# Best Practices for Dug-Out Earth Dam Design & Construction

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Mitacs

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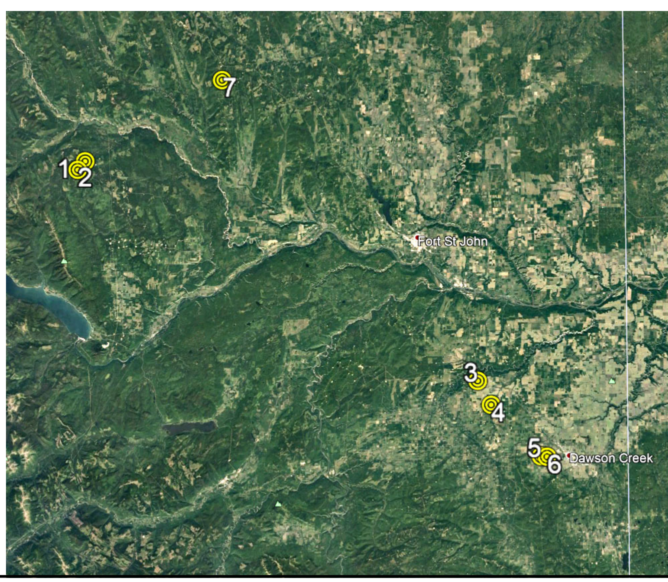
## Objective

- Examine best practices for design and construction of dugout earth dams for fresh water storage

## Fieldwork 2018-19

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## Questions

- Are existing recommendations being followed?
  - In what areas were they not?
- Are existing recommendations adequate or should they be changed?
- Should recommendations change to reflect what was observed or should existing recommendations be followed?
- What should be recommended based on observations?

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## Seven Key Areas of Dam Design and Construction

- Dam geometry and stability
- Freeboard and design flood
- Spillway and outlet
- Seepage and drainage
- Erosion Protection (covered in another presentation)
- Construction (covered in another presentation)
- Maintenance

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## Existing Best Practices

- Canadian Dam Association (2007, 2013)
  - Minimum factors of safety for slope stability for different loading conditions
  - Geotechnical considerations (filter design criteria)
  - Hydrotechnical considerations (inflow design flood)
  - and others ….
- BC MFLNRORD (2018)
  - Recommended upstream and downstream embankment slopes, minimum freeboard and spillway width
  - and others ….

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## Existing Best Practices

- Canadian
  - BC MoTI
  - BC Ministry of Energy and Mines
  - BC Ministry of Environment, Lands and Parks
  - Alberta Ministry of Agriculture and Forestry
  - Ontario Ministry of Agriculture, Food, and Rural Affairs
- International
  - USSD, USACE, USBR, USASDSO
  - ICOLD, FAO of the UN
  - Australian best practices documents

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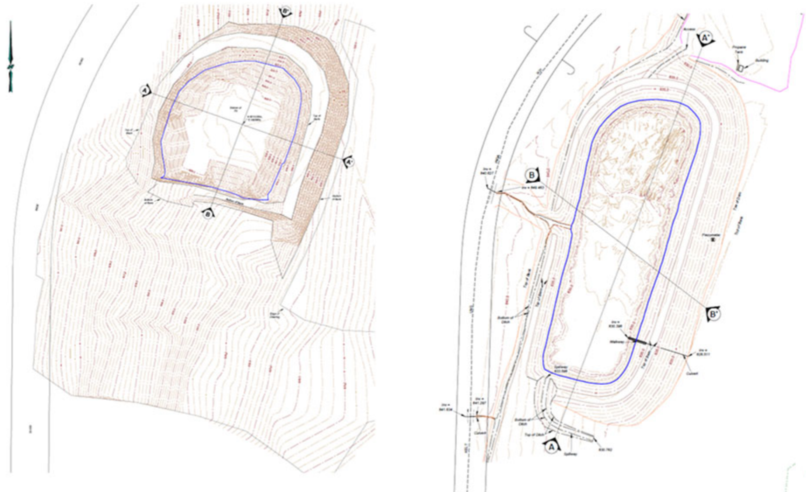
## Construction

- Foundation preparation
- Compaction equipment and lift thickness
- Degree of compaction and water content



[More details in another presentation]

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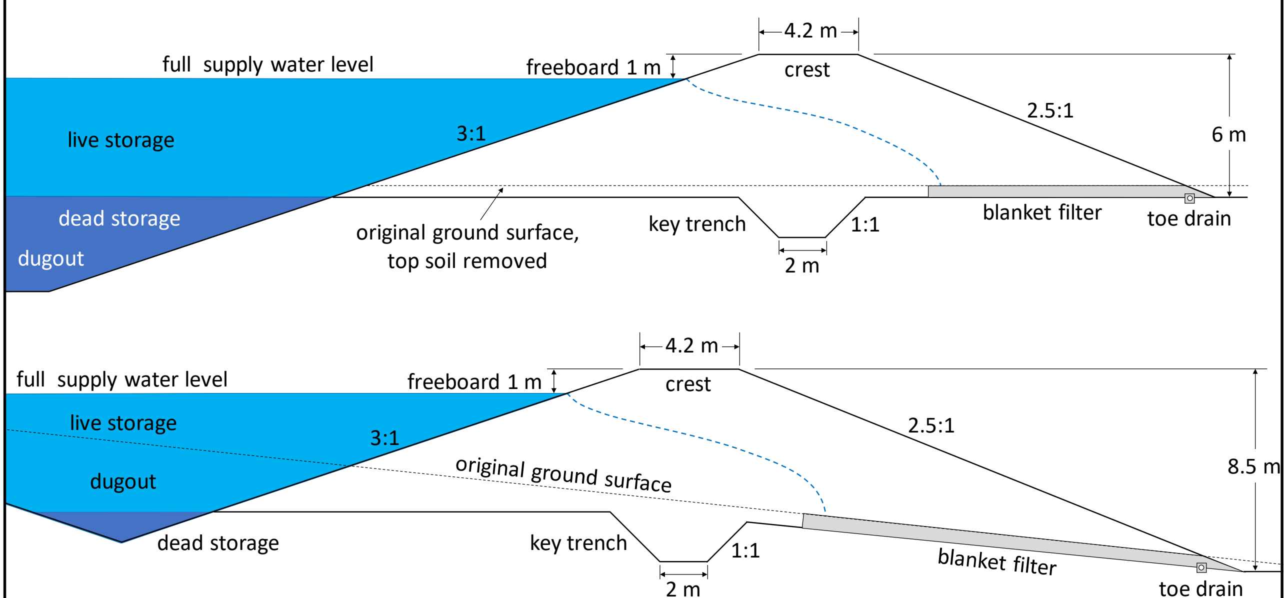


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## Summary of Investigated Dams

As-built

| Dam | Max. Height (m) | Live Storage ($m^3$) | Classification | Age (Years) | Soil Type | Slope U/S (H:V) | Slope D/S (H:V) | Regulator |
|---|---|---|---|---|---|---|---|---|
| 1 | 9.1 | 64,060 | significant | 7 | CL | 3.3:1 | 2.3:1 | OGC |
| 2 | 7.7 | 75,517 | significant | 7 | CL | 2.7:1 | 3:1 | OGC |
| 3 | 6 | 200,000 | high | 1 | CL | 2.7:1 | 3.2:1 | OGC |
| 4 | 5.3 | 161,800 | high | 3 | CH | 2.7:1 | 4:1 | OGC |
| 5 | 11.3 | $1.03 \times 10^6$ | high | 2 | CL | 3:1 | 2.5:1 | MFLNRORD |
| 6 | 12 | 379,000 | high | 44 | CL | 3:1 | 3:1 | MFLNRORD |
| 7 | 9.6 | 107,000 | significant | 3 | CL | 3:1 | 3:1 | MFLNRORD |



## Slope Recommendations

Slopes should not be steeper than these values unless careful analysis and justification is provided

| Source | Upstream Slope | Downstream Slope |
|---|---|---|
| BC MFNLRORD | 3:1 | 2.5:1 |
| BC MEM | 3:1 | 3:1 |
| United Nations Food and Agriculture Organization | 3:1 | 2:1 |
| United States Bureau of Reclamation | 3:1 | 2.5:1 |
| Depart. Primary Industries and Water of Tasmania | 3:1 | 3:1 |
| Eyre Peninsula Natural Resources Management Board | 3:1 | 3:1 |

## Cracking and Slumping if Too Steep

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## Slumping in a Cut Slope

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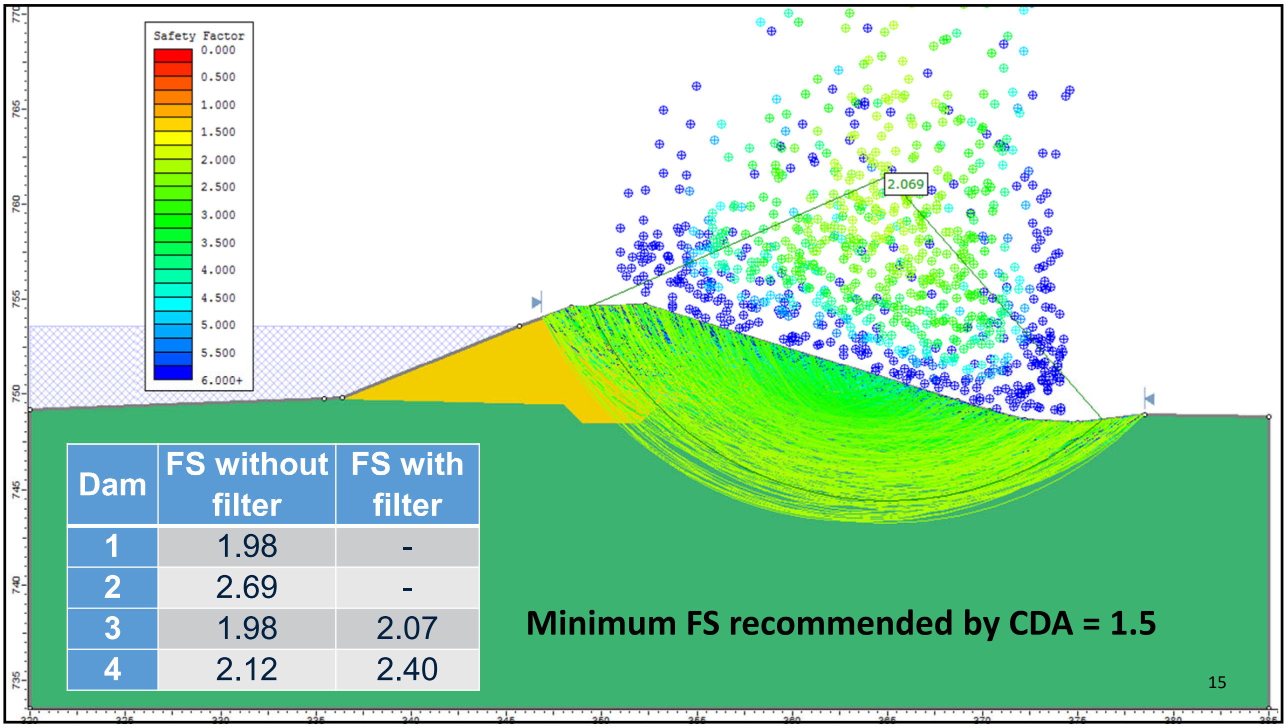


| Dam | FS without filter | FS with filter |
|---|---|---|
| 1 | 1.98 | - |
| 2 | 2.69 | - |
| 3 | 1.98 | 2.07 |
| 4 | 2.12 | 2.40 |

**Minimum FS recommended by CDA = 1.5**

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## Embankment Stability

- Stability is sensitive to the shear strength (c’ and ϕ’) for both the foundation and the embankment
- Excess pore pressures can also be important

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## Crest Width Recommendations

| Source | Equation | Min. *W* (m) |
|---|---|---|
| MFLNRORD (2018) | $W = 0.2H + 3$ | 3 |
| Lewis (2014) | $W = \sqrt{H} + 1$ | 2.5 |
| Stephens (2010) | $W = 0.4H + 1$ | 3 |

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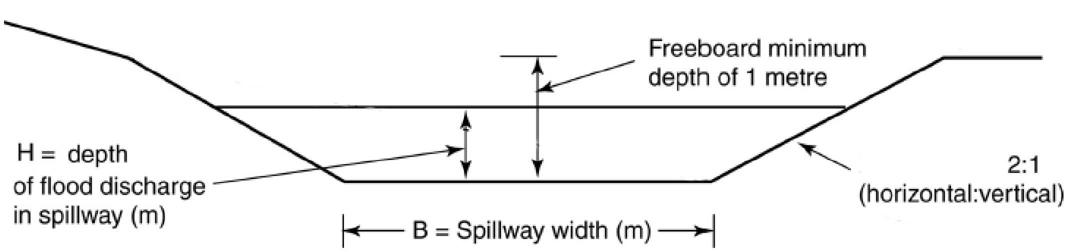
## Inflow Design Flood and Spillway

- Watersheds are typically very small
- Inflow design flood easily handled by 4 m wide spillway
- Spillway capacity is ~10 $m^3/s$, if spillway width is 4 m

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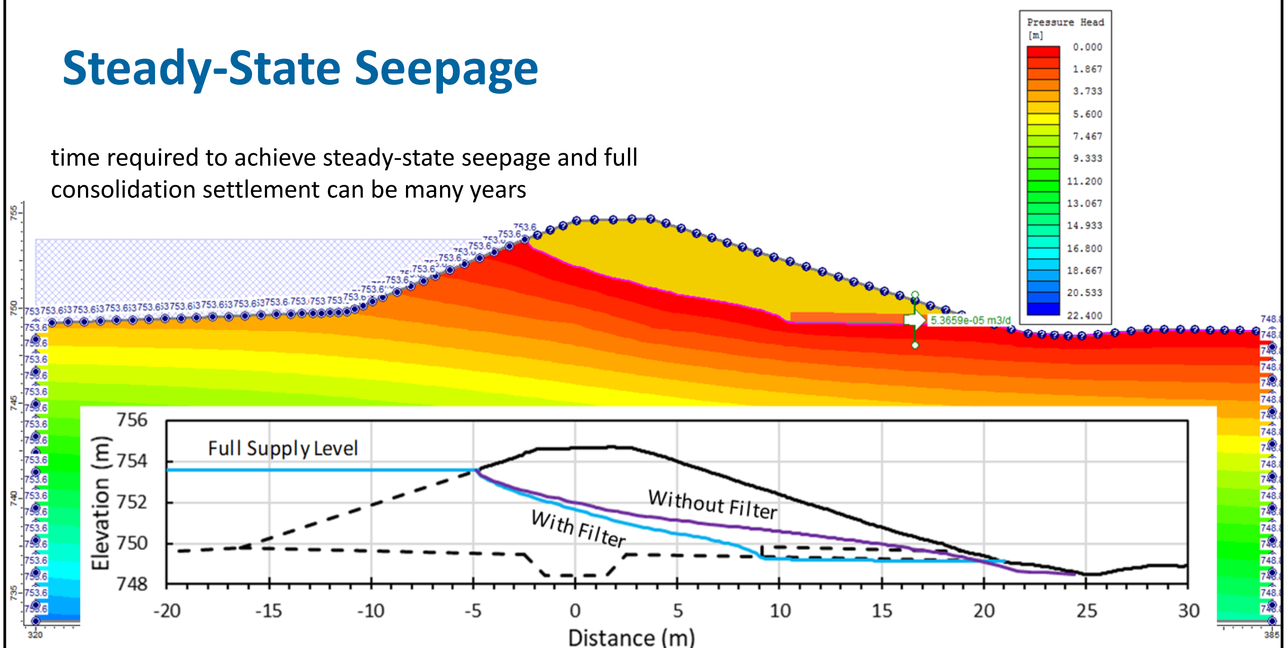
## Steady-State Seepage

time required to achieve steady-state seepage and full consolidation settlement can be many years

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## Internal Seepage

- Key trench
- Filters (blanket and toe drains)

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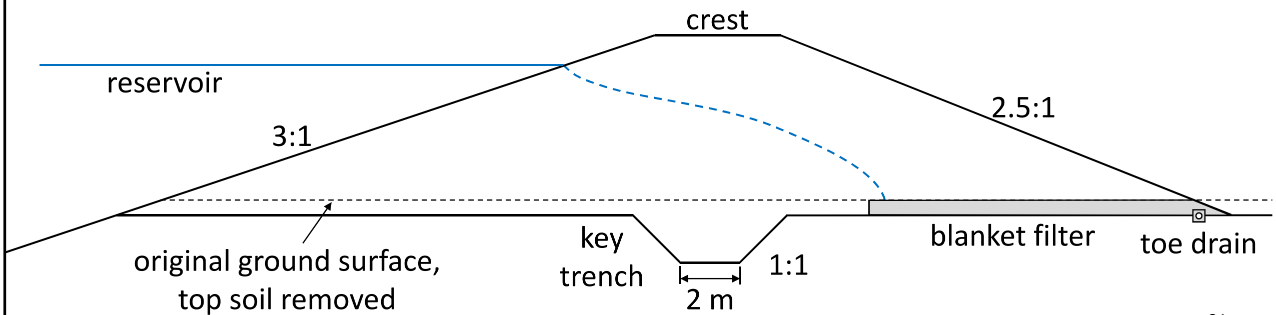
## Key Trench

- Side slopes no steeper than 1:1 for a depth up to 3 m
- Minimum width equal to the width of a bulldozer or scraper






## Key Trench

- Placed in layers with maximum 0.1 m thickness
- Well compact every layer
- Complete whole dam length at once, or each section must key into subsequent sections
- Remove water before placing fill

(Gerard Degoutte 2012, Small dams, guidelines for deign, construction and monitoring, ICOLD Bulletin 91)

## Blanket Filter/Drain

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## Toe Drain

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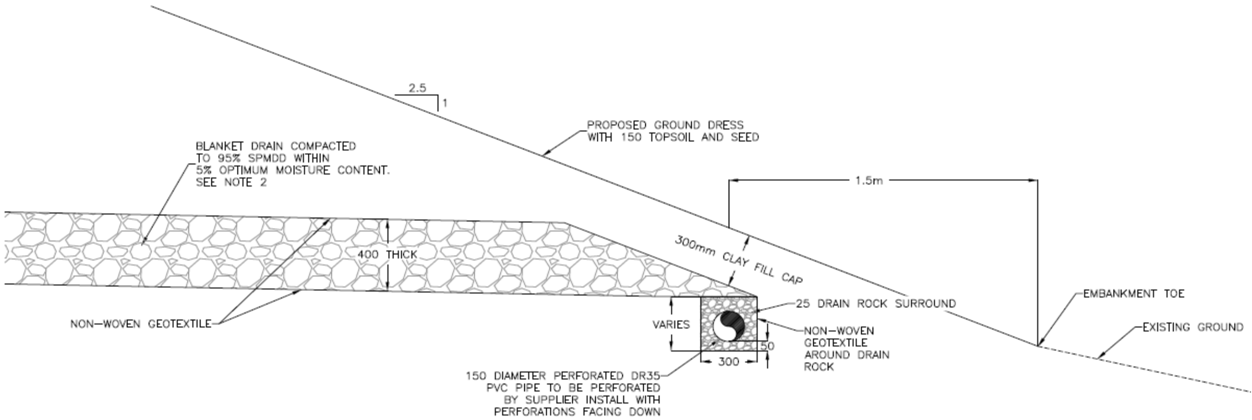
## Internal Seepage

- Blanket and toe drains

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## Seepage Cut-Off Collars on Low-Level Outlet

- Use of many types of seepage cut-off collars is no longer best practices

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## Surface Erosion Protection

- Wave action (upstream slopes)
- Precipitation runoff (crest and embankment slopes)

[More details in another presentation]

## Erosion Protection

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## Maintenance

- Vegetation
- Slopes
- Spillways
- Animal activity
- Booms
- Riprap
- Instrumentation
- Etc.

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## Recommendations

- Dams should meet minimum CDA (2007) factors of safety for end-of construction, steady-state, seismic, and rapid drawdown conditions
- Soil strength characterization (e.g., cohesion) is critical for drained and undrained stability analyses
- Embankment slopes should be a maximum of 2.5:1 (d/s) and 3:1 (u/s)
- Blanket drains with geotextile should be used in dams higher than 4 m
- Seepage cut-off trenches (shear keys) should be used

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## Recommendations

- Minimum freeboard should be 1 m
- For dams with no or small watersheds, a 4 m wide spillway will pass the IDF (check IDF for watershed)
- Roads with culverts should not cross a spillway
- Surface erosion protection is required on upstream and downstream slopes
- Riprap is typically the most effective protection for wave erosion

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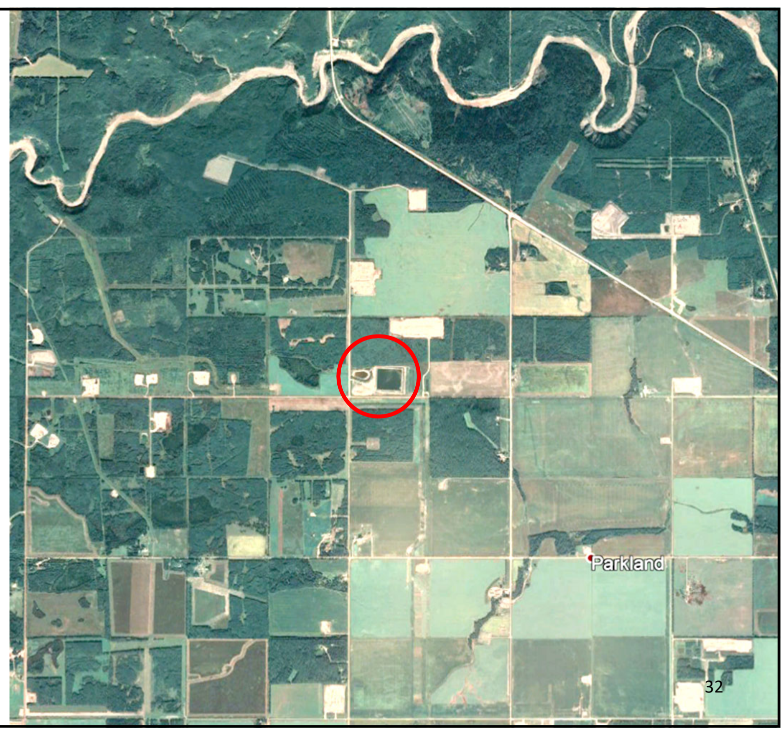
## Dam 3

- We will look at one typical dam located NW of Dawson Creek and west of the Alaska Highway

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## Dam Constructed in 2018

- Organic soil was removed
- Soil compacted in 25 cm lifts with a sheepsfoot roller (sheepsfoot is best for clay soils)
- Excess stripped silt and clay was stockpiled along with topsoil and hydro-seeded

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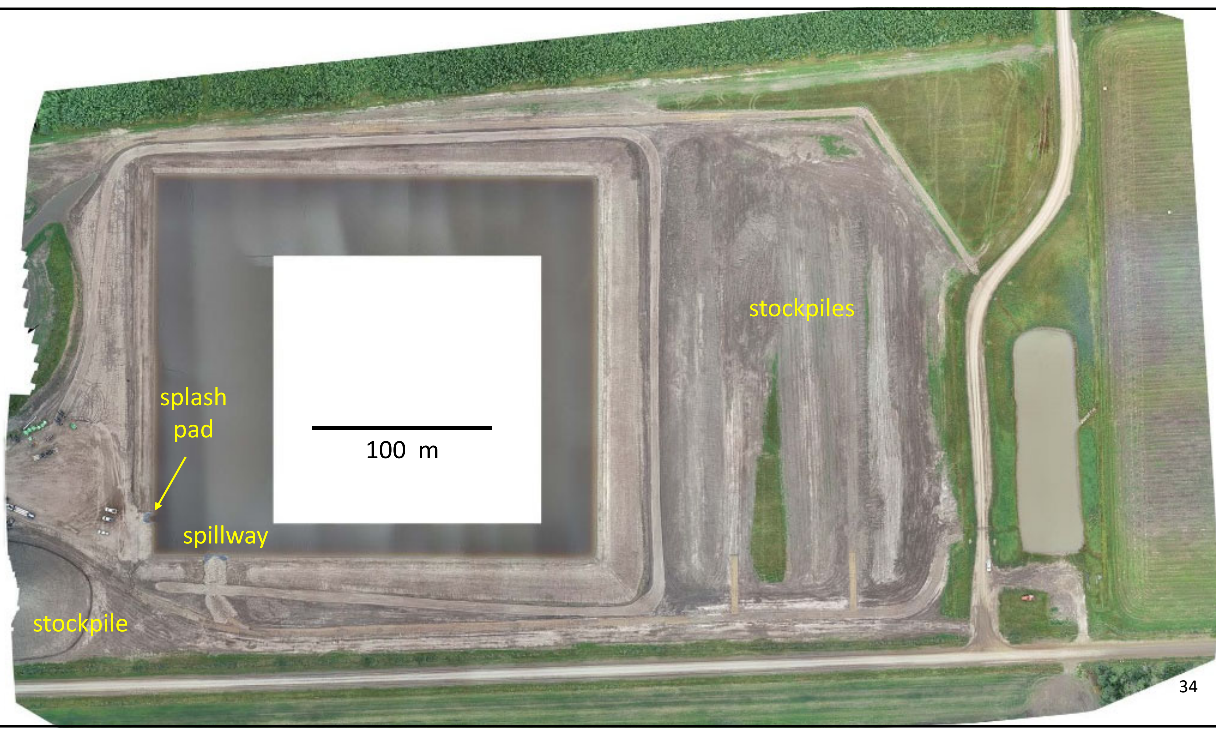


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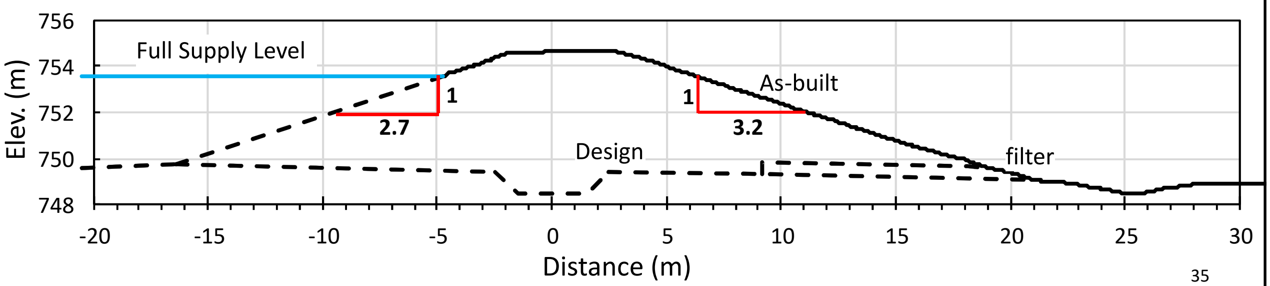
## Dam Geometry

- Maximum 6 m berm height
- 3H:1V design slopes (as-built differs)
- Horizontal blanket drain with geotextile used where berm height exceeds 2.5 m

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## Geometry Considerations

- Plan Submission Requirements for the Construction and Rehabilitation of Small Dams (MFLNRORD, 2018)
  - Minimum upstream slope 3:1
  - Minimum downstream slope 2.5:1
  - Minimum crest width = 0.2H+3 m (H = berm height)
- Dam slopes were designed to meet these slope requirements but the upstream slope is steeper at 2.7:1
- Design crest width of 5 m meets the minimum 4.2 m requirement, but the as-built crest width is ~4 m

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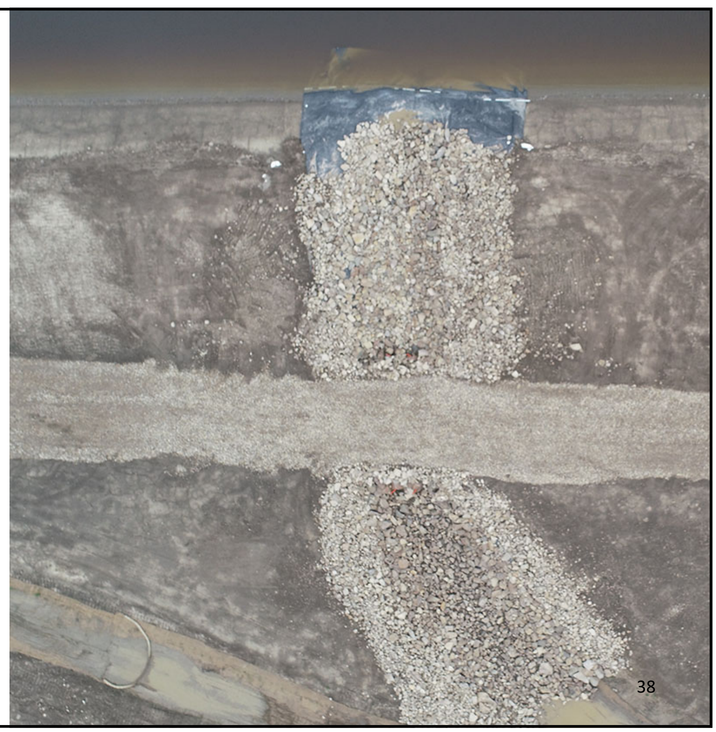
## Dam Operation

- High consequence dam
- 200,000 $m^3$ water storage
- Water level and use is controlled by pumping in and out
- No watershed providing inflow


## Spillway

- 4 m wide spillway lined with rip rap and non-woven geotextile
- Access road crosses spillway, with two 760 mm CSP culverts



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## Spillway

- Inflow design flood ~2.3 $m^3/s$
- But culverts limit the capacity to ~1.4 $m^3/s$

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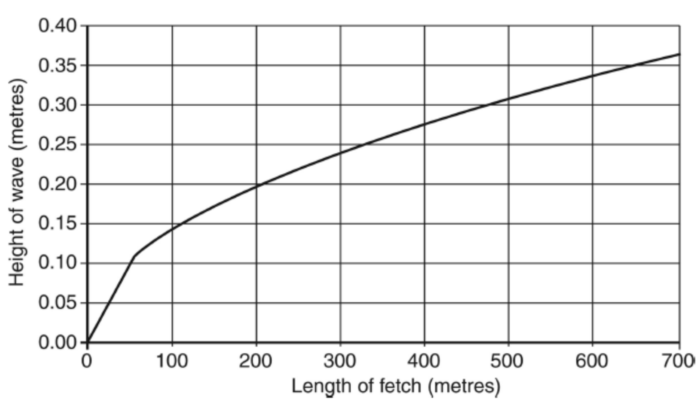
## Freeboard

- Maximum wave height <0.5 m
- 1 m freeboard is sufficient

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## Settlement Allowance

- Embankments will settle after construction
- Embankment height should be overbuilt an extra 5 to 10% to account for post-construction settlement
- Achieving a horizontal crest profile after construction is helpful for future monitoring

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## Riprap

- Class 25 kg riprap in the spillway is smaller than recommended using USACE method, but there is geotextile
- No other riprap in use except at the splash pad
- Riprap displaced off the geotextile

## Soil Properties

| % gravel (>2 mm) | % sand (0.06 to 2 mm) | % silt (0.002 to 0.06 mm) | % clay (<0.002 mm) | *w* (%) | *LL* (%) | *PL* (%) | *PI* (%) | Activity | USCS |
|---|---|---|---|---|---|---|---|---|---|
| 2-8 | 10-15 | 49-59 | 20-35 | 15 | 29-40 | 14-18 | 14-24 | 0.5-0.7 | CL |

Lean clay or lean clay with sand

From dam, may be < $w_{opt}$

Medium plasticity

Low activity

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## Soil Mineralogy

- Bulk x-ray diffraction and clay speciation tests

| Quartz | Albite | K-feldspar | Calcite | Dolomite | Illite/Mica | Mixed-layers | Chlorite | Kaolinite | Gypsum | Total Feldspar | Total Carbonates | Total Clays |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 46.6 | 4.0 | 2.0 | 6.1 | 4.6 | 24.2 | 0.6 | 3.5 | 6.2 | 2.1 | 6 | 10.7 | 34.5 |

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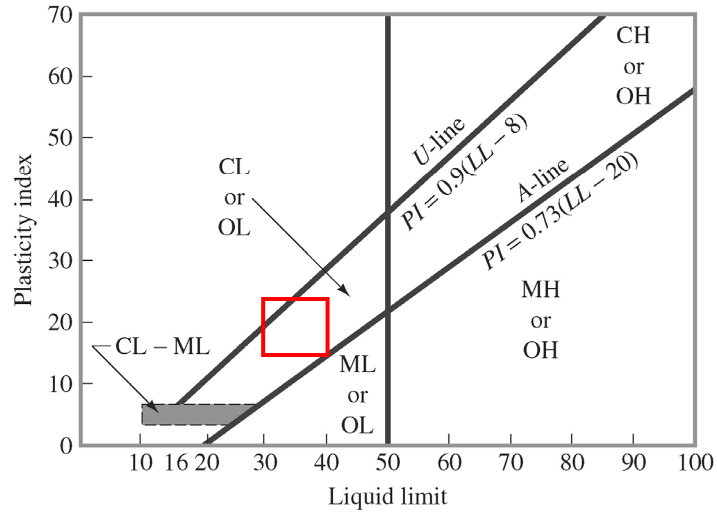
## Clay Mineralogy

- Dispersive smectite group clay minerals (e.g. bentonite and montmorillonite) not detected
- Inorganic clay of low to medium plasticity
- Soil activity is low

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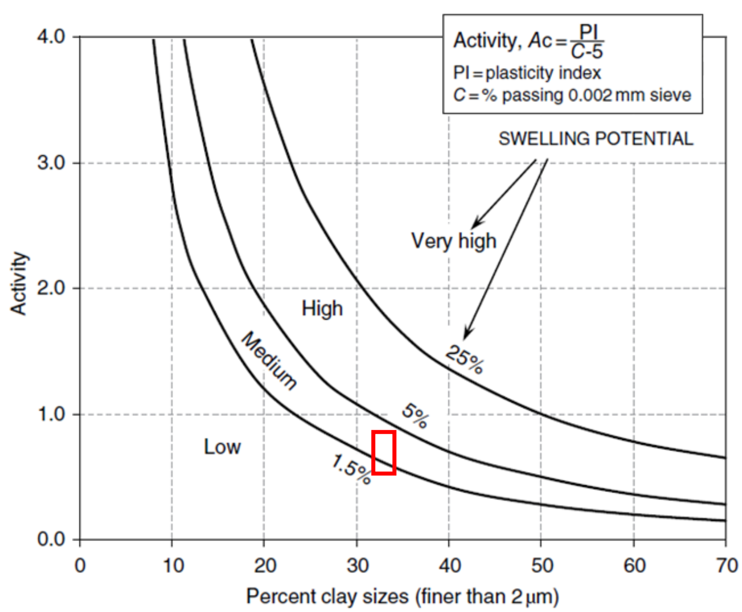
## Swelling Potential

- Generally low swelling potential
- Cracks occur when the soil dries
- Impact of shrinkage cracking needs further research

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## Cracking

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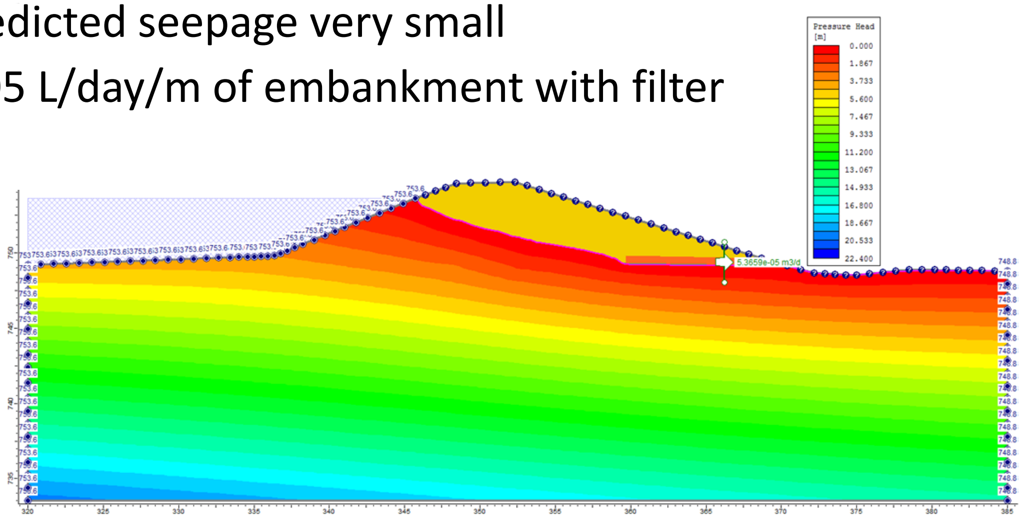
## Seepage Analysis

- Predicted seepage very small
- 0.05 L/day/m of embankment with filter

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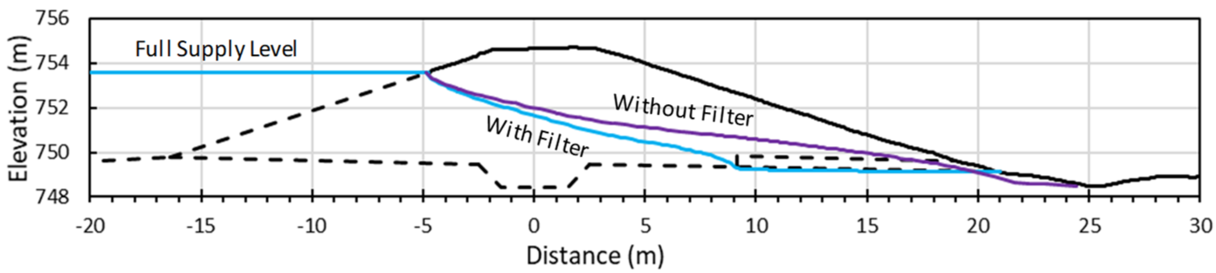
## Seepage Analysis

- Filter lowers the phreatic line and directs seepage into the blanket drain
- Blanket filter helps to relieve pore pressures generated in the foundation as the soils consolidate






## Filter Design

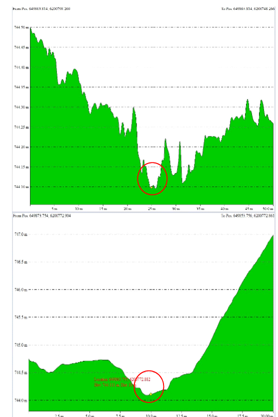
- CDA (2007) filter criteria based on Sherard et al. (1984, 1989)
- Grain size analysis of filter (D15) and embankment (d85) soils

| $D_{15}$ (mm) | $d_{85}$ (mm) | Sherard et al. Criterion (1984) | Meets Sherard Criterion? | Meets Terzaghi Criterion? |
|---|---|---|---|---|
| 0.33 | 0.042 | $D_{15} \leq 0.5$ mm | Yes | **No** |

- Non-woven geotextile is needed between the sand filter and the silty clay

## Water in Ditch

- Water in ditch attributed to low spots, likely no relationship with seepage



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## Wave Erosion

- Scarp grew from 10-20 cm (Aug. 2018, left) to 50-60 cm (May 2019, right)
- Booms installed to dissipate wave energy

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## Vegetation

- Vegetation is slowly starting to grow after one year

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## Decommission Planning

- Stockpiles east of the dam contain different soils strategically separated for infilling the reservoir when decommissioned

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