NIBIO
NORSK INSTITUTT FOR BIOØKONOMI

NIBIO REPORT

Vol. :2, NR.: 84

Environmental monitoring of the archaeological deposits at Øvregaten 19, Bergen

Status report III

OVE BERGERSEN

NIBIO Environment and Natural resources

TITTEL/TITLE

Environmental monitoring of the archaeological deposits at Øvregaten 19, Bergen

Status report III

FORFATTER(E)/AUTHOR(S)

Ove Bergersen

DATO/DATE:	RAPPORT NR./ REPORT NO.:	TILGJENGELIGHET/AVAILABILITY:	PROSJEKT NR./PROJECT NO.:	SAKSNR./ARCHIVE NO.:
15.6 .2016	2(84) 2016	Open	2110811	16/1310

ISBN-NR./ISBN-NO:	ISBN DIGITAL VERSJON/ ISBN DIGITAL VERSION:	ISSN-NR./ISSN-NO:	ANTALL SIDER/ NO. OF PAGES:	ANTALL VEDLEGG/ NO. OF APPENDICES:
978-82-17-01663-2		2464-1162	18	2

OPPDRAGSGIVER/EMPLOYER:	KONTAKTPERSON/CONTACT PERSON:
Riksantikvaren Distriktskontor Vest	Rory Dunlop Norsk institutt for kulturminneforskning (NIKU), Distriktskontor Bergen

STIKKORD/KEYWORDS:	FAGOMRÅDE/FIELD OF WORK:
Redox conditions, preservation, organic remains, degradation, soil moisture & temperature	Environmental Monitoring, Archaeology - Soil chemistry

SUMMARY:

This report contains all the monitoring data collected in the course of three years, from 2013 to May 2016. The deposits had high contents of organic material and high water content before monitoring started. Data showed minimum temperatures close to 0-2°C under winter conditions and maximum temperatures at 14°C during the period from May to September in 2013. In 2014 the minimum temperature increased to 6-7°C and the maximum temperature increased to 17-18°C. Data recorded in 2015 showed minimum temperature 7-9°C and maximum temperature at 16-19°C. The average and median values calculated in 2013 were about 11°C, 13°C in 2014 and 14°C in 2015. High soil moisture was found in all layers, and fluctuated with precipitation. This increased more frequently in 2014 and 2015 under periods with high precipitation. This high precipitation frequency the last two years and infiltration of roof water has decreased the redox potential to more anoxic conditions, which is positive for the preservation of the archaeological remains. The previous status report II, written in 2015, informs that the redox sensor was malfunction because of the great curve drop in 2014 for sensors in layer 2 and 3. In 2015, the redox sensors all show more stable conditions of -400, -311 to -11 mV in layers 2, 3 and 4.

COUNTRY:	Norway
COUNTY:	Hordaland
MUNICIPALITY:	Bergen
STED/LOKALITET:	Øvregaten 19

GODKJENT /APPROVED	PROSJEKTLEDER /PROJECT LEADER
Trond Mæhlum	Ove Bergersen
SENIORFORSKER	SENIORFORSKER

CONTENTS

1 INTRODUCTION 5
1.1 Background 5
1.2 Fault report 5
2. METHODS AND EQUIPMENT 7
2.1 Initial preservation conditions at the monitoring site 7
2.2 Equipment used for monitoring in unsaturated deposits..8
3. RESULTS AND DISCUSSION 10
3.1 Presentation of data.. 10
4. CONCLUSION 16
5. REFERENCES 17
6. APPENDIX 18

1 INTRODUCTION

1.1 Background

NIBIO has been commissioned by the Directorate for Cultural Heritage, through NIKU Bergen, to conduct monitoring of protected archaeological deposits in Øvregaten 19, Bergen. Rory Dunlop is the archaeologist from NIKU and the project leader.

After analysing the preservation condition of soil samples from the site in 2012 (Bergersen, 2013), the monitoring equipment was installed in Jan. 2013, and the monitoring plan will continue for five years. The main goal is to find out what happens when organic archaeological layers are exposed to infiltrated precipitation water in the ground close to a new building.

One of the most important issues is to protect the deposits from decay by keeping them as wet as possible. This can be done by infiltrating rainwater from neighbouring roofs into the ground. The main goals are to keep the deposits' water content high and stable so that the redox potential will remain as low as possible, and to ensure that these soil conditions will prevail for a long time. The monitoring data will show how well these goals have been achieved.

NIBIO's task is to evaluate the preservation conditions and their stability in the various archaeological deposits at Øvregaten 19 (Bergersen, 2013). More information on the site and data from the first year of monitoring are presented in Bergersen (2014, 2015).

This report provides a summary of the status after three years of monitoring, and it is also interesting to compare data from 2013, when the new building was constructed, with data from 2014 and 2015, after its completion.

1.2 Fault report

After three years of monitoring at the site, sensor 4 measuring soil temperature and moisture in the top layer (layer 1) started to show signs of instability and finally broke down. In the report Bergersen (2015), we assumed that the redox sensors 2 and 3 gave unreliable data in the status report II. In 2015 we observed that the redox sensors in layers 2, 3 and 4 showed low redox-potential values. We trust the data since it corresponds with the heavy precipitation period between 2014 and 2015. Table 1 gives a new overview of the sensors and their status in the period 2014 to May 2016. The sensor battery was recharged in late June 2015 (see appendix 2).

Table 1. Overview of functioning status of the sensors in the profile at Øvregaten 19.

Sensors	Layer	Deep m	Deep masl	Running 2013	Stopped 2014	Running 2015	Running 2016
Sensor 1	**4**	0.30	11.8	ok		ok	ok
Redox 1	**4**	0.30	11.8	ok		ok	ok
Sensor 2	**3**	0.25	12.0	ok		ok	ok
Redox 2	**3**	0.25	12.0	ok		ok	ok
Sensor 3	**2**	0.15	12.2	ok		ok	ok
Redox 3	**2**	0.15	12.2	ok		ok	ok
Sensor 4	**1**	0.10	12.3	ok	Feb-14		

2. METHODS AND EQUIPMENT

2.1 Initial preservation conditions at the monitoring site

Evaluations of the degree of preservation for each specific soil sample at the site where the sensors were installed before monitoring are listed and presented in Appendix 1 (Bergersen, 2013). The monitoring site – a soil profile on the southwestern side of a small test-pit (Figure 1) – was 40 cm deep and 40 cm in diameter. Sensors 1 & 2 were installed 25 cm below the surface while sensors 3 and 4 were installed approximately 15 cm below the surface.

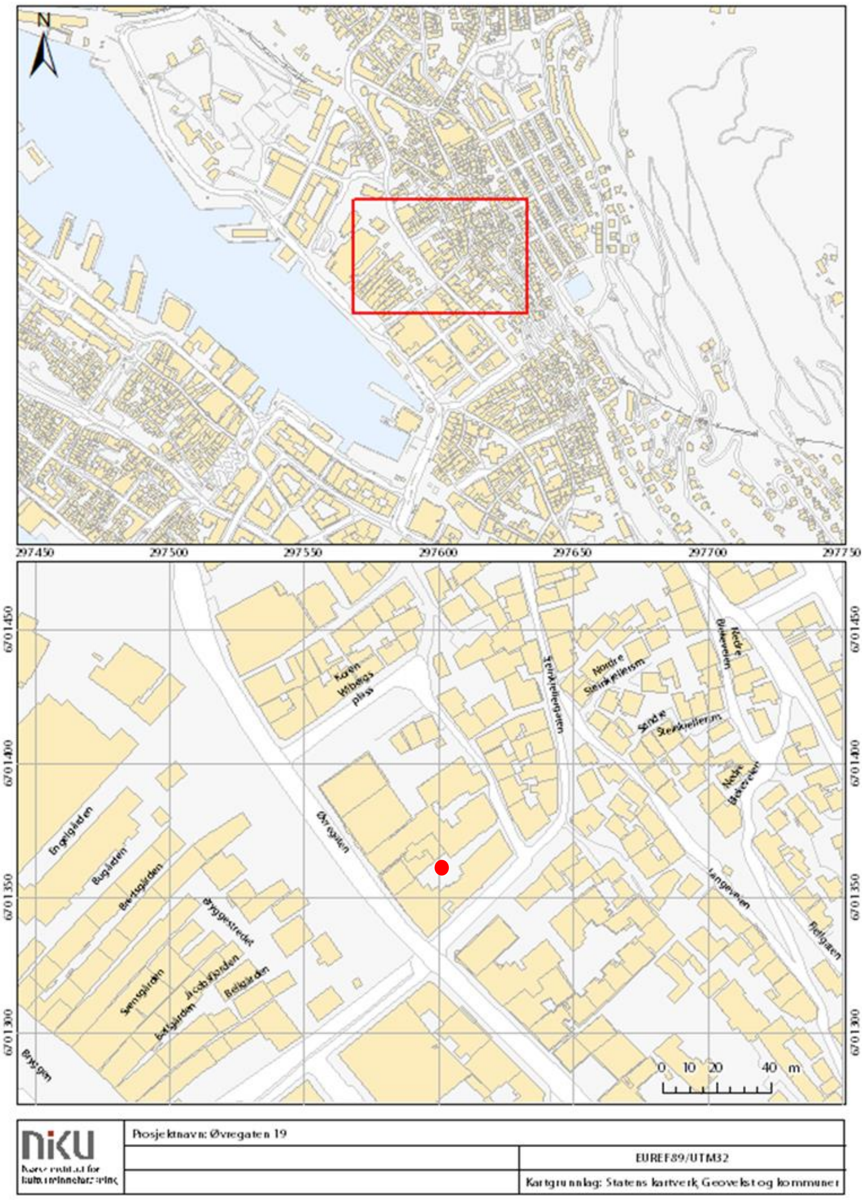


Figure 1. The monitoring site's location (the red dot) marks the approximate position of the installed sensors.

The scales in Appendix 1 follow the same gradient from 1 to 5, 1 (lousy), 2 (poor), 3 (medium), 4 (good), 5 (excellent) (Riksantikvaren & NIKU 2008; Standard Norge 2009). In the chemical analysis, the concentration levels and relationship between reduced and oxidized species dictates a preservation status from the scale of 1 to 5. All redox potential values are recalculated as the 0.1M Ag/AgCl electrode has its own electropotential at + 0.290mV.

2.2 Equipment used for monitoring in unsaturated deposits

The sensors that have been installed are TRIME-PICO 32 from IMKO Modultechnik Gmbh. These sensors can be installed in a heterogeneous and sandy stone-rich type of soil that is often found at archaeological sites. The sensors have universal calibration for mineral soils as standard. All sensors were connected to an automatic standard logger from SEBA Hydrometrie GmbH (http://www.seba-hydrometrie.de/en/applications.html). The data is made accessible on a website via mobile modem technology. The logger and battery were placed in a waterproof box close to the site (Figure 2).

The four sensors for monitoring soil temperature and moisture were placed in different layers as illustrated in Figure 3. In addition, three sensors for monitoring redox potential (Hanna instrument no. HI2930B/5) were installed in three layers with high moisture content. The latter sensors will hopefully provide information about the redox or oxygen content in the soil and groundwater. We hope to observe high moisture stability when rain and roof water enters the deposits close to the new building.

Sensors for soil temperature, moisture and redox potential were installed in the profile in January 2013.

Figure 2. A waterproof cabinet for the automatic logger from SEBA Hydrometrie GmbH was installed on the wall close to the site.

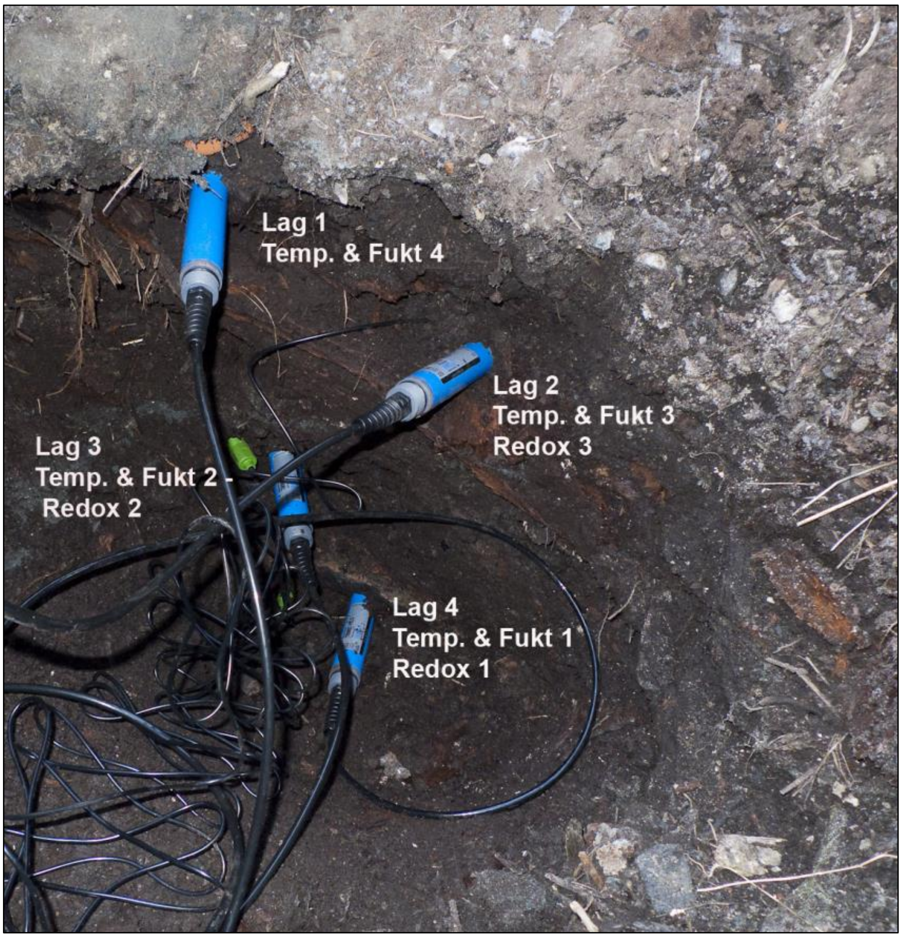


Figure 3. Profile where monitoring sensors were installed in four layers. Blue sensors measure temperature and moisture, and the green sensor measures redox.

- Layer 1 between 12,30 and 12,35 moh. Relatively porous humus/wood chips (Sensor 4)
- Layer 2 between 12,20 and 12,25 moh. Compact humus/wood chips (Sensors 3)
- Layer 3 between 11,95 and 12,00 moh. Relatively porous humus/wood chips (Sensors 2)
- Layer 4 between 11,75 and 11,80 moh. Compact humus/wood chips (Sensors 1)

Quite decayed timber was found under a dark fire stratum between layers 4 and 3 (sensors 1 and 2). A timber stratum, probably a floor, was observed under layers 1 and 2 close to redox, temperature and moisture sensor no. 3 and close to temperature and moisture sensor no. 4 (data from Utne, 2011).

Climate data (mean daily air temperature and precipitation) is obtained from station Bergen at *www.yr.no*

3. RESULTS AND DISCUSSION

3.1 Presentation of data

This report contains all the data collected in the course of three years, from 2013 to 2016. The measured values from the different sensors at the excavation site are presented in figures 4, 5 and 6 and table 1, 2 and 3. Tables 1, 2 and 3 compare min, max, median and average data measured from each year 2013, 2014 and 2015.

The average and median temperature in the profile was estimated to about 10°C in 2013, but increased to 13°C in 2014 and around 14°C in 2015 (Table 1). Why the temperature increase is difficult to explain, but it seems to be connected to the new house build close to the excavation site since the outside temperature and weather report in Bergen has been colder the last two years of monitoring (Figure 4). Figure 4 presents the soil temperature in the different layers and the median curve illustrates increased temperature the last two years.

In this report we have calculated the median* value for the data series from all sensors.

** Median value: In statistics, median is defined as the value of the number that divides a selection into two parts, so that each part has an equal amount of elements. The advantage of using the median value instead of a mean or average value is that the median is stable in the event of extreme observations (which can arise due to e.g. measurement errors).*

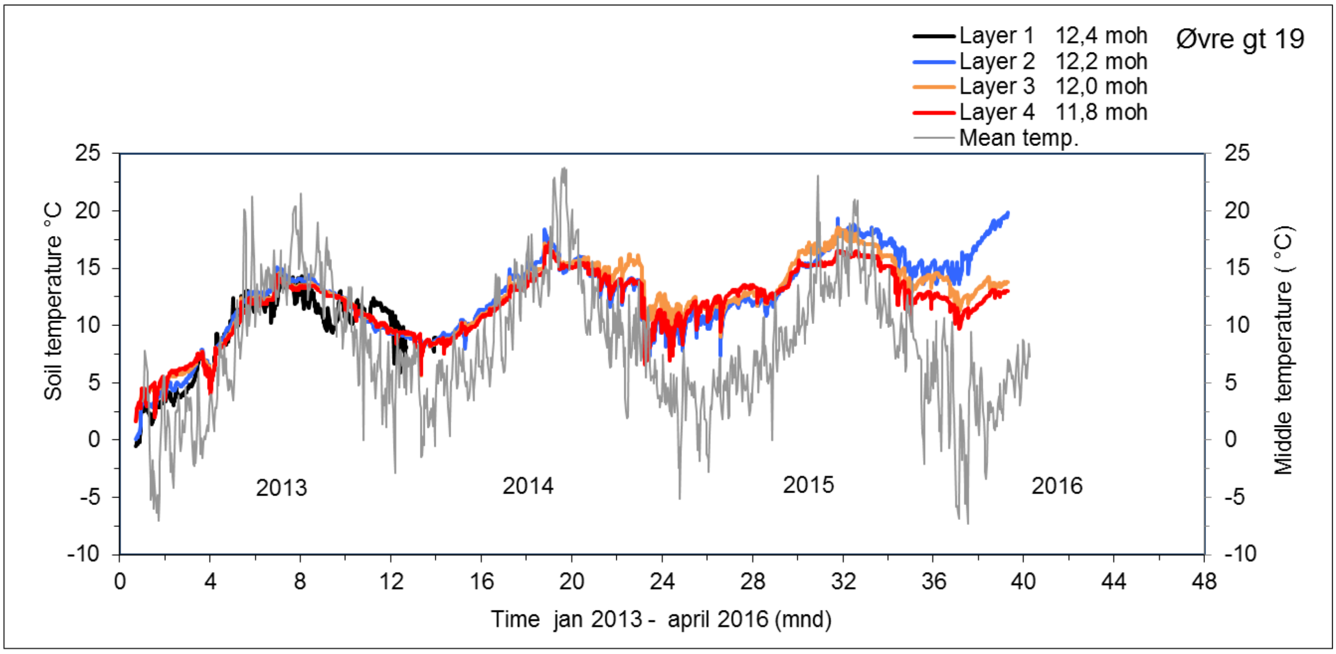
Table 1. Minimum, maximum, median and average values for soil temperature measured in three years. Sensor in layer 1 malfunctioned in 2014. The abbreviation "moh" stands for "metres above sea-level".

2013	Layer 1 12,3 moh °C	Layer 2 12,2 moh °C	Layer 3 12,0 moh °C	Layer 4 11,8 moh °C
Min	-0.5	0.1	1.7	1.6
Max	14.5	15.1	14.6	14.4
Median	10.7	10.7	10.7	10.7
Average	9.2	9.8	9.8	9.7

2014	Layer 1 12,3 moh Malfunctioning	Layer 2 12,2 moh °C	Layer 3 12,0 moh °C	Layer 4 11,8 moh °C
Min		7.2	5.7	5.7
Max		18.4	17.2	17.3
Median		12.9	12.9	12.3
Average		12.3	12.5	12.0

2015	Layer 1 12,3 moh Malfunctioning	Layer 2 12,2 moh °C	Layer 3 12,0 moh °C	Layer 4 11,8 moh °C
Min		7.4	9.0	6.9
Max		19.3	18.5	16.5
Median		14.2	13.7	13.2
Average		14.0	14.2	13.5

Extra high temperature was observed in upper layer 2 beginning of 2016 (Figure 4). Increased temperature from 10 to 14°C in the soil will expand possible degradation of organic material. Research on decay of organic matter from anoxic soil sample in Trondheim (Petersén & Bergersen, 2015) and soil samples from Bryggen in Bergen carried out at the National Museum in Denmark (Hollesen & Matthiesen, 2011) show that increase temperature from 10 to 15 °C, expand the degradation rate of organic matter even more with presence of oxygen.



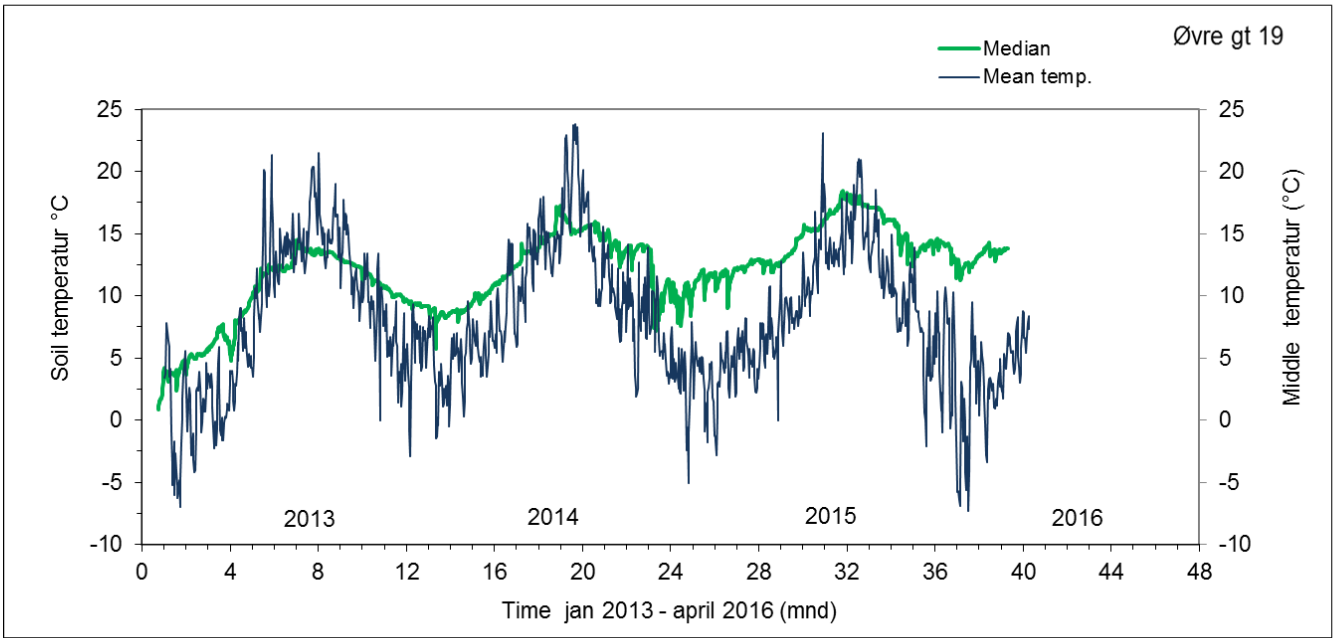


Figure 4. The three years (2013, 2014 & 2015) of monitoring data for soil temperature and estimated median of all temperature sensors at Øvregaten 19 compared with middle temperature per day in center of Trondheim (www.yr.no). The abbreviation "moh" stands for "metres above sea-level".

Table 2. Minimum, maximum, median and average values for soil moisture measured in three years. Sensor in layer 1 malfunctioned in 2014. The abbreviation "moh" stands for "metres above sea-level".

2013	Layer 1 12,3 moh	Layer 2 12,2 moh	Layer 3 12,0 moh	Layer 4 11,8 moh
Fuktighet	%	%	%	%
Min	31	43	39	51
Max	100	100	66	100
Median	79	66	43	69
Average	**77**	**67**	**44**	**70**

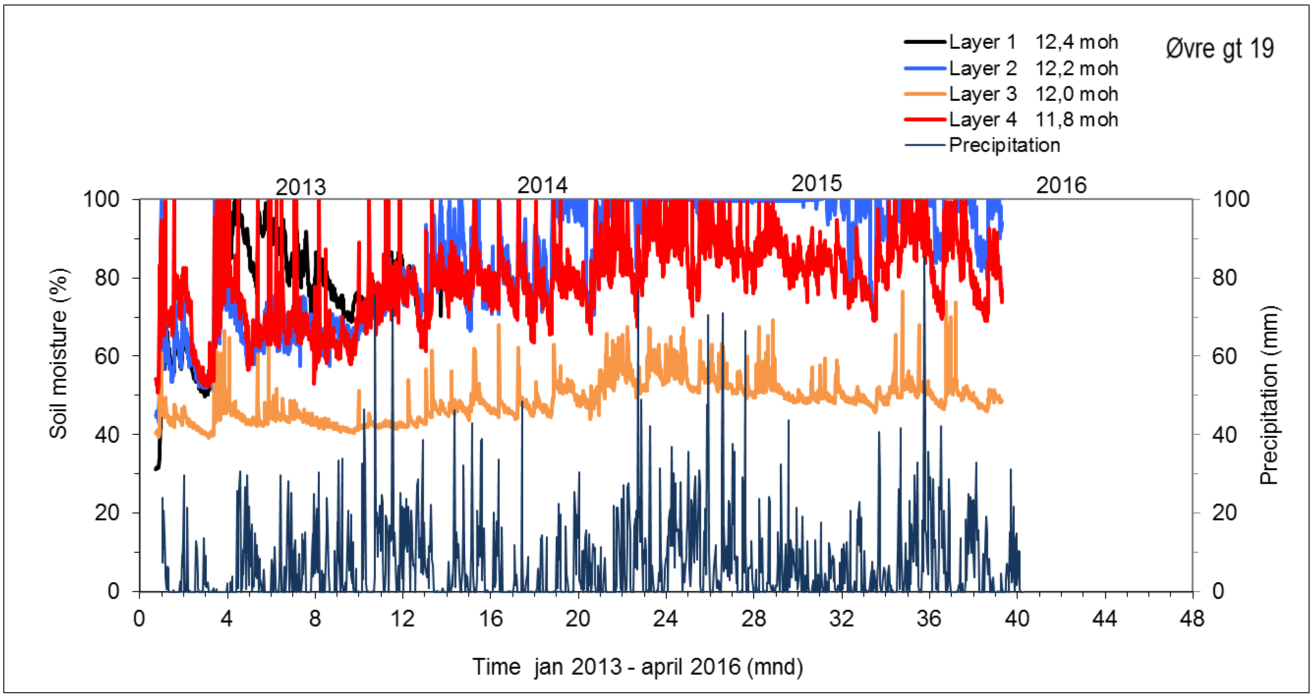
2014	Layer 1 12,3 moh	Layer 2 12,2 moh	Layer 3 12,0 moh	Layer 4 11,8 moh
Fuktighet	Malfunctioning	%	%	%
Min		66	42	61
Max		100	68	100
Median		88	48	80
Average		**88**	**50**	**80**

2015	Layer 1 12,3 moh	Layer 2 12,2 moh	Layer 3 12,0 moh	Layer 4 11,8 moh
	Malfunctioning	°C	°C	°C
Min		69	46	69
Max		100	77	100
Median		100	51	86
Average		99	52	86

The soil moisture or water content still found higher in layers 1, 2 and 4 (80-99 %), compared with the sensor in layer 3 where an average moisture content was measured lower at 50 % in 2015 (Table 2 & Figure 5). The median value was found to be similar to that of the average water content. Precipitation has had a considerable effect on the soil moisture content and during the 2014 and 2015 period, with more frequent precipitation, the calculated median moisture level at the site increased, and fluctuation can still be observed (Figure 5). This more frequent precipitation influenced the redox conditions in the excavation site from 2014 and 2015. This observation also shows that the infiltration of roof water into the site, has made the preservation conditions better the last two years of monitoring with decreased redox potential and anoxic soil.

The lowest redox potential was measured in layer 2 &3 of the pit. The redox potential was also negative in the deepest area (layer 4) shown in table 3 and figure 6. Last year we measured data with variation in redox over a very small vertical distance in the pit of 40cm (Bergersen, O. 2015). We thought that the redox sensor was malfunction because of the great curve drop in 2014 for sensors in layer 2 and 3 (Figure 6). Table 3 show average redox values from 2013 to 2014 range from +411 to +298 mV layer 2. For layer 3 it range from -141 to +167 mV. In 2015, the redox sensors all show more stable conditions of average/median values at (-400, -311 &-11) mV in layer 2, 3 and 4 (Table 3).

All layer of the pit has medium to high contens of organic material which can absorb and store water. That helps to continue low redox and anoxic conditions in the pit in future. Even layer 3 containing less organic matter and moisture contents, show anoxic conditions in 2015 (Figure 6). Hopefully stable anoxic conditions will continue in future.



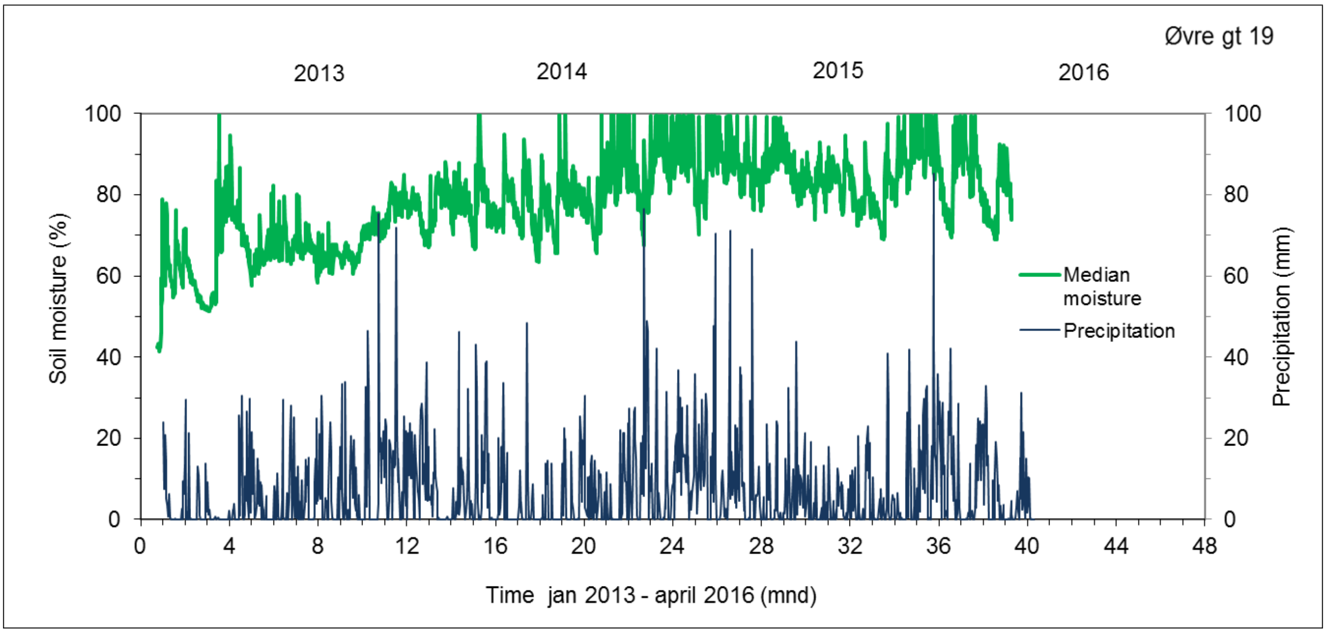


Figure 5. The three years (2013, 2014 & 2015) of monitoring data for soil moisture and estimated median of all soil moisture sensors at Øvregaten 19 compared with middle precipitation per day in center of Bergen (www.yr.no). The abbreviation "moh" stands for "metres above sea-level".

OPPGITT PREC: I mm/uke?

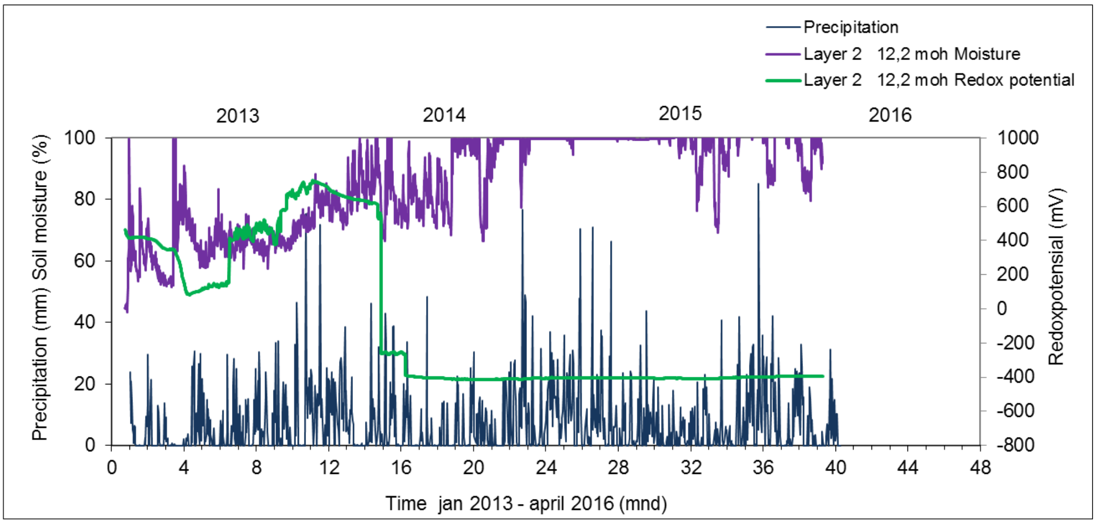
After the last two years of monitoring from April 2014 to April 2016, it can be observed that conditions in the upper part of the digging depression have an increasingly positive impact on the organic cultural layer. The moisture level has increased to approximately 99% and 86% in layers 2 and 4 and 52% in layer 3 after infiltration of high frequent precipitation (Figur5 & 6). The water content in the profile was relatively low compared with the present situation (May 2016) and varied between 50% and 75% (Appendix 1).

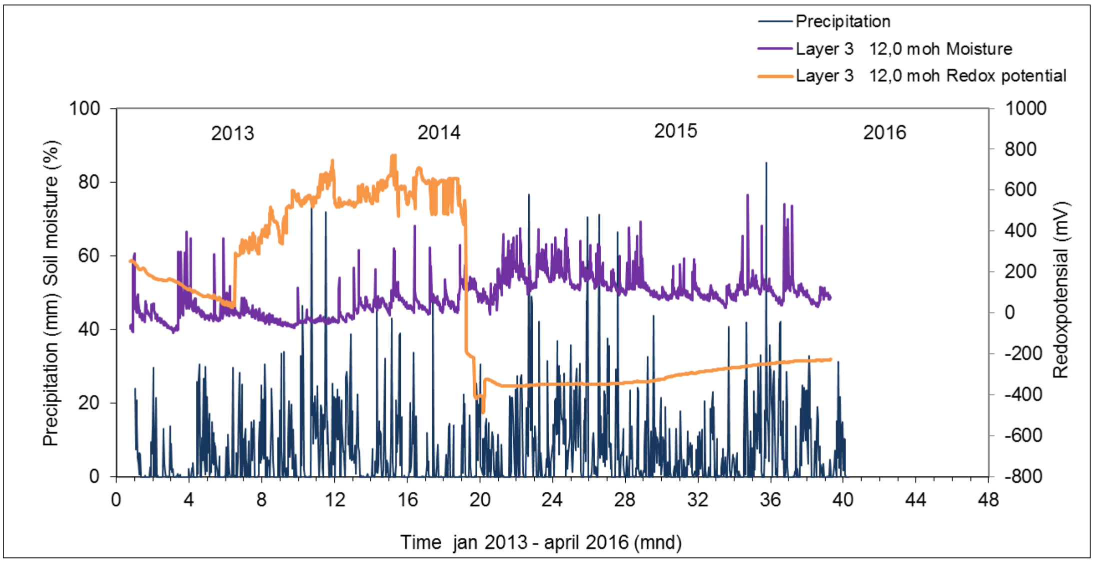
Table 3. Minimum, maximum, median and average values for soil redox potential measured in three years. The abbreviation "moh" stands for "metres above sea-level".

Redox potensial Eh **2013**	**Layer 2 12,2 moh** mV	**Layer 3 12,0 moh** mV	**Layer 4 11,8 moh** mV
Min	82	30	-513
Max	751	747	-14
Median	417	251	-137
Gj.Snitt	411	298	-123

Redox potensial Eh **2014**	**Layer 2 12,2 moh** mV	**Layer 3 12,0 moh** mV	**Layer 4 11,8 moh** mV
Min	-413	-488	-28
Max	699	771	-8
Median	-405	512	-23
Gj.Snitt	-141	167	-20

Redox potensial Eh **2015**	**Layer 2 12,2 moh** mV	**Layer 3 12,0 moh** mV	**Layer 4 11,8 moh** mV
Min	-408	-349	-25
Max	-397	-247	-3
Median	-406	-324	-10
Gj.Snitt	-405	-311	-11





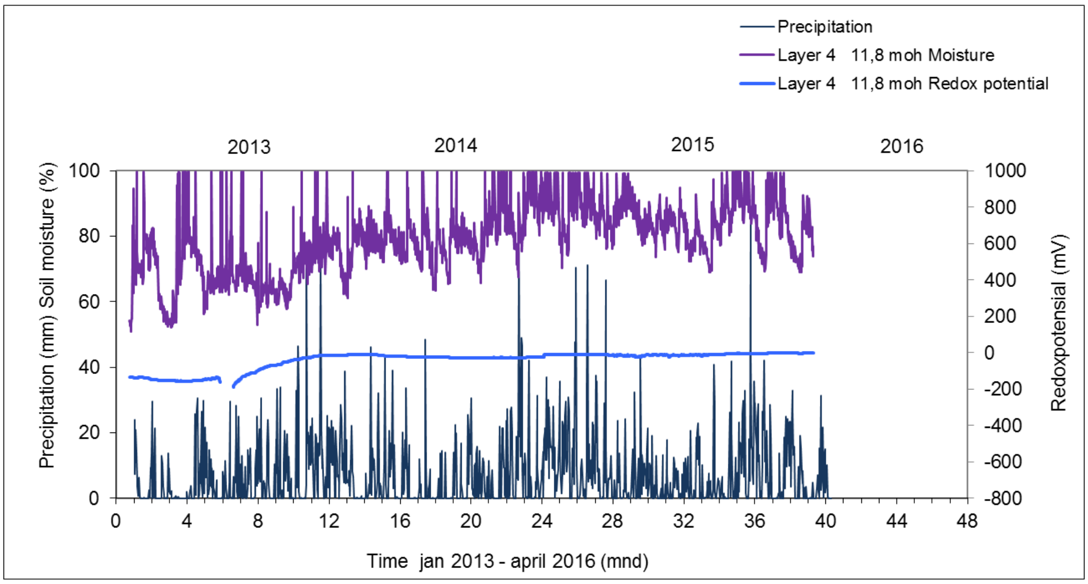


Figure 6. The three years (2013, 2014 & 2015) of monitoring soil moisture compared to redox potential at 12.2 moh, 12.0 moh and 11.8 moh at Øvregaten 19 compared with middle precipitation per day in center of Bergen (www.yr.no). The abbreviation "moh" stands for "metres above sea-level".

4. CONCLUSION

Data collected during 2013 to April 2016 at Øvregaten 19, Bergen, shows that the soil temperature followed the mean air temperatures in 2013 before the new house was finished. The average and median values calculated in 2013 were about 11°C, 13°C in 2014, and 14°C in 2015. In the last two years of monitoring, the calculated average and median temperatures also increased by 4-5°C in the pit even though the middle air temperature looks to have remained unchanged. New building with heated room with windows (see appendix 2) close to the pit is a rational explanation. Increased soil temperature could accelerate possible degradation of organic material in the pit significantly if oxygen is present.

This fluctuation increased more frequently in 2014 and 2015 under periods with high precipitation. This high precipitation frequency the last two years and infiltration of roof water has decreased the redox potential to more anoxic conditions in the upper part of the pit. Half of 2014, 2015 and today all layers show stable reduced anoxic conditions, which is a positive result for the preservation of archaeological remains into the future.

5. REFERENCES

Bergersen, O. 2013. Geochemical analysis of samples after drilling to explain the preservation condition archaeological deposits at Øvregaten 19, Bergen. Bioforsk Report, Vol 8 (53) 2013.

Bergersen, O. 2014. Environmental monitoring of the archaeological deposit at Øvregaten 19, Bergen. Status report I 2014. Bioforsk Report, 9 (42) 2014.

Bergersen, O. 2015. Environmental monitoring of the archaeological deposit at Øvregaten 19, Bergen. Status report II 2015. Bioforsk Report, 10 (35) 2015.

Hollesen, J. & Matthiesen, H. 2011. The effect of temperature on the decomposition of urban layers at Bryggen in Bergen. Nationalmuseet in Denmark. Report no. 11031048. 2011.

Petersen, A. H. & Bergersen, O. 2015. In situ preservation in the unsaturated zone: Results from environmental investigations at the “Schultz gate” case study in the medieval town of Trondheim, Norway. *Conservation and Management of Archaeological Sites* 2015. Vol. 18. Bioforsk & NIKU (in press)

Riksantikvaren & NIKU 2008. *The Monitoring Manual. Procedures and Guidelines for Monitoring, Recording, and Preservation Management of Urban Archaeological Deposits*.

NS 9451:2010. Norwegian Standard 2009: Cultural Property. Requirements on Environmental Monitoring and Investigation of Archaeological Deposits.

Utne, E. 2011. Øvregaten 19, Bergen: Arkeologisk etterundersøkelse, 2010. NIKU Oppdragsrapport 95/2011.

6. APPENDIX

No	Subject
1	Preservation conditions and chemical analysis of the soil samples from the monitoring site (2013)
2	Field report battery shift (2016)

Appendix 1

Information about the preservation conditions in the soil where the monitoring is being conducted at Øvregaten 19 (Bergersen, 2013).

Physical conditions in different soil samples at Øvregaten 19. The abbreviation "moh" stands for "metres above sea-level".

Sample nr	Deep (moh)	Stratum nr NIKU	Organic content & water content	pH & conductivity	Redox conditions	Preservation condition	
Profil with sensores							
Layer 1 2013	**12.30**	3	High org. & water content	Neutral & low	Nitratered. - Oxidizing	Poor	A2
Layer 2 2013	**12.20**	5	Medium org. - & high water content	Weak acid & low	Oxidizing	Poor	A2
Layer 3 2013	**12.00**	8	High org. & water content	Neutral & low	Oxidizing	Poor	A2
Layer 4 2013	**11.80**	10	High org. & water content	Neutral & low	Oxidizing	Poor	A2

Chemical conditions in different soil samples. The abbreviation "moh" stands for "metres above sea-level". DM = dry matter

Sample nr	Deep (moh)	Stratum nr Niku	Nitrate - N (mg/kg DM)	Ammonium-N (mg/kg DM)	Sulphate (mg/kg DM)	Sulphide (mg/kg DM)	Iron (II) (mg/kg DM)	Iron (III) (mg/kg DM)	Percentage of Iron (II)
Profil with sensores									
Layer 1 2013	**12.30**	3	**3.32**	**12**	**3**	**49**	**72**	**237**	**23%**
Layer 2 2013	**12.20**	5	**< 0,1**	**16**	**16**	**44**	**135**	**223**	**38%**
Layer 3 2013	**12.00**	8	**< 0,1**	**8**	**46**	**53**	**58**	**297**	**16%**
Layer 4 2013	**11.80**	10	**< 0,1**	**13**	**101**	**64**	**84**	**574**	**13%**

< 0,1 = Under detection limit

Chemical and physical conditions in different soil samples. The abbreviation "moh" stands for "metres above sea-level". DM = dry matter

Sample nr	Deep (moh)	Stratum nr NIKU	Dry matter %	Organic matter %	Water content %	pH	Conductivity $uScm^{-1}$
Profil with sensores							
Layer 1 2013	**12.30**	3	**35**	**32**	**65**	**7.3**	**614**
Layer 2 2013	**12.20**	5	**40**	**30**	**60**	**6.3**	**1840**
Layer 3 2013	**12.00**	8	**43**	**23**	**57**	**7.2**	**254**
Layer 4 2013	**11.80**	10	**25**	**60**	**75**	**6.9**	**488**

Low organic matter 10-20%
Medium organic matter 30-40%
High organic matter 50-60%

Low water content10-20%
Medium water content 30-40%
High water content 50-60%

Comparing the archaeological preservation state with chemical preservation conditions for organic and inorganic materials, and redox condition. The abbreviation "moh" stands for "metres above sea-level".

Profile monitoring area

Deep (moh)	Sample stratum	Preservation Acheologic *	Preservation Organic material	Preservation Inorganic material	Redoks condition *
12.30	1	B2- B3	Poor	Medium	B2
12.20	2	B2- B3	Poor	Poor	B2
12.00	3	B2- B3	Poor	Medium	B2
11.80	4	B3	Poor	Medium	B2

Lousy to poor	Oxidizing condition
Medium	Reduced condition
Good to excellent	* SOPS :

Status after Norsk Standard NS 9451:2009

Appendix 2

Technical report - sensor maintenance at Øvregaten 19, Bergen

Sensors and logger were checked in June 2015.

The logger battery was recharged in late June 2015.

The battery capacity for the monitoring equipment is still satisfactory and is expected to work well for the rest of the monitoring period.

Øistein Johansen

Senior instrumentation engineer

NIBIO instrumentation department, Ås

Location of Cabinet with the logger at Øvregate 19 (June 2016)

NIBIO
NORSK INSTITUTT FOR
BIOØKONOMI

Norsk institutt for bioøkonomi (NIBIO) ble opprettet 1. juli 2015 som en fusjon av Bioforsk, Norsk institutt for landbruksøkonomisk forskning (NILF) og Norsk institutt for skog og landskap.

Bioøkonomi baserer seg på utnyttelse og forvaltning av biologiske ressurser fra jord og hav, fremfor en fossil økonomi som er basert på kull, olje og gass. NIBIO skal være nasjonalt ledende for utvikling av kunnskap om bioøkonomi.

Gjennom forskning og kunnskapsproduksjon skal instituttet bidra til matsikkerhet, bærekraftig ressursforvaltning, innovasjon og verdiskaping innenfor verdikjedene for mat, skog og andre biobaserte næringer. Instituttet skal levere forskning, forvaltningsstøtte og kunnskap til anvendelse i nasjonal beredskap, forvaltning, næringsliv og samfunnet for øvrig.

NIBIO er eid av Landbruks- og matdepartementet som et forvaltningsorgan med særskilte fullmakter og eget styre. Hovedkontoret er på Ås. Instituttet har flere regionale enheter og et avdelingskontor i Oslo.

nibio.no