Geotechnical Considerations when Using Thermal Conduction Heating under Buildings and Sensitive Infrastructure

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Niels Ploug – Krüger, Denmark

What is Subsidence?

- Vertical downward movement of the ground
- Can occur when:
  - Groundwater table declines
  - Shrinking of clays
  - Natural consolidation of low-density soils
  - Dissolution of rock minerals
  - Sink holes
  - Mining
  - Thawing permafrost
  - Thermal remediation???

Land subsidence in California

https://www.usgs.gov/special-topics/water-science-school/science/land-subsidence

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What Sites to Focus On?

What Sites?

- Below buildings
- Below utilities
- Below sensitive infrastructure
- When planning future construction in treatment area
- Generally 20-25% of thermal sites

Florida Site, Clays and Sands

Skuldelev, Denmark, Peat

Monthey, Switzerland, Near Railroad

Richmond, CA, Bay Mud

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Geologies

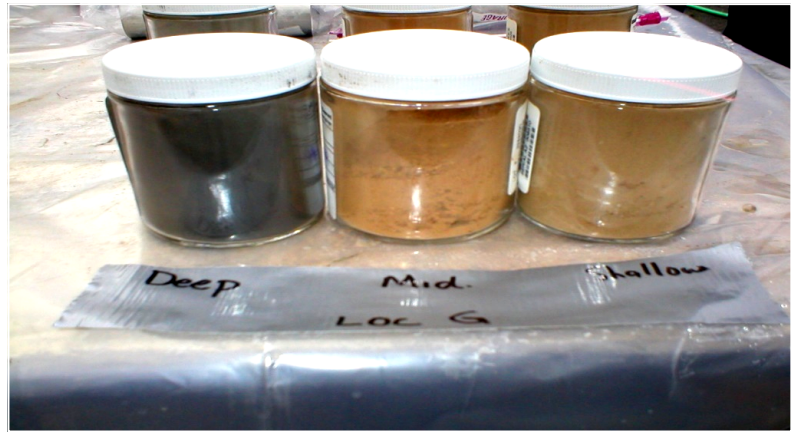
What Geologies Are More Likely to Change?

Less likely to change

- Sedimentary geologies made up of quartz and clay minerals
  - Sands
  - Gravels
  - Silts and clays (types not affected by change in saturation)
- Bedrock

More likely to change

- Organic materials
  - Peat
  - High organic clays, meadow matts
- Clays knowns to swell/shrink with varying water contents.
- Smectite, montmorillonite and bentonite
- Soft limestones, where temps >500°C can impact the minerals



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Factors to Consider

- Building foundations method and quality
- Depth of treatment
- Organic content
- Types of clays
- Target temperature
- Saturated vs. vadose zone
- Pile downdrag forces due to settlement
- Thermal boring locations

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Technologies and Testing

ISTR Methods

SEE

- SEE most often utilized in high permeability material good grain-to-grain contact. Less likely to cause geotechnical changes.

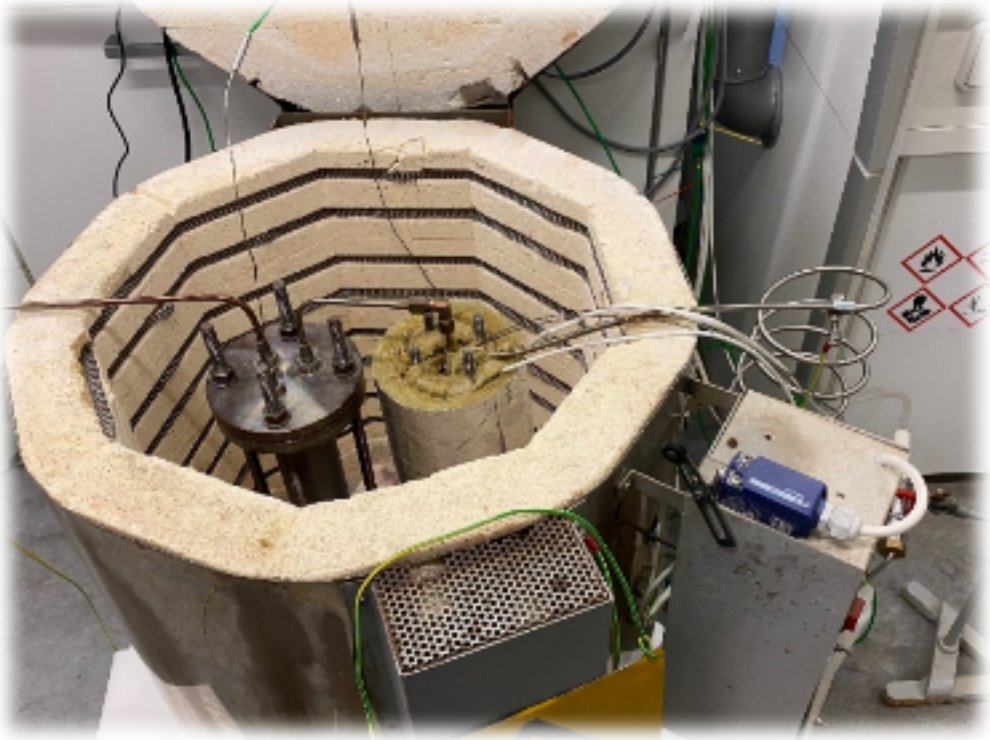
ERH and TCH

- Typically 15-50% of water is removed.
- ERH and TCH dewatering and vacuum extraction can enhance oxidation and shrinkage of organic layers.
- Small volume surrounding TCH borings may dry out in 100°C application. Typically <3%.

Testing options

Usefull tests

• Particle size with hygrometer	ASTM D422
• Moisture Content	ASTM D 2216
• Atterbergs Limits	ASTM D 4318
• Shrinkage limits	ASTM 4943
• Moisture, ash and organic content	ASTM D2974
• Solid specific gravity	ASTM D854
• Modified Protor Compaction Test	ASTM D1557



If any indication of geotechnical risks:
Have geotechnical evaluation performed by a geotechnical company

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Field Monitoring Program

- Baseline photographic and video survey, register of existing cracks
- Precision surveying from multiple points (baseline, during, after)
- TCH heater temperature
- Monitor temperatures specifically near sensitive structures
- Plan circuiting to operate heating system near structures separately

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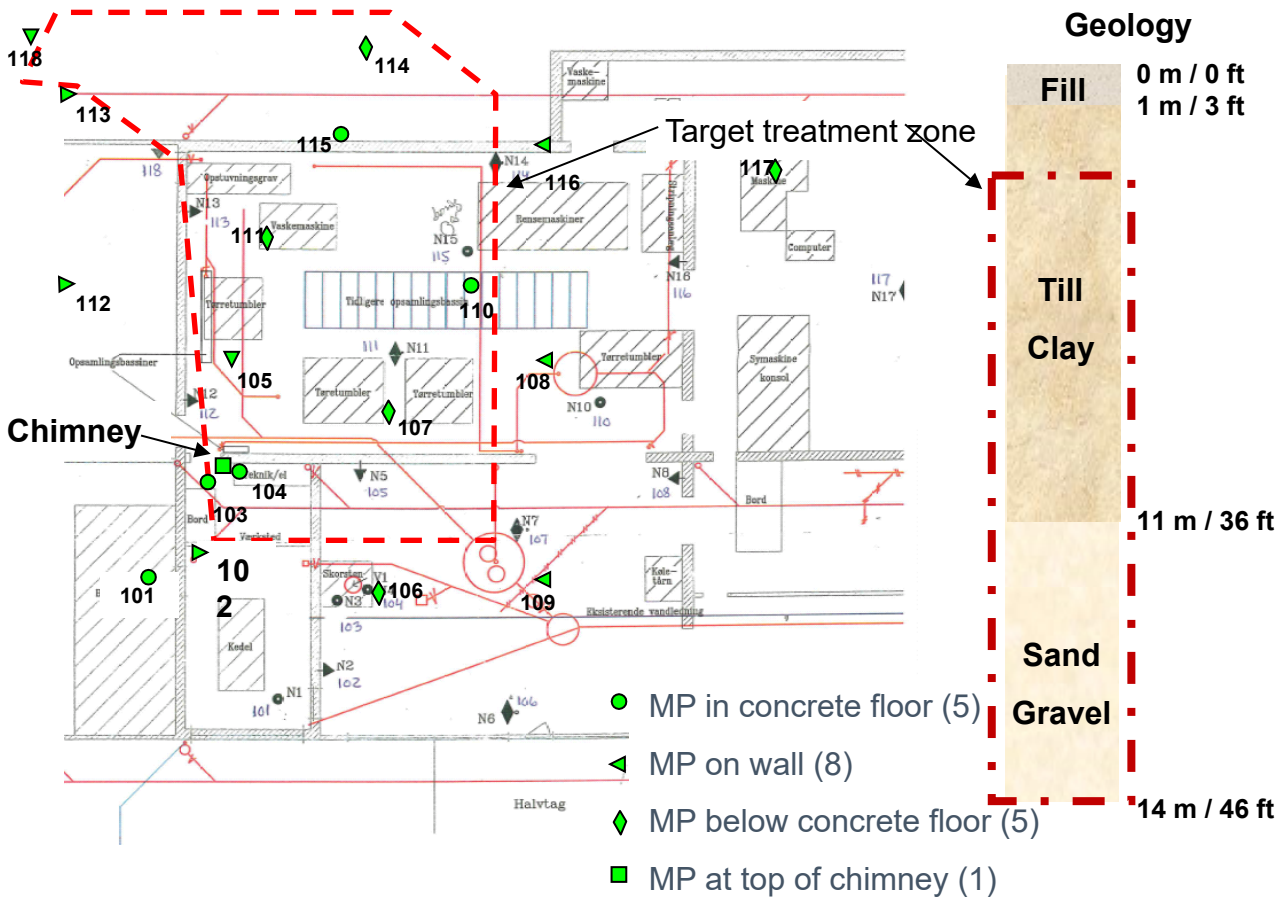
Case – Clays and Sands

Elevation Survey Points

Odense, Denmark

Heaters:	45
Steam:	9
MPE:	3
Area:	222 m^2 (2,390 ft^2)
Volume:	2,220 m^3 (2,903 cy)
Duration:	105 days

- 18 monitoring points defined in building
- 11 monitoring events during treatment



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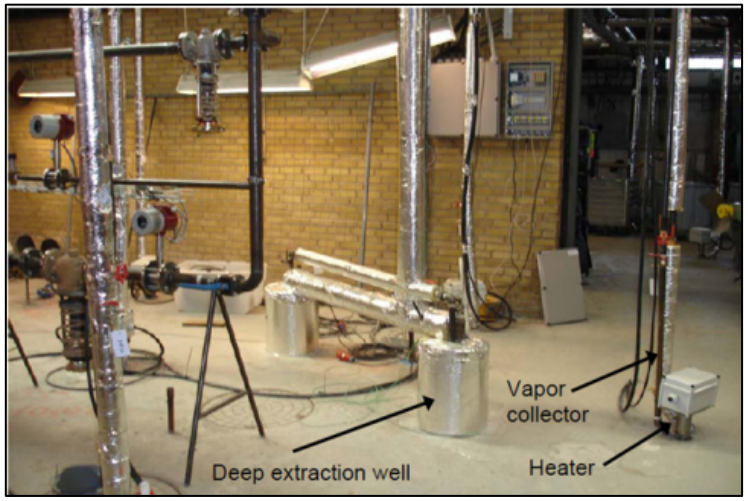
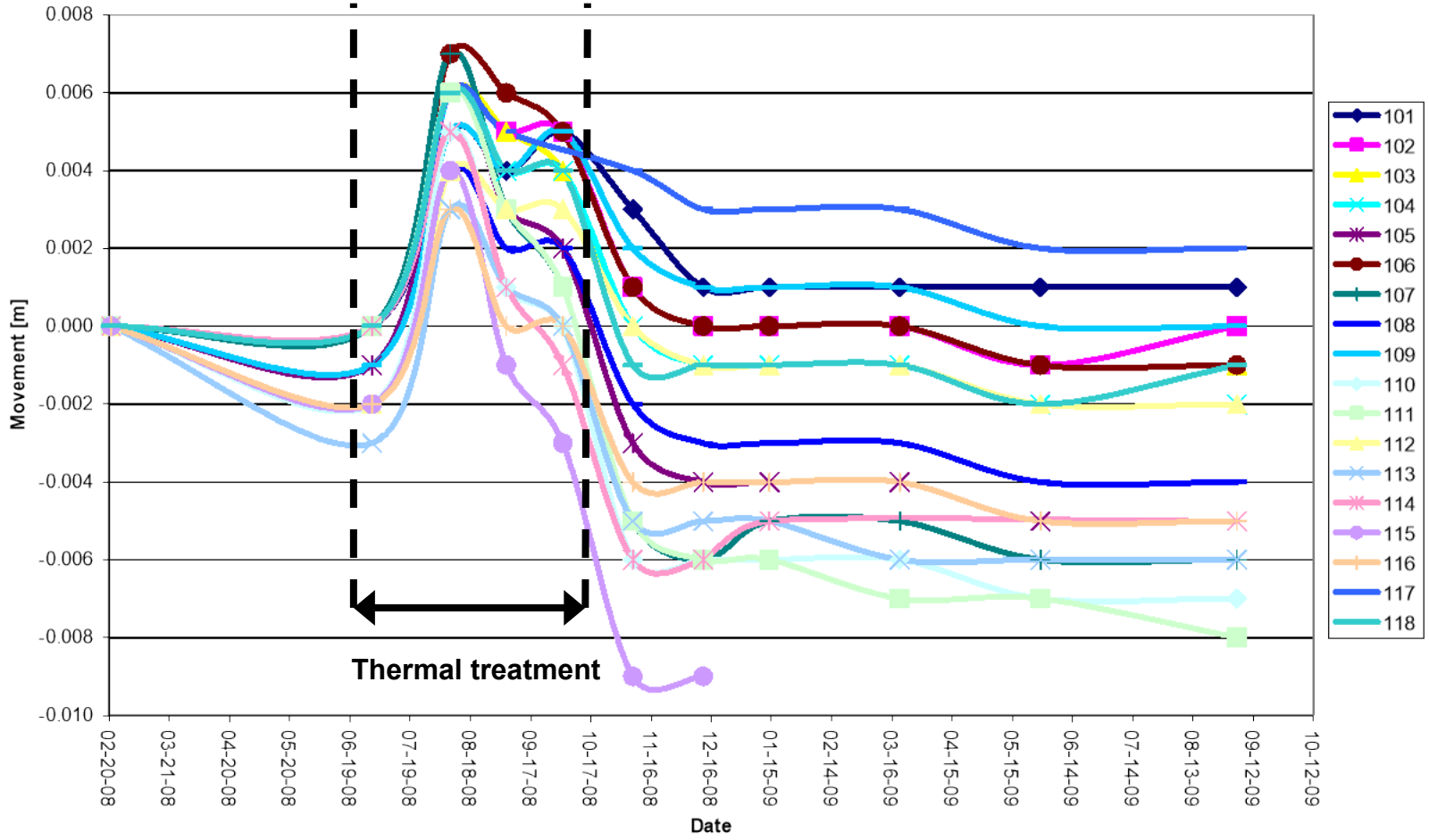
Elevation Survey Results



11 months after treatment

Average movement:	< -3 mm (0.10 inch)
Maximum settlement:	-9 mm (-0.35 inch)
Maximum lift:	2 mm (0.08 inch)



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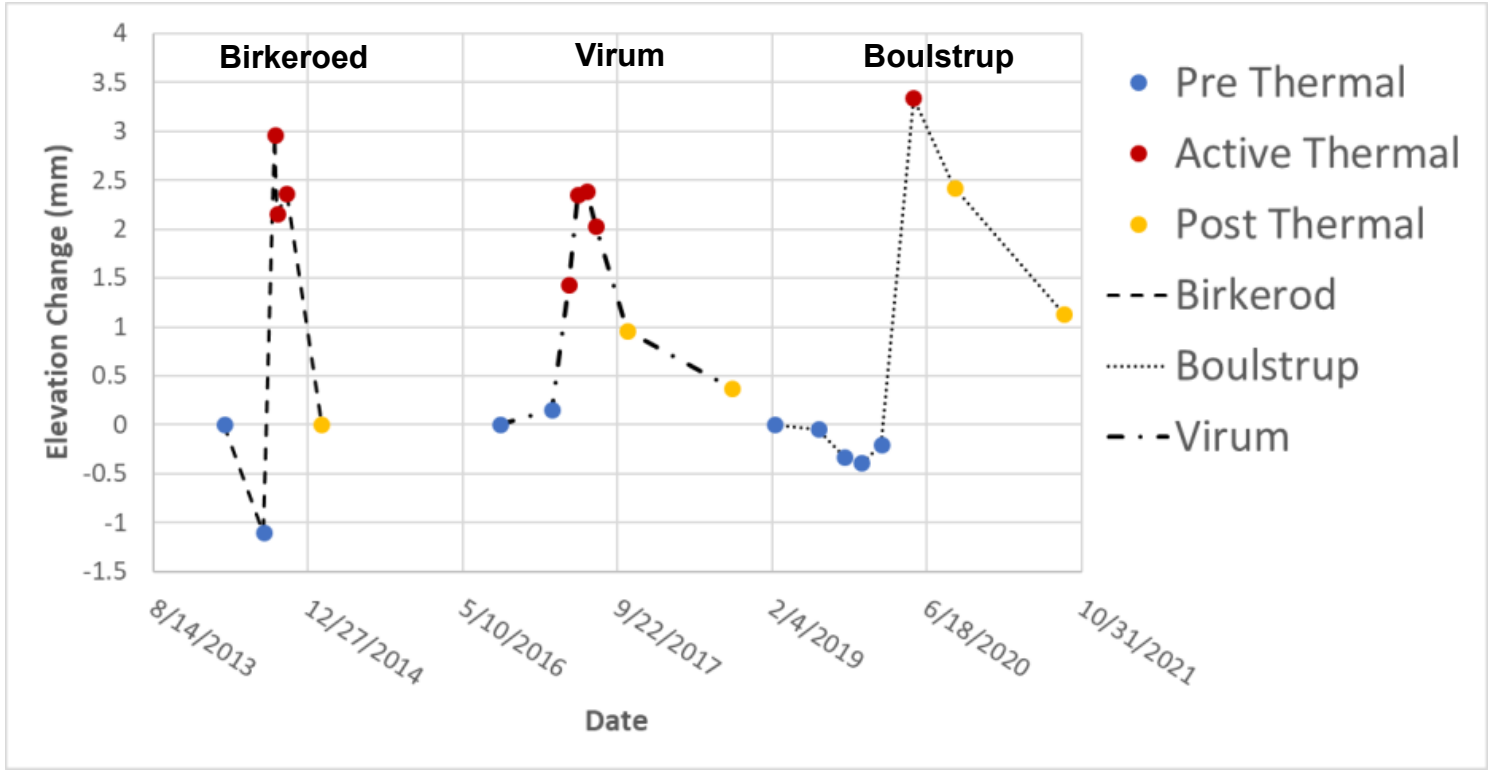
Additional Sites Below Buildings

Site Location	Year completed	Number of points	Number of rounds	COCs and temperature	Geology	During operation [mm (inches)]	Post Operation [mm (inches)]
Birkeroed, Denmark	2015	24	6	CVOCs at 100 °C	Clays	2.5 (0.10)	0.0 (0.00)
Virum, Denmark	2018	88	8	CVOCs at 100 °C	Till clay	2.0 (0.08)	0.7 (0.03)
Boulstrup, Denmark	2020	20	7	CVOCs at 100 °C	Clays and sands	3.3 (0.13)	1.9 (0.07)

Virum, Denmark



-> Generally, no net movement or a small net lift of the buildings were observed

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Case – Peaty Soils

Peat and High Organic Contents

Skuldelev, Denmark

Heaters: 53

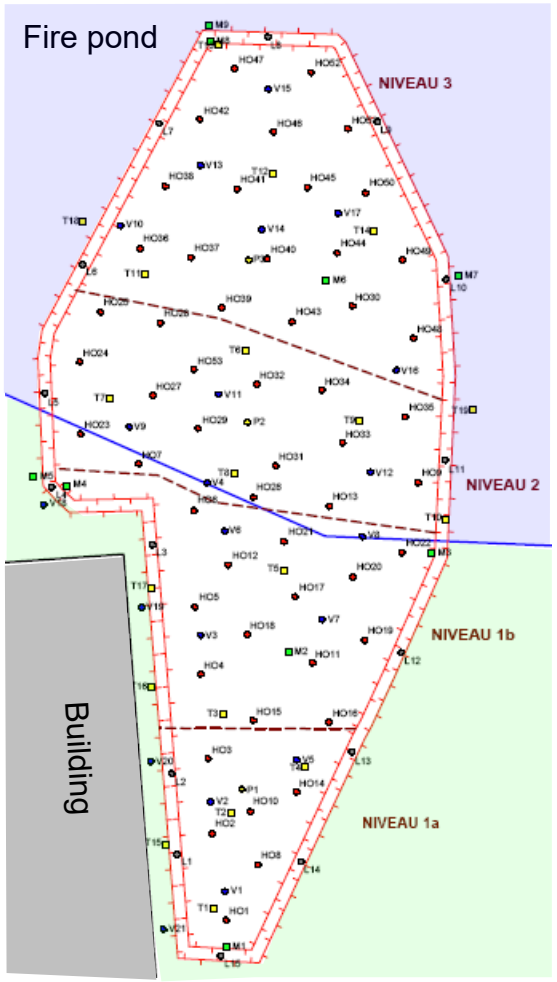
Extraction: 21

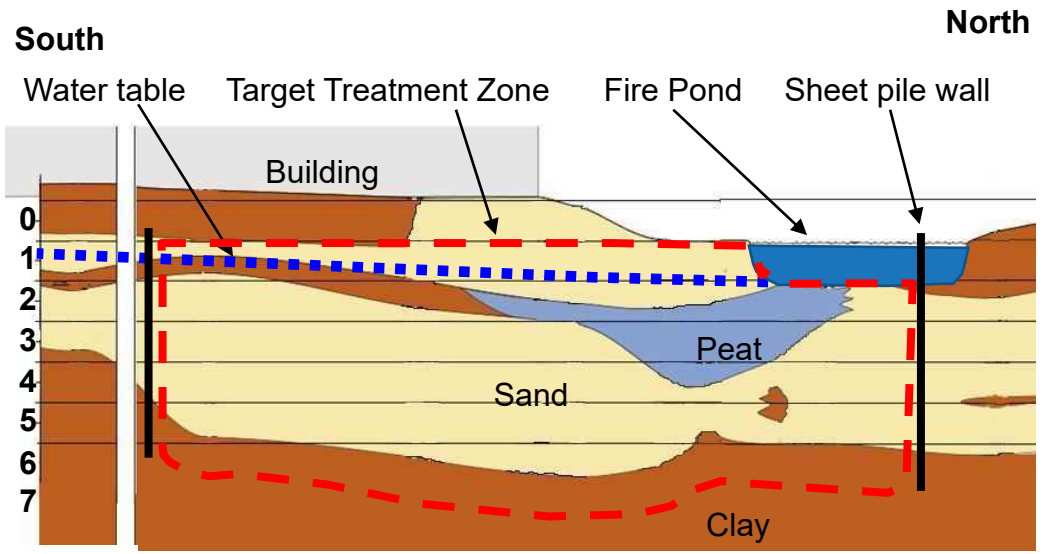
Area: 260 m^2 (2,800 ft^2)

Volume: 1,694 m^3 (2,216 cy)

Duration: 83 days

Mass: 400 kg (900 lbs) of PCE





Site treated to 7 m bgs (23 ft bgs)

Peat layers up to 2.3 m thick (7.5 ft)

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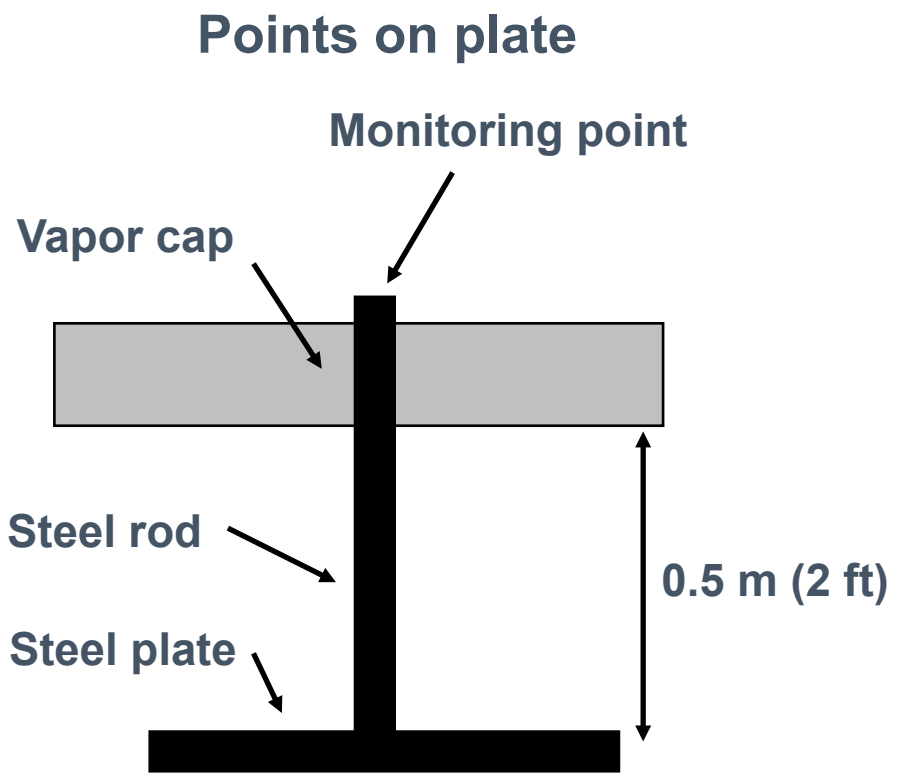
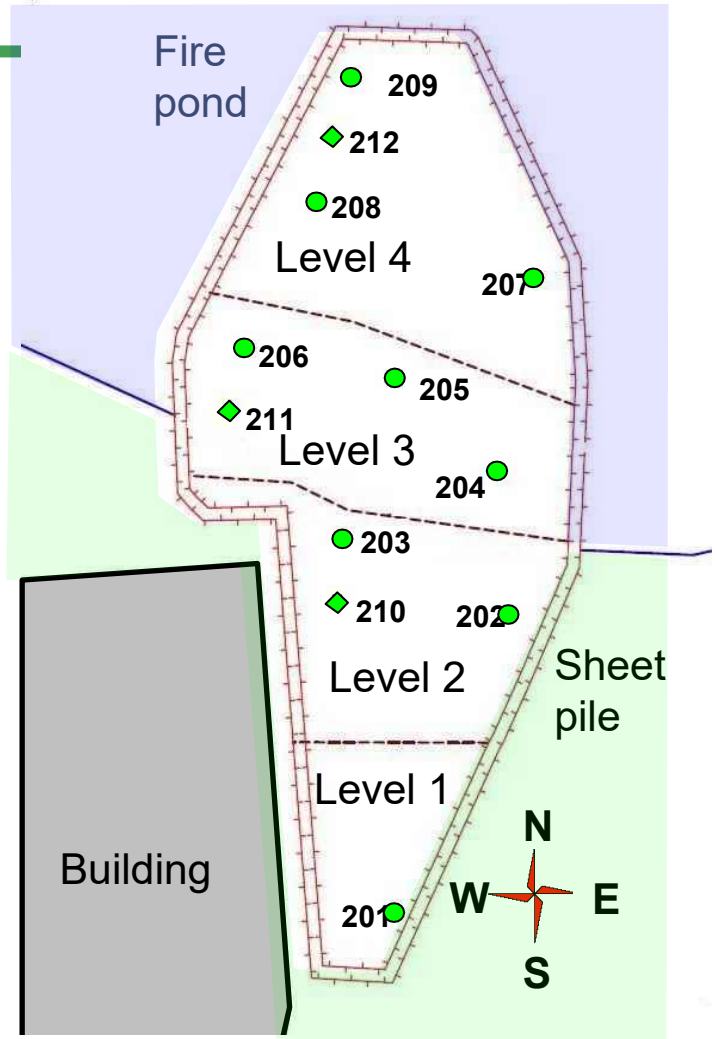
Elevation Survey Points

Movements were observed from 12 monitoring points

- 9 points on surface cover
- 3 points on plate 0.5 m (2 ft) below cover





Monitoring point in vapor cap (9)

Monitoring point below vapor cap (3)

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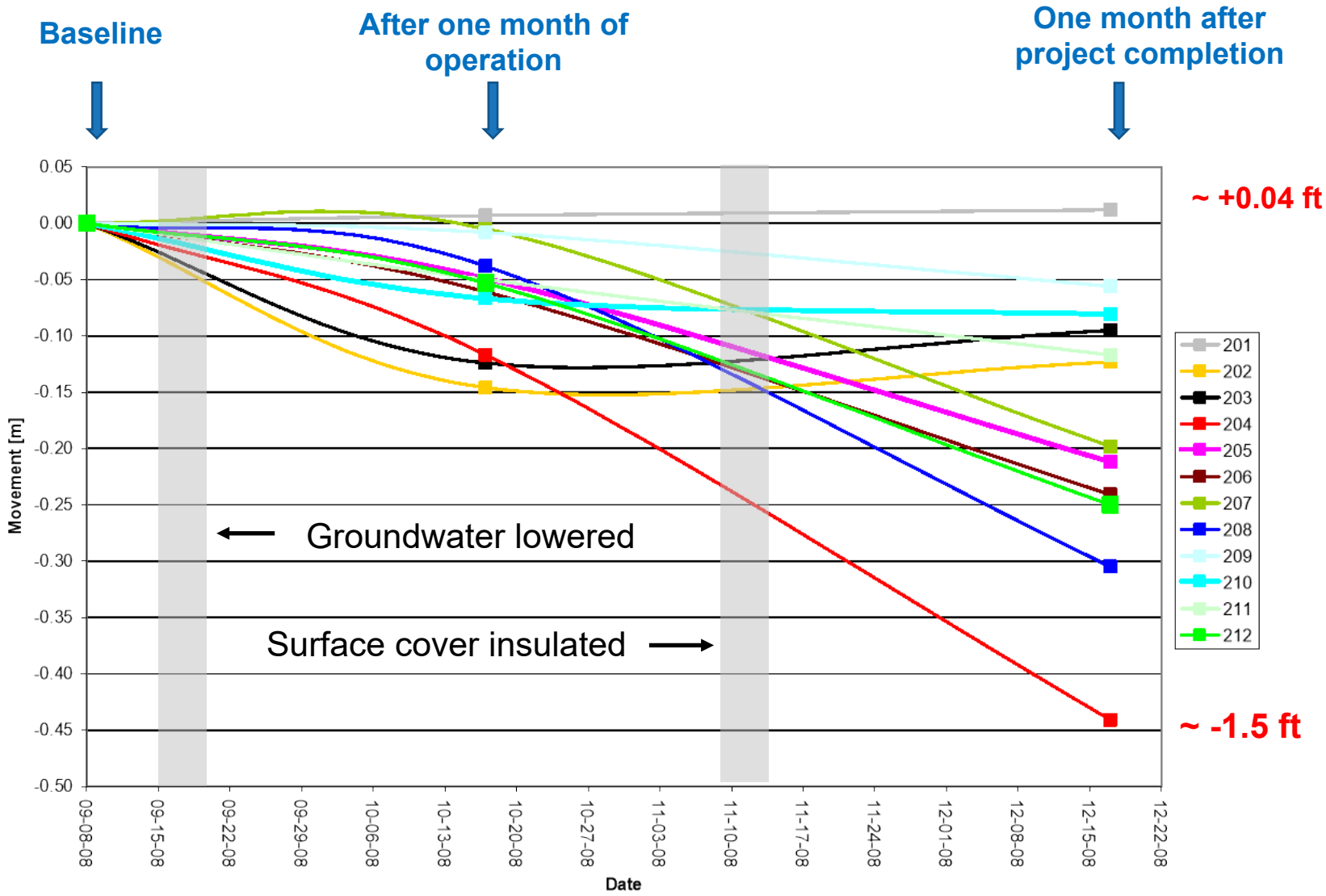
Elevation Survey Results



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Elevation Survey Results

Location	Monitoring points	Max peat layer depth [mm (ft)]	Minimum movement [mm (ft)]	Maximum movement [mm (ft)]	Average movement [mm (ft)]
Level 1	Point 201	No peat	12 (0.04)		12 (0.04)
Level 2	Points 202-203 and 210	600 (2.0)	-81 (-0.27)	-121 (-0.40)	-100 (-0.33)
Level 3	Points 204-206 and 211	2300 (7.5)	-117 (-0.38)	-441 (-1.45)	-253 (-0.83)
Level 4	Points 207-209 and 212	1900 (6.2)	-56 (-0.18)	-305 (-1.00)	-202 (-0.66)

Vertical Elevation Change

In areas **without** the presence of peat:

12 mm (+ 0.04 ft)

In area **with** up to 7.5 ft of peat:

-441 mm (- 1.45 ft)

Before

After

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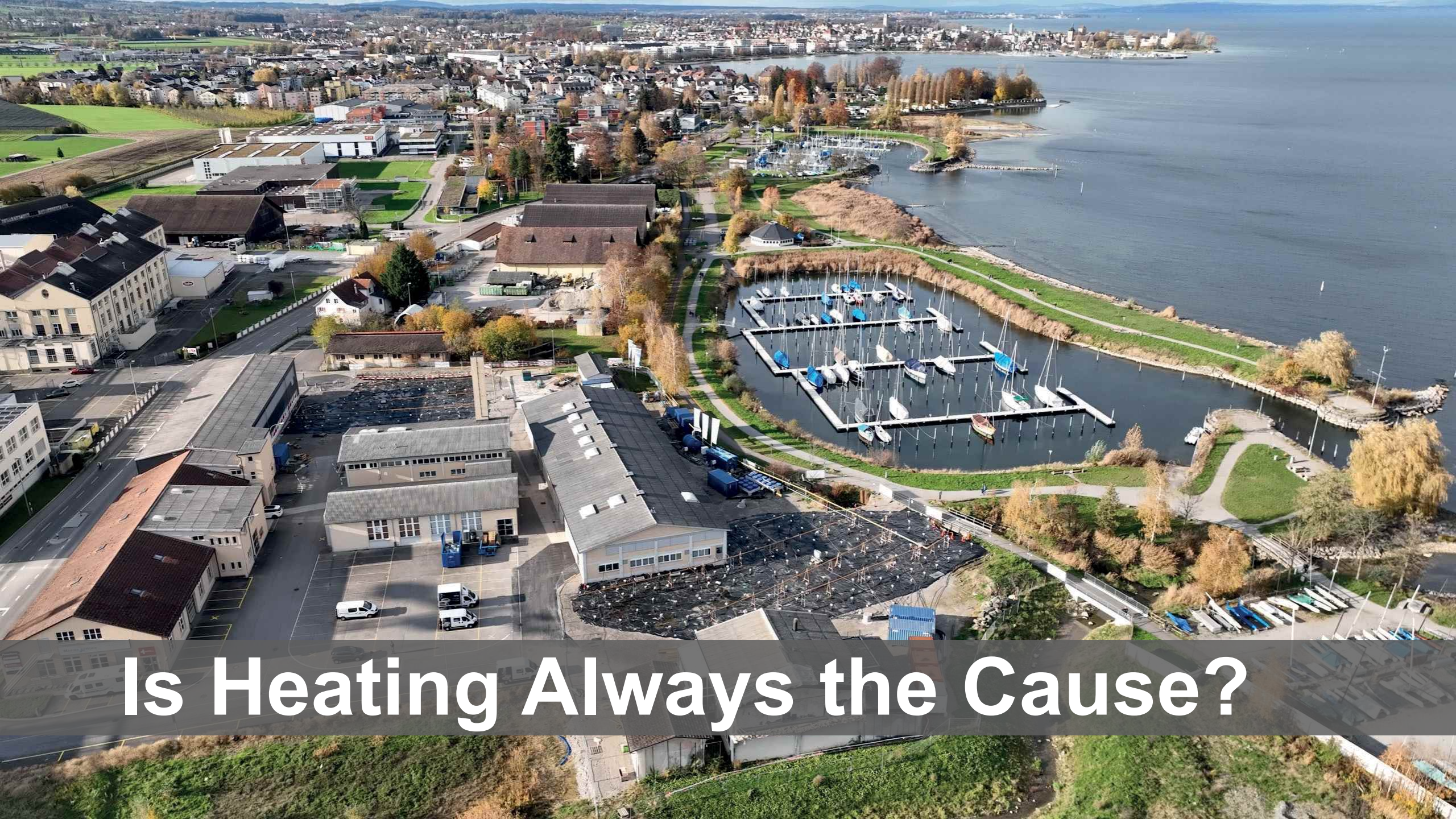
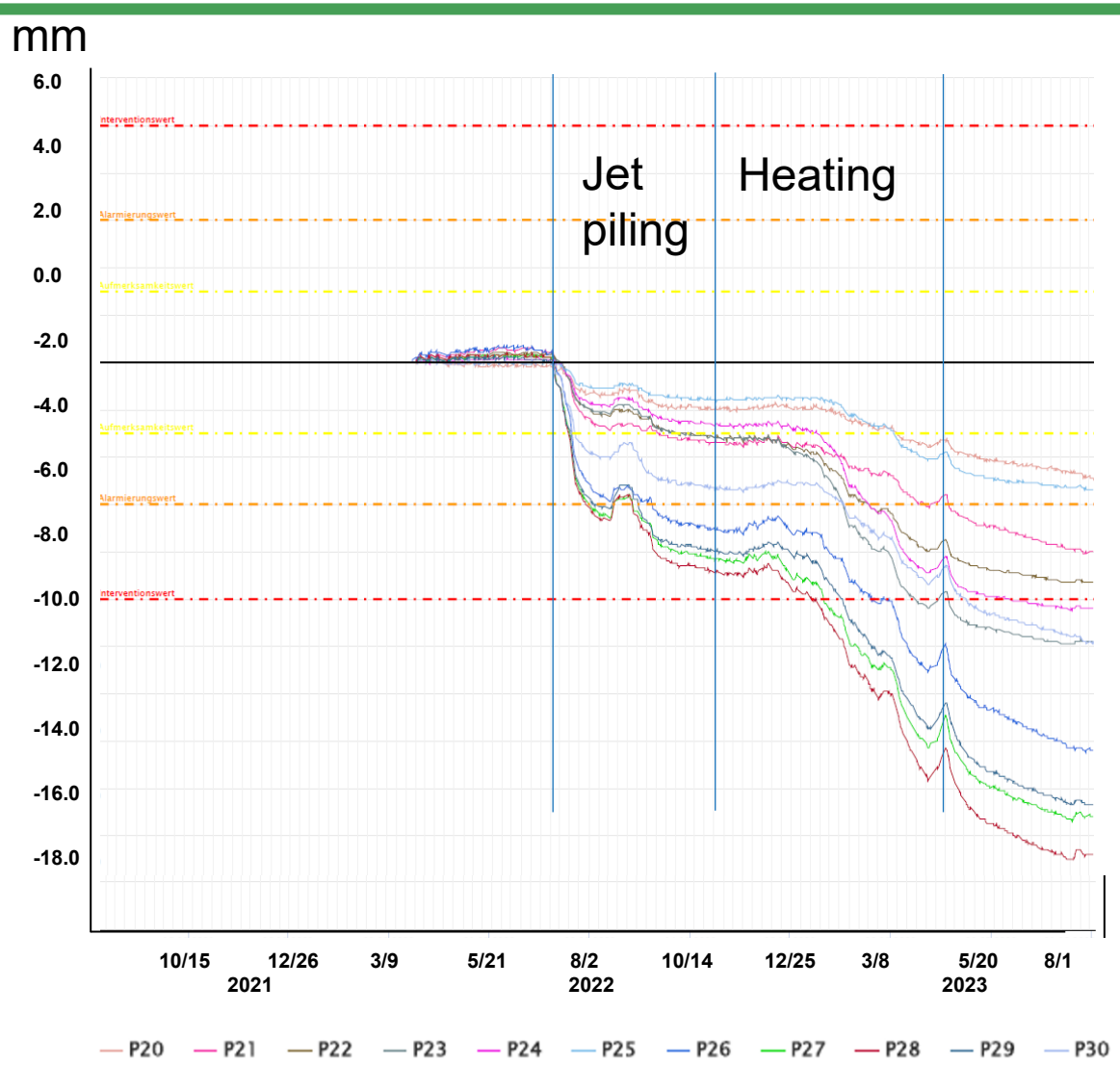


Is Heating Always the Cause?

Marina Horn, Switzerland

- Geology: silt and sands, high organic content from 7 m and down
- Jet piling: 0.5 to 6.5 mm subsidence (0.02 to 0.26 inches)
- Thermal treatment: 2.0 to 9.0 mm subsidence (0.08 to 0.35 inches)
- Initial vertical movements unrelated to heat-up



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Summary

- Clays, sands and silts typically experience limited vertical movement. A net lift has been observed on several sites
- Thick, organic rich layers shrink and lead to subsidence during thermal
- If in doubt – complete a geotechnical assessment

Marl, treatability testing

Organic Clay

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