

Temperature as Tracer for In Situ Detection of Internal Erosion

Jürgen Dornstädter & Barbara Heinemann

GTC Kappelmeyer GmbH
Karlsruhe / Germany

www.GTC-info.de

Temperature distribution in soil

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

t time [s]

T temperature of fluid and porous soil [°C]

Thermal diffusivity

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

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

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]

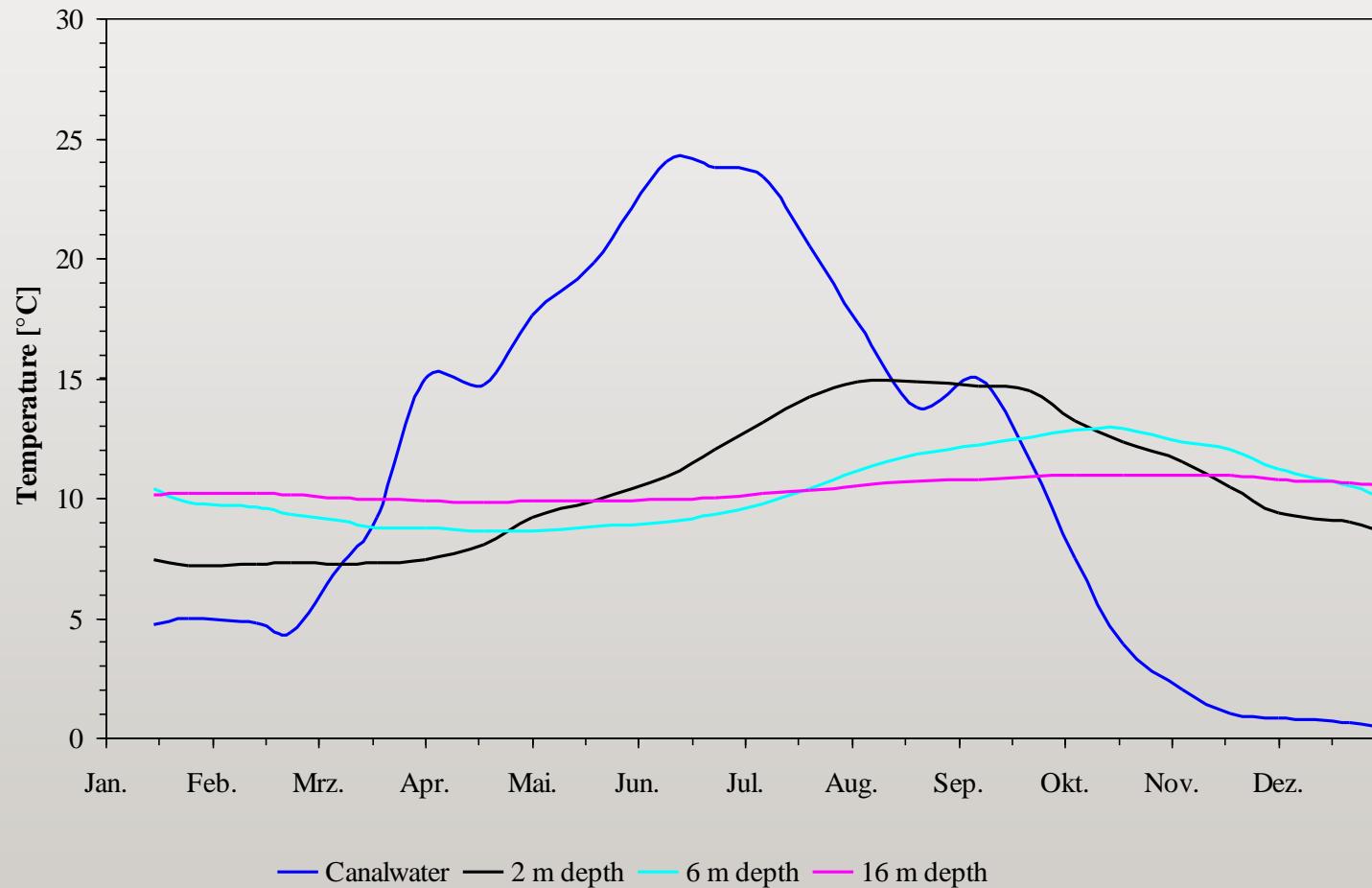
K_s thermal conductivity of soil [W/m/K]

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

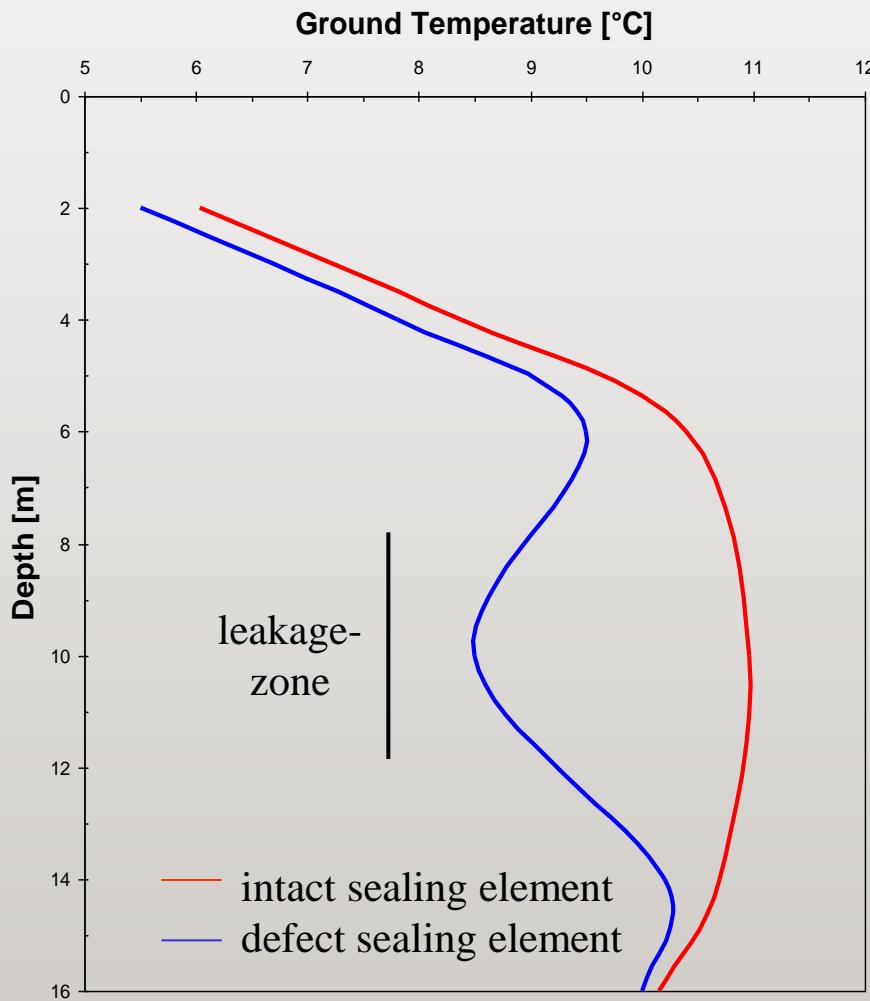
\underline{I} unit matrix [-]

darcy velocity > 10⁻⁷m/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”*

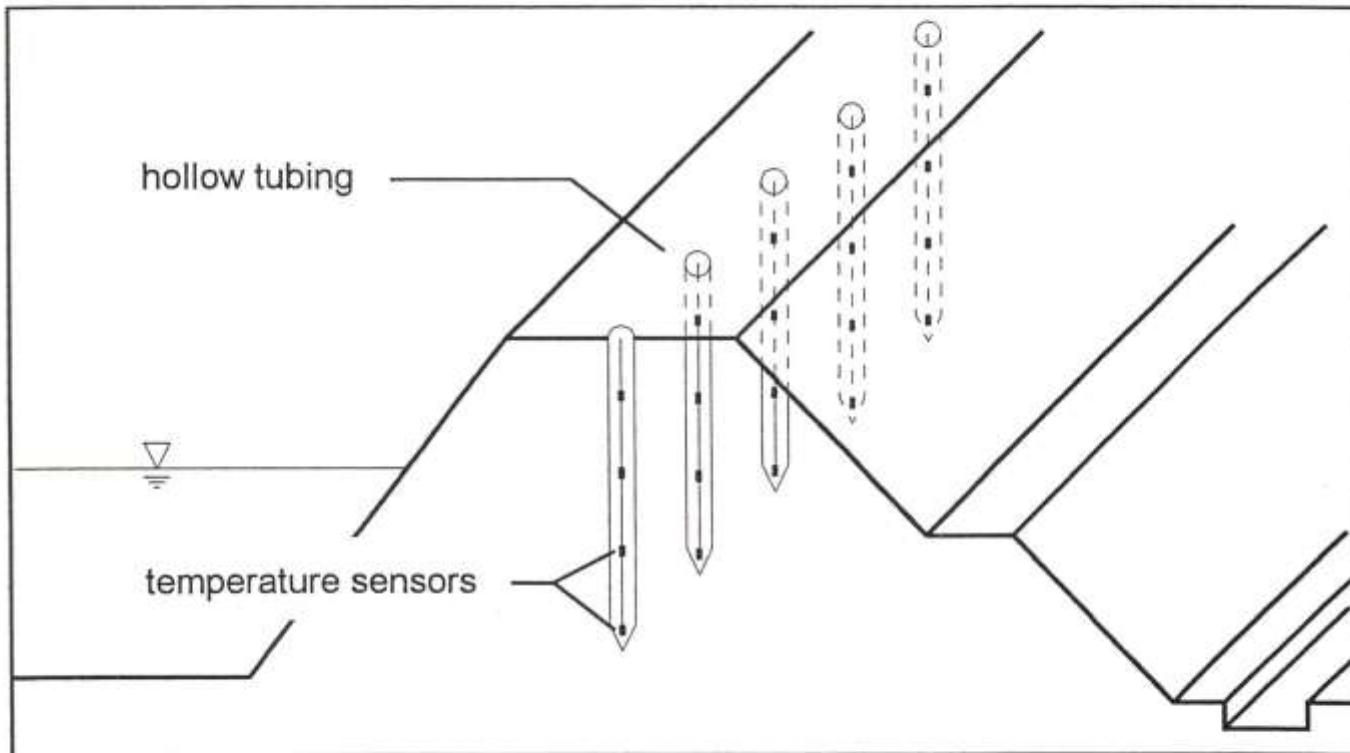
Driving and Pulling of the Metal Tubes



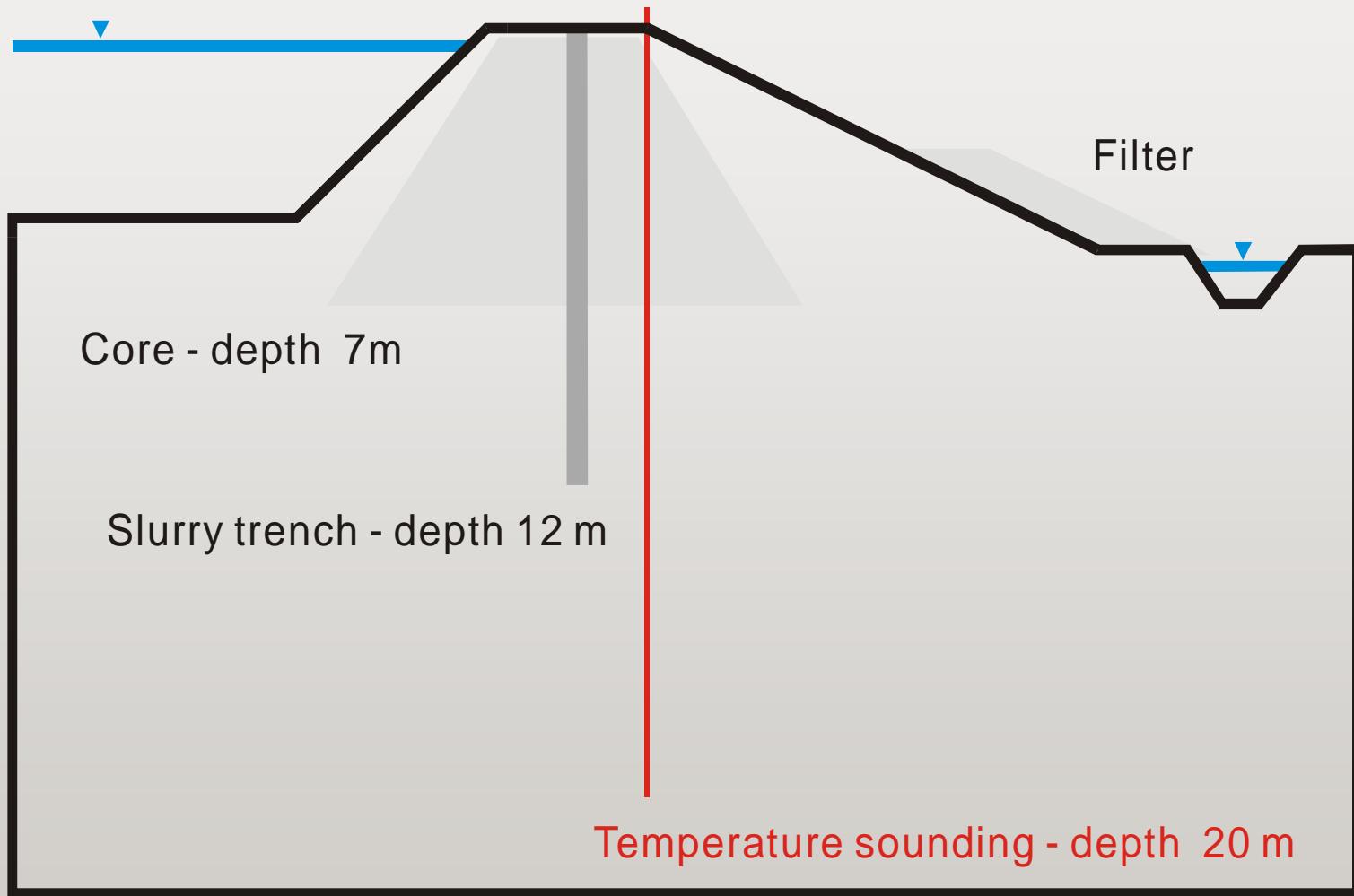
Temperature Measurements



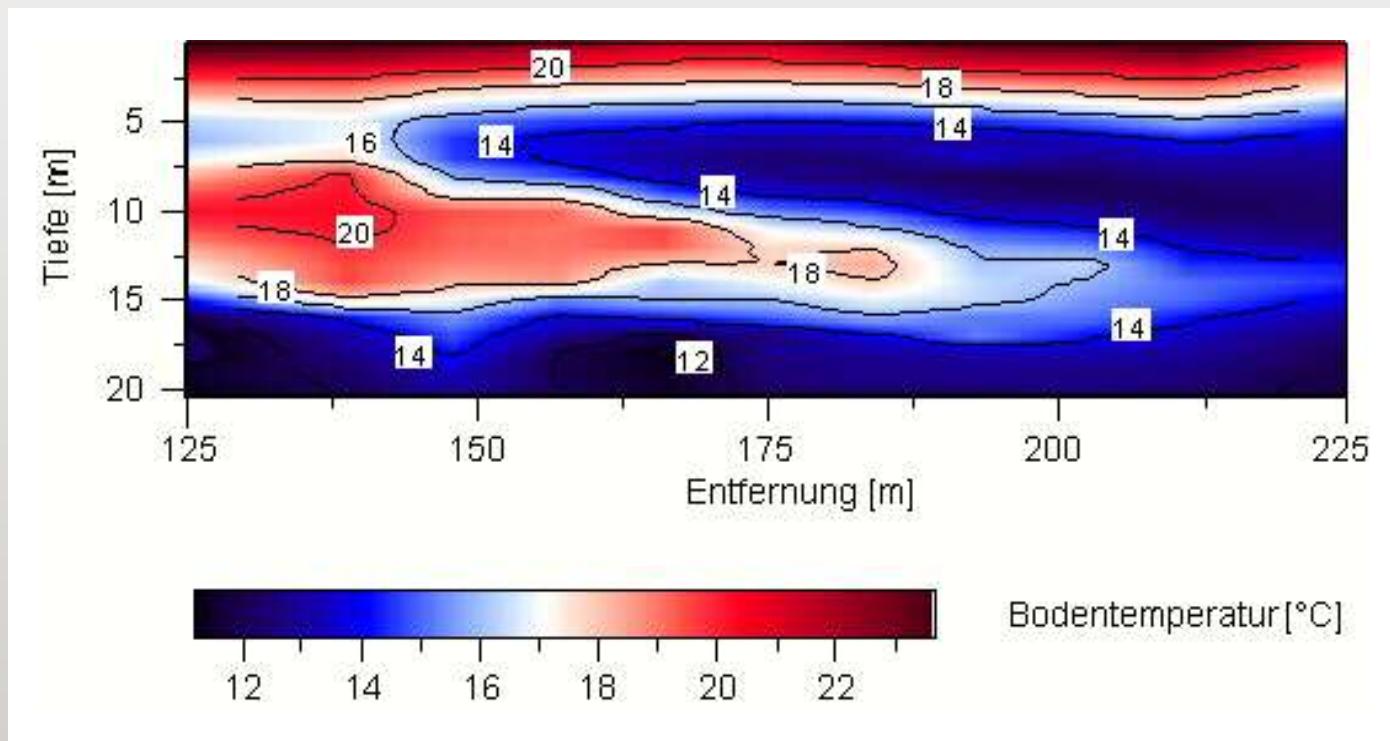
Ground temperature soundings along dam axis



Example 1: cross section

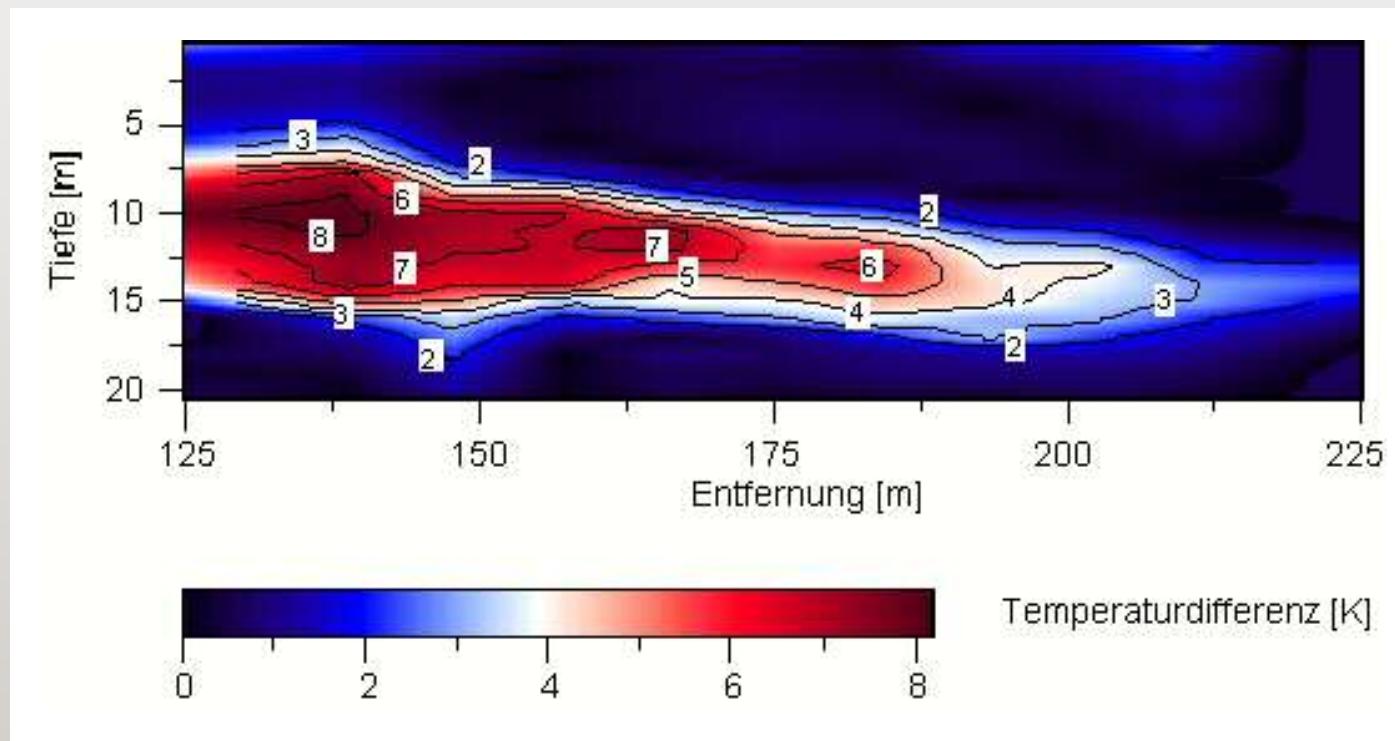


Ground temperature distribution inside and underneath an earth fill dam along the dam



Water temperature: 20.5 °C

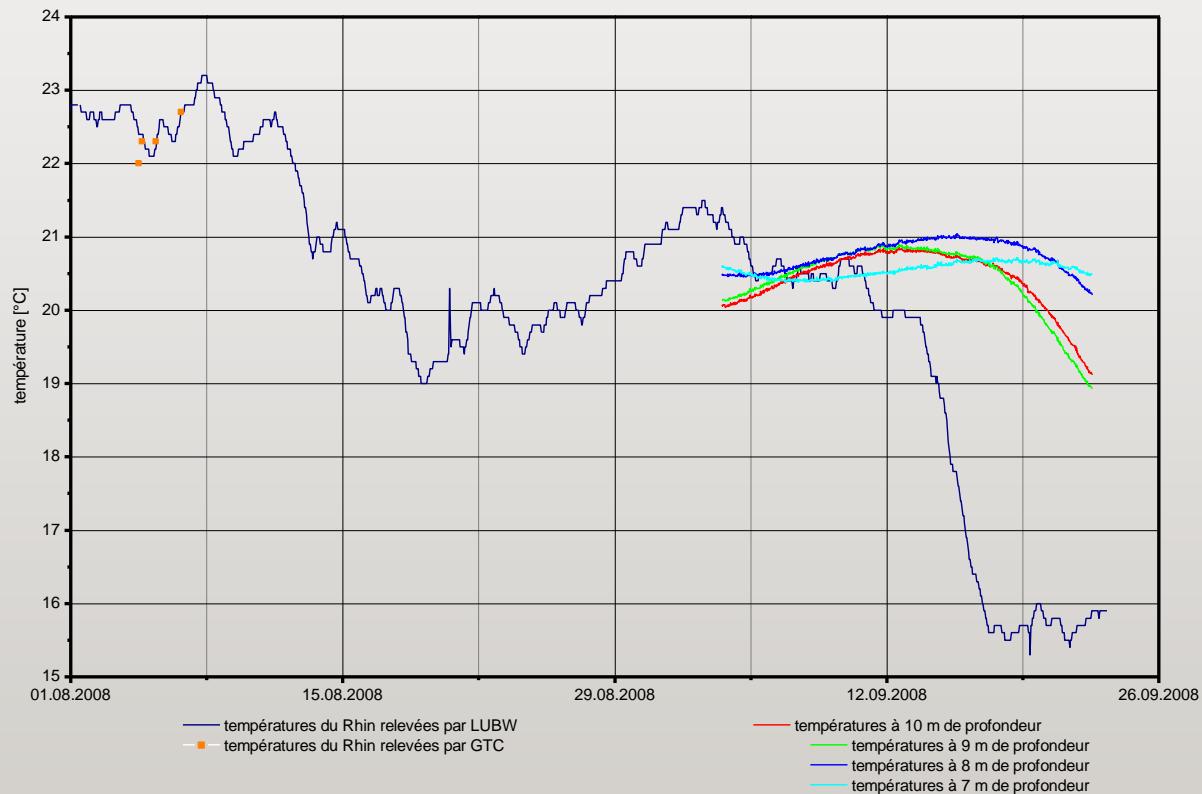
Ground temperature anomaly inside and underneath an earth fill dam



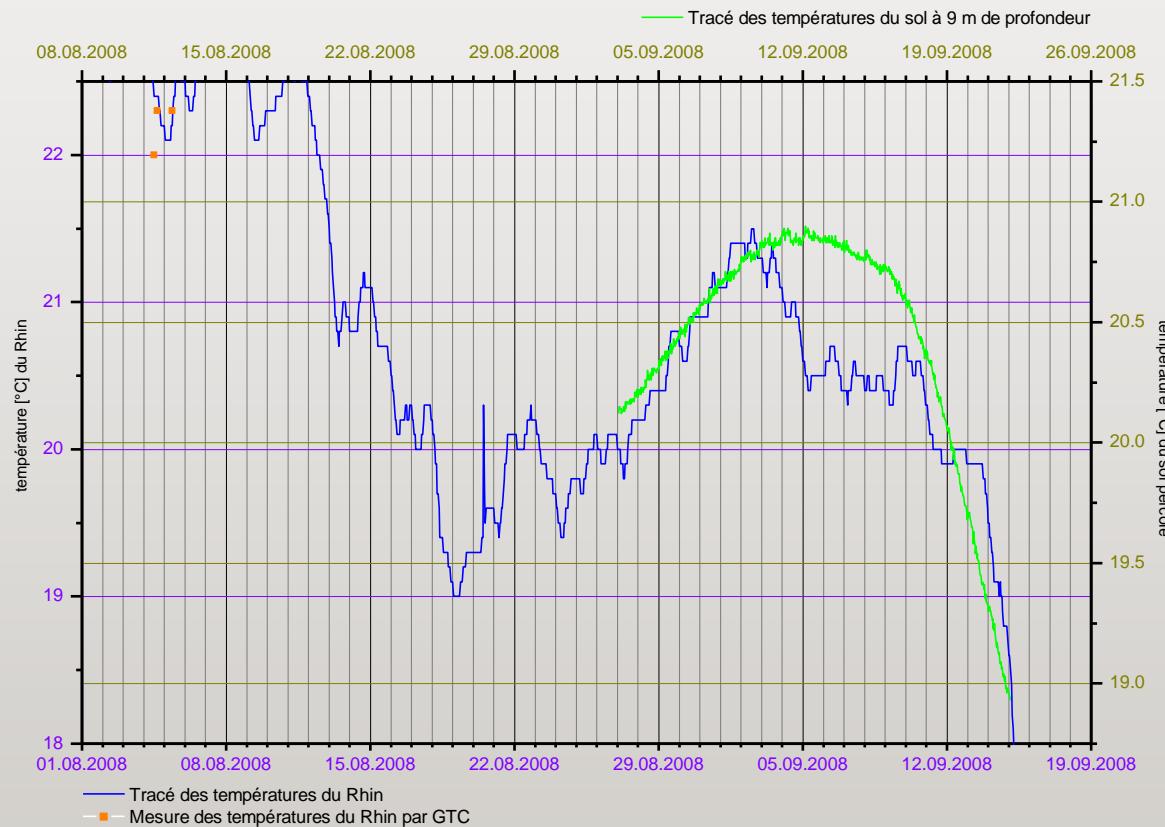




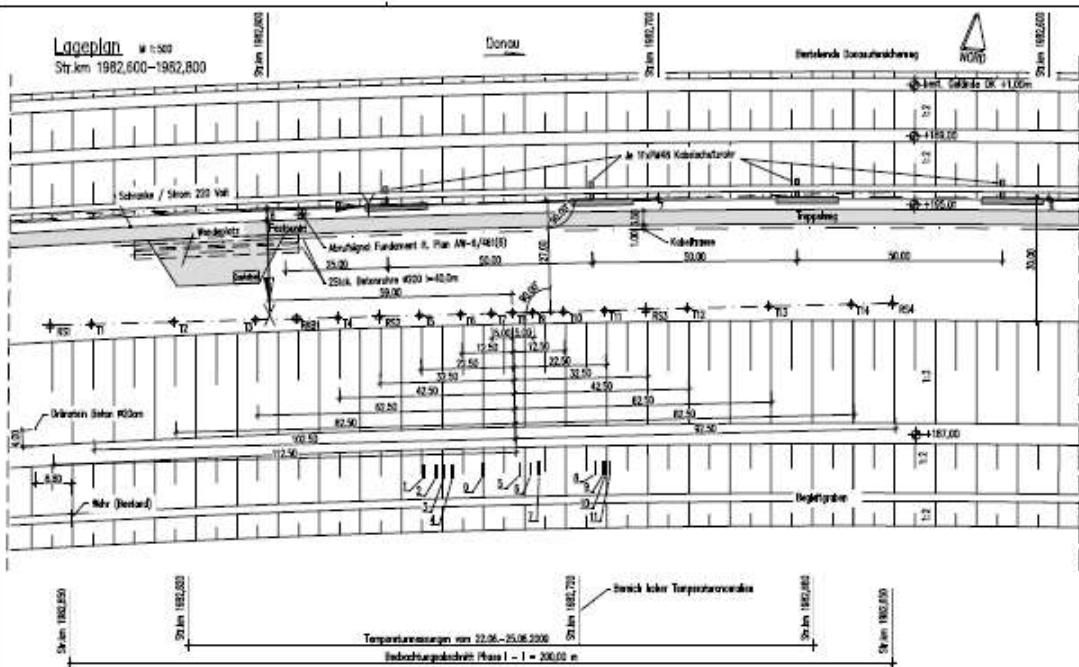
Water temperature variation vs. Ground temperature variation in an earth fill dam



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



$$dt = 7 \text{ days} ; dx = 20 \text{ m} \Rightarrow v = 3,3 \times 10^{-5} \text{ m/s}$$



Koordinaten:

Koordinaten des H&M-Passat			
Alle Koordinaten berechnet mit der Abstandsfunktion			
St. Num.	X	Y	Im Plan
1090	118,00	2000,00	Ja

- AW-4/289/04a, Rednes Uhr NW, Wandschl., Logiplatz 11/1000, 07.03.1977
 - AW-4/278/04b, Rednes Uhr Durchschl. Obersteig, Registriert II, M=1-10
Stahl 1882/2000-1982/2000, 16.02.1974
 - 01998_2008_EBM_W, Obersteiguhren für Rechenstühle wegen Verbaufälligkeit abmontiert, 11.06., 19.11.2008
 - G-00-041-10, Wandschl., Logiplatz, Registriert II, Stahl 1-1-
M=1-1000, 25.05.2010

Koordinaten des 100-Punktes			
Alle Koordinaten bezogen auf die Ausschnittsecke			
Sp. km	X	Y	Im Plan
1000/000	1138,208	2000,024	■
1000/000	1138,408	2011,009	■
1000/000	1138,608	2022,009	■

Koordinaten Umtagungsroute		
No.	Position X Rechtsrücken [m]	Position Y Hochwasser [m]
0		100,50
1		100,50
2		100,50
3		100,50
4		100,50
5		100,50
6		100,50
7		100,50
8		100,50
9		100,50
10		100,50
11		100,75

lokale Koordinaten im Messnetzpunkt		
	Position X - Hochwasser [m]	Position Y - Hochwasser [m]
1001	29,35	65,00
1002	29,35	65,00
1003	29,35	65,00
1004	29,35	65,00
1005	29,35	65,00
11	29,35	-45,00
12	29,35	-55,00
13	29,35	-55,00
14	29,35	-55,00
15	29,35	-55,00
16	29,35	-45,00
17	29,35	-25,00
18	29,35	-15,00
19	29,35	-15,00
190	29,35	77,50
111	29,35	77,50
112	29,35	111,00
113	29,35	111,00
114	29,35	141,50

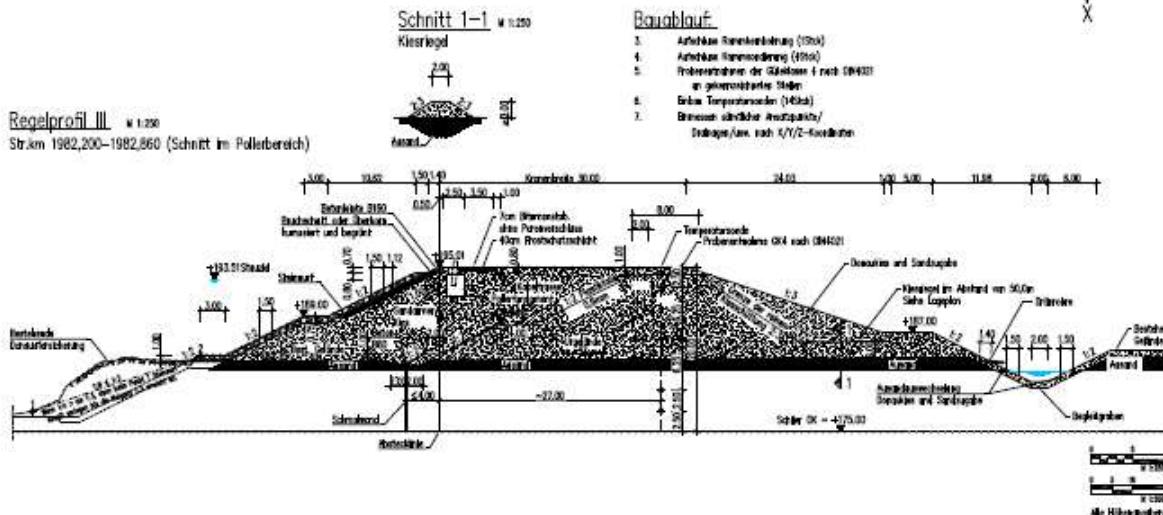
Lokales Koordinatensystem:
0/0 = HM-Platz 8
Position 1=Hockert =
Achse zwischen HM-Platz 8-7



Legende Messtechnik

Legende Betsand

		→	Reisezeit Distanz
		→	Anzahl
		→	Kilometer
		→	Kilometer Kilometertabelle

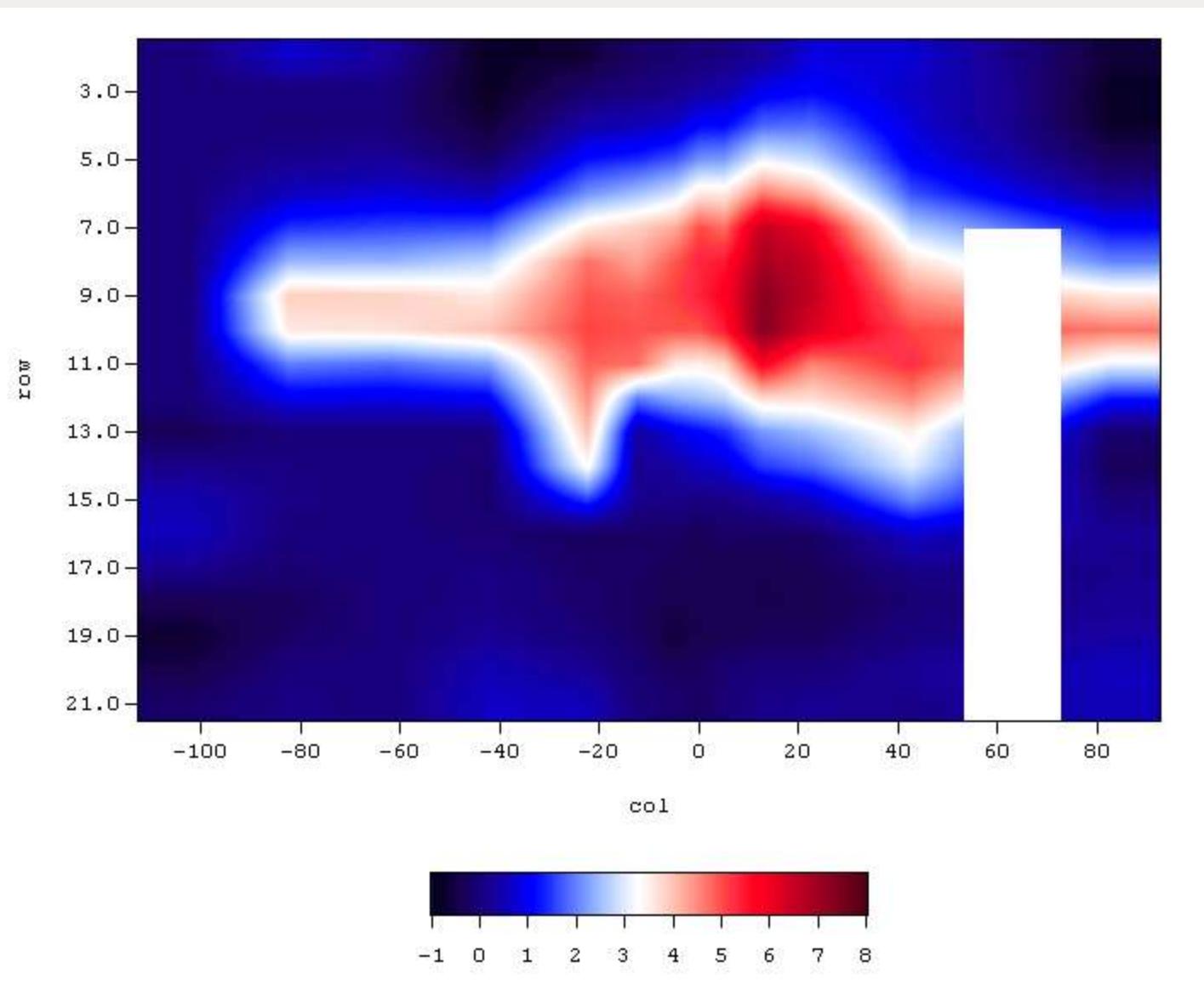


Eugen Blaustein

3. Arbeitseinsatzentlastung (Stk)
 4. Arbeitseinsatzvermeidung (Rita)
 5. Problemorientierung der Qualität nach DIN ISO 9000
- an gesuchte/erwartete Stellen
 6. Große Temperaturweiten (Walter)
 7. Einfluss ständiger Reisequipschaft/
Technikarbeiten nach U27-Erfordernissen

Regelprofil III n 1:250





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*10⁻³ m³/s

Frost-Pulse-Method

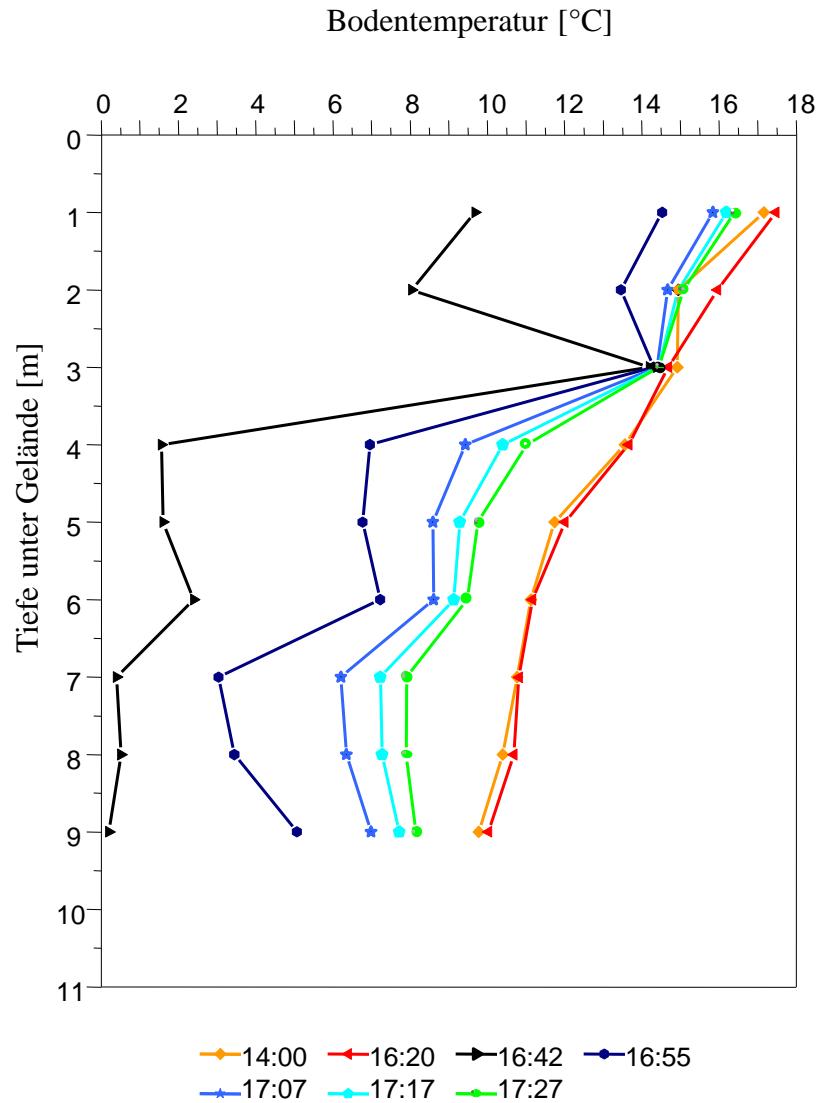
Heat-Pulse-Method



Frost-Pulse-Method

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

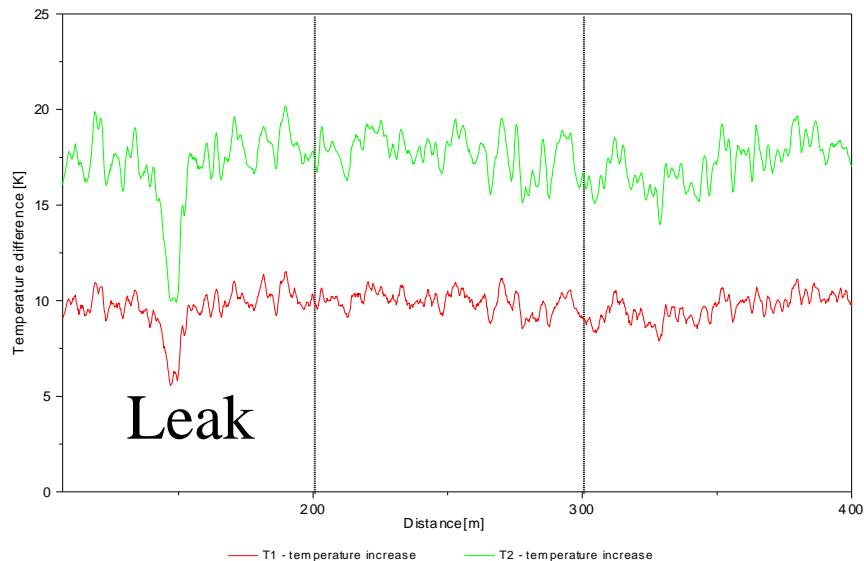
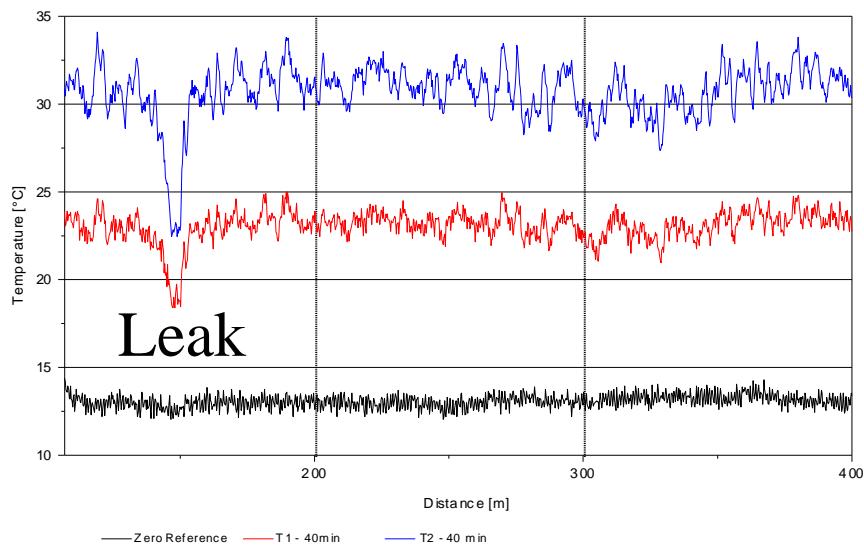




*Thermal recovery
to equilibrium
after injecting CO₂*

Earthfill dam – Asphalt concrete membrane Heatable fibre optic cables installed

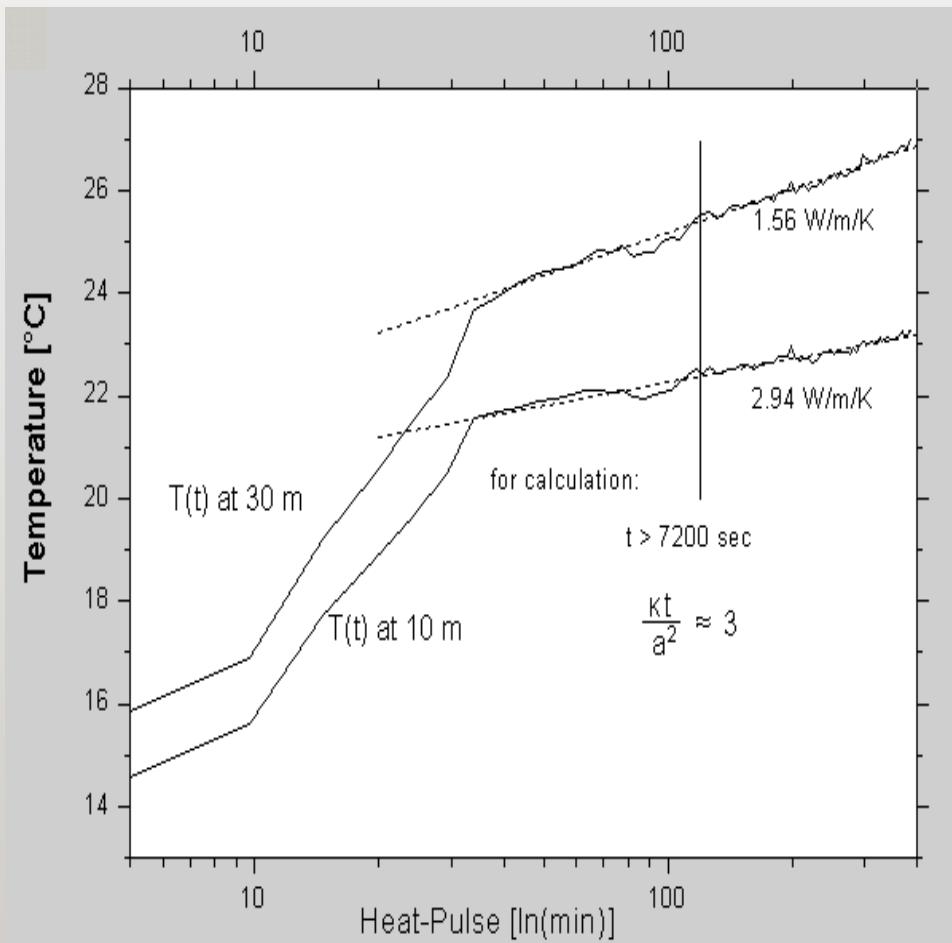




Temperature distribution along fibre optical cable before (*black line*) and after heat up (*red and blue line*)

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

