UMS
measure to know

Soil water extraction methods

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Content

1 Soil water extraction

1.1 Extraction methods

To extract soil water in the unsaturated zone the soil water tension (retention force) has to be surpassed by the sampler‘s potential - a vacuum needs to be applied.
The vacuum should be as close as possible to the in-situ soil water tension, as i.e. carbon will fall out in high vacuum.
Variations of the pressure difference between the sampler’s inside and outside will lead to different filtration results - thus, memory effects occur. This is prevented by a tension controlled vacuum unit.
Please note that water can only be extracted if water is available.
The bigger the soil pores are, the less water is available at rising tensions!
Sampling is possible in stony soils up to pF 1, in sandy soils up to pF 2, and in clay soils up to pF 2.7.
Suction cups always act as chemical and physical filter. High vacuum applied at soils close to saturation cause transport of small particles into the sampler‘s pores. There is nearly no chance to reverse this process even by applying pressure, as around the cup an area of small particles will get accumulated.
The effective active suction force is the difference of soil water tension and applied vacuum.

UMS offers three different vacuum methods - the most suitable will depend on your task.

1.1.1 The simple method

Discontinuous evacuation is the simplest method. Evacuate your sampling bottle down to approx. 50 kPa. If the soil water tension is lower than 50 kPa, soil water solution will be extracted until vacuum and soil water tension are equalized. When the samples are collected, the bottle is evacuated again.

Applications
- For qualitative analysis of soil water

Benefits
- Low cost
- Easy handling

Limits
- Discontinuous sampling
- Undefined sampling

Tools
- Pore water samplers
- Hand-operated vacuum floor pump VPS-1 or portable vacuum case VacuPorter

1.1.2 The constant vacuum method

A constant vacuum is continuously maintained by a regulated vacuum pump. The vacuum can be set between atmospheric pressure and 85 kPa.
Leachate samplers for example are supplied with approx. 6 kPa, while pore water samplers in silt and loam are supplied with 10 to 30 kPa. As clay soils retain water even at higher tensions a vacuum from 30 to 85 kPa could be applicable.

Applications
- Long term monitoring projects
- Studies on leachate
- Soil water extraction from a certain pore size with a vacuum which is exactly suitable to the pore size.

Benefits
- Defined sampling

Limits
- Constant vacuum ignores changing soil water tensions

Tools
- Pore water or leachate samplers
- Vacuum station VS without controlling Tensiometer

1.1.3 Tension controlled extraction

A Tensiometer measures the soil water tension. The programmable vacuum station VS automatically supplies a vacuum in correspondence to the measured tension. Due to the numerous functions of the unit an optimal adaptation to the sampling task is possible.

Benefits
- Constant sorption and constant filter effects
- Prevents memory effects

Limits
- Takes samples from various pore sizes depending on the current vacuum

Tools
- Pore water or leachate samplers
- Vacuum station VS with controlling Tensiometer

1.2 Experiences and recommendations

1.2.1 Sandy soils

When sampling in coarsely to medium grained sandy soils it can be a problem that, in the unsaturated range, the water content often is too low to extract a sufficient amount of solution.
In sandy soils the method with constant vacuum should be applied as drainage water occurrences are only short. Drainage water will rush trough quickly and either no solution is won, or only some solution is extracted by chance.

In contrary, if there are only sand fractions up tp 50% the sampled amount can be quite high [Riess 1993].

1.2.2 Vacuum ranges

If the applied vacuum is too high the soil around the cup is drained, and with unfilled soil pores the conductivity drops considerably. The effect depends on the soil type and is the most significant in sandy soils.
Therefore, the vacuum should only be as low as necessary. In general it is sufficient to apply a vacuum which is 20 kPa lower than the soil water tension (see chapter "Extraction methods").

With the discontinuous method (consecutive vacuum - no vacuum - cycles) the natural water movement is disturbed. Especially in sandy soils it can happen that the capillary contact ruptures with a decreasing vacuum.

1.2.3 Pore clogging

Over an extended period of time the ceramic pores might get clogged by fine particles. To flush the ceramic while installed normally is just a temporarily solution as the fine material is only flushed into the area right around the ceramic.
Therefore, clogging should be prevented right from the beginning by keeping the flow-through low and constant, for example with Tensiometer controlled vacuum and with a vacuum just a low as necessary [Riess 1993].

1.2.4 Achievable sample amounts

You can expect the following sample amounts:

- Maximum: in free water and with a vacuum of 50 kPa approximately 5 ml per 10 minutes.
- Minimum: in sandy loam soil with 50 kPa approximately 5 ml per hour.

In high-flow ceramics the flow rate is max. three times as high.

1.3 Further notes

- Interfering sorption effects get smaller over a longer period.
- In case sampled solution should be stored with protective gas.
- As suction cups have a small catchment area heterogeneous soils cause some difficulties. Depending on the hydraulic contact to primary or secondary pores (cracks, macro pores) diverse water is sampled.
- As samples can only be extracted from moist soil no sampling is possible in hot and dry seasons.
- Mouse holes can cause some troubles as soil water quickly flows into deeper layers where it might accumulate [Riess 1993].

Please observe the following:

- ! Long tubes and bubbles in tubes cause a certain resistance. This has to considered when planning your suction tube system.
- ! To avoid incorrect regulation the vacuum should be measured close to the pump and not next to the suction cup.
- ! Pump and vacuum units have to be protected from water intrusion by sufficient measures (overflow protection, adequate volume, water sensors on vacuum ports).
- ! All parts of a vacuum system have to be implosion proof.
- ! Suction cups should not be installed too close to Tensiometers. Provide sufficient space between samplers, Tensiometers and soil moisture probes.
- ! If suction cups and sampling bottle are installed at different levels you must consider the potential difference when selecting your vacuum. Please read chapter “Level difference”.

2 Vacuum systems

2.1 Sampling bottles

2.1.1 Sampling bottle cap

The sampling bottle normally picks up the suction tube of a sampler and a vacuum tube to evacuate the bottle.
The cap of the sampling bottle has 3 tube nozzles.
The left (blue) tube as seen on the photo is the vacuum tube.
The right tube is the suction tube of the sampler. Insert this tube far enough into the bottle so the silicone tube section will not get in contact with the sampled solution.

The third nozzle is not open but optionally can be used for connecting another suction tube or to conduct the vacuum to another sampling bottle. To do so, cut off the tip of the nozzle. Cut off the upmost section for a thin suction tube or the lower section for a thicker vacuum tube.

2.1.2 Suitable material

Glass is the best material for sampling, storage and transportation. If a vacuum is applied to a glass bottle it must be implosion proof. Glass bottles must have a plastic coating as an implosion protection. UMS supplied sampling bottles type SF are implosion proof.

Bottles made of polyethylene, polypropylene or polyamide normally are not suitable for applying a vacuum, but, depending on the substances, can be used for transportation or storage of the solution.

2.1.3 Volumes

UMS bottles are available with a volume of half litre (SF-500), 1 litre (SF-1000) or 2 litres (SF-2000).

Which size is the best depends on the application:
1. What sample amounts are expected during which interval?
2. Are several samplers connected to the bottle for getting a mixed sample?
3. With discontinuous sampling the sampling bottle is also the vacuum buffer. Note that the vacuum is already used up when the bottle is only partially filled with solution. Therefore, the sampling bottle should have 3 times of the volume you want to sample at least with the discontinuous sampling method.

With the overflow protector SF-protect you can also adjust or limit the volume to be sampled. For example, if you want to sample an amount of 100 ml push the vacuum tube deeper into the sampling bottle so the protector is positioned at the appropriate level.

2.1.4 Overflow protector

An optional overflow protector which is inserted into the sampling bottle is available for usage in automatic vacuum systems (see left photo).
The valve consists of a capillary membrane which is permeable to air when dry, but tight if it gets wet. The overflow protector prevents that soil water solution is drawn out of the sampling bottle and into the vacuum unit. As soon as the sampling bottle is full the protector closes. Thus, this bottle is cut off from the vacuum system while the other bottles still continue to work.
Simply attach the SF-protect to the end of the vacuum tube. The protector opens up again as soon as the sampling bottle is emptied.
Note that then the vacuum system has to have a main line, and each sampling bottle is connected to the mail line with T-fittings (see right photo).

The purpose of the overflow protection is to prevent damages to the vacuum unit and to avoid that solution from one bottle contaminates other bottles in case of unexpected incidents. It is not intended as an automatic stop switch, mainly because the membrane has to completely dry off before it again is permeable to vacuum.
Therefore, the size of the sampling bottles and the collection interval should ensure that no overflow occurs at all.
A further buffer bottle still is recommendable.

2.2 Solution storage

The soil water samples should be stored dark and at soil temperature. Therefore, the sampling bottles can be placed in a buried box, so the storage temperature is identical to the soil temperature, and the samples are protected against sunlight.

❗ The sampled solution should be stored dark and at soil temperature to prevent algae growth, for example inside a buried box.

2.3 Vacuum buffer bottle

In automatic vacuum systems it is recommendable to insert a buffer bottle before the input of the vacuum pump. It prevents that water enters the pump in case a sampling bottle overflow. It also serves as a vacuum buffer.

UMS vacuum units VS to VS-pro (not the VacuPorter) have a water intrusion detector which will shut off the pump when water enters the vacuum port. Note that the unit remains shut down until the detector has completely dried out again.

2.4 Suction tubes

2.4.1 Tube material

Suitable material for the suction tube (also check the suitability list in the appendix):

- Polyethylene, polypropylene or polyamide: for anions and cations.
- Stainless-steel capillary tubes: for all substances but not for metals and heavy metals.

UMS samplers are designed that the sampled solution will not have contact to any material other than the cup material and the suction tube material if connected properly.

2.4.2 Suction tube dimension

In general suction tubes should be as short as possible for the following reasons:

- Little dead volume and real-time sampling.
- Low reflow with rising water tension as the solution left inside the tube is always drawn back into the soil.
- Least possible flow resistance.

Air bubbles inside the tube create a high flow resistance which will be highest in thin and long tubes. In a 20 meter long tube with an inner diameter of 1.6 mm the flow resistance in worst case can be up to 50 kPa.

Please refer to chapter „Installation“ for instructions how to install the suction tubes.

2.5 Vacuum tubes

Observe the following points about the vacuum tube:

- Keep vacuum tubes as short as possible. With longer tubes the risk of leakage, damage or rodent bite rises.
- The distance between the pump/vacuum unit can be up to 200 meters. In a tight system the pumped volume will be low and pressure drop is neglectable.
- Recommendable inner diameter for a vacuum tube is 4 to 10 mm. Select the inner diameter depending on the tube lengths, number of samplers and the sampling method.

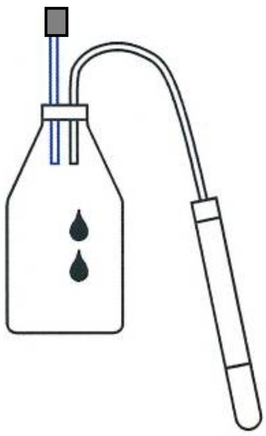
❗ You must ensure that the complete system is tight.

2.6 Possible setups

As described in chapter „Extraction methods“ there are three possible sampling methods. Following some suggestions how to assemble a system depending on the sampling method.

2.6.1 Setup for discontinuous sampling

A soil water sampler is connected to a sampling bottle. The sampling bottle is evacuated, for example with the vacuum floor pump VPS-2 or the VacuPorter. Solution is extracted from the soil until the decreasing vacuum drops below the soil water tension.
Note: the sample amount can be max. 2/3 of the bottle volume.



2.6.2 Setup for constant vacuum method

Each soil water sampler is connected to a sampling bottle. With a vacuum tube network several sampling bottles are connected to a vacuum controlling unit like the VS units. The vacuum units are set to the desired vacuum and keep up a constant vacuum by controlling and re-establishing the vacuum.

Note the following when connecting sampling bottles:
Several sampling bottles can be connected in a row by using the third tube connection on the sampling bottle cap (upper scheme on the next page), or by using T-fittings (lower scheme).
If a sampling bottle is equipped with an overflow protection valve (see chapter above) you must use T-fittings as a blocked valve would block the whole system.

In systems with automatic vacuum units sufficient measures should be applied to avoid that the pump draws up water or the system gets blocked by overflowing bottles.

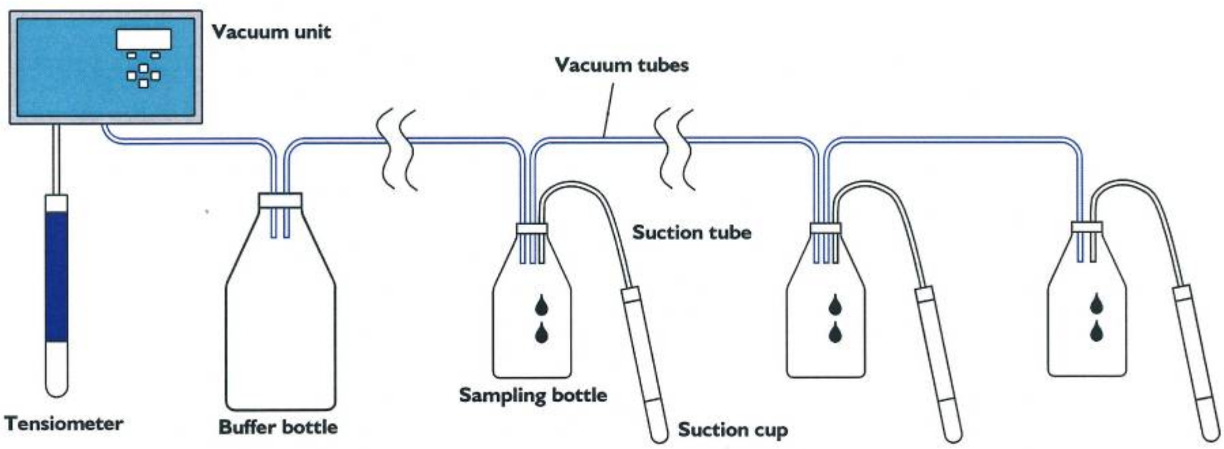


Fig: Sampling bottles connected in row using 3rd nozzle on the cap

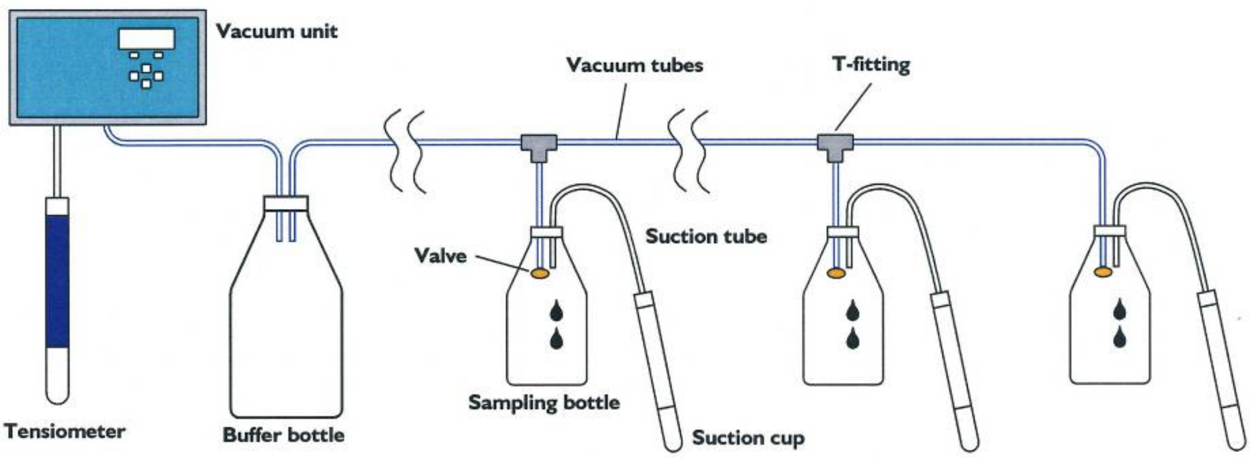


Fig: Sampling bottles connected to main vacuum line with T-fittings, Tensiometer and overflow valves are optional

2.6.3 Setup for Tensiometer controlled vacuum

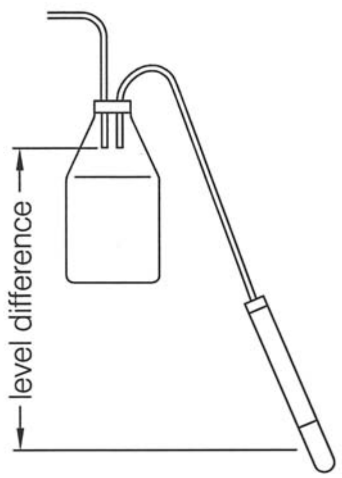
Samplers, sampling bottles and vacuum tubes are connected the same way as with the constant vacuum method (see figures above). A controlling Tensiometer is connected to the VS unit and the vacuum is regulated in dependence of the current soil water tension.

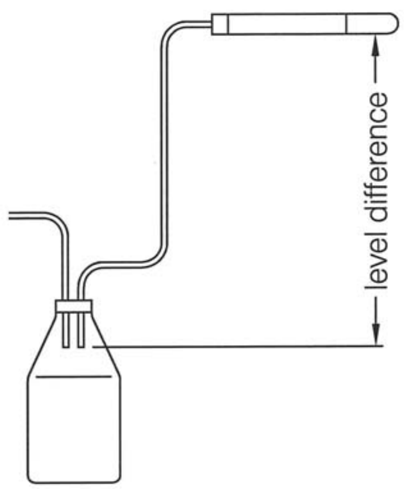
2.7 Level differences

It is recommendable to place the sampling bottle at the same height as the suction cup. Consider the following if this is not the case.

If a sampling bottle is placed in a higher level than the suction cup (left figure) the level difference causes a pulling water column which reduces the effective vacuum on the sampler. If for example the suction cup is 1 meter beneath the level of the bottle the vacuum at the sampler is approximately 10 kPa lower than the vacuum inside the bottle.

To compensate the level difference when the sampling bottle is higher than the suction cup add 1 kPa to the vacuum for each 10 cm of level difference (or exactly 0.98 kPa per 10 cm water column).





Accordingly, if the sampling bottle is lower than the suction cup, for example in a manhole (right figure), the effective vacuum on the sampler is higher than inside the bottle - if the tube is completely filled with water. In a normal situation there will be vapor and bubbles inside the tube. Therefore, you do not reduce the vacuum so solution is extracted even with bubbles inside the tube.

❗ Do not compensate the level difference if the sampling bottle is lower than the suction cup.

2.8 Collection interval

It depends on the research task how often the extracted solution should be collected from the sampling bottles.
For long term monitoring studies an interval of 1 to 2 weeks might be applicable. If you want to specifically gain the peaks from intense rain incidents the collection time should be shorter.

If you want to know the chronological change of the sample amount you can place the sampling bottle on a scale and log the weight with a data logger, or insert a vacuum-tight tipping counter with logger before the sampling bottle.

2.9 Power management

A soil water extraction system which cannot be supplied by mains power requires either battery, solar or wind energy. It is necessary to establish a power management plan in consideration of amount and intervals of extraction, possible leakage and shut-down.

2.10 Collecting sampled solution

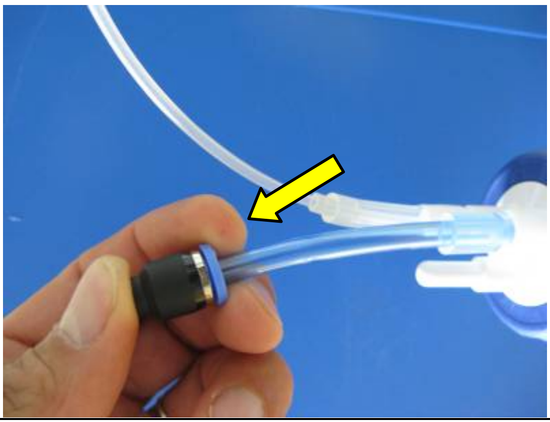
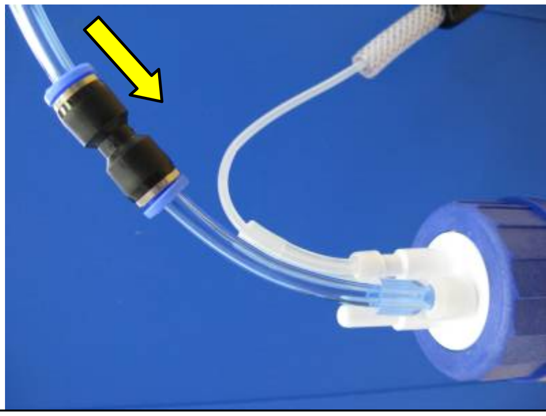
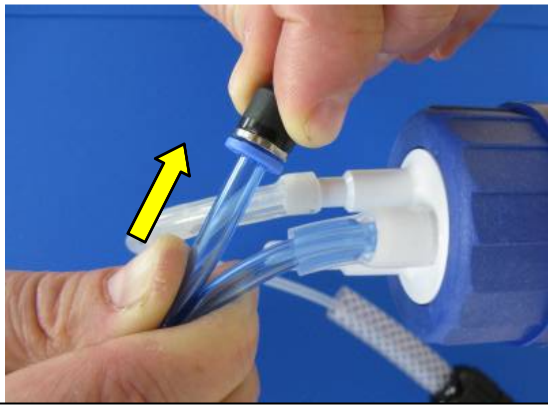
2.10.1 Discontinuous method

UMS sampling bottles are either plugged with a clamp or with a fitting as seen the photo.

Open the vacuum tube to vent the bottle. Screw off the cap and collect the sample, or replace the bottle with a clean one.

Put back the bottle cap and evacuate the bottle with your pump. Now bend the vacuum tube to seal it and remove your pump. Reattach the fitting or the clamp.

Procedure of the discontinuous method

1. Take off the plug from the sampling bottle	
2. Connect the vacuum tube from the pump with the connector piece. Evacuate the bottle to the needed vacuum.	
3. Bend the blue tube on the sampling bottle to retain the vacuum when you take off the connector piece.	
4. Immediately put back the plug on the tube of the bottle. Now you can release the short tube.	

2.10.2 Continuous method

In a system with continuous vacuum, switch off the vacuum unit. Then vent the system. Now collect all samples from the sampling bottles and reassemble the system.

In case check the Tensiometer readings and the sampled amounts and adjust the settings of your vacuum unit.

3 Scientific background

3.1 Supporting institutes

The recommendations in this manual were written in cooperation with the following institutes:

- Österreichischen Bundesamt für Wasserwirtschaft Petzenkirchen, Österreichischen Arbeitsgruppe Lysimeter, http://www.lysimeter.at/
- University of Hohenheim and Technical University Munich,
- Helmholtz Zentrum München, Deutsches Forschungszentrum für Umwelt und Gesundheit,
- Bayerischen Landesanstalt für Wald und Forstwirtschaft
- Bayerischen Landesamt für Wasserwirtschaft.

These recommendations compile some basic information and experiences for the extraction of soil water. This cannot be exhaustive and cannot replace detailed consulting as the complete process, sampling conditions, soil type, extraction method and intervals, sample storage and last but not least the analysis have to be designed in accordance with the individual task.

Note:
The information for suitability of materials on the following page base on experienced data, laboratory analysis or (unevaluated) citation in literature. It was initially created in a UMS workshop about soil water sampling in the year 2000 and is elaborated since. The list is published in all conscience but makes no claim to be complete, and therefore cannot replace specific consulting. Please do not hesitate to contact us.
Furthermore, we would be grateful to learn about your experiences and recommendations.

3.2 Table of suitability

	Al2O3 ceramic sintered material	**Polyethylene/ Nylon**	**Silicon carbide**	**Borosili-cate glass**
UMS type:	SK20 SKPE25	SPE20	SIC20, SIC40 SIC300	SG25 SPG120
Suitable for determination of ...				
Anions:				
NO3- Nitrate	+++	+++	+++	+++
SO42- Sulphate	+++	+++	+++	+++
PO43- Phosphate	+++	+++	+++	+++
Cl- Chloride	+++	+++	+++	+++
Cations:				
Ca2+ Calcium	+ [1]	++ [1]	+++	+ [1]
K+ Potassium	+ [1]	++ [1]	+++	++
Na+ Sodium	++[1]	+ [1]	+++	
NH4+ Ammonium	+++	+++	+++	+++
Al3+ Aluminium	---(critical [2])	++(critical with pH<2[1])	++	+++
Cu2+ Copper	---[3] [5][8]	+++	+++	+++
Cr2+ Chromium	--	+++	+++	+++
Fe2+ Iron	- [2]	+++	+++	+++
Mg2+ Magnesia	--	+++	+++	+++
Ni2+ Nickel	--	+++	+++	+++
Elements				
S Sulphur	+ [1]	+ [1]	+++	+++
P Phosphorus	++ [2]	+++	+++	+++
Si Silicon	---	+++	-	+++
DOC	++ [8]	++[3]	++	+
TOC	++ [1]	+ [1]	++	+
Humins:				
Heavy metals:				
Cd Cadmium	--- [6]	+[6]	-	-
Pb Lead	--- [5] [6]	+[6]	-	-
Herbicides	+ (Atrazin) [3] [7][8]	+(Atrazin) [7]		/
Pesticides	/	/		/
Fungicides	/	/		/
PAK				
Trace elements	-	/		/

Literature source	Caption
[1] Göttlein, 1996 [2] Grossmann et al., 1987 [3] Klotz, Unold, 2000 [4] Riess, 1993 [5] Guggenberger und Zech 1992 [6] Haberhauer 1997 [7] Schroll 1996 [8] Klotz, 1997	--- completely unsuitable -- unsuitable - only for experts, requires good knowledge and suitable conditioning of the suction cups / no experiences + limited suitability ++ suitable after conditioning and sufficient forerun for flushing +++suitable after sufficient forerun for flushing

3.3 UMS sampler types

3.3.1 Suction cups

SK20
SK20 simple ceramic cup with removable shaft. For continuous and discontinuous extraction. Suitable for determination of nitrate and common organic and inorganic substances.

SIC20
Pore water sampler SIC20 with removable shaft like the SK20, but with a SiC silicon carbide cup instead of the ceramic cup. SiC is sintered at 2500°C and is less absorbent/desorbent than ceramic or borosilicate. The bubble point 90 kPa. UMS SiC cups are patented.

SPE20
Instead of a ceramic cup the SPE20 pore water sampler has a porous PE-nylon-membrane which is specially suitable for heavy metals and whenever ceramics are inappropriate.

SKPE25
The sampled solution is stored inside the shaft and is collected by applying a pressure to the additional tube. With ceramic cup.

SG25
Pore water sampler with porous borosilicate glass cup. Borosilicate is suitable for phosphate and DOC. Available with a diameter of 20 mm or 25 mm

3.3.2 Suction plates

SIC300
Suction plate made of porous silicon carbide for laboratory use or field leachate sampling. The plate is backed with a butyl rubber foil and a bottom tube connector to apply a 6 kPa vacuum. Bubble point is 10 kPa.

SPG120
Leachate sampling plate made of porous borosilicate glass. Suitable for phosphate and DOC. With tube connector ending inside the plate’s center. Utility patented.

3.3.3 Lysimeter KL2

The leachate bucket can be buried in situ to collect leachate - or can be used as a laboratory soil column and lysimeter. On the bottom of the polyethylene bucket a 0.5 bar high flow ceramic plate is fixed.

4 Appendix

4.1 Glossary

Suction cup, pore water sampler or lysimeter
Different terms are common. In this context it is an instrument consisting of a hydrophilic membrane, shaft and suction tube which is used to extract soil water solution from unsaturated zones.
We do not use the term lysimeter for pore water samplers as we define a lysimeter as a monolithic soil column.

Lysimeter
Container with defined surface, filled with soil and with at least one outlet. Used for quantification of water and substance flows, decay/reaction processes and simulation.

Tensiometer
Instrument for measuring soil water tension.

Vacuum
Pressure below atmospheric pressure.

4.2 Units

	pF	hPa	kPa=J/kg	MPa	bar	psi	%rH
Wet	1	-10	-1	-0,001	-0,01	-0,1450	99,9993
	2,01	-100	-10	-0,01	-0,1	-1,4504	99,9926
Field capacity	2.53	-330	-33	-0,033	-0,33	-4,9145	99,9756
Tensiometer ranges*	2.93	-851	-85,1	-0,085	-0,85	-12,345	
	3	-1.000	-100	-0,1	-1	-14,504	99,9261
	4	-10.000	-1.000	-1	-10	-145,04	99,2638
Permanent wilting point	4.18	-15.136	-1.513	-1.5	-15	-219,52	98,8977
	5	-100.000	-10.000	-10	-1 00	-1.450,4	92,8772
Air-dry**	6	-1.000.000	-100.000	-100	-1 000	-14.504	47,7632
Oven-dry	7	-10.000.000	-1.000.000	-1.000	-10 000	-145.038	0,0618

* standard measuring range of Tensiometers
** depends on air humidity

Note: 1 kPa corresponds to 9,81 cm water column

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6 Index

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UMS measure to know

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Strictly observe rules for disposal of equipment containing electronics.
Within the EU: disposal through municipal waste prohibited - return electronic parts back to UMS.

Rücknahme nach Elektro G
WEEE-Reg.-Nr. DE 69093488