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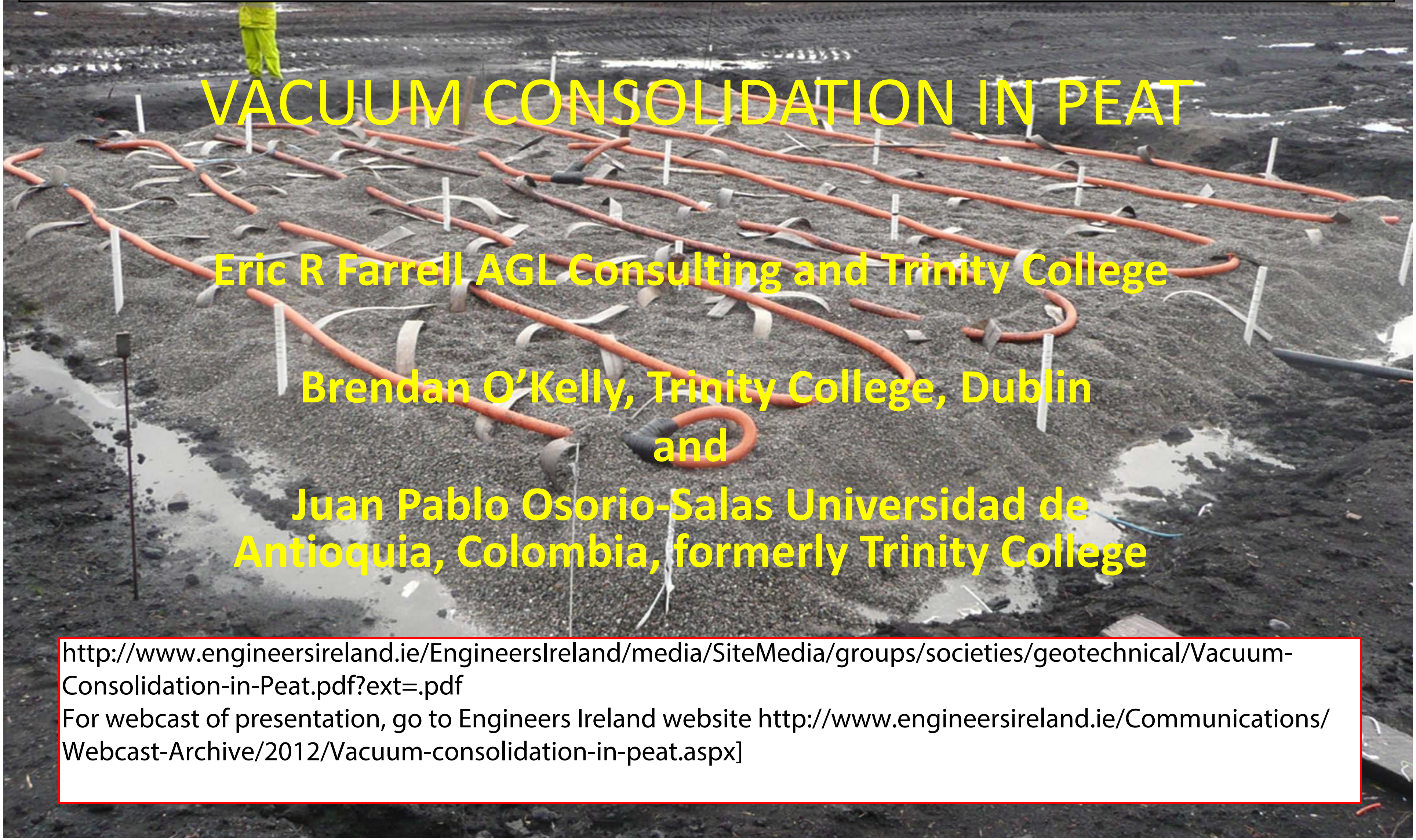

VACUUM CONSOLIDATION IN PEAT

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and
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http://www.engineersireland.ie/EngineersIreland/media/SiteMedia/groups/societies/geotechnical/Vacuum-Consolidation-in-Peat.pdf?ext=.pdf
For webcast of presentation, go to Engineers Ireland website http://www.engineersireland.ie/Communications/Webcast-Archive/2012/Vacuum-consolidation-in-peat.aspx]

Structure of Presentation

- Background
- Principles of vacuum consolidation
- Current practical applications
- TCD/NRA test site
  - Geotechnical/geology/hydrogeology of test site
  - Construction of test area
  - Instrumentation
  - Benchmark ground movement readings.
- Results from vacuum consolidation test
  - Vacuum achieved
  - Settlement versus time
  - Practical difficulties
- Numerical modelling
  - Laboratory parameters
  - Soil model
  - Comparison of field performance with predictions
- Conclusions

PRINCIPLES OF VACUUM CONSOLIDATION

- Vacuum consolidation is a construction method used to accelerate ground settlement by reducing the air pressure at the ground surface.

- Normally atmospheric pressure (p_{atm}) is taken as the base line when computing $\sigma' = \sigma - u$.

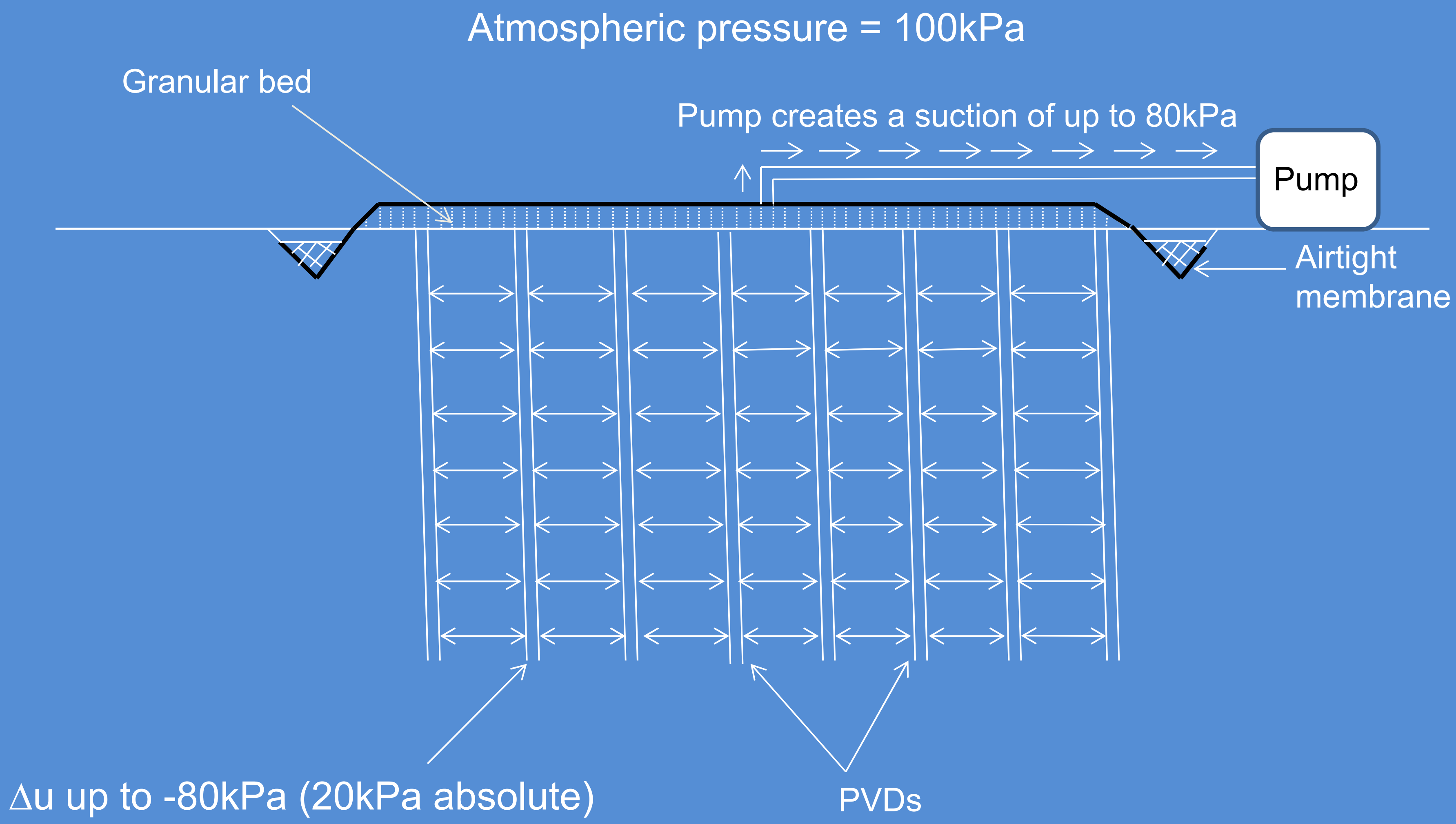
- p_{atm} is about 100kPa, and the pwp can reduced below atmospheric using vacuum pumps. This increases the effective stress without generally increasing the shear stresses.

- Vacuum consolidation was originally proposed by Kjellman in Sweden in the 1950s.

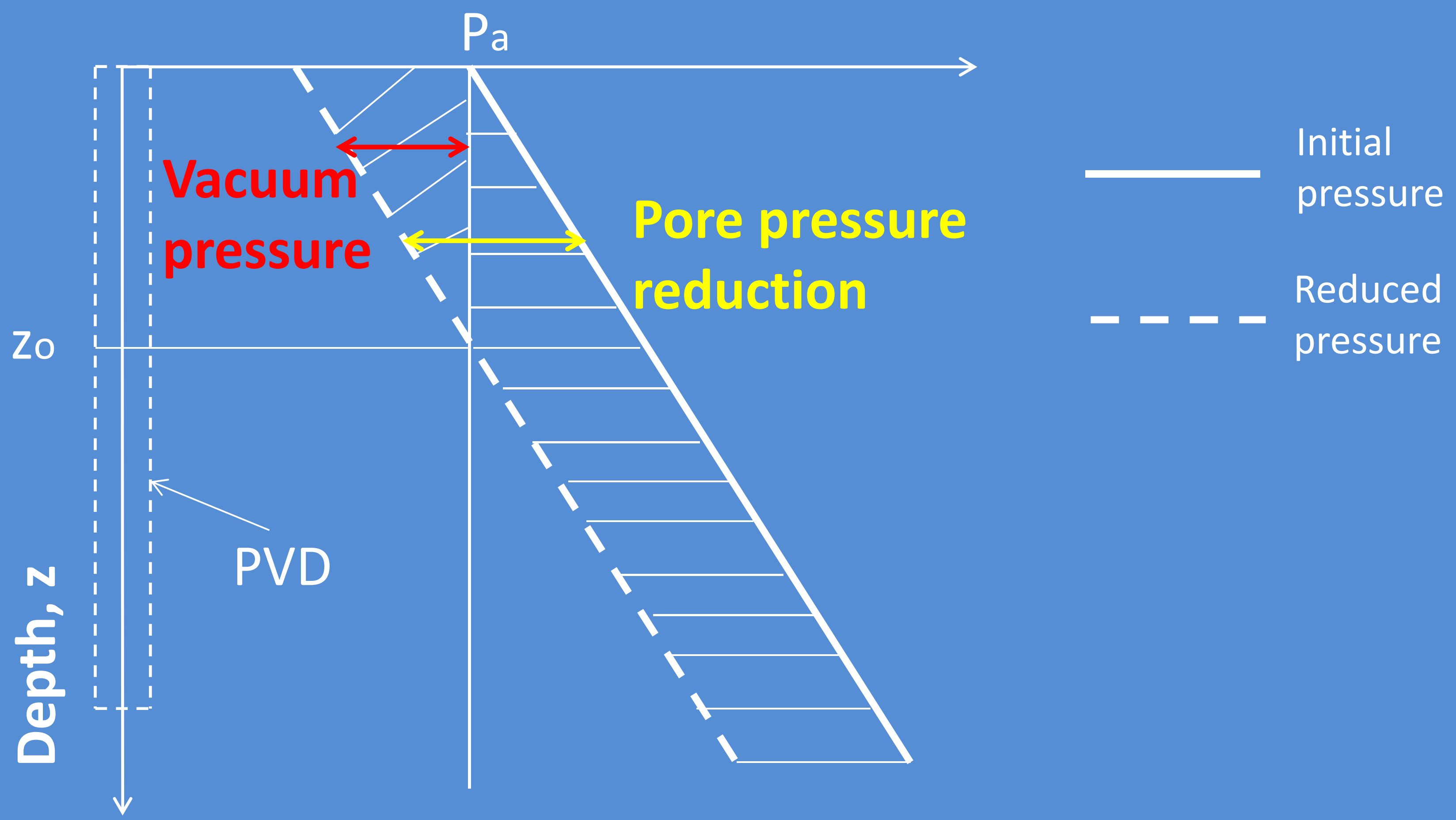
Background - Rampart roads

- The construction of roads over peat bogs in the 18th & 19th centuries opened up the bog for harvesting
- The easiest place to harvest was adjacent to the roads, roads ended up elevated above the adjacent ground. These are called Rampart Roads. Heights of 9m have been recorded.
- Many of these roads are used today, resulting in narrow and very dangerous roads.
- Vacuum consolidation may assist in overcoming some of the challenges in widening these roads.

VACUUM CONSOLIDATION

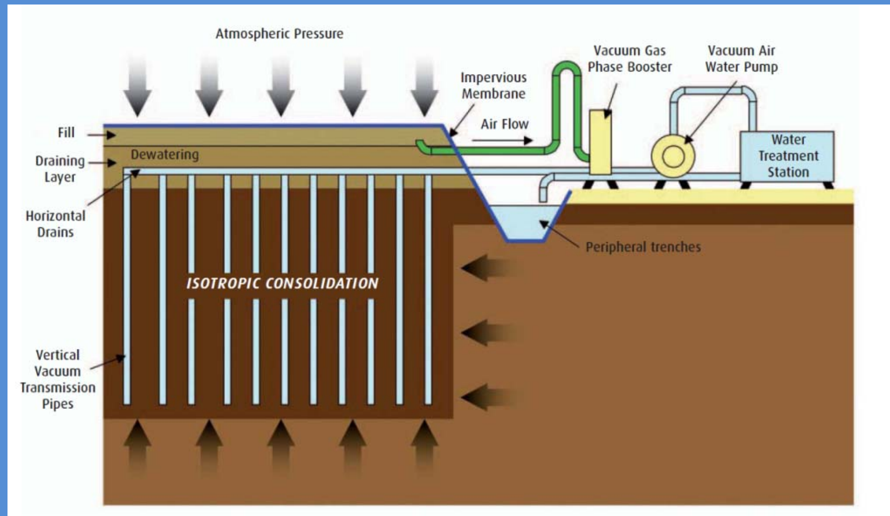


VACUUM CONSOLIDATION

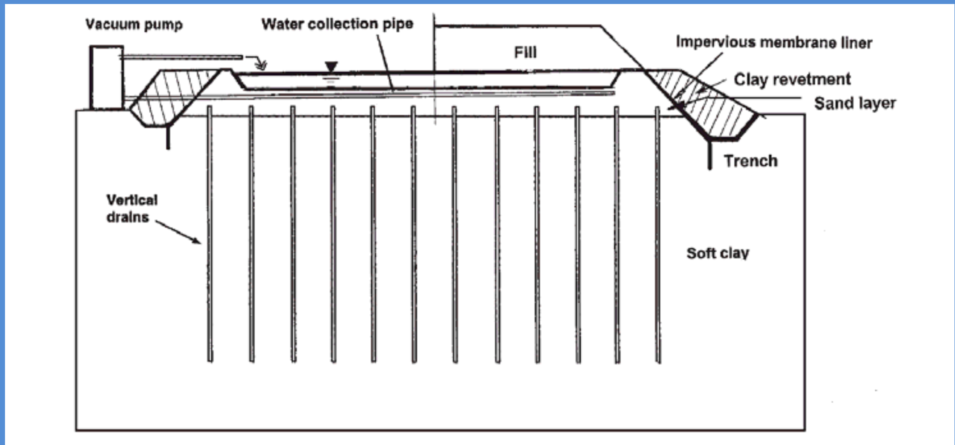


Current applications

Menard vacuum



Baudrain – Cofra bv



Shang, Tang & Miao (1998)

Hayashi et al, 2003

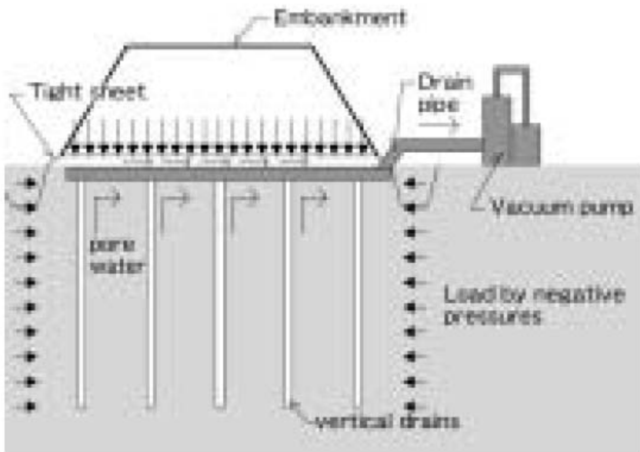
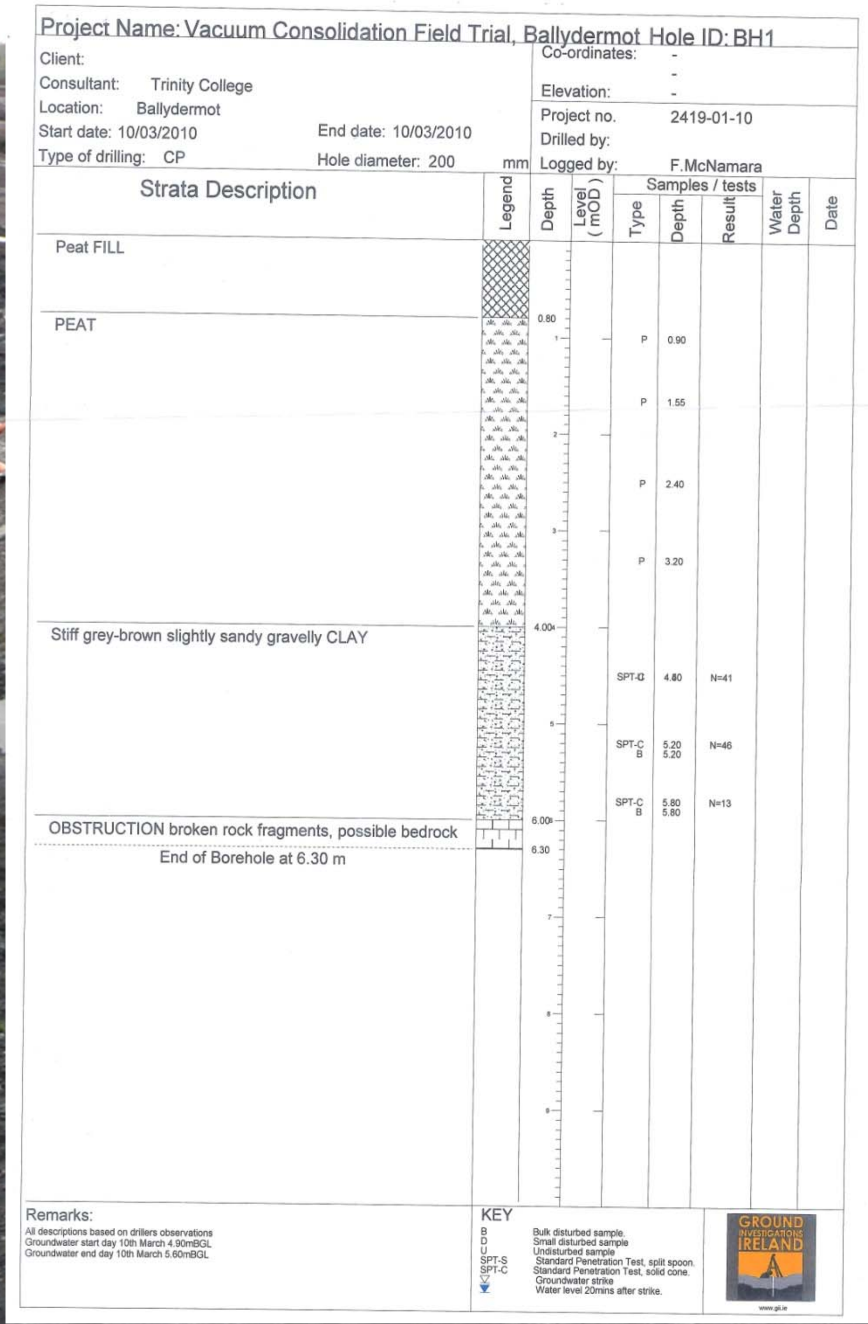


Figure 1. Typical setup of vacuum consolidation method

TCD/NRA TEST SITE



Project Name: Vacuum Consolidation Field Trial, Ballydermot **Hole ID:** BH1

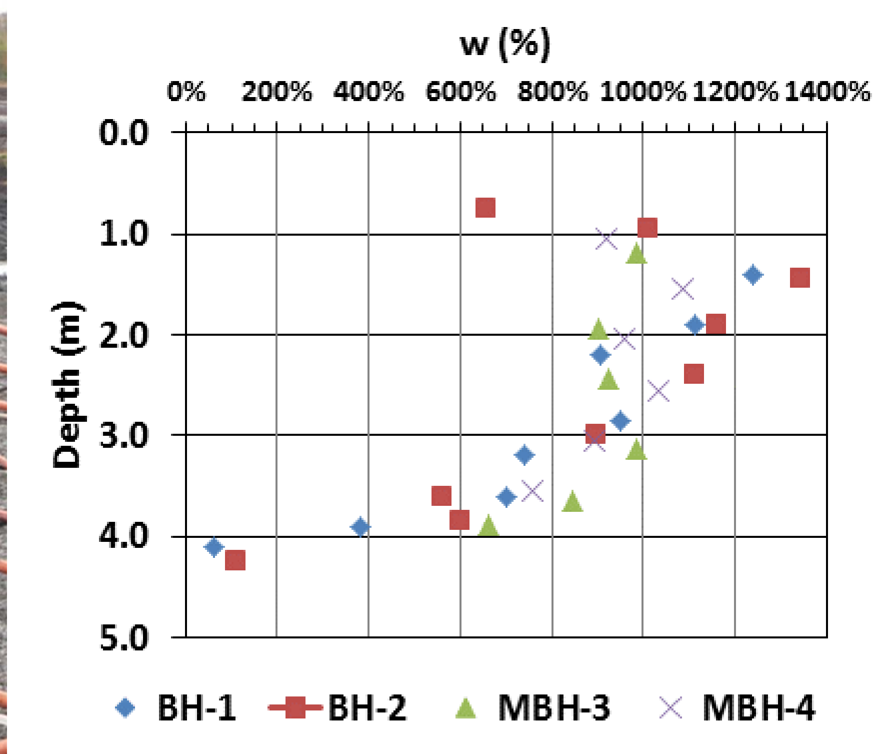
Client:		Co-ordinates:	-
			-
Consultant:	Trinity College	Elevation:	-
Location:	Ballydermot	Project no.	2419-01-10
Start date: 10/03/2010	End date: 10/03/2010	Drilled by:	
Type of drilling: CP	Hole diameter: 200 mm	Logged by:	F.McNamara

Strata Description	Legend	Depth	Level (mOD)	Samples / tests: Type	Samples / tests: Depth	Samples / tests: Result	Water Depth	Date
Peat FILL		0.80						
PEAT		4.00		P	0.90			
				P	1.55			
				P	2.40			
				P	3.20			
Stiff grey-brown slightly sandy gravelly CLAY		6.00		SPT-C	4.80	N=41		
				SPT-C B	5.20 5.20	N=46		
				SPT-C B	5.80 5.80	N=13		
OBSTRUCTION broken rock fragments, possible bedrock		6.30						
End of Borehole at 6.30 m								

Remarks:
All descriptions based on drillers observations
Groundwater start day 10th March 4.90mBGL
Groundwater end day 10th March 5.60mBGL

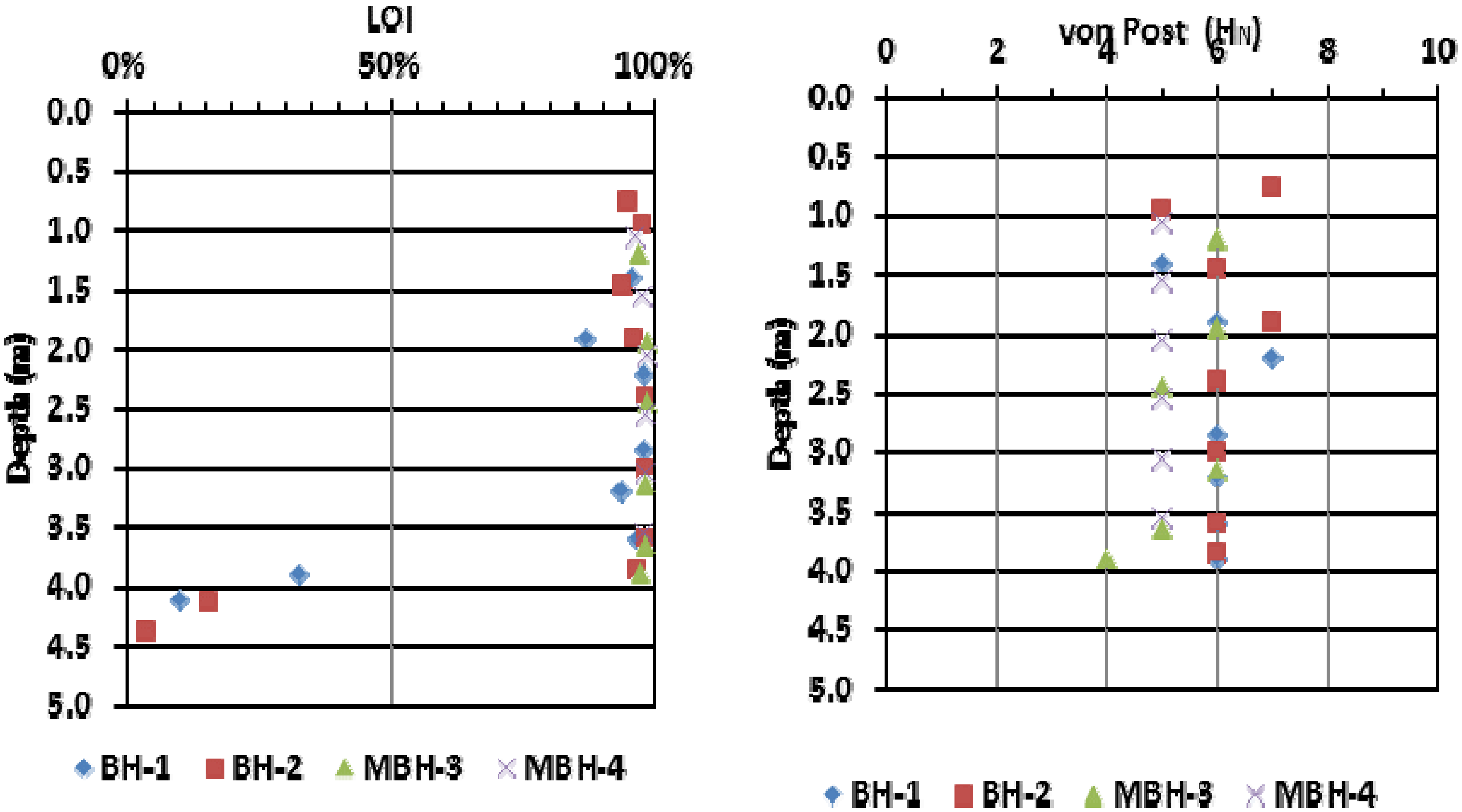
KEY
B Bulk disturbed sample.
D Small disturbed sample
U Undisturbed sample
SPT-S Standard Penetration Test, split spoon.
SPT-C Standard Penetration Test, solid cone.
▽ Groundwater strike
▼ Water level 20mins after strike.

GROUND INVESTIGATIONS IRELAND
www.gii.ie



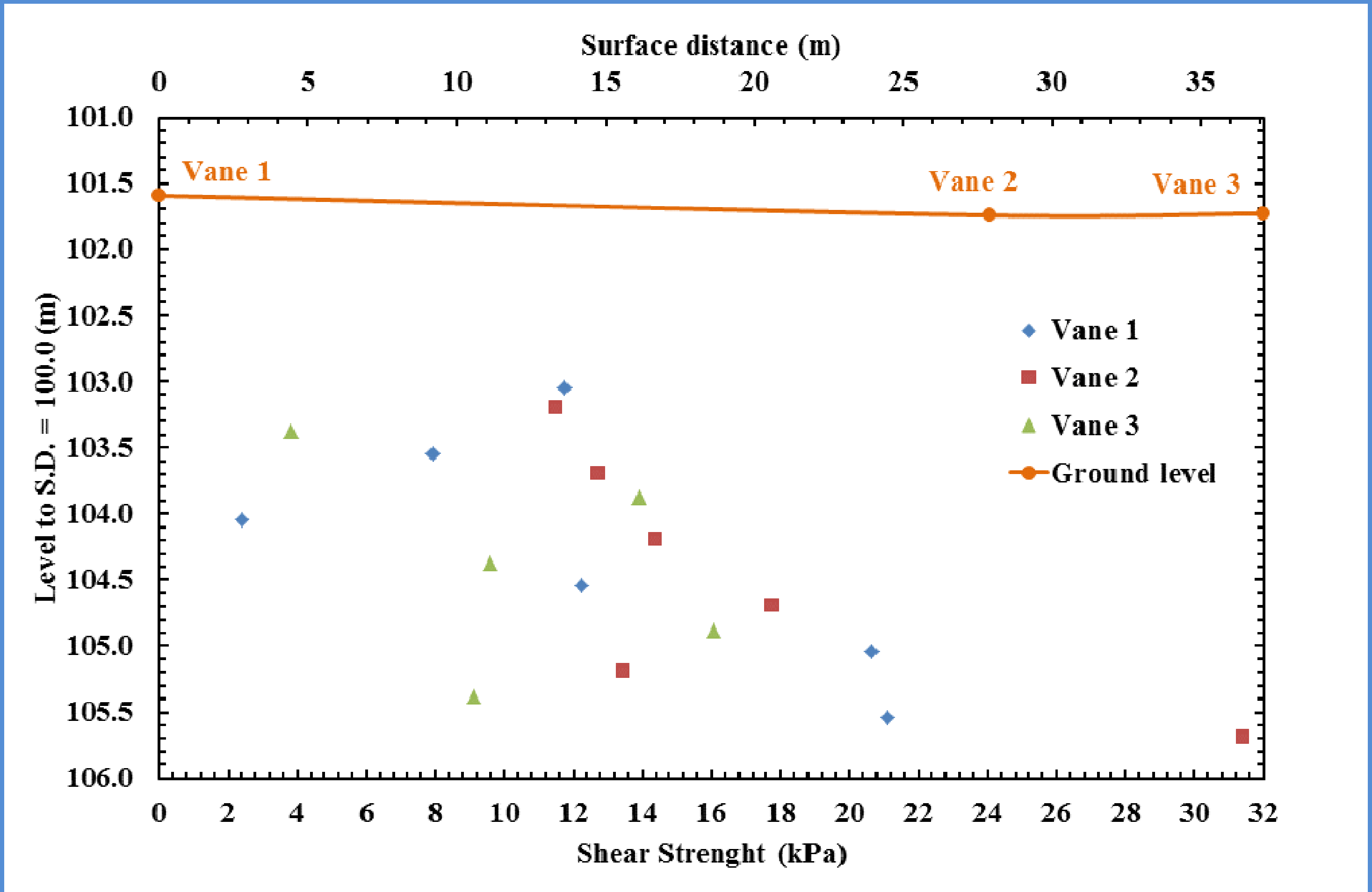
Raised Bog under milled peat production, therefore some peat has been removed. Site is at edge of bog.

Top 1m - very clayey sandy Gravel f% ≈ 30%
Below – slightly clayey sandy Gravel f% ≈ 4-11%
K = 1.96×10^{-6} to 1.15×10^{-5} m/s

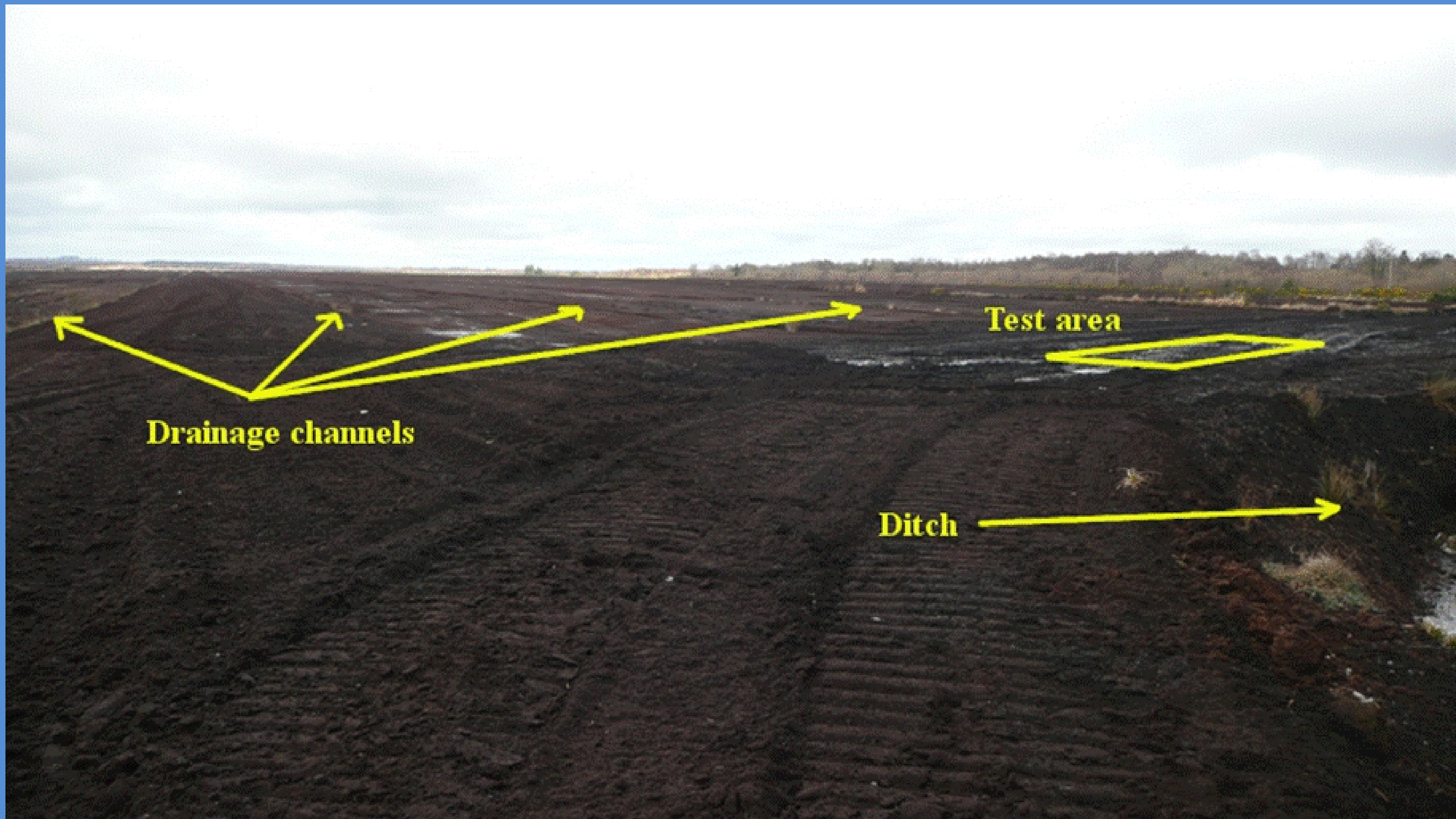


LOI
0%
50%
100%
Depth (m)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
BH-1
BH-2
MBH-3
MBH-4
von Post (HN)
0
2
4
6
8
10
Depth (m)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
BH-1
BH-2
MBH-3
MBH-4

In-situ vanes (55mm x 110mm)



Hydrogeology



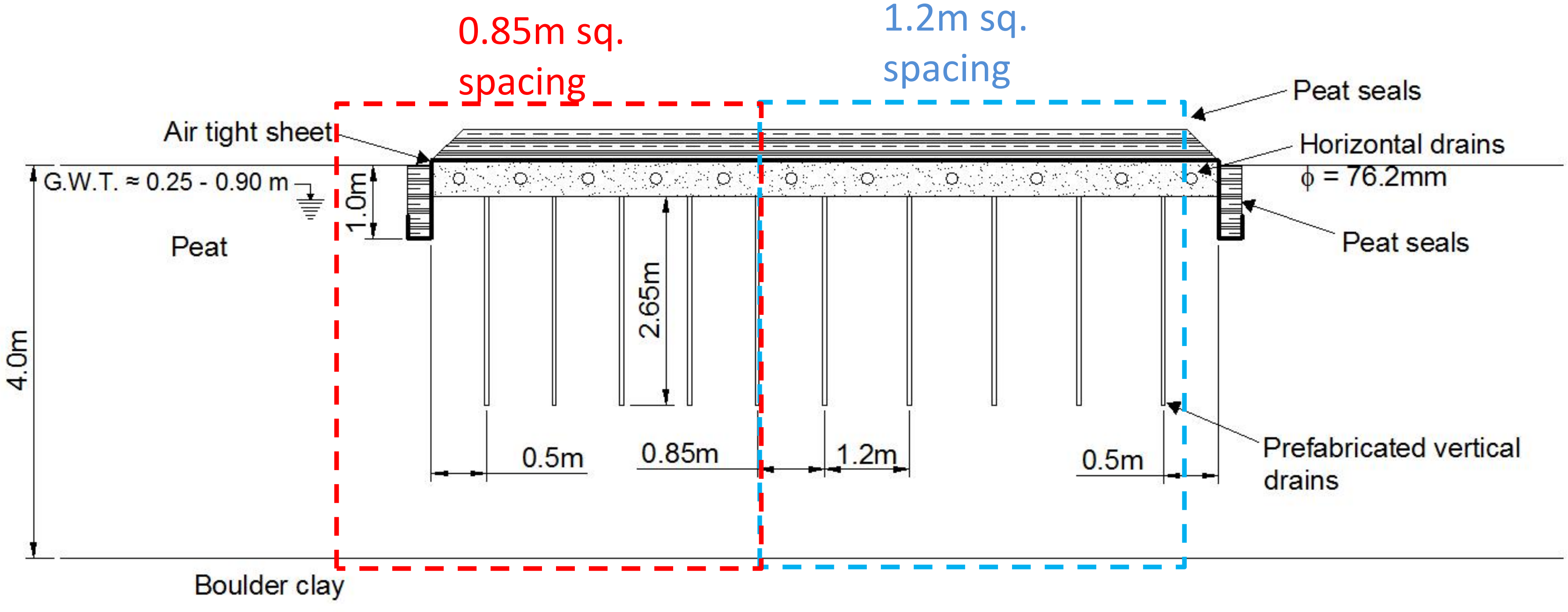
Drain within 8m of edge of test area.

TCD/NRA VACUUM CONSOLIDATION FIELD TRIAL

Table 1 – Simplified soil profile

Layer	Depth (m)	Description	Observations and properties
1	0 – 0.7	Man-made fill	Black peat; occasional plastic bags, gravel, pieces of geotextile, machine parts.
2	0.7 – 4.0	Pseudo-fibrous peat	w = 561 – 1340% G_S = 1.38 – 1.59 LOI = 87 – 99% γ_h = 9.57 – 10.56kN/m^3 e_o = 6.78 – 14.83 S_r = 94 – 100% pH = 4.5 – 6.2 Von Post = $H_4 – H_7$ C_c = 2.2 – 6.4
3	4.0 – 7.0	Glacial till	The clay fraction reduces with depth , about 30% fines in top metre, reducing to 4-11%.

TCD/NRA VACUUM CONSOLIDATION FIELD TRIAL

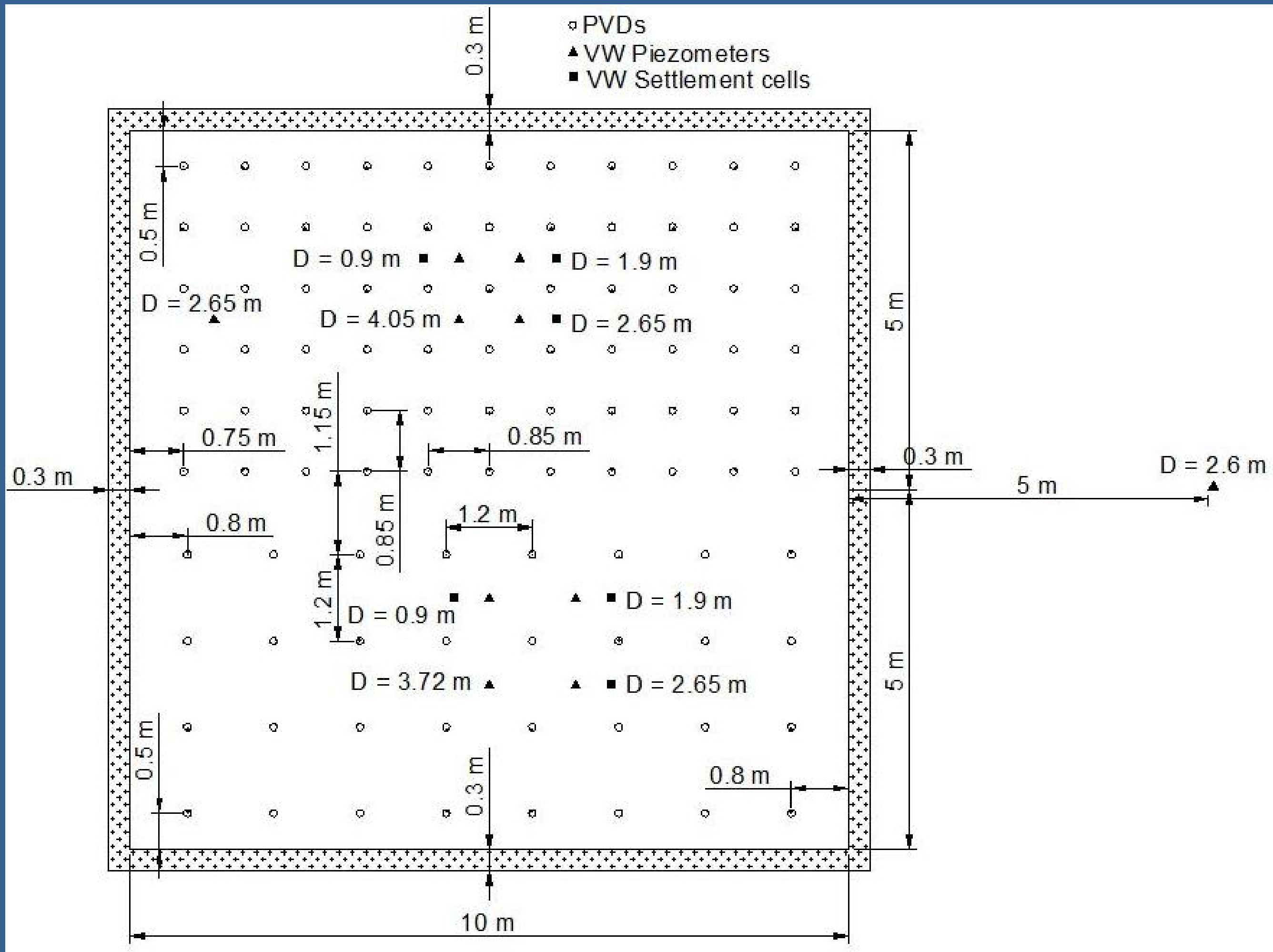


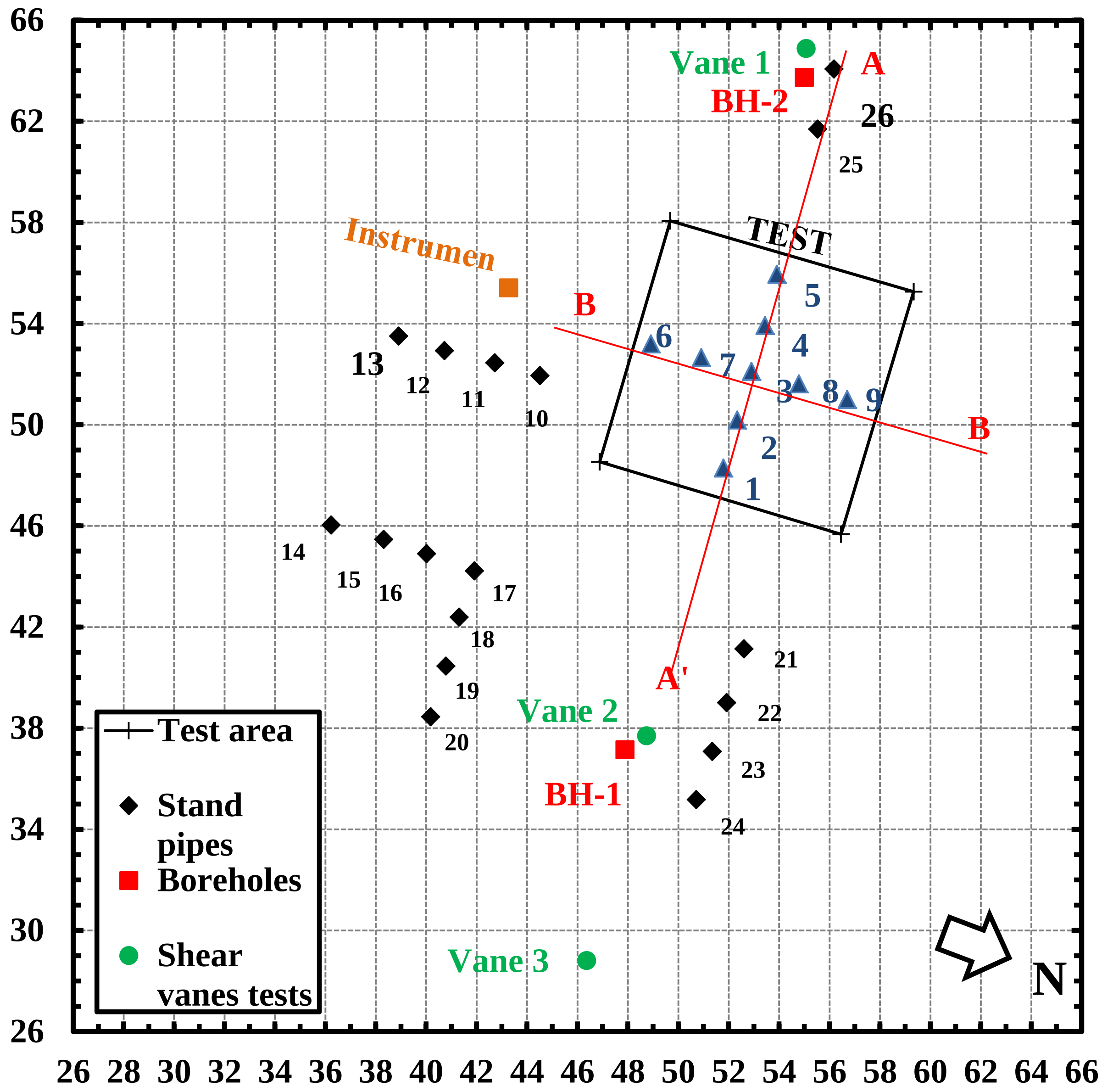
Instrumentation

- 10 No. Vibrating wire (VW) piezomters (also calibrated for suction)
- 6 No. push-in VW settlement cells 0.9m, 1.5m & 2.65m
- Settlement plates
- Standpipes
- Barometric pressure/temp.
- Rain gauge
- Water meter
- Air pressure gauges

Acknowledge assistance of NVM Ireland Ltd.

TCD/NRA VACUUM CONSOLIDATION FIELD TRIAL





Vane 1
A
BH-2
26
25
TEST
Instrumen
5
B
6
4
13
7
12
11
3
8
9
10
B
2
1
14
15
16
17
18
21
A'
19
Vane 2
22
20
23
BH-1
24
Vane 3
N
Test area
Stand pipes
Boreholes
Shear vanes tests

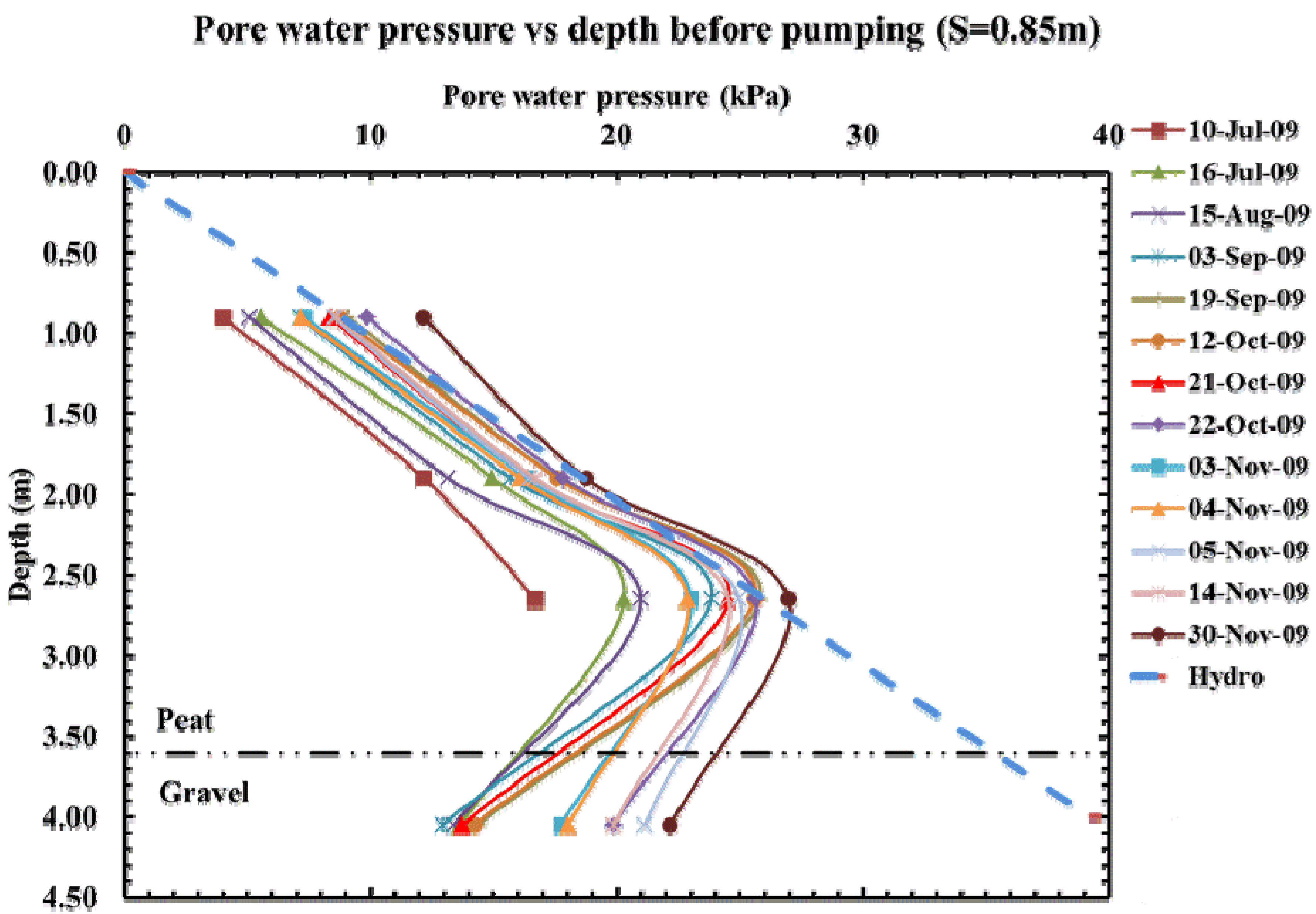

Pumping system: 30th Nov 2009 – 23rd Jun 2010
• 1.5kW Centrifugal pump
• 38mm diameter jet pump

Pumping system: 29th Jul 2010 – 29th Oct 2010

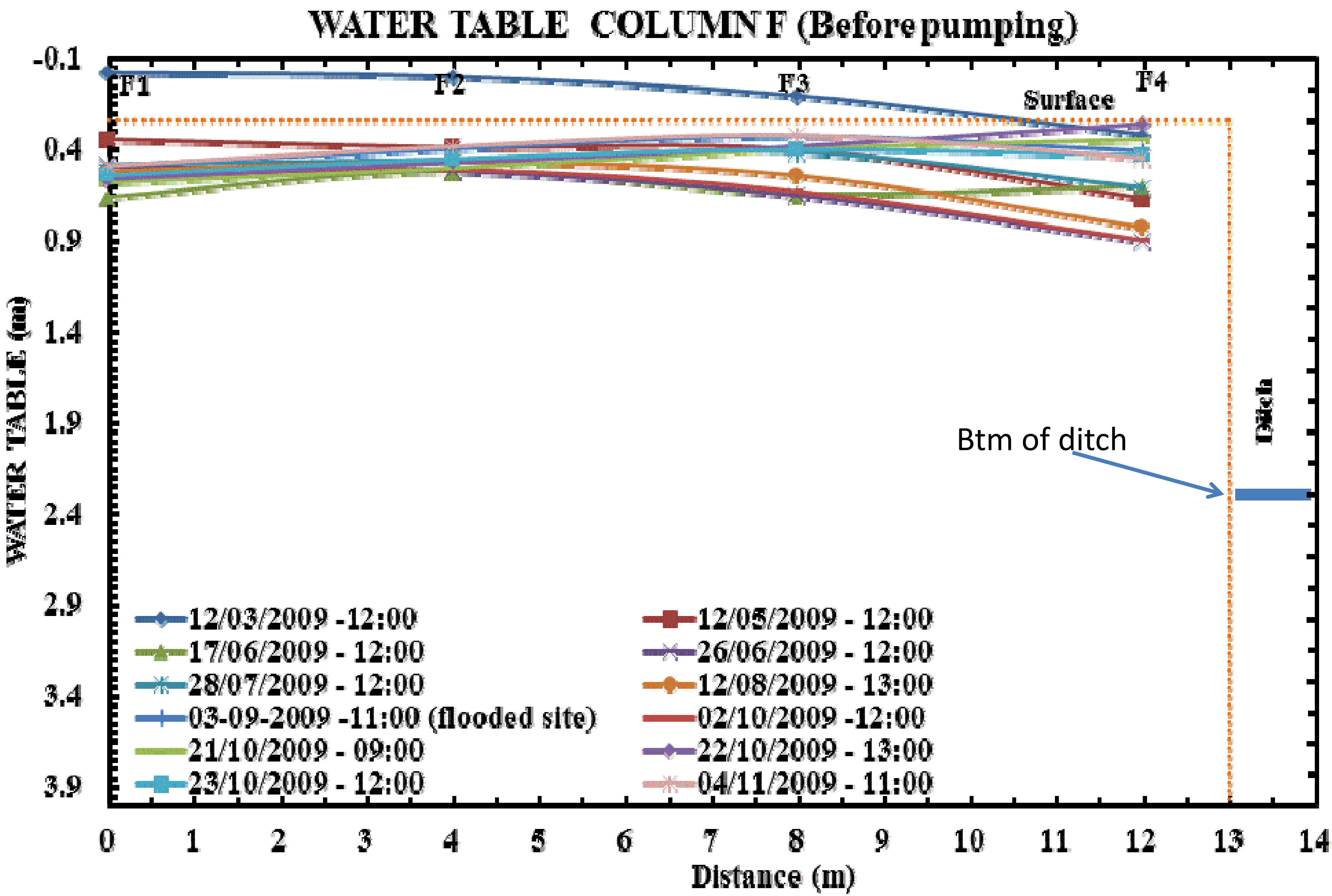
- 2.2kW Liquid ring pump
- 1.5kW Centrifugal pump
- 38mm diameter jet pump

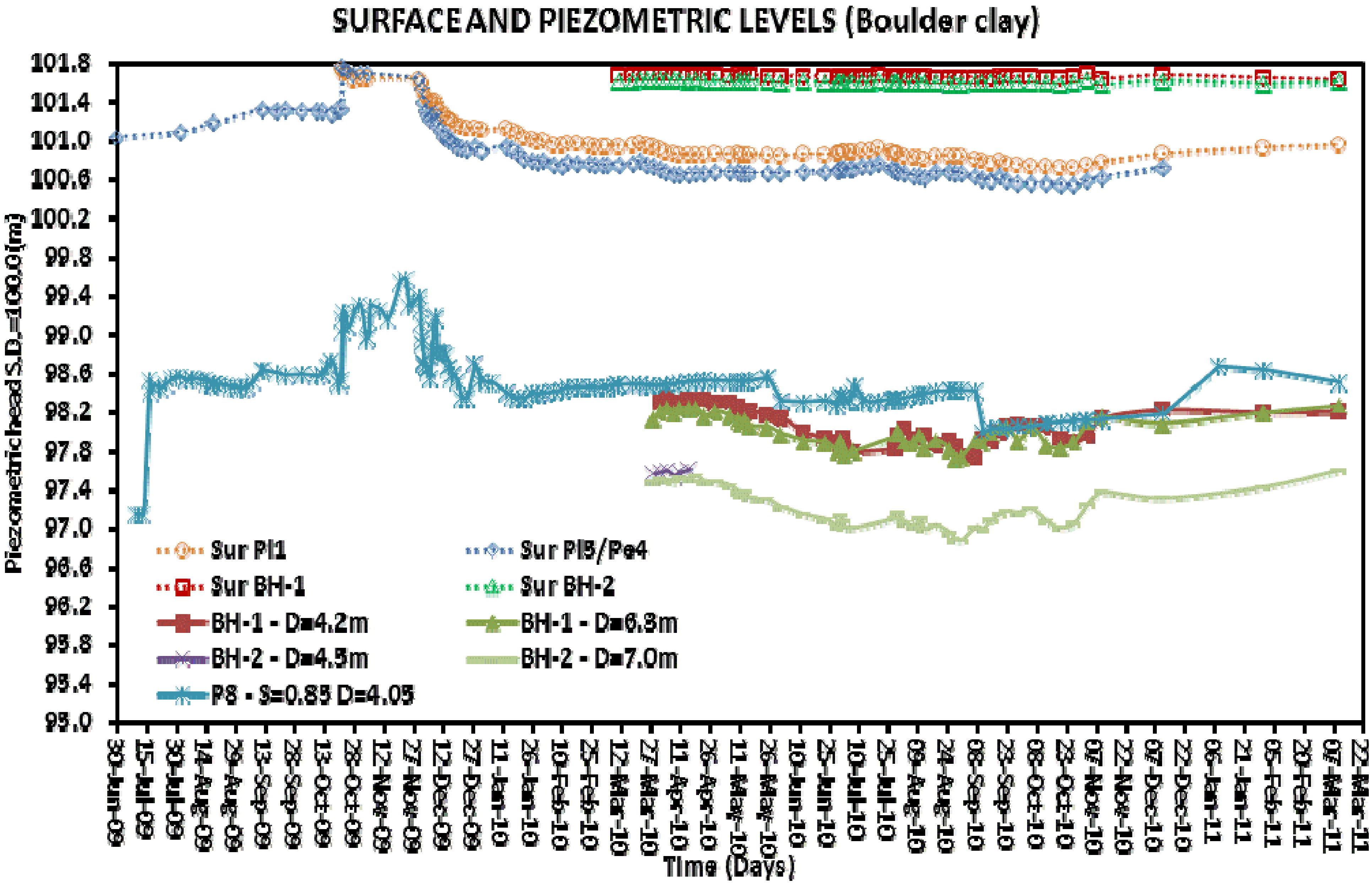
MONITORING BEFORE PUMPING

- Prior to starting the TCD/NRA vacuum consolidation field trial, four months of baseline monitoring were conducted.
- The vacuum consolidation trial was run from 30^{th} November 2009 and was terminated on 29^{th} October 2010

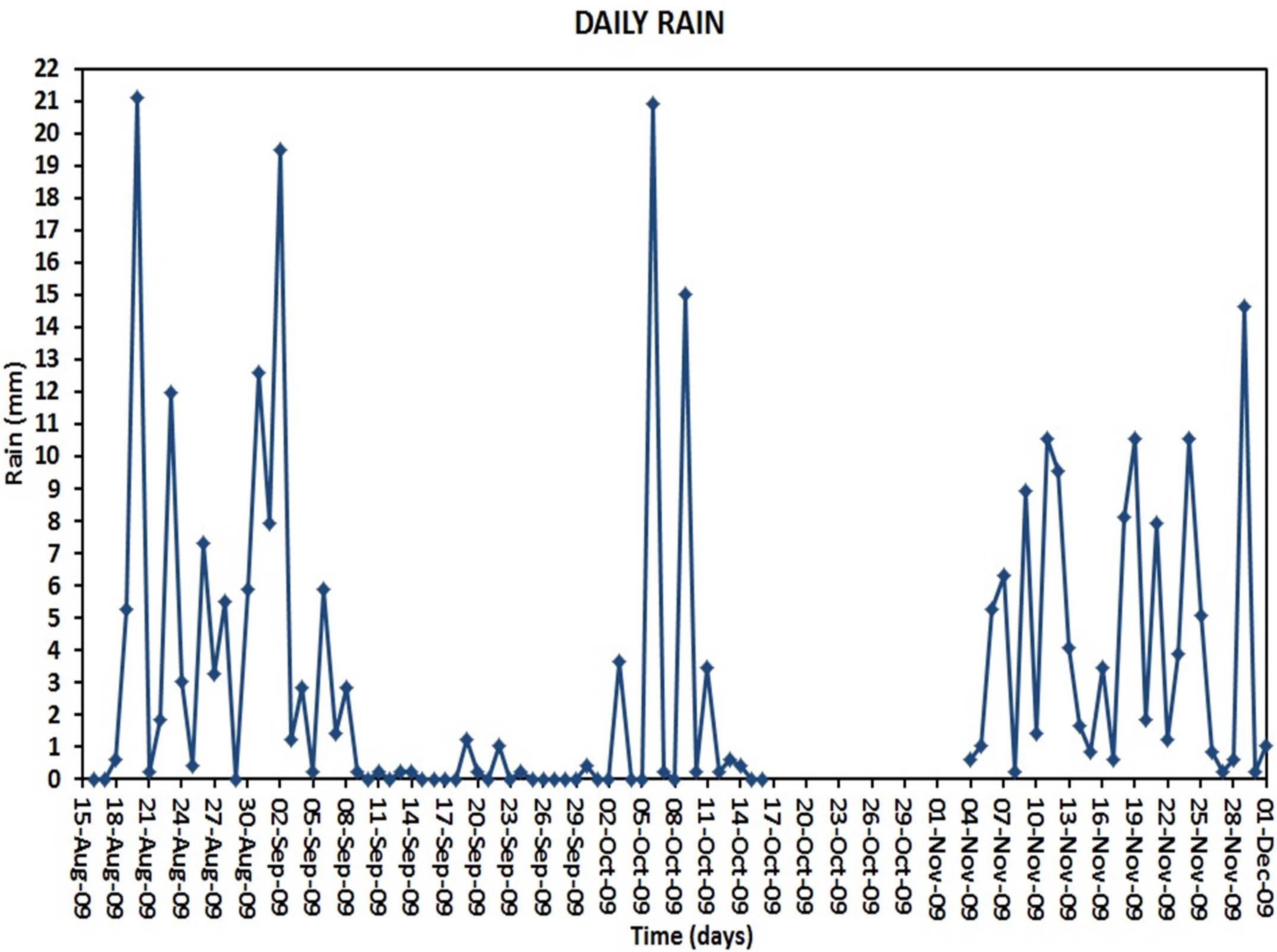


Pore water pressure vs depth before pumping (S=0.85m)
Pore water pressure (kPa)
0
10
20
30
40
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
Depth (m)
Peat
Gravel
10-Jul-09
16-Jul-09
15-Aug-09
03-Sep-09
19-Sep-09
12-Oct-09
21-Oct-09
22-Oct-09
03-Nov-09
04-Nov-09
05-Nov-09
14-Nov-09
30-Nov-09
Hydro

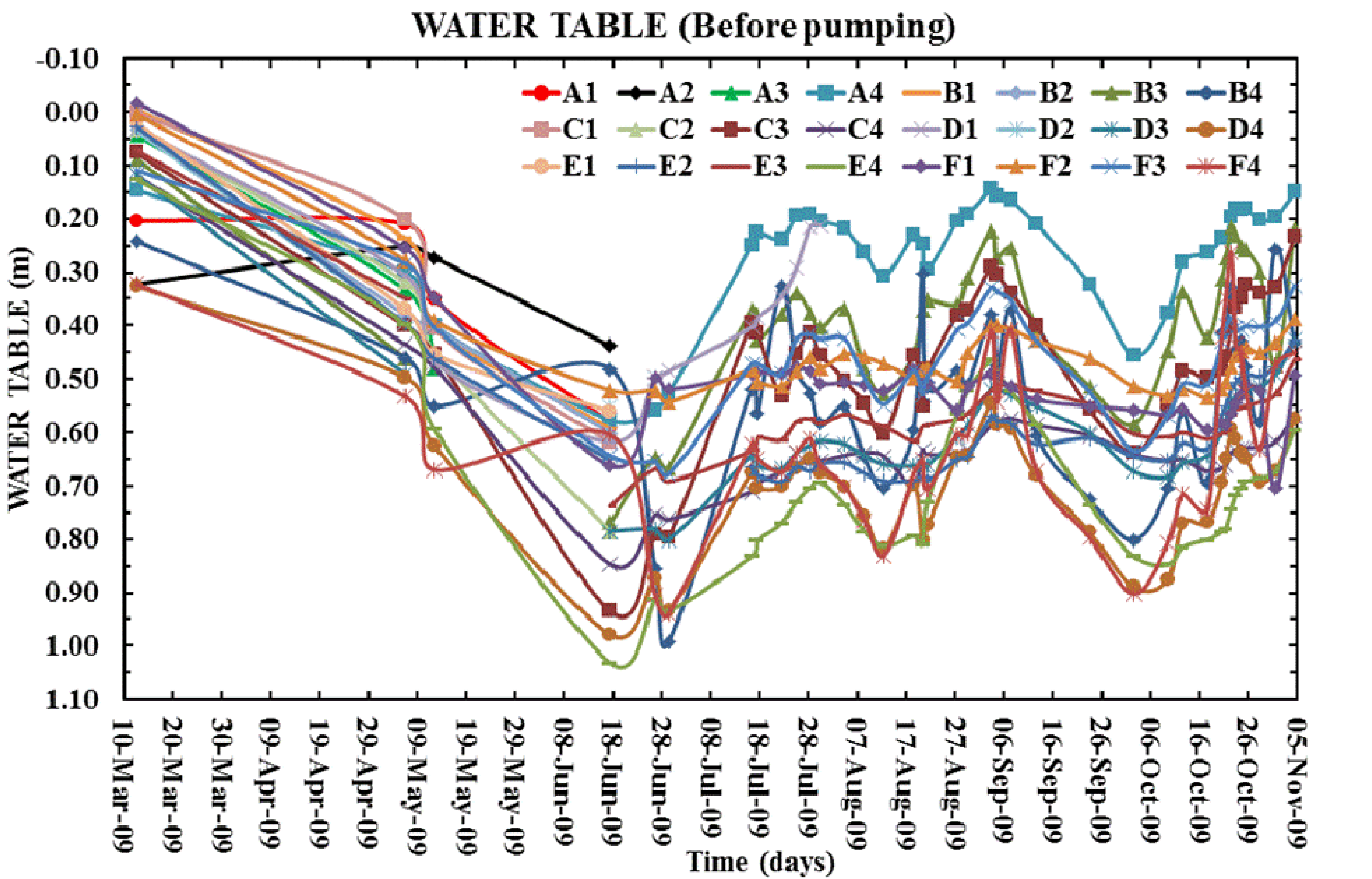

WATER TABLE COLUMN F (Before pumping)
-0.1
0.4
0.9
1.4
1.9
2.4
2.9
3.4
3.9
WATER TABLE (m)
F1
F2
F3
F4
Surface
Ditch
Btm of ditch
12/03/2009 -12:00
12/05/2009 - 12:00
17/06/2009 - 12:00
26/06/2009 - 12:00
28/07/2009 - 12:00
12/08/2009 - 13:00
03-09-2009 -11:00 (flooded site)
02/10/2009 -12:00
21/10/2009 - 09:00
22/10/2009 - 13:00
23/10/2009 - 12:00
04/11/2009 - 11:00
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Distance (m)



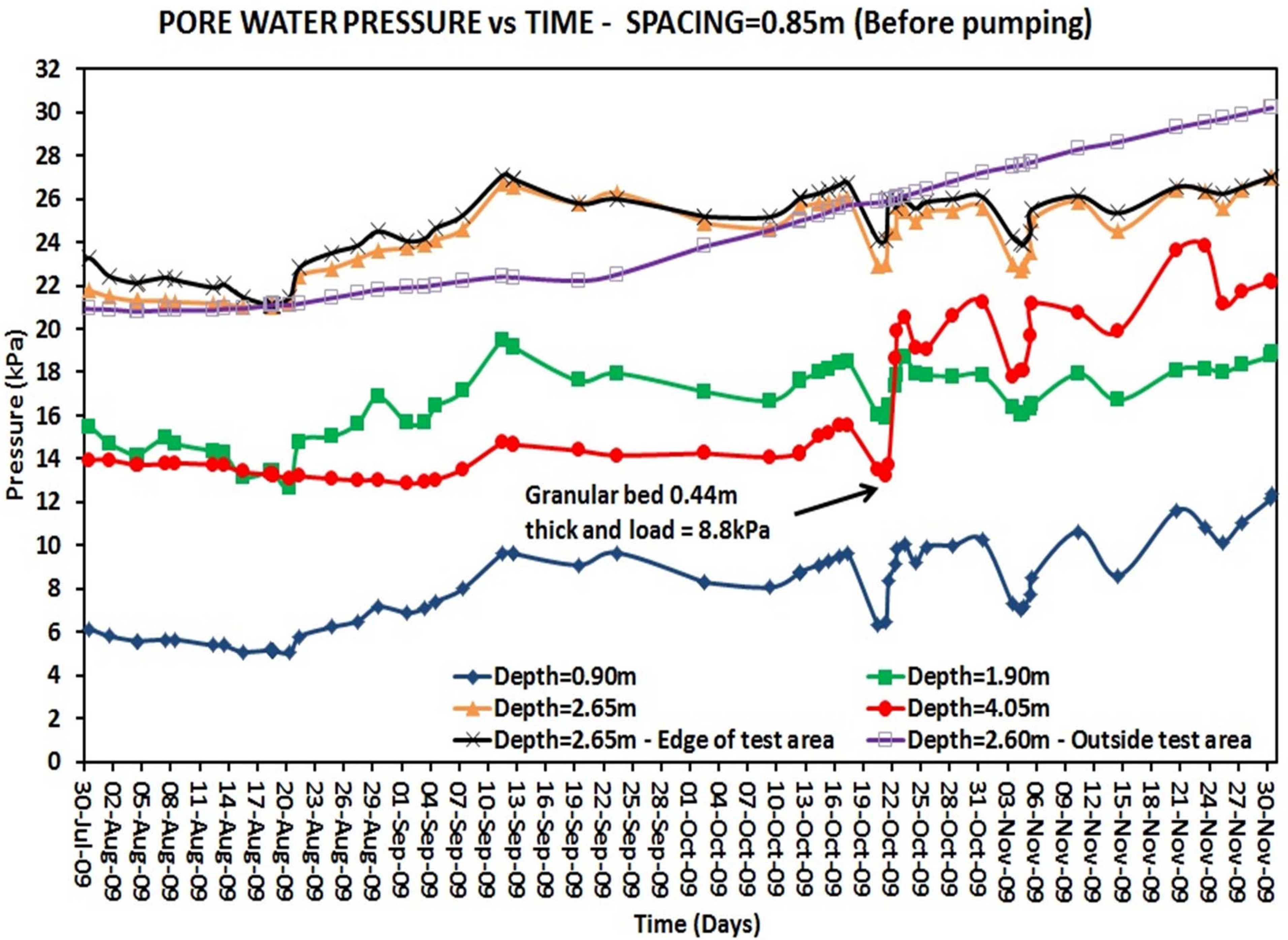
SURFACE AND PIEZOMETRIC LEVELS (Boulder clay)
Piezometric head S.D.=100.0 (m)
Time (Days)
101.8
101.4
101.0
100.6
100.2
99.8
99.4
99.0
98.6
98.2
97.8
97.4
97.0
96.6
96.2
95.8
95.4
95.0
Sur Pl1
Sur Pl5/Pe4
Sur BH-1
Sur BH-2
BH-1 - D=4.2m
BH-1 - D=6.3m
BH-2 - D=4.5m
BH-2 - D=7.0m
P8 - S=0.85 D=4.05
30-Jun-09
15-Jul-09
30-Jul-09
14-Aug-09
29-Aug-09
13-Sep-09
28-Sep-09
13-Oct-09
28-Oct-09
12-Nov-09
27-Nov-09
12-Dec-09
27-Dec-09
11-Jan-10
26-Jan-10
10-Feb-10
25-Feb-10
12-Mar-10
27-Mar-10
11-Apr-10
26-Apr-10
11-May-10
26-May-10
10-Jun-10
25-Jun-10
10-Jul-10
25-Jul-10
09-Aug-10
24-Aug-10
08-Sep-10
23-Sep-10
08-Oct-10
23-Oct-10
07-Nov-10
22-Nov-10
07-Dec-10
22-Dec-10
06-Jan-11
21-Jan-11
05-Feb-11
20-Feb-11
07-Mar-11
22-Mar-11



DAILY RAIN
Rain (mm)
Time (days)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
15-Aug-09
18-Aug-09
21-Aug-09
24-Aug-09
27-Aug-09
30-Aug-09
02-Sep-09
05-Sep-09
08-Sep-09
11-Sep-09
14-Sep-09
17-Sep-09
20-Sep-09
23-Sep-09
26-Sep-09
29-Sep-09
02-Oct-09
05-Oct-09
08-Oct-09
11-Oct-09
14-Oct-09
17-Oct-09
20-Oct-09
23-Oct-09
26-Oct-09
29-Oct-09
01-Nov-09
04-Nov-09
07-Nov-09
10-Nov-09
13-Nov-09
16-Nov-09
19-Nov-09
22-Nov-09
25-Nov-09
28-Nov-09
01-Dec-09

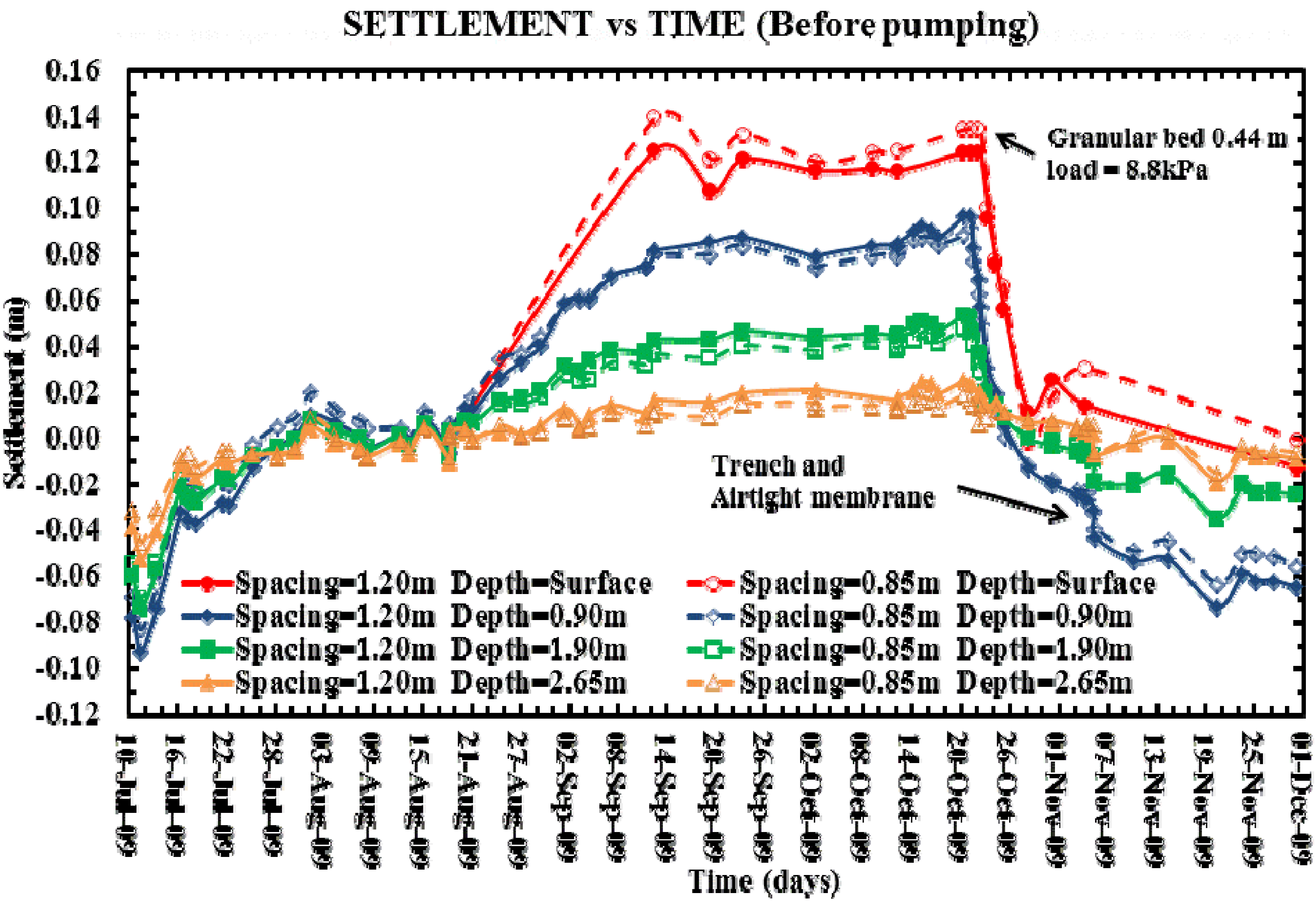


WATER TABLE (Before pumping)
WATER TABLE (m)
Time (days)
A1
A2
A3
A4
B1
B2
B3
B4
C1
C2
C3
C4
D1
D2
D3
D4
E1
E2
E3
E4
F1
F2
F3
F4
-0.10
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
10-Mar-09
20-Mar-09
30-Mar-09
09-Apr-09
19-Apr-09
29-Apr-09
09-May-09
19-May-09
29-May-09
08-Jun-09
18-Jun-09
28-Jun-09
08-Jul-09
18-Jul-09
28-Jul-09
07-Aug-09
17-Aug-09
27-Aug-09
06-Sep-09
16-Sep-09
26-Sep-09
06-Oct-09
16-Oct-09
26-Oct-09
05-Nov-09



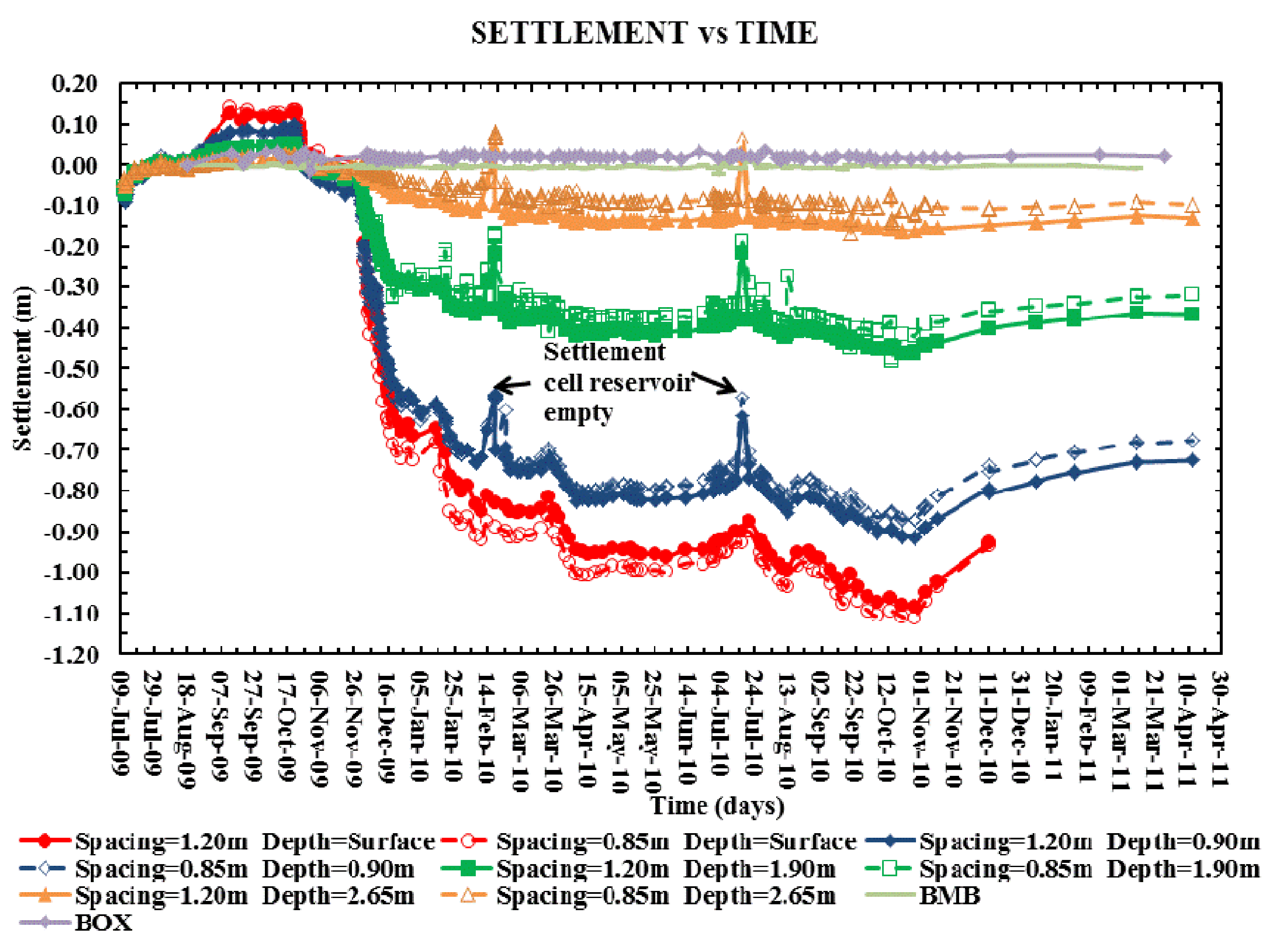
PORE WATER PRESSURE vs TIME - SPACING=0.85m (Before pumping)
Pressure (kPa)
Time (Days)
Granular bed 0.44m thick and load = 8.8kPa
Depth=0.90m
Depth=1.90m
Depth=2.65m
Depth=4.05m
Depth=2.65m - Edge of test area
Depth=2.60m - Outside test area

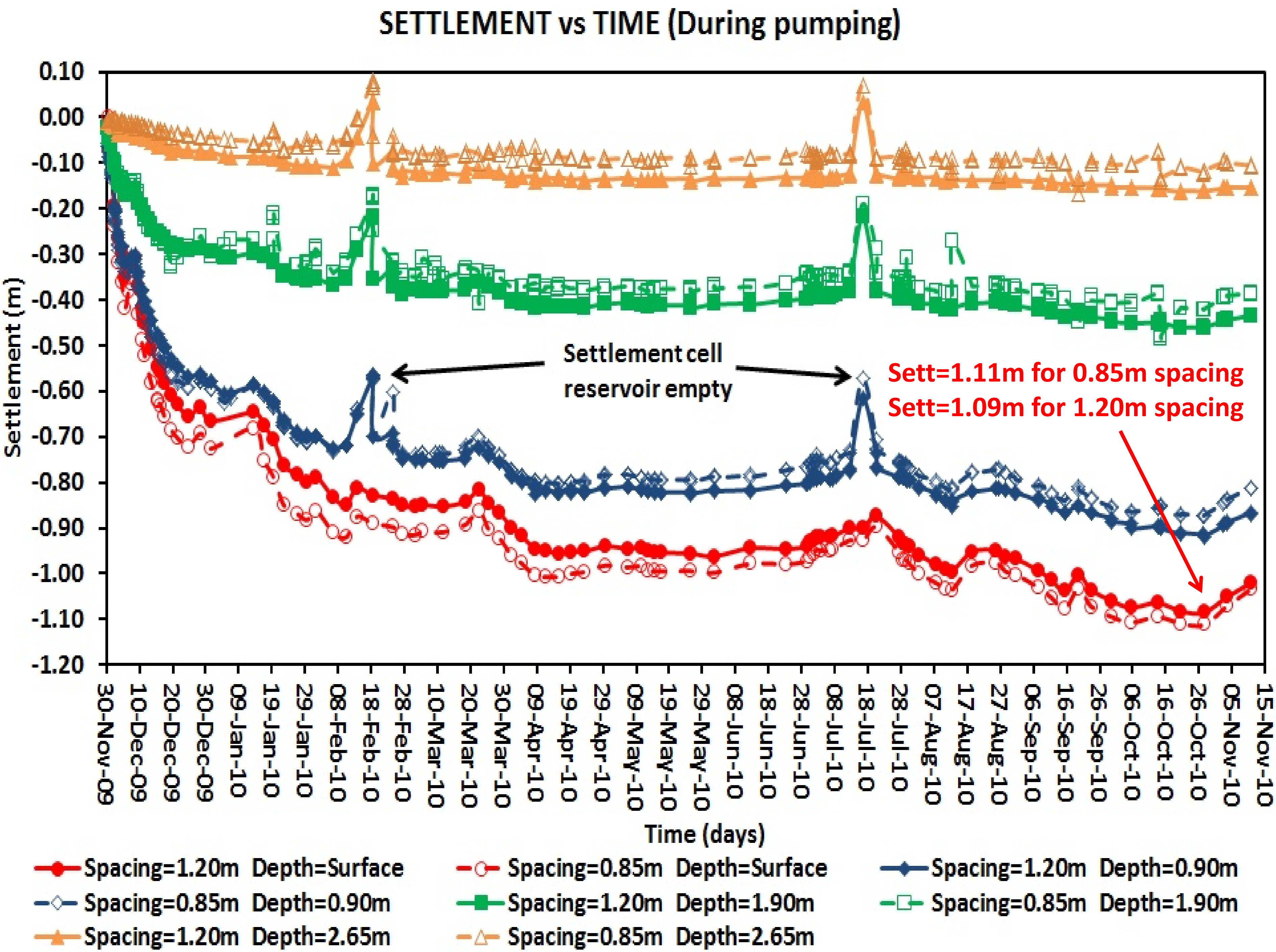
Flooding in August 2009


SETTLEMENT vs TIME (Before pumping)
Settlement (m)
Time (days)
Granular bed 0.44 m
load = 8.8kPa
Trench and
Airtight membrane
Spacing=1.20m Depth=Surface
Spacing=1.20m Depth=0.90m
Spacing=1.20m Depth=1.90m
Spacing=1.20m Depth=2.65m
Spacing=0.85m Depth=Surface
Spacing=0.85m Depth=0.90m
Spacing=0.85m Depth=1.90m
Spacing=0.85m Depth=2.65m
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
-0.12
10-Jul-09
16-Jul-09
22-Jul-09
28-Jul-09
03-Aug-09
09-Aug-09
15-Aug-09
21-Aug-09
27-Aug-09
02-Sep-09
08-Sep-09
14-Sep-09
20-Sep-09
26-Sep-09
02-Oct-09
08-Oct-09
14-Oct-09
20-Oct-09
26-Oct-09
01-Nov-09
07-Nov-09
13-Nov-09
19-Nov-09
25-Nov-09
01-Dec-09

MONITORING DURING PUMPING

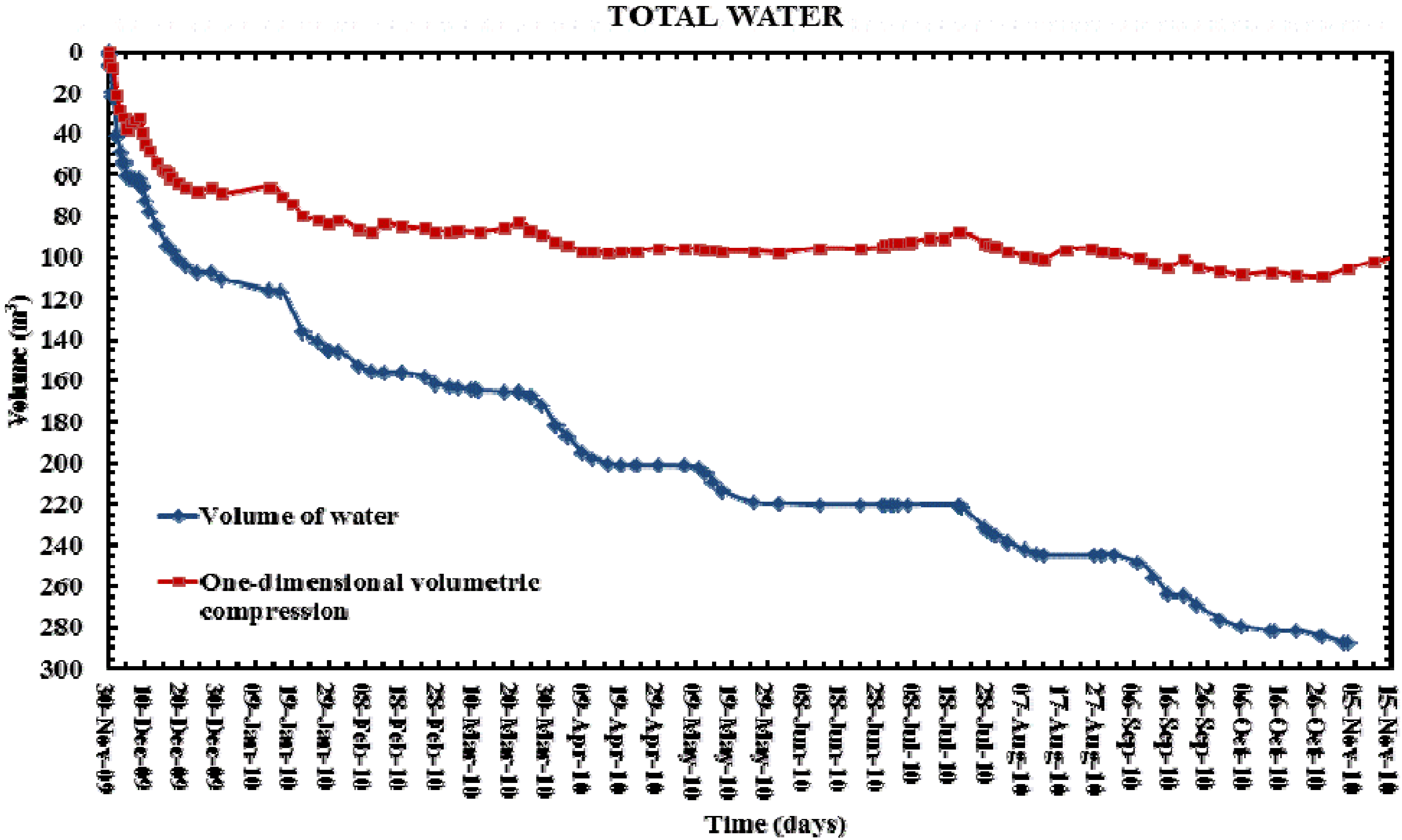
- The TCD/NRA vacuum preloading field trial commenced on the 30th November 2009.
- The results for the eleven months of pumping presented here.
- Rain, water table, vacuum, settlement and pore water pressure are presented.

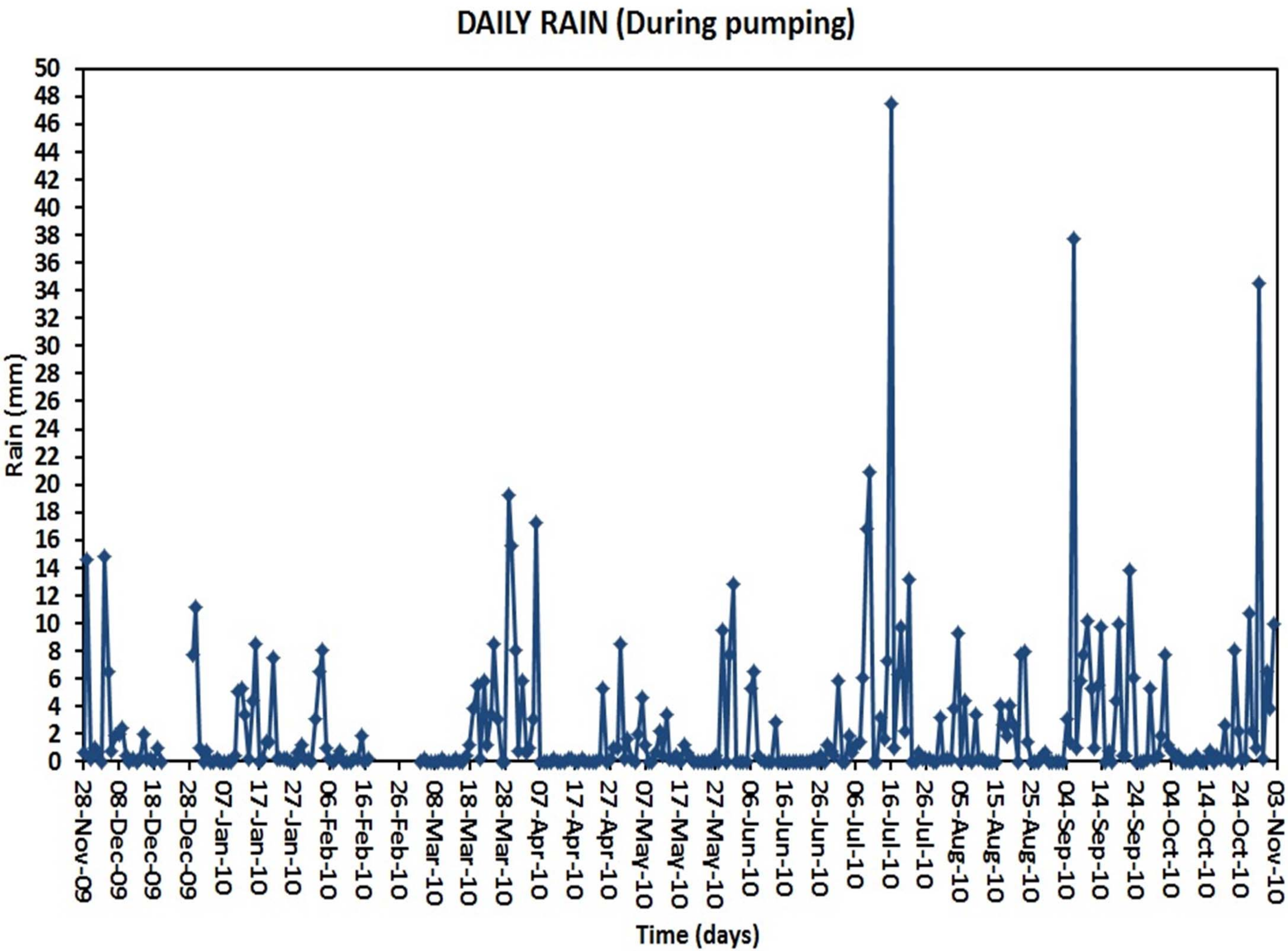

SETTLEMENT vs TIME
Settlement (m)
Time (days)
Settlement cell reservoir empty
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.60
-0.70
-0.80
-0.90
-1.00
-1.10
-1.20
09-Jul-09
29-Jul-09
18-Aug-09
07-Sep-09
27-Sep-09
17-Oct-09
06-Nov-09
26-Nov-09
16-Dec-09
05-Jan-10
25-Jan-10
14-Feb-10
06-Mar-10
26-Mar-10
15-Apr-10
05-May-10
25-May-10
14-Jun-10
04-Jul-10
24-Jul-10
13-Aug-10
02-Sep-10
22-Sep-10
12-Oct-10
01-Nov-10
21-Nov-10
11-Dec-10
31-Dec-10
20-Jan-11
09-Feb-11
01-Mar-11
21-Mar-11
10-Apr-11
30-Apr-11
Spacing=1.20m Depth=Surface
Spacing=0.85m Depth=Surface
Spacing=1.20m Depth=0.90m
Spacing=0.85m Depth=0.90m
Spacing=1.20m Depth=1.90m
Spacing=0.85m Depth=1.90m
Spacing=1.20m Depth=2.65m
Spacing=0.85m Depth=2.65m
BMB
BOX

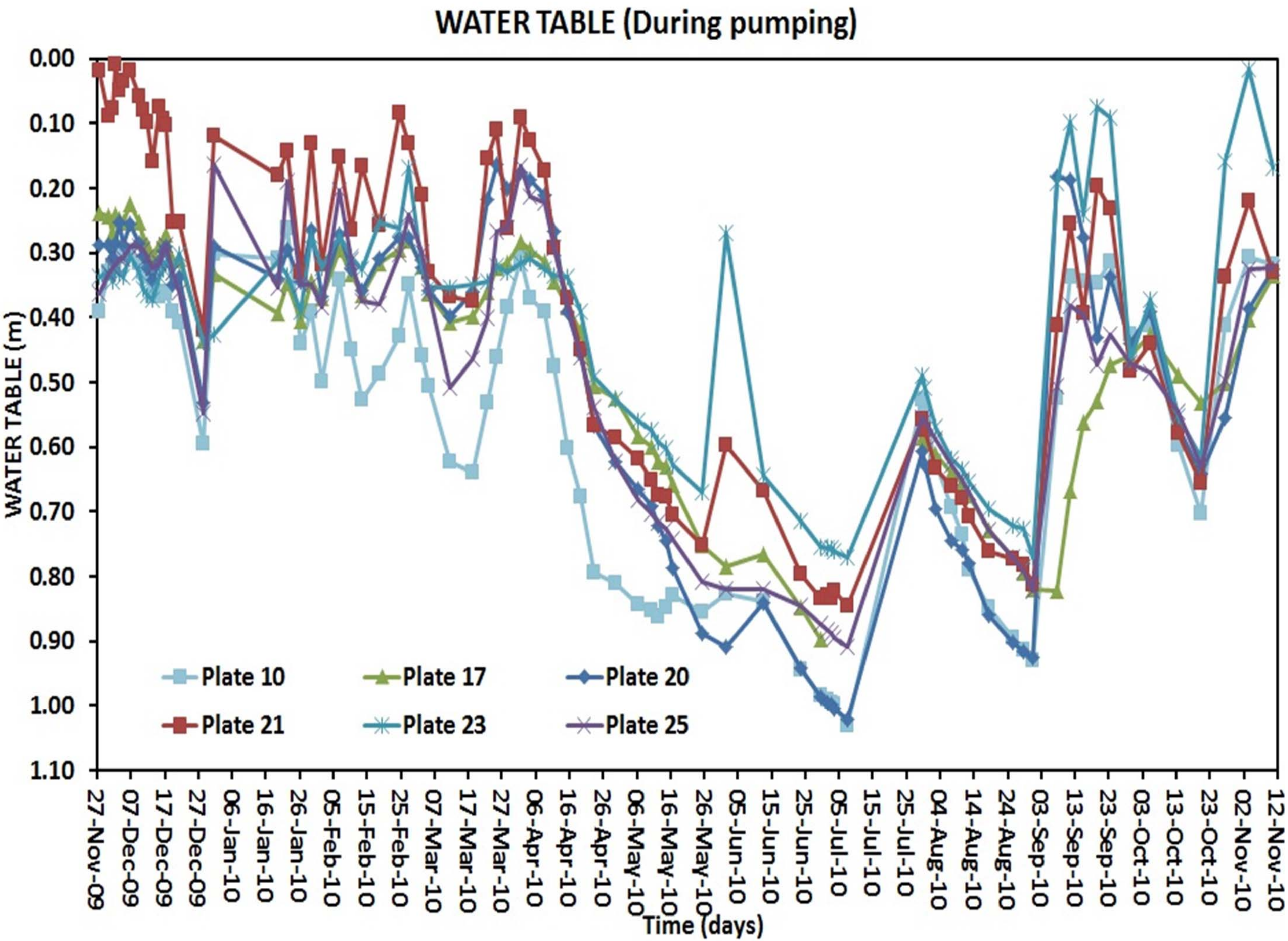


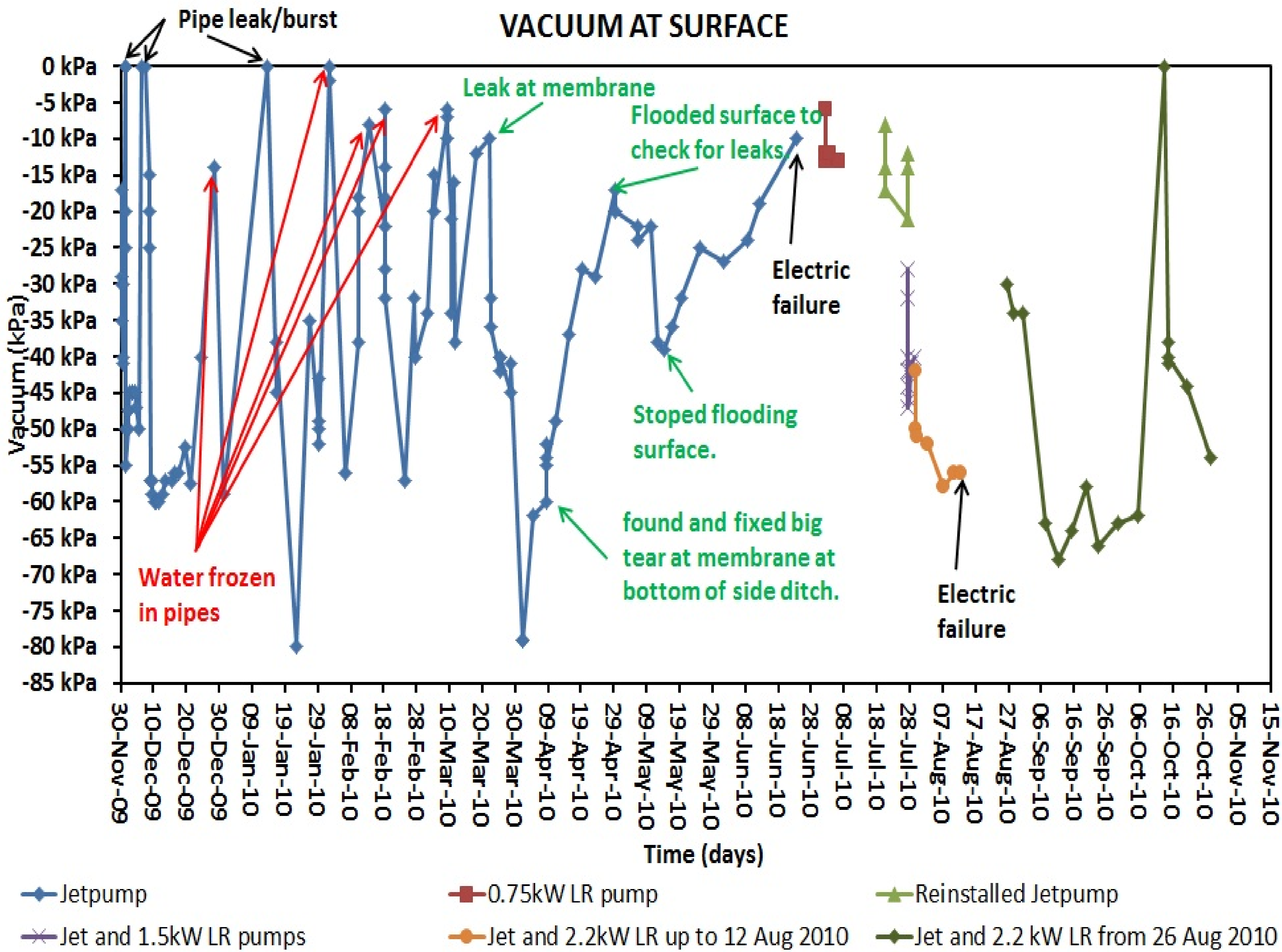
SETTLEMENT vs TIME (During pumping)
Settlement (m)
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.60
-0.70
-0.80
-0.90
-1.00
-1.10
-1.20
Settlement cell reservoir empty
Sett=1.11m for 0.85m spacing
Sett=1.09m for 1.20m spacing
30-Nov-09
10-Dec-09
20-Dec-09
30-Dec-09
09-Jan-10
19-Jan-10
29-Jan-10
08-Feb-10
18-Feb-10
28-Feb-10
10-Mar-10
20-Mar-10
30-Mar-10
09-Apr-10
19-Apr-10
29-Apr-10
09-May-10
19-May-10
29-May-10
08-Jun-10
18-Jun-10
28-Jun-10
08-Jul-10
18-Jul-10
28-Jul-10
07-Aug-10
17-Aug-10
27-Aug-10
06-Sep-10
16-Sep-10
26-Sep-10
06-Oct-10
16-Oct-10
26-Oct-10
05-Nov-10
15-Nov-10
Time (days)
Spacing=1.20m Depth=Surface
Spacing=0.85m Depth=Surface
Spacing=1.20m Depth=0.90m
Spacing=0.85m Depth=0.90m
Spacing=1.20m Depth=1.90m
Spacing=0.85m Depth=1.90m
Spacing=1.20m Depth=2.65m
Spacing=0.85m Depth=2.65m

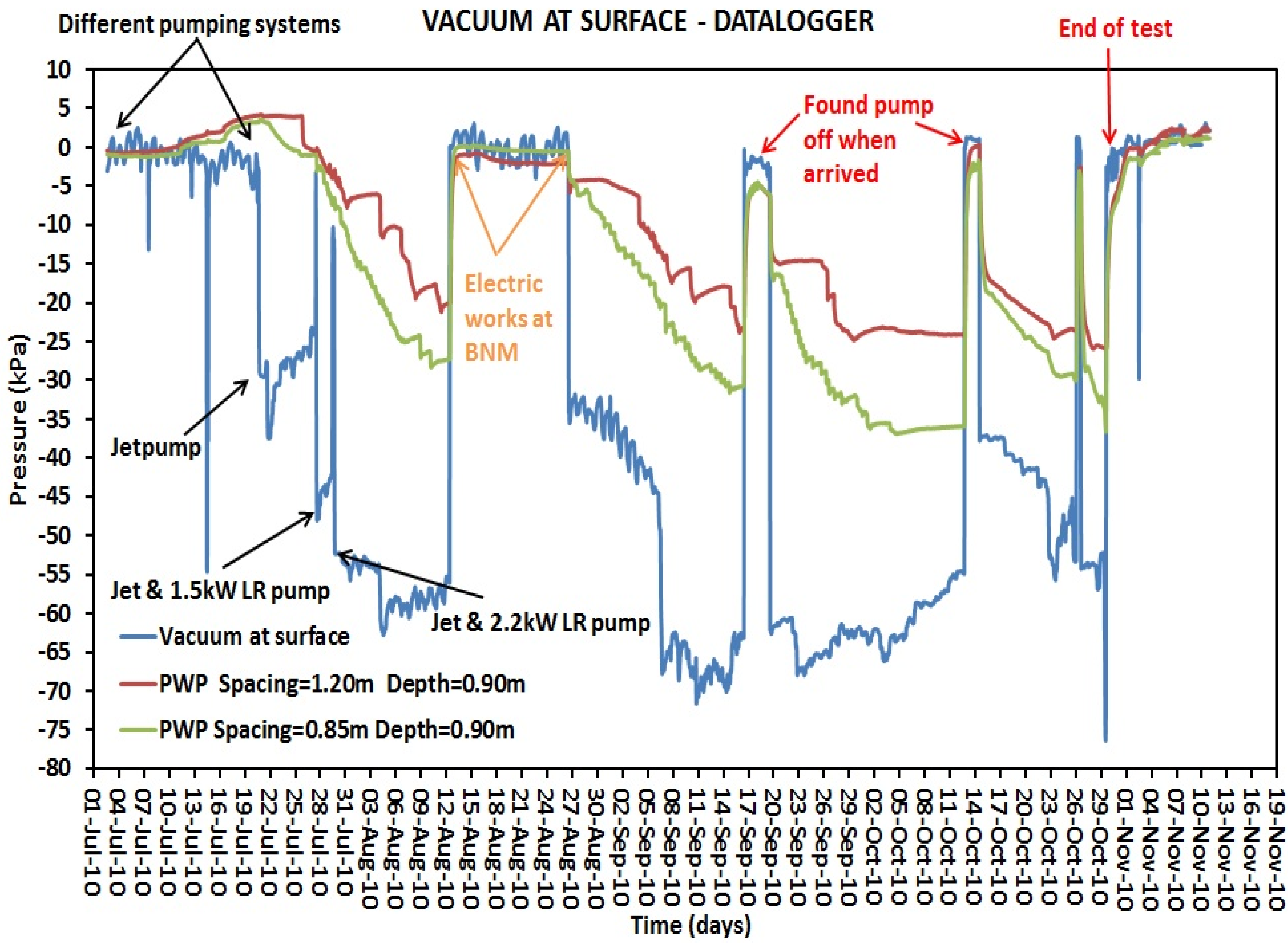
Volume of water extracted



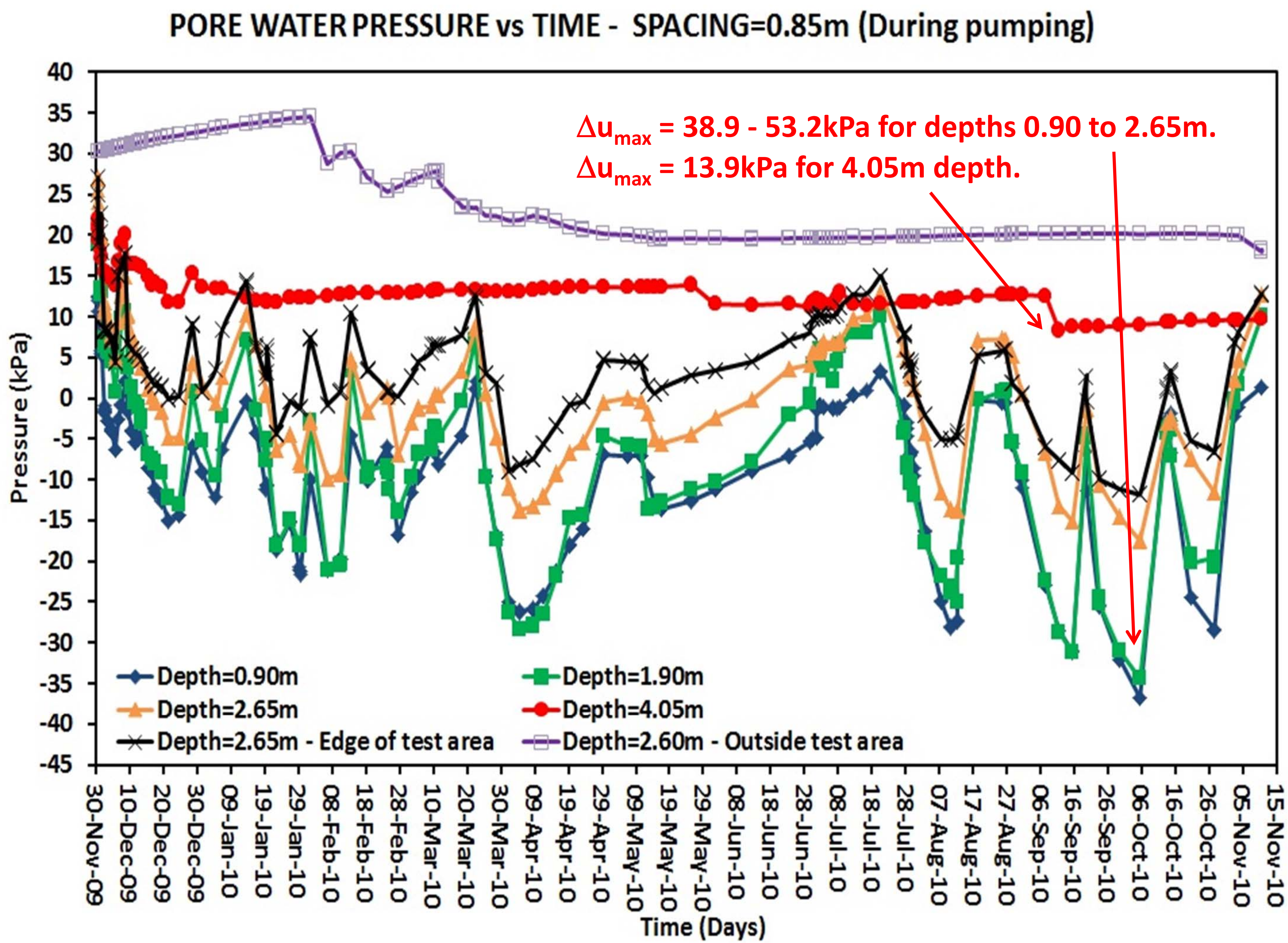

DAILY RAIN (During pumping)
Rain (mm)
Time (days)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
28-Nov-09
08-Dec-09
18-Dec-09
28-Dec-09
07-Jan-10
17-Jan-10
27-Jan-10
06-Feb-10
16-Feb-10
26-Feb-10
08-Mar-10
18-Mar-10
28-Mar-10
07-Apr-10
17-Apr-10
27-Apr-10
07-May-10
17-May-10
27-May-10
06-Jun-10
16-Jun-10
26-Jun-10
06-Jul-10
16-Jul-10
26-Jul-10
05-Aug-10
15-Aug-10
25-Aug-10
04-Sep-10
14-Sep-10
24-Sep-10
04-Oct-10
14-Oct-10
24-Oct-10
03-Nov-10


WATER TABLE (During pumping)
WATER TABLE (m)
Time (days)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
27-Nov-09
07-Dec-09
17-Dec-09
27-Dec-09
06-Jan-10
16-Jan-10
26-Jan-10
05-Feb-10
15-Feb-10
25-Feb-10
07-Mar-10
17-Mar-10
27-Mar-10
06-Apr-10
16-Apr-10
26-Apr-10
06-May-10
16-May-10
26-May-10
05-Jun-10
15-Jun-10
25-Jun-10
05-Jul-10
15-Jul-10
25-Jul-10
04-Aug-10
14-Aug-10
24-Aug-10
03-Sep-10
13-Sep-10
23-Sep-10
03-Oct-10
13-Oct-10
23-Oct-10
02-Nov-10
12-Nov-10
Plate 10
Plate 17
Plate 20
Plate 21
Plate 23
Plate 25

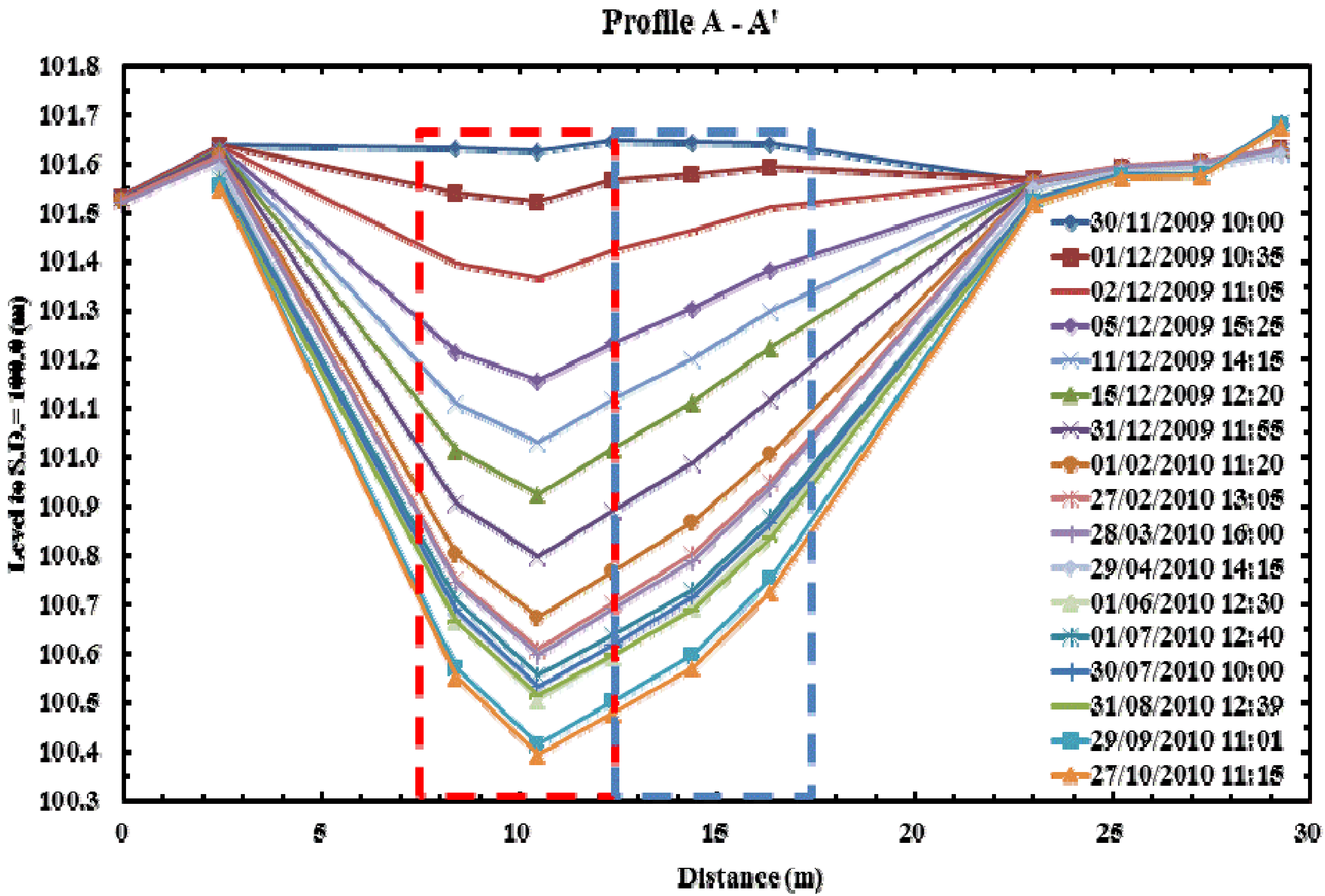

VACUUM AT SURFACE
Pipe leak/burst
Leak at membrane
Flooded surface to check for leaks.
Electric failure
Stoped flooding surface.
found and fixed big tear at membrane at bottom of side ditch.
Water frozen in pipes
Electric failure
0 kPa
-5 kPa
-10 kPa
-15 kPa
-20 kPa
-25 kPa
-30 kPa
-35 kPa
-40 kPa
-45 kPa
-50 kPa
-55 kPa
-60 kPa
-65 kPa
-70 kPa
-75 kPa
-80 kPa
-85 kPa
Vacuum (kPa)
30-Nov-09
10-Dec-09
20-Dec-09
30-Dec-09
09-Jan-10
19-Jan-10
29-Jan-10
08-Feb-10
18-Feb-10
28-Feb-10
10-Mar-10
20-Mar-10
30-Mar-10
09-Apr-10
19-Apr-10
29-Apr-10
09-May-10
19-May-10
29-May-10
08-Jun-10
18-Jun-10
28-Jun-10
08-Jul-10
18-Jul-10
28-Jul-10
07-Aug-10
17-Aug-10
27-Aug-10
06-Sep-10
16-Sep-10
26-Sep-10
06-Oct-10
16-Oct-10
26-Oct-10
05-Nov-10
15-Nov-10
Time (days)
Jetpump
0.75kW LR pump
Reinstalled Jetpump
Jet and 1.5kW LR pumps
Jet and 2.2kW LR up to 12 Aug 2010
Jet and 2.2 kW LR from 26 Aug 2010



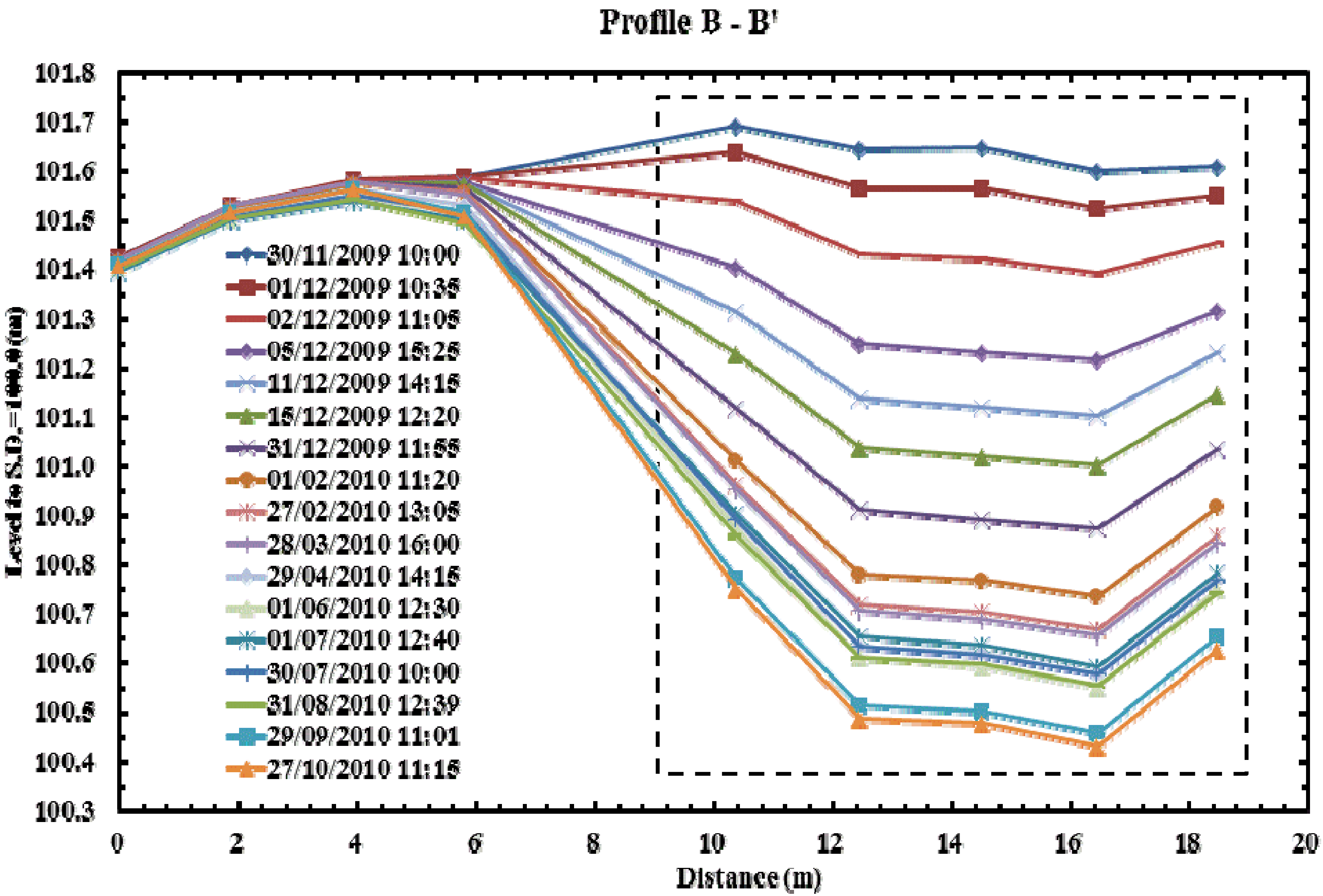
VACUUM AT SURFACE - DATALOGGER
Different pumping systems
End of test
Found pump off when arrived
Electric works at BNM
Jetpump
Jet & 1.5kW LR pump
Jet & 2.2kW LR pump
Vacuum at surface
PWP Spacing=1.20m Depth=0.90m
PWP Spacing=0.85m Depth=0.90m
Pressure (kPa)
Time (days)
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
01-Jul-10
04-Jul-10
07-Jul-10
10-Jul-10
13-Jul-10
16-Jul-10
19-Jul-10
22-Jul-10
25-Jul-10
28-Jul-10
31-Jul-10
03-Aug-10
06-Aug-10
09-Aug-10
12-Aug-10
15-Aug-10
18-Aug-10
21-Aug-10
24-Aug-10
27-Aug-10
30-Aug-10
02-Sep-10
05-Sep-10
08-Sep-10
11-Sep-10
14-Sep-10
17-Sep-10
20-Sep-10
23-Sep-10
26-Sep-10
29-Sep-10
02-Oct-10
05-Oct-10
08-Oct-10
11-Oct-10
14-Oct-10
17-Oct-10
20-Oct-10
23-Oct-10
26-Oct-10
29-Oct-10
01-Nov-10
04-Nov-10
07-Nov-10
10-Nov-10
13-Nov-10
16-Nov-10
19-Nov-10

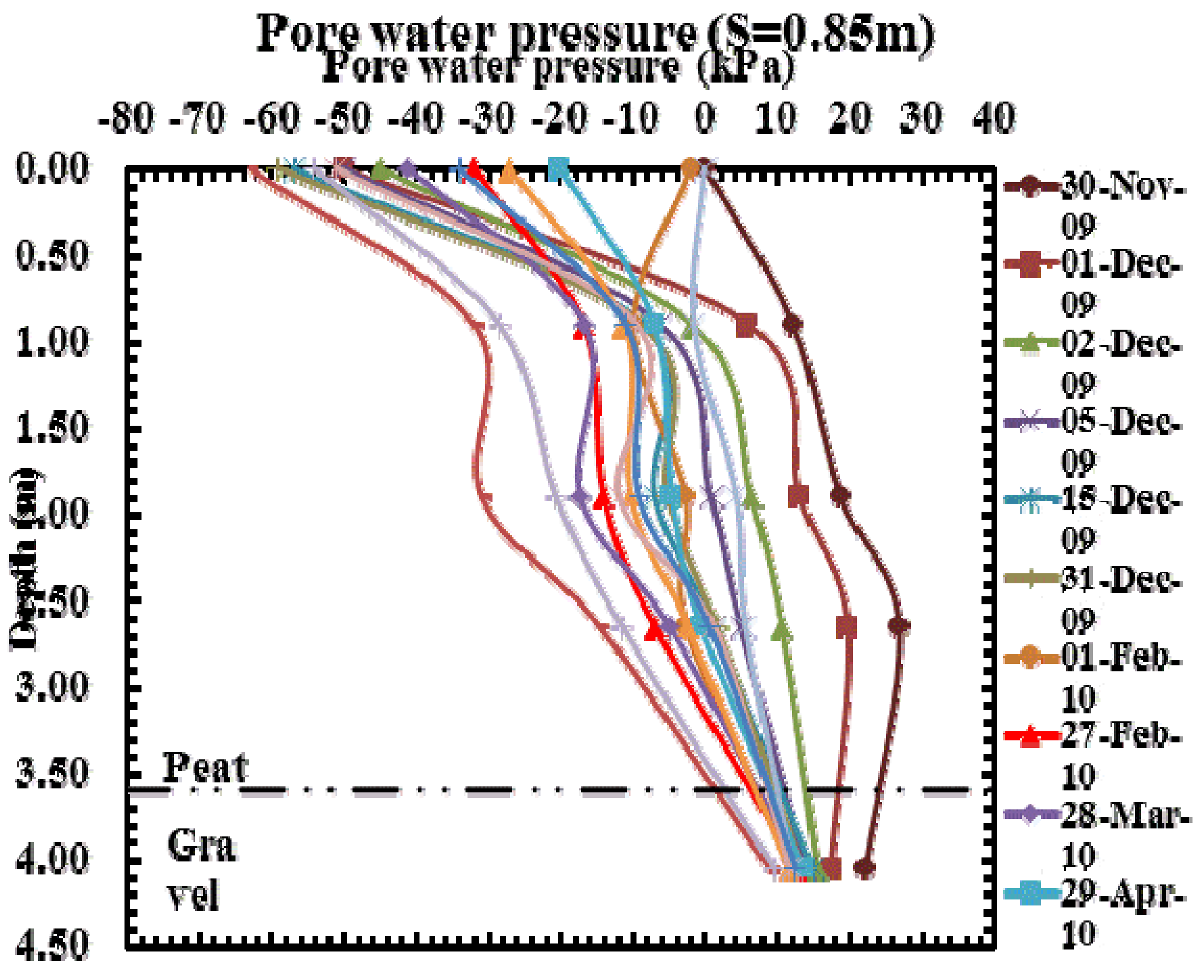


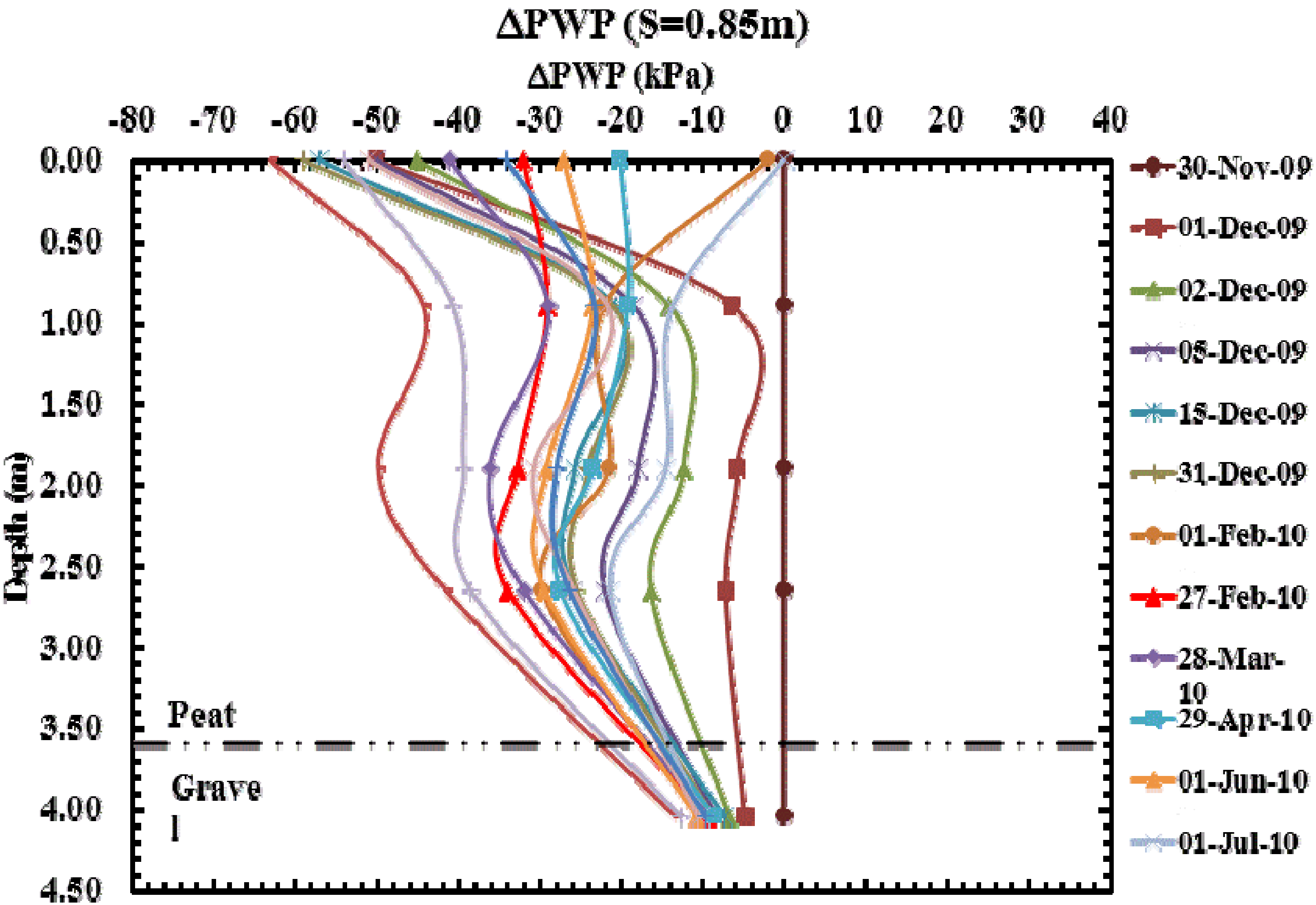
PORE WATER PRESSURE vs TIME - SPACING=0.85m (During pumping)
Δu_{max} = 38.9 - 53.2kPa for depths 0.90 to 2.65m.
Δu_{max} = 13.9kPa for 4.05m depth.
Pressure (kPa)
Time (Days)
Depth=0.90m
Depth=1.90m
Depth=2.65m
Depth=4.05m
Depth=2.65m - Edge of test area
Depth=2.60m - Outside test area
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
30-Nov-09
10-Dec-09
20-Dec-09
30-Dec-09
09-Jan-10
19-Jan-10
29-Jan-10
08-Feb-10
18-Feb-10
28-Feb-10
10-Mar-10
20-Mar-10
30-Mar-10
09-Apr-10
19-Apr-10
29-Apr-10
09-May-10
19-May-10
29-May-10
08-Jun-10
18-Jun-10
28-Jun-10
08-Jul-10
18-Jul-10
28-Jul-10
07-Aug-10
17-Aug-10
27-Aug-10
06-Sep-10
16-Sep-10
26-Sep-10
06-Oct-10
16-Oct-10
26-Oct-10
05-Nov-10
15-Nov-10

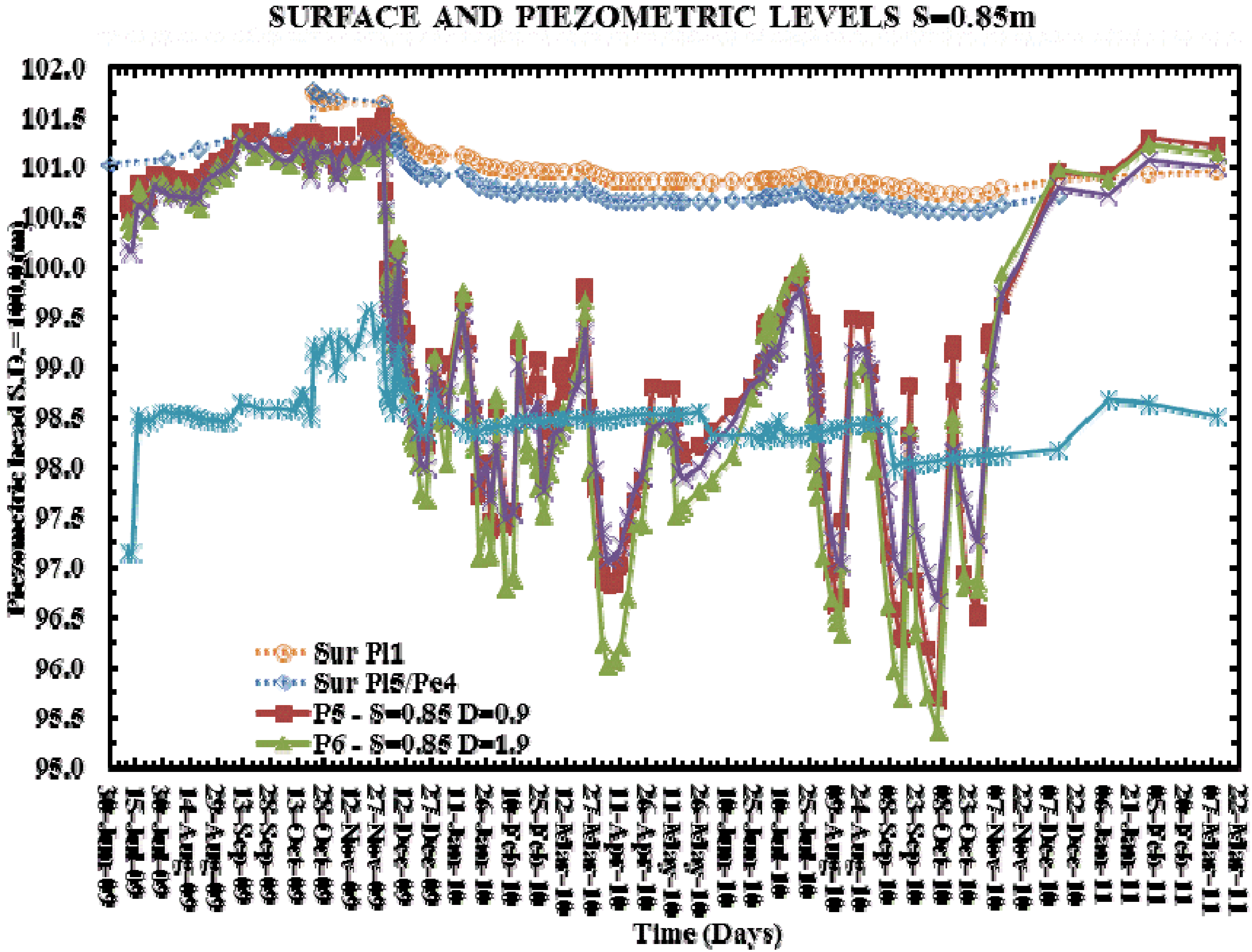


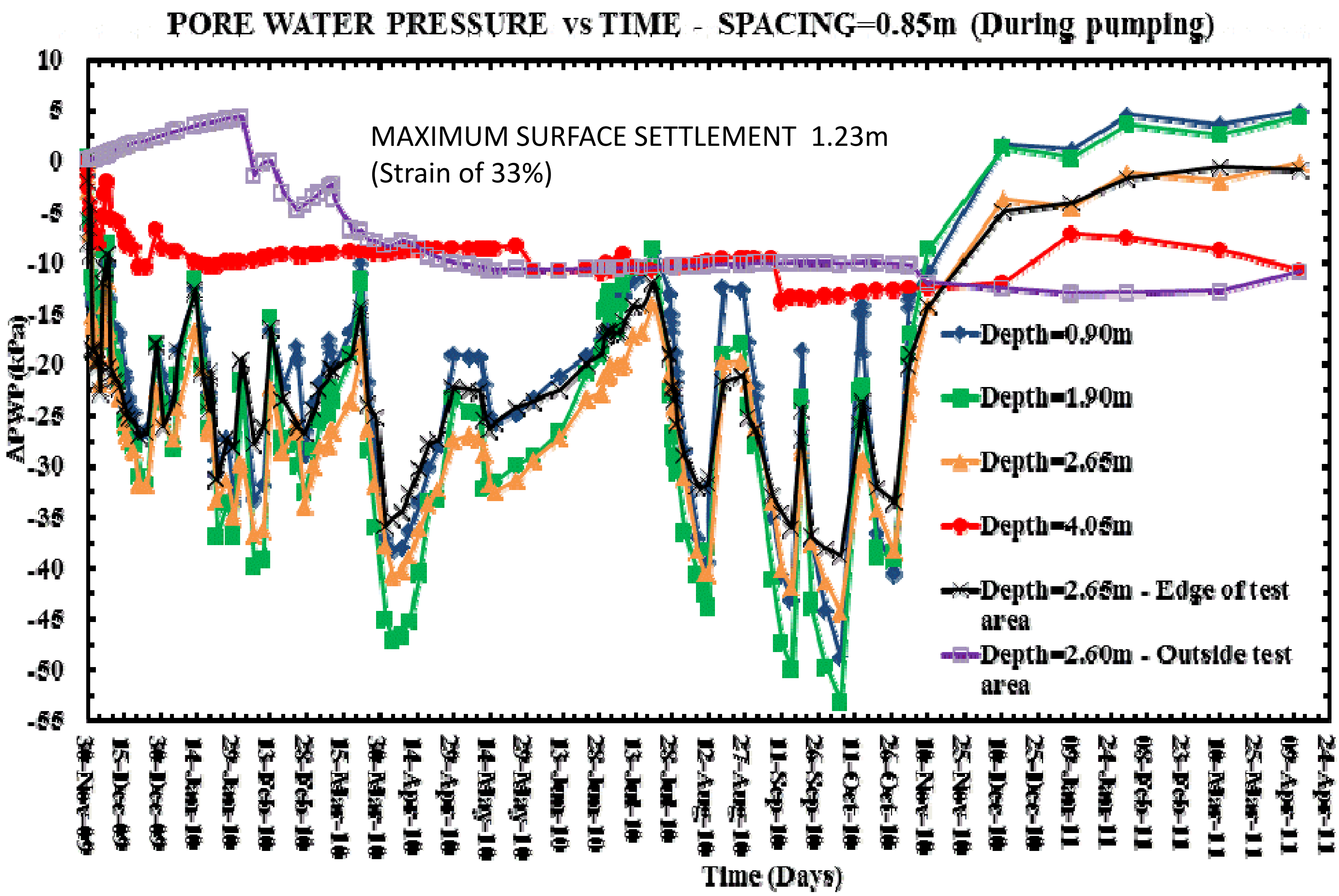
Profile A - A'
Level to S.D. = 100.0 (m)
Distance (m)
30/11/2009 10:00
01/12/2009 10:35
02/12/2009 11:05
05/12/2009 15:25
11/12/2009 14:15
15/12/2009 12:20
31/12/2009 11:55
01/02/2010 11:20
27/02/2010 13:05
28/03/2010 16:00
29/04/2010 14:15
01/06/2010 12:30
01/07/2010 12:40
30/07/2010 10:00
31/08/2010 12:39
29/09/2010 11:01
27/10/2010 11:15


Profile B - B'
101.8
101.7
101.6
101.5
101.4
101.3
101.2
101.1
101.0
100.9
100.8
100.7
100.6
100.5
100.4
100.3
0
2
4
6
8
10
12
14
16
18
20
Distance (m)
30/11/2009 10:00
01/12/2009 10:35
02/12/2009 11:05
05/12/2009 15:25
11/12/2009 14:15
15/12/2009 12:20
31/12/2009 11:55
01/02/2010 11:20
27/02/2010 13:05
28/03/2010 16:00
29/04/2010 14:15
01/06/2010 12:30
01/07/2010 12:40
30/07/2010 10:00
31/08/2010 12:39
29/09/2010 11:01
27/10/2010 11:15


Pore water pressure (S=0.85m)
Pore water pressure (kPa)
-80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
Depth (m)
Peat
Gra vel
30-Nov-09
01-Dec-09
02-Dec-09
05-Dec-09
15-Dec-09
31-Dec-09
01-Feb-10
27-Feb-10
28-Mar-10
29-Apr-10


ΔPWP (S=0.85m)
ΔPWP (kPa)
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
Depth (m)
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
Peat
Gravel
30-Nov-09
01-Dec-09
02-Dec-09
05-Dec-09
15-Dec-09
31-Dec-09
01-Feb-10
27-Feb-10
28-Mar-10
29-Apr-10
01-Jun-10
01-Jul-10

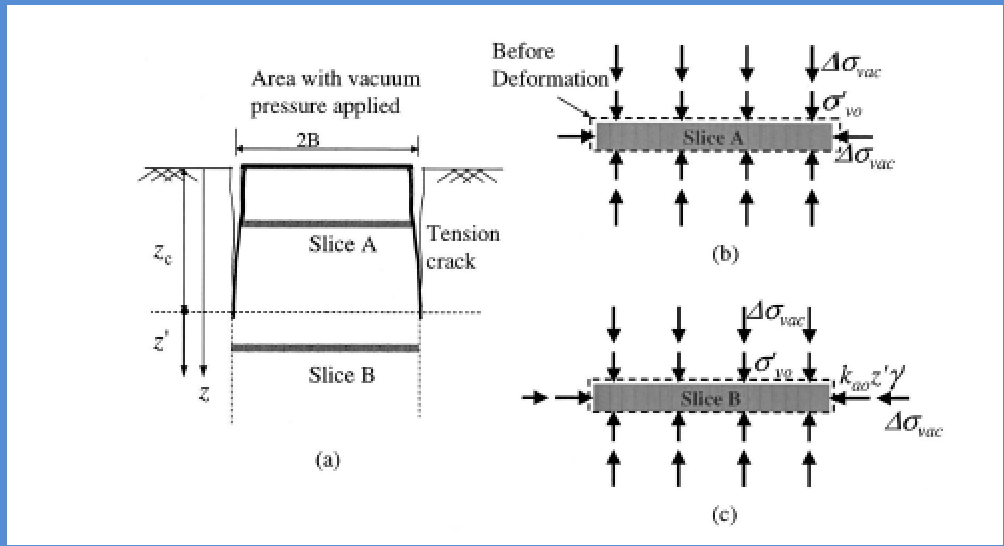

SURFACE AND PIEZOMETRIC LEVELS S=0.85m
Piezometric head S.D. = 100.0 (m)
102.0
101.5
101.0
100.5
100.0
99.5
99.0
98.5
98.0
97.5
97.0
96.5
96.0
95.5
95.0
Sur Pl1
Sur Pl5/Pe4
P5 - S=0.85 D=0.9
P6 - S=0.85 D=1.9
30-Jun-09
15-Jul-09
30-Jul-09
14-Aug-09
29-Aug-09
13-Sep-09
28-Sep-09
13-Oct-09
28-Oct-09
12-Nov-09
27-Nov-09
12-Dec-09
27-Dec-09
11-Jan-10
26-Jan-10
10-Feb-10
25-Feb-10
12-Mar-10
27-Mar-10
11-Apr-10
26-Apr-10
11-May-10
26-May-10
10-Jun-10
25-Jun-10
10-Jul-10
25-Jul-10
09-Aug-10
24-Aug-10
08-Sep-10
23-Sep-10
08-Oct-10
23-Oct-10
07-Nov-10
22-Nov-10
07-Dec-10
22-Dec-10
06-Jan-11
21-Jan-11
05-Feb-11
20-Feb-11
07-Mar-11
22-Mar-11
Time (Days)



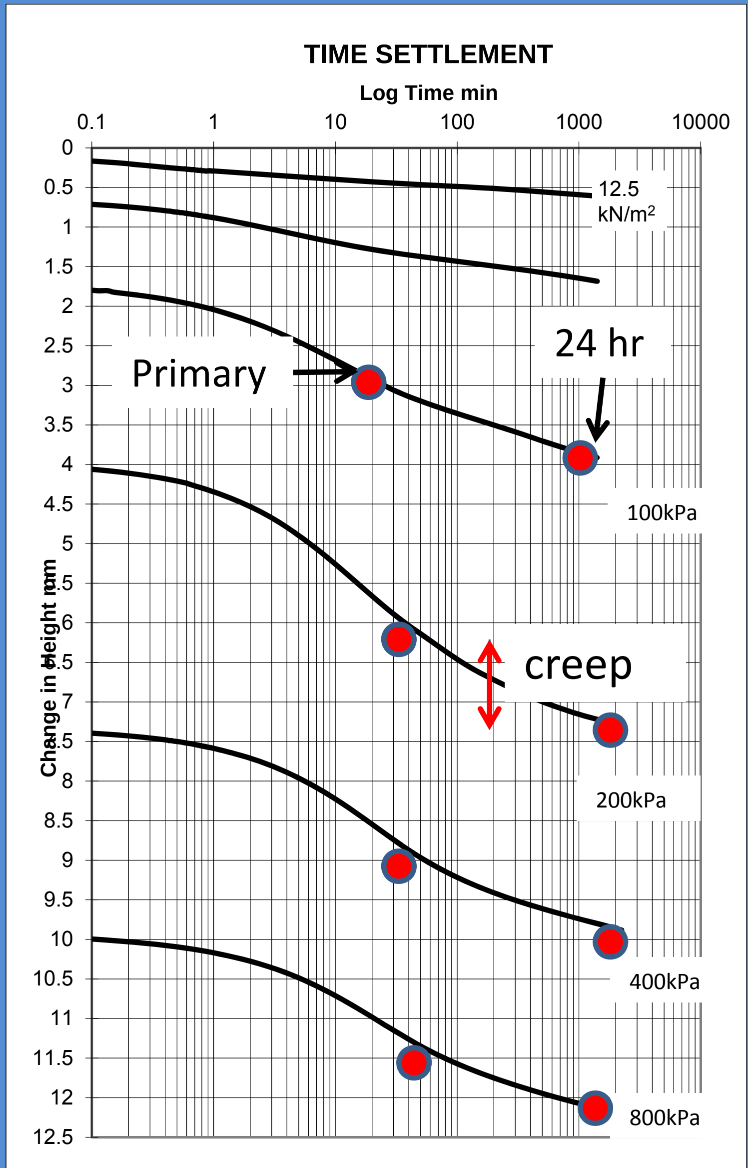
PORE WATER PRESSURE vs TIME - SPACING=0.85m (During pumping)
MAXIMUM SURFACE SETTLEMENT 1.23m
(Strain of 33%)
APWP (kPa)
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
Depth=0.90m
Depth=1.90m
Depth=2.65m
Depth=4.05m
Depth=2.65m - Edge of test area
Depth=2.60m - Outside test area
30-Nov-09
15-Dec-09
30-Dec-09
14-Jan-10
29-Jan-10
13-Feb-10
28-Feb-10
15-Mar-10
30-Mar-10
14-Apr-10
29-Apr-10
14-May-10
29-May-10
13-Jun-10
28-Jun-10
13-Jul-10
28-Jul-10
12-Aug-10
27-Aug-10
11-Sep-10
26-Sep-10
11-Oct-10
26-Oct-10
10-Nov-10
25-Nov-10
10-Dec-10
25-Dec-10
09-Jan-11
24-Jan-11
08-Feb-11
23-Feb-11
10-Mar-11
25-Mar-11
09-Apr-11
24-Apr-11
Time (Days)

Visual 1st June 2010

CRACKS AT EDGE



Chai et al. (2005)

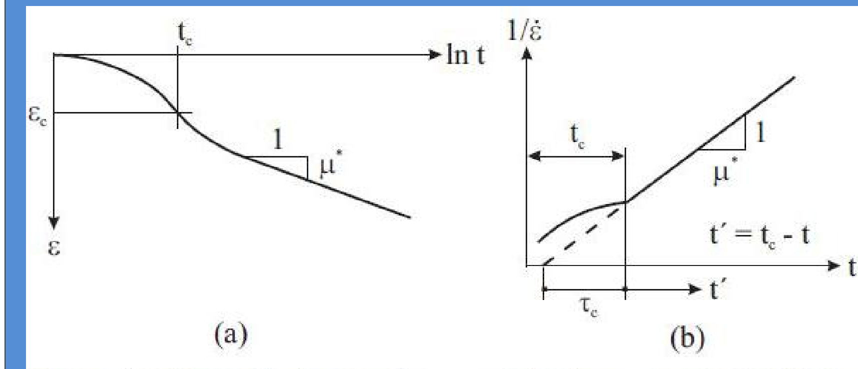


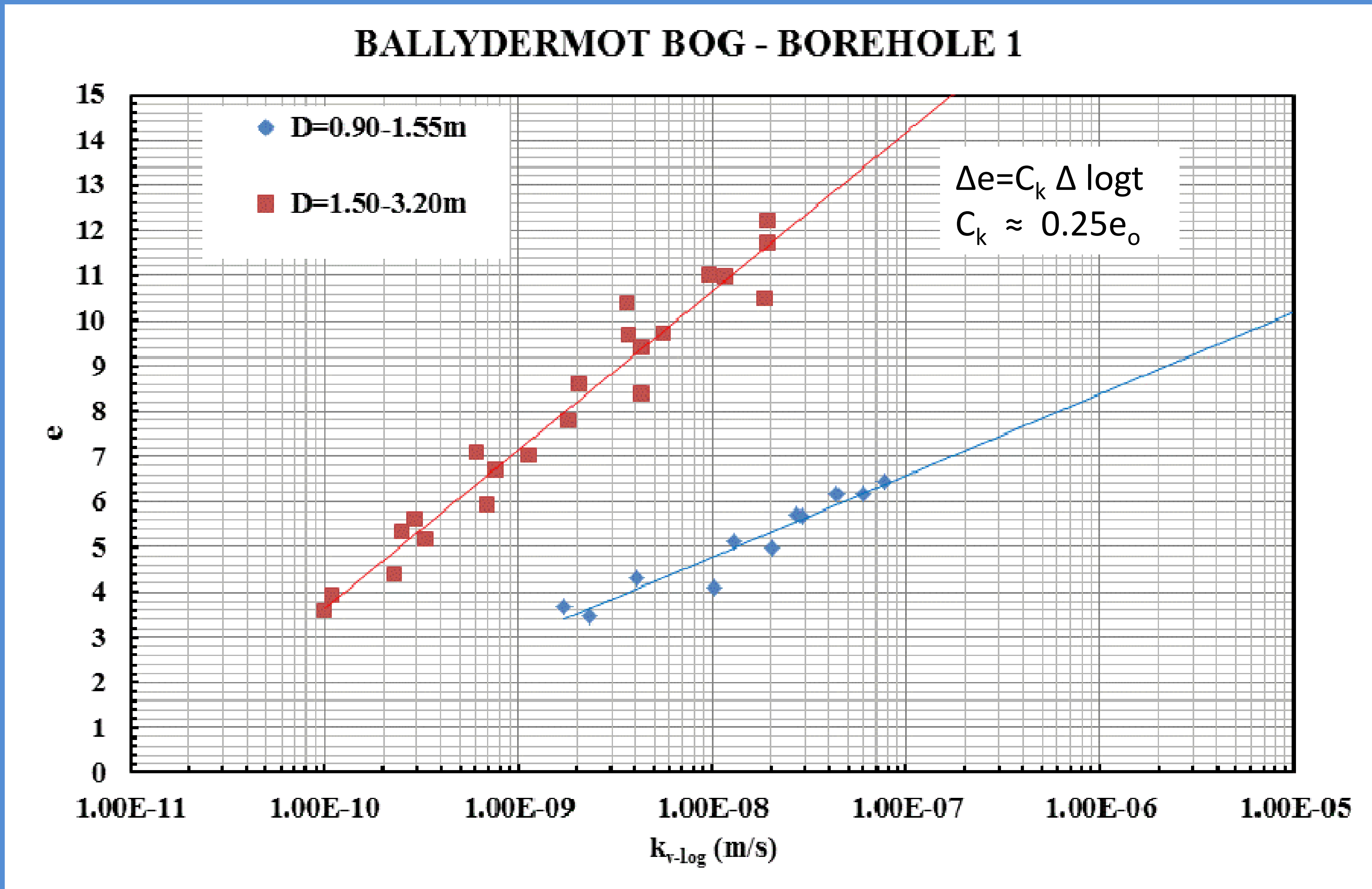
SETTLEMENT OF PEAT

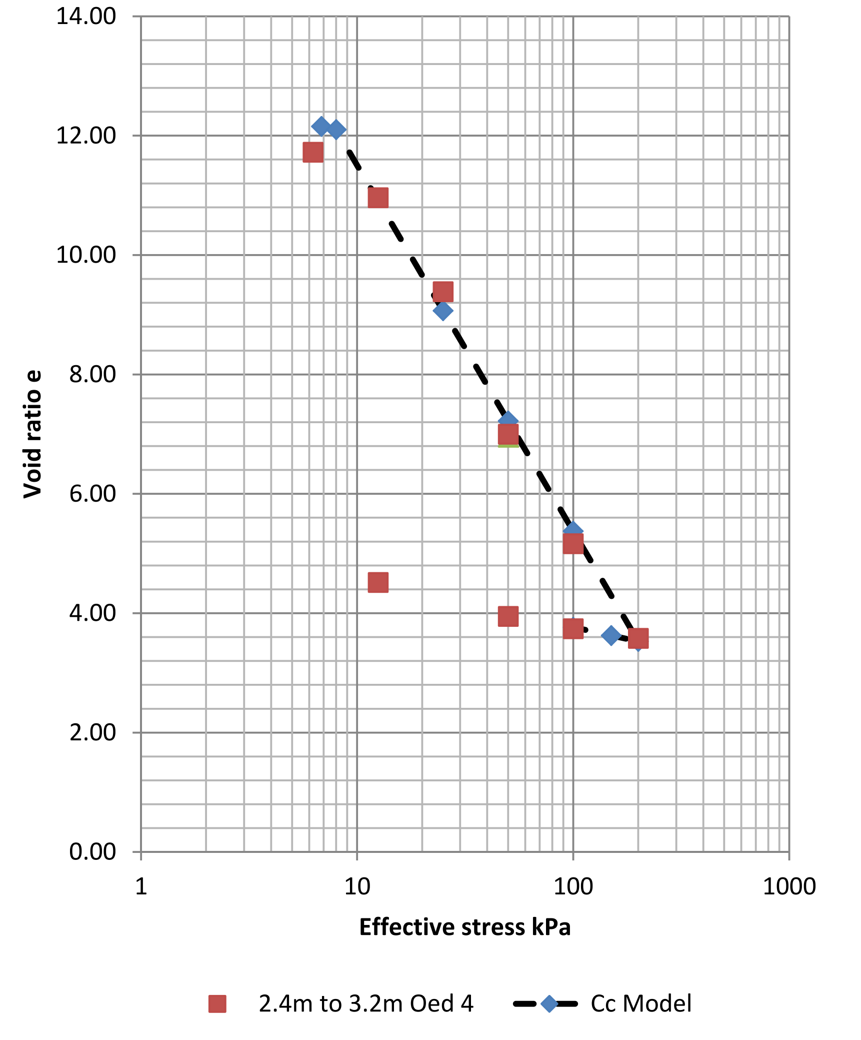
Rate of settlement

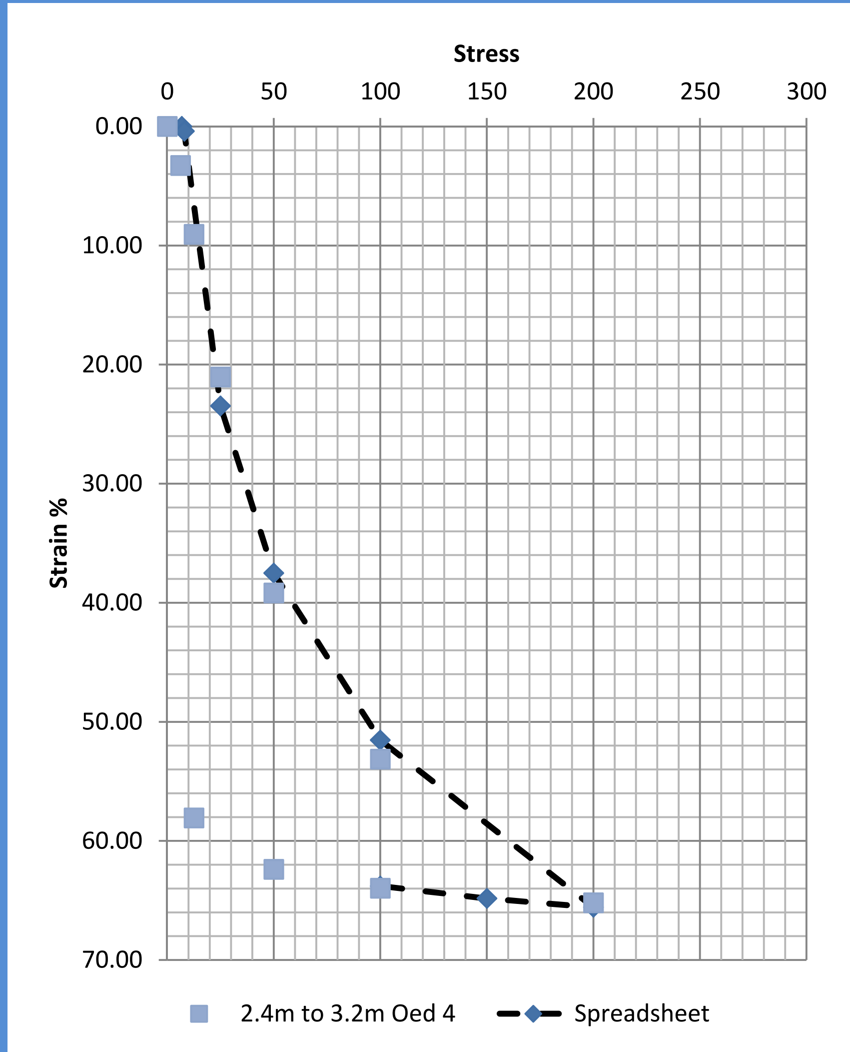
c_v; c_{vh}; c_{hh}

k ; k_v; k_h



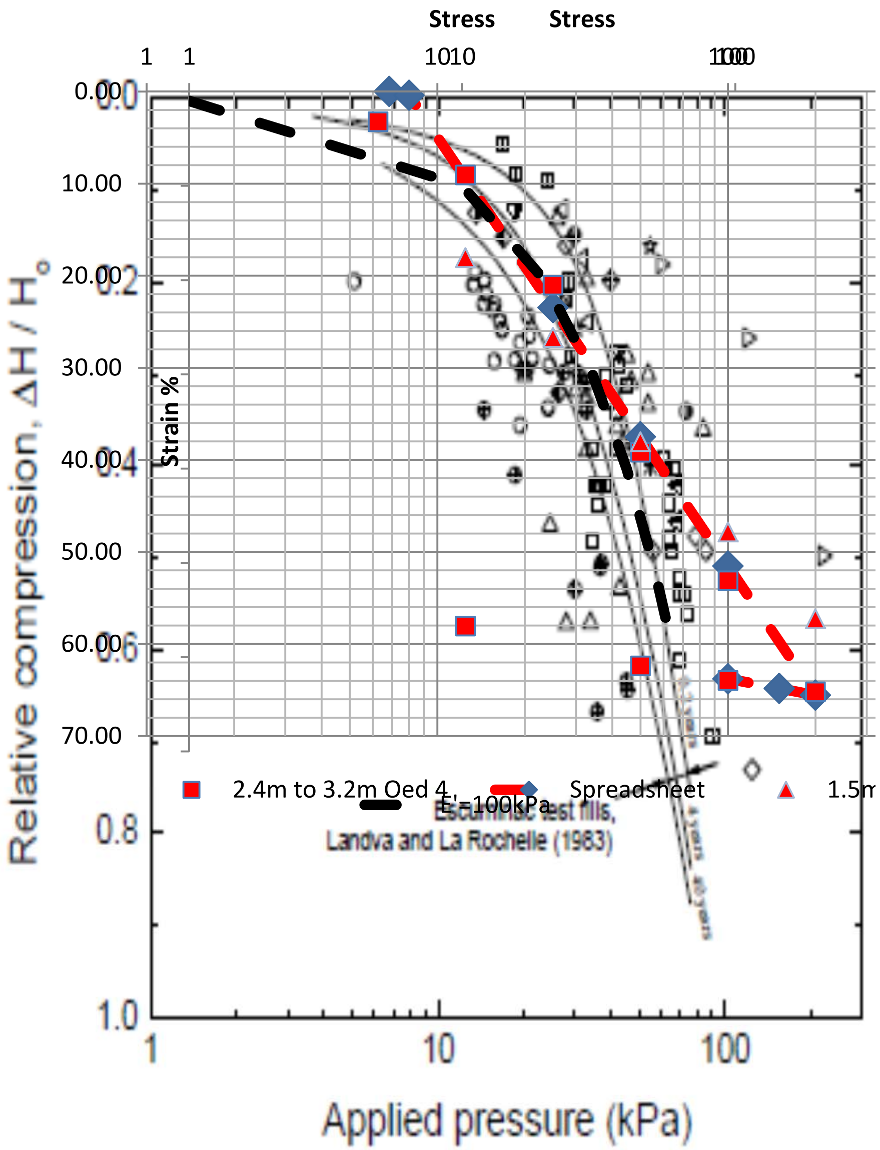

BALLYDERMOT BOG - BOREHOLE 1
D=0.90-1.55m
D=1.50-3.20m
Δe=C$_k$ Δ logt
C$_k$ ≈ 0.25e$_o$
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
e
1.00E-11
1.00E-10
1.00E-09
1.00E-08
1.00E-07
1.00E-06
1.00E-05
k$_{v-log}$ (m/s)


14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Void ratio e
1
10
100
1000
Effective stress kPa
2.4m to 3.2m Oed 4
Cc Model


Stress
0
50
100
150
200
250
300
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
Strain %
2.4m to 3.2m Oed 4
Spreadsheet

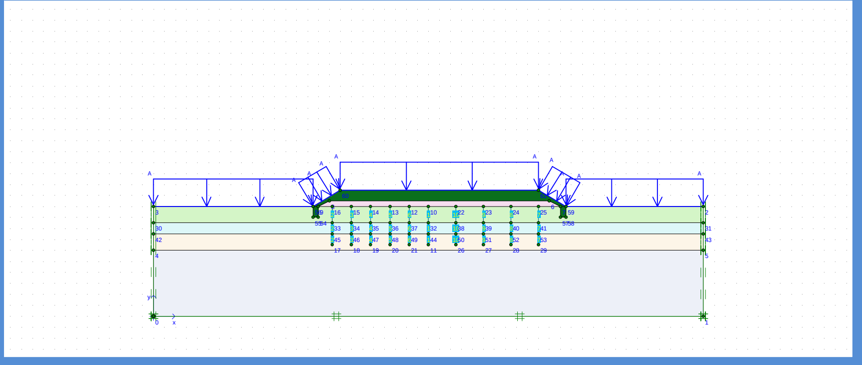
Soil models investigated

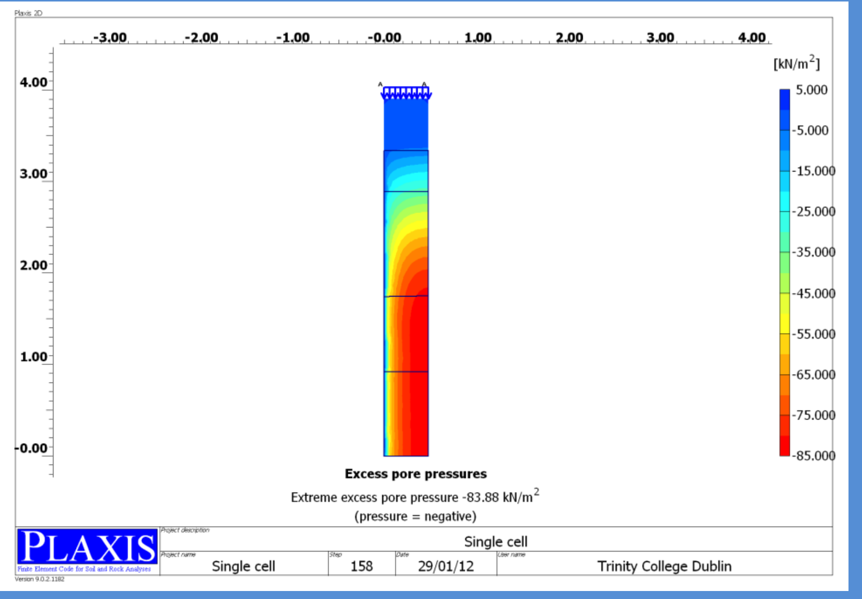
- Simple EOP C_s & C_c ($C_R = C_c/\{(1+e_o)\}$ & R_R) and σ_{vc}'
- Soft Soil model (SS) Plaxis ($\lambda^* = C_c/\{2.3(1+e_o)\}$, κ^*)
- Soft Soil Creep model Plaxis ($\lambda^* = C_c/\{2.3(1+e_o)\}$, κ^*, μ^*)
-

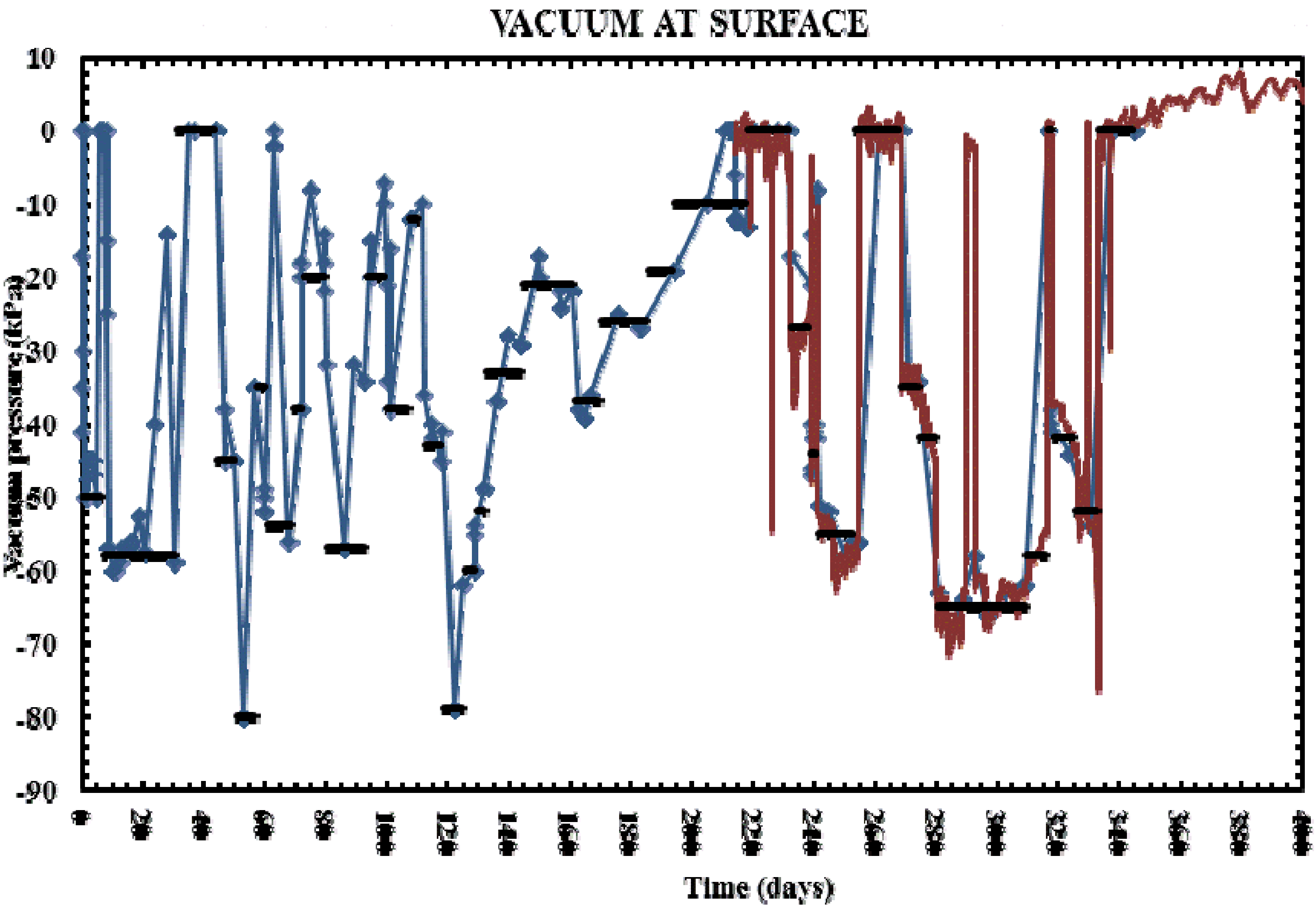

Stress
Stress
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
0.0
0.2
0.4
0.6
0.8
1.0
Strain %
Relative compression, ΔH / H₀
2.4m to 3.2m Oed 4
E'=100kPa
Spreadsheet
Escuminac test fills,
Landva and La Rochelle (1983)
1
10
100
Applied pressure (kPa)

E'= 100kPa

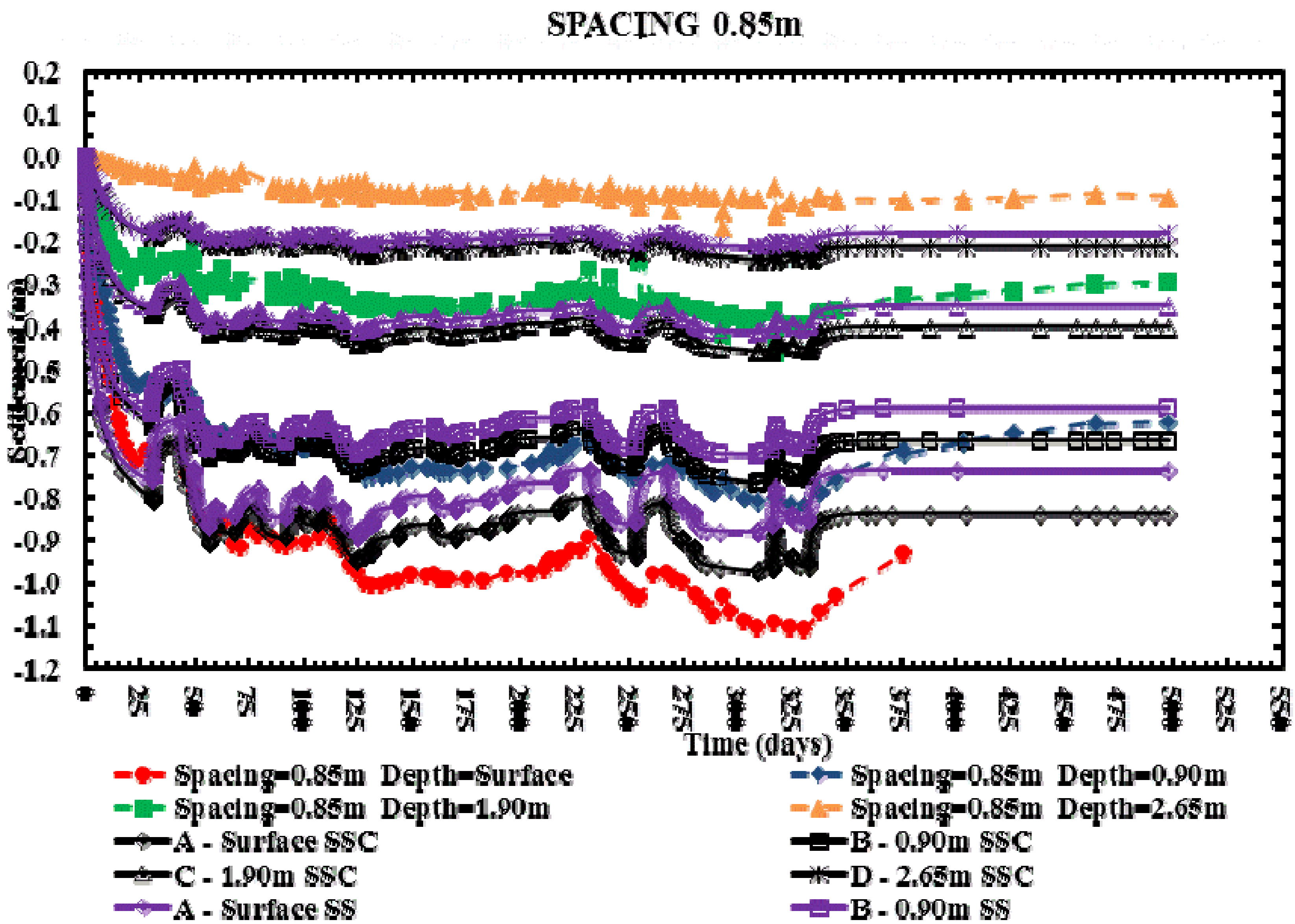
Modelling vacuum consolidation







VACUUM AT SURFACE
Vacuum pressure (kPa)
Time (days)
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400



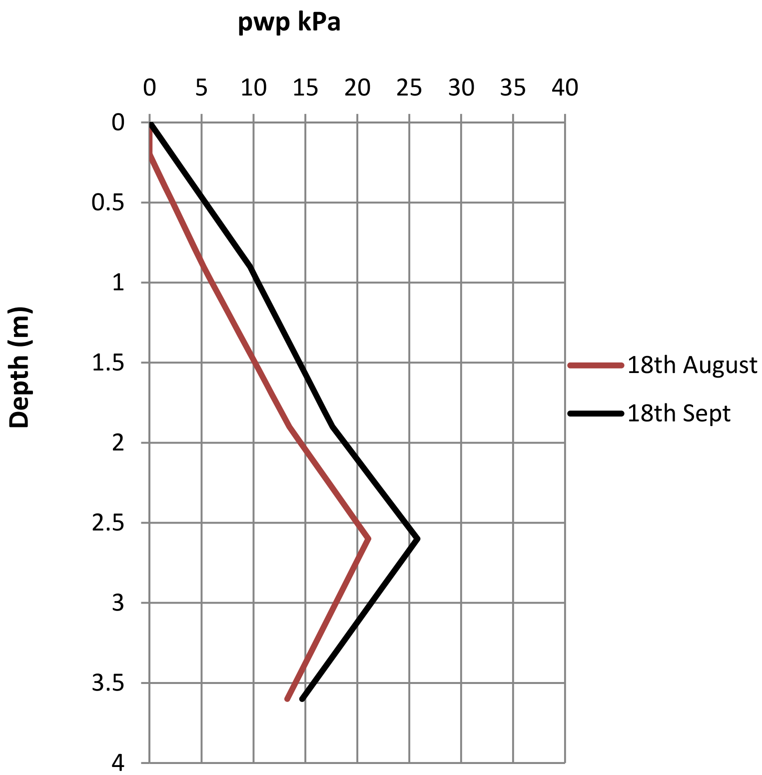
SPACING 0.85m
Settlement (m)
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
500
525
550
Time (days)
Spacing=0.85m Depth=Surface
Spacing=0.85m Depth=0.90m
Spacing=0.85m Depth=1.90m
Spacing=0.85m Depth=2.65m
A - Surface SSC
B - 0.90m SSC
C - 1.90m SSC
D - 2.65m SSC
A - Surface SS
B - 0.90m SS

VALUES USED ON BACK ANALYSIS WITH SSC MODEL

	Upper peat	Middle peat	Lower peat
POP	10	5	11
l*	0.125	0.16	0.16
k*	0.05	0.055	0.04
m*	0.0065	0.0078	0.009
g	10.45	10.1	10.06
e_o	7.42	13.81	12.05
k_v=k_H (m/day)	0.3	0.2	0.01
c_k	1.8	3.44	3.44

PARAMETERS INTERPRETED FROM LABORATORY OEDOMETER TESTS

	Upper peat	Middle peat	Lower peat
POP	10	5	11
l*	0.11 to 0.125	0.14 to 0.16	0.16 to 0.2
k*	0.022 to 0.05	0.03 to 0.055	0.033 to 0.04
m*	0.0065 to 0.008	0.0078 to 0.01	0.0065 to 0.009
g	10.45	10.1	10.06
e_o	6.78 – 8.69	13.43 – 14.5	11.5 – 12.5
k_v=k_H (m/day)	0.011 to 0.128	0.0053 to 0.011	0.0015 to 0.0029
c_k	1.8	3.44	3.44



- Swell using simple soil model = 0.161m
- Swell measured = 0.13m
- Equivalent E’ ≈ 100kPa at this very low effective stress.

CONCLUSIONS

- The TCD/NRA vacuum preloading field trial was implemented and showed that this technique can be successfully used in peat soils.

- The drainage system comprising PVDs, horizontal drains and a granular bed, was effective in distributing the applied vacuum pressure and collecting the drained water.

Practical difficulties/Observations

- Summer conditions general water table was lower than side barrier.
- Higher suctions achieved with vacuum pump but more stable values with liquid ring pump
- Pore pressure reduction at edges was slightly lower (2kPa to 8.5kPa) than at centre.
- ΔPWP roughly uniform with depth
- Vacuum pressure adequately transmitted in 0.85m and 1.2m spacings.

continued

- Calcification of pumps a significant issue

- Freezing, tears, bursts electrical cuts affected the performance.

- Airtight cover could be improved, use of water seal should be considered.

- Vacuum consolidation had little effect on the water table outside the test area.

- Behaviour can be simulated using standard soil models.

ACKNOWLEDGEMENTS

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- Trinity College Dublin.
- Geotechnical Trust Fund Award (Engineers Ireland).
- Universidad de Antioquia
- Bord na Móna