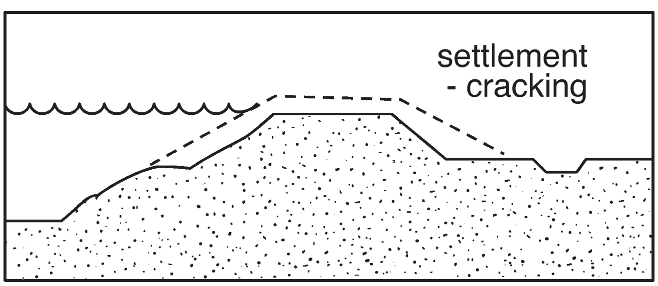
Settlement is a common sign of the internal erosion of embankment material. Excessive settlement of the dike or foundation materials can reduce freeboard and create the potential for overtopping. Settlement can be caused by:

- poor foundation conditions (loose, unconsolidated foundation soil is being loaded by the weight of the overlying embankment)
- poor construction practices such as inadequate or inconsistent compaction, or leaving large amounts of organic material (wood waste, vegetation) in the foundation or embankment
- use of poor quality fill in embankment construction
- prolonged erosion from wind or water
- animal burrows

Settlement can be observed in two types of depressions:

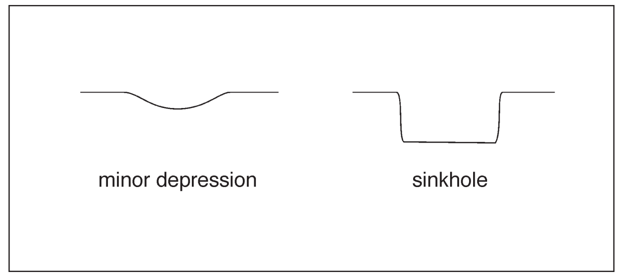
- Minor Depressions
- Sinkholes

Depressions and sinkholes may be a sign of concerns such as internal erosion from seepage or a hole in a floodbox conduit. These are potentially serious causes for failure which could compromise the ability of the dike to operate successfully in a flood event.



Minor Depressions

Minor Depressions are characterized by having gently sloping, bowl like sides and are caused by the same factors as mentioned for settlement only at a much smaller scale. These depressions may be difficult to observe unless there is adequate management and maintenance of vegetation on the crest and slopes of the dike.



Sinkholes

Sinkholes usually have steep, bucket-like sides and are a more serious type of depression. Depressions and sinkholes weaken the dike by decreasing the length of the normal path of water seepage through the dike. Sinkholes also provide an entrance point for surface water into the embankment and, depending on the size and depth of the sinkhole, may lead to dike failure. In addition sinkholes can pose a danger to vehicular and pedestrian traffic. Animal burrows and decaying vegetation, e.g. rotting stumps, embedded within or under the dike fill are common causes of sinkholes. During inspection look for settlement in the both the crest and slopes of the embankment.

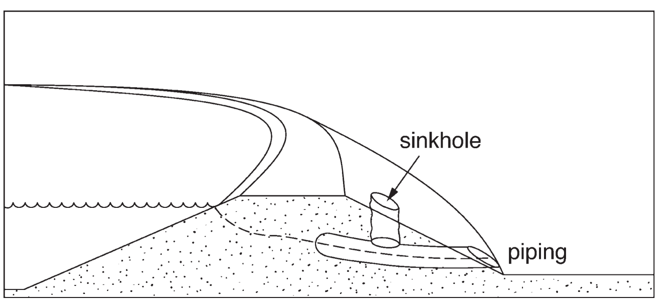
Possible Action

- If changes in the crest elevation or sinkholes are identified corrective action must be completed well in advance of the next high water period.

Seepage/Piping

During high water conditions, most dikes have a certain amount of seepage resulting from water percolating slowly through the dike and its foundation. Seepage occurs in all dikes and is considered normal as long as the water remains clear and the flow is not concentrated or changes dramatically in velocity and quantity.

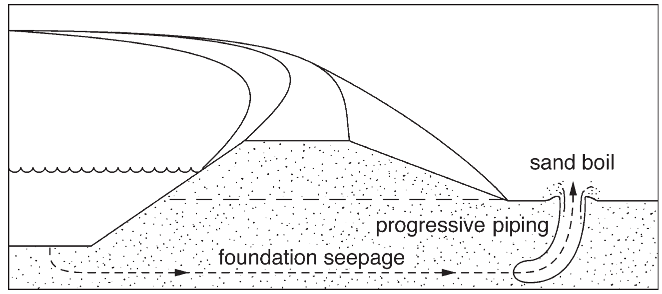
However, if the seepage water is turbid (cloudy), this is an indication that soil particles, or the fines (sand and silt content of gravel) are suspended in the water and are being transported out of the embankment. If uncontrolled, seepage can progressively mine soil from the embankment or its foundation, which could create instability and result in rapid failure of the dike. In this situation, erosion of the soil begins on the landside of the embankment, either in the dike itself or its foundation, and progressively works toward the waterside, eventually developing a direct conduit for water flow through the dike called a ‘pipe’.



Boil

A boil is an upwelling of water on the land side of the dike, near the toe or farther away. Piping through weak areas of foundation materials can result in a boil due to hydraulic pressure during high water conditions. Boils can occur anywhere from the landside dike fill toe to a considerable distance inland. Boils are an indication that a concentrated pipe has developed through a weak layer of material in the foundation of the dike.

Localized lush vegetation on the slopes of the embankment or on the land adjacent to the dike is



often an indicator of an area where seepage is occurring. While it is assumed that embankments built of gravel will be less susceptible to piping, gravels generally contain a certain amount of fines (sand, silt) that may be washed through the embankment with seepage. When the fines of the gravel are removed, voids are created and the gravel may become unstable. During high water any changes in seepage flow rate, water clarity or location, which are different from past seepage history, are cause for concern. Any new upwellings of water on the landside of the dike at the toe or in its general vicinity indicate a possible boil.

Possible Action

- The boil should be monitored for changes in size and relationship to ocean/river water levels.
- Construction of a temporary sandbag ring to reduce seepage flows may be necessary until permanent repairs can be carried out.

Cracking

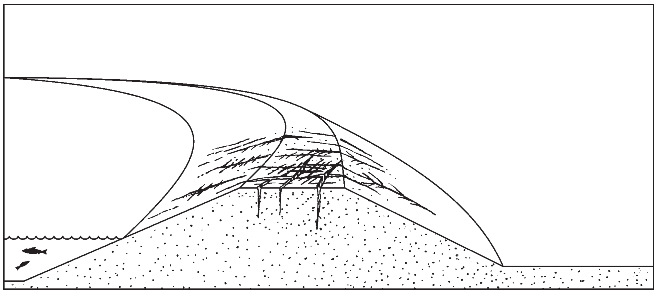
Cracks are splits in the crest or the slopes of the dike. Cracking is categorized as:

1. Desiccation Cracking
2. Transverse Cracking
3. Longitudinal Cracking

1. Desiccation Cracking

Desiccation Cracking usually occurs in highly plastic soil, such as clay, which expands and contracts with alternating wet and dry weather. Desiccation cracks usually develop in a random, honeycomb pattern along the surface of the embankment. Such cracks provide an entrance point for surface water which can saturate the dike and cause slope failures. In severe cases desiccation cracks can concentrate surface runoff, eventually forming gullies and causing surface erosion.

Possible Action



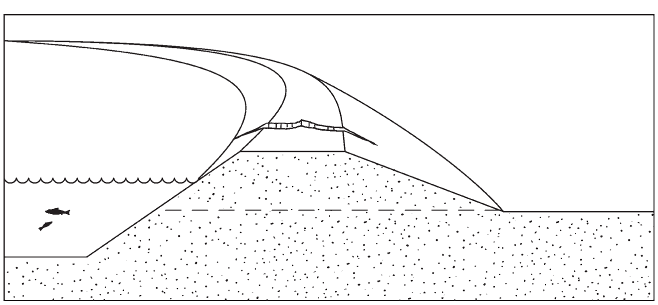
- Where dike inspections identify desiccation cracks the dike surface in that area is to be re-graded and compacted and groundcover resowed. The area should continue to be monitored.

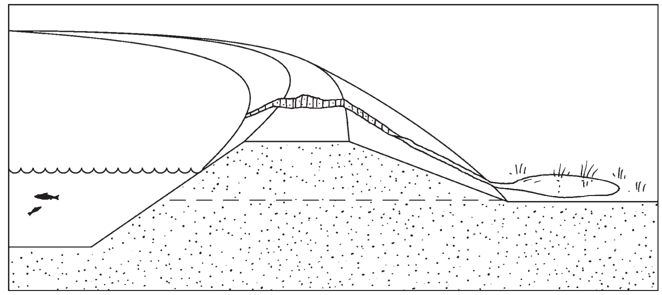
2. Transverse Cracking

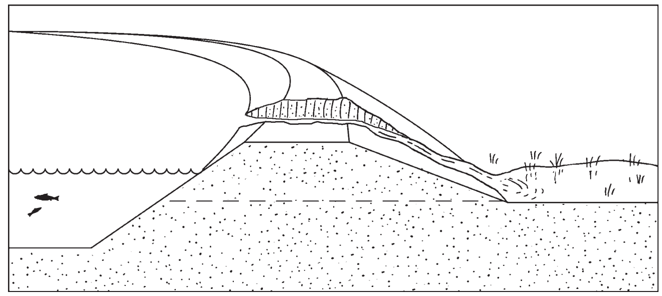
Transverse Cracking forms in a direction roughly perpendicular to the length of the dike, that is, across the dike from the waterside to the landside. The presence of transverse cracking may indicate differential settlement within the dike material or the underlying foundation soils, usually between two adjacent portions within the dike indicating instability of the dike or foundation material.

Transverse cracking may be a serious concern for dike management as:

- these cracks provide an entry point for water into the dike which could create a seepage path and/or a potential piping failure
- water flowing across the dike fill at a lower elevation in the crack can result in rapid erosion of the dike material







Possible Action

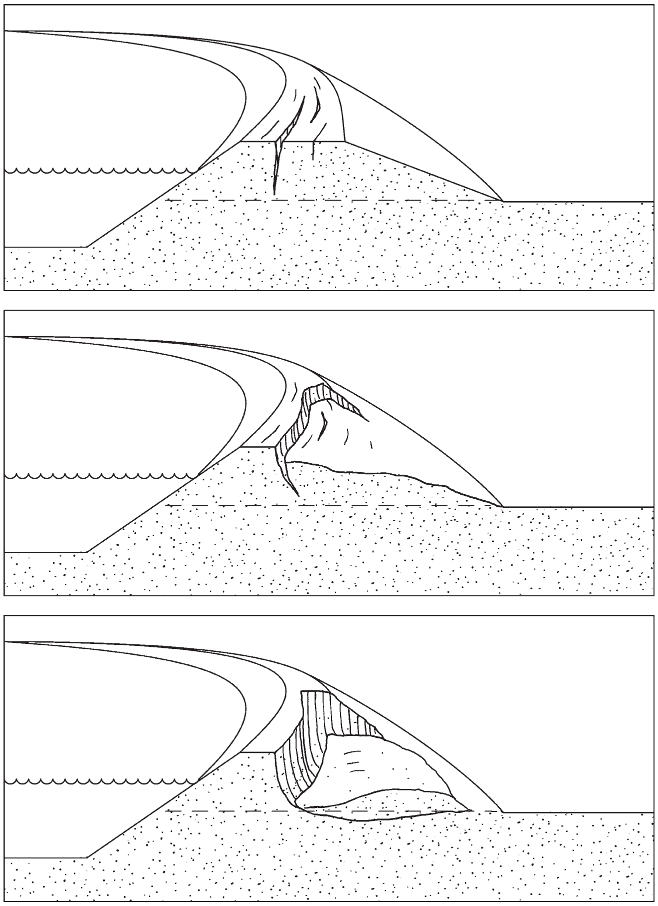
- Transverse cracks should be excavated and back-filled with compacted material to prevent seepage. The area should be monitored for future movement.
- Where the transverse crack has extended completely across the crest of the dike, or there is a difference in elevation between the sides of the crack, the dike must be repaired before the next high water period.

3. Longitudinal Cracking

Longitudinal Cracking forms in a direction roughly parallel to the length of the dike. This form of cracking is an indication of either uneven fill settlement within the dike or the initial stage of a slope failure or slide.

Longitudinal cracking is a serious concern for dike management as:

- these cracks provide an entry point for water into the embankment
- they result in an area along the crest that has high instability and therefore can not be used to move equipment or emergency vehicles
- these cracks reduce the effective crest width
- slope stability failure is accelerated



Development of a Slope Failure from Longitudinal Cracking

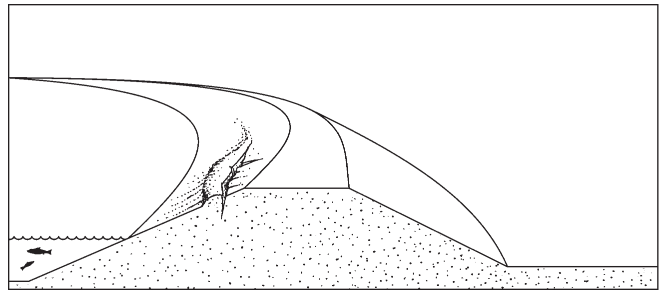
Possible Action

- Given the serious potential for slope failure longitudinal cracks need to be closely monitored and repairs made before the next high water period.

Slope Instability

Instability of the dike is very serious concern as it is a direct threat to the integrity of the dike and possible breaching. Instabilities such as slides or bulging of the slopes can compromise crest elevation or increase the occurrence of erosion, seeping or piping. Slope instability occurs in situations where:

- the dike fill material is saturated from an extended flood event followed by a rapid drop in water levels
- the dike has been constructed with steep side slopes which cannot be sustained when the embankment material is saturated
- ice action or wave erosion have created vertical slopes on the riverside of the dike



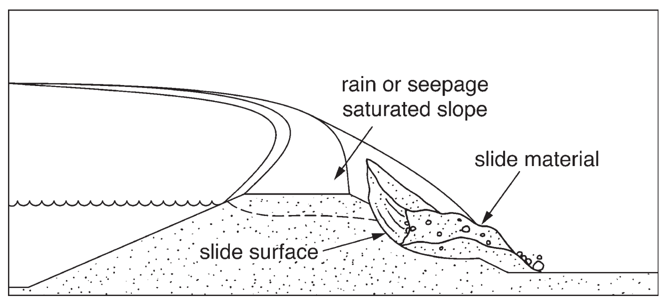
- previous erosion has left dike slopes steep and unsupported

Visual clues of instability may appear as:

- slides (shallow or deep-seated)
- bulges

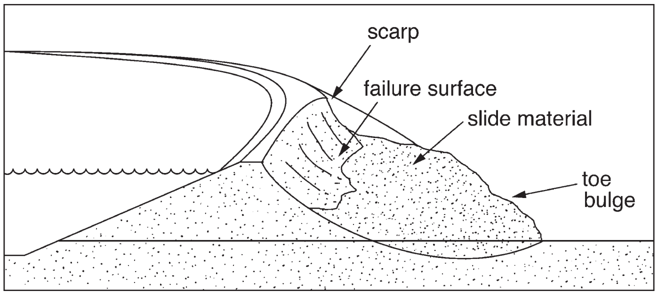
Slides

Slides (sometimes known as sloughs) are displaced material in the dike slope. Shallow Slides are often the result of a rapid drop in river water levels. This can lead to localized problems such as the obstruction (blockage) of water conveyance structures. In addition, these slides may also indicate a loss of strength in the embankment material as a result of saturation of the slope from either seepage or surface runoff.



Deep-Seated Slides are serious threats to the safety of the dike and are characterized by:

- Scarp. A scarp is a relatively flat area with a steep back slope
- Toe Bulge. A toe bulge is usually associated with the spreading of the dike fill or with slides and is accompanied by settlement
- Arc-Shaped Cracks. Arc-shaped cracks in the slope are indications that a slide is beginning. This type of crack may develop into a large scarp in the slope located at the top of the slide



Bulges often appear along the embankment slope indicating the start of a slide or slough. The area above the bulge may show evidence of cracks and scarps. If the bulge material is excessively moist or soft, this indicates that seepage may be occurring.

Possible Action

- Where there is evidence of slope instability the dike must be repaired before the next high water period.

Uncontrolled Vegetative Growth

Uncontrolled vegetation growth is one of the most common problems encountered on dikes in British Columbia. Uncontrolled vegetation growth is harmful to the integrity of the dike in the following ways:

- it can obscure the view of the embankment and prevent a thorough inspection for possible cracks, seepage or other evidence of problems along the dike
- it can slow the response time of emergency vehicles and equipment
- large trees could be uprooted during a storm and the resulting large hole left by the sudden movement of the roots system could lead to breaching of the dike
- root systems can decay and rot, providing a conduit for water to pass through
- root systems can cause the uplift of concrete slabs or structures
- weeds can discourage the growth of desirable grasses and ground cover
- provides a habitat for, and encourages, burrowing animals

Mowing dike slopes.

Possible Action

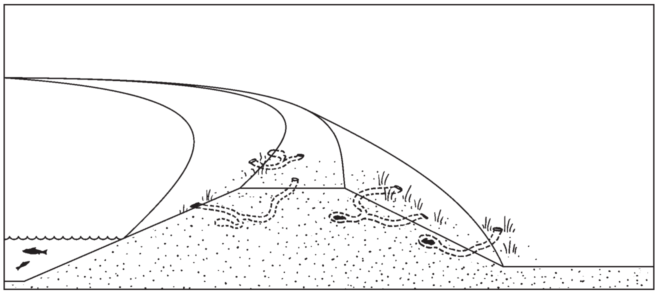
- Remove cuttings and other wood debris from the embankment area.
- The embankment should be seeded with an appropriate grass.
- Uncontrolled vegetation growth must be removed in accordance with vegetation management guidelines.
- Prevent or remove re-occurring growth as part of a regular maintenance program.
- A vegetation management plan should be submitted to the federal and provincial agencies if habitat removal is planned.

Animals/Rodent Activity

Regular livestock traffic crossing the dike can seriously displace embankment material possibly reducing the crest elevation and/or the cross-sectional width and will contribute to erosion on the dike slopes.

Rodents, notably beavers, may locate on dikes when there is uncontrolled vegetation growth. These rodents can cause a variety of different types of damage to a flood protection system, including:

- burrows and tunnels within the embankment which can lead to sinkholes and piping
- block culverts and floodgates with wood debris and cause internal flooding
- fall trees across the dike fill preventing vehicle access



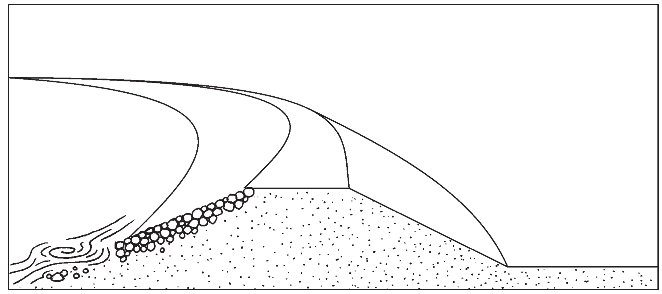
- Note: beavers will burrow from a calm body of water for several metres to reach drier dike embankment material

Possible Action

- Livestock access to the embankment should be discouraged. Where damage is noted grading of the surface and re-sowing of ground cover to prevent erosion is recommended.
- Rodent control is best achieved through the management of vegetation of the embankment surfaces to ensure that habitat conducive to rodents is not established. Where rodents have become established it is imperative to remove the rodents and habitat.
- Rodent burrows need to be excavated and re-filled with compacted fill material similar to the original fill of the embankment. In extreme cases "wire" mesh can be placed over the embankment slope to discourage rodent activity.
- Removal of beaver dams, trapping of beavers for re-location of the beaver colony.

Toe Scour

Toe scour is the deepening of the river bed by the removal of material adjacent and below the toe of the riprap. Since riprap is very expensive to produce and install, it is usually only placed where there is the greatest possibility of active erosion taking place (such as the outside bends in rivers). Inherently, these areas often have the highest water velocities. This fact makes toe scour a very real possibility. Once undermined by the actions of the river the toe portion of the riprap may sink into these holes causing the upper rock to be displaced, resulting in a much steeper slope or complete loss the rock protective layer. If the riprap or erosion protection is displaced or lost the embankment fill becomes vulnerable to erosion and possible breaching. Toe scour can occur rapidly if there is a sudden change to the normal flow of the river due to the formation of log jams, ice jams, shifting river bed materials or man made obstacles. Some toe scour may occur after placing riprap on previously



unprotected slopes.

Annual visual inspection of the riprap surface at low water, either walking at water level or from a boat is required. The riprap surface and alignment should be continuous and relatively smooth so that the floodwaters, floating debris and backeddies do not remove rocks from the riprap. If the riprap surface appears to be slumping down into the water it is an indication that toe scour may be initiating.

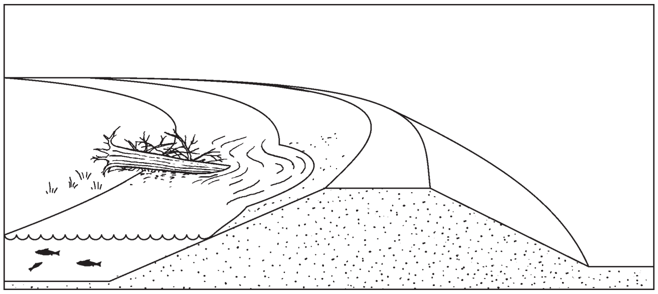
Possible Action

- If inspection indicates the possible presence of toe scour, repair as soon as physical conditions (easier to do during low water) and regulations allow. Often early recognition and repair prevents more widespread damage.

Changing river flow patterns

The natural tendency of rivers to meander can change areas of direct impingement (areas that are subject to erosion) however this is usually a relatively slow process. When it does occur quickly, it is usually as a result of:

- Ice jams
- Log jams
- Landslides
- Man made alterations
- Erosion (mid-stream bars)
- Gravel bars/deposition



These additional erosive forces applied against existing bank protection works or unprotected areas can increase the chance of dike failure.

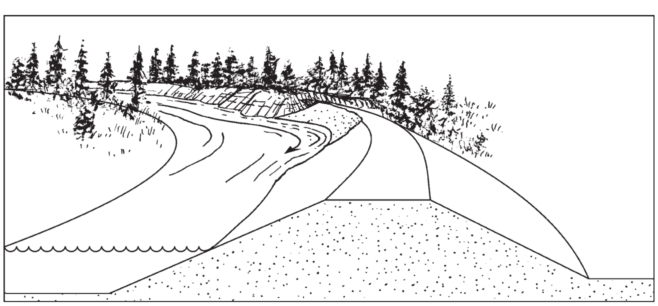
Possible Action

- If there is an immediate and direct threat to the integrity of the flood protection system and such failure would lead to widespread flooding , then the local emergency plan must be activated and emergency repairs made.
- If only minor erosion takes place, steps should be taken to either reinforce the new impingement area or correct the in-stream obstruction.
- As the flow pattern change may be a slow process, monitor areas of impingement.

Outflanking

Outflanking is the loss of the riprap's supporting (underlying) material at or near its upstream extremity. This can cause rapid loss of not only the remaining downstream riprap but the now exposed dike as well. This can be caused by:

- not connecting erosion protection material to a hardpoint
- not extending the riprap upstream far enough (well past area subject to erosion at time of construction)
- improperly constructed upstream key



- sudden and unexpected change in the river flow pattern causing erosion of the bank material upstream of the existing bank protection works

The most vulnerable time for outflanking to occur is during high water conditions. The upstream extremity of all erosion protection works should be constantly checked at this time.

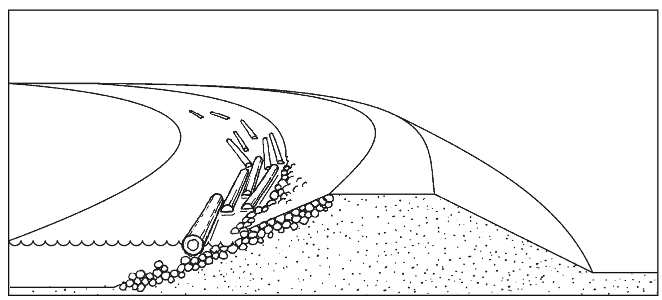
Possible Action

Early detection and reinforcement of the upstream key is by far the best way to combat outflanking once it has started.

Ice and Floating Logs (Trees)

Moving ice can exert extremely powerful forces which can grind down and/or displace large sections of riprap. The result is weakening or complete loss of erosion protection.

During high water conditions, upstream logs are floated and mobilized by the current as are uprooted trees. If the current takes them near riprap they can displace rock by simply scraping along it or by



ramming into the rock then swinging around in a downstream direction, prying the rock loose in a lever like action.

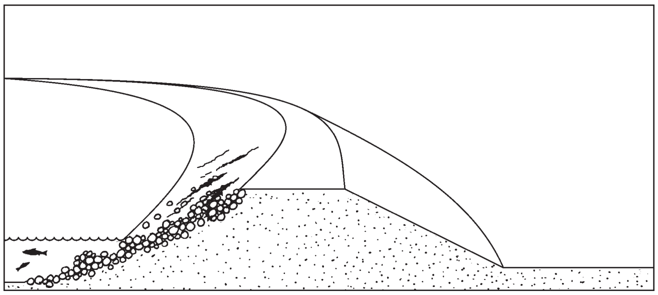
Possible Action

- Monitor erosion rates and do necessary reinforcing if needed.

Degrading (Weathering)

Degrading is the chemical or mechanical disintegration of rock used in the riprap surface. Degradation can significantly affect the engineering properties of the rock and the rock mass, reducing its effectiveness as an erosion protection barrier. Certain types of rock are more susceptible to degrading and it is therefore critical to consider this factor in the selection of material for the erosion protection or when maintaining the riprap.

Degradation can be caused by severe temperature changes (freeze and thaw cycle), sun, wind, rain, abrasion, plant and animal activity, and chemical action. The effects of weathering of the rock generally decrease with depth of the erosion protection.



However, the actions of waves and ice-flows on the erosion protection may accelerate the degradation of the riprap.

Riprap should be inspected annually for degradation by walking along the protected surface of the embankment to observe the condition of the riprap. Riprap that is fracturing or crumbling is evidence of degradation. Look for cracks, spalls and use a rock hammer to test for soundness.

Possible Action

- Monitor the erosion protection material for any sudden changes. Degradation may increase with age of the material. Where concerns are noted it may be appropriate to have the erosion protection material tested in an engineering laboratory.
- Where identified, initiate immediate repairs as soon as physical conditions and regulations allow. This may involve the removal of degraded material and replacement with appropriate materials.
- Photograph and mark the areas for later inspection.

Floodboxes

A floodbox is a culvert through the dike that allows the normal passage of water (by gravity) from internal drainage systems to the river/ocean. It has a valve or gate that can close during highwater conditions preventing backflow from the river/ocean to the land protected by the dike. Debris blockage or improperly or partially closed gates can cause internal flooding. The floodbox can sustain damage as a result of:

- Internal or differential settlement, separation
- Corrosion
- Lack of maintenance
- Ice damage
- Damage by floating logs and debris
- Gravel and sand deposition
- Concrete deterioration
- Vandalism
- Beaver (rodent) activity

Floating debris from the internal drainage system can also become lodged in the culvert. Trash racks or floating debris catchers are often placed at or near the culvert intake. They too can become clogged.

Blocked floodbox outlet.

Since the outside surface of the culvert is relatively smooth, it presents a possible avenue for a seepage path. Cutoff collars which increase the seepage path are routinely placed around the culvert pipe during installation. However, older dikes may not have been fitted in this way. All joints within the culvert itself are susceptible to leakage, settlement and/or corrosion.

Ensure that inspection is done both internally and externally and when installed, including looking up the barrel or culvert with a flashlight. Check the freedom of the gate to move; difficulty may indicate corrosion or blockages.

Possible Action

- Reduce effects of floating debris by the installation of trashracks or floating booms.
- Clean out intake and outlet areas regularly.
- Install protective guards at the outlet.
- Use corrosive resistant paints on metal surfaces.

Pumps and Pumping Stations

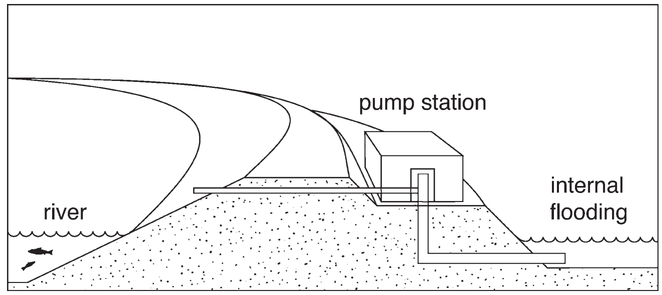
In areas where the closing of the floodbox gate would cause serious internal flooding, pumps are employed to carry the water over the dike and discharge it into the river/ocean. Permanently mounted pumps contained within a building are called pumping stations. If a pump fails, internal flooding can result.

As with any mechanical/electrical device, a pump/pump station has certain potential problems such as:

- Weather damage (e.g. electrical supply lines)
- Corrosion
- Lack of maintenance
- Inlet and outlet debris blockages
- Gate leakage
- Ice damage
- Motor or engine malfunction
- Blocked access
- Vandalism
- Damaged fuel storage or electrical feed installations
- Damaged control units

Regular maintenance and working knowledge about pumps is essential to prevent and repair any problems.

Inspection should include running the pumps, checking to ensure pumps are operating according to specifications, checking switching devices and ensuring power sources are operative.



Possible Actions

- Emphasize testing, maintenance and repair.
- Ensure a copy of all operating and maintenance procedures are located in the pumping station.
- Train operating personnel.
- Place guards, locks, warning signs etc. to combat vandalism.

Relief Wells

Relief wells may be installed near the land side toe of the dike to reduce potentially damaging uplift pressure from foundation seepage. Uplift pressure from excessive seepage during high water can cause internal erosion of foundation material or embankment instability.

Properly installed relief wells aid in controlling the location and quantity of seepage under a dike. Turbid water in the well may indicate piping in the foundation materials.

Possible Action

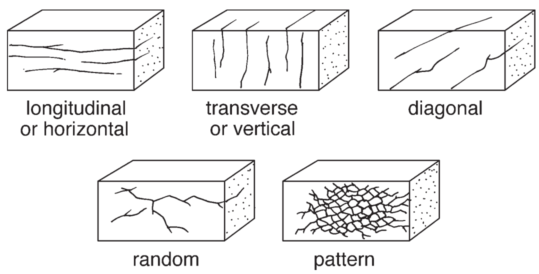
- Build a sandbag ring around the well.
- Check wells periodically for silt buildup and flush wells clear of fine material when necessary.

Concrete Deterioration

Concrete is used in flood control structures such as floodbox headwalls, certain types of erosion control, weirs, drop structures, footbridges and pumpstations. There are a number of ways that concrete can deteriorate that causes it to lose strength, separate or break apart. This deterioration can weaken the design strength of a concrete structure and even cause it to fail. It can also result in distortion of a structure such as a slide gate, causing binding.

The types of concrete deterioration are:

Cracking - usually caused by poor foundations (settlement), weathering, excessive stress, poor workmanship or inadequate concrete mix design. The five basic cracking patterns are longitudinal (horizontal), transverse (vertical), diagonal, random and pattern.



Disintegration - crumbling into small particle

Spalling - loss of small pieces of concrete especially at edges

Efflorescence - leaching of calcium compounds from within the concrete and deposition on the surface

Drummy Concrete - weakness beneath the surface detected by a hollow sound when struck with a hammer

Popouts - small portion of the concrete surface that breaks away due to internal pressure

Pitting - small cavities in the concrete surface.

Scaling - peeling away of a concrete surface

Faulty concrete mixes - poor strength

Chemical attack - by sulfates, acids, or an alkali-aggregate reaction

Metal corrosion of the reinforcing steel - by the formation of iron oxide (rust) often caused by salt contact

Erosion - by fast moving water containing abrasive material such as sand and gravel, debris and ice

Cavitation - caused when water flowing at high velocity suddenly changes direction causing areas of low pressure sufficiently strong enough to pluck out individual pieces of aggregate. This sometimes occurs near pump intakes.

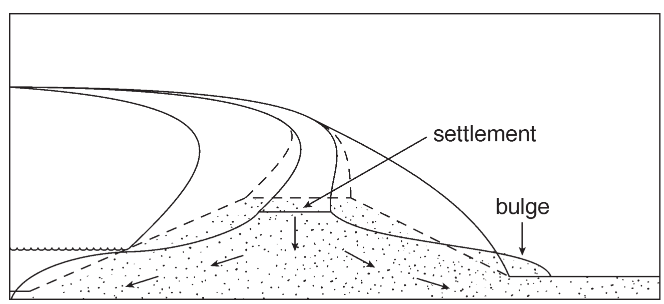
Possible Actions

- Monitor routinely.
- Repair minor external damages.
- Major problems affecting the performance and/or safety of the appurtenant works require expert advice.

Possible Effects of Earthquakes

Large earthquakes have the potential to severely damage flood protection works in British Columbia. The most pronounced effect of a severe earthquake on dike fill is likely to be settlement and lateral spreading (resulting in loss of crest elevation). A severe earthquake could result in widespread damage to the flood protection system which could not be completely repaired before high water conditions occur, especially in tidal areas.

The effects of an earthquake on dikes could be intensified by the liquefaction of the foundation material during an earthquake. Liquefaction is more likely to occur in saturated foundations and embankments comprised of loosely compacted, non-plastic soils such as sand and silts. These soils, when subjected to earthquake shaking, may become “quick” and may flow resulting in deformation or failure of the dike. Some cracking and structural faults in the embankment may be difficult to detect, because of overlying structures or vegetation.



Possible Action

- Follow the guidelines in the local emergency plan, and when safe, make a rapid surveillance inspection of the entire flood protection system.
- A detailed examination of the works may be advisable to locate hidden problems.

Uncontrolled Vegetation Growth on Erosion Protection Works.