Temperature as Tracer for In Situ Detection of Internal Erosion

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Temperature distribution in soil

$$\frac{\partial}{\partial t}(n\rho c_f + (1-n)\rho_s c_s)T = \nabla \cdot (nK_f + (1-n)K_s)\underline{\underline{I}}\nabla T + \nabla n\underline{\underline{D}}_H \nabla T - \nabla n\rho c_f \underline{v}T$$

t time [s]

T temperature of fluid and porous soil [°C]

$\underline{v}$ darcy velocity [m/s]

n effective porosity [-]

ρ density of fluid [kg/m3]

ρ_s density of porous soil [kg/m3]

c_s heat capacity of porous soil [J/kg/K]

c_f heat capacity of fluid [J/kg/K]

K_f thermal conductivity of fluid [W/m/K]

K_s thermal conductivity of soil [W/m/K]

$\underline{\underline{D}}_H$ thermo-mechanical dispersion [W/m/K]

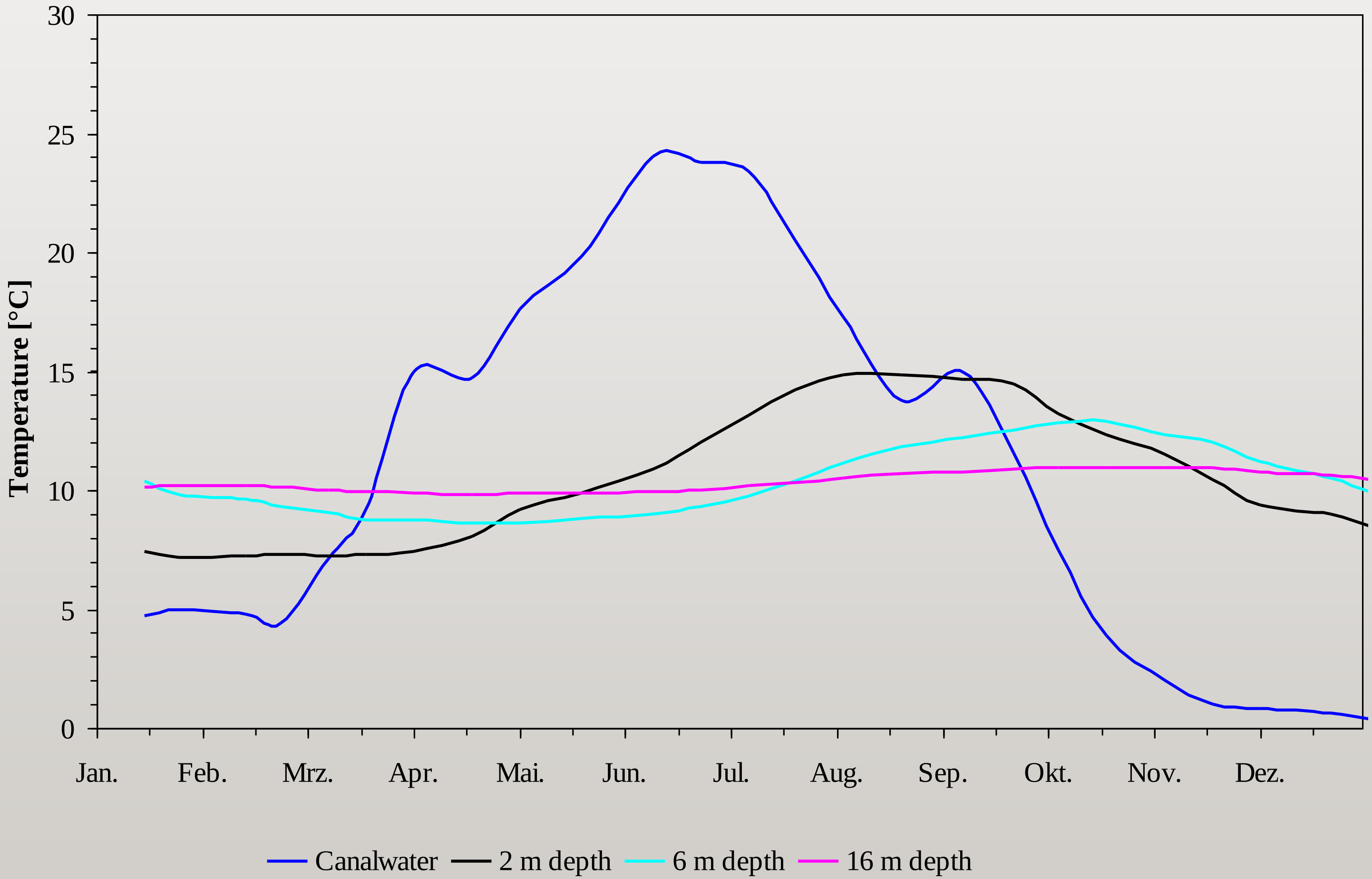
$\underline{\underline{I}}$ unit matrix [-]

Thermal diffusivity

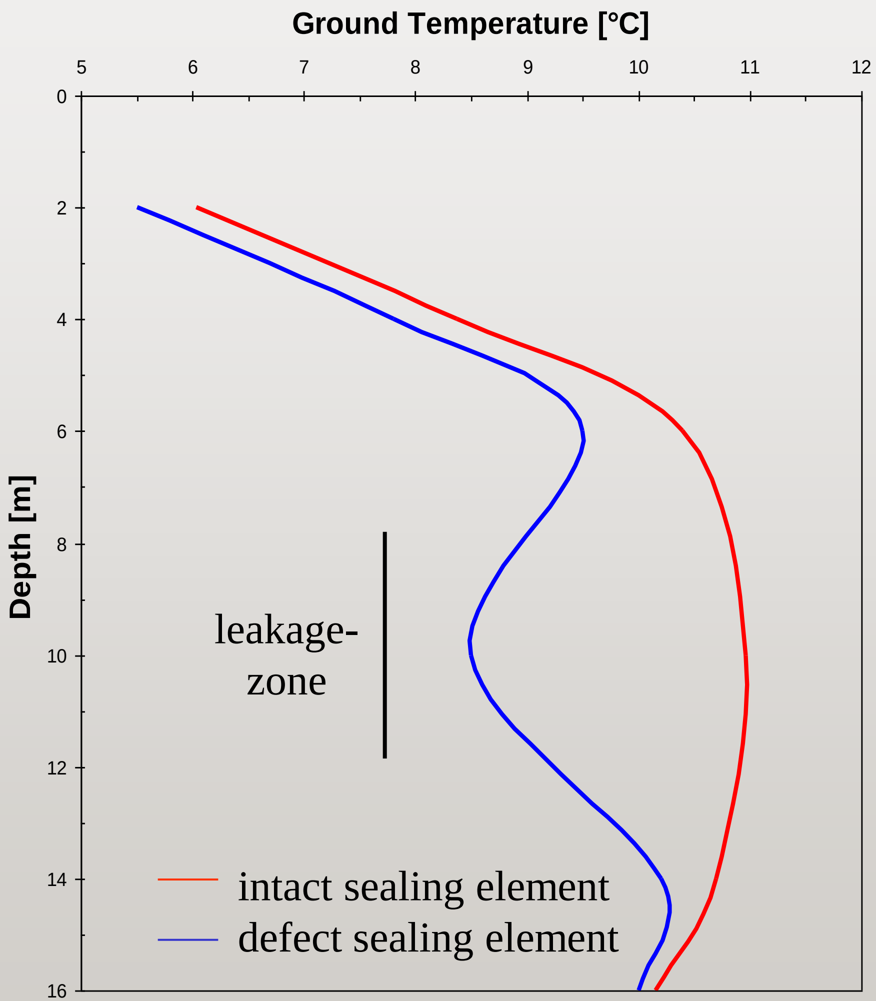
$$\kappa = \frac{nK_f + (1-n)K_s}{n\rho c_f + (1-n)\rho_s c_s}$$

darcy velocity > 10^{-7}m/s => convective heat transport > conductive heat transport => ground temperature anomaly

Annual temperature variation in a navigational canal compared to undisturbed ground temperatures in a dam at 2, 6 and 16m depth



Ground temperature depth distribution in winter

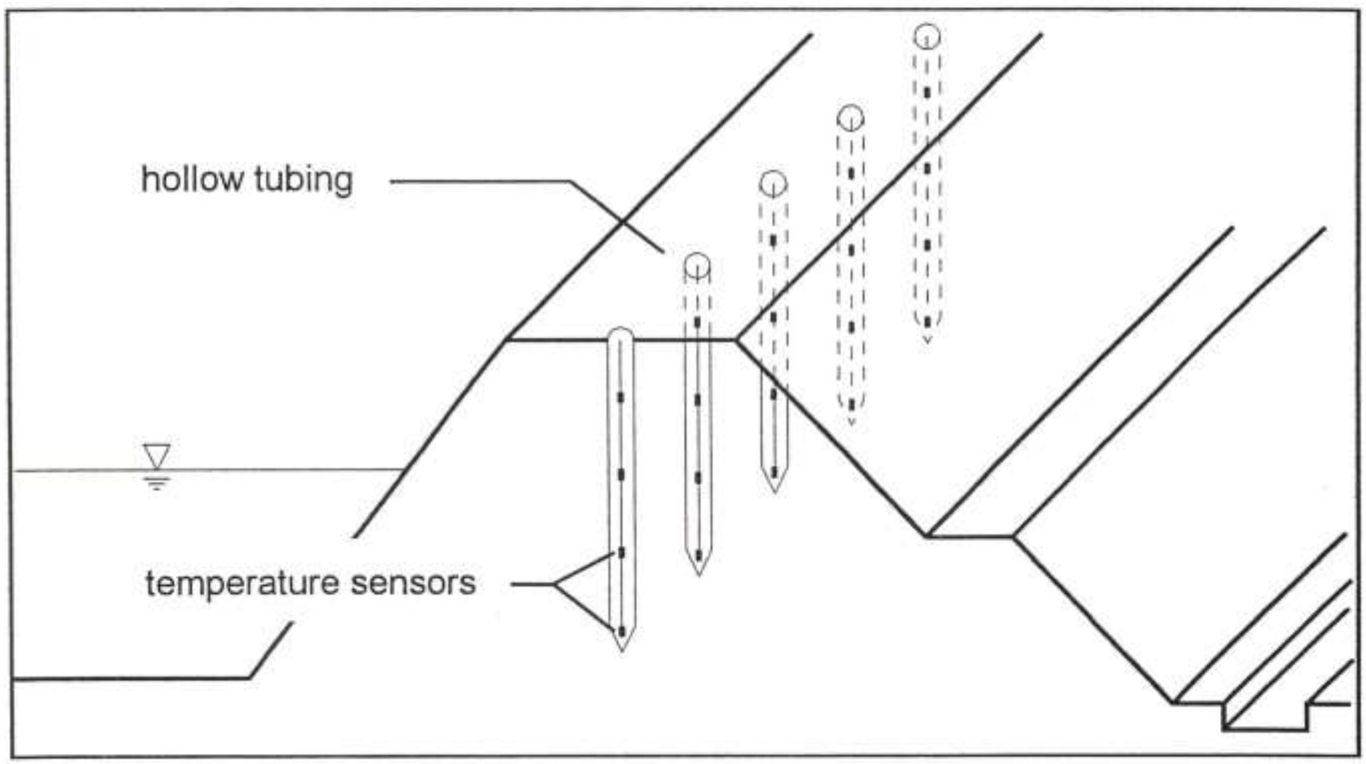


Temperature is used as a "tracer"

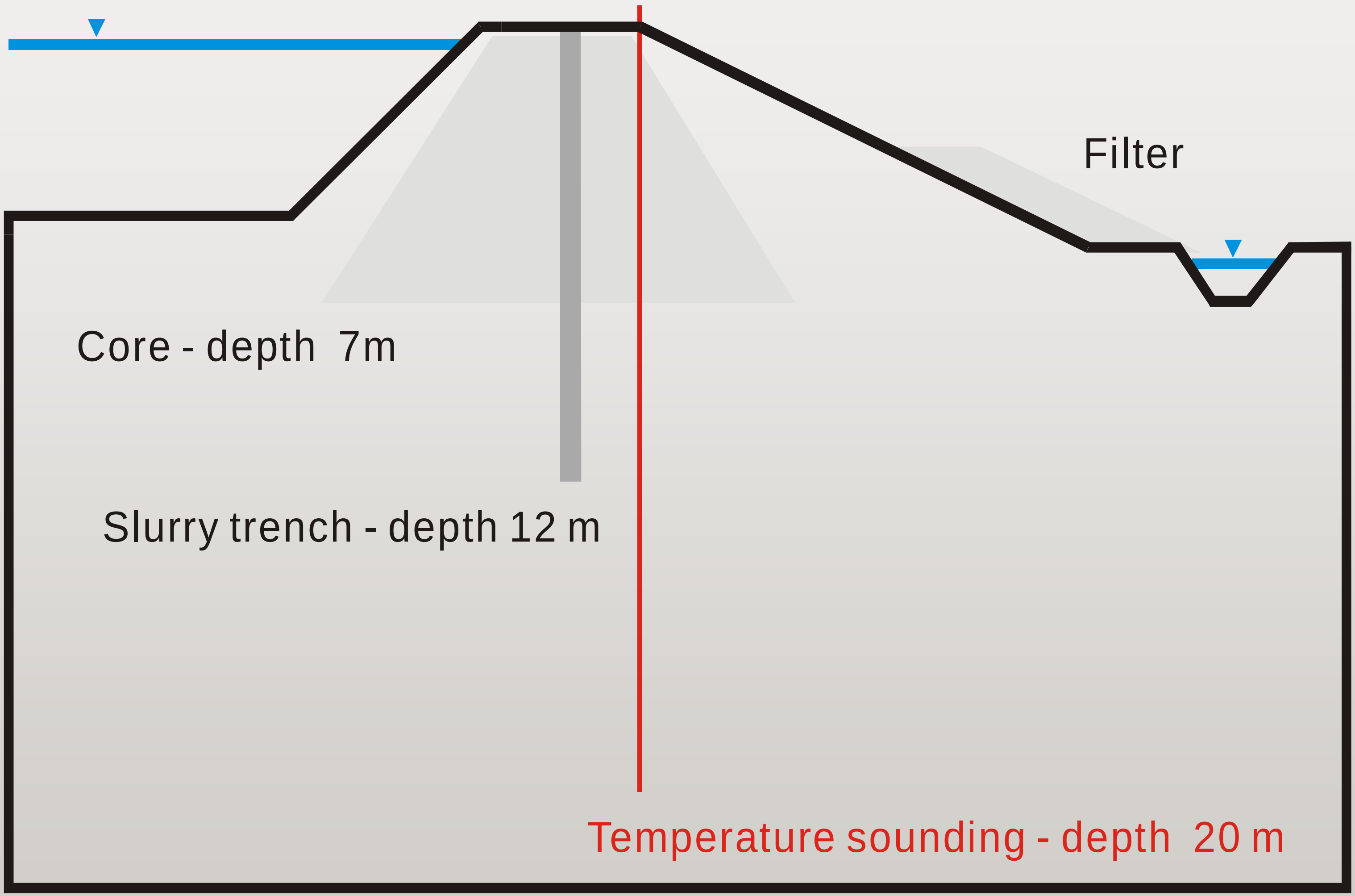
Driving and Pulling of the Metal Tubes

Temperature Measurements

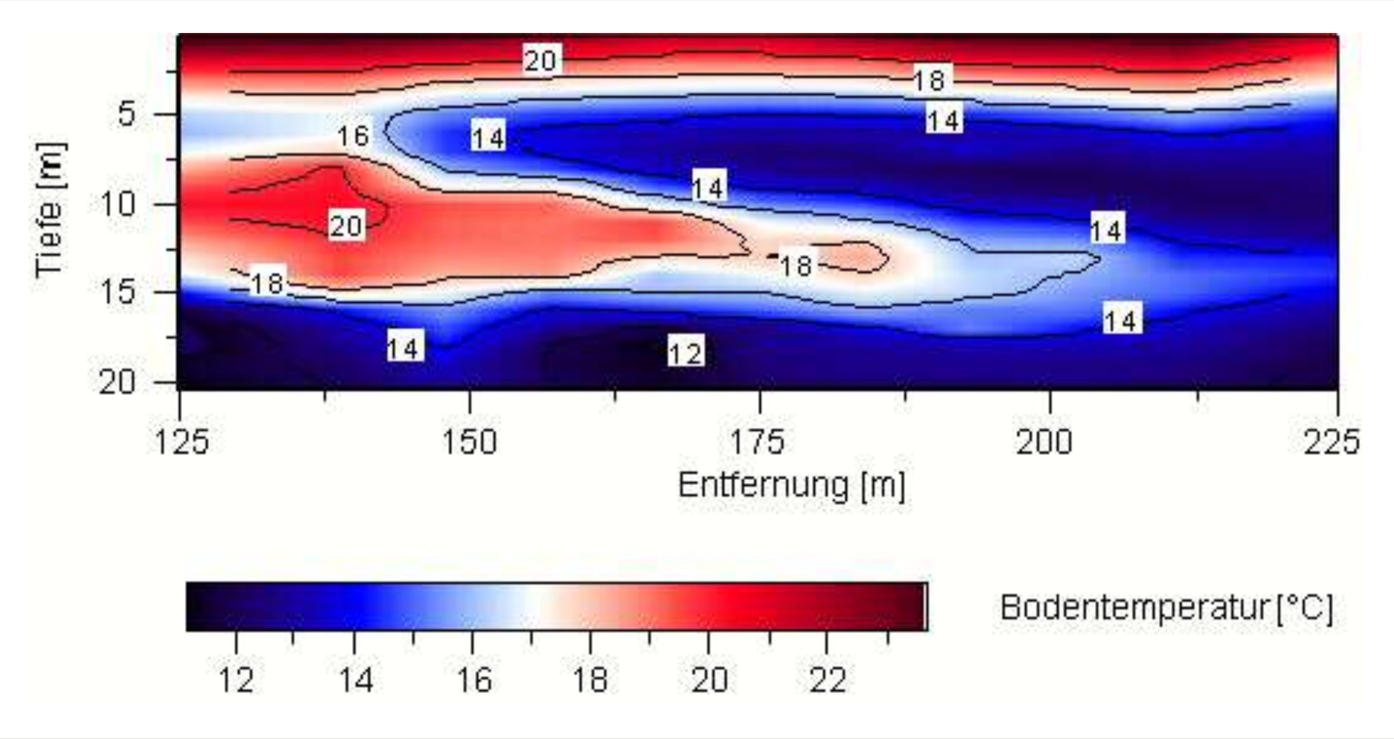
Ground temperature soundings along dam axis



Example 1: cross section

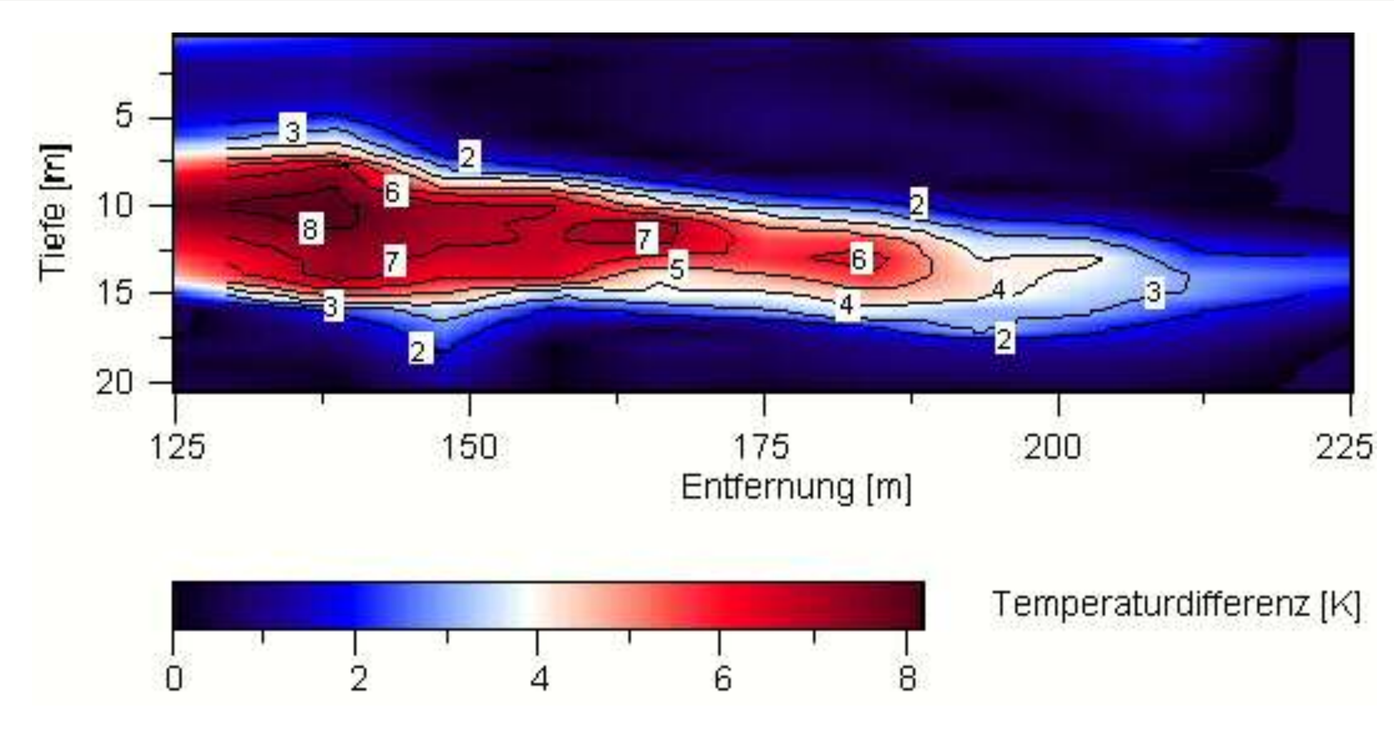


Ground temperature distribution inside and underneath an earth fill dam along the dam



Water temperature: 20.5 °C

Ground temperature anomaly inside and underneath an earth fill dam

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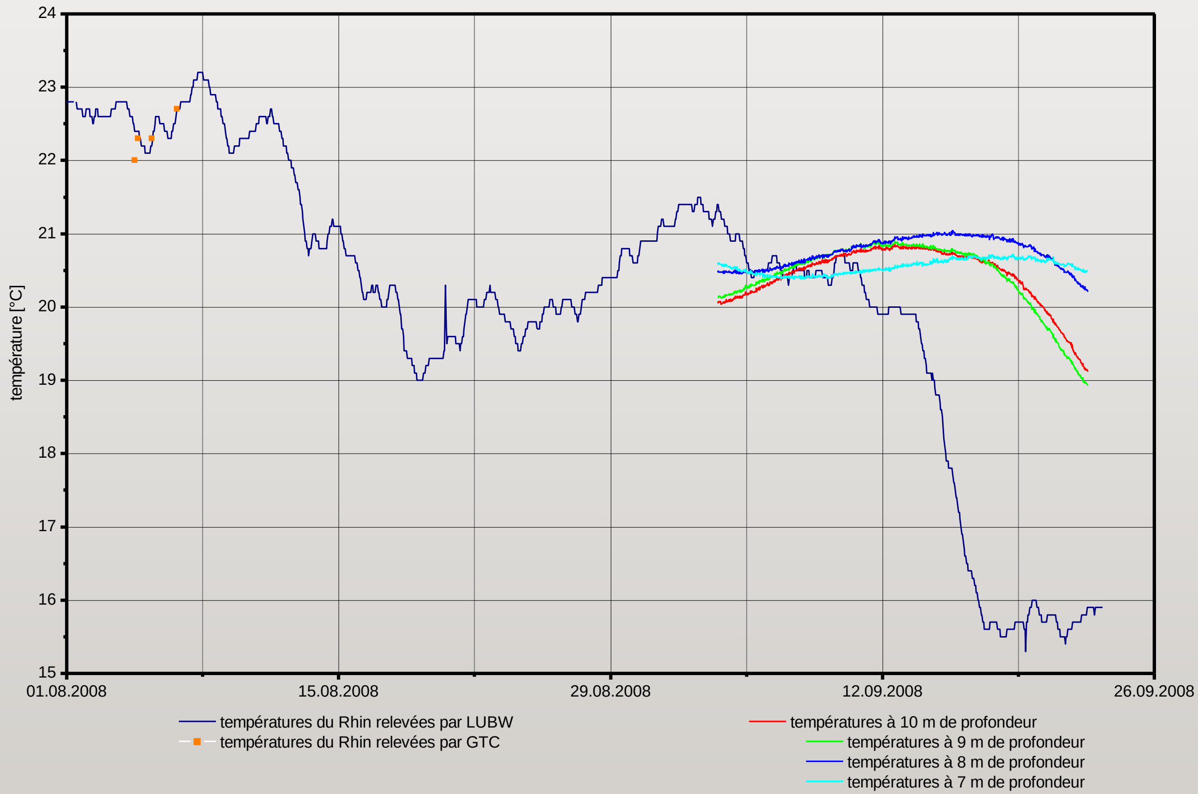
Häwa 1

Water temperature variation vs. Ground temperature variation in an earth fill dam



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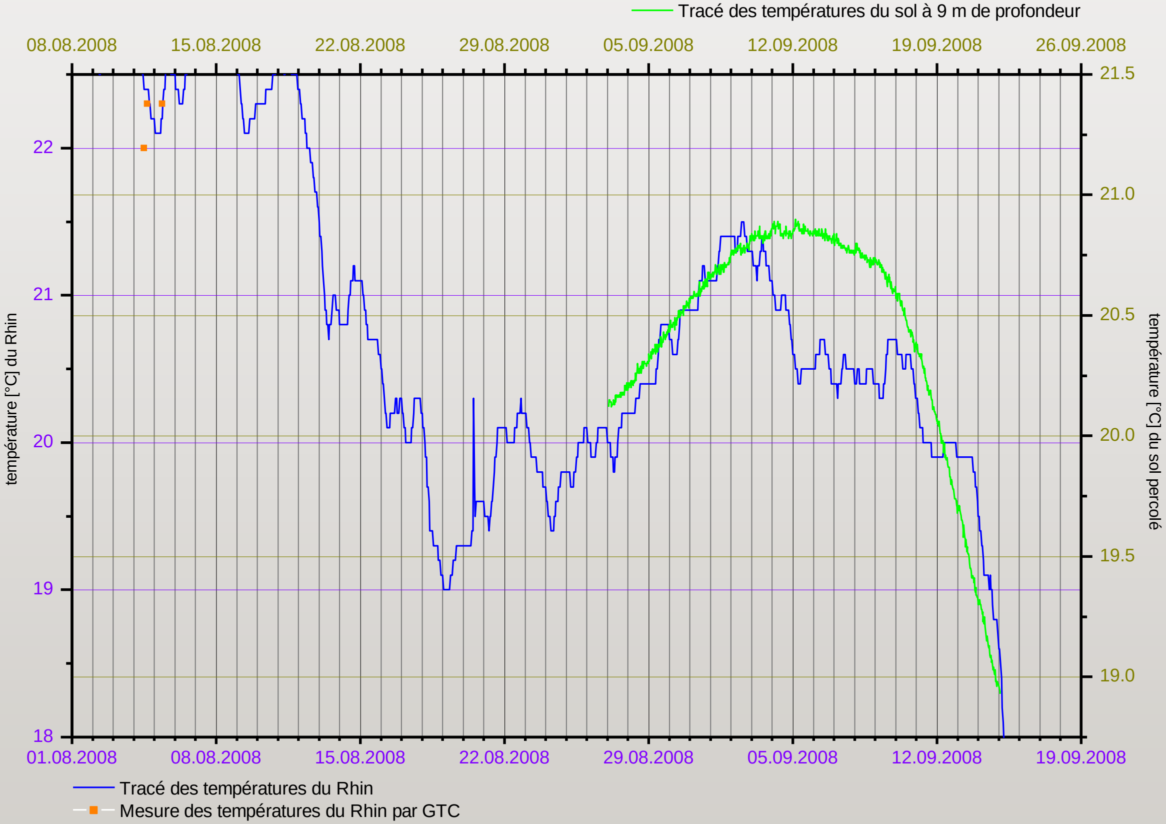
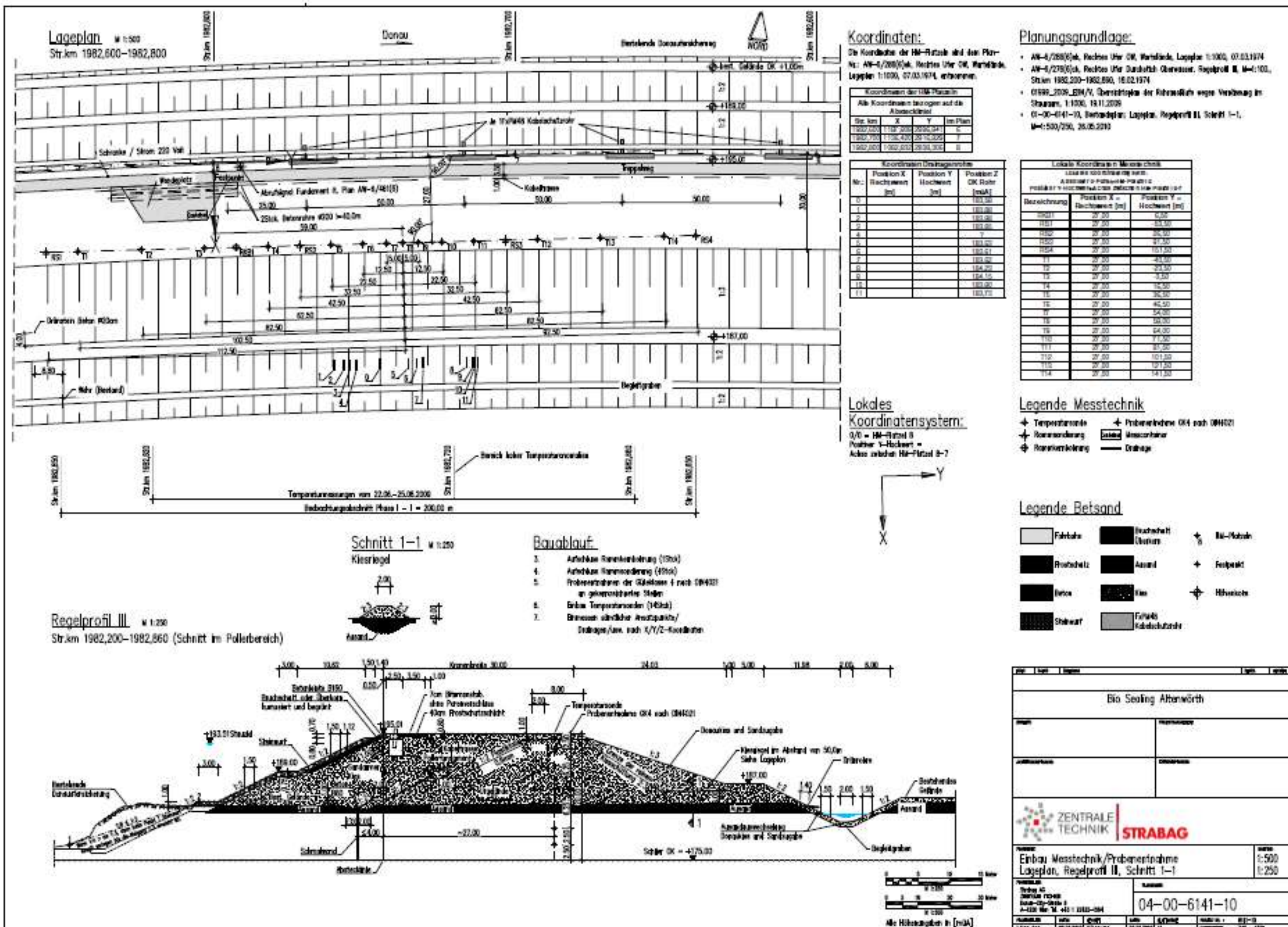
Water temperature variation vs. Ground temperature variation in an earth fill dam



dt = 7 days ; dx = 20 m => v = 3,3 x 10^{-5} m/s



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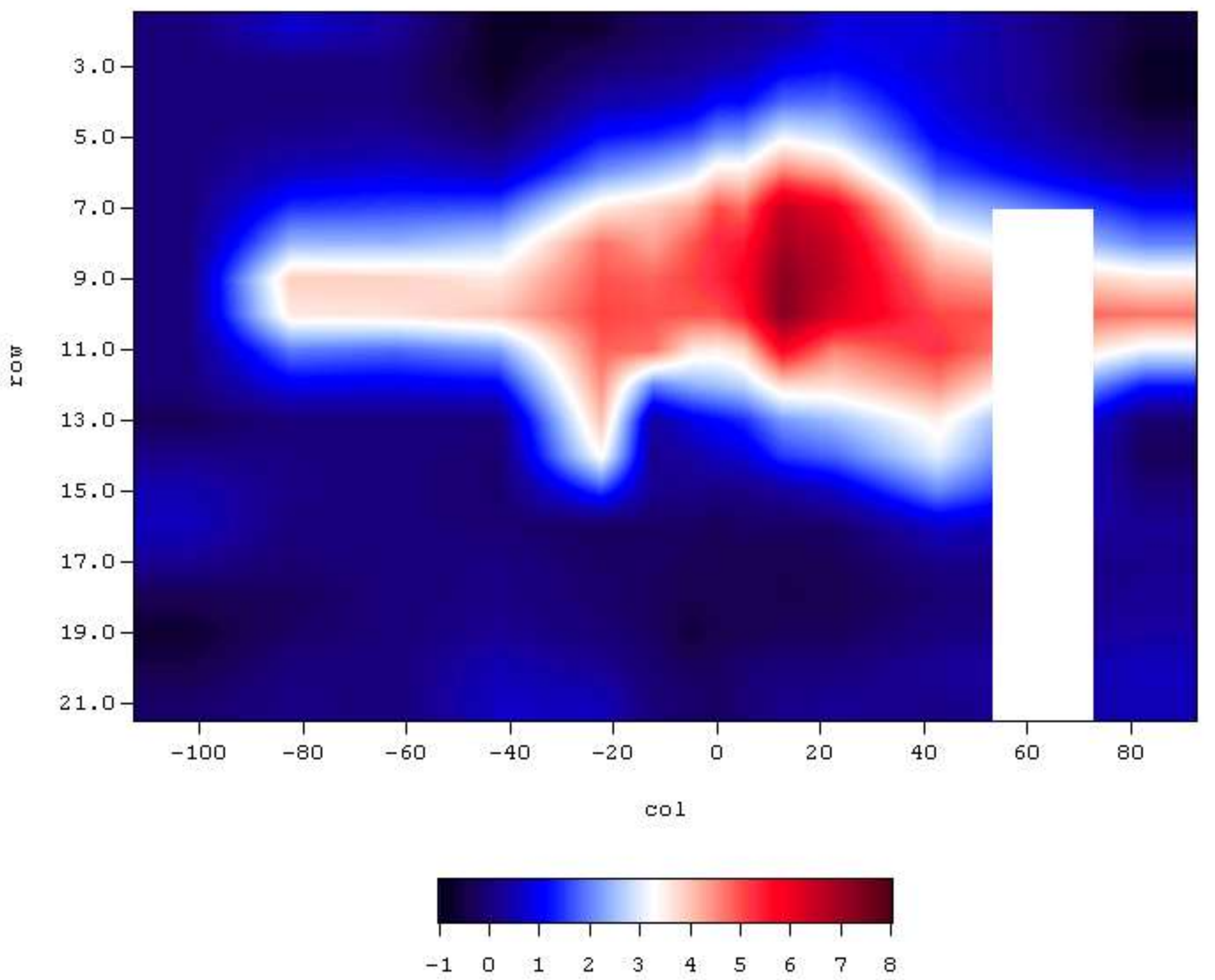

row
3.0
5.0
7.0
9.0
11.0
13.0
15.0
17.0
19.0
21.0
col
-100
-80
-60
-40
-20
0
20
40
60
80
-1
0
1
2
3
4
5
6
7
8

Sondierung	PhaseShift [s]	Abstandsg. [m/s]	Filterg. [m/s]	Sondierung	Höhe [m]	Breite [m]	Fliessrate [m^3/s]
T1	konduktiv	Nicht messbar	Nicht messbar	T1	Nicht messbar	20	Nicht messbar
T2	1820000	2.20E-05	4.40E-06	T2	4	20	3.52E-04
T3	1820000	2.20E-05	4.40E-06	T3	4	20	3.52E-04
T4	1820000	2.20E-05	4.40E-06	T4	4.5	20	3.96E-04
T5	1530000	2.61E-05	5.23E-06	T5	9	15	7.06E-04
T6	1570000	2.55E-05	5.10E-06	T6	6	8.75	2.68E-04
T7	1480000	2.70E-05	5.41E-06	T7	6	6.25	2.03E-04
T8	1420000	2.82E-05	5.63E-06	T8	5	5	1.41E-04
T9	1370000	2.92E-05	5.84E-06	T9	6	6.25	2.19E-04
T10	1280000	3.13E-05	6.25E-06	T10	6	8.75	3.28E-04
T11	1310000	3.05E-05	6.11E-06	T11	5	15	4.58E-04
T12	1470000	2.72E-05	5.44E-06	T12	6.5	30	1.06E-03
T13	-	-	-	T13	-	-	-
T14	1640000	2.44E-05	4.88E-06	T14	4	30	5.85E-04

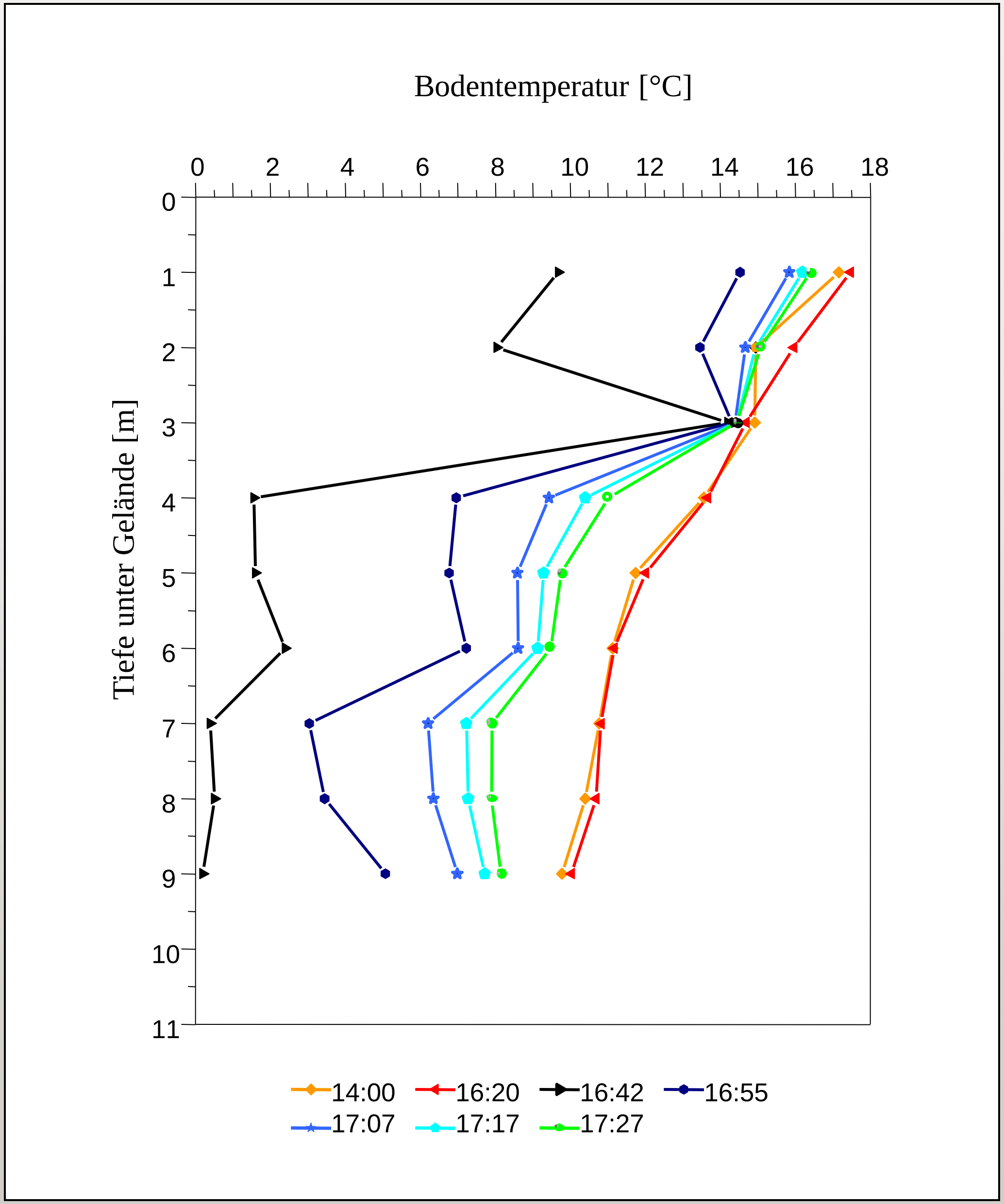
Total $5{,}07 \cdot 10^{-3}$ m^3/s

Frost-Pulse-Method

Heat-Pulse-Method

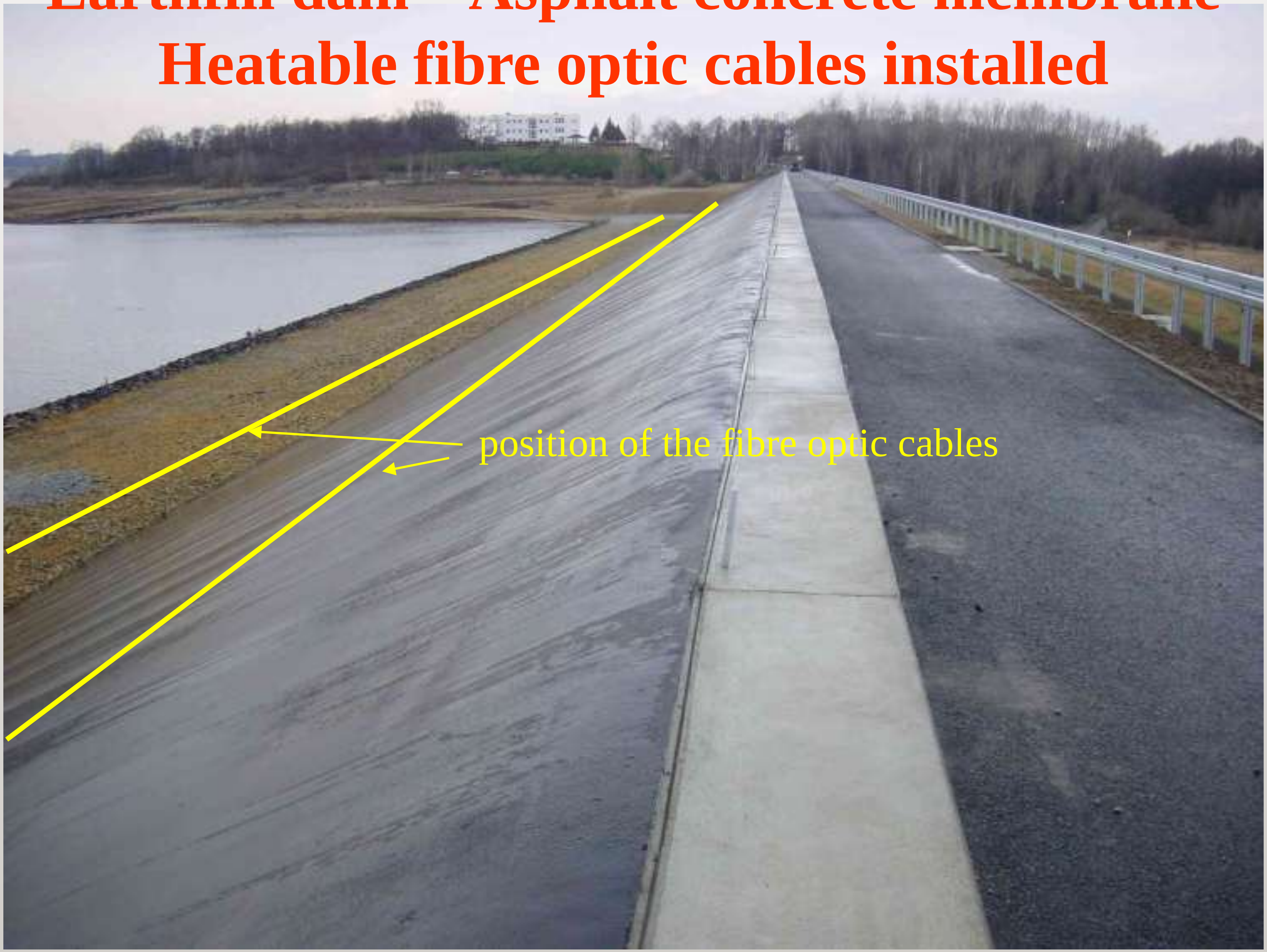
Frost-Pulse-Method

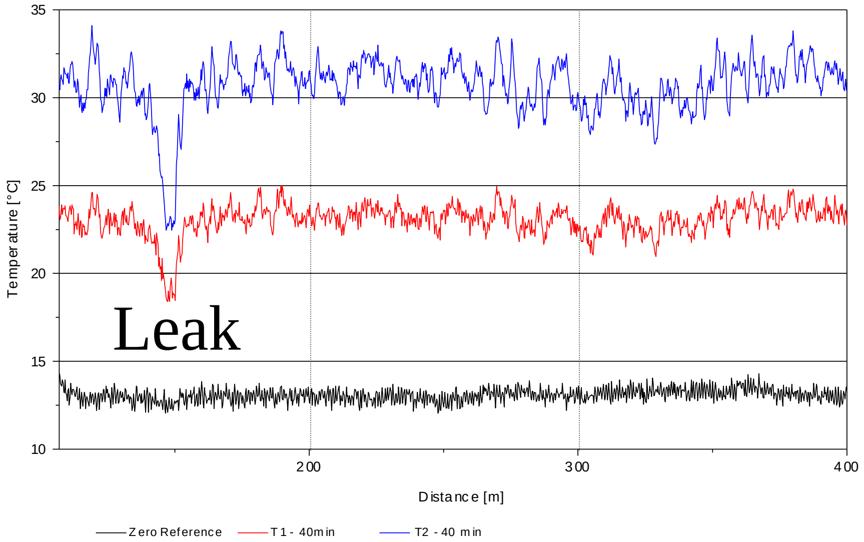
Freezing of the ground by injection of liquid CO_2 into the temperature probe



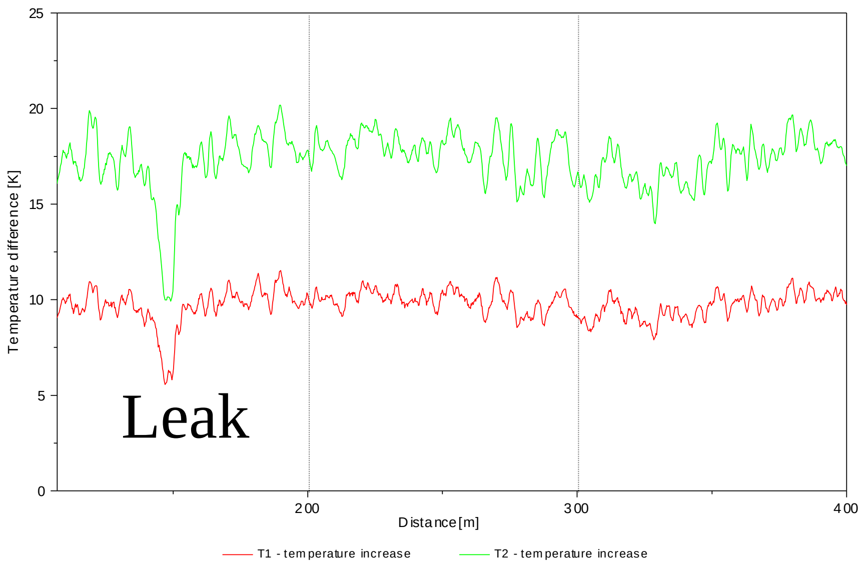
Thermal recovery to equilibrium after injecting CO_2

Earthfill dam – Asphalt concrete membrane
Heatable fibre optic cables installed



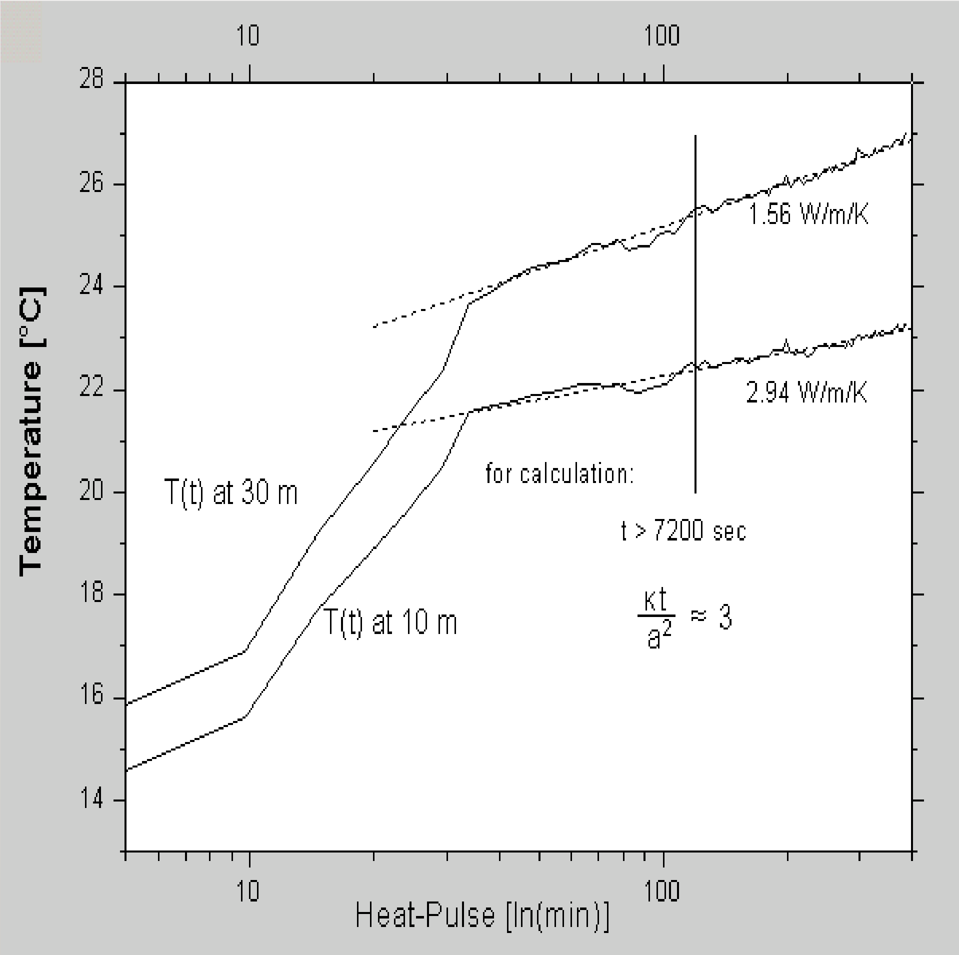


Temperature distribution along fibre optical cable before (*black line*) and after heat up (*red and blue line*)



Temperature difference along fibre optical cable to the initial temperature before heat up (*red and green line*)

Estimation of darcy velocity distribution along a heated fibre optic cable



Effective thermal conductivity can be derived from Heat Pulse Method

Effective = conductive + convective thermal conductivity

Convective thermal conductivity is proportional to flow velocity

(Peclet number)

Internal erosion detected !

Thank you for your attention