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Lessons Learned from Field Applications of CCBE

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Content

- Preamble
- Historical and conceptual background
- The **Manitou** case study - from lab to field
- The **LTA** site – ongoing field work since 1996
- The **Lorraine** site - a large scale in situ laboratory
- The **BGMI** cover – for semi-arid conditions
- Final remarks

Preamble

- **Industrial NSERC Chair** : research partnership between University and Industry, to address issues of concern for the Participants.
- NSERC Polytechnique-UQAT Chair : officially created in May 2001, after 2 years of discussion and planning with the Participants, including NSERC.
- Partners were heavily involved in defining the research program (1999-2001).
- Research partnership involves 2 universities, 5 mining companies, 3 consulting firms, and 5 governmental agencies.

Participants

BARRICK

AGNICO-EAGLE
DIVISION LARONDE

noranda

DESSAU SOPRIN

Les Ressources Aur inc.
Gestionnaire Mine Louvicourt

NSERC CRSNG

SNC•LAVALIN Environnement

INMET MINING

Golder Associés

CONSEIL RÉGIONAL DE DÉVELOPPEMENT DE L'ABITIBI-TÉMISCAMINGUE

Environnement Québec

Ressources naturelles Québec

Recherche, Science et Technologie Québec

Commanditaire : ICM CIM

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The mission

- To develop geo-environmental tools and techniques for an integrated management of solid and liquid mining wastes, including:
  - tailings
  - waste rock
  - sludge from AMD treatment plant
- To train specialists (HQP) in these areas
- To organize courses and scientific exchange forums for participants, and the community

  (e.g. Rouyn-Noranda Symposium 2002, 2005)

- Research conducted by :
  - Chair Holders (Aubertin and Bussière)
  - Three new professors (Zagury, Benzaazoua, Mbonimpa); 4 regular collaborators (Prof. Chapuis, Chouteau, Simon, Belem)
  - Five post-doctoral researchers.
  - More than 50 graduate students involved.
  - Technical support staff (lab and field)
  - Collaborators from other universities (UBC, U of T, ENPL-Nancy, U-Qld, INRS, Laval)

Projects Organisation Chart
NSERC Polytechnique - UQAT Industrial Chair
Environment and Mine Wastes Management

Project 1
Integrated Solid and Liquid Wastes Management During Operation

- 1.1 - Tailings disposal
  - 1.1.1 - Physical stability of tailings impoundment
  - 1.1.2 - Development of integrated tailings management approaches
- 1.2 - Rock wastes disposal
  - 1.2.1 - Hydrogeotechnical behaviour of waste rock piles
  - 1.2.2 - New rock wastes management approaches for minimizing environmental impacts
- 1.3 - Disposal of treatment sludge
  - 1.3.1 - Hydro-mechanical characterization of sludge
- 1.4 - Re-use and recycling
  - 1.4.1 - Re-use of various mine wastes
- 1.5 - Backfill-rockmass interactions
  - 1.5.1 - Backfill mechanical behaviour and modeling

Presentation

Project 2
Reclamation of Mining Sites with AMD

- 2.1 - Control of AMD production using covers
  - 2.1.1 - Long term behaviour of layered cover systems to limit AMD
  - 2.1.2 - Fluid flow
- 2.2 - Use of water to limit production of AMD
  - 2.2.1 - Water cover and elevated water table for preventing AMD
- 2.3 - Prediction of AMD
  - 2.3.1 - AMD prediction for selecting reclamation measures
- 2.4 - Passive treatment of AMD
  - 2.4.1 - Metal speciation and ecotoxicity
  - 2.4.2 - Engineering of passive treatment systems

Historical and conceptual background on CCBE

- **Idea of using capillary barrier effects to control deep infiltration of water is not new (agricultural needs, strategic projects, environmental issues, etc.):**

  - Eagleman and Jamison (1961), Corey and Horton (1969), USA;

  - Rançon (1972, 1979, France), Frind et al. (1976, Canada), Johnson et al. (1983, USA) for radioactive wastes;

  - Landfills and other waste disposal facilities (e.g. Clothier et al. 1977; Zaslavsky et al. 1977, 1981; Andersen et al. 1985, 1986; Andre-Jehan, Barres, et al. 1988, Miyazaki, 1988, Ross, 1990, etc.)

- **Technology emerged with improved understanding of unsaturated soils behaviour; studies in soil physics, hydrogeology, and geotechnique** (e.g. Childs & Collis-George, Brooks & Corey, Gardner, Bear, Mualem, Hillel, Haverkamp, Parlange, Steenhuis, Kovàcs, van Genuchten, Gillham, Fredlund, etc.)

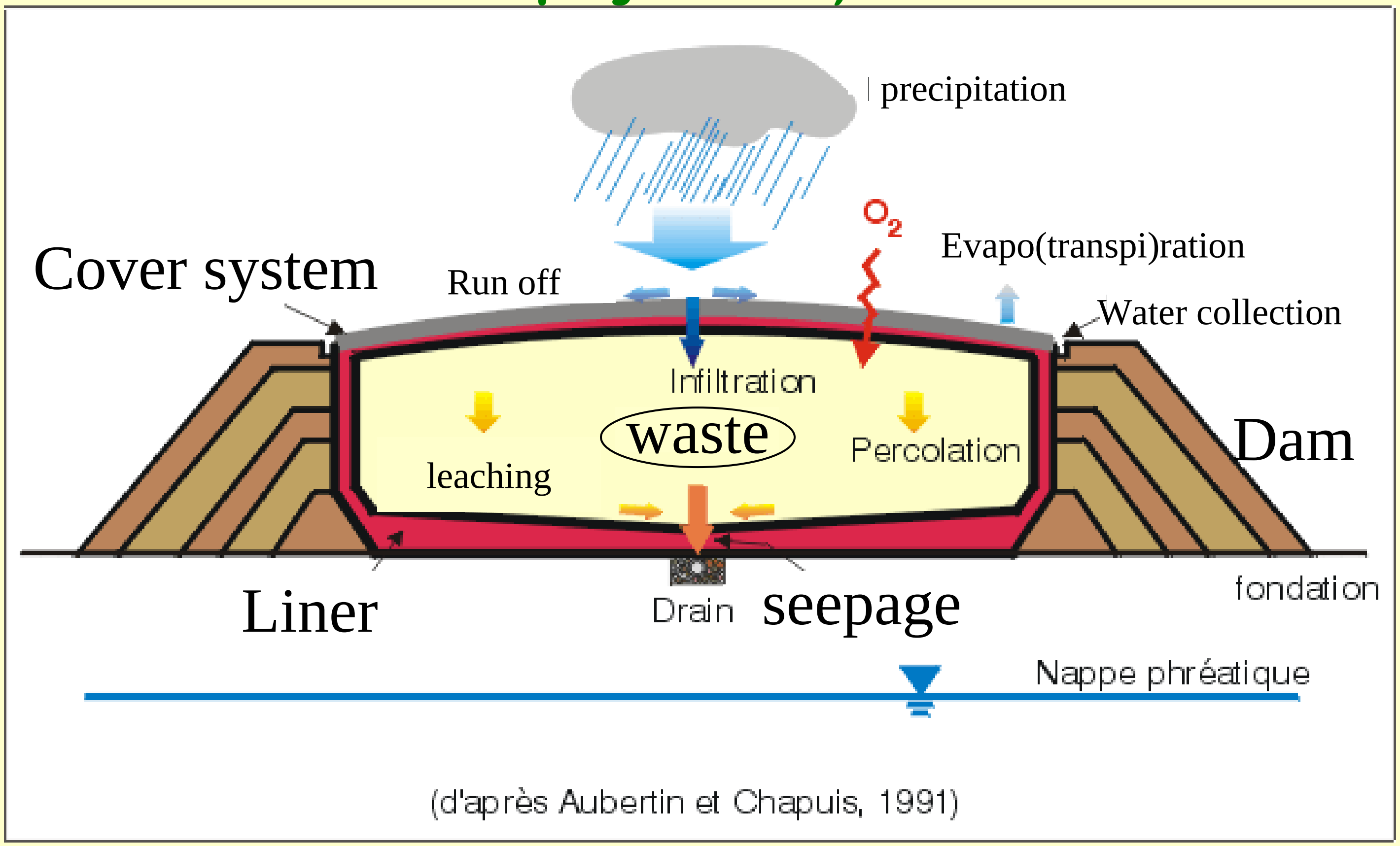
CCBE in mining

Control the production of AMD (ARD):

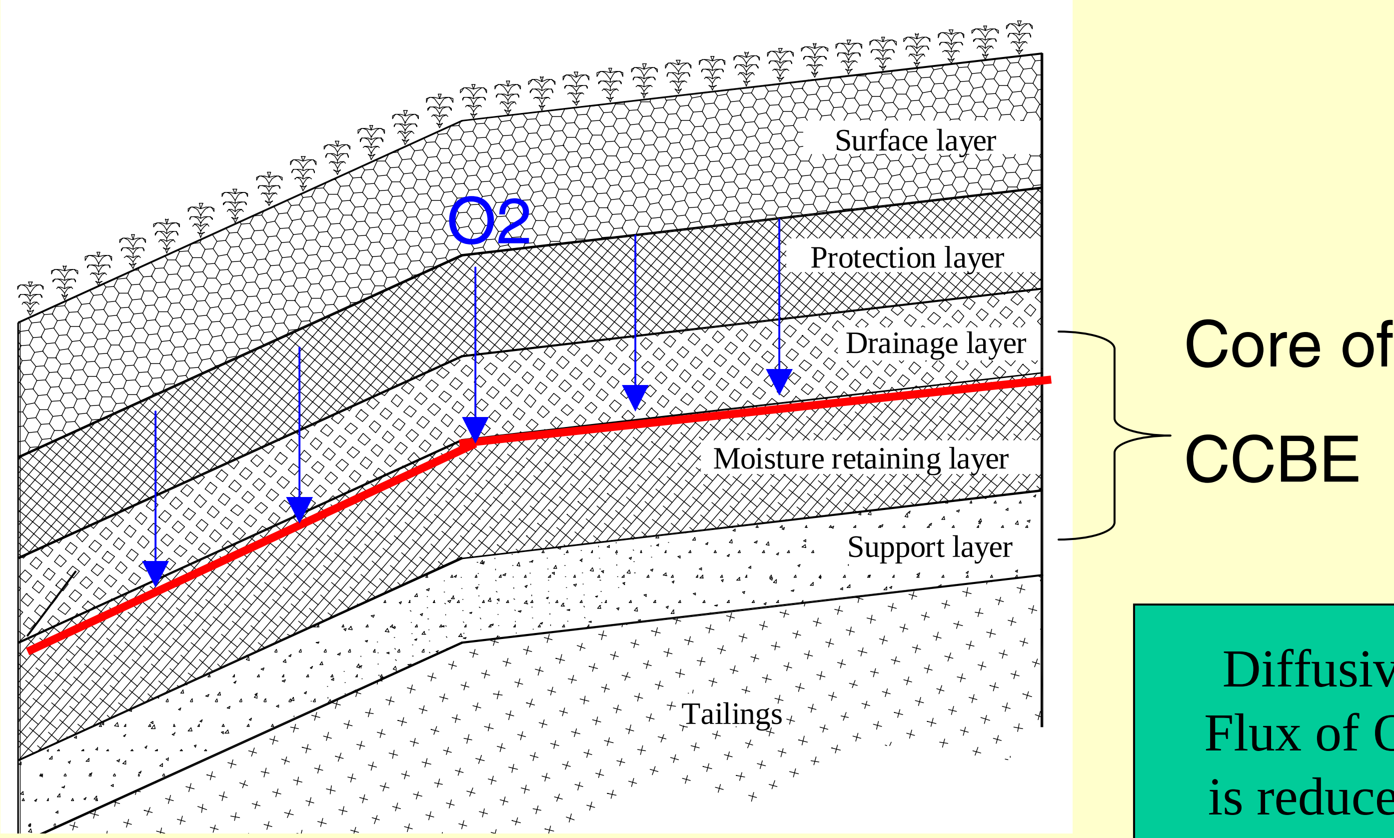
- **Main concepts** and first applications have been investigated in Scandinavia (Magnusson et al. 1983, 1985; Rasmusson and Ericksson 1986, 87; Collin 1987, etc.);

  and in Canada (SRK 1987, 1988; Nicholson et al.1989, 1991; Yanful and St-Arnault 1990, 1991; Barbour, Wilson 1990; Aubertin and Chapuis 1990, 1991; etc.)
- **Basic principles** have been well established.
- **Field experience** has shown the many facets of CCBE; induced much progress over the last 15 years or so.
- Significant progresses, fuelled by our **needs** and by the newly **available means** for characterisation, modelling, and monitoring capabilities.

Cover is part of a complex system, that must me evaluated and understood; involves various specialties (geotech., hydrogeol., geochem.; forestry and soil physics…)



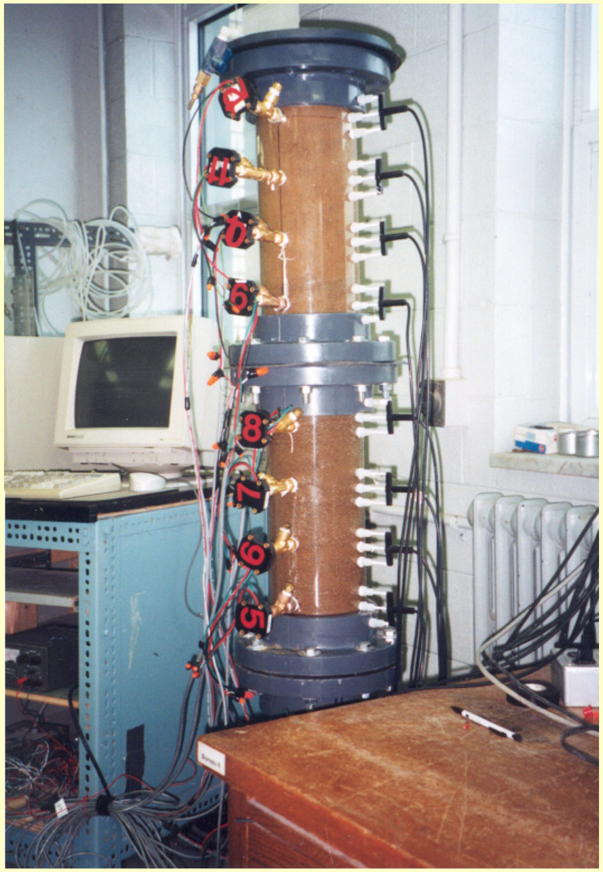
Proposed structure; for humid conditions, CCBE can act as an efficient oxygen barrier

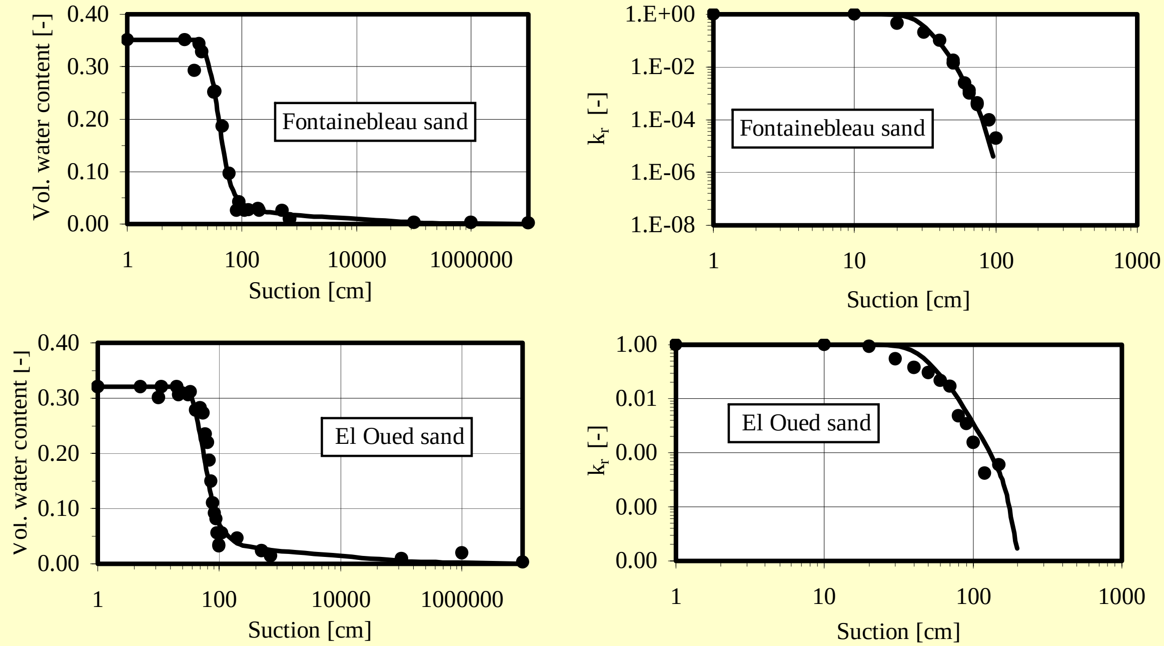


(Aubertin et al., 1995)

Diffusive Flux of O_2 is reduced when S_r is high

Hydraulic properties required for design: k_{sat}, WRC, k_u

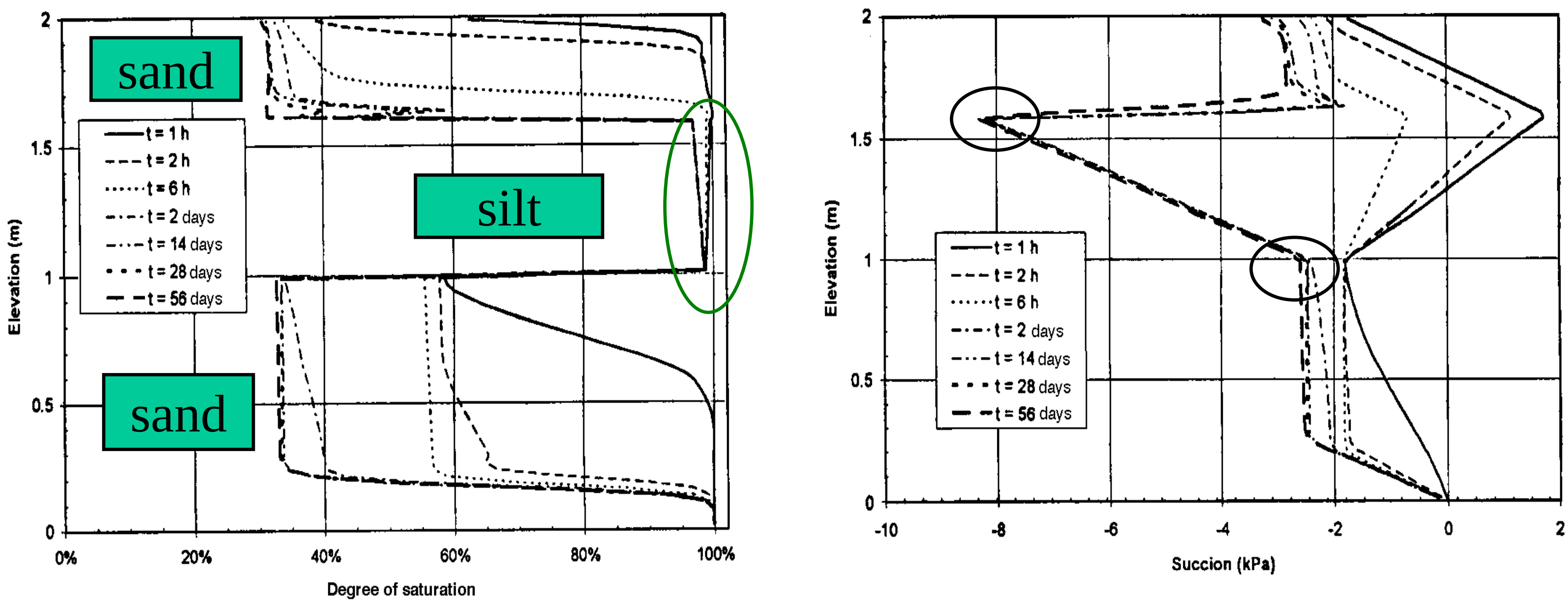




Properties can be measured, or estimated ("predicted") for preliminary stages of the analysis.

Measured (full point) and predicted (full line) WRC (left side) and k_r values (right side); data taken from Soeiro (1964); Taken from Mbonimpa et al. (2004)

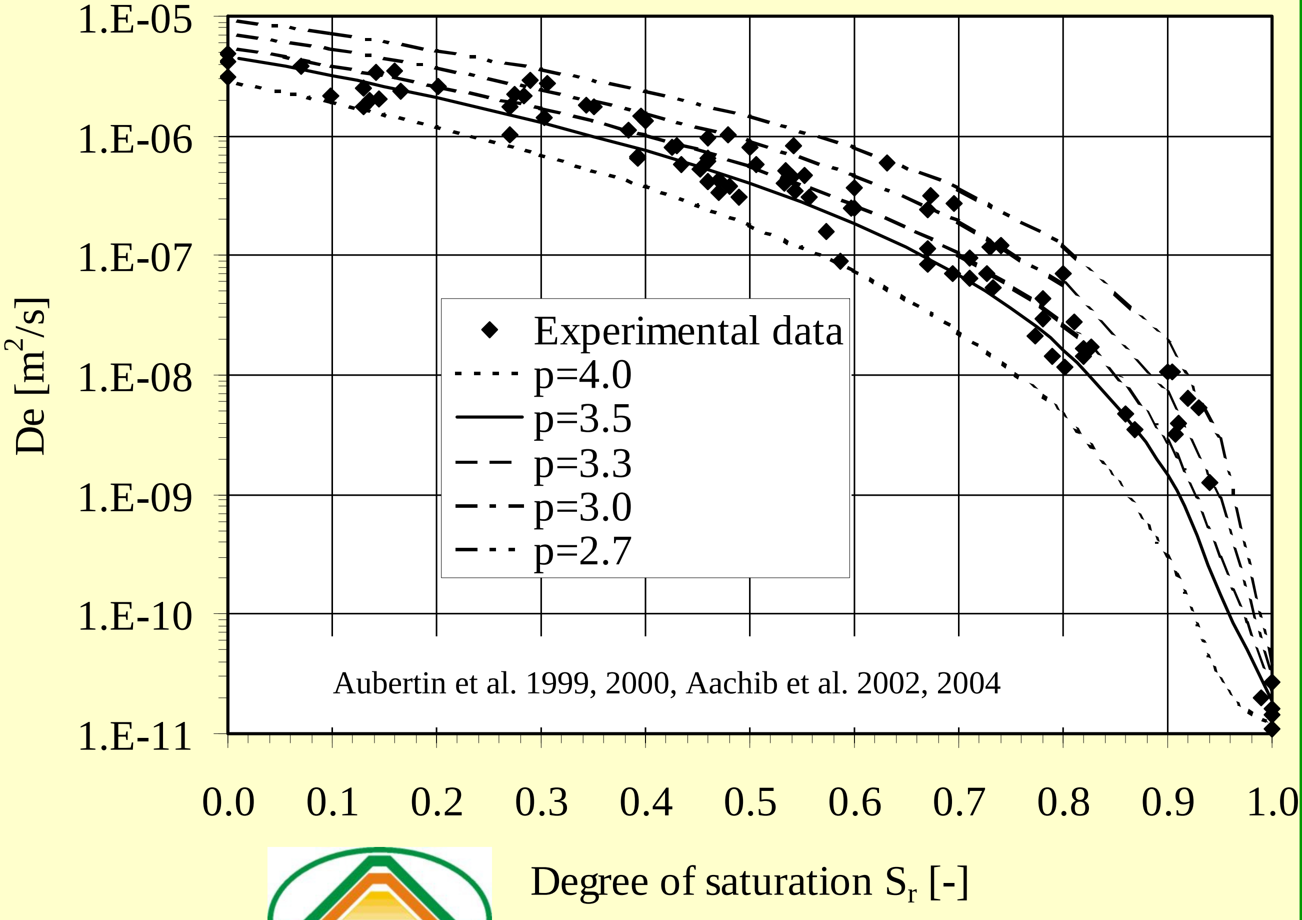
Expected behavior of CCBE; based on 1D numerical calculations for drainage conditions (3 layer system: sand/silt/sand)



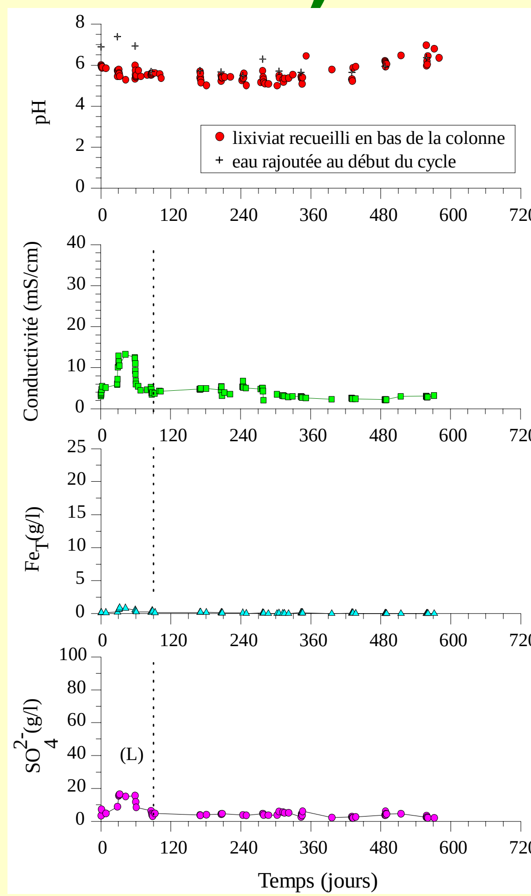
Aubertin et al. 1996

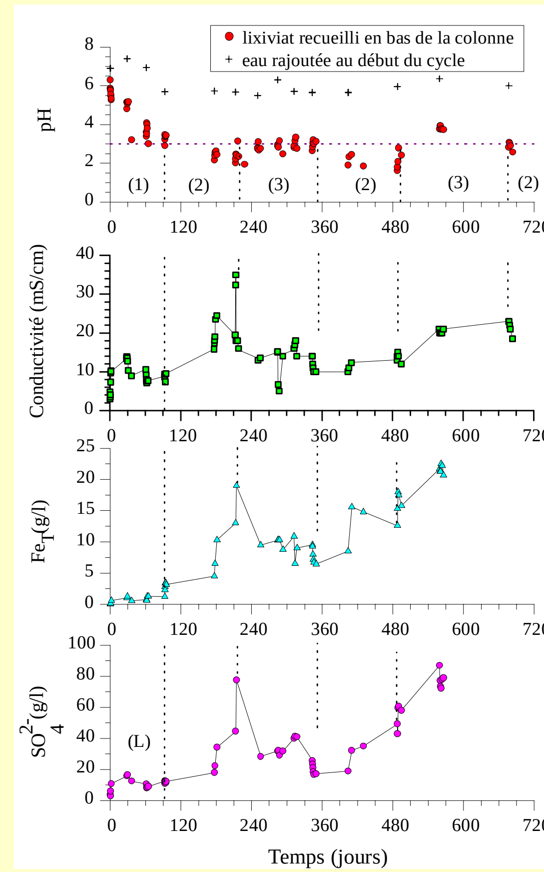
The effective diffusion coefficient

$$D_e = \frac{1}{n^2}\left[D_a^o \, \theta_a{}^p + H \, D_w^o \, \theta_w{}^p \right]$$

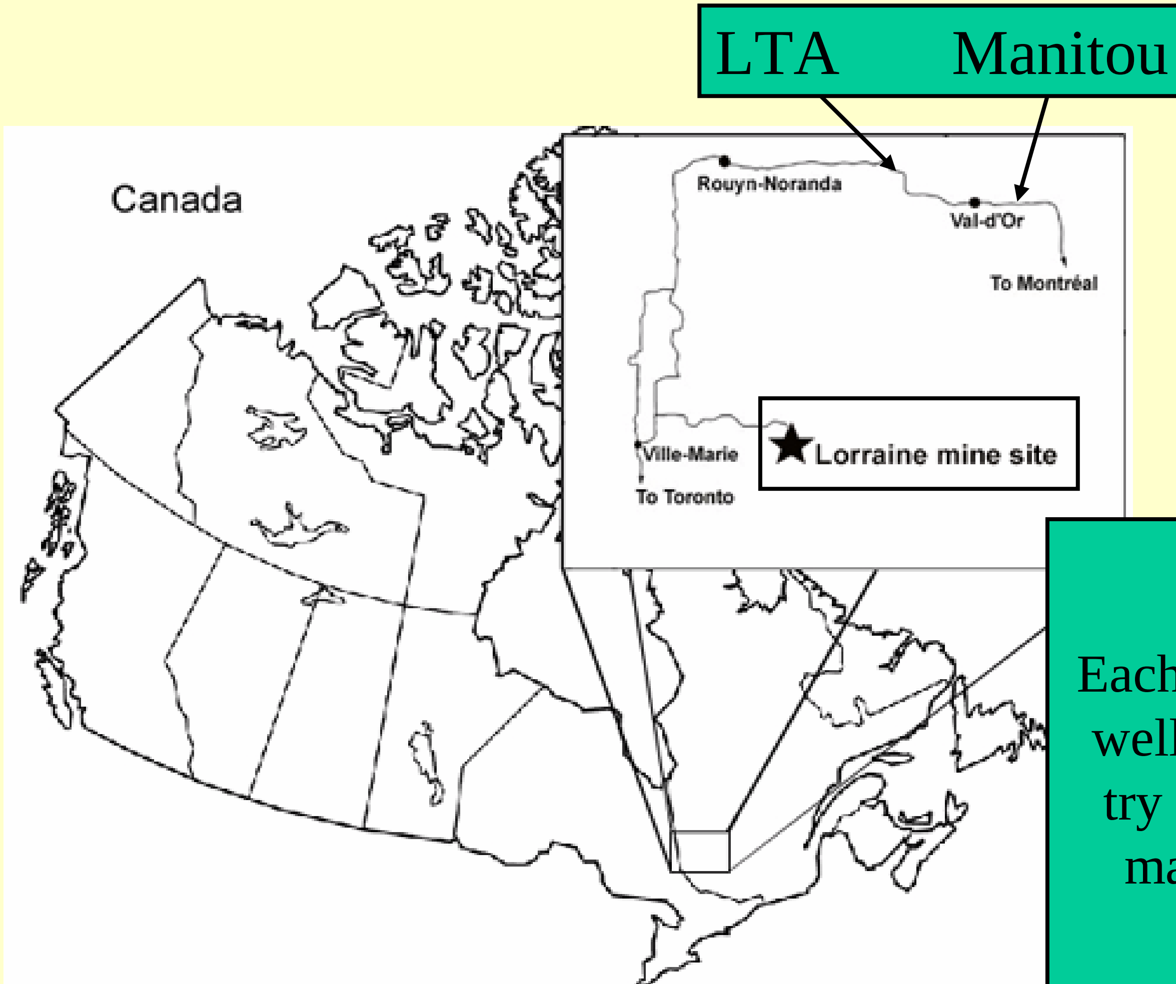


Characteristics of leachate, with and without covers built with tailings (Aachib et al. 98; MEND 2.22.2b)





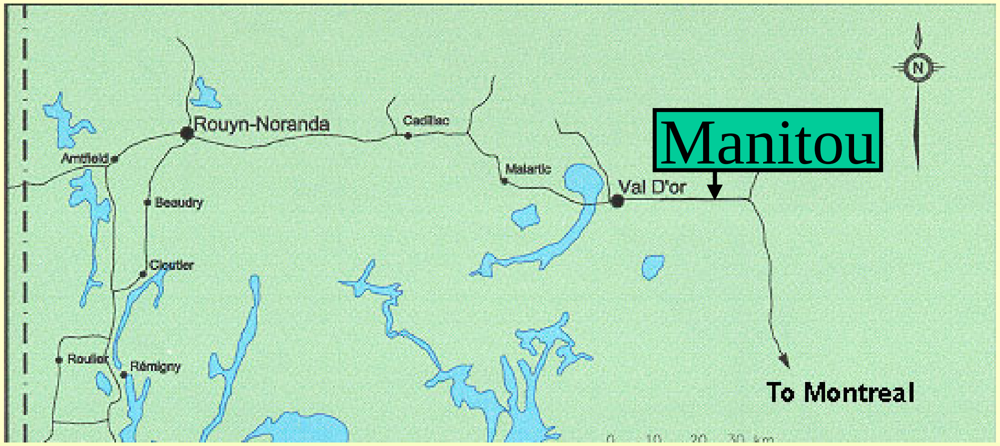
3 sites in Québec (and one in Nevada)



Each case has been well documented; try to summarise main features..

Manitou site;

study conducted with MRN & MEND

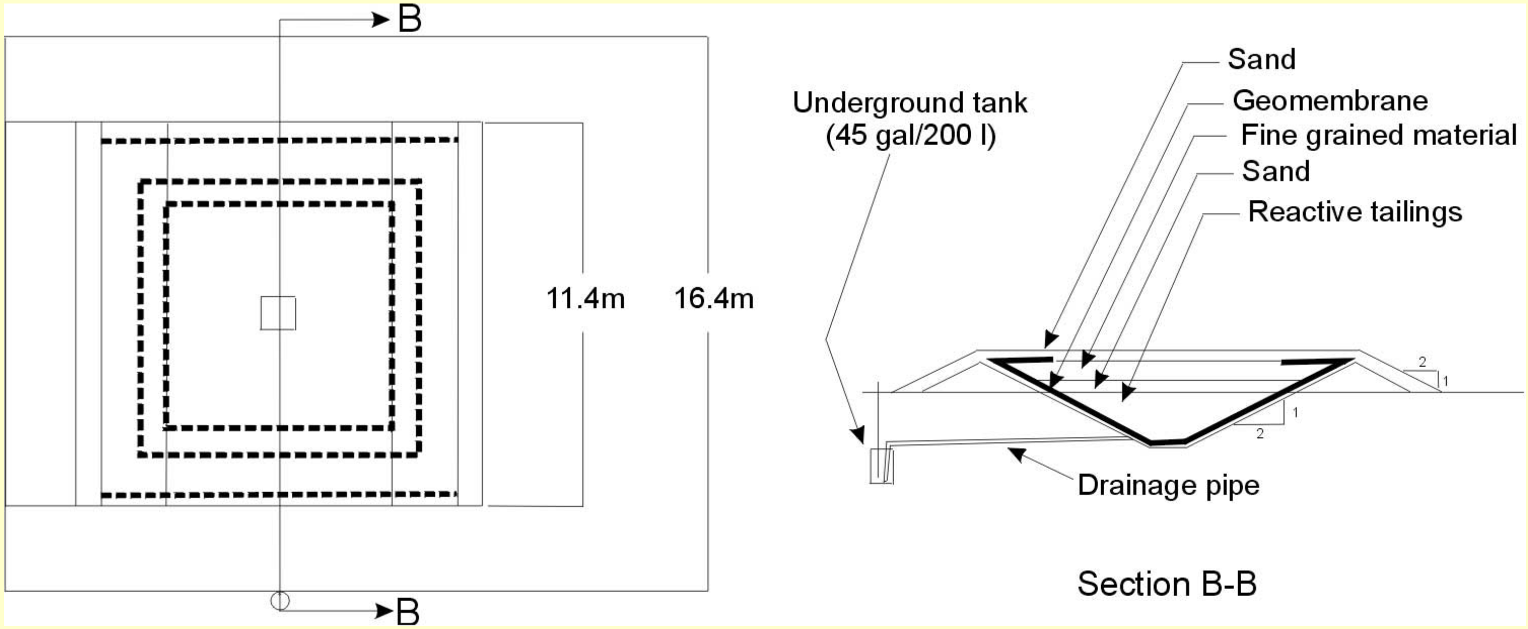


(after Fontaine, 1999; Dagenais, 2002)

Field test Plots close to Tailings impoundment

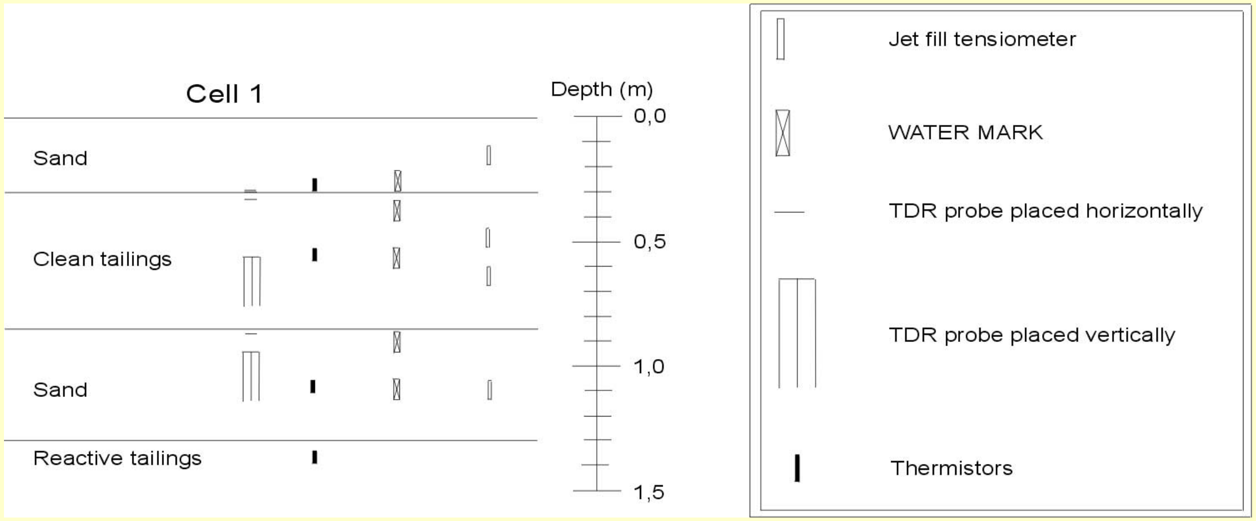
Manitou study:

non-acid generating tailings in covers



Field tests plots (6 cells) MEND 2.22.2c

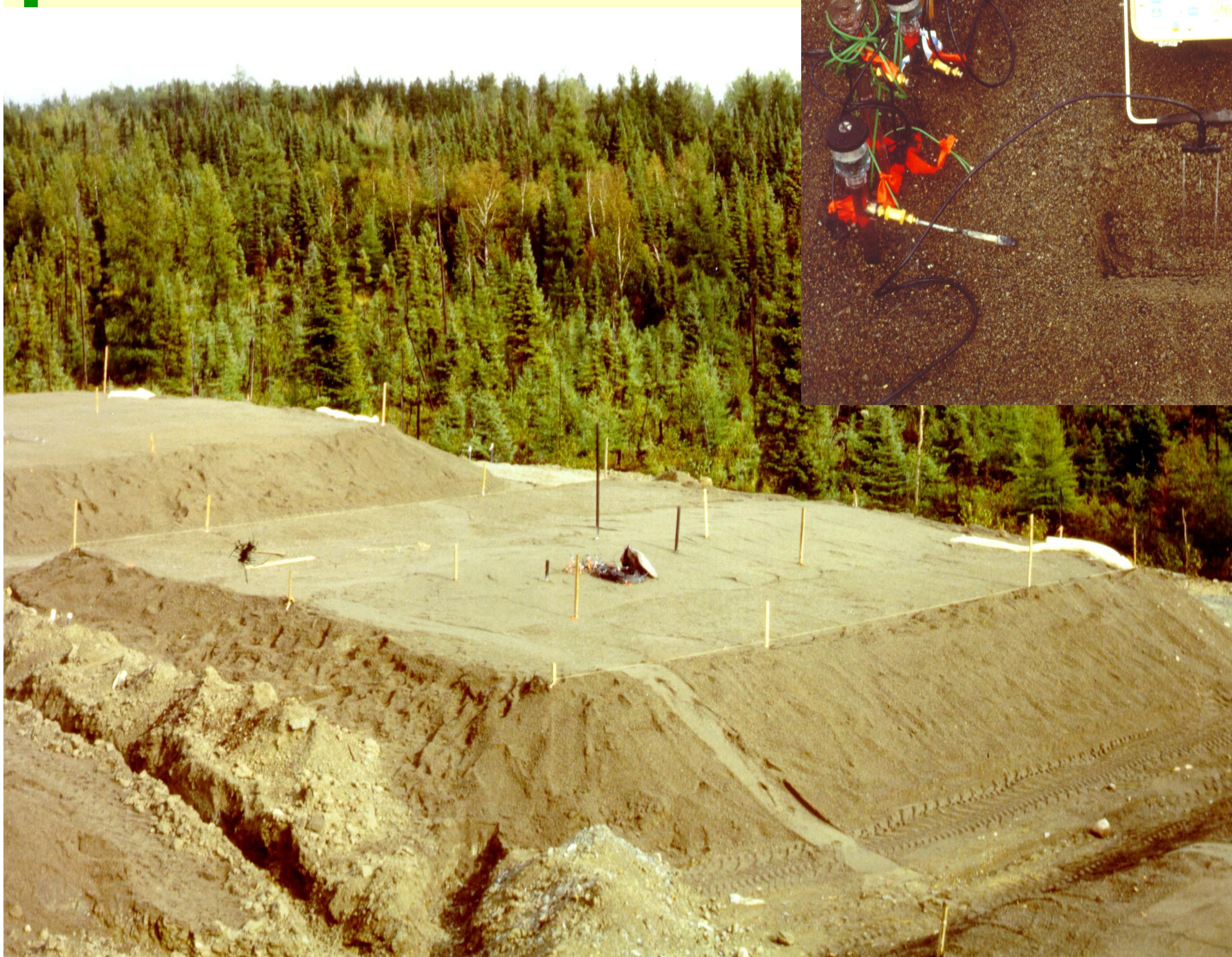
(Aubertin et al. 1997,99; Bussière et al. 1999 ++);

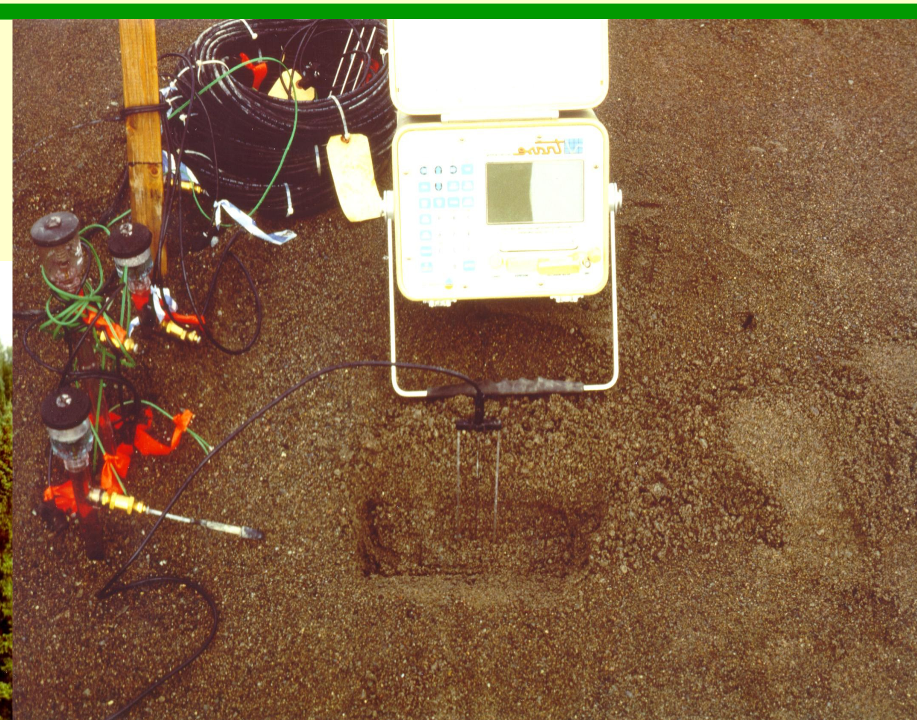


Cell construction At Manitou

CCBE: sand, over tailings or silt, over sand, over reactive tailings

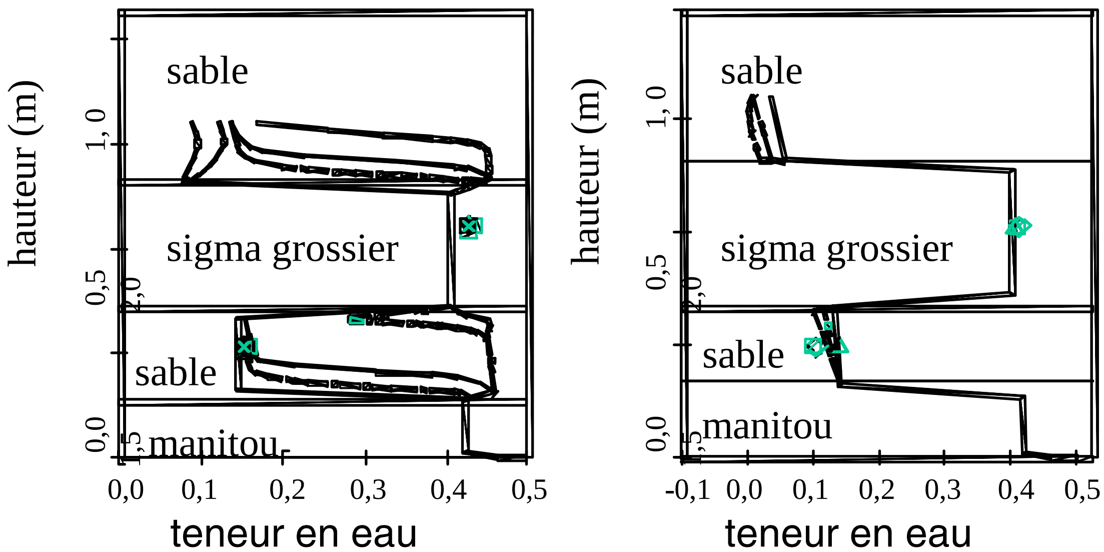
Cell construction At Manitou

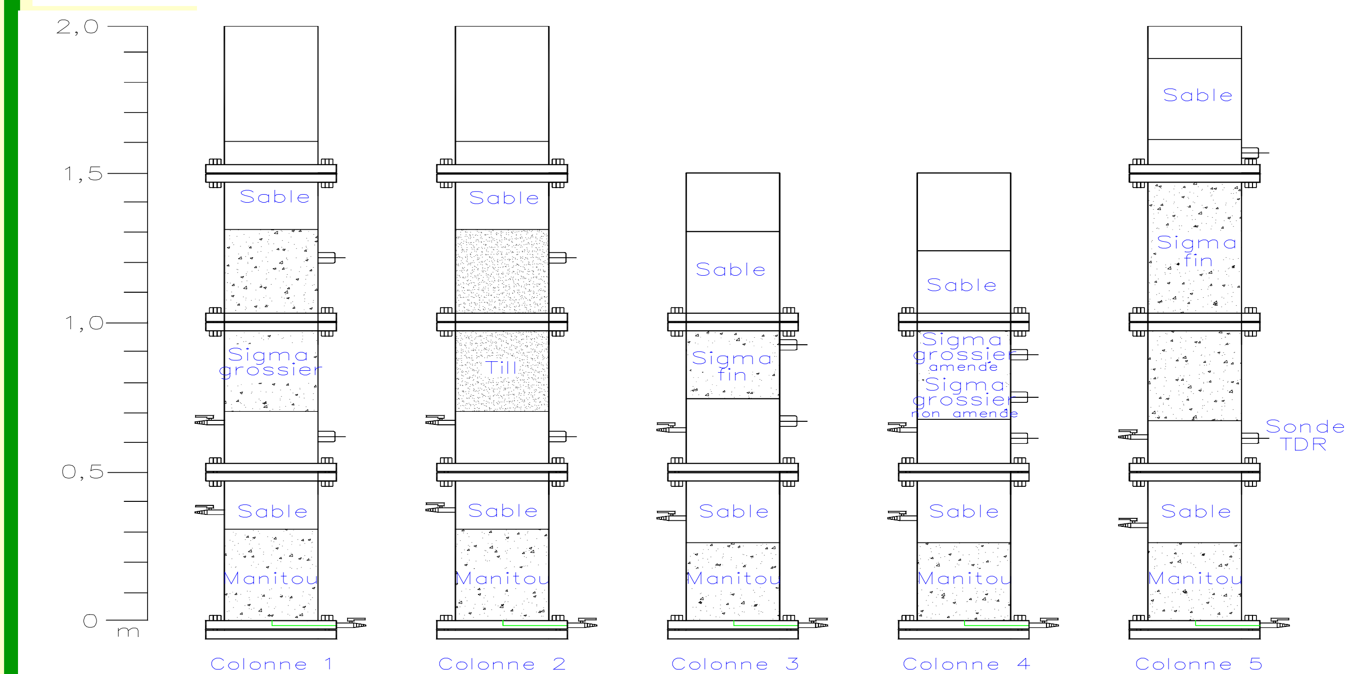




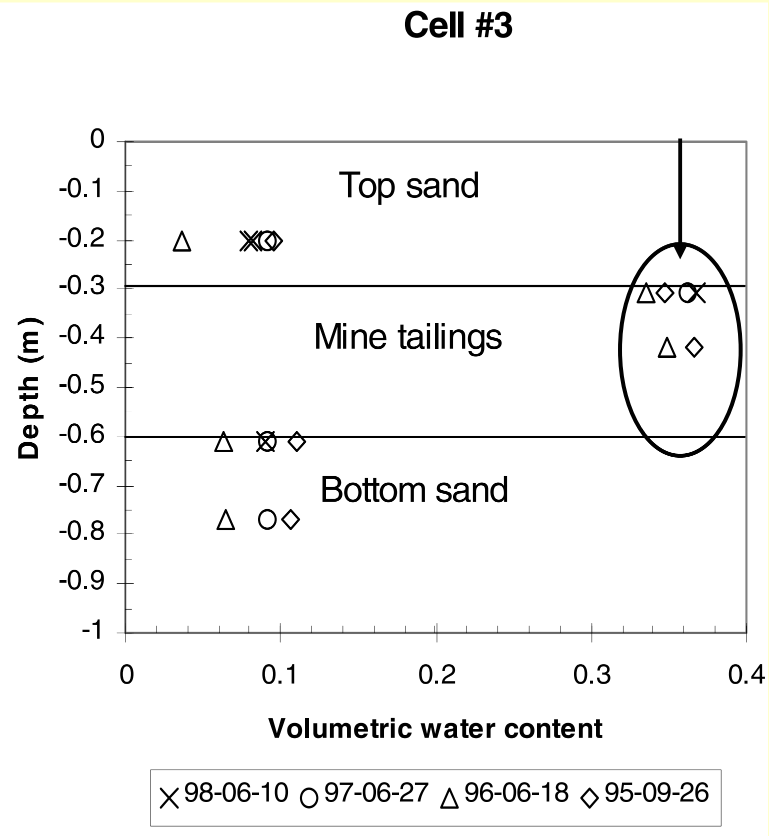
Instrumented cells (6) at Manitou, With leachate collection

Combined with lab columns





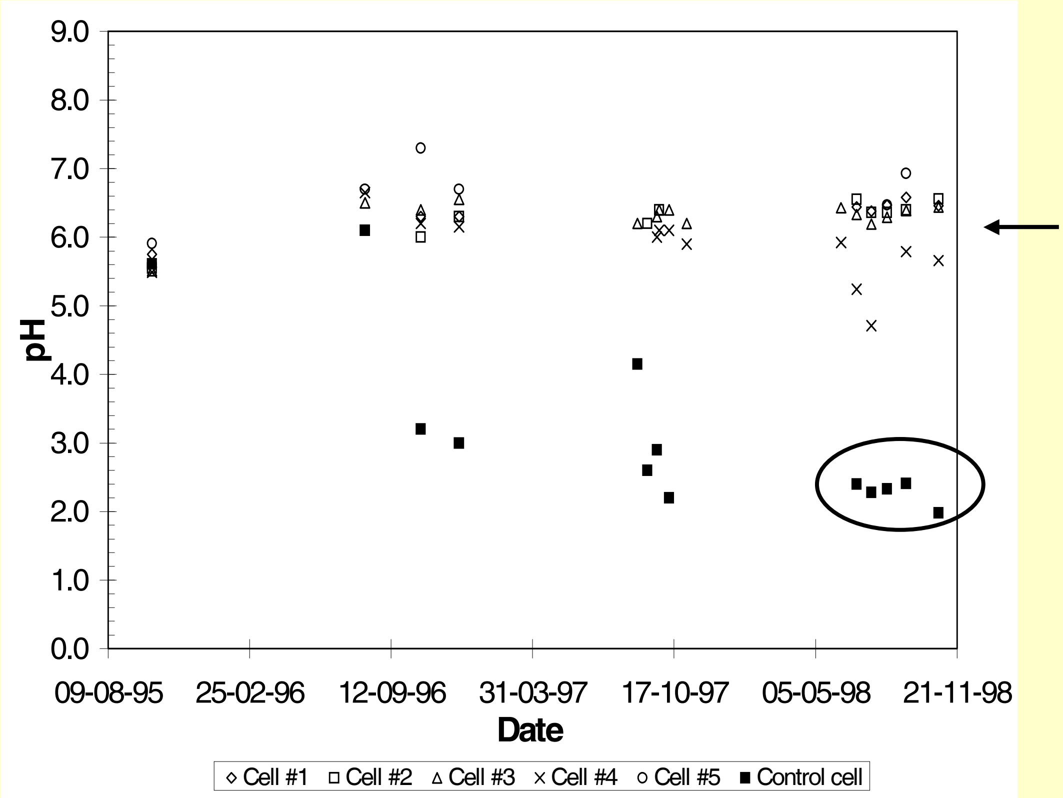
In situ behaviour; water content remained fairly stable over 4 years



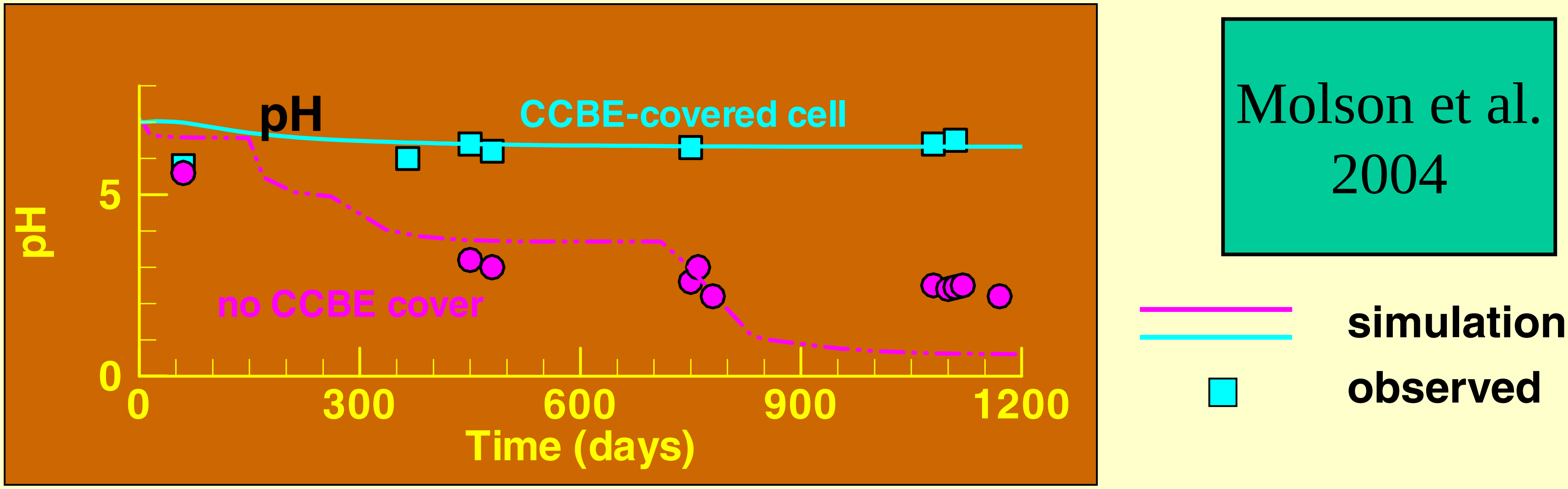
Well developed Capillary Barrier Effects

Geochimistry of leachate: with and without CCBE

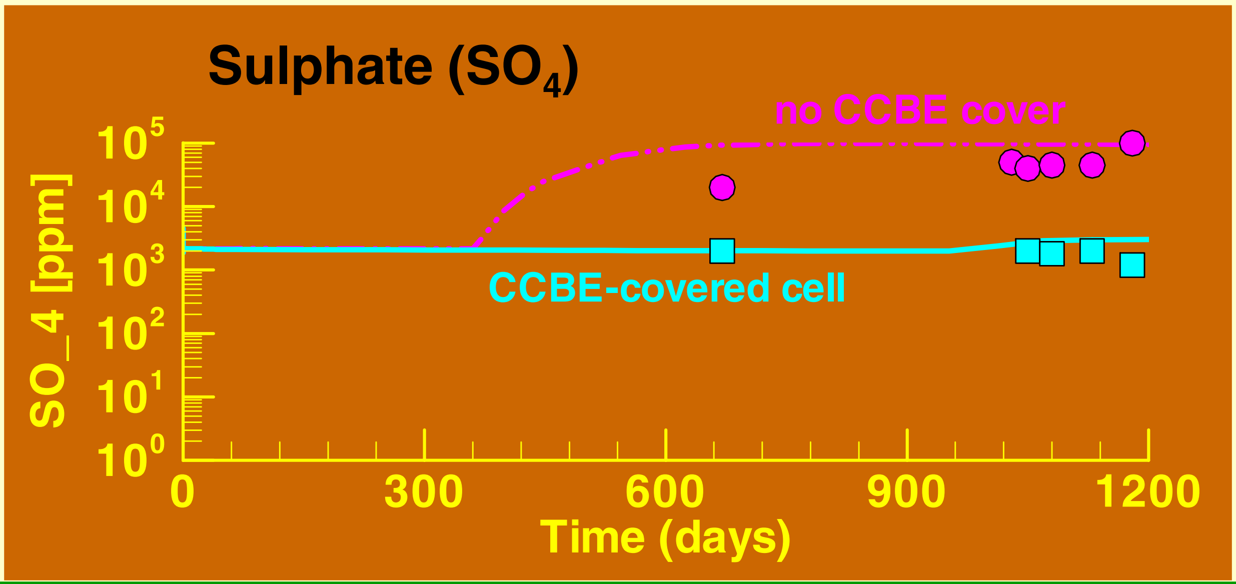
- pH of leachate (also Metals and Sulfates)



Measured vs calculated (coupled reactive transport modelling – Min3P/PolyMin)



Molson et al. 2004



Low oxygen flux; mostly dissolved in water

Field work on Manitou site has shown us that…

- **Predictive tools** can be used to estimate key parameters: k_{sat}, WRC (SWCC), k_u, D_e, etc.

- Predictive models do not replace actual testing on real materials.
- Values obtained should be confirmed by in situ measurements.

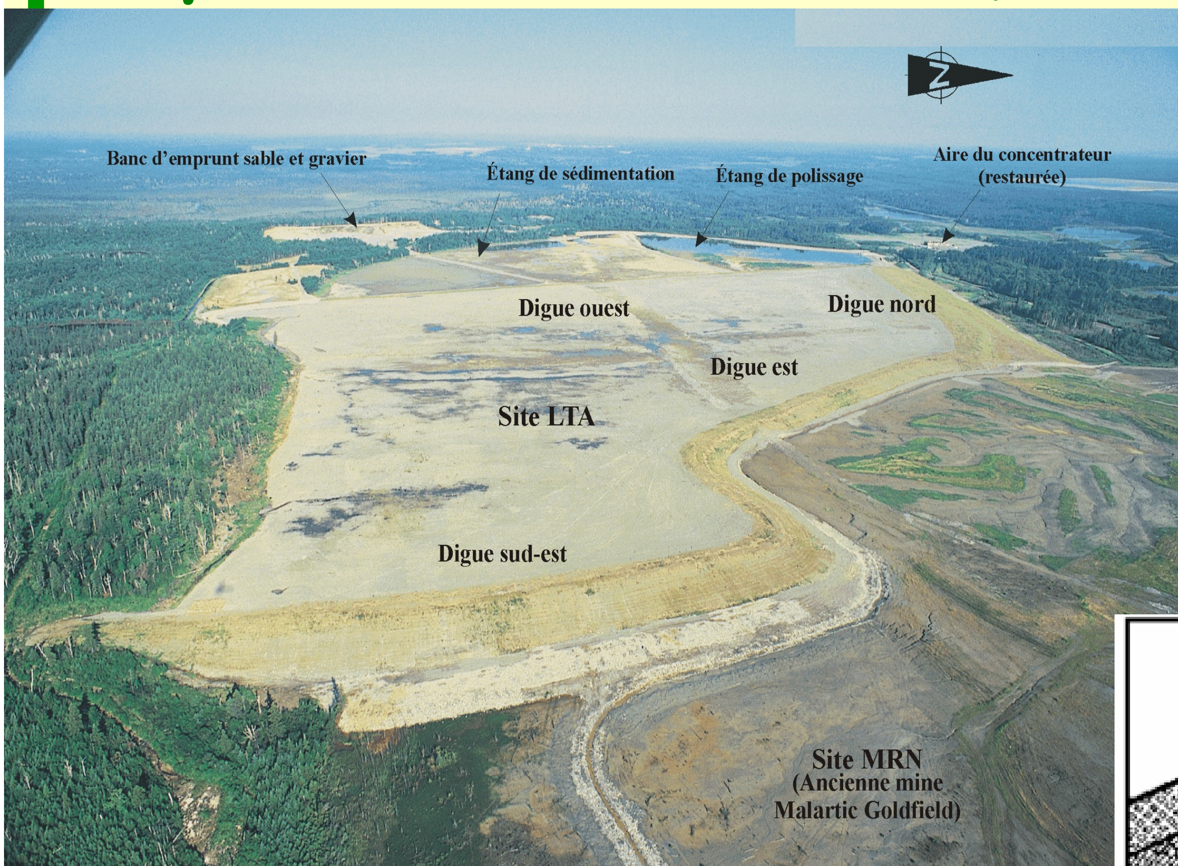
- CCBE **behaved as expected** (from numerical calculations) in the field; confirmed (and completed) by lab experiments.
- **Non-acid generating tailings** (natural or desulphurized) can be used to construct an efficient CCBE.
- Site is to be reclaimed in the coming years…

LTA case (ongoing since 1996..)

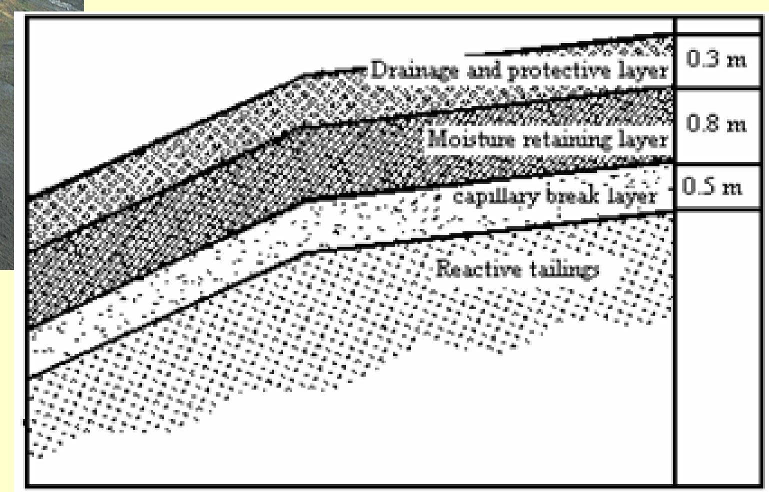
One of the First Large Scale Applications of CCBE

(map adapted from Fontaine, 1999)

LTA tailings impoundment; cover installed upon closure in 1996, using MRN tailings

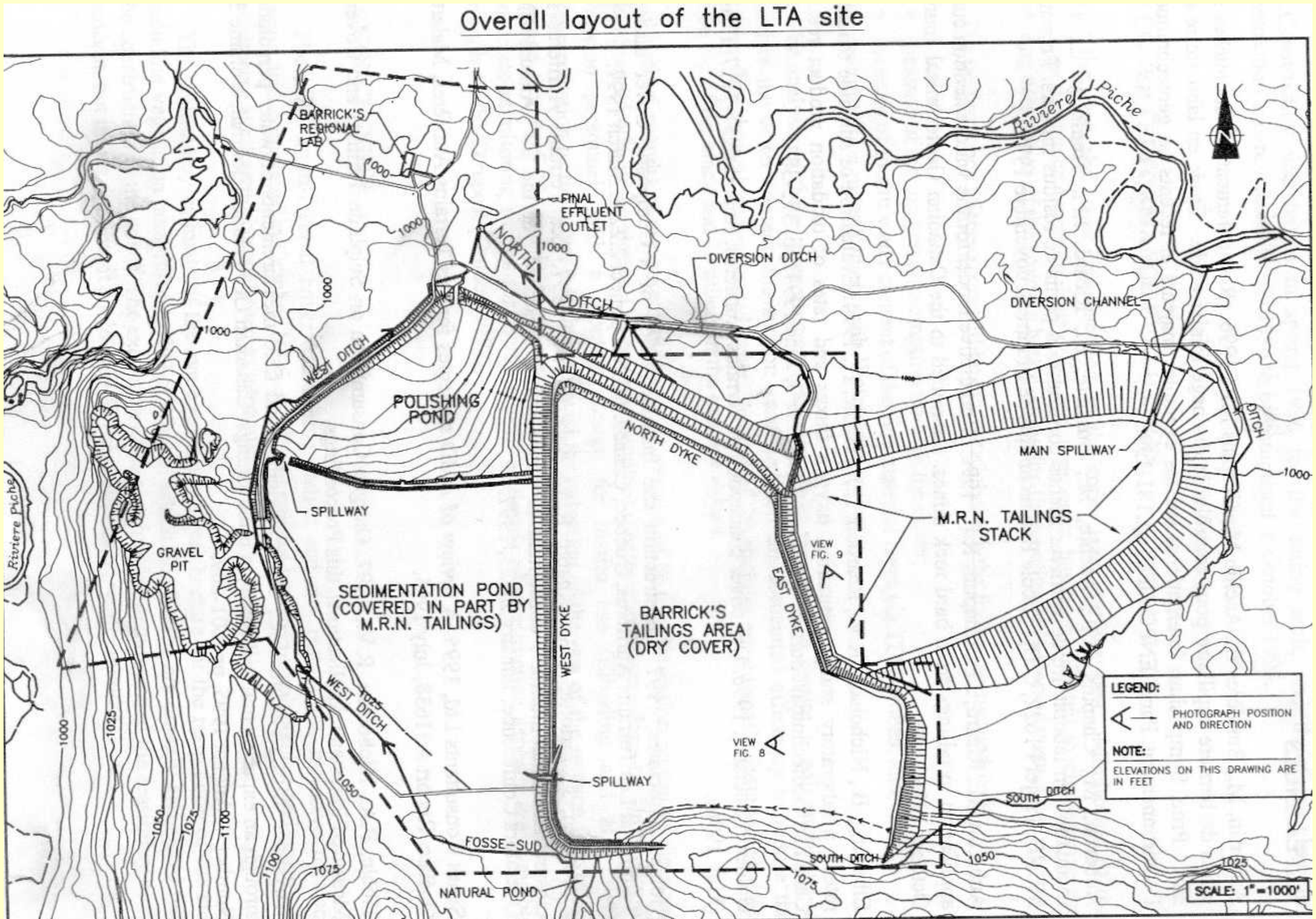


Worked with Barrick and Golder

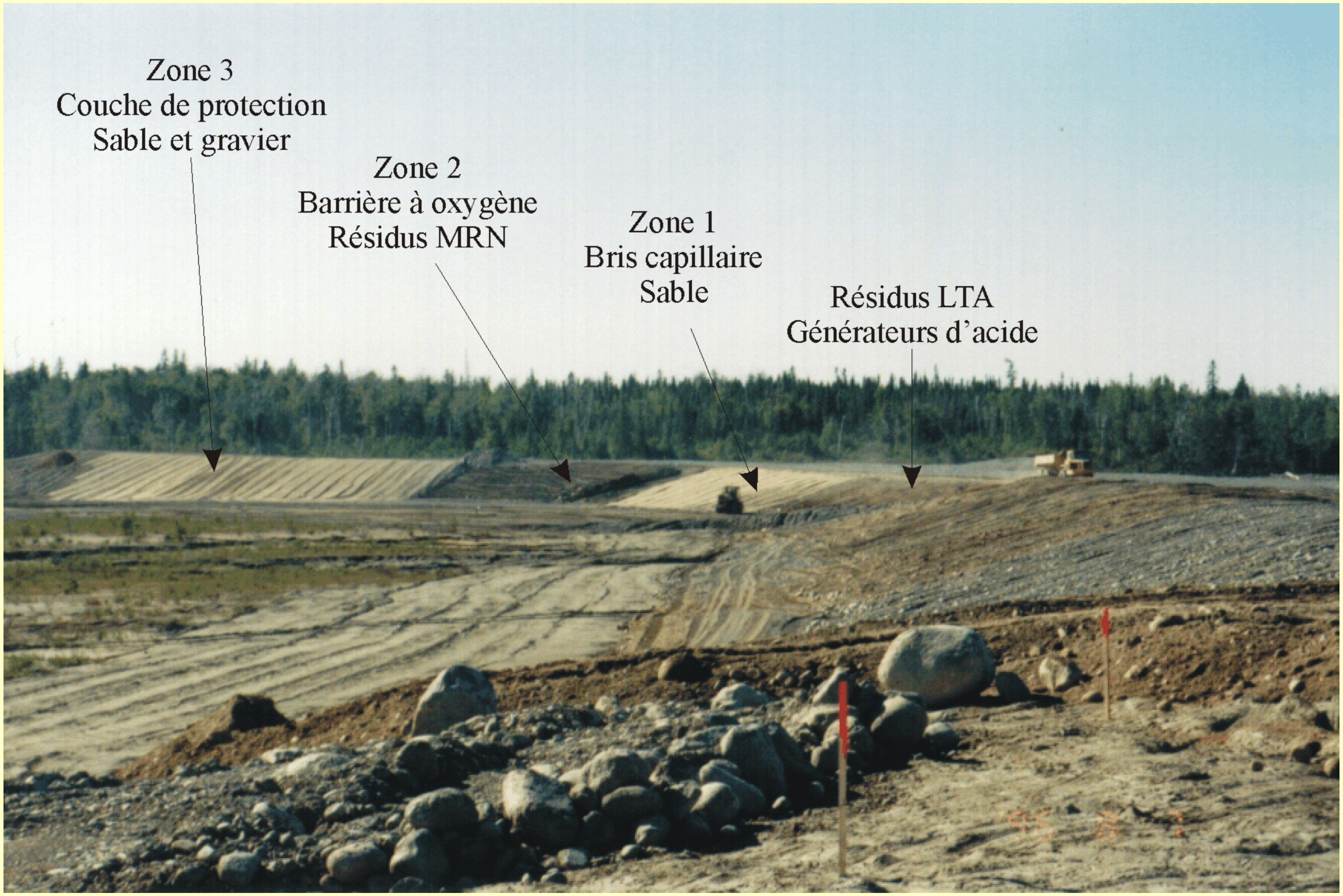


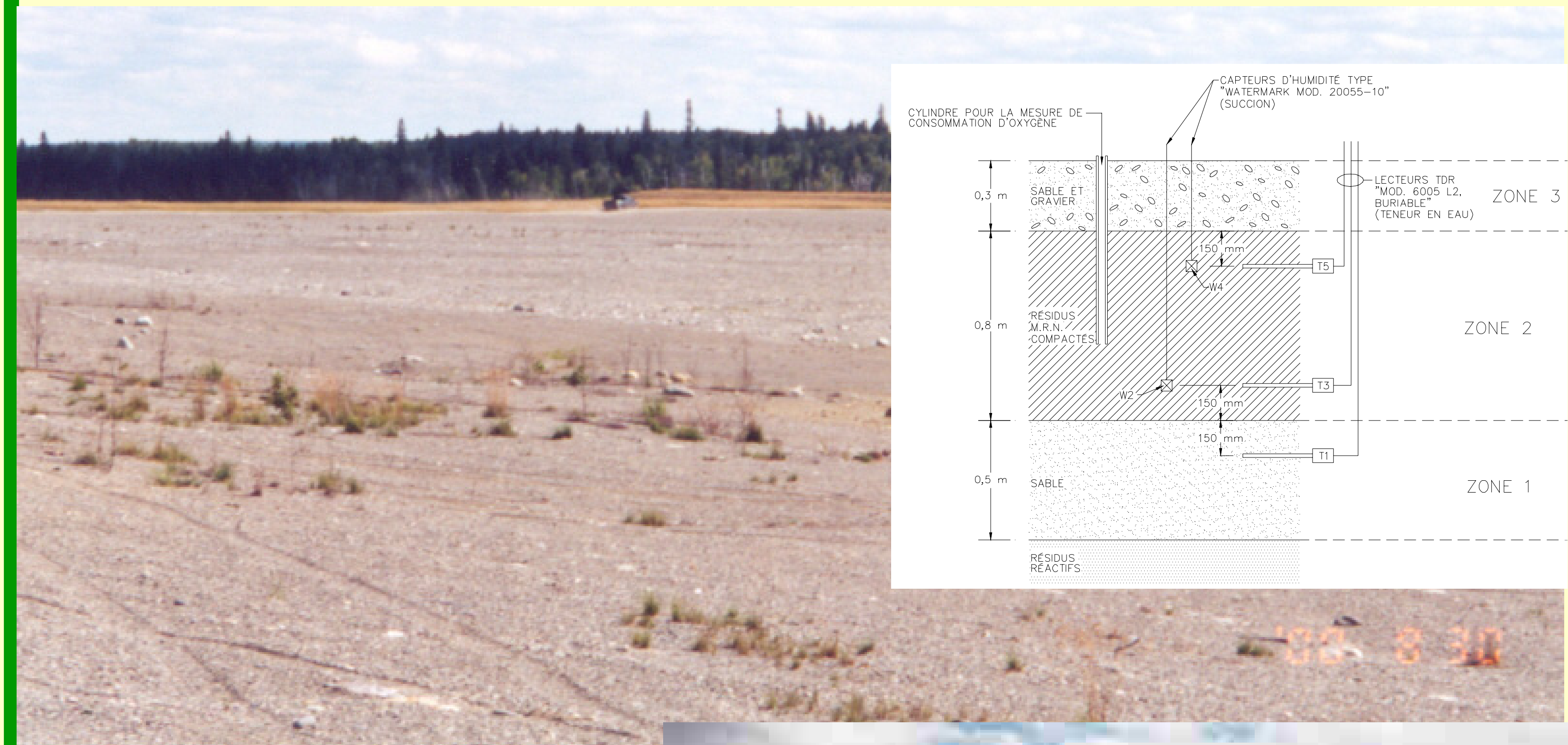
LTA cover

- **The area covered is about 65 ha**



CCBE construction at LTA (mostly winter time)



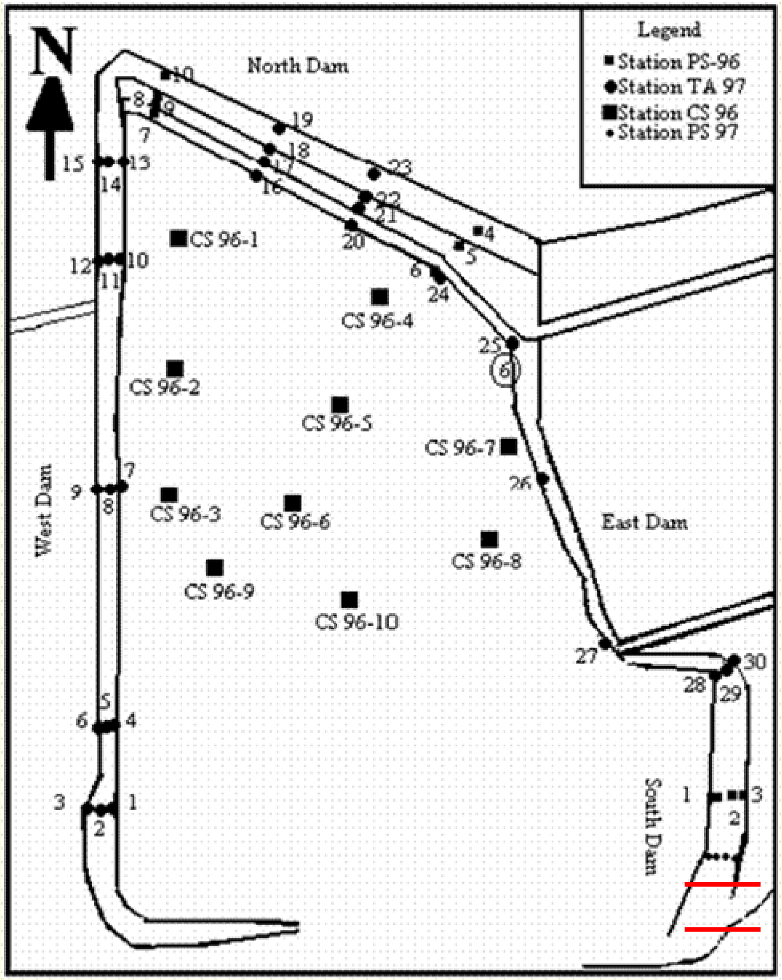


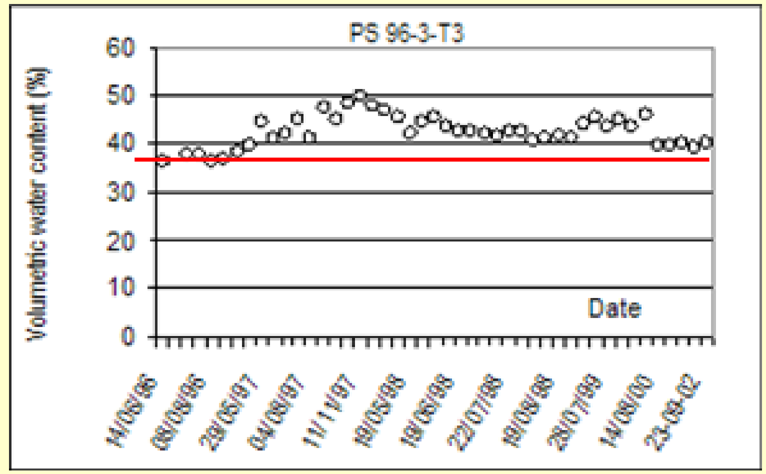
Instrumented and Monitored since 1996

- **LTA cover (top of dyke): 65 ha; < 90k$/ha**

Comparison between measured and calculated water content; results met target.

Monitoring stations
Along a grid



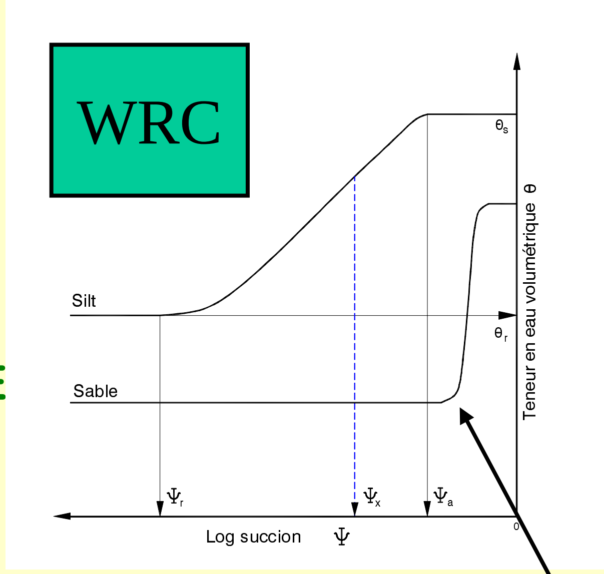


LTA CCBE: efficient to reduce oxygen flux

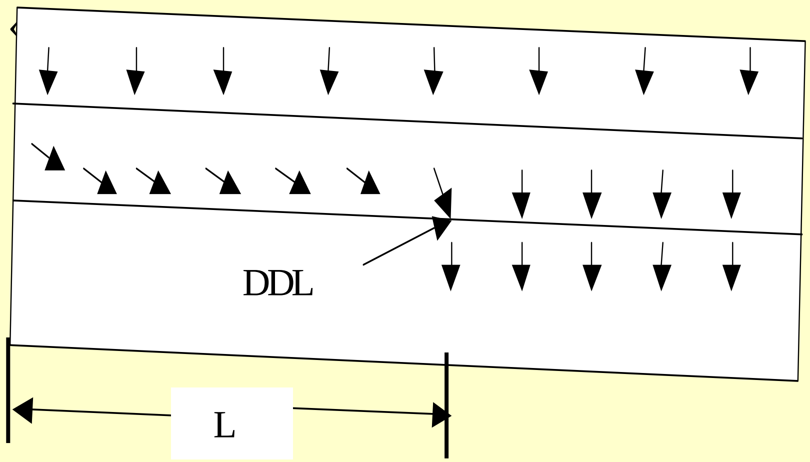
In 1996, started working on the influence of slope on cover behaviour : largely neglected aspect at the time…

In inclined CEBC,

water tends to flow above and
in the water retention layer;
- accumulates along the slope;
- may reach DDL point where suction
 at the interface with coarse material reaches WE
- loss of water retention by deep percolation
- also risk of desaturation in the upper parts



WEV

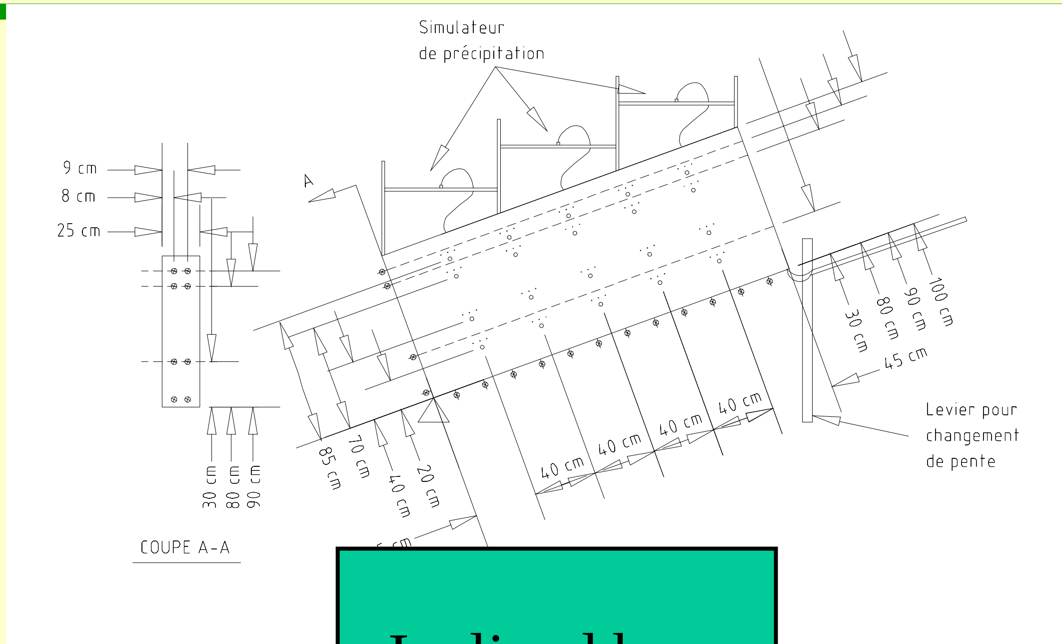


Sand

Silt

Sand

Papers by
Aubertin et al. 1997
and Bussière et al.
1997, 1999, 2000, etc.

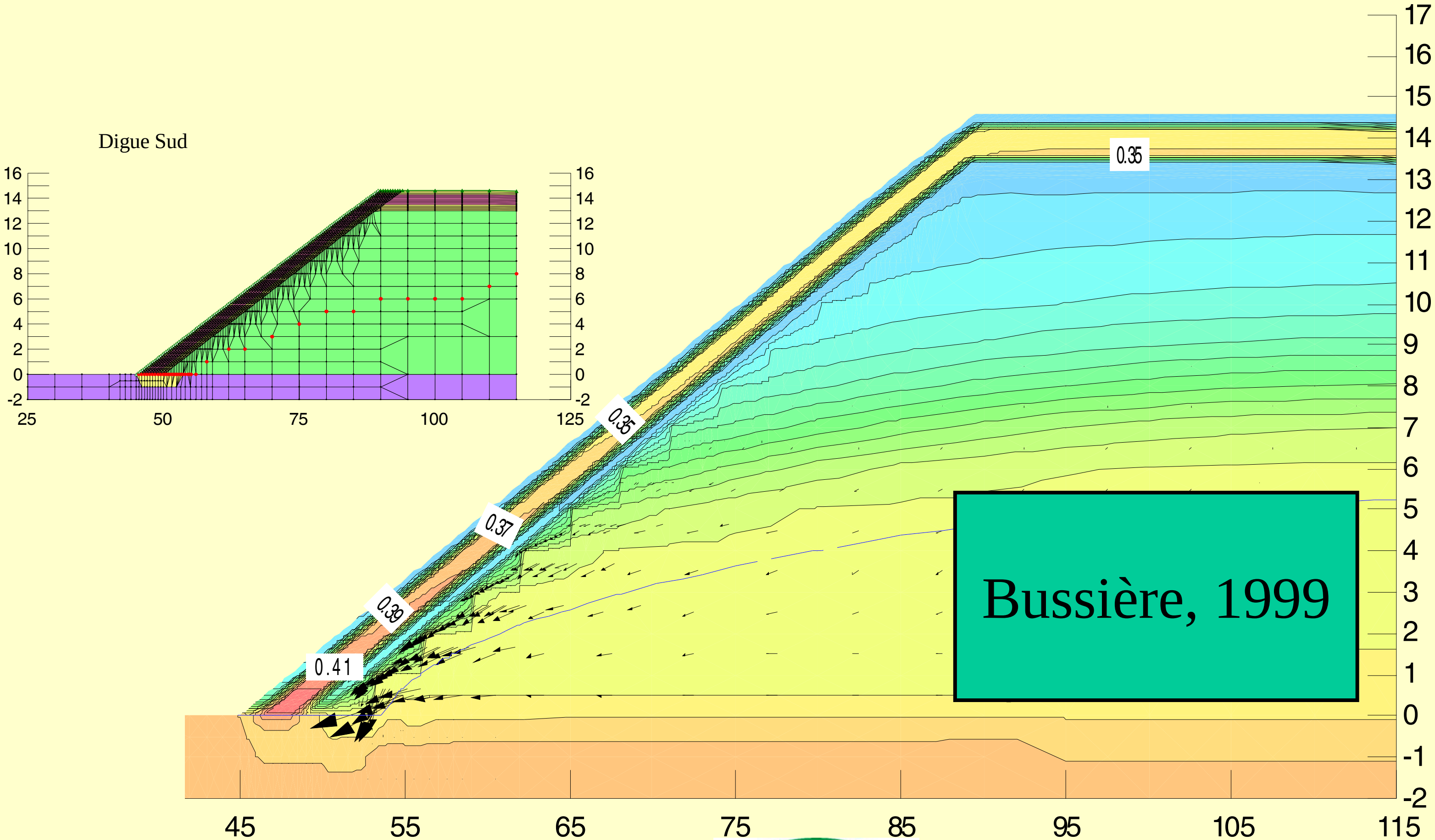


Inclined box
Tests in the lab

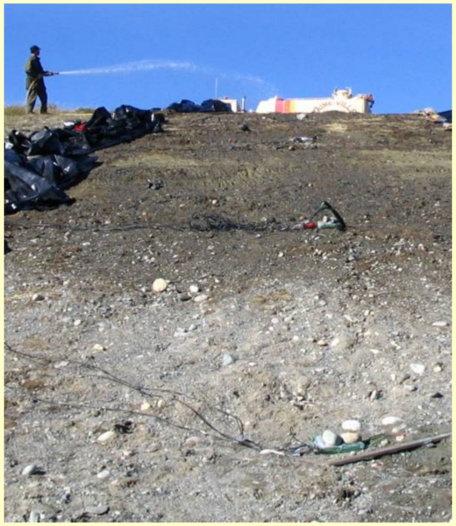
Bussière et al.
1998, 2000

DDL phenomena was studied with numerical models, physical models, and field measurements.

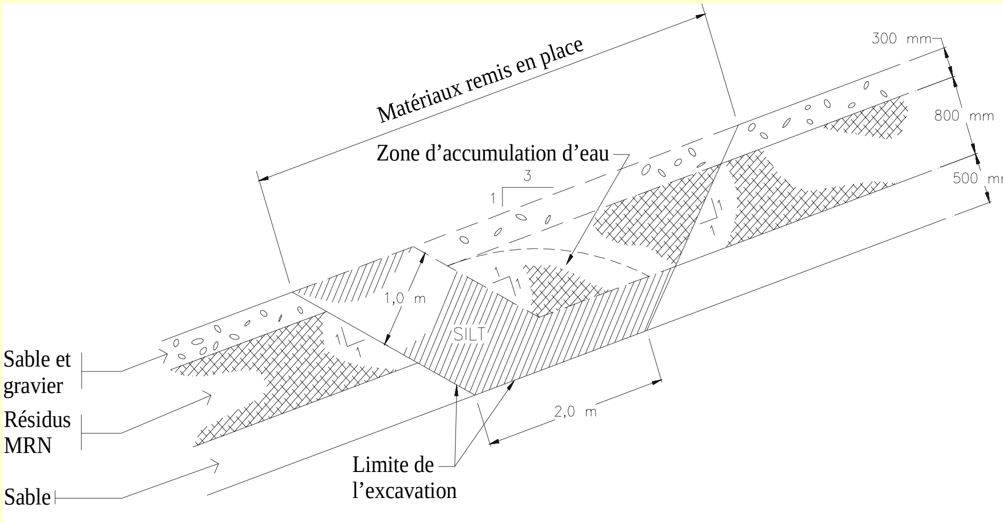
Modelling results showing the influence of elevation on volumetric water content



Field Infiltration Tests with instrumentation ; confirmed calculation results

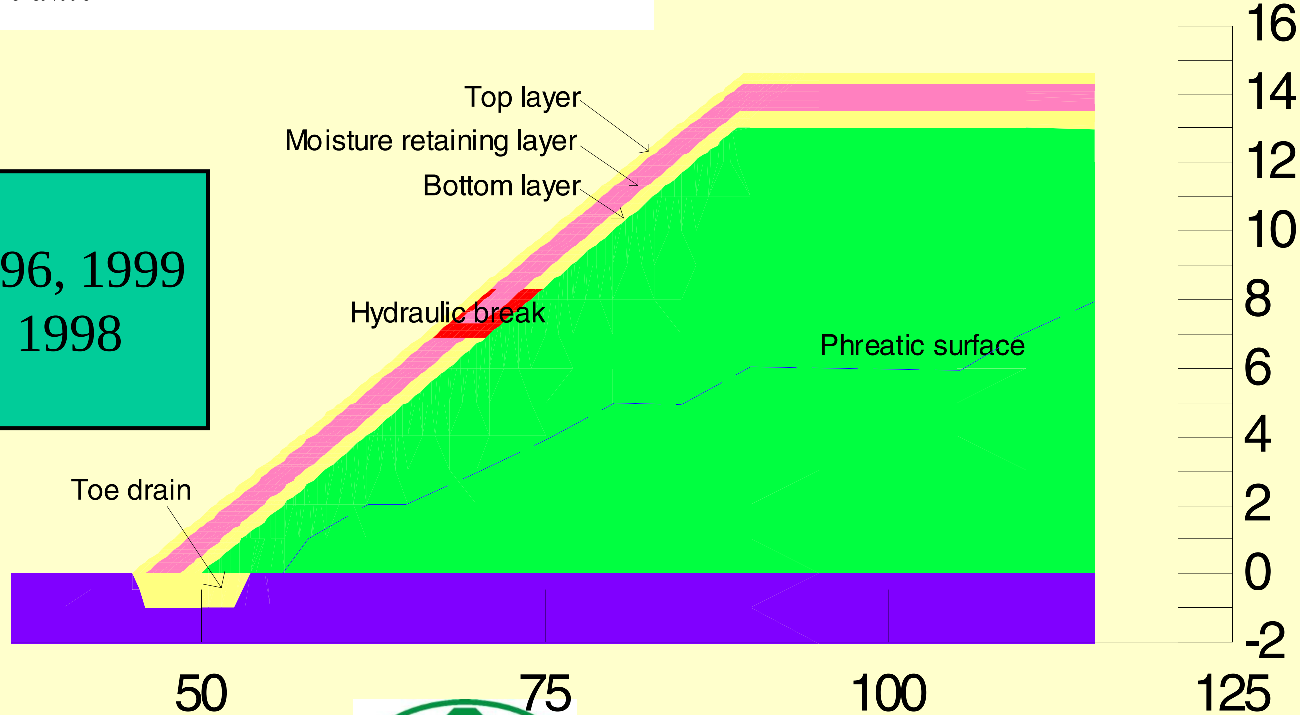


Suction (or hydraulic) breaks



South-East dam

Aubertin et al.1996, 1999
Bussière et al. 1998



Field tests:
i)1997
ii)2004

During the LTA site study, we learned (and confimed) that …

- Predictive models based on simple geotechnical properties (i.e. grain size, porosity, consistency limits, etc.) can also be used (after proper calibration) to evaluate the range of properties for a **heterogeneous** material deposit…

- **In situ monitoring** is key for evaluating the actual performance of the cover system.
- Also provides information to **reconstruct the in situ WRC**, and to follow its evolution in time.
- **Freeze-thaw cycles** may affect permanently the behaviour of clayey soils; low plasticity silts (like hard rock mine tailings) are less prone to permanent damage because of healing capacity.

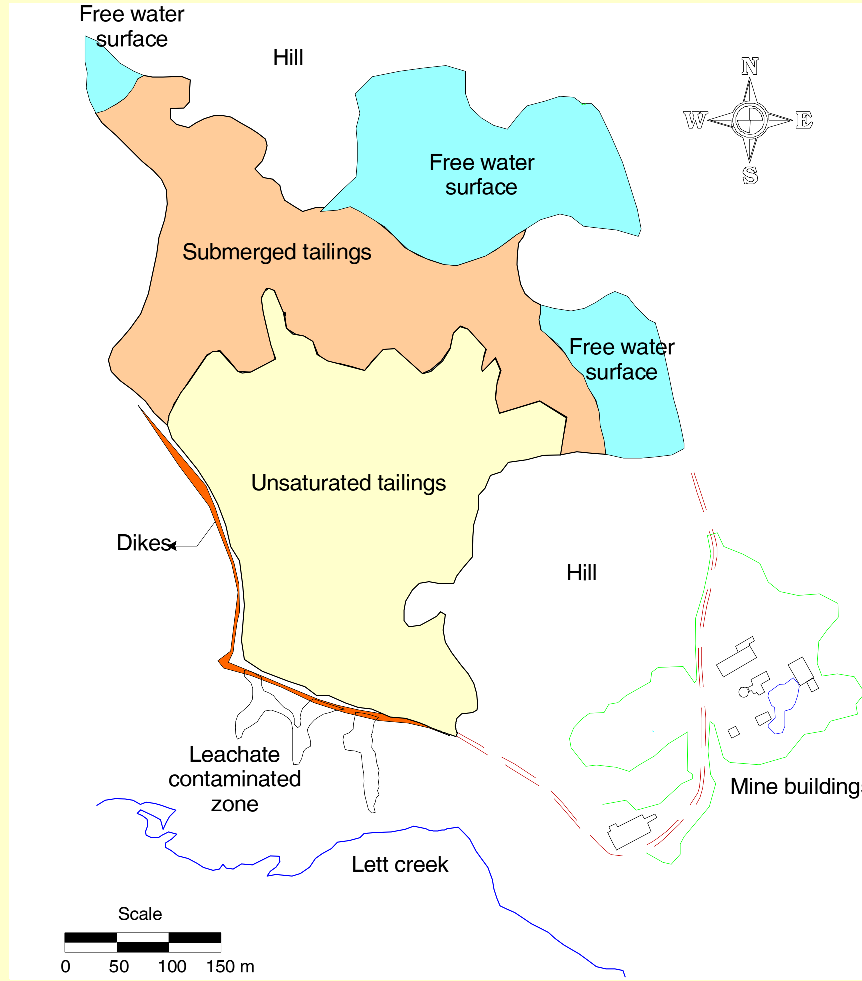
During the LTA site study, we learned (and confimed) that …

- **Slope** (inclination, length) has a major influence of CCBE response used as oxygen barrier (or as a SDR-type cover)
- Analysis should make use of 2D models (or 3D in some cases).
- In the case of sloping areas, **steady-state solutions** are of little use; transient analysis are required.
- **Extreme events** (Precipitation, Drought,) may control the system design …

During the LTA site study, we learned (and confimed) that …

- Low plasticity soils (silts and sand) allow winter construction of the cover; materials should not be too wet…
- In a humid climate, CCBE may be **less effective the first year**; needs time to « recharge »; spring thaw may be very helpful for increasing the water content of the retention layer.
- Small amounts of **sulphide in the cover** material may be beneficial as it reduces the O_2 flux; must assess long term depletion (temporary contribution)

Lorraine site (helped MRN, Dessau-Soprin)



A long term process - 40 cm of suphides depletion in 35 years, with 5 more meters to go…

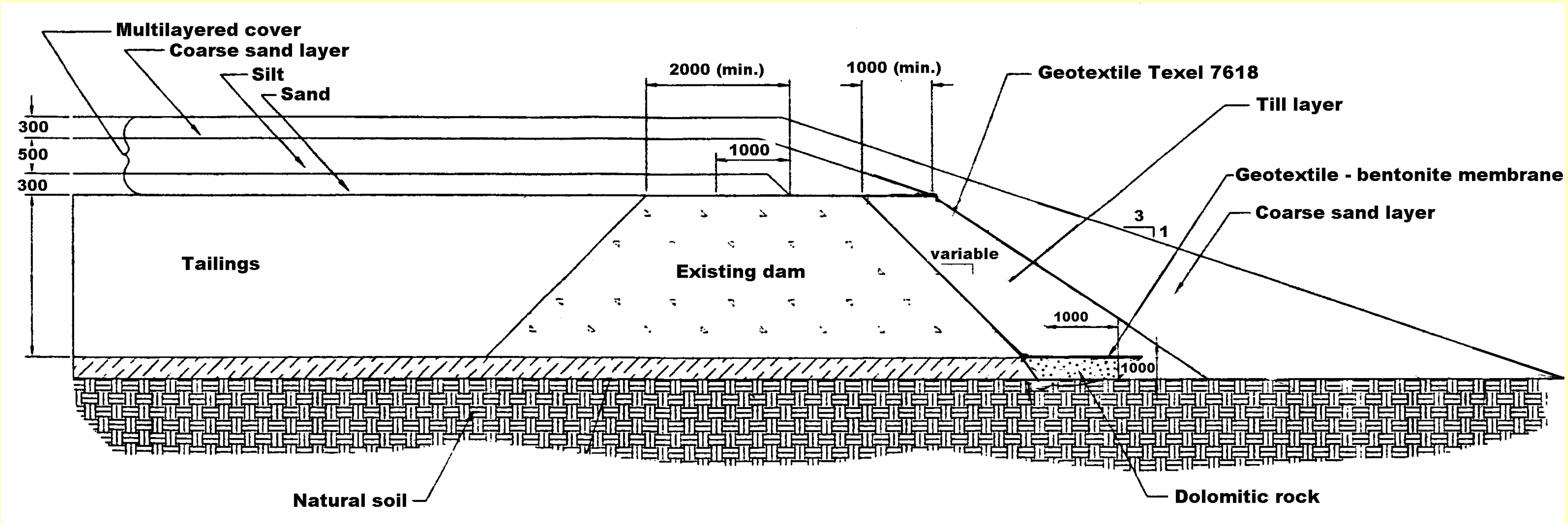
Site Lorraine, Témiscamingue

Lorraine before and after (winter construction)

CCBE:
15 ha;
< 100k$/ha

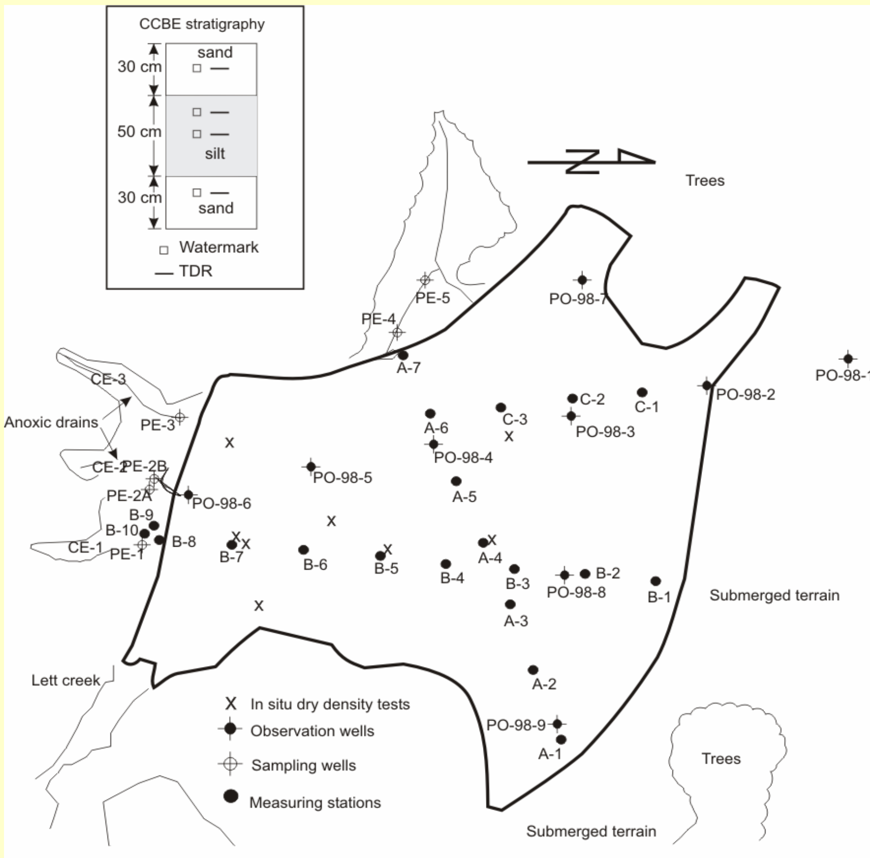
Cover configuration

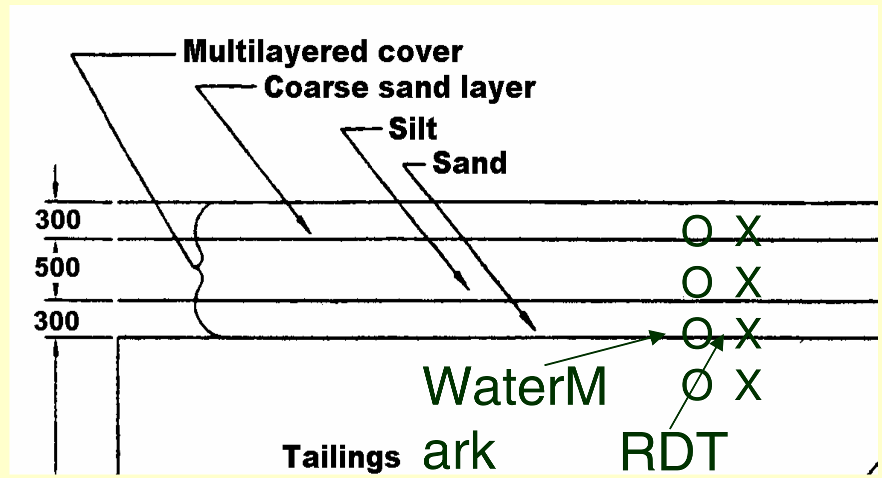
Target Flux : 20 - 40 g/m^{2}an



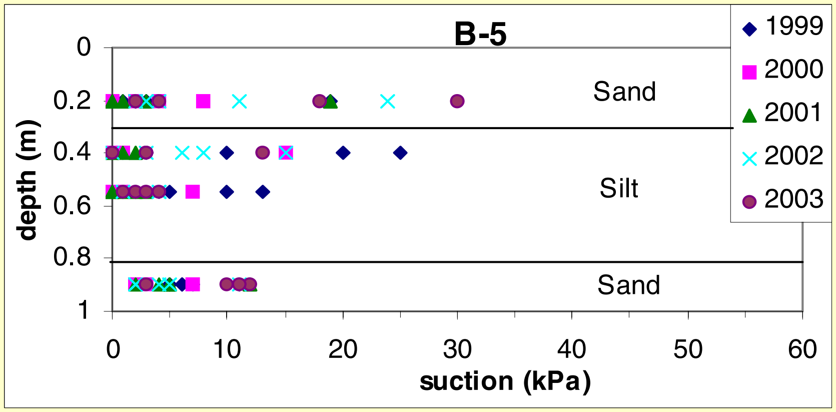
(Fontaine, 1999)

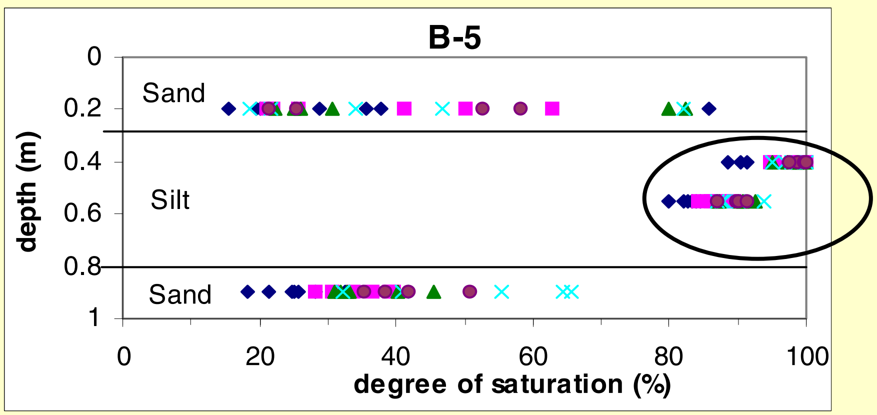
Instrumentation CCBE at the Lorraine site





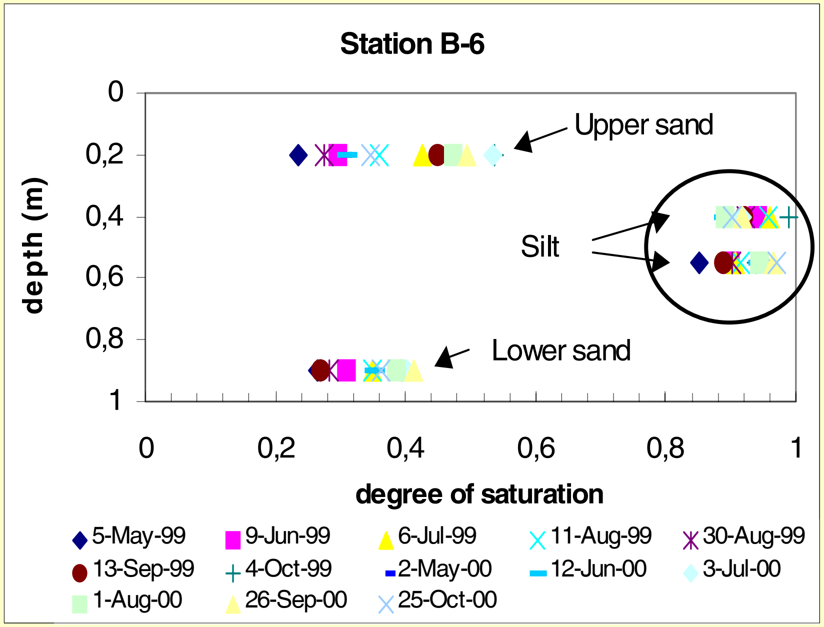
Degree of saturation and suction profiles for station B-5

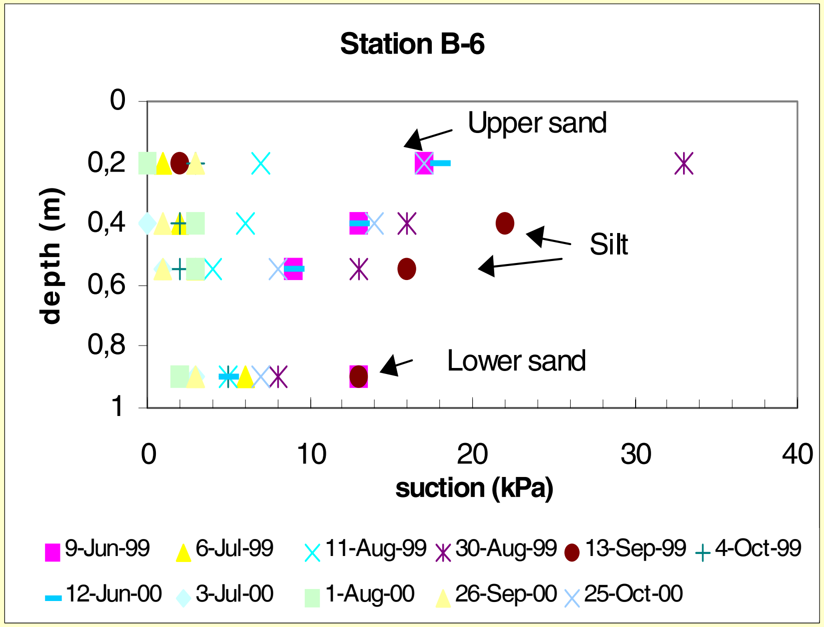




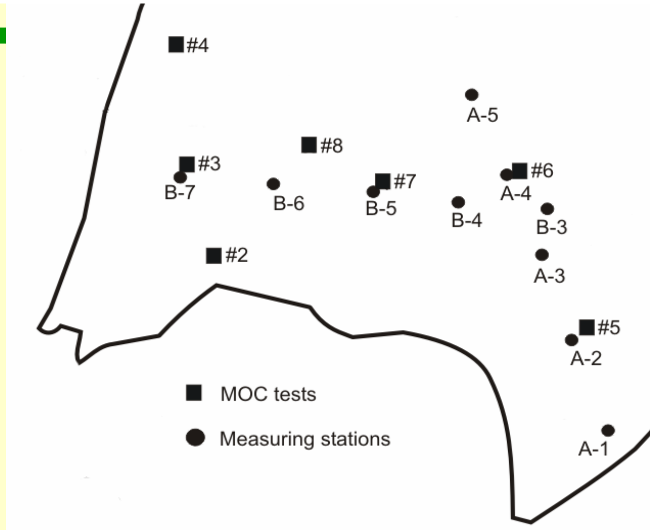
Results from field monitoring

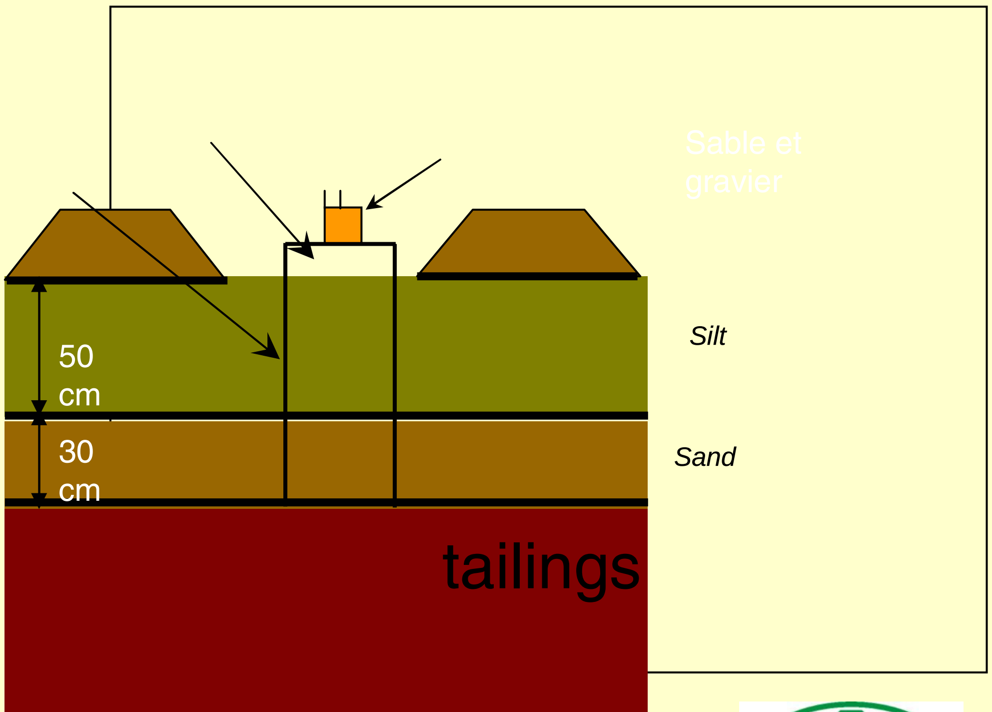
Hydraulic respons of CCBE



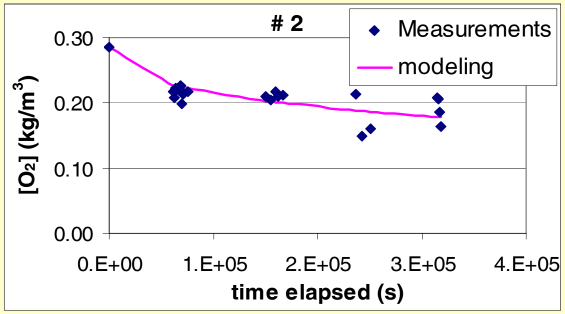


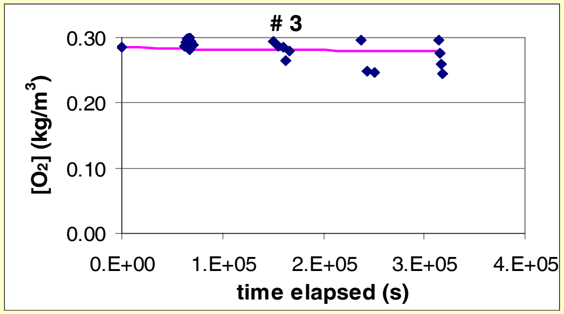
Modified O_2 consumption tests (adapted from Elberling and Nicholson 1994)

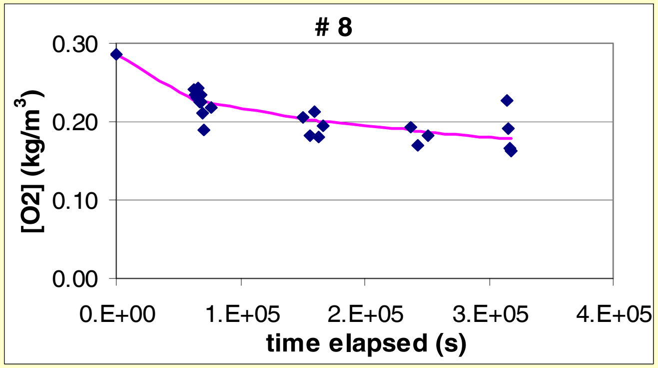




Measured and modelled oxygen concentration decrease in the reservoir of the modified consumtion tests performed at the Lorraine site

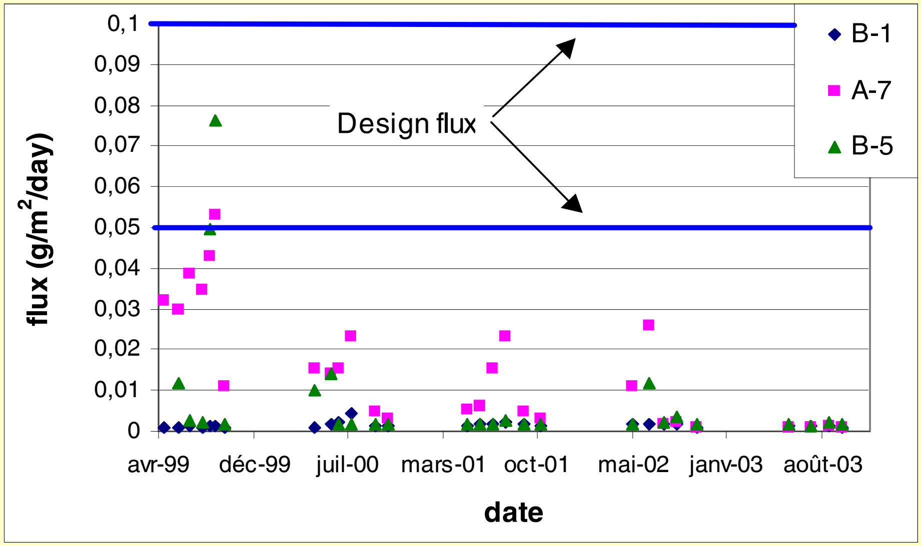






Dagenais, 2005

Estimated maximum daily oxygen flux through the CCBE



Dagenais et al. 2005

Lessons ensuing from Lorraine case

- Various means exist to **evaluate the efficiency of a CCBE**
- Should monitor suction and water content along a systematic grid (and compare results with WRC, and modelled results).

- Use in situ values of **n and** θ to estimate effective diffusion coefficient **D_e**, which is used to **calculate the flux** under steady and transient conditions
- In situ **modified oxygen consumption tests** can also be used to evaluate the flux through a cover.

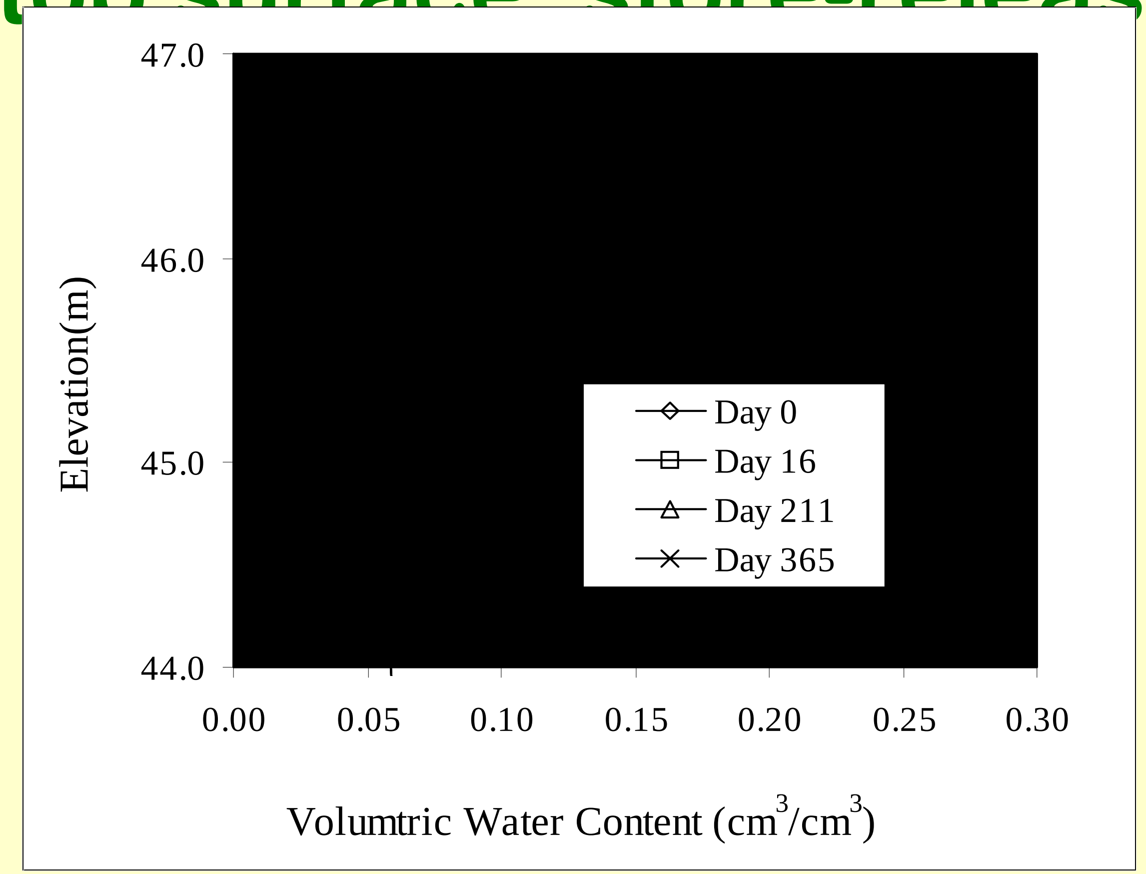
- Water balance from modelling calculations agrees with measured (collected) seepage.
- Water seeping out of old site, already well oxidized; will have to be treated for decades ; use of passive system.

BGMI – Cover installed on heap leach pad; « experiment » for future dump closure

Semi-arid; SDR cover

Top surface; single layer; 1 m of Carlin silt

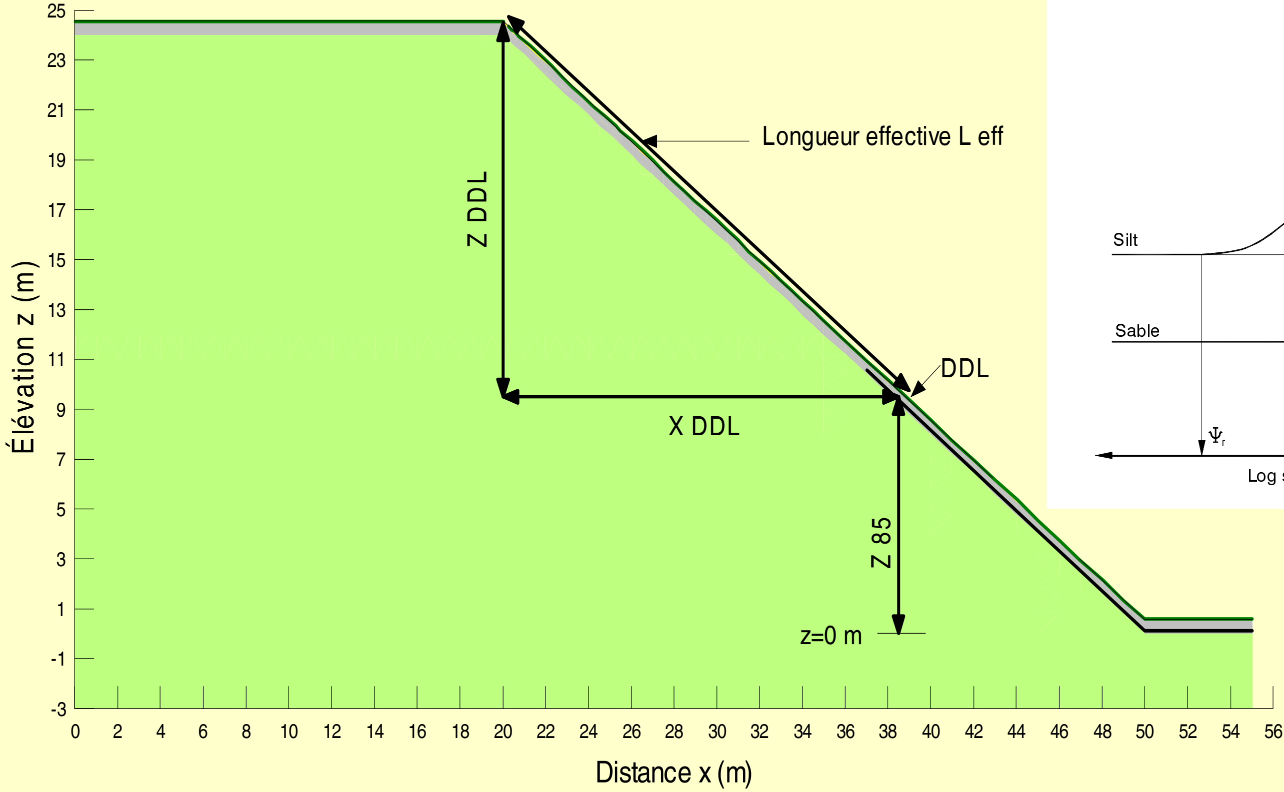
Volumetric water content in the CCBE for top surface: store-release

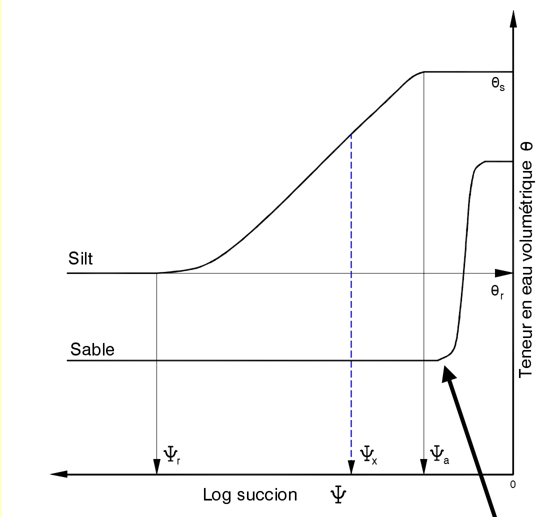


Need to Look at Optimum Layer thickness

Zhan et al. 2000

Study on Effective Length; influenced by amount of precip, hydraulic properties, and cover configuration.



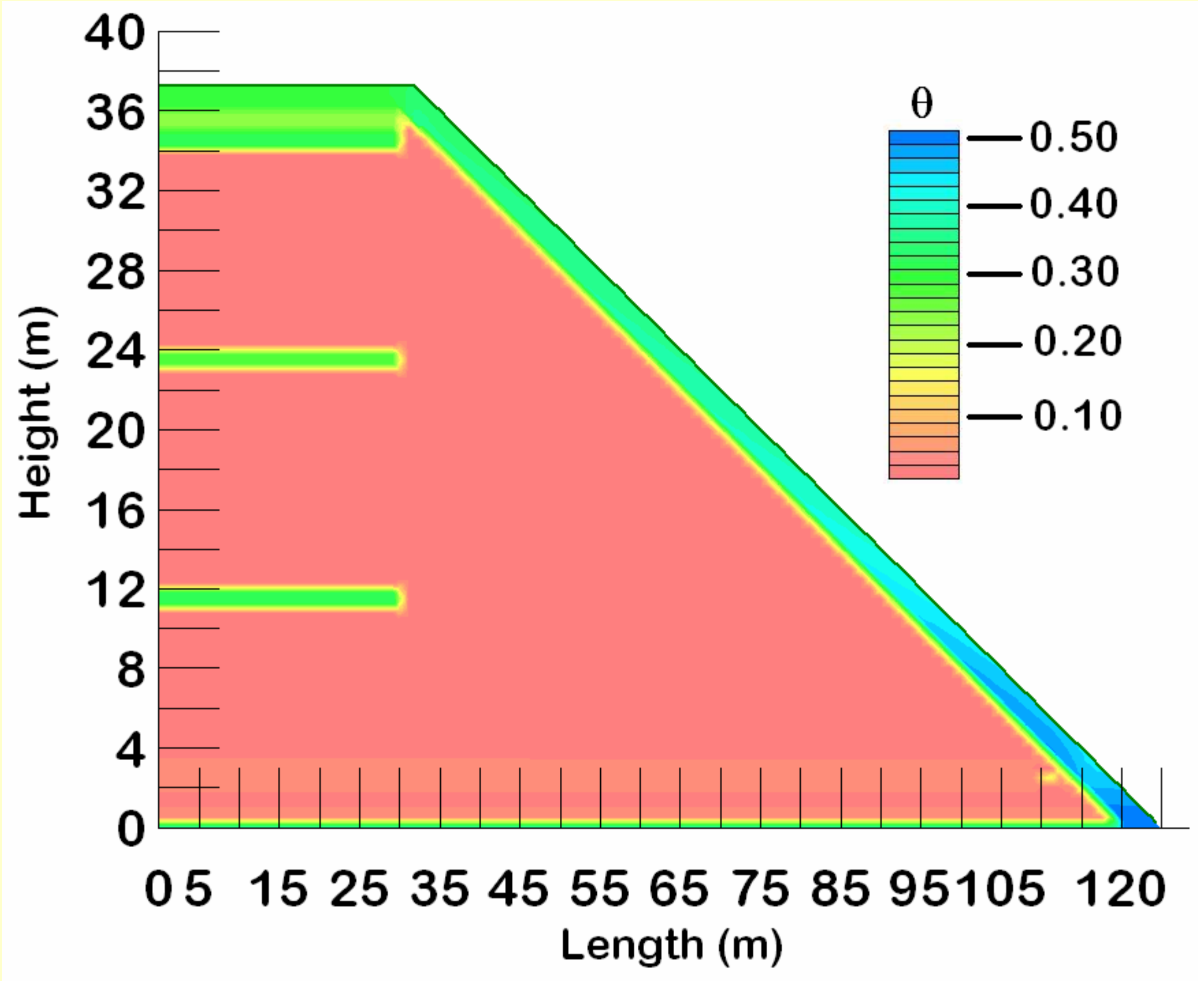


Apithy 2003

SDR cover

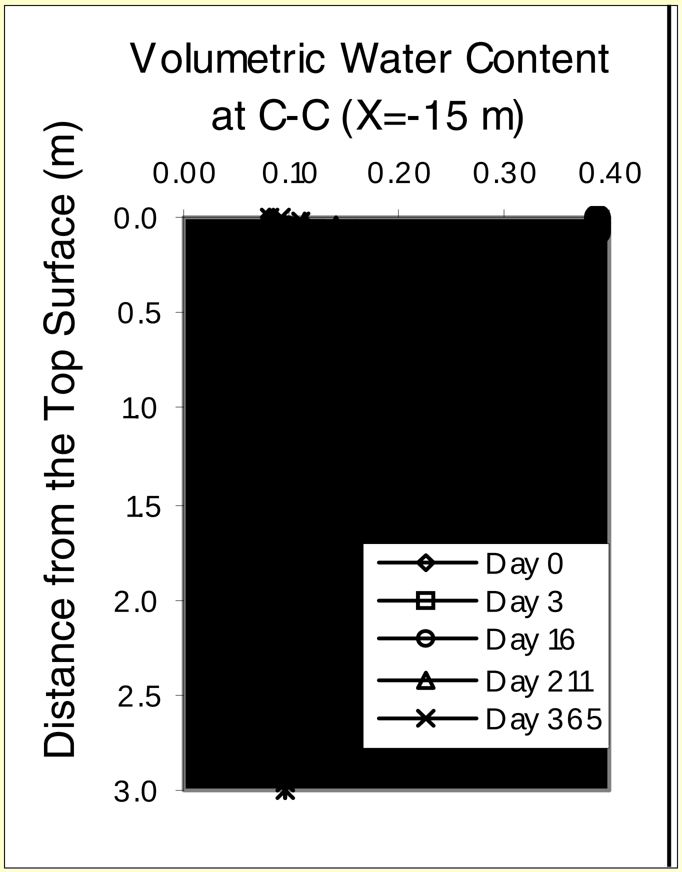
Effective Cover for sloping areas

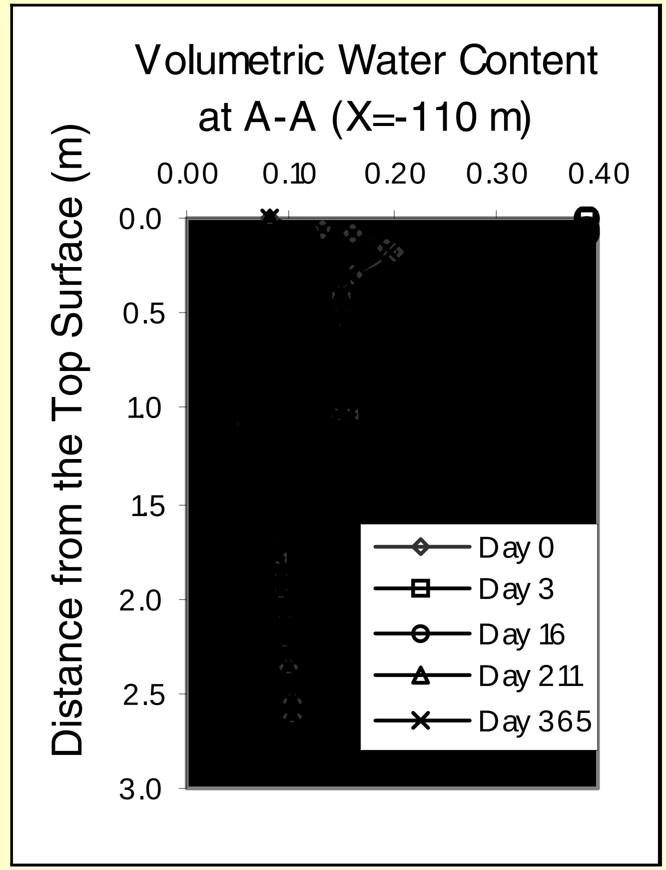
- No water below the cover



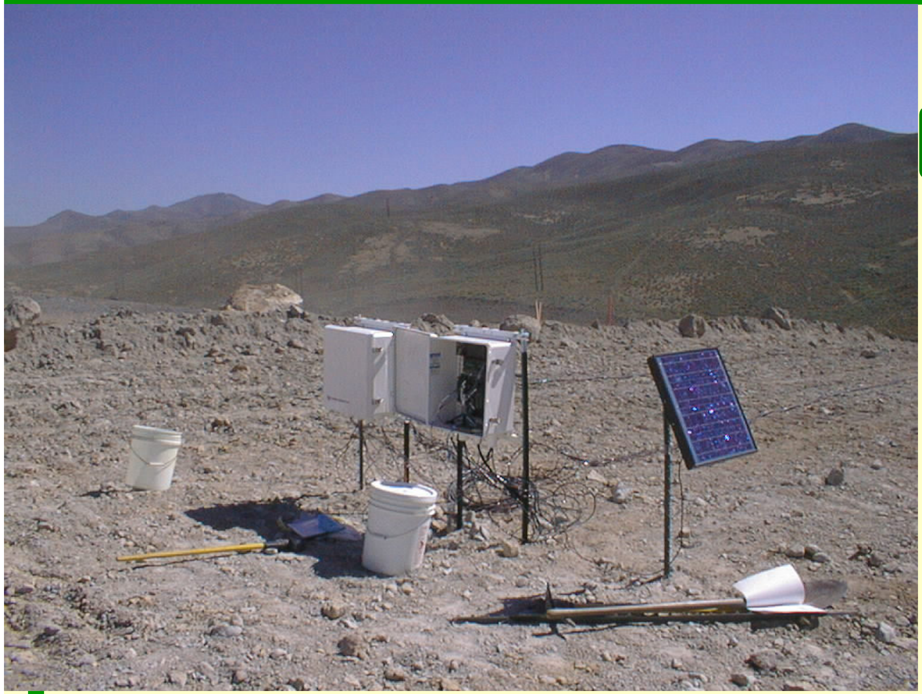
Martin et al. 2004, 2005

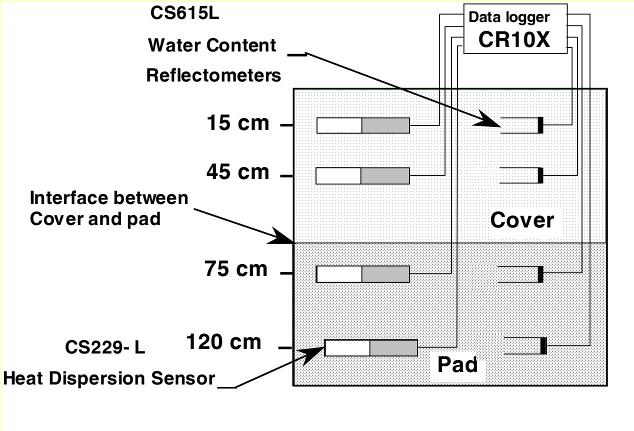
Calculations with HYDRUS 2D (Zhan et al. 2001)



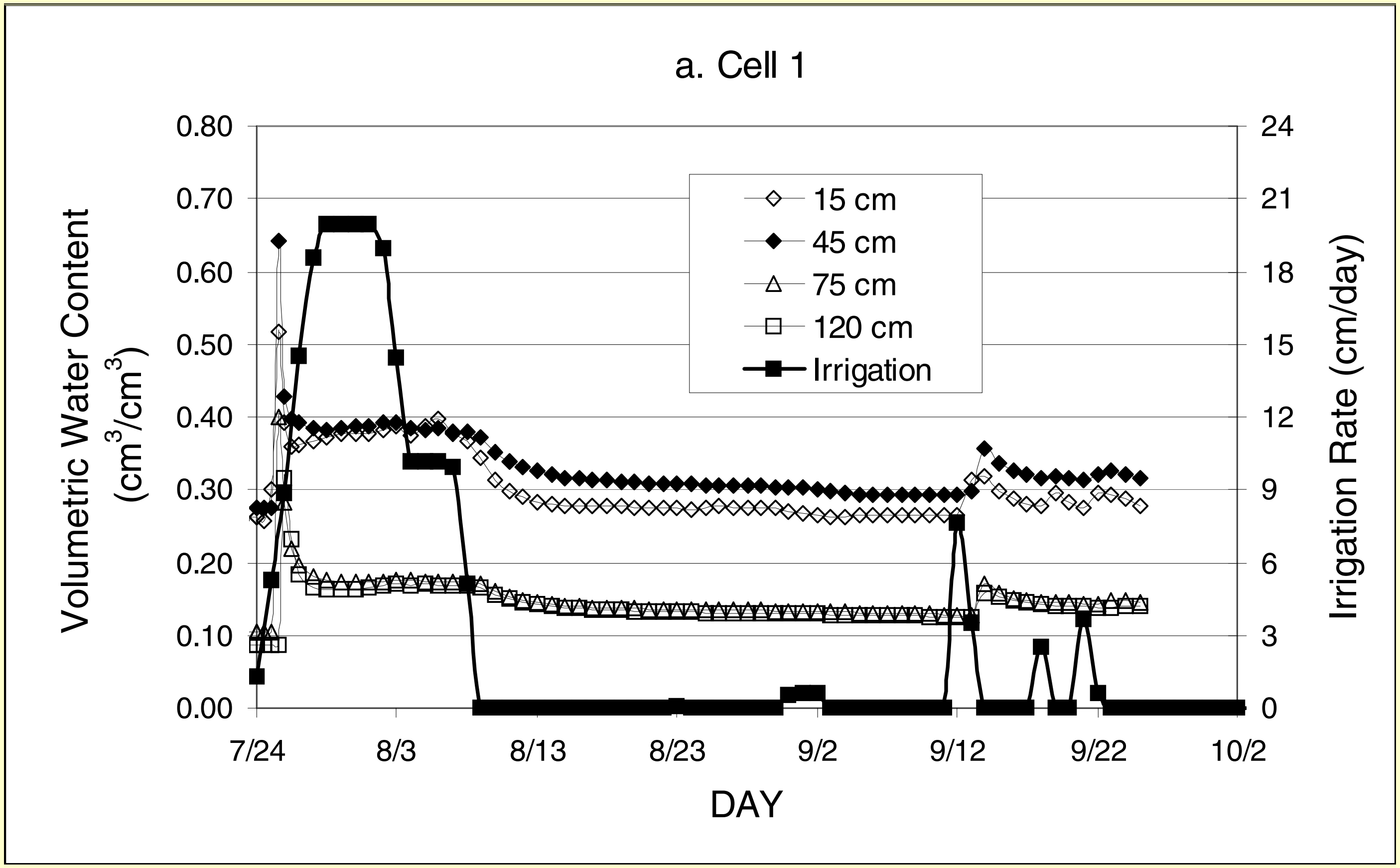


In situ tests at BGMI





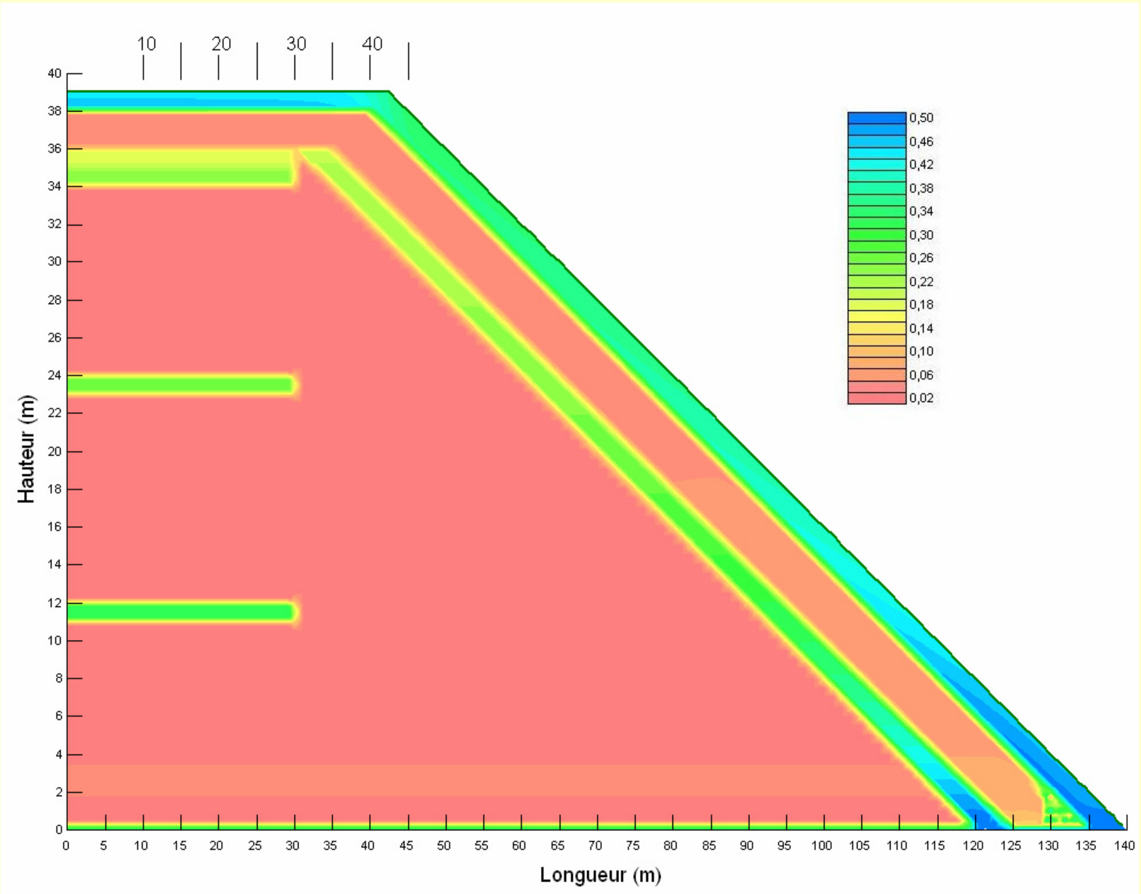
Measurements during infiltration for extreme conditions



Zhan et al. 2001

New concept of SDR cover when single layer system is not efficient: Layered cover for large volume of water (wet climate)

Martin et al. 2005



At BGMI, we learned that..

- SDR cover works well to **divert** water along a sloping area.
- Same principles as for analysis of CCBE.
- **Erosion** is a major concern on long, inclined slopes.
- Must work to optimise the profile; hydraulic behaviour should not be adversely affected by rills and gullies.
- Vegetation may play a key role for surface stabilisation.

Final remarks

- Well designed and constructed **CCBE can be an effective** for controlling the water and/or oxygen flux to the reactive tailings and rock wastes.

- Much preferable to install CCBE **soon after closure;** otherwise, may also have to mitigate indirect oxidation (by Fe^{+3}).

- Analysis and design should make use of **various tools available**:
  - lab testing and predictive models;
  - physical models to compare various configurations and validate numerical results under well controlled conditions;
  - monitored field test plots to evaluate the cover behaviour under realistic conditions;
  - numerical calculations to make comparison with observed responses, and to do parametric analysis to assess the influence factors…

Final remarks

- **Iterative process** leading to optimum solution for design of CCBE.

- **Various materials** can be used in CCBE; key is creating the difference in hydraulic properties (i.e. AEV, WEV, k) between the layers.

- Requires also extensive **monitoring** to make sure that the cover is responding as expected.

- May not be a “walk-away” solution…
- Maintenance is required (may include control of vegetation)

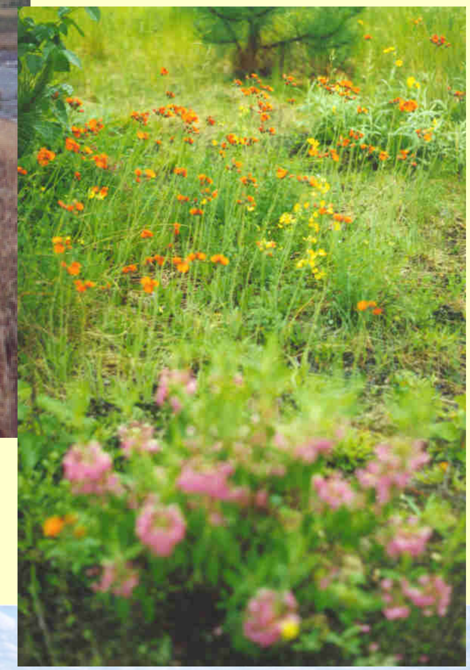
- Work is **ongoing** at these and other sites to improve our knowledge.

- Covers will be part of the **Phase II program for the Industrial Chair** (2006-2011)

Well designed and maintained covers can lead from this…

Covers for reclamation on a large scale

To this…



Industrial NSERC Polytechnique-UQAT Chair

The end, for now…