Mapping, monitoring and modelling preservation conditions of cultural deposits

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Outline

Groundwater and cultural heritage
State of preservation and preservation conditions
How to evaluate decay rates
Example from Bryggen:
  • Unsaturated zone
  • Saturated zone
Groundwater and Cultural heritage

• More archaeological materials are preserved at waterlogged sites, compared to dry sites
• The prehistoric collections at Danish Museums are dominated by artefacts from waterlogged sites…
Decay of organic material

• Oxygen is the biggest threat against preservation of organic material

• Oxygen diffusion through air > 1000 times faster than through still water
Finds recorded on www.dkconline.dk

Listed area.
Drainage and settling

Physical settling

Oxidation of organic matter

\[ \text{O}_2 \]
Soil surface has settled by 2 m in Åmosen...
Collaps and fungal decay of wood
Why do we have a seminar on Ground water and Cultural heritage?

...that’s why!
State of preservation, preservation conditions, and decay rates

State (SOPS 1-5)

"Excellent"

"Lousy"

Past  Present  Future  Time
State of preservation, preservation conditions, and decay rates

State (SOPS 1-5)

"Excellent"

"Lousy"

Past  Present  Future

Time

Slope = decay rate
Depends on the **conditions**
(PresCon 1-5)
State of preservation, preservation conditions, and decay rates

State (SOPS 1-5)

"Excellent"

Good preservation state, but bad preservation conditions

"Lousy"

Past Present Future

Time
State of preservation, preservation conditions, and decay rates

State (SOPS 1-5)

"Excellent"

"Lousy"

Time

Past
Present
Future
State of preservation, preservation conditions, and decay rates

State (SOPS 1-5)

"Excellent"

"Lousy"

Past  Present  Future  Time

Mitigation
Evaluation of decay rates

Three approaches to determine decay rates:
Check the state of preservation of the find every year or decade
Make model experiments in the laboratory or in the field
Measure environmental parameters and use decay model
Example: Bryggen in Bergen

- Thick cultural deposits
- Still ca. 100,000 m³ left
- Focus on organic material

70 m quay front

Up to 10 m thick layers
Mapping the state of preservation

Kilde: Hans de Beer (NGU)
Program: GSI3D
O₂ diffusion in air and in water

O₂ in water flowing through the soil

Other oxidants (Mn- and Fe-oxides, nitrate, sulfate, fermentation)
Unsaturated zone

Data from NGU.
Settling

Data from Multiconsult.
Drainage and settling

Physical settling

Oxidation of organic matter

Water

Air

Organic

Inorganic
Humid, but not waterlogged

"Dry"

Complex situation:
Oxygen transport takes place both in air filled pores (fast) and in water filled pores (slow)
Testpit opened in 2006 and 2010 to describe state of preservation and install monitoring equipment.

Key questions:
What is the state of preservation?
Where and when does the decay take place?
What is the exact correlation between infiltration, water content, oxygen and decay?
How wet is wet enough to stop decay?
Can we predict and document the effect of different remediation actions?
Monitoring equipment used

Water content  Temperature  Redox potential

Oxygen (optical sensors)  Data logger  Wood samples
Wood samples after 4 years in soil

- Decay by fungi
- Decay by bacteria
Raw data from monitoring

Temperature

Temperature (°C)

No data

Box 4.12 3.92 3.68 3.46 3.21 3.06 2.77 2.5 2.31 met.no
Raw data from monitoring

Water content

Moisture (%vol)

Precipitation (mm)

3,92 m asl (sand)
3,60 m asl (backfill)
3,31 m asl (sand)
3,09 m asl (organic)
2,77 m asl (lime)
2,37 m asl (gravel)
2,0 m asl (organic)

Work (table 2)

Precipitation
Raw data from monitoring

Oxygen content

- Excavation
- Mitigation started
- Exchange drain
- 10 channel oxygen logger
- Infiltration started

- 3.92 m asl (sand)
- 3.68 m asl (backfill)
- 3.46 m asl (backfill)
- 3.31 m asl (sand)
- 3.21 m as (backfill)
- 3.06 m asl (organic)
- 2.77 m asl (lime)
- 2.50 m asl (lime)
- 2.31 m asl (gravel)
- 2.00 m asl (organic)
Correlation rain/water/oxygen

Winter 2012

For each layer is determined "how wet is wet enough"
Laboratory studies of decay – or ”how to convert monitoring data to degradation rates”

Oxygen consumption measured for different samples at different temperatures and water contents
Conditions in unsaturated zone

Oxygen is mainly found in upper 1 m, but after prolonged dry periods also down to 2 m

Good correlation to decay seen on modern wood samples

Good correlation between rain, water content, oxygen concentration and degradation

Modelling and documentation of the effect of mitigation is ongoing

Oxygen saturation in soil profile.
Surface: 4.2 m  Ground water 0.2-2 m asl
Monitoring saturated zone:
Focus on groundwater-level, -flow, -chemistry and -processes
Decay of organic material

- Oxygen is the biggest threat against preservation of organic material
- Oxygen diffusion through air > 1000 times faster than through still water
- Water flow may increase the transport
- Other oxidants are less reactive but can be present in large quantities

O₂ diffusion in air and in water

Other oxidants (Mn- and Fe-oxides, nitrate, sulfate, fermentation)

O₂ in water flowing through the soil
More than 40 dipwells placed around Bryggen

Soil samples from installation analysed for state of preservation and chemical properties

Automatic logging of groundwater level and temperature

Sampling of groundwater for chemical analysis
Distribution of sulphate

Sulphate, Autumn 2011 (mmol/L)

- 0.4 til 12.5 (6)
- 0.3 til 0.4 (2)
- 0.2 til 0.3 (3)
- 0.1 til 0.2 (6)
- 0 til 0.1 (21)
Water supplying oxygen (and nitrate)

Most dipwells show stagnant, anoxic conditions, but a few are oxic and more dynamic (MB5)
The effect is studied in the laboratory.
Water supplying oxygen, nitrate and sulphate

Reactivity at unlimited supply of oxidants (note log-scale)
Combination with flow rates and supply (FeFlow)

Map: Hans de Beer, NGU
Modeling of groundwater flow, chemistry, and processes (PHREEQC)

Central Bryggen: Very low decay rate due to anoxic conditions and slow water flow
Mapping of preservation conditions and decay rates

Mapping is used to prioritize mitigation work at Bryggen:

In area A the groundwater level and soil moisture is being increased

In area B the groundwater flow rate is being lowered

In area C the frequency of flooding has been reduced

In area D mitigation is not necessary as the decay rate is extremely low in the deeper layers
Summary

• Groundwater and Cultural Heritage are closely linked
• Quantity, quality and flow of water are all important
• State of preservation and decay rates of archaeological deposits are used to prioritize the need for mitigation
• Decay rates are estimated based on environmental monitoring, study of archaeological material, model experiments, and numerical modelling
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