In situ permeability measurement with the BAT Permeameter

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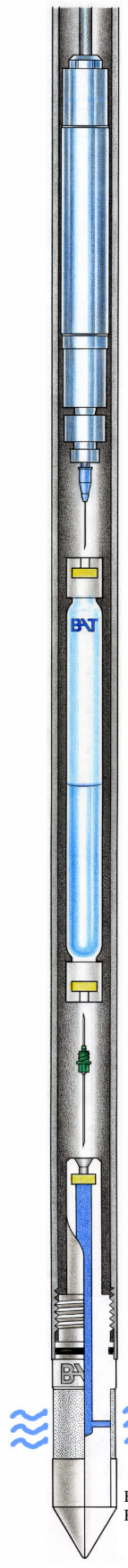
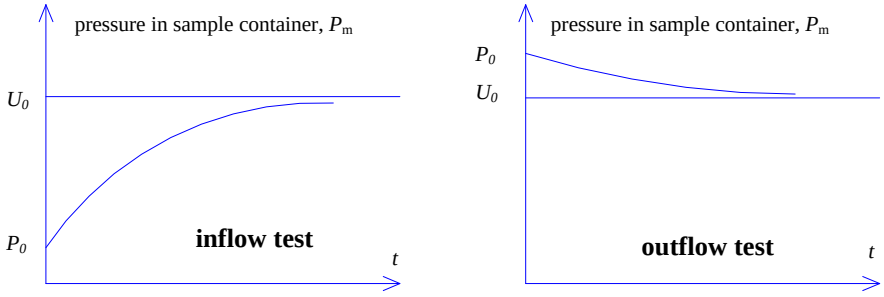
System description



System layout (in- or outflow test)

The BAT Permeameter is used for in-situ evaluation of soil permeability. The method used for evaluation of the coefficient of permeability *k* is of the type ”falling head”-test. Depending on the groundwater situation, unsaturated or saturated zone, the test can either be done as an inflow or outflow test. Volume changes in the system are calculated based on measured pressure changes and by using Boyle´s law.



Calculation of the coefficient of permeability , *k*

The calculation of the out- or inflow volume in the sample container is made by using Boyle´s law which is as follows:

$$p_0 V_0 = p_t V_t \quad \text{N.B. } p \text{ represents absolute pressure} \qquad (1)$$

(After completion of the test the actual out- or inflow volume can also be measured, and by using formula (1) to calculate the theoretical flow volume the quality of the test can easily be checked)

The permeability coefficient, *k*, is calculated using the following equation:
(Bengtsson, P-E, 1984; Torstensson & Petsonk, 1986)

$$k = \frac{P_0 V_0}{F \cdot t \cdot 10^3}\left(\frac{1}{U_0 P_0} - \frac{1}{U_0 P_m} + \frac{1}{U_0^2}\ln\left(\frac{P_0 - U_0}{P_0} \times \frac{P_m}{P_m - U_0}\right)\right) \qquad (2)$$

where

k	coefficient of permeability	[m/s]
P_0	initial system pressure	[m H_2O]
V_0	initial system volume of air	[ml]
F	form factor of filter (3)	[mm]
t	time for the test	[s]
U_0	pore pressure at equilibrium	[m H_2O]
P_m	system pressure at time t	[m H_2O]

The equation for the form factor *F* of the filter element is as follows:

$$F = \frac{2pl}{\ln\left(\frac{l}{d} + \sqrt{1 + \left(\frac{l}{d}\right)^2}\right)} \qquad (3)$$

where l length of filter [mm]; d diameter of filter [mm]

For the BAT MKIII Filter Tip shown to the left the form factor is F = 230 mm. (l = 35mm, d = 31,5mm)

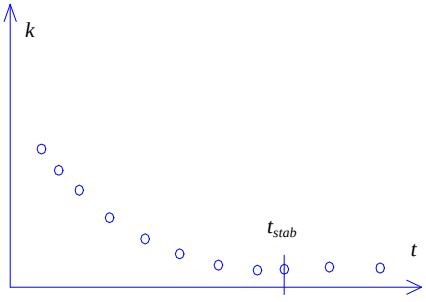
Time for stabilisation - time of testing

The *k*-value can be computed at any time.

The BAT system makes use of only small volume changes. Thus the test can be carried out quickly.

Typical stabilisation times, t_{stab}, as a function of the *k*-value are summarised below.

$k \approx 10^{-7}$ m/s ; $t_{stab} \approx$ 1 minute
$k \approx 10^{-8}$ m/s ; $t_{stab} \approx$ 5 minutes
$k \approx 10^{-9}$ m/s ; $t_{stab} \approx$ 1 hour
$k \approx 10^{-10}$ m/s ; $t_{stab} \approx$ 5 hours



Theory of the BAT Permeability Test

´The BAT Permeability Test is a type of ”falling head” test. The evaluation of the test is made by using Hvorslev´s equation *).

Parameters:

F =	Hvorslev´s flow factor	mm
k =	coefficient of permeability	m/s
U_0 =	equilibrium pore pressure in-situ (absolute)	m H_2O
P_0 =	initial system pressure (absolute)	m H_2O
P_m =	system pressure at time t (absolute)	m H_2O
V_0 =	initial system volume of air	ml
t =	time for the test	s

At any time t the corresponding coefficient of permeability k can be calculated using the following equation (see foregoing page):

$$k = P_0 \cdot V_0 / (F \cdot t \cdot 10^3) \cdot \{1/U_0 \cdot P_0 - 1/U_0 \cdot P_m + 1/U_0^2 \cdot \ln[(P_0 — U_0)/P_0 \cdot P_m/(P_m - U_0]\}$$

This equation has been derived, based on the following assumptions:

Constant temperature
It has been assumed that the temperature of the test equipment remains constant during the test. This means that Boyle´s law is applicable:

$$P_0 \cdot V_0 = P \cdot V \text{ (constant)} \qquad \text{Boyle´s law}$$

For installation depths, greater that one meter below ground surface this condition is normally fulfilled.

For shallow installation depths, however, significant temperature changes of the testing equipment can be experienced during the test. In this case the general gas law would be applicable:

$$P_0 \cdot V_0 / T_0 = P \cdot V / T \text{ (constant)} \qquad \text{general gas law}$$

in which: T = absolute temperature

The BAT Permeameter also contains a temperature sensor. Generally, the temperature shall always be measured simultaneously with the pressure measurements.

Contact BAT Geosystems for information on performing calculations, which consider the effect of temperature variation of the test equipment.

Pressure head
The above calculations do not take into account the effect of the column of water, present within the system, nor its variation during the test. Normally, that is, when large pressure differences are used, this has a negligible effect on the evaluation of permeability data.

For small pressure differences, however, this factor must be considered. Contact BAT Geosystems for information on performing calculations using such a method.

Evaluation of k - value
The coefficient of permeability, k , can normally be evaluated at a pressure equalisation (pressure dissipation or pressure recovery) of 50%. The corresponding system pressure is denoted P_{50}. Reference is made to ”Protocol sheet” and ”Excel calculation sheet”.

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*) Hvorslev, M.J. 1951. Time lag and soil permeability in ground water observations. Corps of Engineers, Waterways Experiment Station. Vicksburg, Mississippi. Bull. 36, 50 pp.

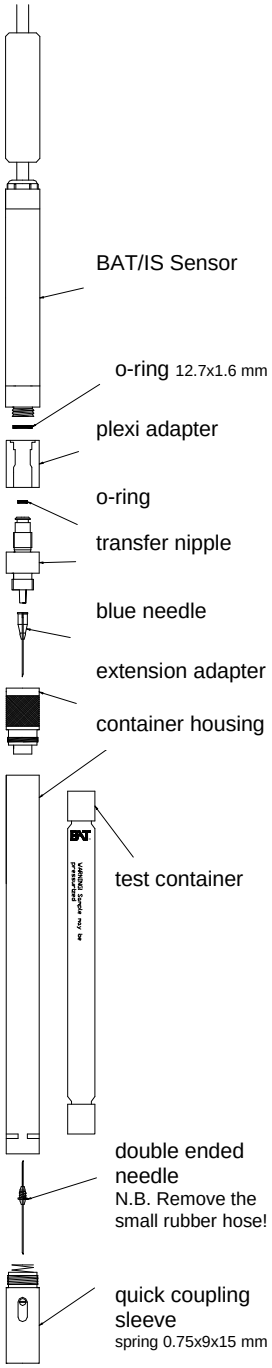
Introduction

The BAT Permeability Set consists of the following items:

Contents:

1. Container housing
2. Test container (35 ml)
3. Extension adapter
4. Quick coupling sleeve
5. Spare screws and springs
6. Screwdriver for mounting of double ended needle
7. Spare septas
8. Syringe (25 ml)
9. Container for used needles
10. Double ended needles
11. Vacuum pump
12. Blue needles

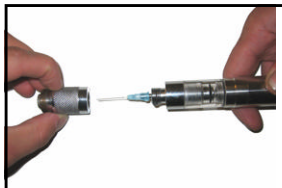
Complete system:



PRECAUTIONS

- Handle all parts carefully, especially the glass containers.
- Use only sharp needles. In general do not re-use needles, especially in case the set is used for sampling.
- Store the set in a dry and safe place.
- Do not use any tools to assemble the set. Finger tight is enough.

Assembly



Transfer nipple & extension adapter

- screw the transfer nipple until it seats in the plexiadapter. Make sure the parts all are dry.
- Attach a blue needle onto the transfer nipple.
- Mount the extension adapter onto the transfer nipple.

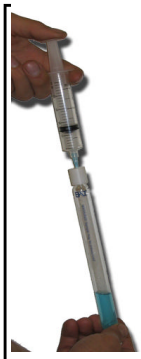
Test container

Outflow test

- Open the test container in one end by removing the screw cap and the septum.
- Fill the test container with a selected volume of water. Using a syringe. It is recommended to use 10 ml, see APPENDIX 1.
- Close the test container. Finger tight is enough!

Inflow test

- For an inflow test, make sure the test container is dry.



Initial system pressure P_0

Outflow test

- The initial system pressure P_0 is applied by injecting or extracting a volume of air, $?V$, to/from the test container, using a syringe, equipped with a blue, hypodermic needle.
- For calculation of P_0 and $?V$, see APPENDIX 1.

Inflow test

- For an inflow test a volume of air, $?V$, is extracted from the test container, see APPENDIX 1.

Container housing assembly / IS Field Unit

- Carefully insert the prepared sample container into the container housing.
- Connect the IS Field Unit, choose Display Mode (see page 7).
- Screw the container housing with the open end onto the extension adapter.
- Check the P_0 value with the IS Field Unit (see also comments in APPENDIX 1).
- After assembly hold the test unit pointing downwards at all times.

Double ended needle & Quick coupling sleeve

- Prepare the double ended needle for mounting.
- N.B. Remove the small rubber hose.

- By using the needle adapter in the handle of the screwdriver, screw the double ended needle until it seats into the quick coupling sleeve.
- Finally, screw the quick coupling sleeve onto the container housing.
- DONE!

Preparations and performing a test

General

- Use the BAT Test Protocol to fill in the required information.

- Measure the atmospheric pressure using the Field Unit and note the pressure on the protocol. Start logging the airpressure using the Field Unit´s internal sensor. An interval of 30 minutes is recommended (see separate manual). (See page 7 for interpretation of displayed values of the Field Unit)

- Measure the actual **absolute** pore pressure, U_m. Remember to add 0.2 mH_2O to the measured value, $U_0 = U_m + 0.2$ (see Test Protocol).

Outflow test

- For an outflow test, add 10 ml of water (V_v) to the test container. Since the test container has a volume of 35 ml, the volume of air will be V_0 = 25 ml.

- In order to avoid injection of air into the soil it is recommended to apply an initial system pressure of:

  $P_0 \approx 1.2 \cdot U_0$ (see APPENDIX1)

- WARNING. Application of too high initial system pressure, P_0, may cause hydraulic fracture in the soil surrounding the BAT Filter Tip, which will give misleading results of the permeability testing.

Inflow test

- For an inflow test, the starts with an empty and dry test container.
- Partial vacuum is applied in the test container by using a syringe, see APPENDIX 1.

Temperature equilibrium

- Before starting a permeability test it is important to reach temperature equlibrium, between the permeameter equipment and the interior of the extension pipe at the testing level. During the temperature equalization process the pressure in the test container will change, which can be observed by the IS Field Unit. Wait for a stable pressure reading before starting the test.

- A recommended procedure for reaching temperature equilibrium in a controlled manner is as follows:

1. Unscrew the quick coupling sleeve and lower the permeamer to the bottom of the pipe.

2. Lift the cable approx. 10 cm, attach a clamp to the cable, pull the permeameter up, connect the quick coupling and lower it down the pipe until the clamp carries the system. (N.B. A suitable clamp is included in the BAT Permeability Kit).

3. When the temperature is at equilibrium (i.e. Constant pressure in the tes container), the system is ready for start of a permeability test.

4. To reduce the time for reaching equilibrium, prepare the extension pipe by filling it with water in enough time before the test. Needed volume of water 1 litre.The water also gives a more stable temperature situation during test.

Performing a permeability test

- Make sure that the battery holder of the sensor contains a fresh, alkaline battery.

- Prior to the start of the test, prepare the Field Unit by opening the ”Start Measure” menu. Select both sensor and temperature logging (sensor+temp) and a suitable time interval, 1 to 5 minutes. If the ”clear data”-box is checked, another submenu may occur when selecting OK for start measure. If there are unsaved data in the sensor, you are given a reminder whether you want to overwrite these data or not. Normally these data are of no future value, and then you select the OK-option for overwrite. Do this operation just before the start of the test. Thereafter, return once more to the ”Start Measure” menu and place the marker on the OK-option (without checking the ”clear-data”-box).

- The next step is to connect the test equipment to the BAT Filter Tip.Remove the clamp and gently lower the equipment the remaining 0.1 – 0.2 m down to the Filter Tip. At the same moment the equipment connects to the Filter Tip, press OK on the Field Unit and the test is running. Open the “Display” menu of the Field Unit to have a visual check of the test is running, i.e the pressure shall gradually change.

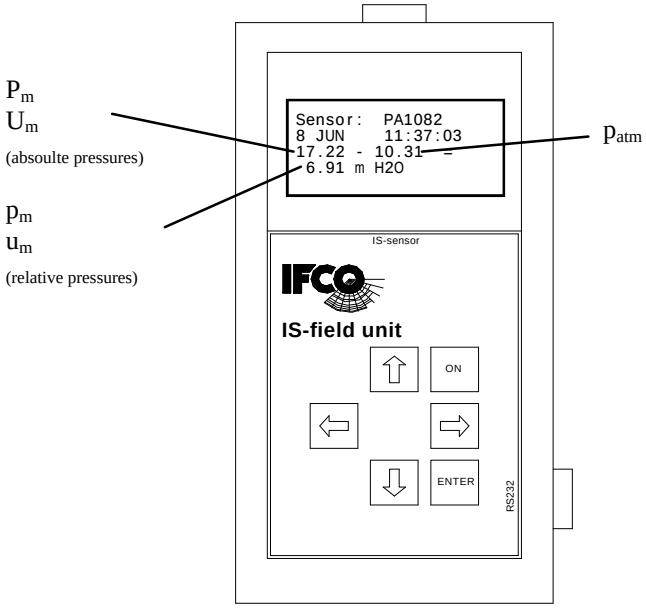
- Depending on soil type the testing time may vary from 5 minutes up to 24 hours. After an hour the measure interval on the sensor can be changed to 30 minutes.

- During the test, the system pressure can be manually monitored, simultaneously to the automatic logging.

- The test can be finished at 50% pressure dissipation (P_{50}). However, if the test proceed further this does not interfer with the data processing, see APPENDIX 1.

- Remove the BAT Permeameter and measure the remaining volume of water, V_{end} , in the test container, using a syringe.

- Manual readings of time and pressure can also be used for evaluating of the permeability. Just insert these values in the Excel-sheet as shown on the next page.



P_m = pressure in test container
U_m= pore pressure

Computer processing

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	**Permeability test in site with the BAT-system**												
2													
3	**Outflow test**												
4													
5	**Note! All pressures are absolute pressures in Pa resp m H2O**												
6													
7	Site	site				In these columns you fill in data from your measurement via Data Logger software							
8	Point	point											
9	Date	date											
10	Installation depth of filtertip	meter/inches											
11	BAT/IS sensor no.	PAXXXX											
12													
13	Length of filter, mm	35			*	(Standard Mk III = 35 mm)		(Ceramic filter =35 mm)					
14	Diameter of filter, mm	25			*	(Standard Mk III =31,5 mm)		(Ceramic filter =25 mm)					
15	Flow factor, mm	193,2											
16	P_0, m H2O	11,206				Initial system pressure							
17	V_w, ml	10				Initial liquid volume							
18	V_0, ml	25			*	Initial air volume							
19	U_0, m H2O	10,00			*	Static pore pressure							
20	Air pressure, Pa	96768	9,9		*	Pa =		$m H_2O$					
21	starting temperature, K	289											
22	V_{calc}, ml	5				Calculated volume remaining after test							
23	V_{real}, ml	5,30				Measured volume remaining after test							
24	P_{01}	10,24			It is not neccessary to run the test further when reaching this pressure								
25	P_{02}	10,60			At this pressure a relevant value of the permeability is given								
26													
27	Date	Time	Pressure	Temp, T	Time elapsed	Time elapsed	Atm	eff Pressure	Pressure	Remaining volume	Permeability	Temp T	T0/Tt
28			Pa	°C		seconds	pressure	m H2O	m H2O	of water in vial, ml	k [m/s]	Kelvin	
29	*	*	*										
30	2004-07-09	23:11:23	1,10E+05	16,4	00:00:00	0	96767,5	11,21	11,21	10,00	#Division/0!	289,4	1
31	2004-07-09	23:15:00	1,10E+05	16,4	00:03:37	217	96767,5	11,10	11,10	9,76	4,33E-09	289,4	1
32	2004-07-09	23:30:00	1,10E+05	16,3	00:18:37	1117	96767,5	11,05	11,06	9,65	1,45E-09	289,3	1
33	2004-07-09	23:45:00	1,10E+05	16,2	00:33:37	2017	96767,5	10,95	11,90	9,42	1,40E-09	289,2	1,001

This is the Excel-sheet used for data-processing of the measured values for an outflow test. In the orange cells you fill in information such as site, depth and date etc. Further down in the sheet you select diameter for the filter (depending on type of filter tip), starting volume, equilibrium pore pressure, U_0 , and initial system pressure, P_0 (all absolute values from the protocol sheet). The atmospheric pressure P_{atm}, shall also be filled in.

In the A ,B,C and D-column at row 30 the values from the IS-sensor are pasted. Please refer to the Pore Pressure manual for how to obtain these sensor data.

Copy and paste the other columns to fit the IS-sensor data. If logging overnight, a manual input for the E-column is needed at the midnight value. The formula that calculates the time elapsed from the previous measurement has to be changed.

> Example: Say that midnight occurs at row 42. The time is 00:00:00 (B42) which cannot be used as a reference in calculations by Excel. The formula in E42 is ”E41+(B42-B41)” and by changing ”B42-B41” to ”B41-B40” this problem is solved.

At the bottom of the sheet, the tabs for the pressure/time curve and permability/time curve are found. Adjust these diagram to fit the actual length of the set of data.

Maintenance and trouble shooting

General advices regarding maintenance:

Before a longer period of storage always

- unscrew the quick coupling sleeve, remove and clean the moving parts inside if necessary
- unscrew the container housing, clean if necessary
- unscrew the extension adapter
- remove all needles (it is recommended not to re-use the needles)
- unscrew the caps of the test container and make sure the parts are dry

Trouble shooting:

Problem	Possible cause	Solution
The pressure will not change when starting the test	The double ended needle has been ben	Change needle
The pressure will not change when starting the test	Obstacles or dirt in the 1" pipe	Try to clean the pipe or in the worst case, reinstall the filter tip
The system pressure, Pm, drops without being connected to the filter tip	Leakage in the test container	Clean the rubber septas or change if necessary Tighten the screw caps
The system pressure, Pm, drops without being connected to the filter tip	Leakage between sensor and plexi adapter or between transfer nipple and plexi adapter	Remove the plexi adapter, clean and change the o-rings and clean the surfaces

For eventual problems with the Field Unit or the sensor, please refer to the Pore Pressure Guide.

Initial system pressure P_0

The initial system pressure P_0 is applied in the test container either by injecting or extracting a volume of air ΔV to/from the test container.

This operation is made, using a syringe, equipped with a blue hypodermic needle.

Outflow test

Reference is made to the BAT Protocol sheet for filling in required information about the test.

- Measure the equilibrium pore pressure U_0 (absolute pressure)
- Open the test container in one end and add a volume of 10 ml water, using a syringe
- Close the test container. Finger tight is enough.

One procedure for application of the initial system pressure P_0 is described below:

- Apply an initial system pressure of:

$$P_0 \approx 1.25 \cdot U_0$$

- Normally, when the test equipment is lowered down the (waterfilled) extension pipe to the level of the BAT Filter Tip the temperature will drop. Accordingly the applied initial pressure will also normally be reduced. For example, a temperature drop of about 10ºC will reduce the applied initial pressure P_0 by about 5%.

Calculation of ΔV

The volume of air, ΔV , to be injected or extracted to/from the test container can be calculated as follows:

Parameters:	V_0 =	initial system volume of air	ml
	P_0 =	applied initial system pressure, ˜ 1.25 $\cdot U_0$ (absolute)	m H_2O
	ΔV =	injected/extracted volume of air	ml

The test container has a volume of 35 ml which gives V_0 = (35 - 10) = 25 ml. Based on the above assumptions ΔV can be calculated using Boyle´s law:

$$\Delta V \approx (3.1 \cdot U_0 - 25) \quad \text{ml}$$

Examples:

U_0 =	7.5	9.5	11.5	m H_2O	(absolute pressure)
ΔV =	-2	4.5	10.5	ml	(negative values = extraction of air)
$P_0 \approx$	9.4	11.9	14.4	m H_2O	(absolute pressure)

WARNING. Application of too high initial system pressure, P_0 ,in relation to the specific circumstances, may cause hydraulic fracture in the soil surrounding the BAT Filter Tip, which will give misleading results of the permeability testing. In case you for example measure higher values of the coefficient of permeability than expected it is strongly recommended that you carry out additional tests at lower initial system pressures P_0 for checking your results.

Inflow test

Reference is made to the BAT Protocol sheet for filling in required information about the test.

- Measure the equilibrium pore pressure U_0 (absolute pressure)
- An empty and dry test container is used for inflow testing, i.e. V_0 = 35 ml
- Apply the initial system pressure P_0 by extracting air from the test container using a syringe equipped with a blue hypodermic needle. The volume of the syringe is 25 ml.

Examples:

Extracted syringe volumes:	1 (25 ml)	2 (50 ml)	3 (75 ml)	
Initial pressure P_0 in test container:	≈ 6	≈ 4	≈ 2.5	mH_2O (absolute)

Protocol—In situ permeability measurement
OUTFLOW TEST

Site:…… Date:……..

Measuring point.: …….. BAT/IS sensor nr.: ……

Installation depth of filter tip:…… Test performed by :…….

Initial atmospheric pressure : ……kPa time: ……
Final atmospheric pressure : ……kPa time: ……

Form factor *F*, BAT MkIII standard filter tip: F = 230 mm
BAT MKIII vadose filter tip: F = 186 mm
BAT MKIII vadose stainless: F = 190 mm

NOTE! ALL PRESSURES ARE IN ABSOLUTE VALUES!

U_0, pore pressure at equlibrium, m H_2O:…….
($U_0 = U_m + 0{,}2$ m H_2O)

P_0, initial system pressure of test (at temperature equilibrium), m H_2O:……..
(displayed P_m value)

P_{50}, system pressure at 50% pressure dissipation, m H_2O: …….
P_{80}, system pressure at 80% pressure dissipation, m H_2O: …….
$P_{50} = P_0 - 0{,}5(P_0 - U_0)$
$P_{80} = P_0 - 0{,}8(P_0 - U_0)$

P_{end}, final system pressure, m H_2O:……

V_v, volume liquid in system at start of test, ml: ……..

$V_{0,}$ volume of air in system at start of test, ml: $(35 - V_v)$ …….

V_{calc}, calculated liquid volume in the sample container at end of test ml:……
$V_{calc} = [P_0 V_v - 35(P_0 - P_{end})]/ P_{end}$

V_{end}, measured volume liquid in the sample container after performed test, ml: …….

coefficient of permeability, *k* = ……. $*10^{-}$ m/s

Notes:……..

Protocol—In situ permeability measurement
INFLOW TEST

Site:…… Date:……..

Measuring point.: …….. BAT/IS sensor nr.: ……

Installation depth of filter tip:…… Test performed by :…….

Initial atmospheric pressure : ……kPa time: ……
Final atmospheric pressure : ……kPa time: ……

Form factor *F*, BAT MkIII standard filter tip: F = 230 mm
BAT MKIII vadoze filter tip: F = 186 mm
BAT MKIII vadoze stainless: F = 190 mm

NOTE! ALL PRESSURES ARE IN ABSOLUTE VALUES!

U_0, pore pressure at equilibrium, m H_2O:……..

P_0, system pressure at start of test (at temperature equilibrium), m H_2O:…….

P_{50}, system pressure at 50% pressure recovery, m H_2O: …….
$P_{50} = P_0 + 0{,}5(U_0 - P_0)$

P_{end}, final system pressure, m H_2O:…….

$V_{calculated}$, calculated volume liquid in system at end of test, ml:……
$V_{calculated} = 35 – (P_0*35)/ P_{end}$

V_{end}, measured volume liquid in sample container at end of test, ml: ……..

coefficient of permeability, *k* = ……. $*10^{-}$ m/s

Notes:……..