Experiences from Dry Cover Projects in Sweden, 1972 – 2004.

Aerial photo of Saxberget mining area

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Selected Dry Cover Projects in Sweden

Basic approach:

Mining operations are limited in time

Several operations - increasing number of inactive objects

Focus need to be on producing units

=> Need for permanent solutions for closure

Walk away solutions = need for qualified measures initially

Quality x Maintenance =

= Performance

No or low maintenance

perpetual water treatment not an option

Future exit ticket the target

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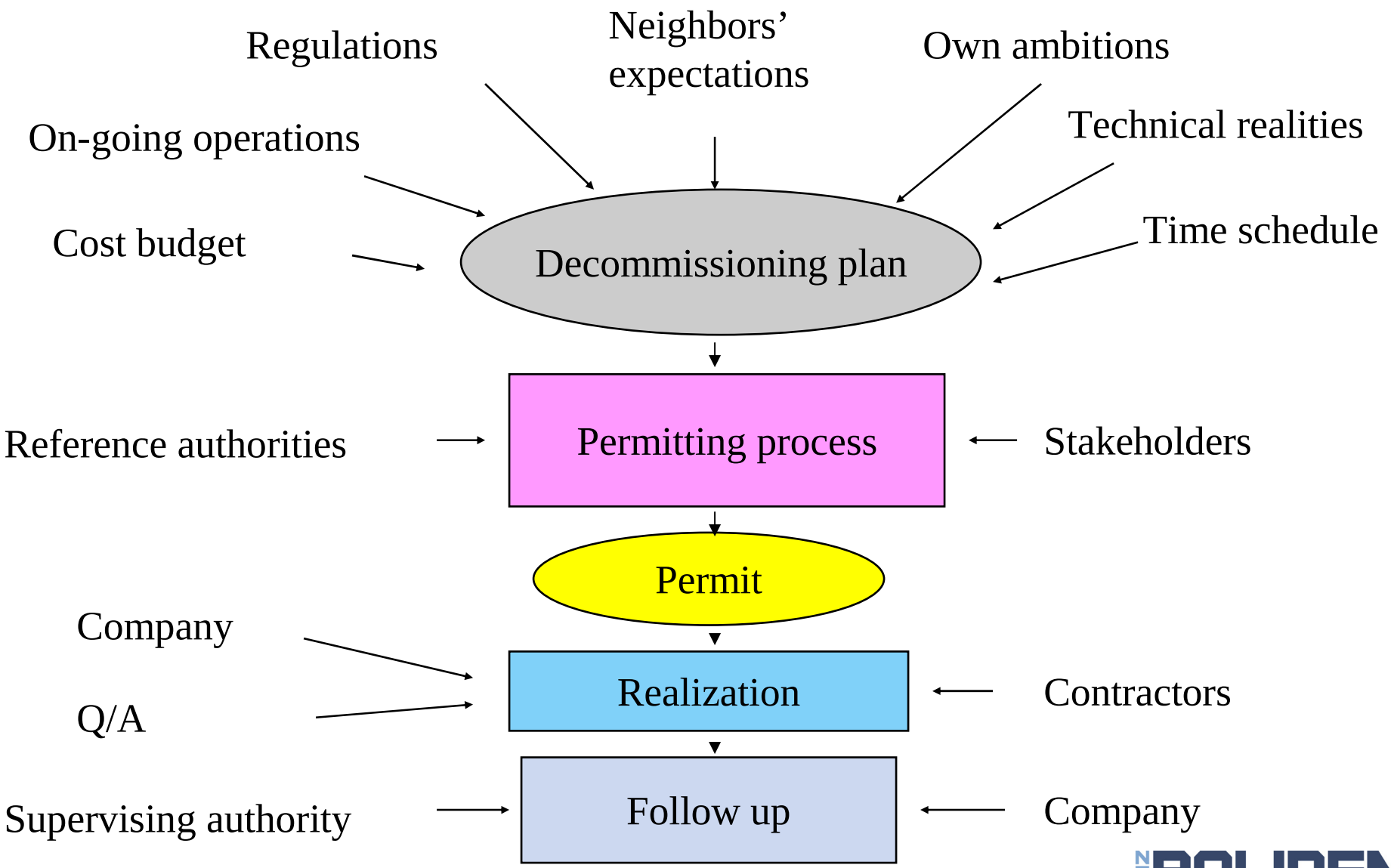
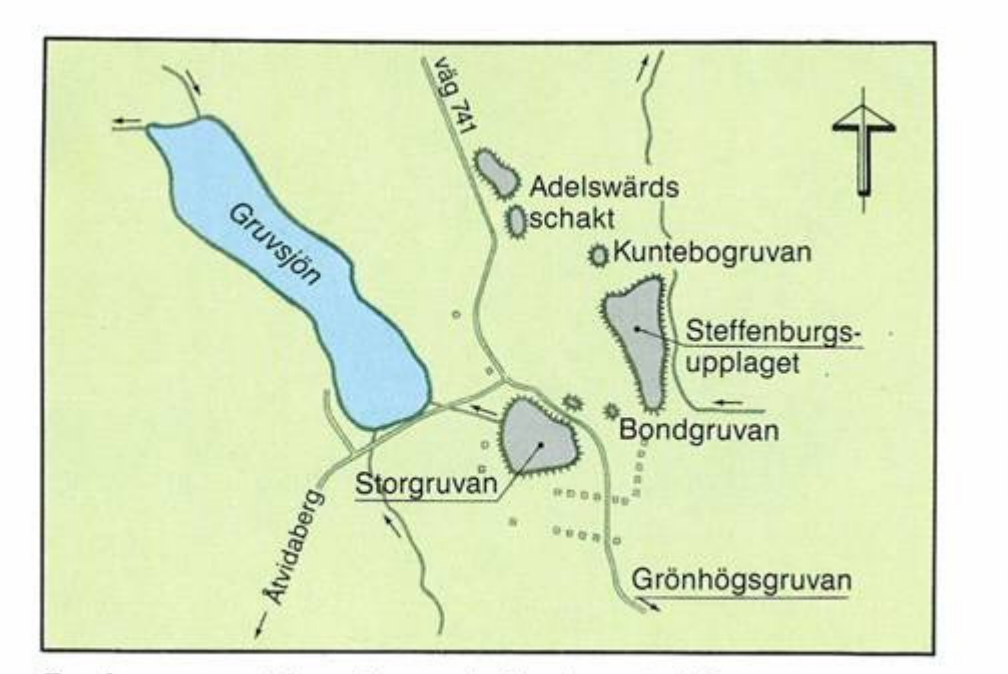
Approval Process for a Decommissioning Plan, Swedish Legislation



Bersbo cover project



The mine area with shafts and waste rock dumps

Oxidized waste rock prior to covering

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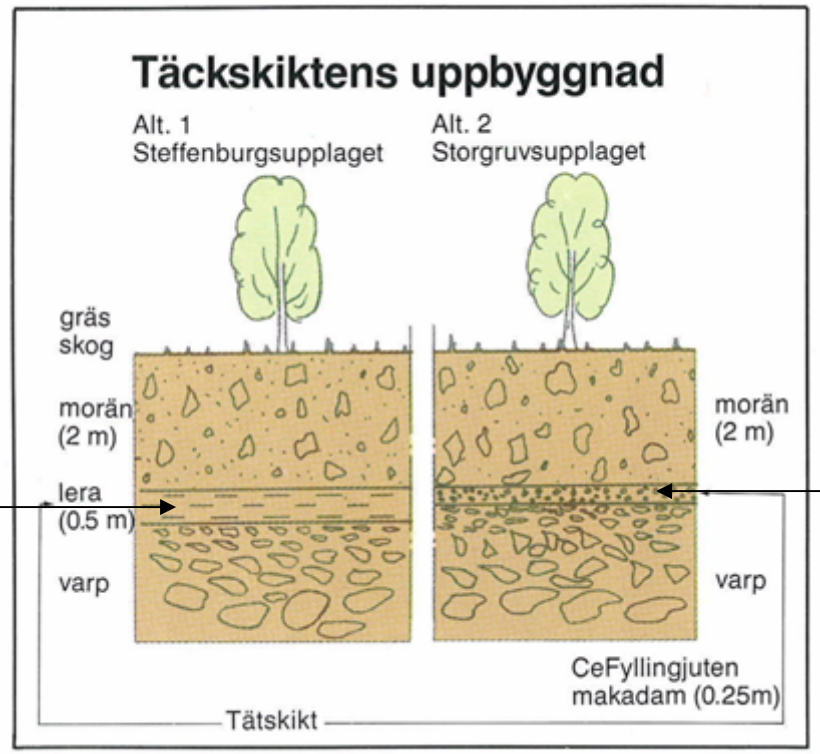
Bersbo, cover principles



Två olika metoder att täcka över varpen kommer att prövas.

Clay

CeFyll
(Fly ash concrete)

Bersbo, follow-up

Table 2. Average values of some selected indicators on pollution based on average values for July-September (b.d. below detection).

	Period	pH	SO_4 ppm	Cd ppb	Cu ppb	Pb ppb	Zn ppb
Leachate	1983-86	3.36	603	197	9643	35	66000
	2002	2.87	307	69	5368	22	30470
Inlet Lake Gruvsjön	1983-88	4.4	700	223	11594	16	99000
	1989-97	3.67	994	148	4477	10	66000
	2002	3.21	307	94	2418	19	52410
Outlet Lake Gruvsjön	1983-88	5.1	84	14	479	0,8	7047
	1988-97	5.06	117	7	205	0,1	3817
	2002	6.07	59	0.55	14	0.52	186
Weir	1983-88	3.93	333	89	4282	14.3	28116
	1989-97	5.47	123	26	793	2.3	5550
	2002	6.21	10	0.71	55	1.49	700
Inlet Lake Risten	1983-88	6.86	29	4.46	90	0.48	1107
	1989-97	6.74	22	0.44	16	0.49	201
	2002	6.67	4	0.02	5.6	0.49	20
Outlet Lake Risten	1983-88	7.39	24	0.03	11	b.d	117
	1989-97	7.55	22	0.05	6.4	b.d	50
	2002	6.77	16	0.23	6.1	0.36	25

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Saxberget mine, prior to reclamation

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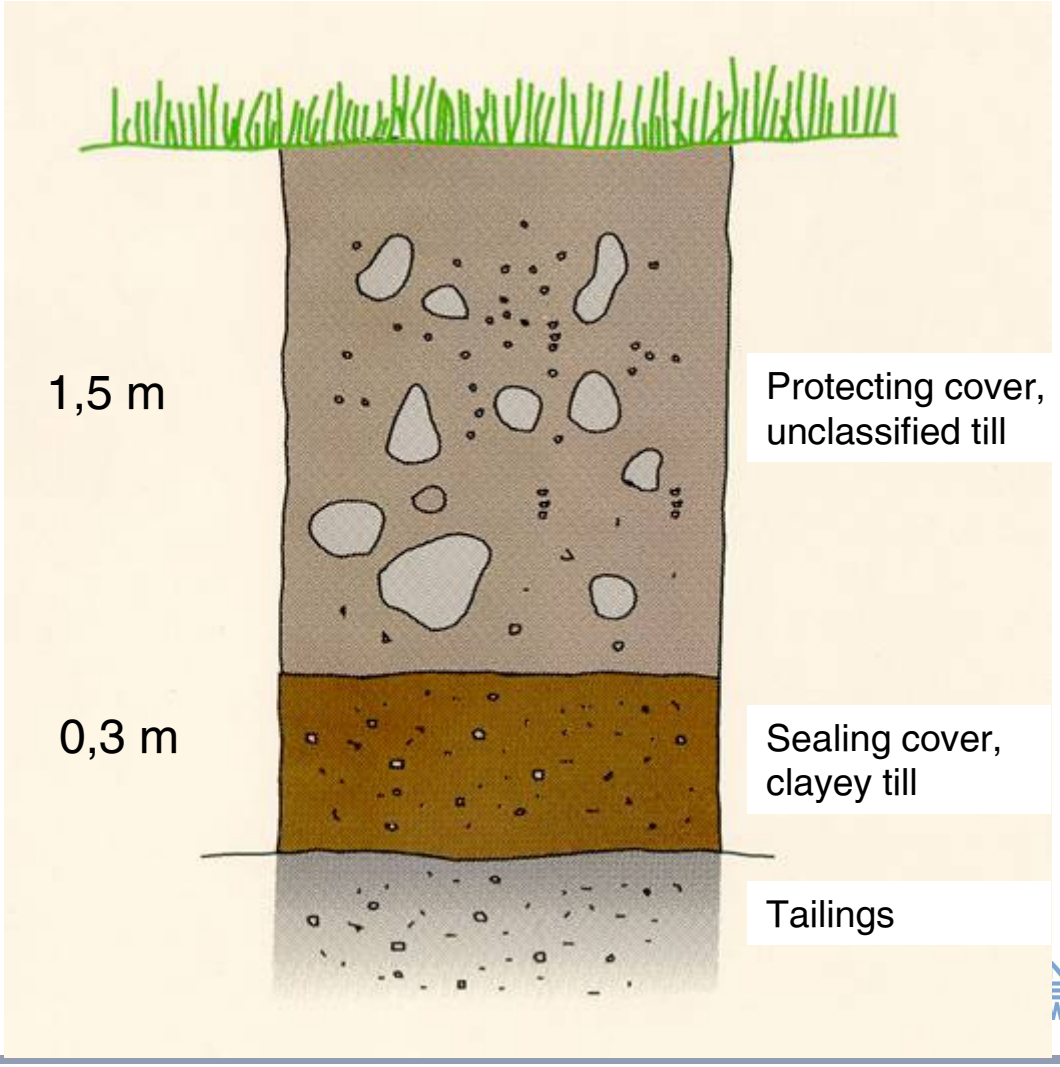
Dry cover on Saxberget tailings pond



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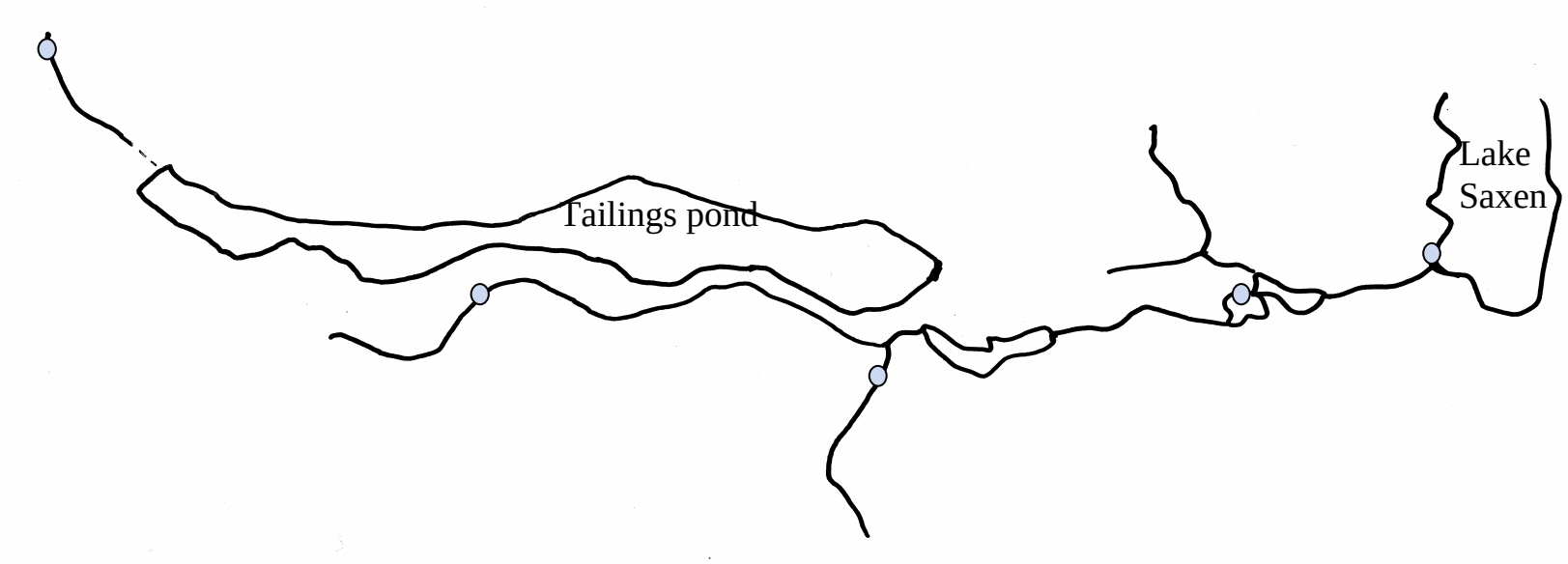
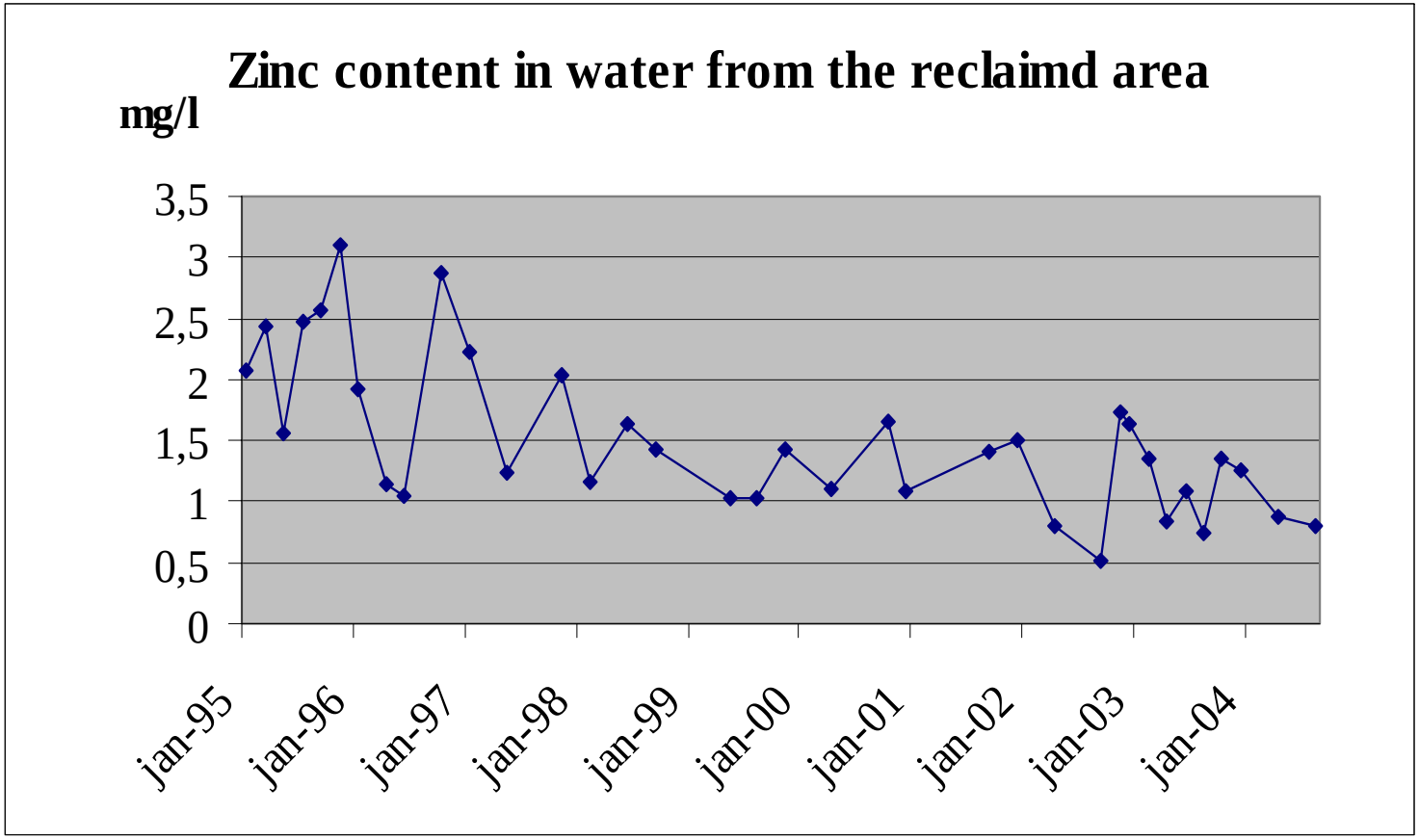
Saxberget monitoring programme

- Sampling interval: 1/year to 12/year depending on sample
- Assay programme: Cu, Pb, Zn, Cd, SO_4, pH, cond
- Cover performance



Saxberget, monitoring programme results



Saxberget, conclusions

Reclaimed upper tailings pond

- The cover reduces the oxygen inflow and water infiltration as predicted
- Slow improvement of drainage water quality
- Significant reduction in mass transport from the area
- Relocated oxide smelter waste a significant pollution source in the pond area
- Cover sensitive to erosion
- Sewage sludge as sealing layer (test plot) well functioning
- Compaction during ”wet” conditions effective

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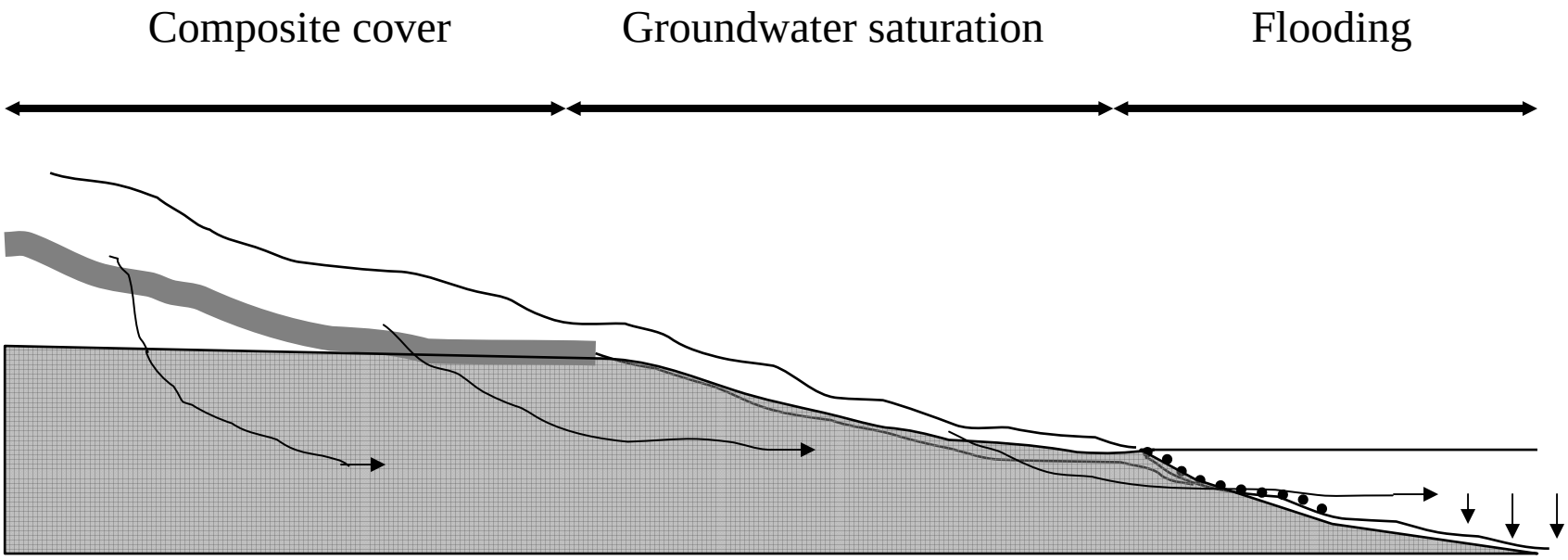
Kristineberg

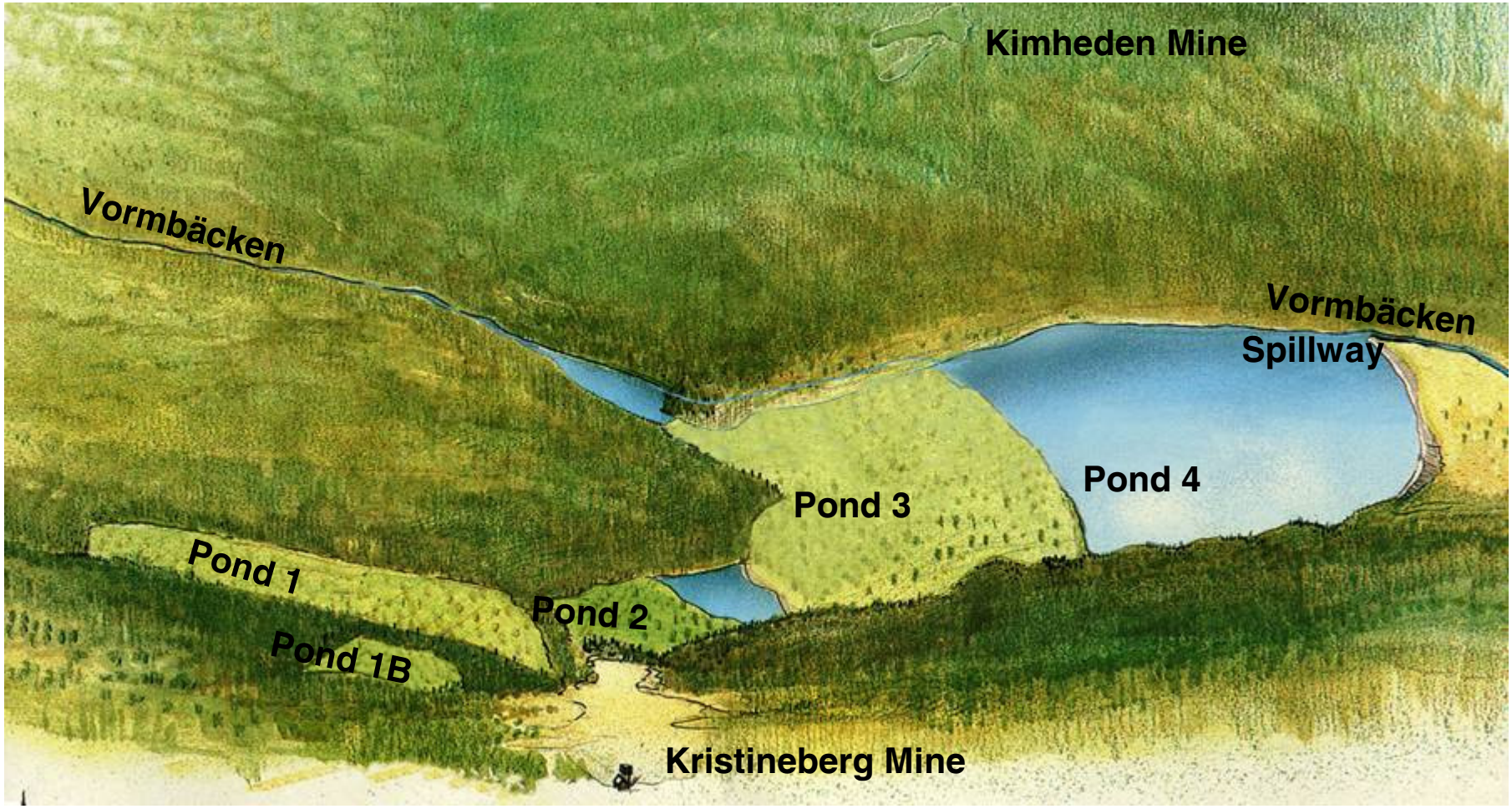
Aerial view of Kristineberg mine site

Integration of reclamation methods

Systems approach



Kristineberg, decommissioning project completed



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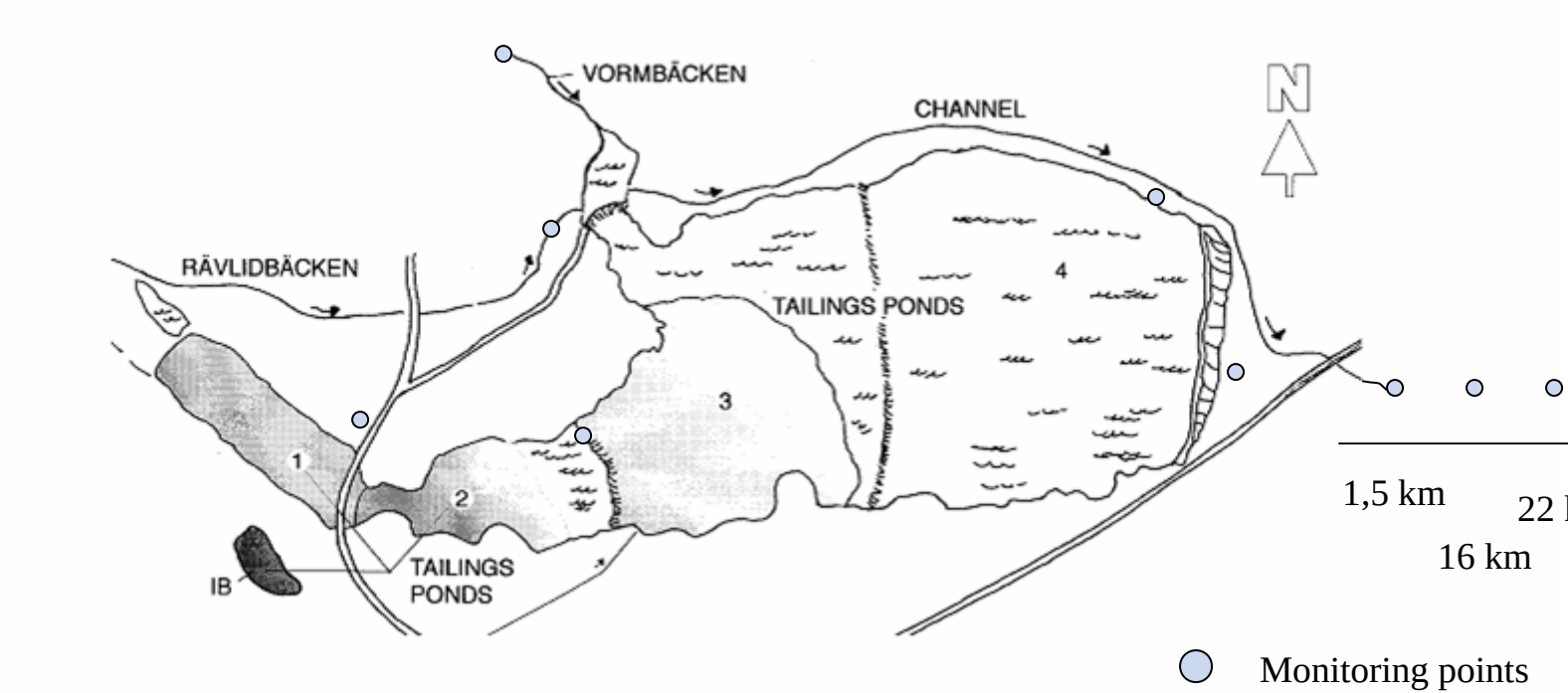
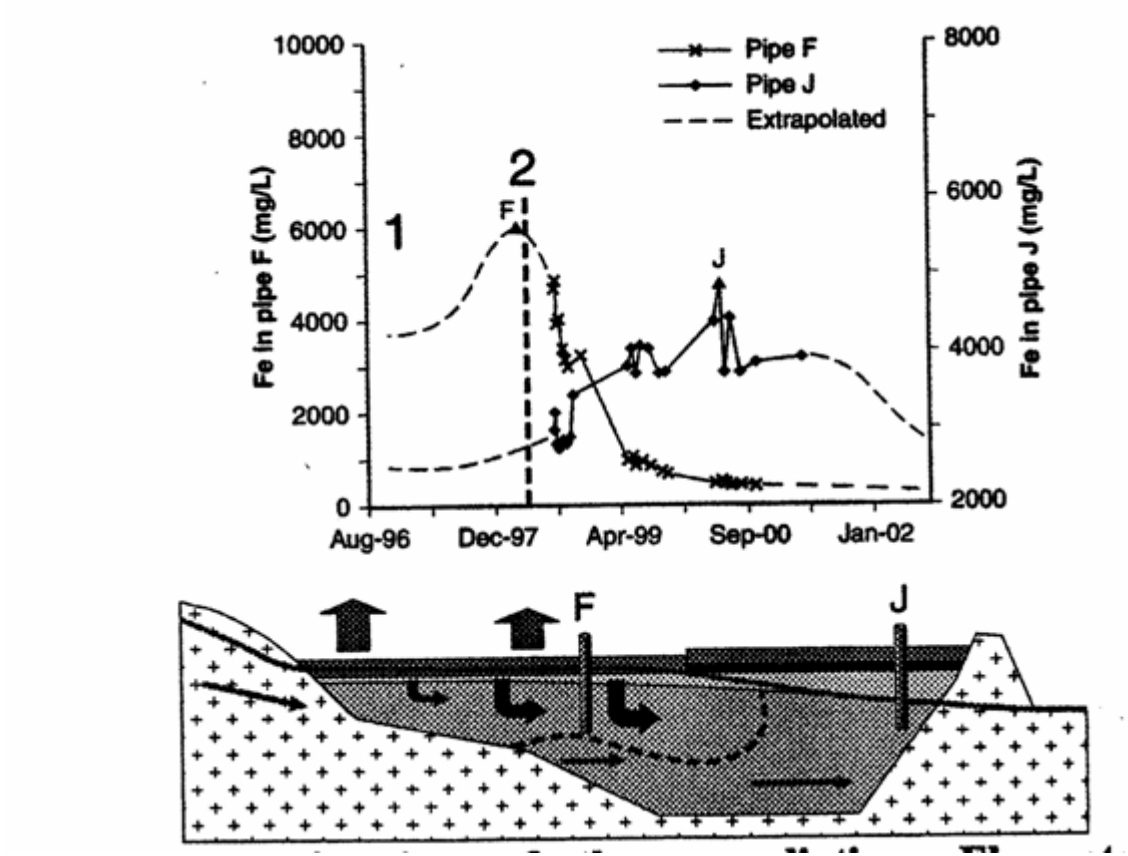
Kristineberg, monitoring programme

- Sampling frequency: Four to six times a year for surface water
- Assay programme: Cu, Pb, Zn, As, Cd, Hg, Fe, SO_2, pH, cond
- Oxygen content and ground water level under sealing layer (pond #1)



Kristineberg, conclusions

Evaluation in cooperation with the MiMi programme



- Systems approach taken, a condition for success
- First seasonal washout mobilized secondary precipitated minerals (as predicted)
- Groundwater quality is steadily improving
- Mobilized elements are precipitated in downstream ponds #2 and #4
- Groundwater saturation is a powerful method, reduces need for composite cover
- 1m protective cover is sufficient for frost protection
- Wetlands not sufficient for metals retention

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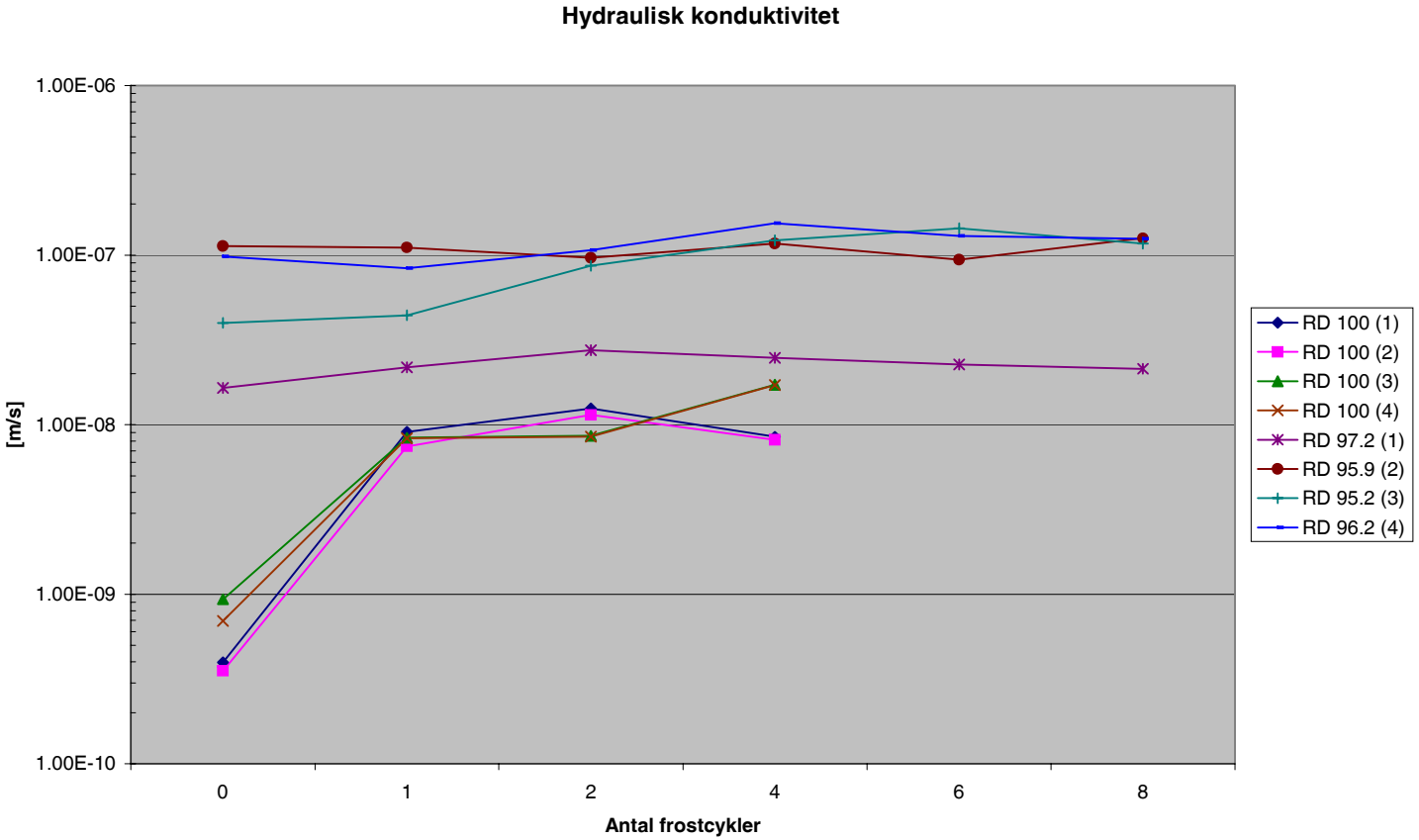
Freeze/thaw impact on Hydraulic Conductivity



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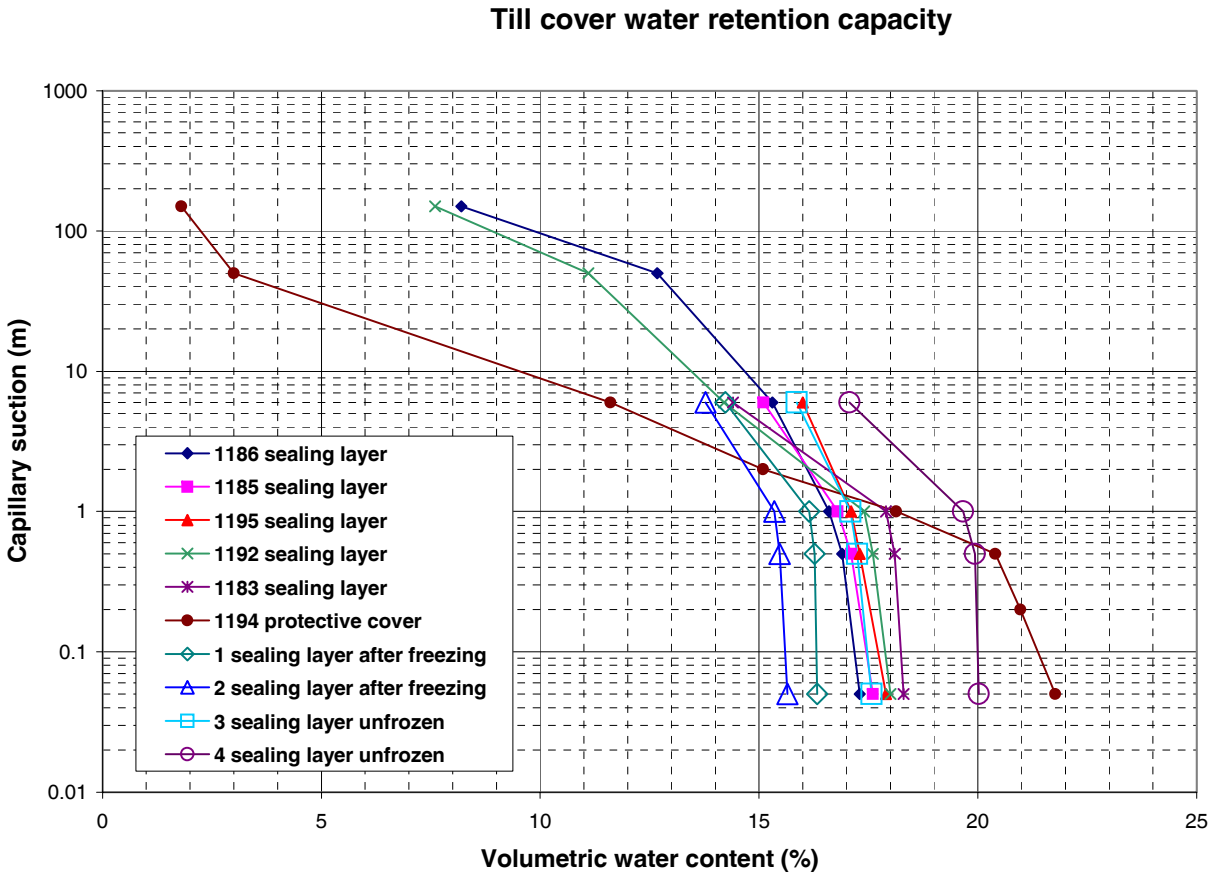
Water Retention Capacity



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Cover performance – field observations at Kristineberg

- Measured oxygen transport through the cover corresponds to theoretical diffusion coefficients for nearly saturated soil. Oxygen transport through the cover varies with the level of saturation , but can generally be approximated to 1 mole/m^2/year.
- Measured infiltration corresponds to measured hydraulic conductivity.
- Maximum frost depth at the field site during 1998-2003; 0.9 m
- The extraordinary dry summer of 2002 resulted in dry conditions and significant oxygen transport in areas with limited cover thickness (0.5 m sealing layer and 0.3 m protective cover).

Till covers – Function and field experience

- **Good function as oxygen barrier if correctly dimensioned and constructed.**
- **Construction important – Use right test methods and ensure sufficient compaction.**
- **Characterize the sealing material's grain-size distribution, compaction properties, hydraulic conductivity, and preferably water retention capacity.**
- **With a proper characterization, QC at construction can be limited to grain-size distribution, water content and compaction (in situ density).**
- **Sealing layers need a sufficient protective cover against drying and frost.**

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Root penetration - observations

Greenhouse

- Root penetration in sealing layer of clayey till: approx 5 cm
- Root penetration in sealing layer of ash and sewage sludge: approx 20 cm

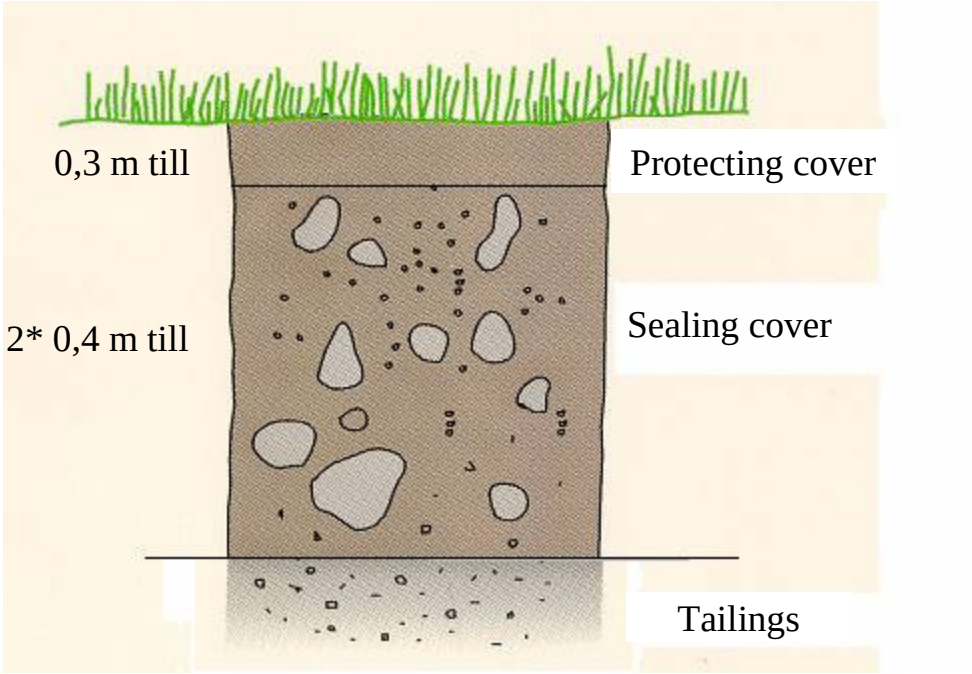
Field observations

- In natural analogues with compact, fine till at a depth of 1.15 m roots were found down to 1.25 m, i.e. 10 cm down into the ”sealing layer”.
- 15 years after the planting of trees in Bersbo, in dry (well drained) sections of the cover, single roots were found down to, but not in, the sealing layer.

Enåsen

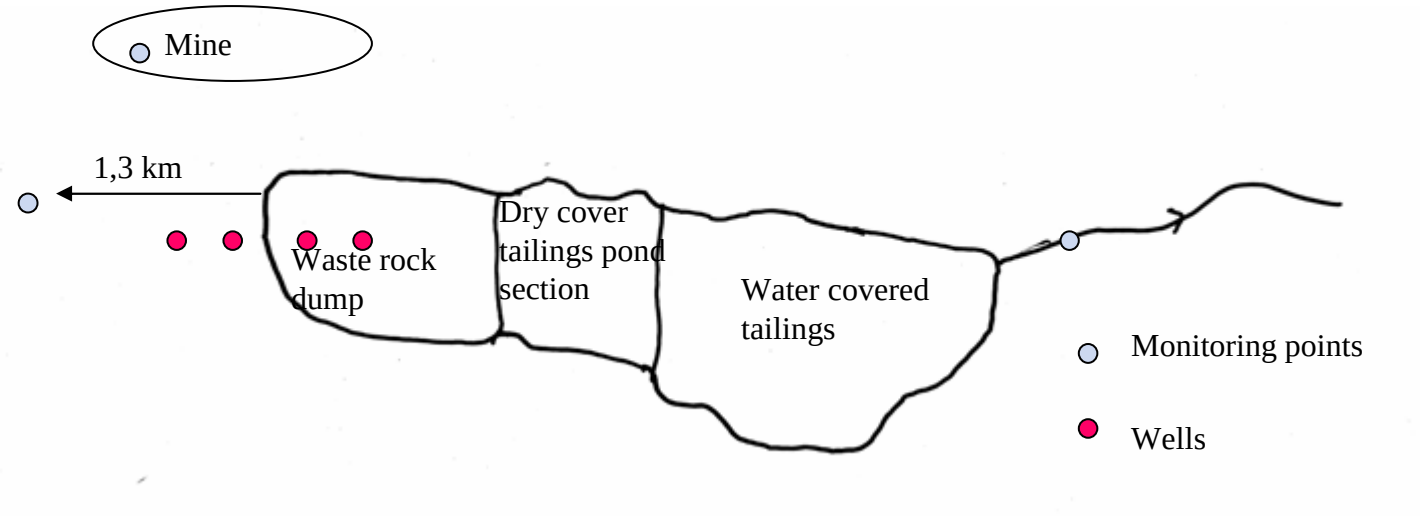
Dry cover section of tailings pond

Cover principle, Enåsen

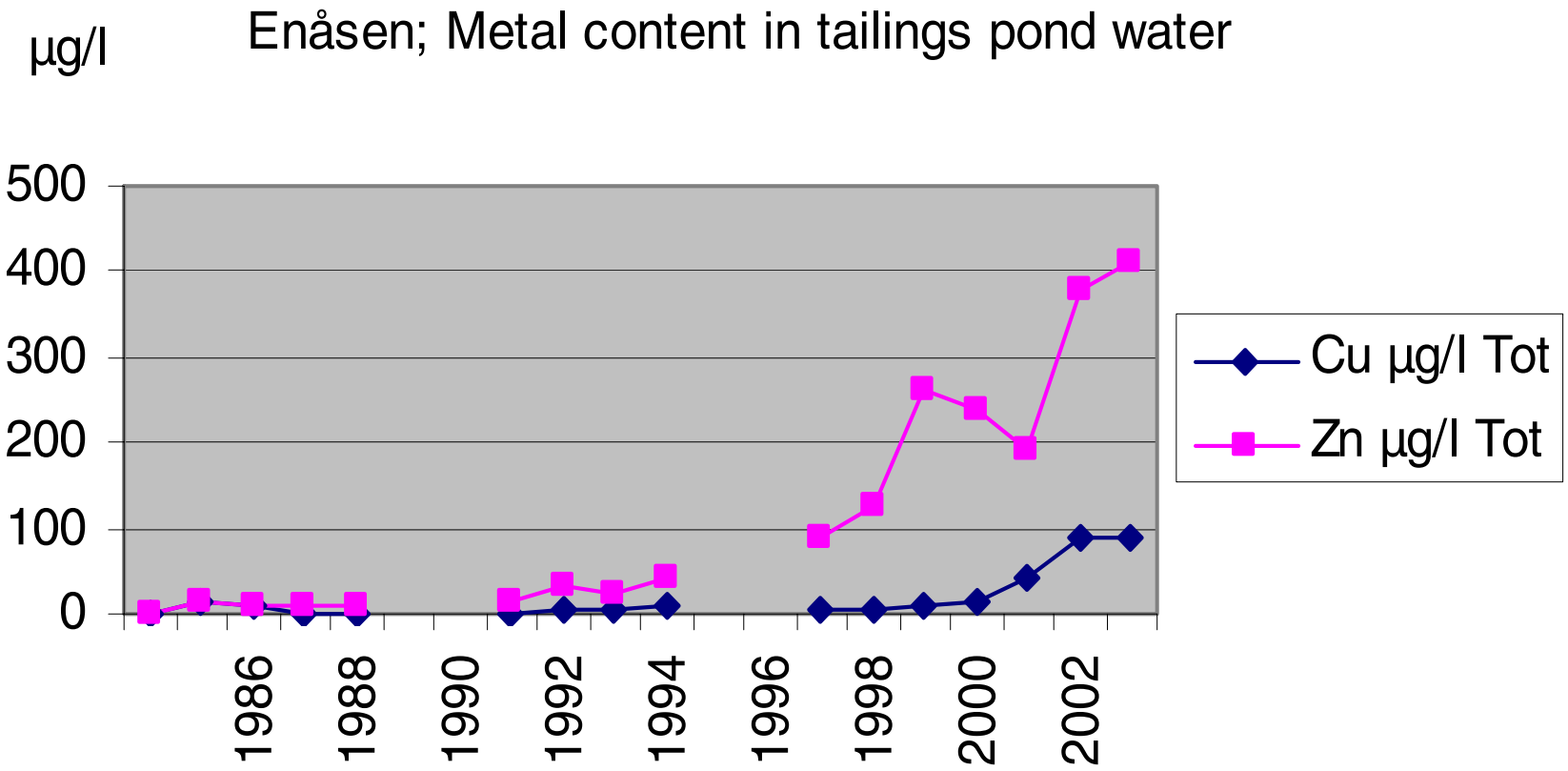


Enåsen monitoring programme

- Sampling interval: Twice a year
- Assay programme: Cu, As, Cd, Fe, Ca, Mg, Na, K, SO_4, Cl, Al, N-tot, NO_2, NO_3-N, NH_4-N, P-tot, PO_4-P, TOC, pH and alkalinity
- Oxygen content measured under dry cover once a year



Monitoring programme results



Enåsen, conclusions

- **Cover functioning**
- **Mechanical problems with oxygen probes (leaks)**
- **pH in water covered pond decreasing, repeated lime treatment necessary**
- **Metals content in pond water increasing**
- **Source for metals, sulphate and thiosulphate being investigated, possibly remains of process water in pores**
- **Limited transport of contaminants from the area (seasonal/snowmelt)**
- **Repeated investigations of ecosystem, without signs of disturbances**

Till covered section of tailings pond

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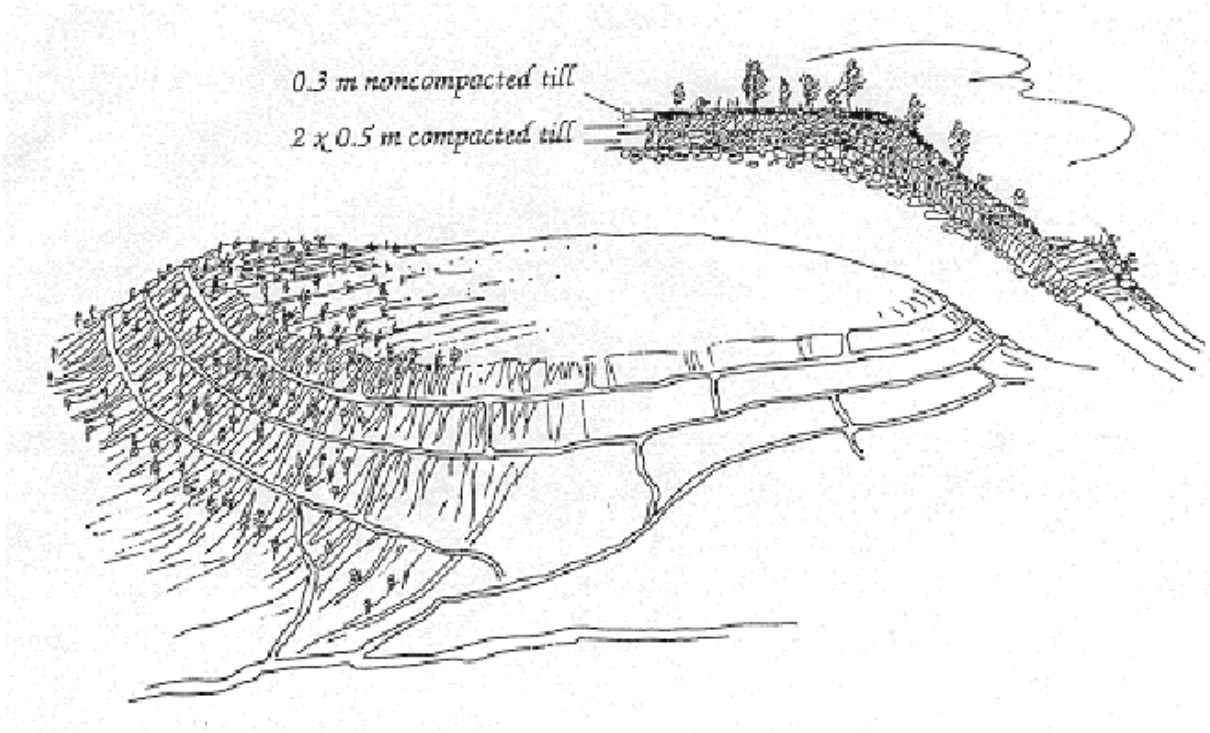
Aitik waste rock cover project



- Permit for cover using 1 + 0,3 m till
- Modelling indicates 99% reduction of oxygen transport
- In total 3500 ha waste rock dumps
- 14 ha covered 1998
- 20 ha to be covered 2005
- Follow up programme in place
- Marginal effects significant
- Severe erosion problems to deal with

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Laver, upper pond

- In operation 1939 – 1946
- Dam failure 1952, snowmelt water
- Pond reclaimed 1972
- Organic cover intended as vegetation base only, no sealing action
- Successful revegetation
- Weathering zone >1 m down in tailings
- Precipitation layer partly in contact with groundwater
- Groundwater sourcing, ongoing erosion
- Limited contaminant transport
- Additional measures planned (organic cover)

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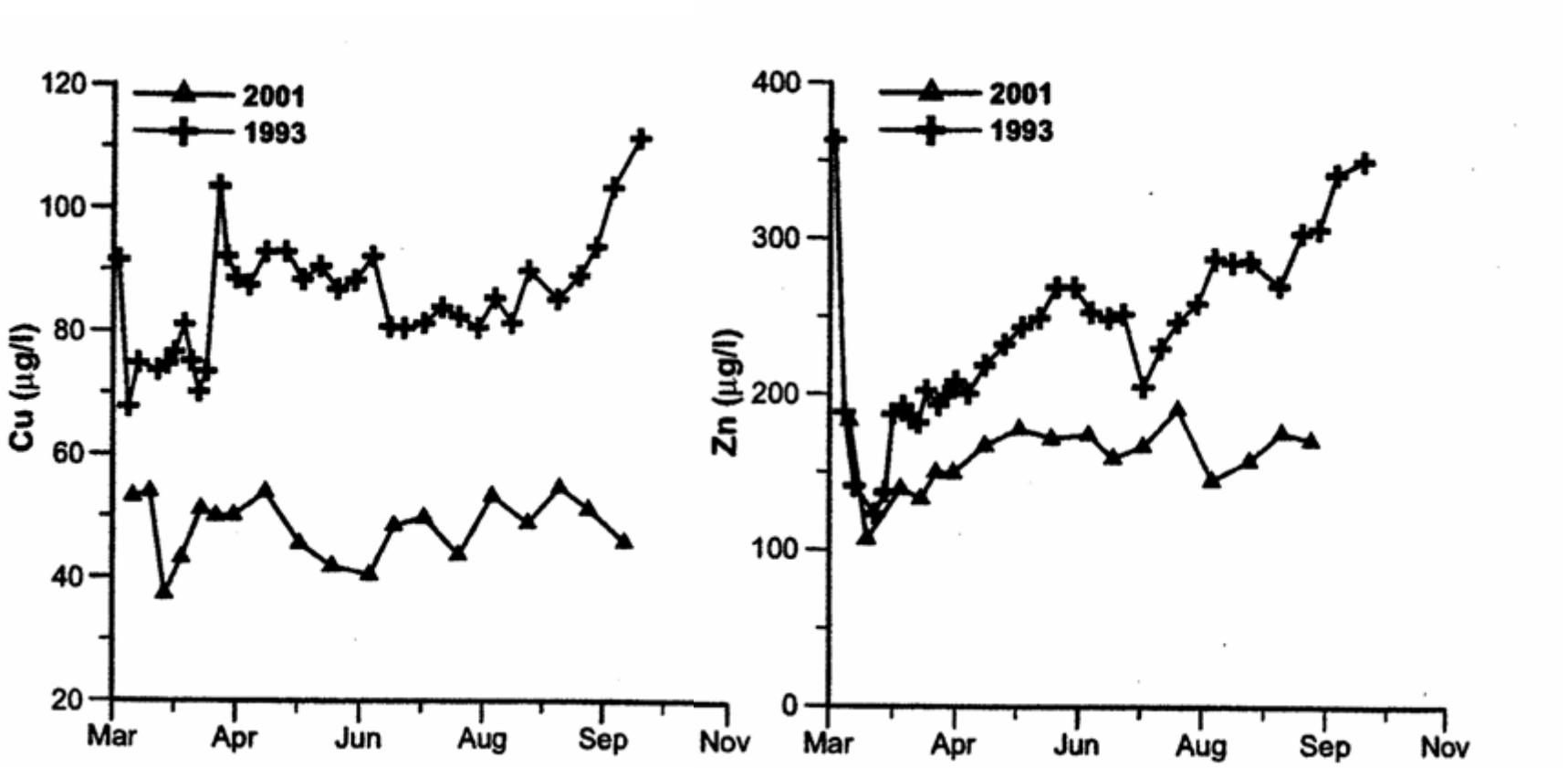
Laver – decreasing transport



Vassbo

- Lead-zinc mine, closed 1975
- Cold and demanding climate
- No pyrite problem
- Initial vegetation establishment using fertilizer,
- sensitive vegetation cover with wind erosion
- Final solution – large scale use of sewage sludge

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Laisvall

- Lead-zinc mine, closed 2001
- Experiences from Vassbo used
- Sewage sludge and other organic material used
- Mechanical stability – wind, surface water and frost/snowmelt effects a challenge.

Boliden's reference list of reclamation projects

Status 2004

Completed or under completion

- Laisvall, Vassbo, Stekenjokk, Saxberget, Näsliden, Enåsen, Rävliden (4 mines), Långsele, Udden, Holmtjärn, Rudtjebäcken, Åsen (2 mines), Gränsgruvan, Kristineberg (5 tailings ponds), Kimheden, Kristineberg (industrial area), Garpenberg (open pit and tailings pond), Boliden (open pit), Långdal, Åkulla East, Åkulla West, Rakkejaur, Aitik (waste rock), Kedträsk, Enåsen (waste rock dump), Åkerberg

With approved plans

- Kankberg, Petiknäs, Renström (industrial area), Boliden (tailings pond), Renström (waste rock)

Plans being produced or subject to revision

- Aitik (tailings pond, open pit, industrial area), Boliden (industrial area), Garpenberg (clarification pond)

Plans pending

- Garpenberg (2 mines, industrial areas)

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Integration of reclamation methods