Measurement

CHAPTER 6 MEASUREMENT OF PERMEABILITY

Direct Measurement

Water Coefficient of Permeability

Indirect Measurement

Water Coefficient of Permeability

Unsaturated Soil Technology

Modified Permeameter for measuring permeability

MEASUREMENT OF PERMEABILITY

Computations using steady state method

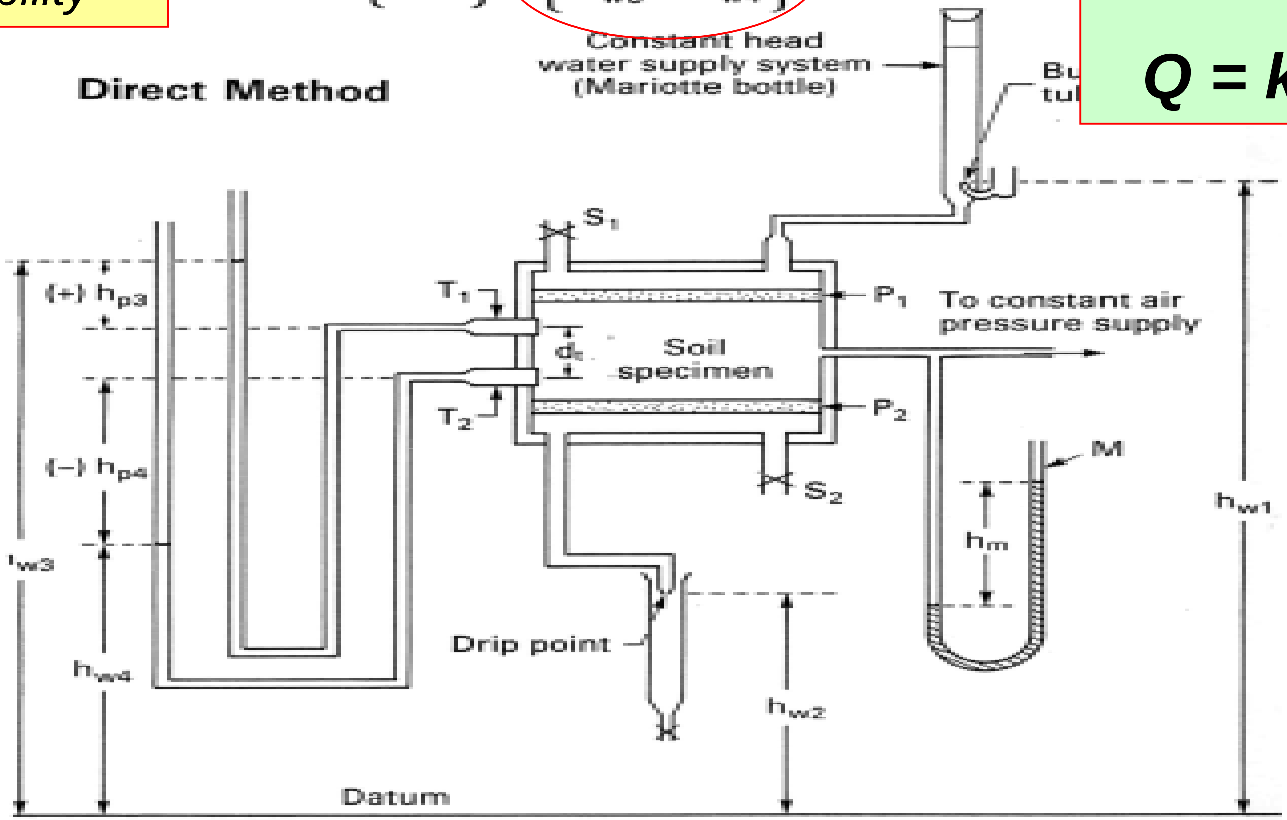
The coefficient of permeability, k_w,

$$k_w = \left[\frac{Q}{A\,t}\right]\left[\frac{d_t}{h_{w3} - h_{w4}}\right]$$

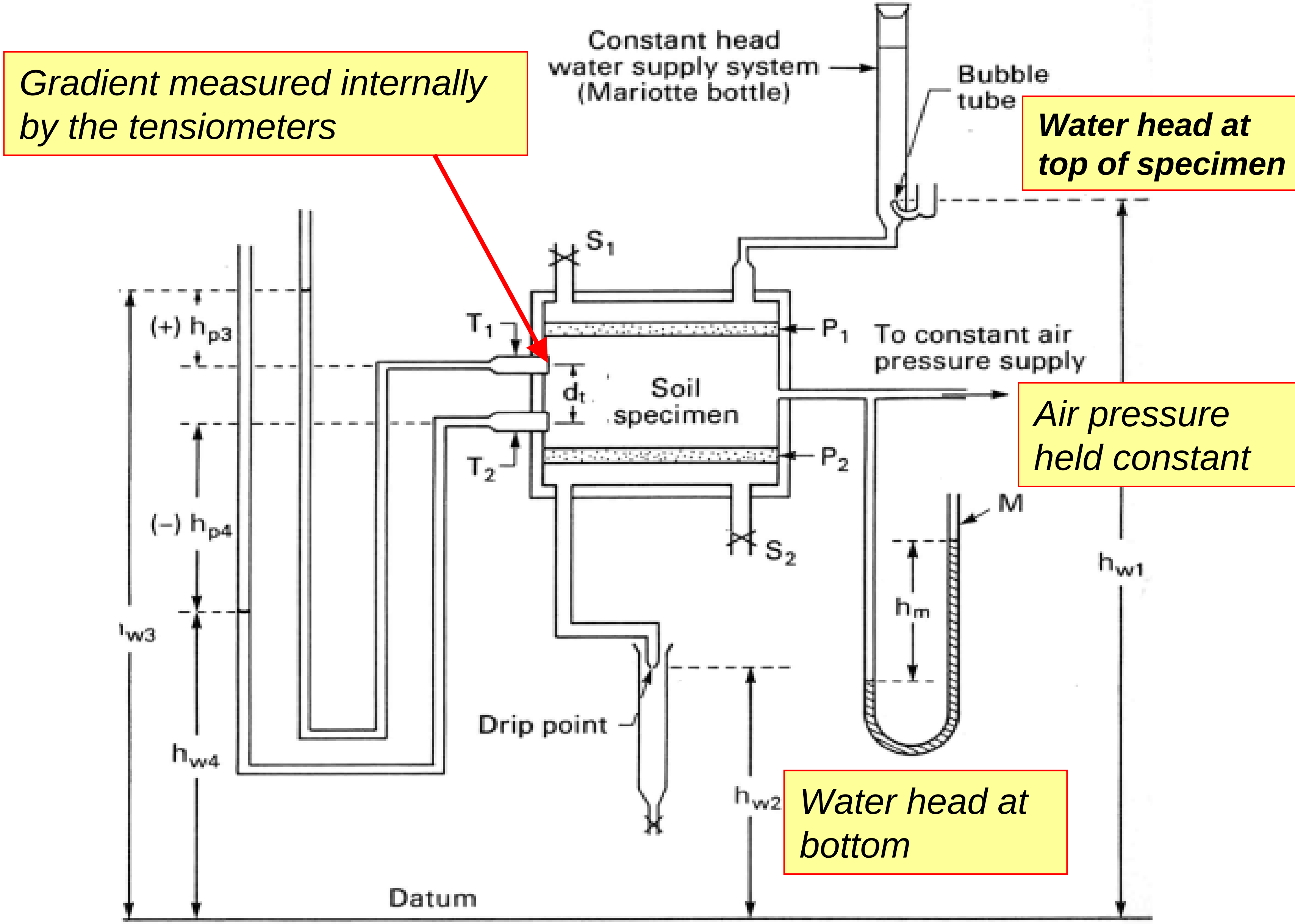
Gradient, i

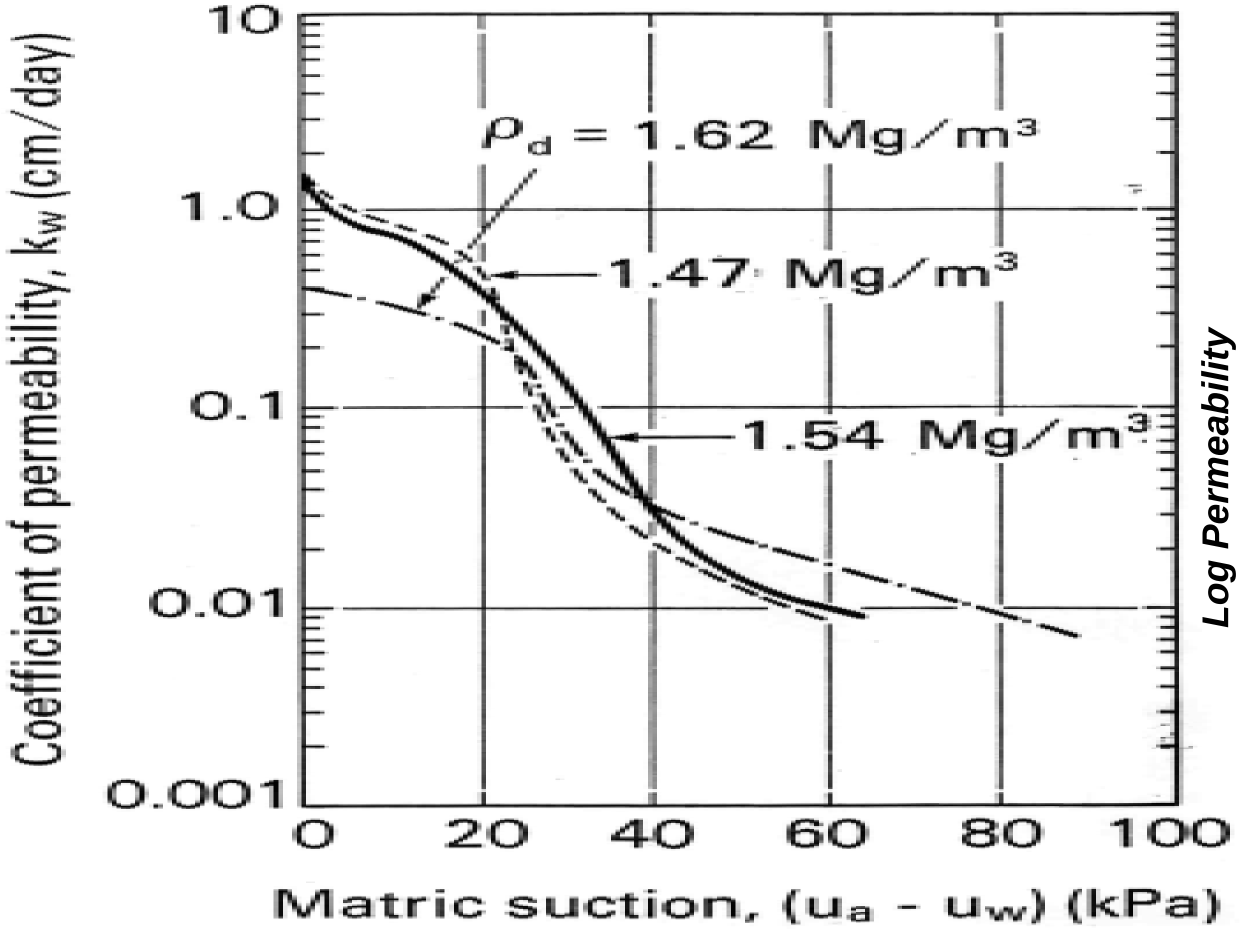
$$vAt = k_w\, i\, A\, t$$

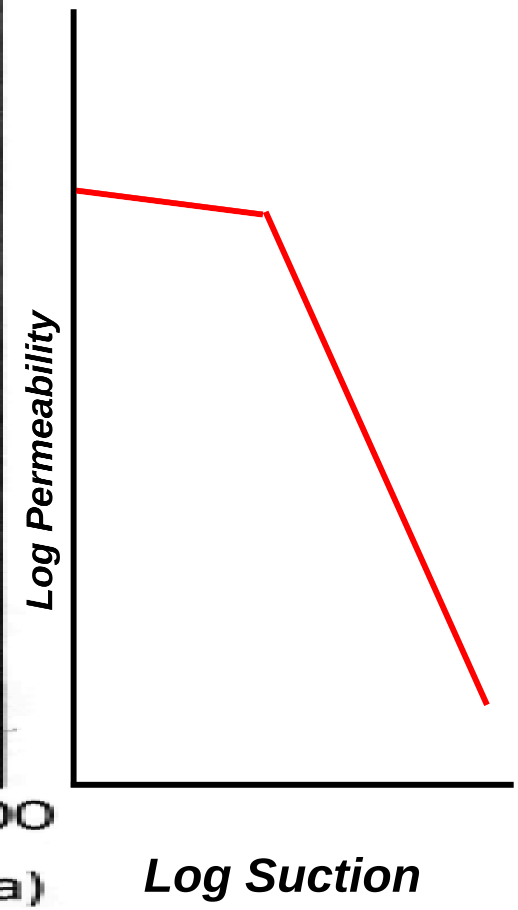
$$Q = k_w\, i\, A\, t$$



Apparatus for the measurement of coefficient of permeability using the steady-state method (from Klute, 1965)

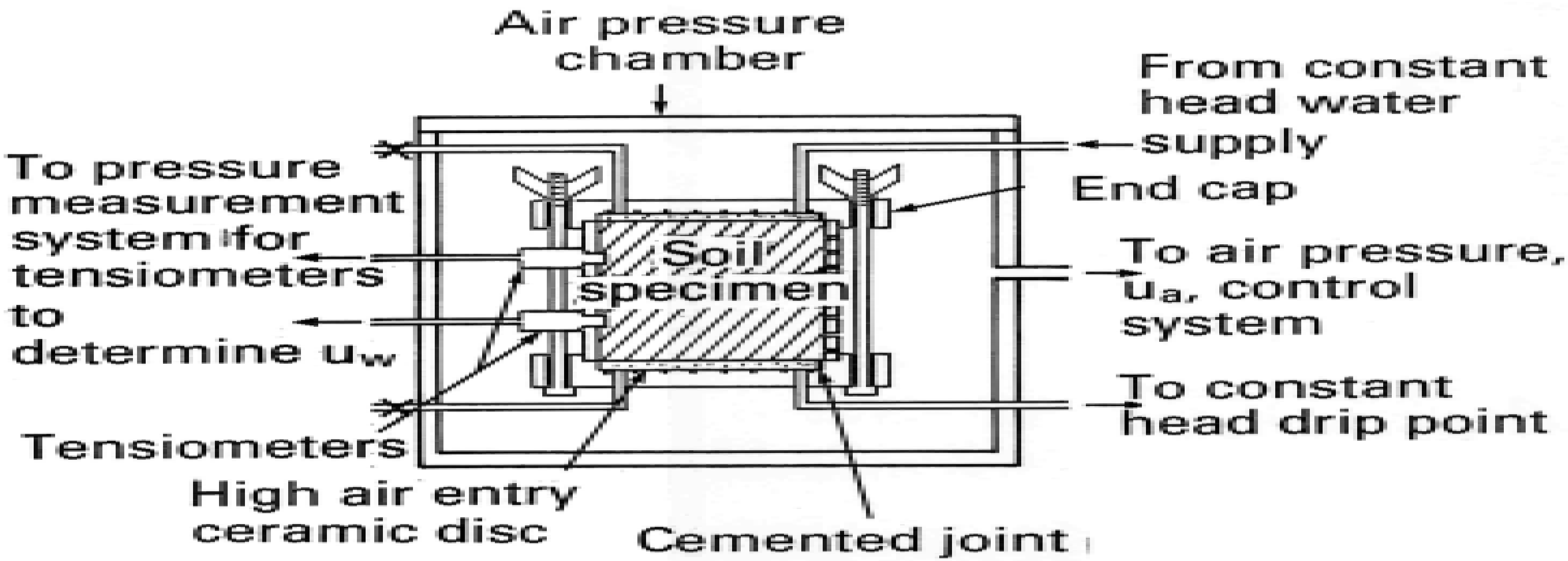

Gradient measured internally by the tensiometers
Constant head water supply system (Mariotte bottle)
Bubble tube
Water head at top of specimen
S1
T1
P1
To constant air pressure supply
Soil specimen
dt
T2
P2
Air pressure held constant
(+) hp3
(–) hp4
hw3
hw4
S2
M
hm
hw1
Drip point
hw2
Water head at bottom
Datum





Coefficient of water permeability as a function of matric suction obtained using the steady state method (after Ingersoll, 1981)

Modified Tempe Cell placed within an air pressure chamber

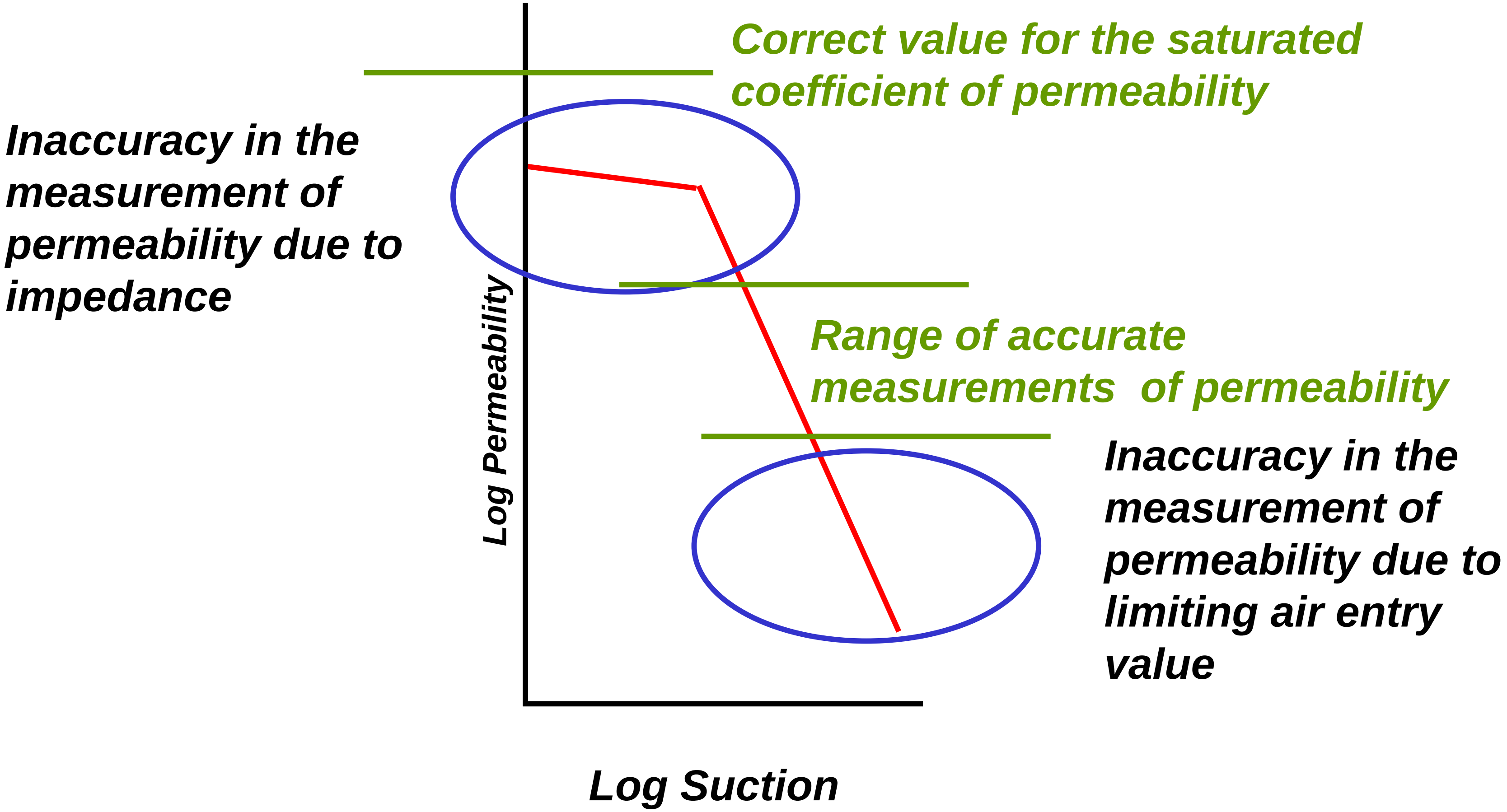


Another apparatus used for the measurement of the coefficient of permeability using the steady-state method (after Klute, 1965a)

Factors Controlling the Measurement of Unsaturated Water Coefficient of Permeability Without Internal Measurement of Water Pressures

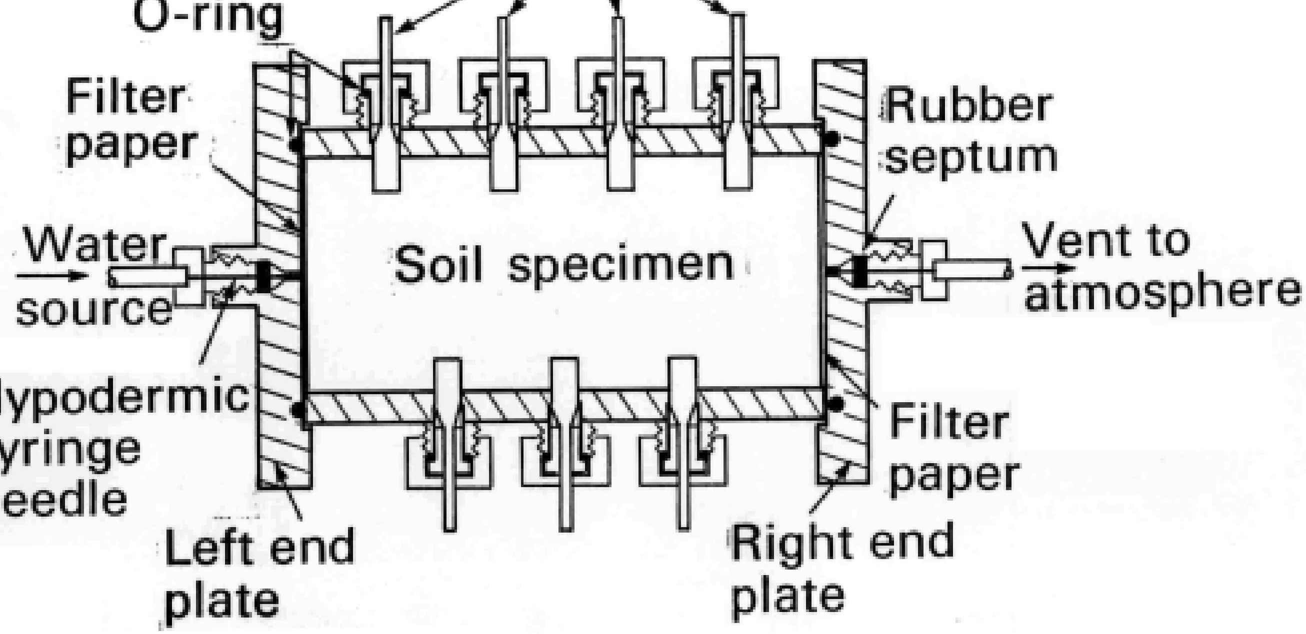
- ***There must be essentially no impedance from the High Air Entry Disks***
  - ***Controls the highest permeability that can be measured***
  - ***Means that the measured results at low suctions are often in question***
- ***The High Air Entry Disk controls the maximum suction that can be applied***
  - ***Controls the lowest permeability that can be measured***

Limits on the Measurement of the Coefficient of Permeability



Instantaneous Profile Method

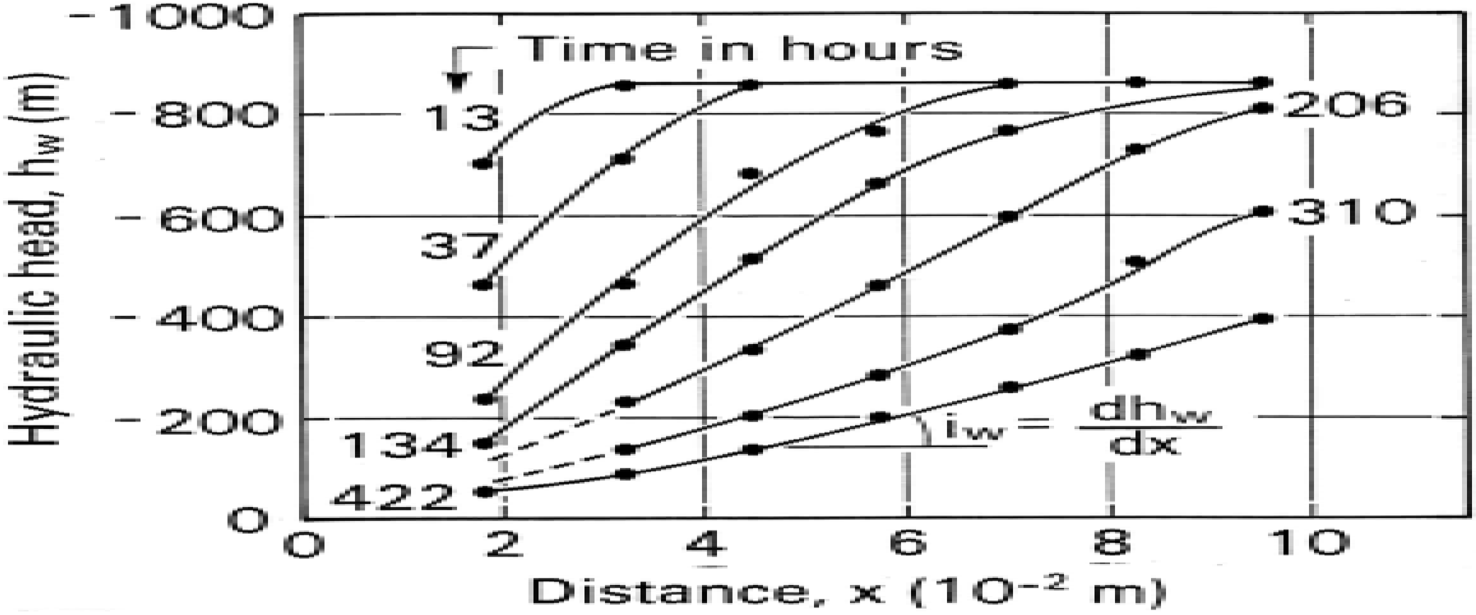
Laboratory test



Apparatus for measuring the coefficient of water permeability using the instantaneous profile method (after Hamilton, Daniel and Olson, 1981)

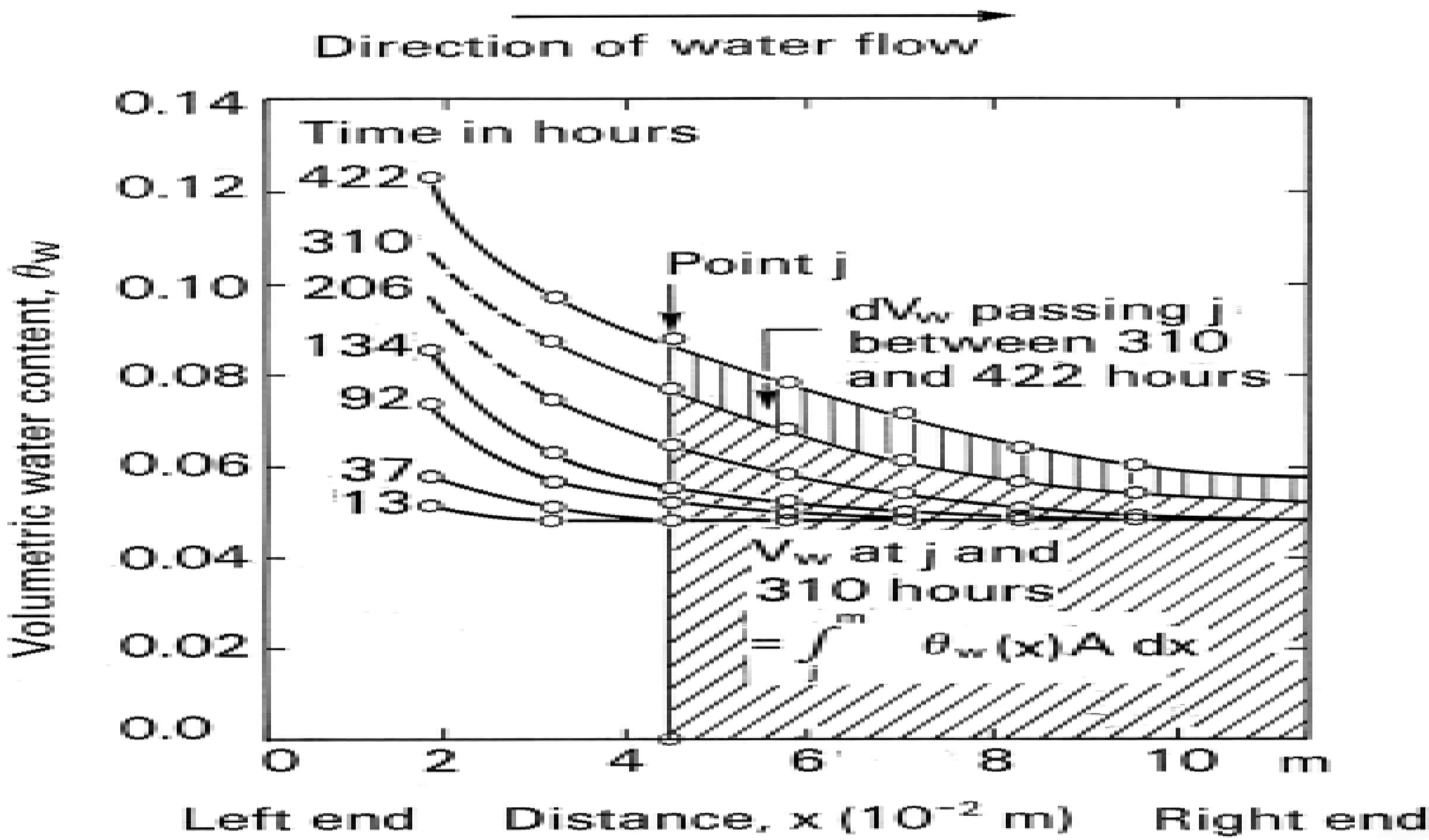
Instantaneous Profile Method

(a) Profile of hydraulic head



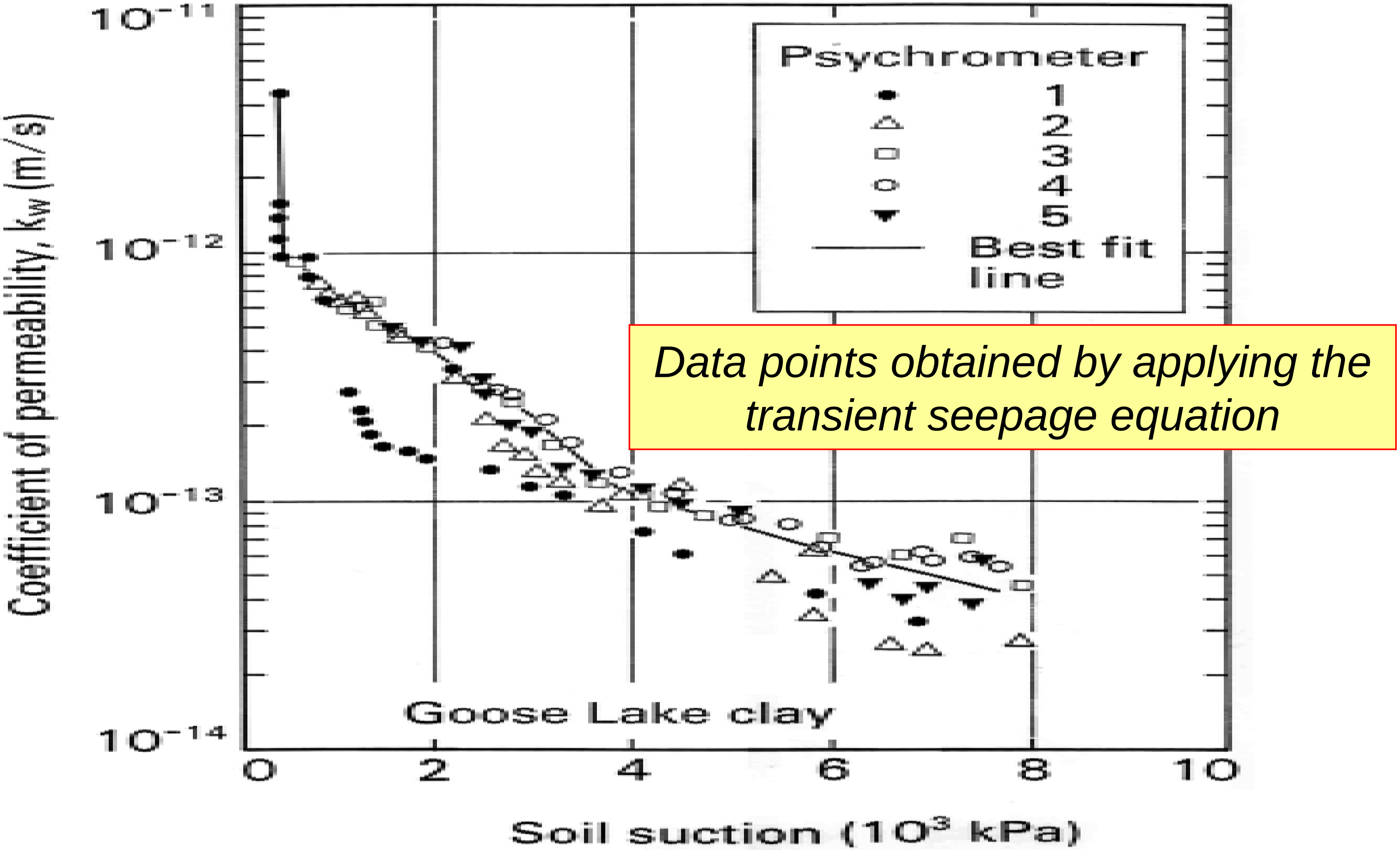
Hydraulic head and water content profile during an unsteady state flow test (after Hamilton, Daniel, and Olson, 1981)

(b) Profile of volumetric water content



Water contents from the SWCC

Hydraulic head and water content profile during an unsteady state flow test (after Hamilton, Daniel, and Olson, 1981)



Unsaturated coefficients of permeability obtained using the instantaneous profile method in the laboratory (after Hamilton, Daniel, and Olson, 1981)

Indirect Methods for the Determination of the Unsaturated Water Coefficient of Permeability

- ***The cost of measuring the water coefficient of permeability is high***
  - ***Costs for the k_w function can be $5000 to $10,000***
- ***The solution is to device Indirect Methods that have sufficient accuracy for geotechnical engineering***
  - ***Accuracy does not need to be high when predicting water pressures (or hydraulic heads)***
  - ***Accuracy needs to be greater for the prediction of water fluxes***

Assumptions for the Indirect Determination of Unsaturated Water Coefficient of Permeability

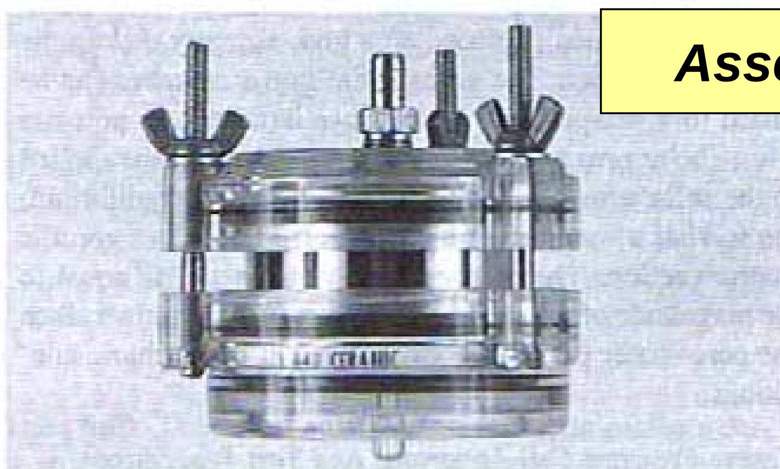
- ***Water can only flow through the water portion of the soil***
  - ***The Soil-Water Characteristic Curve, SWCC, can be used as a measure of the amount of water in the soil at any soil suction***
- ***The saturated coefficient of permeability of the soil will be independently measured***
- ***Empirical theories can be used to compute the unsaturated soil permeability function***

INDIRECT METHODS

To obtain the Permeability Function From the SWCC

Disassembled

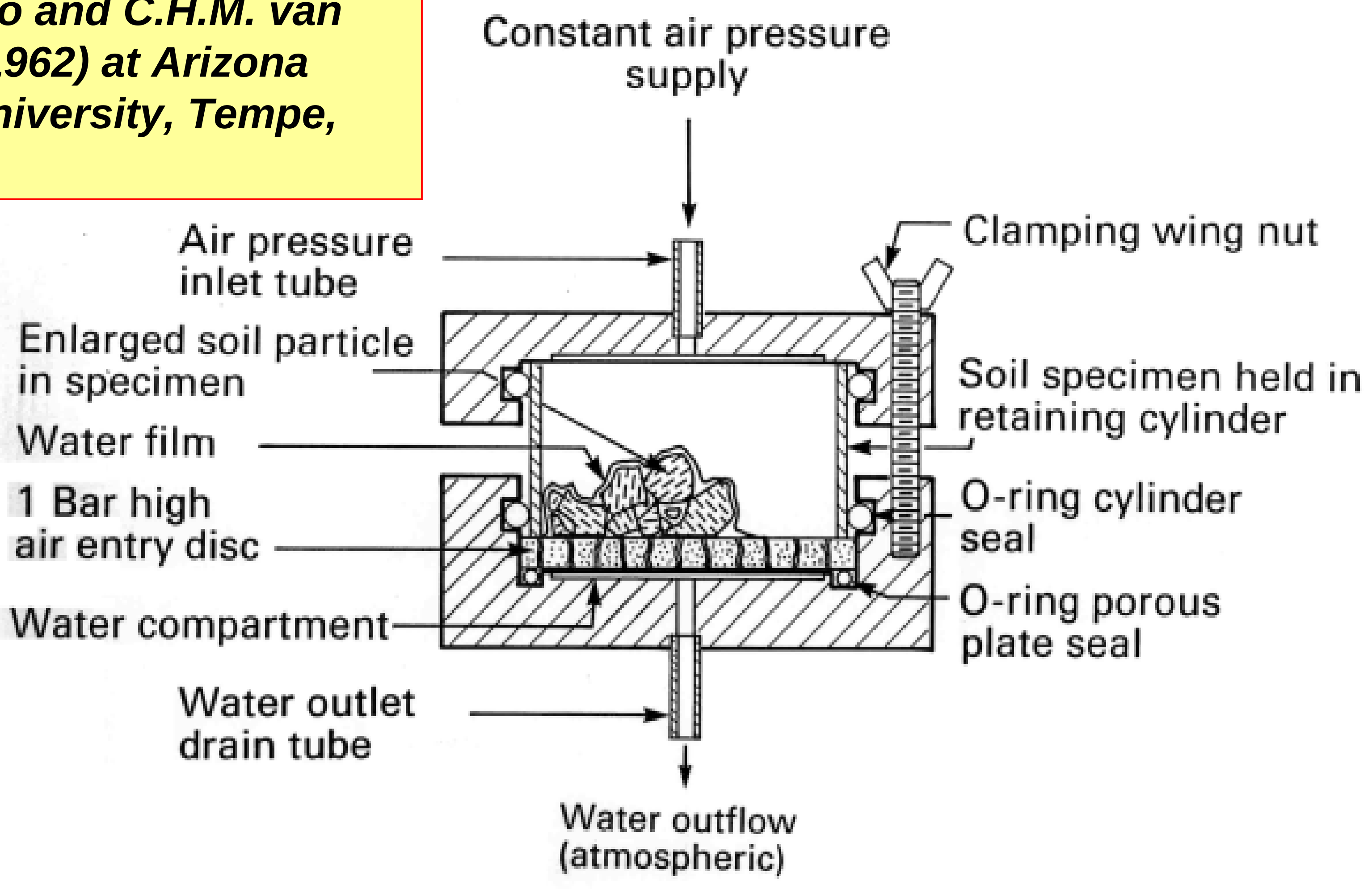
(a)



Assembled

Tempe Pressure Plate Cell Manufactured by Soilmoisture Equipment Corporation Santa Barbara, CA

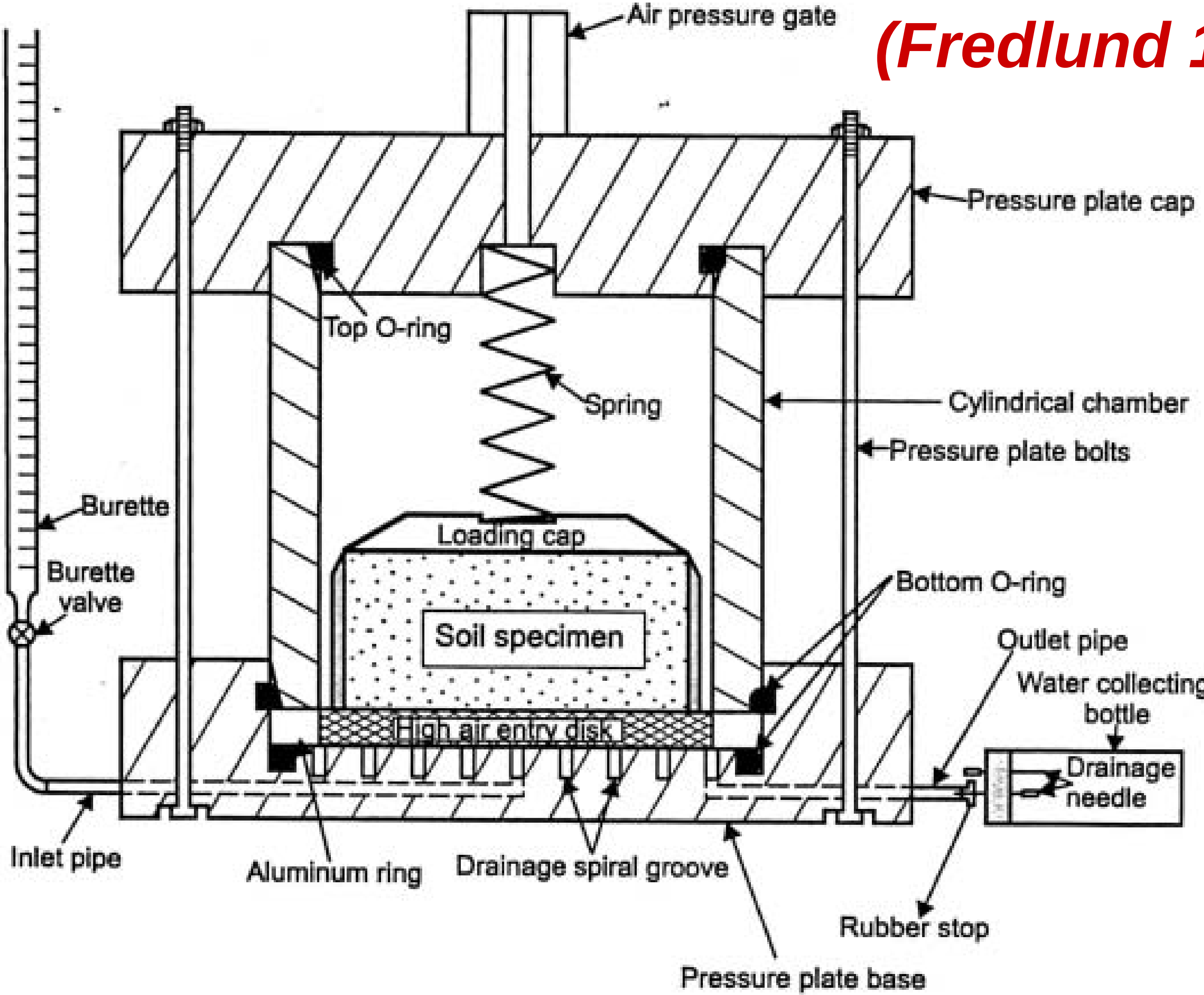
Developed by R.J. Reginato and C.H.M. van Bavel (1962) at Arizona State University, Tempe, Arizona



Cross-section of a Tempe pressure cell (from Soil Moisture Equipment Corporation, 1985)

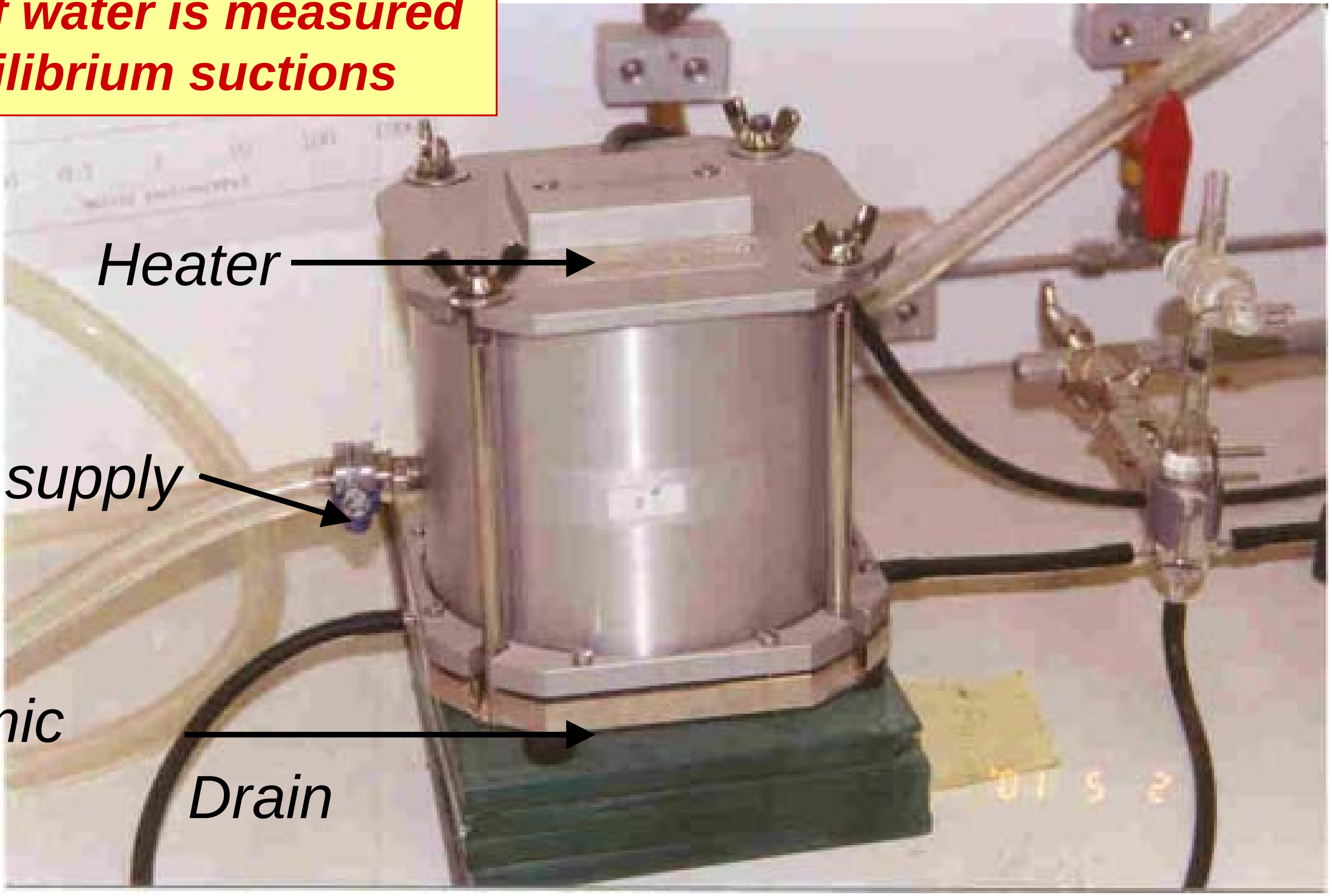
Univ. of Sask. Pressure Plate Cell

(Fredlund 1998)



Volumetric Pressure Plate – 2 Bar

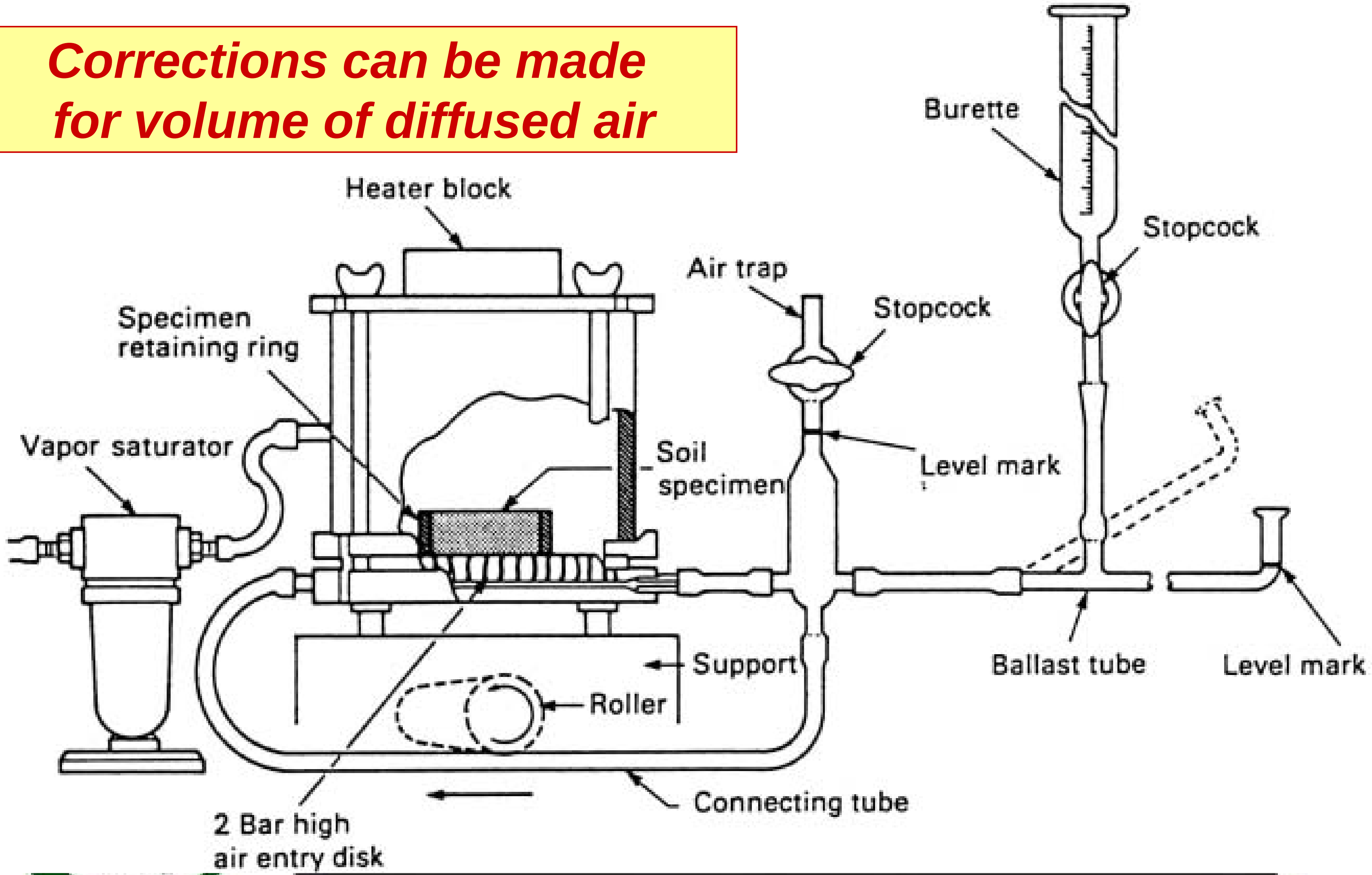
Volume of water is measured at equilibrium suctions



Soilmoisture Equipment Corp.

Volumetric Pressure Plate Extractor with Hysteresis Attachment

Corrections can be made for volume of diffused air



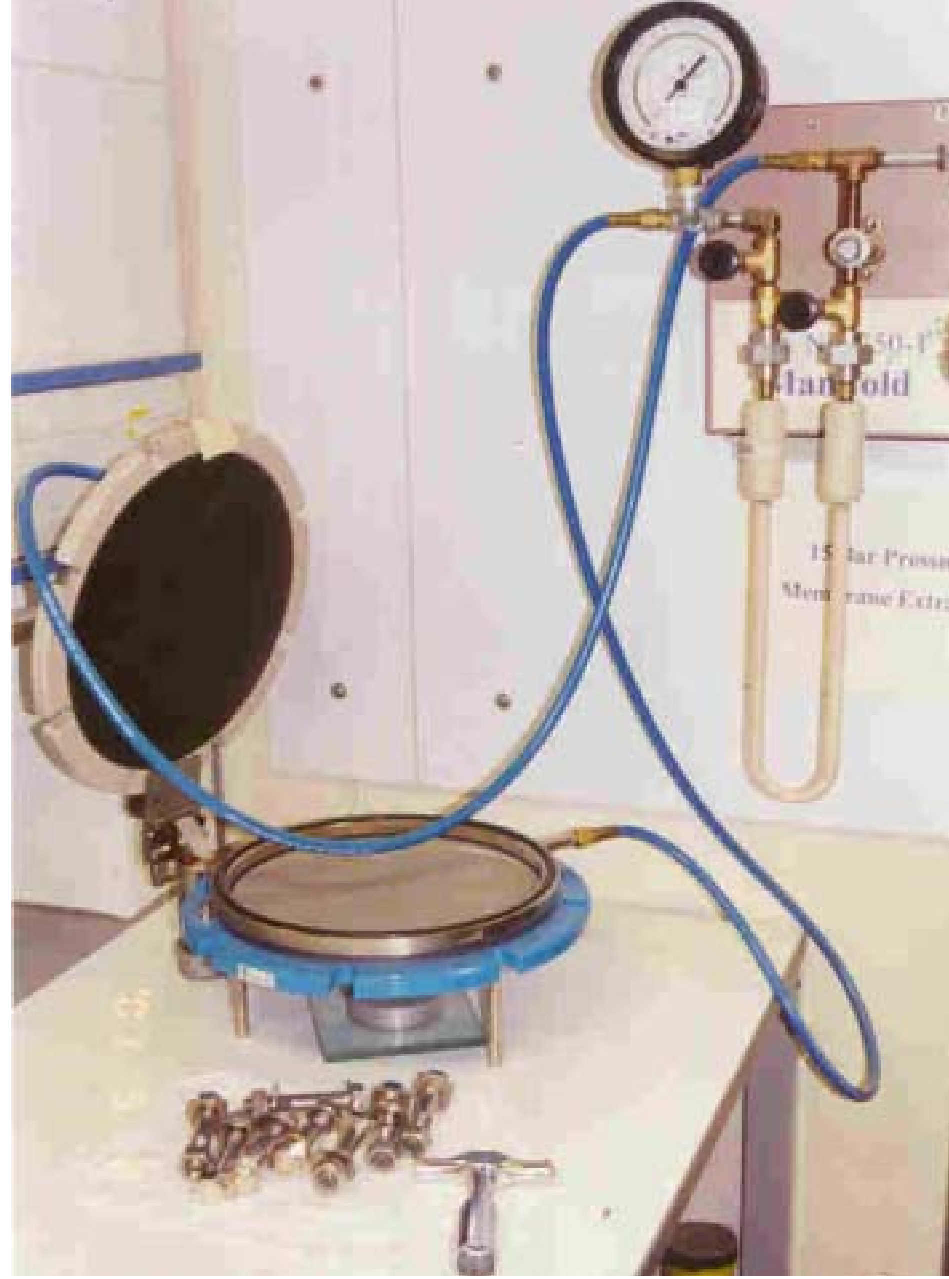
5-Bar Extractor

- ***Can have 3 ceramic plates***
- ***Each plate may have 6 to 12 soil specimens***

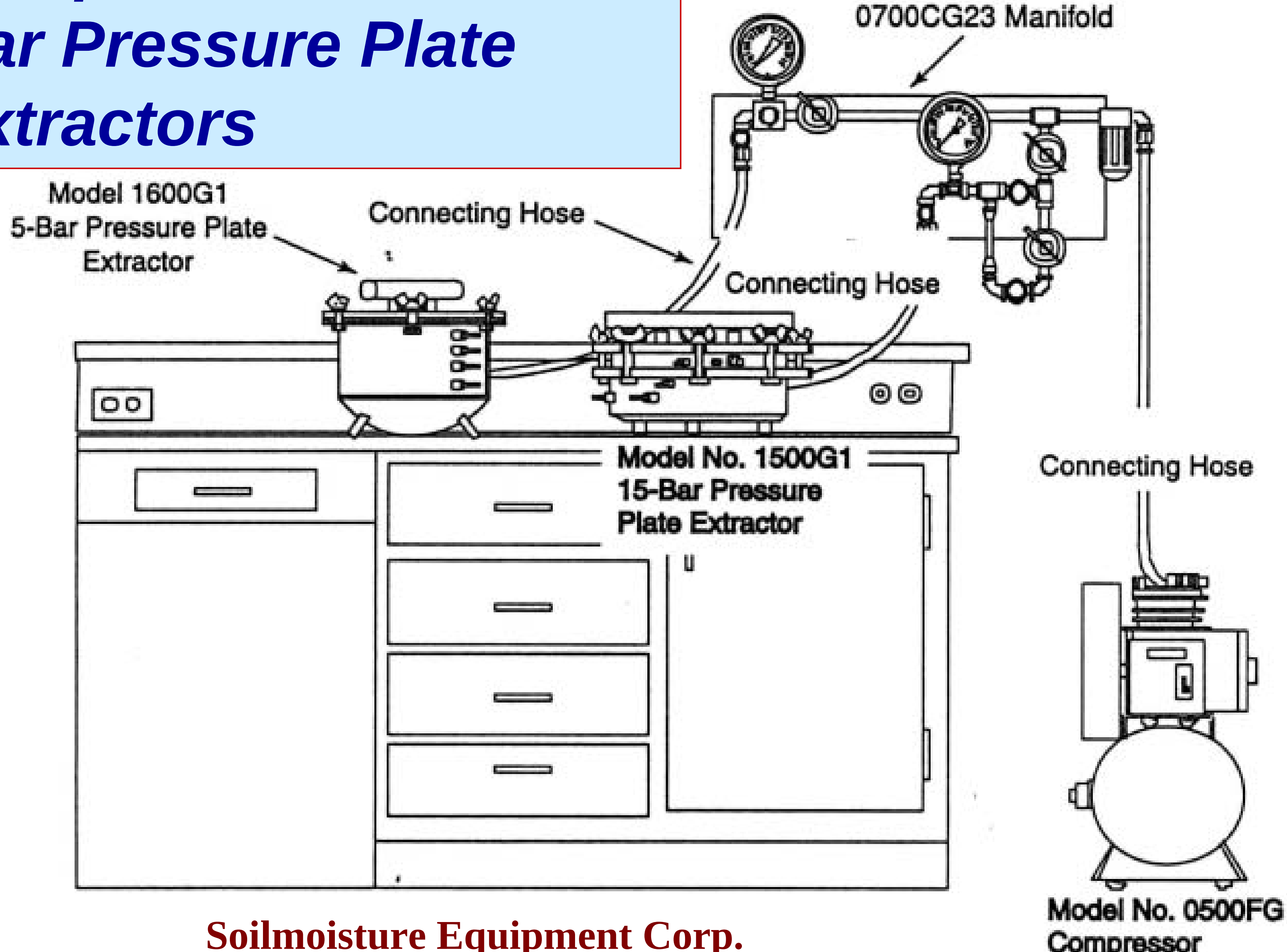
Specimen holders

15-Bar Extractor

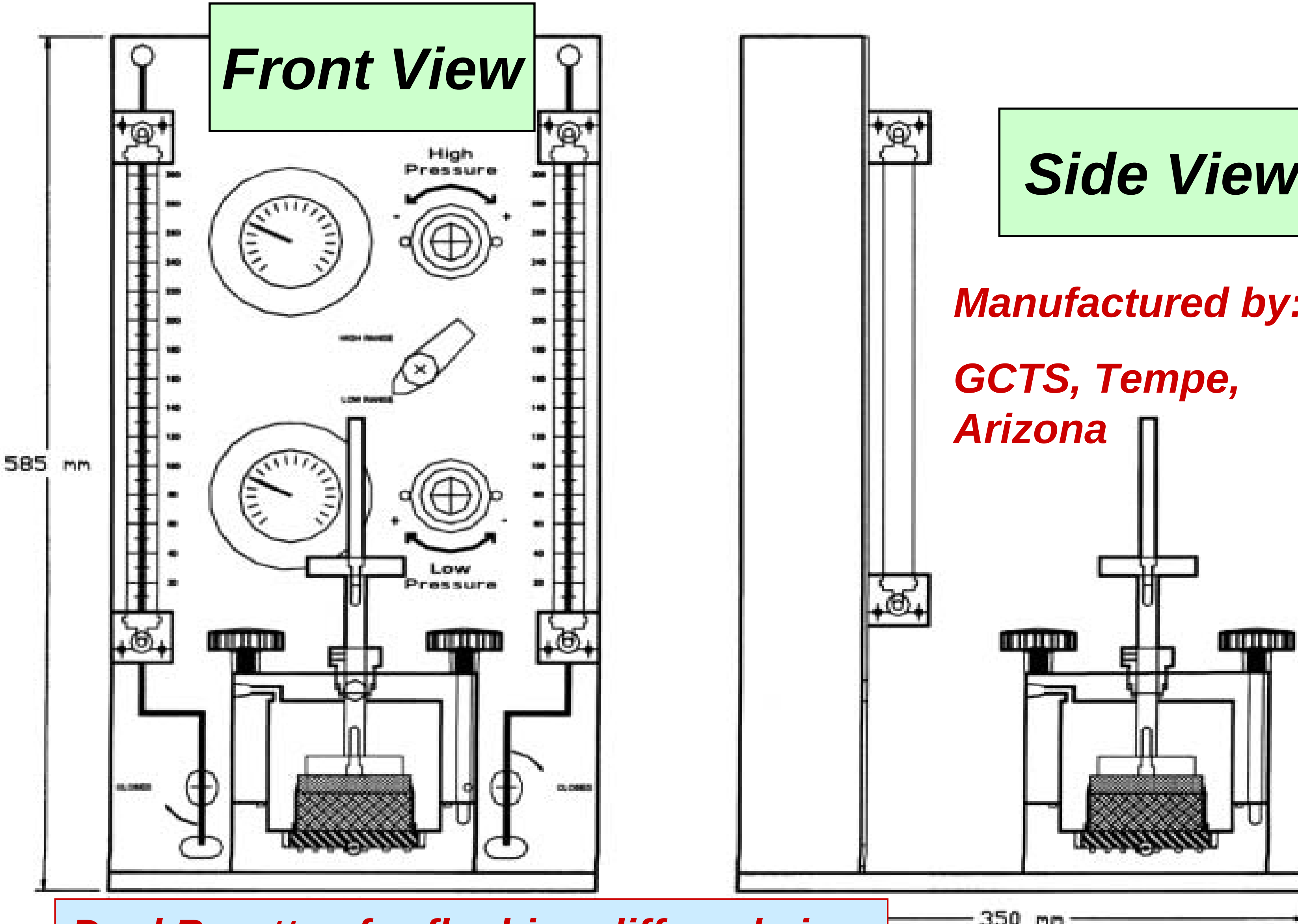
- *Can have 6 to 12 soil specimens*
- *Mercury U-tube to create differential pressure on top of soil specimens*



Setup of 5 Bar and 15 Bar Pressure Plate Extractors



Soil-Water Characteristic Curve Apparatus



Manufactured by:

GCTS, Tempe, Arizona

Dual Burettes for flushing diffused air

SWCC Apparatus Manufactured by GCTS

SWCC Apparatus Manufactured by GCTS with the loading frame apparatus

Ko Loading Apparatus

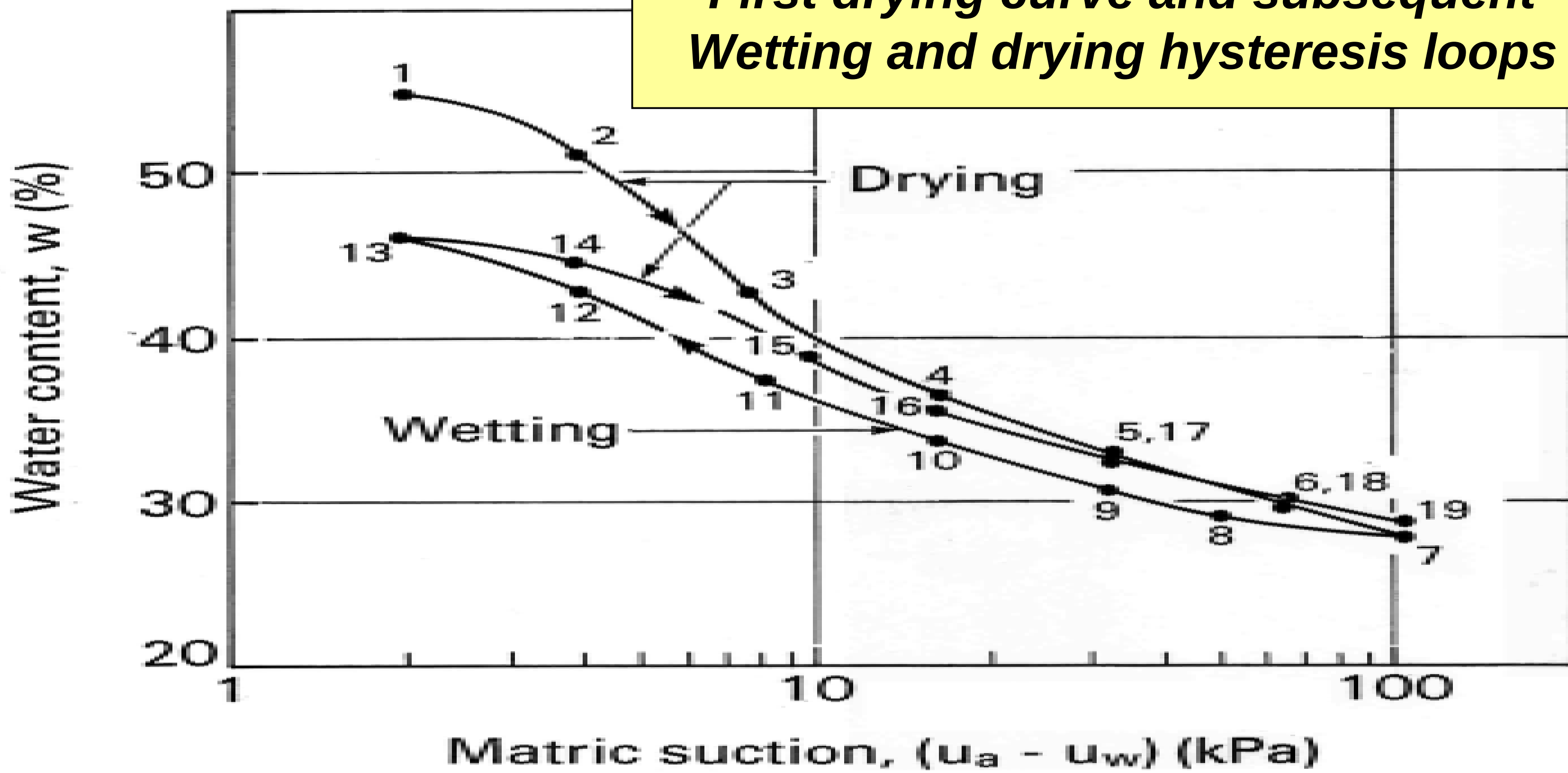
Observations on the Development of Pressure Plate Apparatuses

- ***Soilmoisture Equipment is primarily designed for agricultural purposes***
- ***Matric suctions need to be applied up to at least 500 kPa***
- ***More attention to testing procedure***
- ***More attention to hysteresis***
- ***Ability to measure water and total volume changes***
- ***Ability to apply a vertical load***
- ***Tendency to accept K_o loading***

Observations on the Development of Pressure Plate Apparatuses

- ***More attention to the accuracy required***
- ***Record the classification properties and initial conditions***
- ***More attention to flushing and measuring diffused air***
- ***Ease of assemblage and use***
- ***Attention to safety when using high air pressure***

First drying curve and subsequent Wetting and drying hysteresis loops



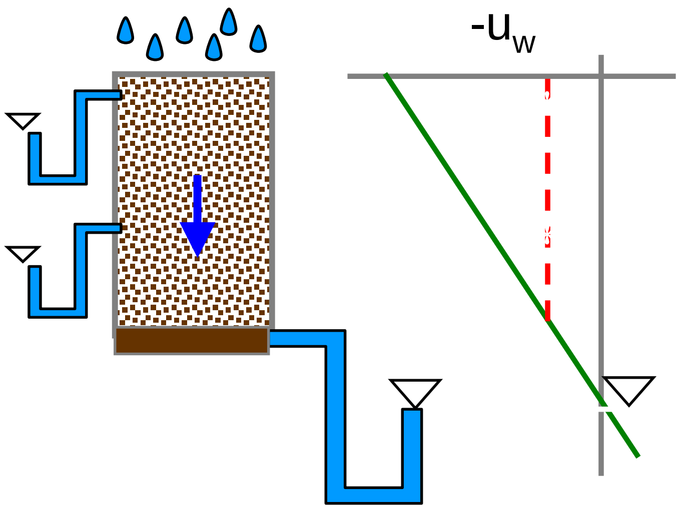
Soil-water characteristic curves for the drying and wetting processes for Aiken clay loam (from Richards and Fireman, 1943)

Forms for the Permeability Function Based on the SWCC

- ***Childs and Collis-George (1950)***
  - ***Summation type integration***
- ***van Genuchten (1980) –Closed form***
- ***van Genuchten-Burdine (1953, 1980)***
- ***van Genuchten-Maulem (1976, 1980)***
- ***Fredlund, Xing and Huang (1994)***
  - ***Integration form***
- ***Rahardjo and Leong (2000)***
  - ***Closed form; raise SWCC to a power***

Simple Laboratory Measurement of Permeability at Various Suctions

- Steady State:controlled flux
  (Stolte et al, Soil Science of America Journal 1994)
  - 'Drip Infiltrometer' Method
    - Apply a known flux at the top of the permeameter
    - Tensiometers to measure pore-water pressure



$$h = Y + \frac{u_w}{\gamma_w}$$

$$\frac{dh}{dy} = \frac{dY}{dy} + \frac{du_w}{\gamma_w dy}$$

=1

= 0 under steady state

$v = k_w \, dh / dy$

- Simple Case:
  - for Q ~ constant, dy/dz = 0 (constant suction with depth)
  - dh/dy = 1; therefore q = k