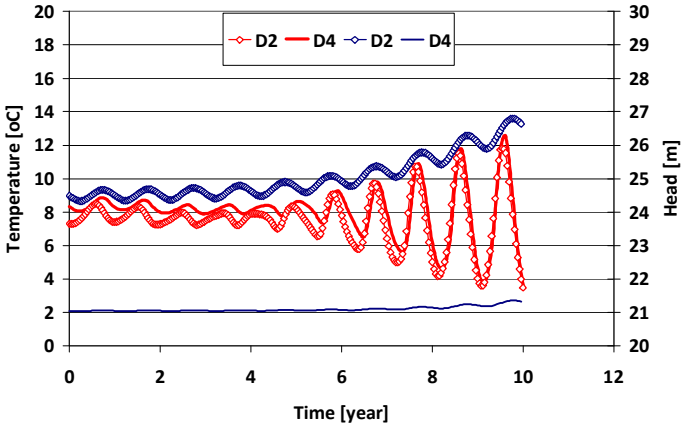
HydroResearch

Experience from internal erosion detection and seepage monitoring based on temperature measurements on Swedish embankment dams

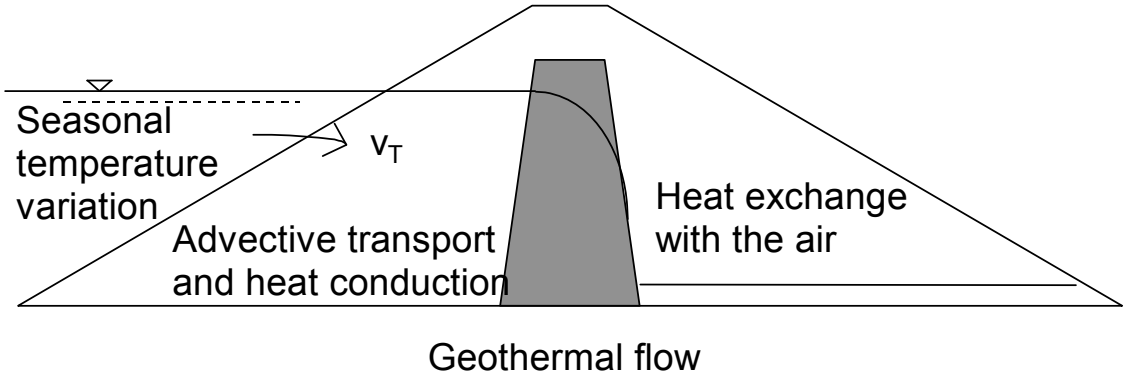
Pontus Sjödahl, HydroResearch
Sam Johansson, HydroResearch



Why measure temperature?

HydroResearch

- Seepage is a fundamental parameter for internal erosion detection
- Temperature depends on the seepage flow
- Sensitive to detect small seepage anomalies
- More and more accepted and used
  especially with fiber optics
- High spatial resolution

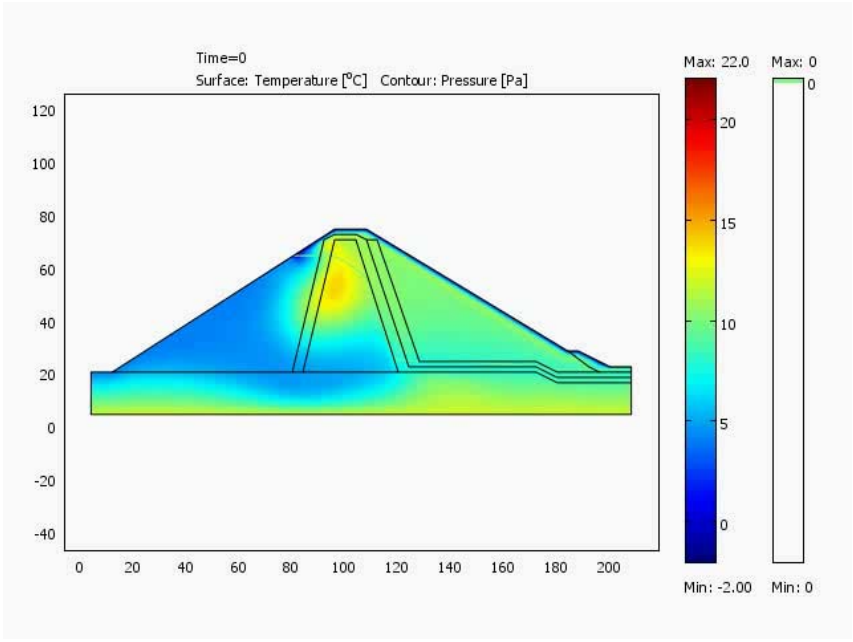


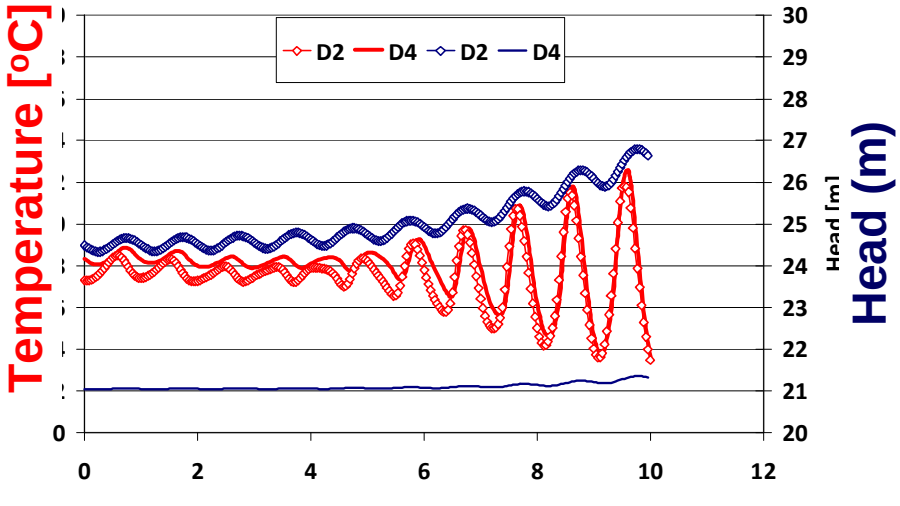
Saturated and un-saturated flow

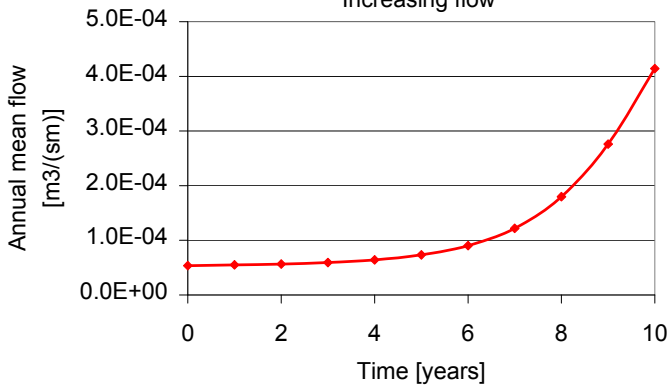
Heat conduction and convection

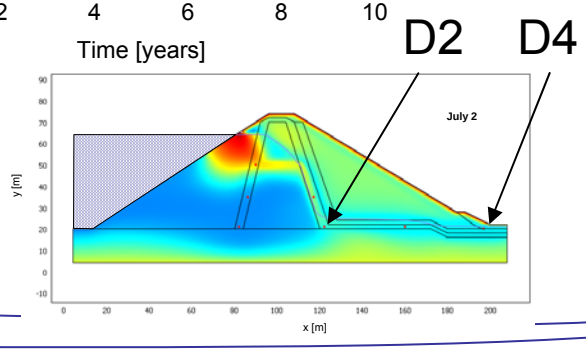
Simulation - a general example

- Slow internal erosion process
- Seepage zone 2 m
- 10 years, increasing hydraulic conductivity at h=50±1 m



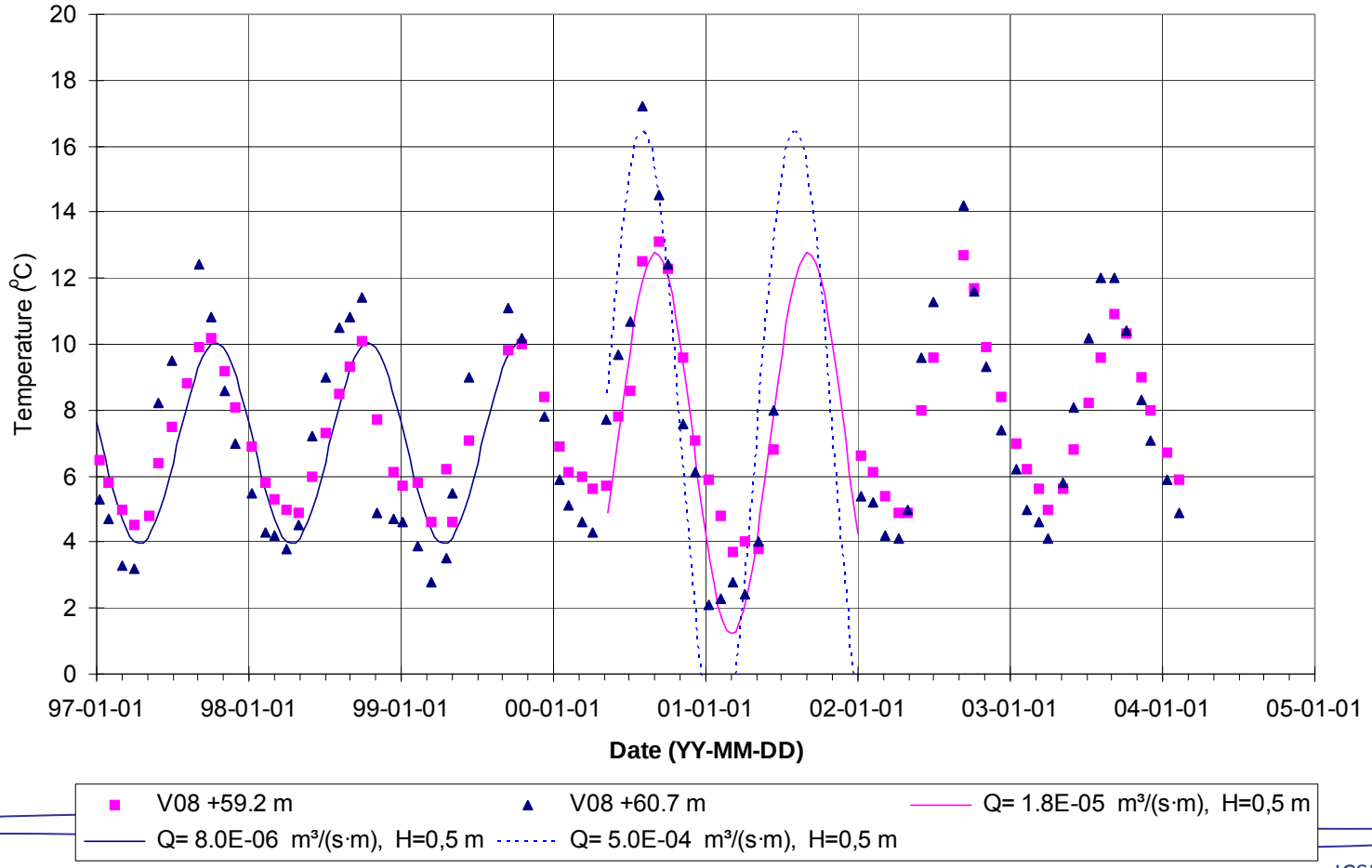






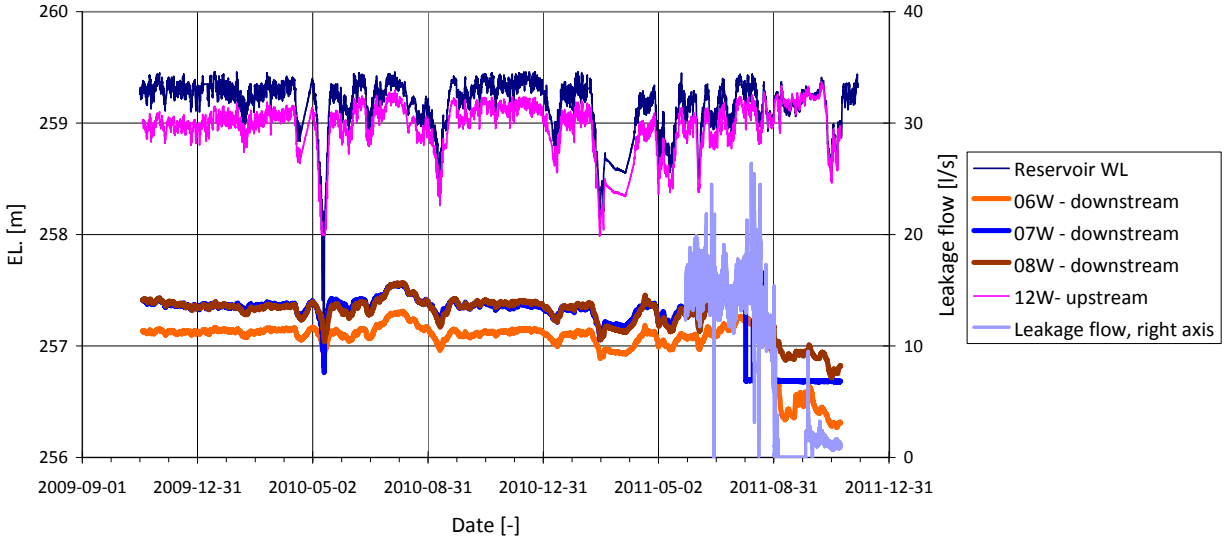
Näs embankment dam

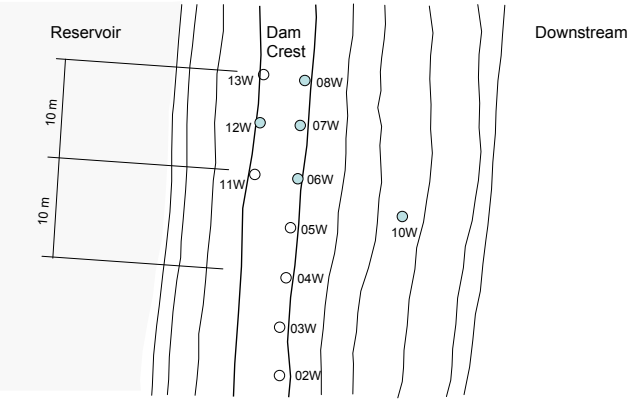
- 15 m high dam, monthly temperature measurements in open standpipes
- Sudden increase in seasonal temperature variation in 2000-2001 followed by a decrease to normal levels
- Interpreted as increased seepage flow (2-60 times)

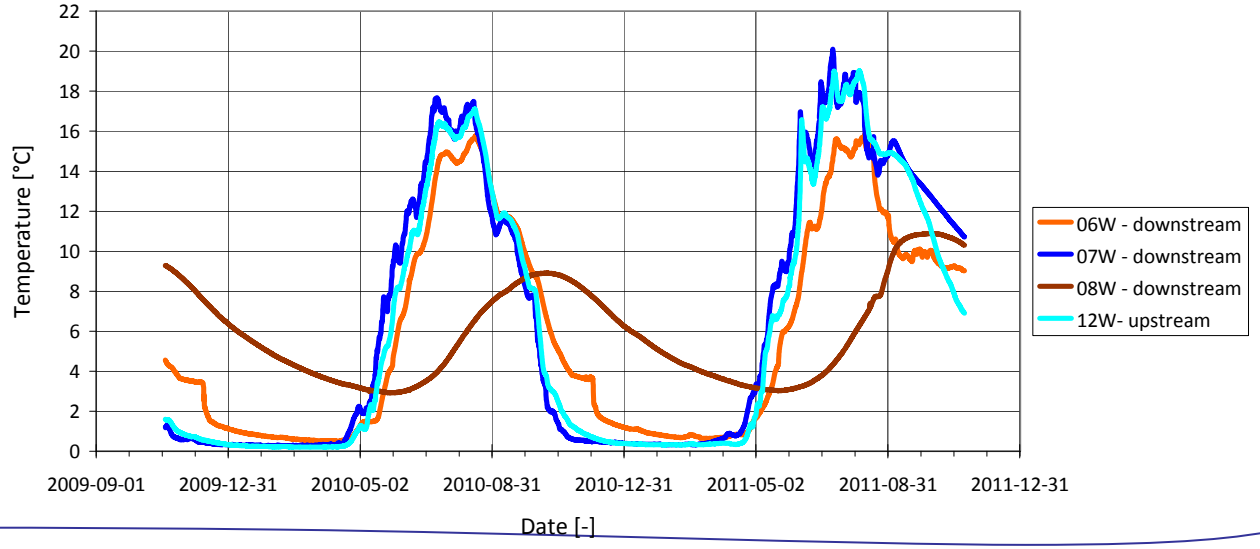


Akkats embankment dam

- Low dam (<9 m) with visual seepage outflow
- Repair works (grouting)
- Seepage decrease
- Pressure decrease
- Temperature confirms decreased seepage







Optical fibre installations in Swedish dams

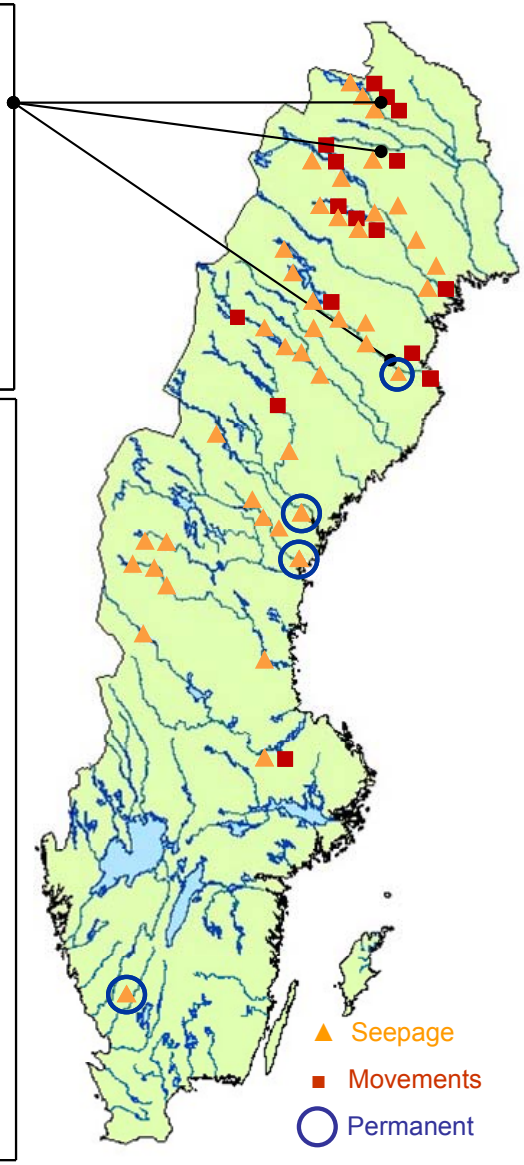
HydroResearch

Tailings dams (3 sites, 7 dams)

Aitik E-F	▲	■	2002
Aitik I-J	▲		2005
Hötjärnsmagasinet - F	▲	■	2008
Hötjärnsmagasinet - H	▲	■	2008
LKAB, CB	▲	■	2010
LKAB, KS	▲	■	2011
LKAD, Loussajärvi	▲	■	2011

Hydro Power dams (43 sites, 62 dams)

Lövön	▲		1998
Sädva		■	1999
Ajaure		■	2001
Vargfors	▲		2001
Hylte dam and dyke	▲		2002
Suorva East		■	2003
Suorva West	▲	■	2003-05
Bastusel (4 dams)	▲		2004
Porsi	▲		2005
Ligga	▲		2005
Seitevare	▲	■	2005
Hällby		■	2005
Gallejaure (left and right)	▲		2005
Vässinkoski	▲		2005
Hällby		■	2005
Bergeforsen	▲		2005



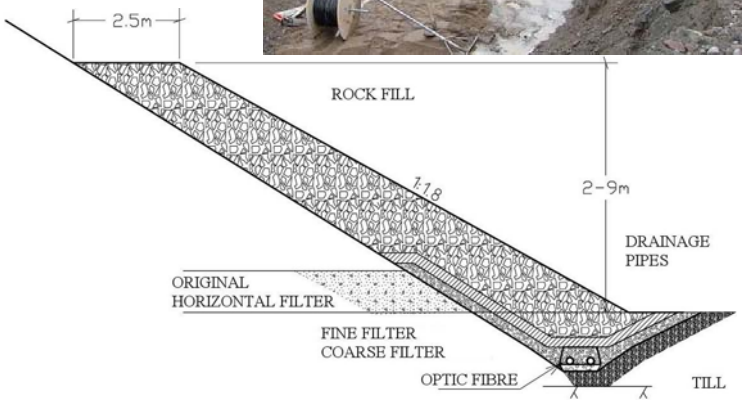
Hydro Power dams (43 sites, 62 dams)

Parki (left and right)	▲	■	2006
Randi (left and right)	▲	■	2006
Boden (left and right)	▲	■	2006
Porjus	▲		2006
Grytfors (left and right)	▲	■	2006
Näs main dam	▲		2006
Stensele (left and right)	▲		2006
Näverede (left and right)	▲		2007
Stadforsen	▲		2007
Hölleforsen	▲		2007
Rebnis	▲		2007
Näs new dam	▲	■	2007
Flåsjön	▲		2007
Grundsjön	▲		2007
Tänger	▲		2008
Ledinge	▲		2009
Furudal	▲		2009
Abelvattnet	▲		2010
Storjuktan	▲		2010
Halvfari	▲		2011
Akkats	▲		2011
Edensfors	▲		2011
Trångfors	▲		2012
Rätan	▲		2012
Grundfors	▲		2012

Optical fibre and DTS measurements

HydroResearch

- Cable easily installed when constructing new drainage and toe berm
- Cable installed upstream of drainage



- Different measurement strategies
  - Reference measurement
  - Repeated measurements (at inspections or similar)
  - Short term monitoring (special occasions, seepage increases, reservoir filling)
  - Continuous monitoring

Aims at ***measuring seepage*** and ***detecting seepage changes***

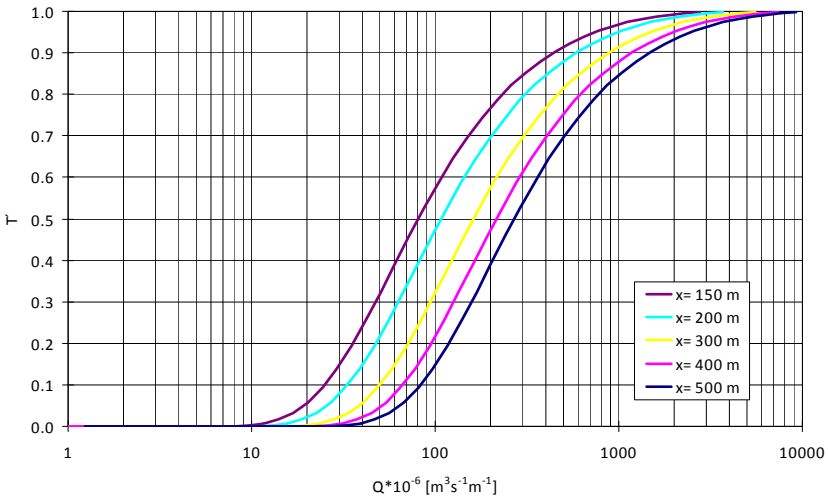
Simplified seepage evaluation using seasonal temperature variation

HydroResearch

- The goal is to find q for a measured T
- Long term measurements
  - Seepage flow depends on the seasonal temperature variation, streaming path length, thermal properties, location, etc)

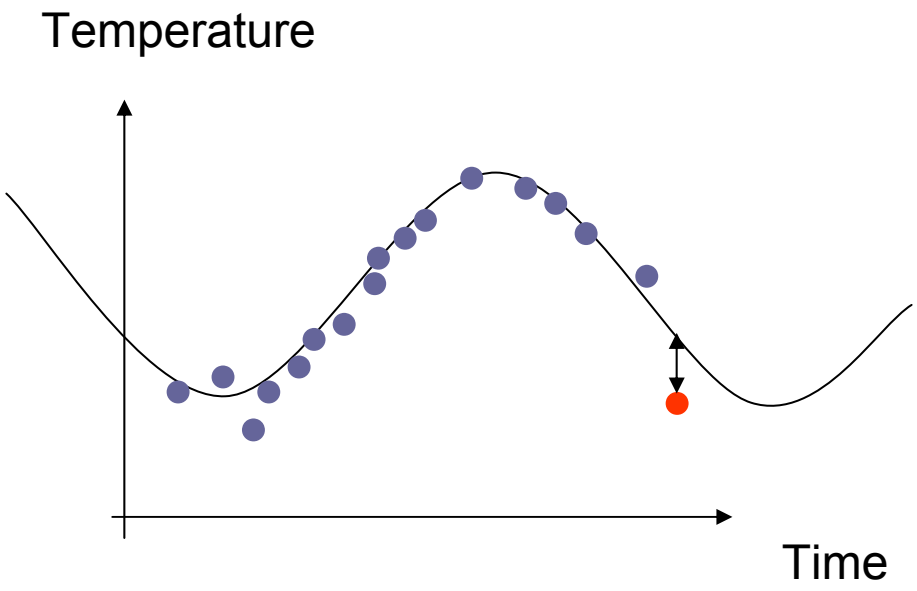
- More advanced methods can be applied, e.g. response curves for each cross-section

$$T' = \frac{T_{max,0} - T_{min,0}}{T_{max,1} - T_{min,1}}$$



Detection of changes

- Detection of seepage increases is essential
- Important complement to seepage evaluation
- Temperature deviations from expected variation
- Temperature deviation from surrounding measuring points



Ledinge dam

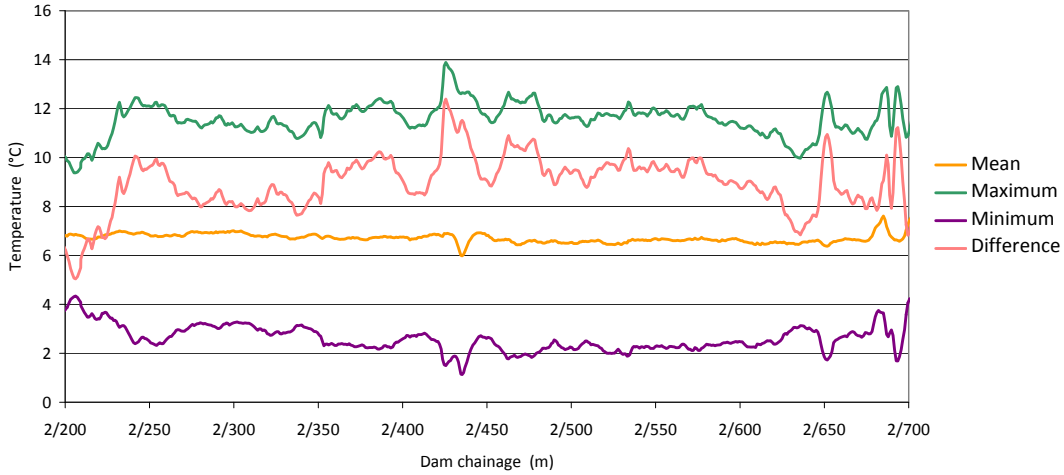
HydroResearch

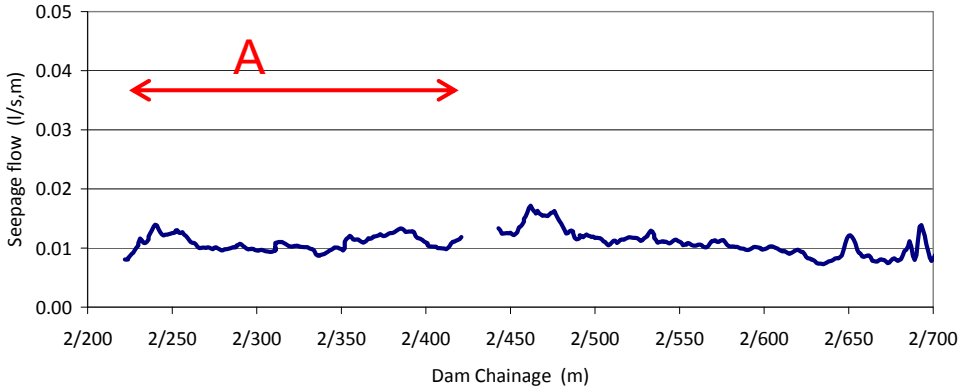
- Dam length 4500 m
- Maximum dam height 12.5 m

- Fibre installations 3600 m in a ditch along the downstream dam toe
- Objective to monitor seepage and seepage flow changes

Application at Ledinge Dam

- Examples of measured temperature and calculated seepage





Information seen in operational centre

Dam chainage | Seepage (l/s) | Alarm

LÄCKAGE I KANAL

SEKTION	FLÖDE l/s	PUNKTER Antal
-0/011 - 0/127	6,39	0
0/147 - 0/310	6,06	0
0/311 - 0/505	4,09	0
0/506 - 0/703	4,71	0
0/704 - 0/904	2,89	0
0/905 - 1/103	3,29	0
1/104 - 1/306	2,71	0
1/307 - 1/485	2,69	0
1/620 - 1/829	2,81	0
1/830 - 2/010	3,33	0
2/011 - 2/221	2,59	0
2/222 - 2/421	2,10	0
2/443 - 2/676	2,63	0
2/795 - 2/938	1,75	0
3/008 - 3/180	1,47	0
3/181 - 3/392	1,82	0
-0/080 - -0/016		0
1/580 - 1/593		0
2/677 - 2/794		0
3/405 - 3/422		0
3/441 - 3/456		0
3/478 - 3/516		0

A

Conclusions

HydroResearch

- Temperature measurements may be a complement to conventional seepage monitoring
- The method is rapidly gaining acceptance
- Examples from field measurements and modelling support the application
- Fibre optics data acquisition techniques well suited for dams.
- Temperature based seepage monitoring system is running at Ledinge dam and similar systems are under implementation for more dams.
  - Seepage calculation is based on seasonal temperature variation. Seepage levels have been stable, typically in the order of a few centilitres per second and meter.
  - Alarm/warning has been set on abnormal temperature changes aiming at early detection of sudden flow increases. After an initial testing period there has been no alarms
- Possibilities to develop the method further both regarding instruments and seepage evaluation.