Newfoundland Labrador

Water Resources Management Division

Dam Break Inundation Mapping and Emergency Management for Water Supply Dams

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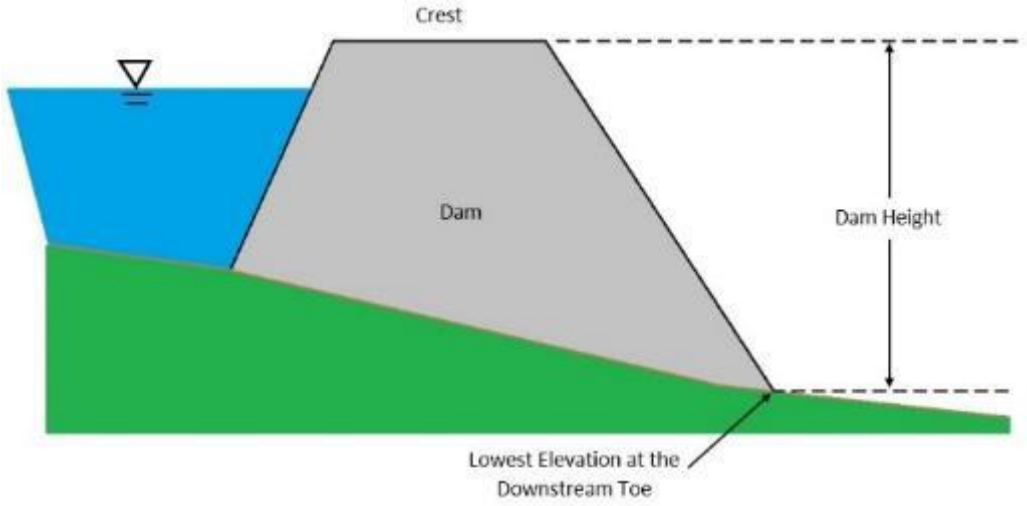
Outline

- What is a Dam?
- Water Supply Dam Failures in NL
- Dam Break Inundation Mapping
- Dam Consequence Classification
- Emergency Plans
- Halifax Case Study
- Key Messages

What is considered a dam in NL?



- Canadian Dam Association based definition
  - A barrier constructed for the retention of water
    Impounds at least 30,000 m^3, or
    - 2.5 m in height measured vertically from the crest to the downstream toe
  - Includes all appurtenances and systems associated with the barrier (eg. intakes, gates, stoplogs, valves, fishways, etc.)

- Very Small Dam
  - a barrier constructed for the retention of water, including water containing other substances, that is greater than 1.0 meter and less than 2.5 meters in height, and that is not otherwise defined as a dam

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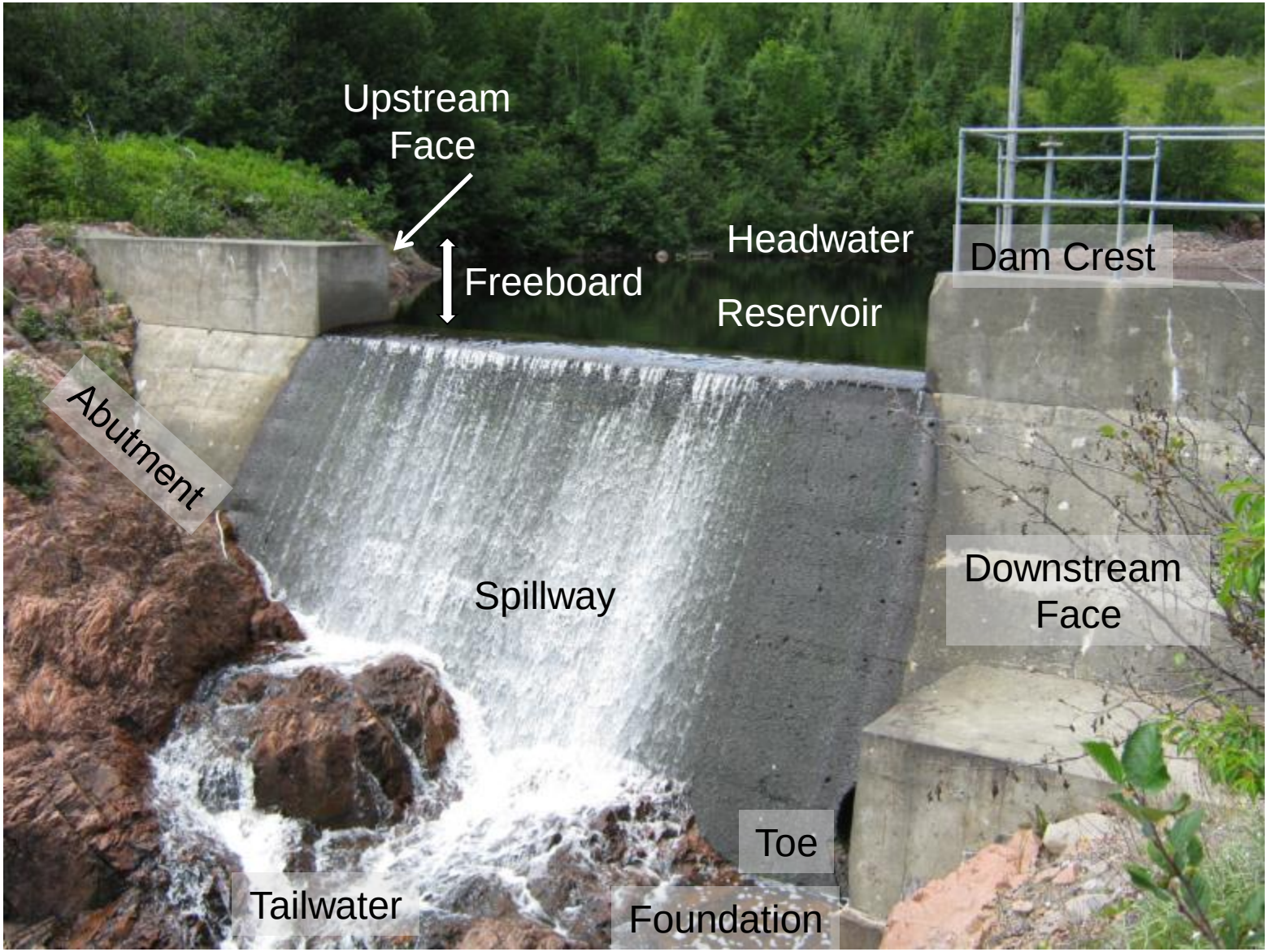
Components of a Dam



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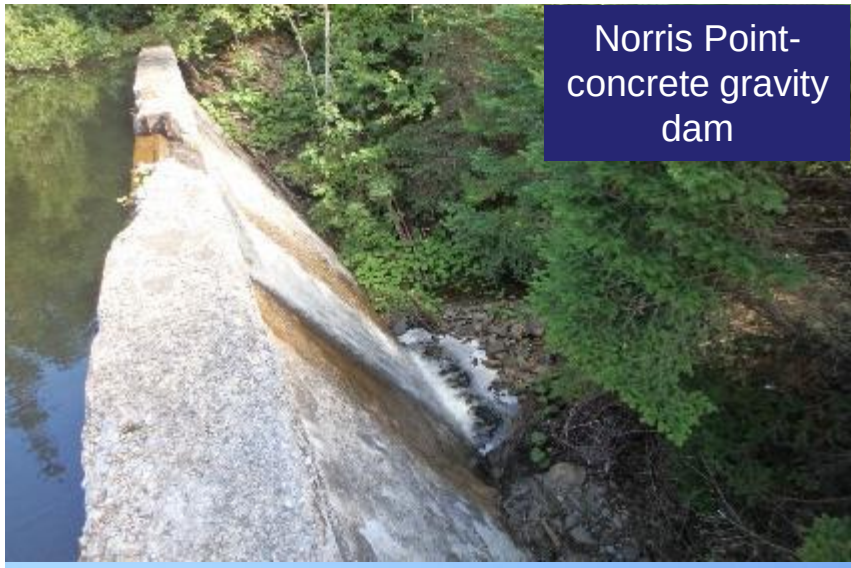
Common Types of Water Supply Dams in NL

Anchor Point- embankment dam with concrete spillway



Norris Point- concrete gravity dam

Tizzard's Harbour- timber/rock crib dam

Mainland- concrete wall dam

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Canadian Dam Association

CDA ACB Canadian Dam Association / Association canadienne des barrages

- Group of Owners, Operators, Regulators, Consultants and Suppliers interested in dam safety
- Provides a forum for the exchange of ideas and experience in the field of dam safety
- Dam Safety Guidelines (2013)
  - Recommend dam owners have:
    - Emergency Preparedness and Response Plan
    - Operation, Maintenance and Surveillance Manual
- Technical Bulletin: Emergency Management for Dam Safety (2019)

- 2022 Conference in St. John's in October 17-19
  - Special Introduction to Dam Safety Session to be offered

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Dam Failure

- An uncontrolled release of the contents of the reservoir
- Two main types:
  - Sunny day dam failure
    - Piping or internal erosion
  - Flood induced dam failure
    - Overtopping
- 14 water supply dams have failed in NL since 1985
  - 38% probability of a water supply dam failure in any given year (1:2.6)

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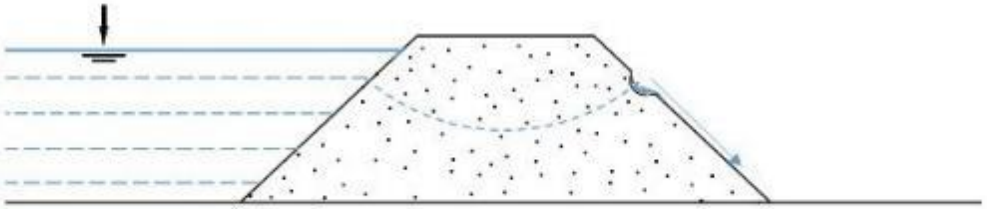
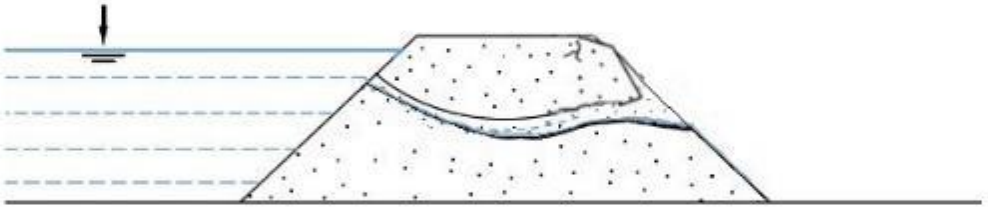
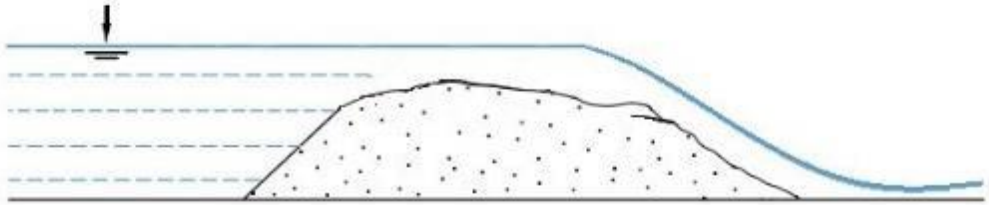
Sunny Day Dam Failure: Earthen Dam



Over time, seepage flow through an embankment can lead to internal erosion, beginning at the downstream slope.



Earthen material is carried out of the embankment by the flow of water, and the resulting void or "pipe" begins to expand.



When the pipe becomes too large, the section of embankment above may collapse, leading to a failure.

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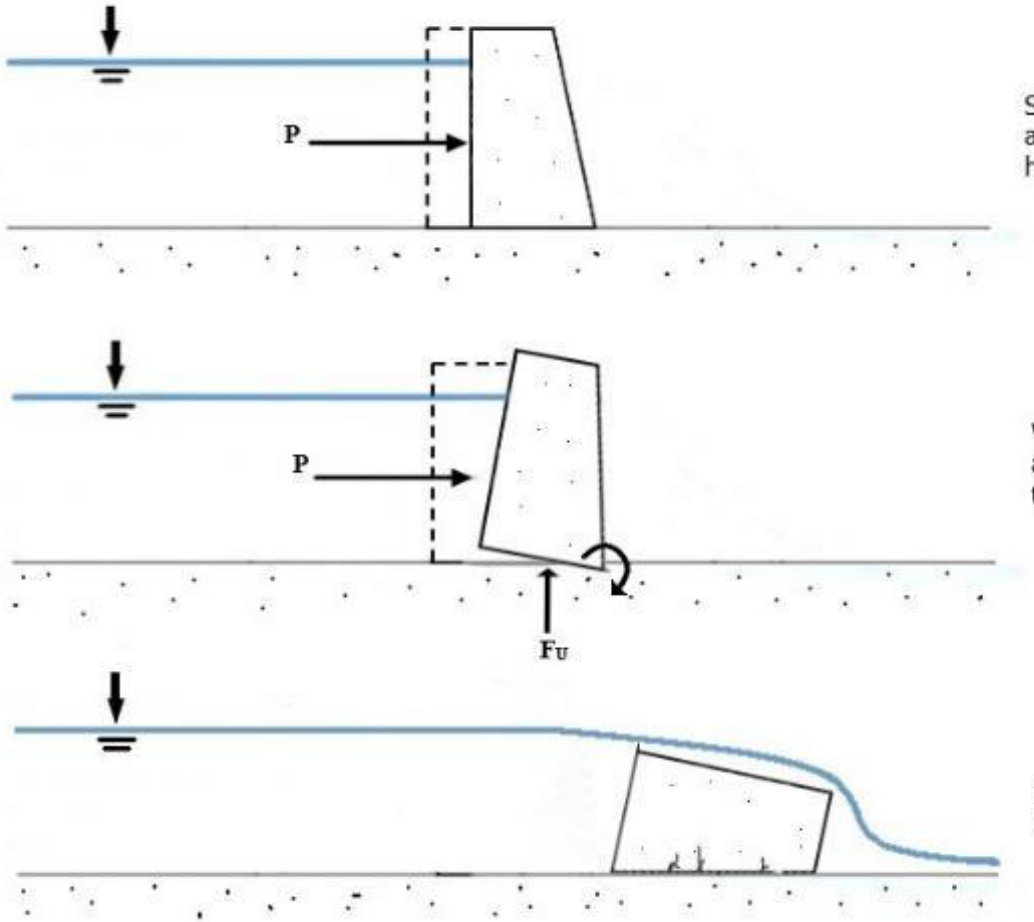
Sunny Day Failure: Concrete Dam



Sliding occurs when the force due to water pressure acting on a dam overcomes the frictional force which holds the dam in place.

Water seeping through the soil under the dam will also apply some pressure, creating an uplift force that can cause tipping.

Sufficient forces will cause the dam to overturn, resulting in failure.

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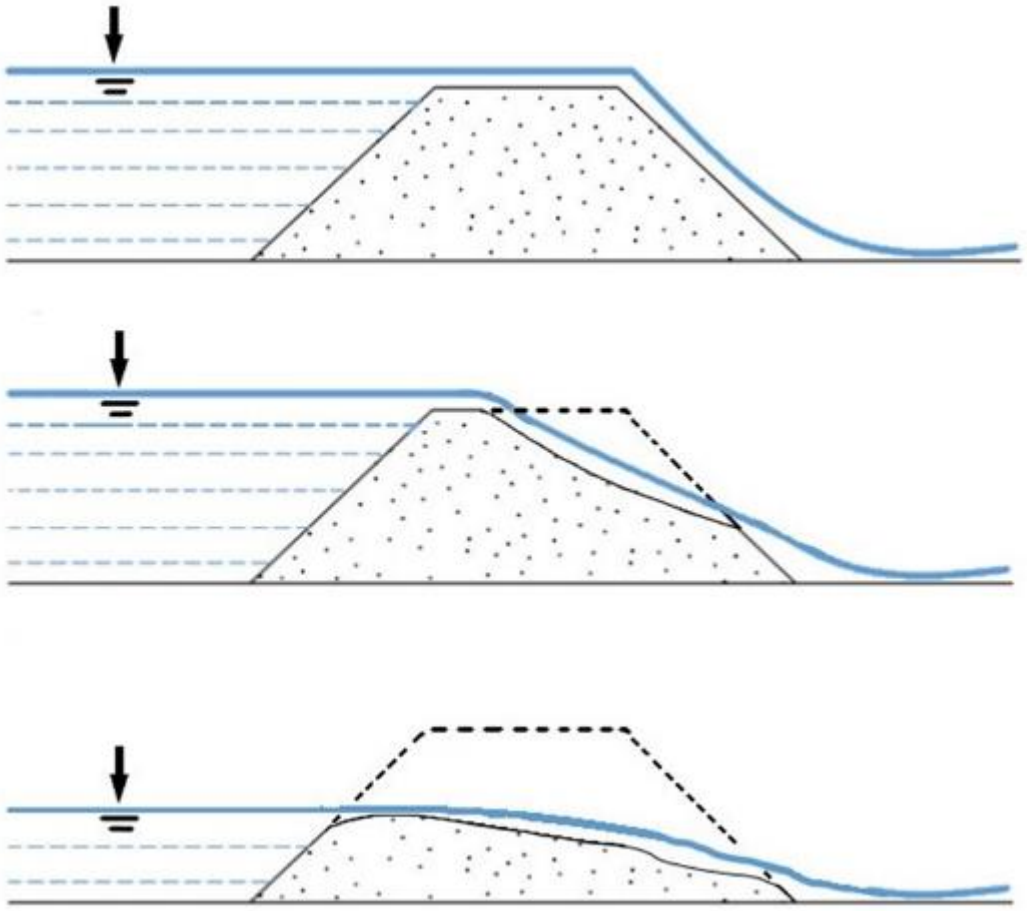
Flood Induced Dam Failure



Storage capacity of the reservoir is exceeded, water begins to flow over top of the embankment.

Shear stress produced by the flowing water erodes the downstream surface of the embankment.

Failure leads to an uncontrolled release of water from the reservoir.

Sunnyside Water Supply Dam Failure

- Occurred in September 2010 (Igor)
- Breach washed away all earthen embankments, undermined the spillway and pump house
- Significant damages to municipal infrastructures

Hermitage-Sandyville Water Supply Dam Failure

- Earth dam washed out due to significant rainfall amounts in April 1998
- Town without drinking water
- Access to community cut
- Dispute over dam ownership may have resulted in failure
  - Improper operation and management practices
- Estimated costs failure approximately $3-million

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King's Point Dam Failure

- Caused by localized heavy rain on June 8, 1995 from tail end of a hurricane
- Flooding compounded by snow cover in headwater area contributing to runoff with warm temperatures
- 10 m section of earthfilled dam on the north side of the concreted spillway failed and left community without drinking water
- Reservoir went dry in a matter of minutes

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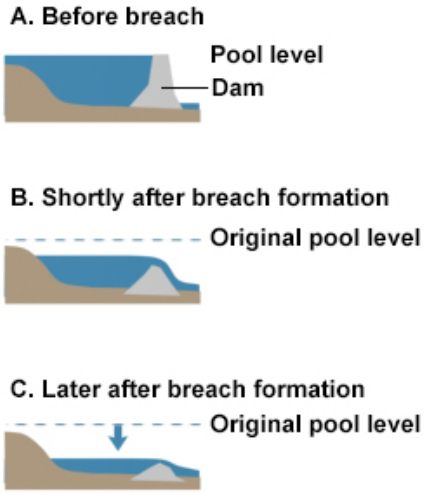
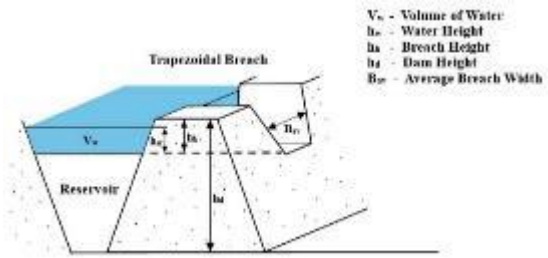
Piccadilly Head Water Supply Dam Failure

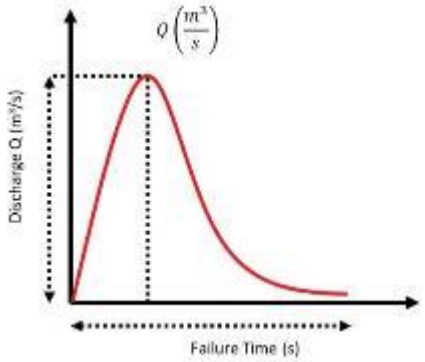
- LSD noticed dam was leaking in Aug 2016
- Internal erosion evident by a whirlpool in reservoir which was cutting into left embankment
- Downstream seepage ~50-75 GPM
- $20,000 for emergency repairs

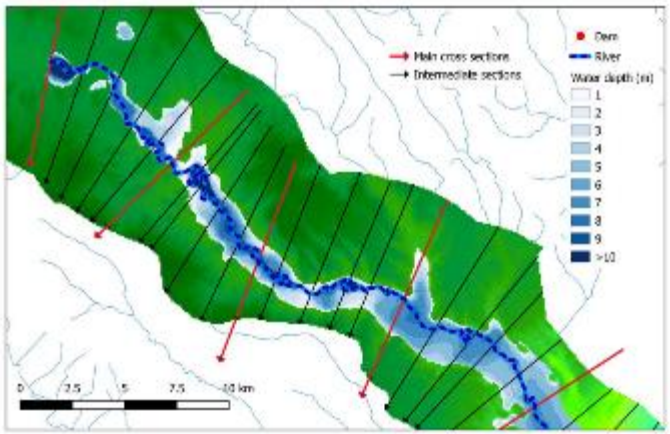
What is Dam Break Analysis and Inundation Mapping?

- A dam break analysis is used to determine:
  - Discharge from a hypothetical breach of a dam as the breach forms and the reservoir drains
  - Flood wave routing to follow the progress of the dam breach wave downstream from the dam until effects are negligible
- Dam break analysis is used to develop a map of the inundated area based on water levels and land elevation









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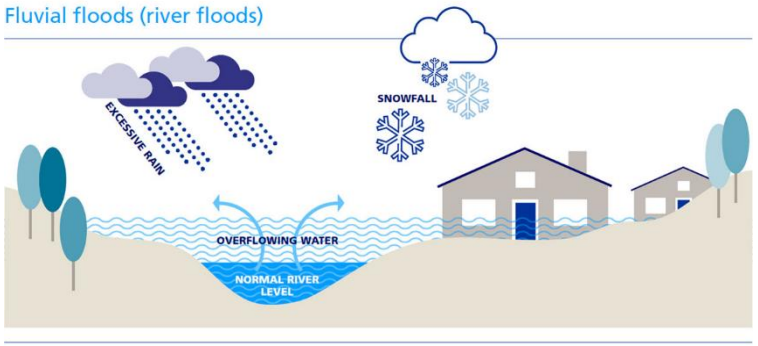
Difference between Dam Break Inundation and Floodplain Mapping

- Dam Breach Inundation Mapping
  - Flood wave due to release of contents of reservoir after a dam failure
  - Can occur on a sunny day or during a rainfall event
  - During a flood-induced dam failure, there may also be fluvial flooding
    - Just as bad as the dam failure flood wave

- Floodplain Mapping
  - Occurs during a rainfall event
  - WRMD has separate mapping for flood risk: https://www.gov.nl.ca/ecc/waterres/flooding/frm/



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Uses of Dam Break Inundation Maps

- Dam consequence classification
  - To identify impacts on population at risk, infrastructure, property, environment
  - Hazard creep
- Emergency management
  - Emergency planning and preparedness
    - Identify evacuation routes
    - Opportunities for building resiliency through land use planning, etc.
      - Bridge/culvert a source of constriction, causing flooding→ increase size
      - Park vs. hospital in a flood area
  - Emergency response
    - First responders

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Dam Break Analysis and Inundation Mapping Methods

- Method of analysis should reflect the required level of accuracy

- Simple
  - More conservative
  - Used as a first approximation and more detailed analysis can be conducted if needed
  - Simplified photo-based topographic mapping method
  - OK to use if no population downstream of dam

- Complex
  - More detailed and accurate
  - Using models
    - HEC-RAS
  - Can run various scenarios
  - Use if there is a population downstream of dam

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NL Water Supply Dams

- 189 water supply dams in the province (both active and inactive)
- Dams classified into three priority levels:
  - Priority 1- population at risk or major infrastructure downstream of dam
  - Priority 2- minor infrastructure downstream of dam
  - Priority 3- no population or infrastructure downstream of dam

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Developing Mapping for NL Water Supply Dams

- 2 NDMP co-funded projects
  - 2018-20 (Golder- complete)
  - 2021-22 (Hatch- in progress)
- Maps developed to date:
  - 41 Priority 1 (complex method)
  - 99 Priority 2 (simplified method)
- 20 additional maps in development using complex method
  - Priority 2 simplified maps that indicated possible population at risk
- Communities given an opportunity to review and provide comments on maps

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Dam Breach Analysis and Mapping

- Simple method:
  - Downstream wave heights are determined based on the height of the dam and distance from the dam downstream (wave height halves every ~16 km)
  - Flood waves are routed to the ocean or large waterbody downstream
  - Results are transferred onto topographic maps to develop the inundation maps
- Complex method:
  - A "sunny-day" scenario
    - Each dam was assumed to breach due to structural failure for concrete and timber crib dams, or via piping in the case of the embankment dams.
  - A "flood-induced" scenario
    - The Probable Maximum Flood (PMF) inflow for each dam is established and the structures are forced to fail under that PMF
  - Hydrodynamic models for the sites were developed using HEC-RAS
  - Models were used to simulate the hydraulic effects of flood flows to prepare inundation maps
  - The results of each HEC-RAS model were input into ArcGIS mapping software and overlaid on aerial imagery and topographic maps to show the extents of the flooding throughout the downstream region

Simple vs. Complex

- Simplified method more conservative, but still fairly accurate
- Conservative is good for emergency response (worst case)
- Never get the perfect map- different users have different needs

St. Anthony Bight: simple method

St. Anthony Bight: complex method

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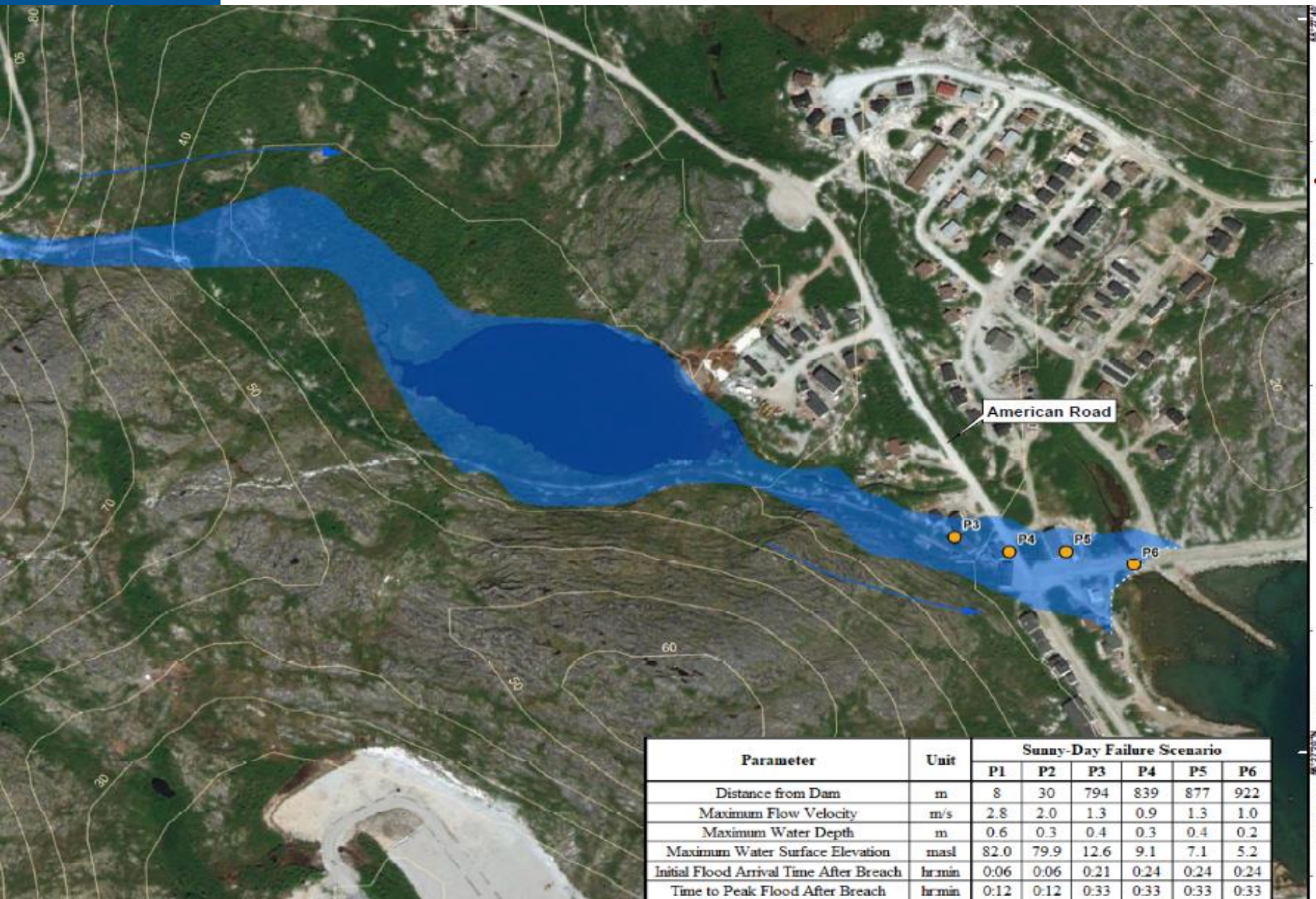
Dam Break Inundation Map Features

- Inundation Area
  - Shows area that will be impacted by dam break flood wave including homes, roads, etc.
- Points of Interest/Cross-Sections
  - Show distance from the dam at points of interest
- Maximum Flow Velocity
  - Maximum water velocity during a flood event gives indication of the force of water on an object (human stability in flood waters is dependent on water depth, velocity, and the person's height and weight)
- Maximum Water Depth
  - Highest water level experienced during the flood event
- Flood Arrival Time
  - The available time for evacuation once the dam is breached.
- Peak Flood Arrival Time
  - Time to maximum water depth during the dam breach and when most damage is expected
- Inundation Duration
  - An estimation of the length of time flooding will be experienced

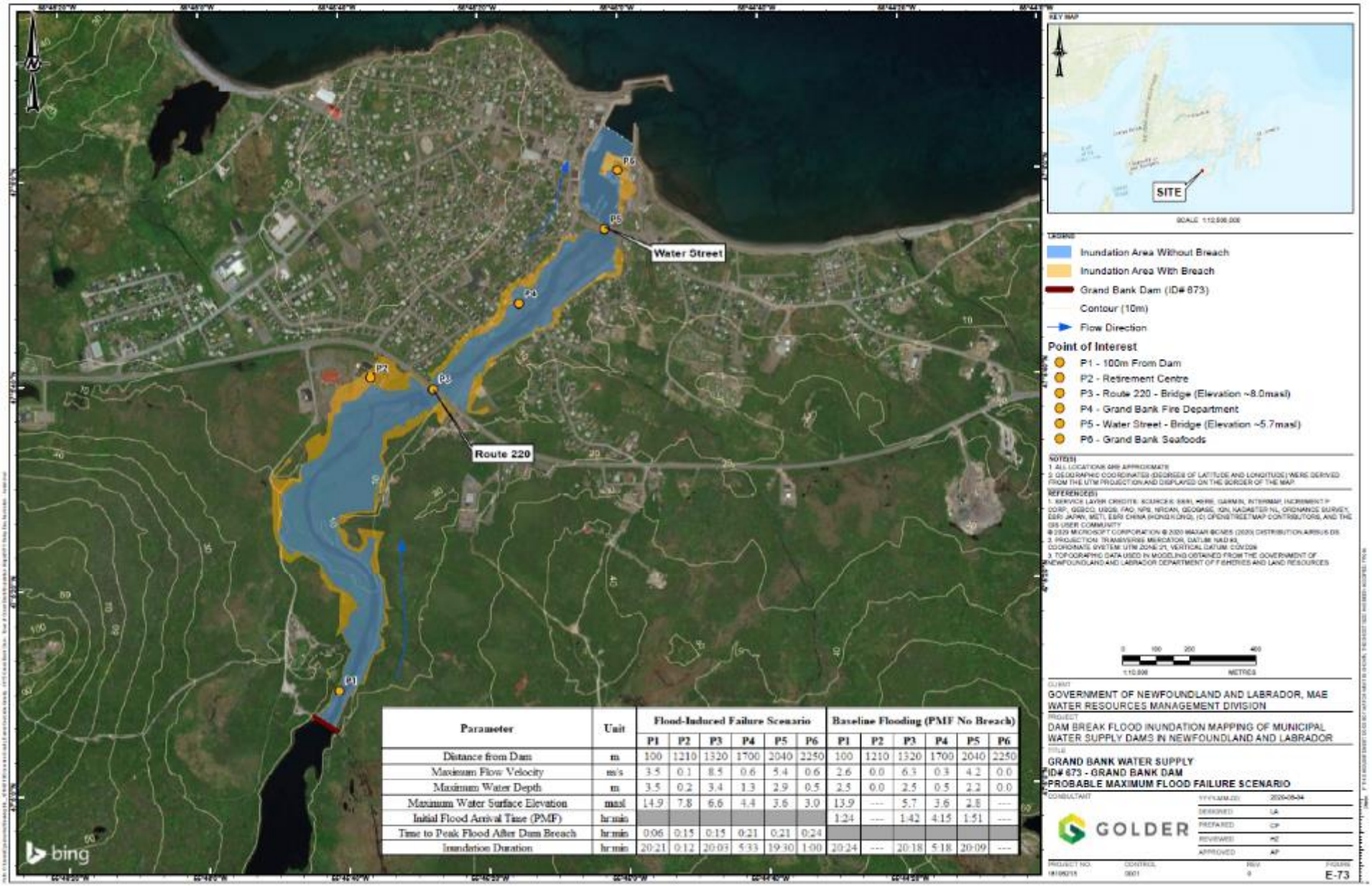
Hermitage-Sandyville: Simplified Method

Hopedale: Sunny-Day Failure



Parameter	Unit	Sunny-Day Failure Scenario					
		P1	P2	P3	P4	P5	P6
Distance from Dam	m	8	30	794	839	877	922
Maximum Flow Velocity	m/s	2.8	2.0	1.3	0.9	1.3	1.0
Maximum Water Depth	m	0.6	0.3	0.4	0.3	0.4	0.2
Maximum Water Surface Elevation	masl	82.0	79.9	12.6	9.1	7.1	5.2
Initial Flood Arrival Time After Breach	hr:min	0:06	0:06	0:21	0:24	0:24	0:24
Time to Peak Flood After Breach	hr:min	0:12	0:12	0:33	0:33	0:33	0:33

Grand Bank: Flood-Induced Failure



Parameter	Unit	Flood-Induced Failure Scenario						Baseline Flooding (PMF No Breach)					
		P1	P2	P3	P4	P5	P6	P1	P2	P3	P4	P5	P6
Distance from Dam	m	100	1210	1320	1700	2040	2250	100	1210	1320	1700	2040	2250
Maximum Flow Velocity	m/s	3.5	0.1	8.5	0.6	5.4	0.6	2.6	0.0	6.3	0.3	4.2	0.0
Maximum Water Depth	m	3.5	0.2	3.4	1.3	2.9	0.5	2.5	0.0	2.5	0.5	2.2	0.0
Maximum Water Surface Elevation	masl	14.9	7.8	6.6	4.4	3.6	3.0	13.9	---	5.7	3.6	2.8	---
Initial Flood Arrival Time (PMF)	hr:min							1:24	---	1:42	4:15	1:51	---
Time to Peak Flood After Dam Breach	hr:min	0:06	0:15	0:15	0:21	0:21	0:24						
Inundation Duration	hr:min	20:21	0:12	20:03	5:33	19:30	1:00	20:24	---	20:18	5:18	20:09	---

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CDA Dam Classification

Dam Class	Population at Risk	Loss of Life	Infrastructure & Economic Losses
Low	None	0	-Low
Significant	Temporary	Unspecified	-Moderate (eg. recreational facilities)
High	Permanent	10 or fewer	-High (eg. commercial facilities)
Very High	Permanent	100 or fewer	-Very high (eg. highway)
Extreme	Permanent	More than 100	-Extreme (eg. hospital)

- A classification system based on the consequences of a dam failure
- Environmental and cultural value losses can also be included

Consequence Classification: Kings Point

- Flood-Induced Failure
  - Consequence classification (preliminary): Significant
  - Estimated Order of Magnitude of Losses: 0-$300,000
  - Total Permanent Population at Risk(PAR): 0
- Similar consequences to what was observed when this dam failed

Background Info					
Dam Name and Number:	#727 Bulley's Pond Dam				
Owner:	Town of King's Point				
Communities Affected:	Town of King's Point				
Transportation Routes Affected:	Main Street				
Flood-Induced Failure Consequence Assessment					
Infrastructure Type	**Number Affected**	**Unit**	**Cost Per Unit**	**Total Repair Costs**	**Reference**
Gravel Road	5	metre	$40.40	$201.98	Gov NL PPA, 2018/2019
Estimated Incremental Loss				**$201.98**	
Estimated Order of Magnitude of Losses				**$0 - $300,000**	
Permanent Population at Risk (total)				**0**	
Permanent Population at Risk (within first three hours)				**0**	
Temporary Population				**Yes - Transportation Routes**	
Loss of Water Supply				**Yes**	
Preliminary CDA Dam Classification (not accounting for loss of water supply)				**Significant**	
Preliminary CDA Dam Classification (accounting for loss of water supply)				**High**	

Emergency Management Plan

- Under the Emergency Services Act, municipalities are required to adopt an Emergency Management Plan
  - Add Dam Failure as a Potential Hazard (where there could be loss of life)
- Incorporate dam break inundation mapping into Municipal Emergency Management Plan
  - How to prepare and manage response to a dam failure
  - Assist in determining areas requiring evacuation during a potential dam break
- Dam owners should routinely exercise their emergency plans

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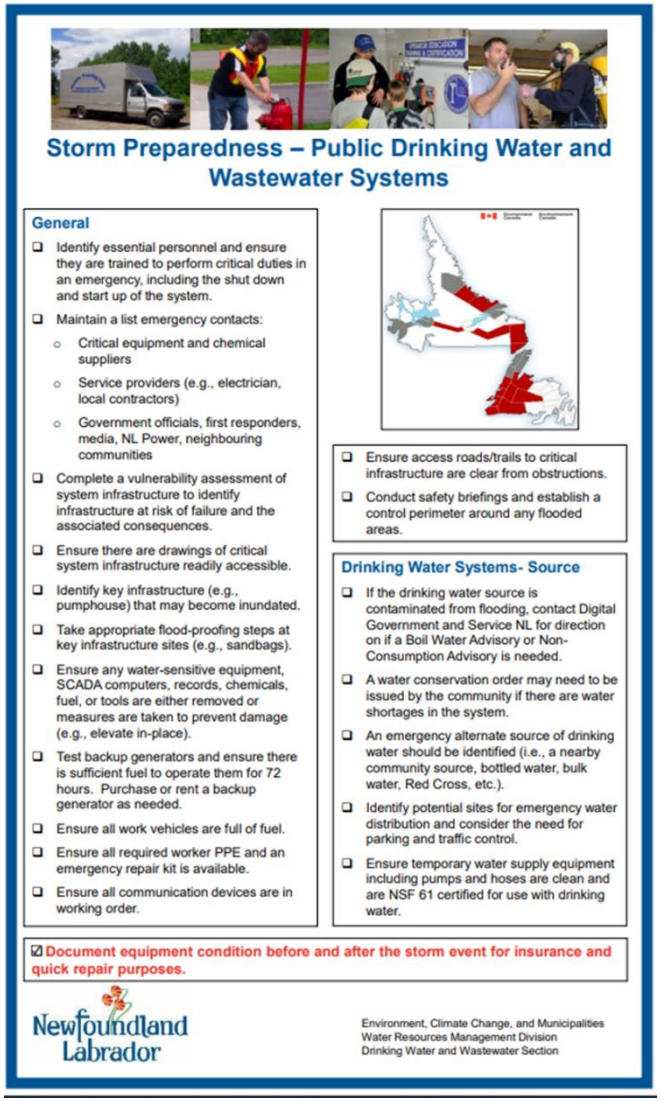
Pre-Emergency

- Keep Emergency Management Plan (EMP) up to date
  - Contact lists
  - Roles and responsibilities
- Test out Emergency Management Plan
  - Tabletop exercise to a full-scale simulation
- Identify dam failure hazard in EMP
- Need to identify conditions that should activate emergency response for a dam hazzard
  - Water level at crest of embankment
- Inspect dam
  - Also before major precipitation events
  - How dam might fail:
    - Failure modes
- Look for unusual conditions in time to take action to reduce likelihood of dam failure
  - Turbid seepage
- Follow operating procedures for flood conditions:
  - Remove debris blocking spillway
  - Remove stoplogs

Standard Operating Procedures



Storm Preparedness – Public Drinking Water and Wastewater Systems

General

- ❑ Identify essential personnel and ensure they are trained to perform critical duties in an emergency, including the shut down and start up of the system.
- ❑ Maintain a list emergency contacts:
  - Critical equipment and chemical suppliers
  - Service providers (e.g., electrician, local contractors)
  - Government officials, first responders, media, NL Power, neighbouring communities
- ❑ Complete a vulnerability assessment of system infrastructure to identify infrastructure at risk of failure and the associated consequences.
- ❑ Ensure there are drawings of critical system infrastructure readily accessible.
- ❑ Identify key infrastructure (e.g., pumphouse) that may become inundated.
- ❑ Take appropriate flood-proofing steps at key infrastructure sites (e.g., sandbags).
- ❑ Ensure any water-sensitive equipment, SCADA computers, records, chemicals, fuel, or tools are either removed or measures are taken to prevent damage (e.g., elevate in-place).
- ❑ Test backup generators and ensure there is sufficient fuel to operate them for 72 hours. Purchase or rent a backup generator as needed.
- ❑ Ensure all work vehicles are full of fuel.
- ❑ Ensure all required worker PPE and an emergency repair kit is available.
- ❑ Ensure all communication devices are in working order.

- ❑ Ensure access roads/trails to critical infrastructure are clear from obstructions.
- ❑ Conduct safety briefings and establish a control perimeter around any flooded areas.

Drinking Water Systems- Source

- ❑ If the drinking water source is contaminated from flooding, contact Digital Government and Service NL for direction on if a Boil Water Advisory or Non-Consumption Advisory is needed.
- ❑ A water conservation order may need to be issued by the community if there are water shortages in the system.
- ❑ An emergency alternate source of drinking water should be identified (i.e., a nearby community source, bottled water, bulk water, Red Cross, etc.).
- ❑ Identify potential sites for emergency water distribution and consider the need for parking and traffic control.
- ❑ Ensure temporary water supply equipment including pumps and hoses are clean and are NSF 61 certified for use with drinking water.

☑ Document equipment condition before and after the storm event for insurance and quick repair purposes.

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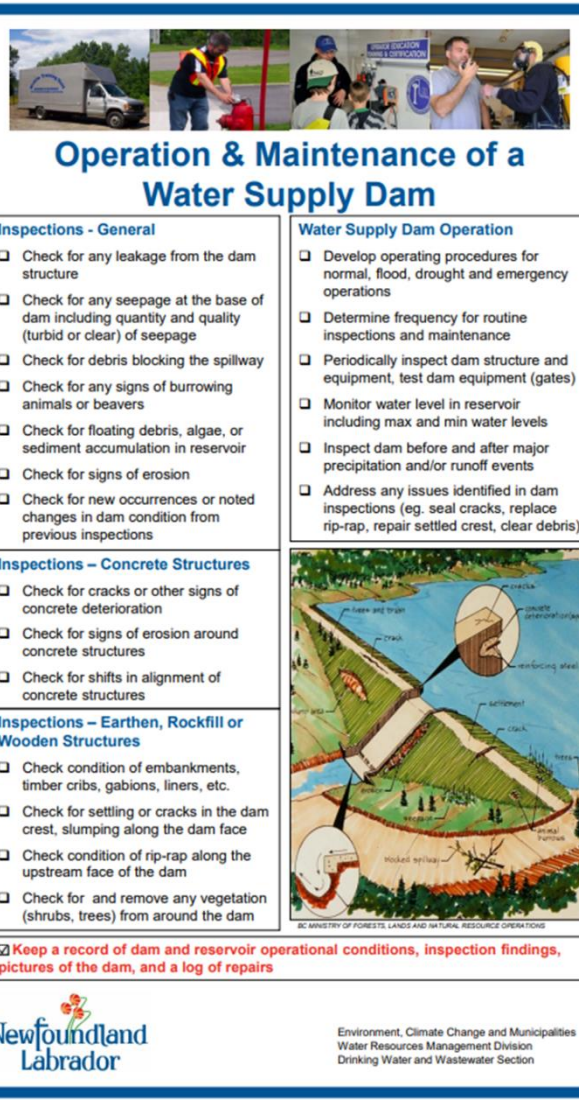
Water Resources Management Division
Drinking Water and Wastewater Section



Operation & Maintenance of a Water Supply Dam

Inspections - General

- ❑ Check for any leakage from the dam structure
- ❑ Check for any seepage at the base of dam including quantity and quality (turbid or clear) of seepage
- ❑ Check for debris blocking the spillway
- ❑ Check for any signs of burrowing animals or beavers
- ❑ Check for floating debris, algae, or sediment accumulation in reservoir
- ❑ Check for signs of erosion
- ❑ Check for new occurrences or noted changes in dam condition from previous inspections

Water Supply Dam Operation

- ❑ Develop operating procedures for normal, flood, drought and emergency operations
- ❑ Determine frequency for routine inspections and maintenance
- ❑ Periodically inspect dam structure and equipment, test dam equipment (gates)
- ❑ Monitor water level in reservoir including max and min water levels
- ❑ Inspect dam before and after major precipitation and/or runoff events
- ❑ Address any issues identified in dam inspections (eg. seal cracks, replace rip-rap, repair settled crest, clear debris)

Inspections – Concrete Structures

- ❑ Check for cracks or other signs of concrete deterioration
- ❑ Check for signs of erosion around concrete structures
- ❑ Check for shifts in alignment of concrete structures

BC MINISTRY OF FORESTS, LANDS AND NATURAL RESOURCE OPERATIONS

Inspections – Earthen, Rockfill or Wooden Structures

- ❑ Check condition of embankments, timber cribs, gabions, liners, etc.
- ❑ Check for settling or cracks in the dam crest, slumping along the dam face
- ❑ Check condition of rip-rap along the upstream face of the dam
- ❑ Check for and remove any vegetation (shrubs, trees) from around the dam

☑ Keep a record of dam and reservoir operational conditions, inspection findings, pictures of the dam, and a log of repairs

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Water Resources Management Division
Drinking Water and Wastewater Section

https://www.gov.nl.ca/ecc/waterres/training/operator-onsite-training/

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Department of Environment & Conservation

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During Emergency

- Declare emergency
  - Are conditions normal?
  - Verify and assess the level of emergency
- Initiate the town emergency management plan
- Contact Emergency Services Division
- Activate the Emergency Operation Center if necessary
- Notify those in the dam break flood area
- Evacuate population at risk if necessary
- Communications
  - Stakeholders
  - Get information out to the public and media
- Take mitigative action:
  - Pump water out of reservoir to draw down water level
  - Controlled breach
  - Increase freeboard
- Technical Memos describing these proceedures are coming soon to the WRMD Dam Safety Program Website: https://www.gov.nl.ca/ecc/waterres/damsafety/#operations
- Set up traffic control

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Emergency Activation Levels

Emergency Classification	Condition	
	Hydrologic Event	Other Events
Normal River Condition	River conditions are normal	
Flood Situation (Blue) Out-of-bank water levels	A 'Flood Warning' has been issued, but situation is not immediately threatening dam integrity.	Not applicable
Dam Alert (Yellow) Abnormal condition that poses a threat	Maximum operating water level is expected to be exceeded, has been exceeded, and is expected to continue to rise.	Abnormal condition affecting dam performance has been identified as requiring response, e.g. • Signs of internal erosion • Increased leakage • Structural deformation or deterioration
Potential Dam Emergency (Orange) Potential failure is developing (50-50 chance dam will fail)	Maximum operating water level has been exceeded, and potential for dam overtopping has been identified.	Water level drop indicative of potential dam failure.
Dam Failure (Red) Failure is imminent or occurring	Control of water levels and flows has been lost and overtopping is occurring or imminent.	Upstream water level is decreasing rapidly, indicative of dam failure. Failure of dam is occurring or imminent.

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Issue Notification Warnings

Time to Impact

- Dam failure mode initiation and development
  - Early detection
- Dam breach initiation
- Flood arrival
  - Avg time to peak flood for water supply dam failures in NL (sunny day): 51 min
  - Range: 6 min- 8.3 hrs

Total Response Time

- Hazzard detected
- Hazzard verified
- Notification of Emergency Response Agencies
- Public Notification
- Protective Actions

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Post-Emergency

- Maintain site in safe and secure condition
- Inspect dam for damage
- Repair dam:
  - Municipal Capital Works funding
  - Gas Tax
  - Special Assistance Grant
- Document the dam failure event in a summary report:
  - Pictures, sketches and any relevant measurements or data taken
  - Document all impacts- to others, financial
  - Recommendations for further actions

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Case Study: Lake Major Dam in Halifax

Nova Scotia

Lake Major dam problem will force evacuation of 135 homes

Officials say there are concerns about flooding if the dam breaks during repair work

CBC News · Posted: Jan 16, 2015 5:06 PM AT | Last Updated: January 17, 2015

Officials describe the reasons behind the precautionary mandatory evacuation and the specifics of the evaluation. 8:41

19 comments

A voluntary evacuation order for 135 homes in the Cherry Brook area caused by the threat of

- High risk of failure due to emergency repairs of the fishway in January 2015
- A voluntary evacuation order for 135 homes
- RCMP and search and rescue teams notify residents by going door to door
- 4 bridges closed
- A hotline was established for residents with questions
- 2 evacuation centers were in place on either side of dam

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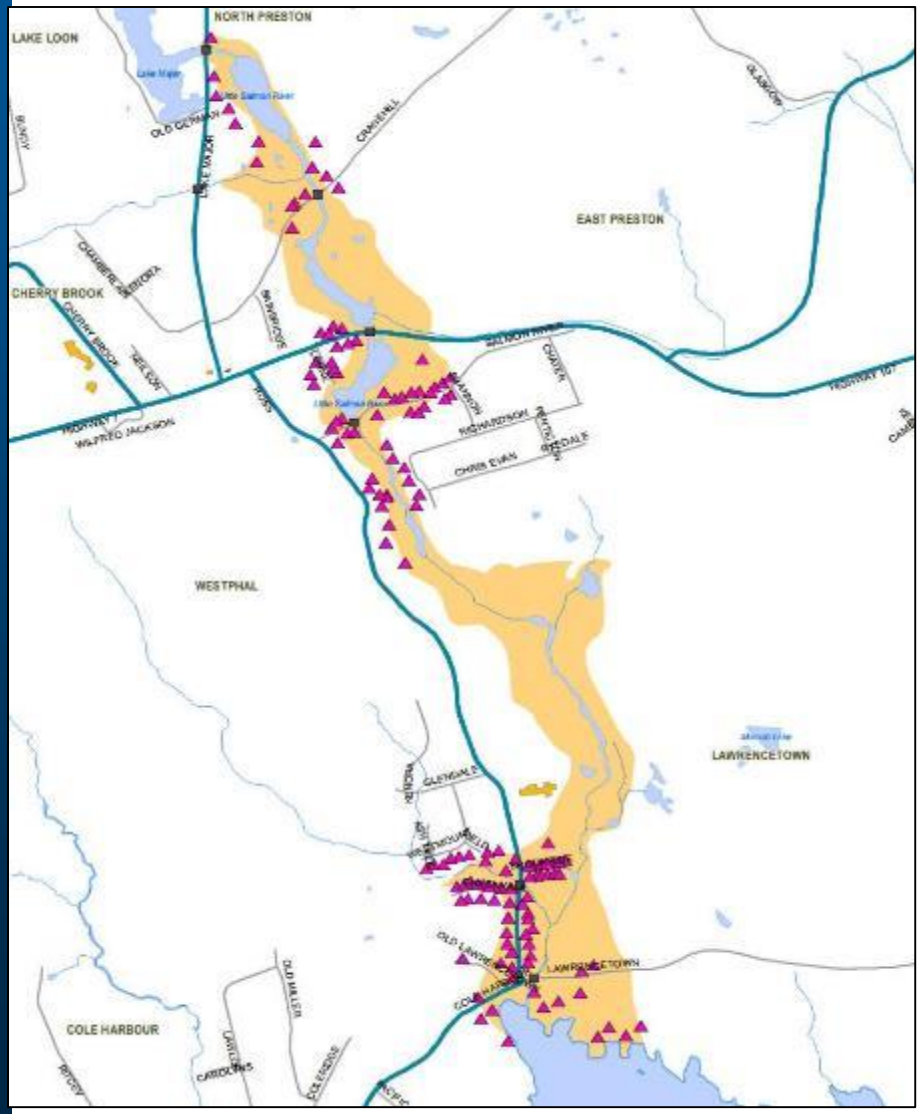
Case Study: Lake Major Dam in Halifax



- The dam break inundation map helped determine affected homes
- The yellow section illustrates the inundation area
- The pink triangle depicts the affected house
- SPOILER: dam did not fail, no lives lost, no property damage, dam replaced in 2018

Water Resources Management Division

Department of Environment & Conservation

Newfoundland Labrador

Key Messages

- Lets prevent dam emergencies in the first place
- Want to reduce or mitigate risks and impacts associated with dam emergencies
- Enhance awareness of hazards posed by dams
- Enhance understanding of the standard of care expected of the dam owner
- Increase understanding of the importance of dam break inundation mapping and incorporation into Emergency Management Plans
- Increases resilience of impacted communities

- Contact us (Paula Dawe: pauladawe@gov.nl.ca or 709-729-4048) if you want:
  - Digital copies of you community dam break flood maps
  - Presentation given to your town council
  - Dam inspection

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Department of Municipal Affairs & Environment