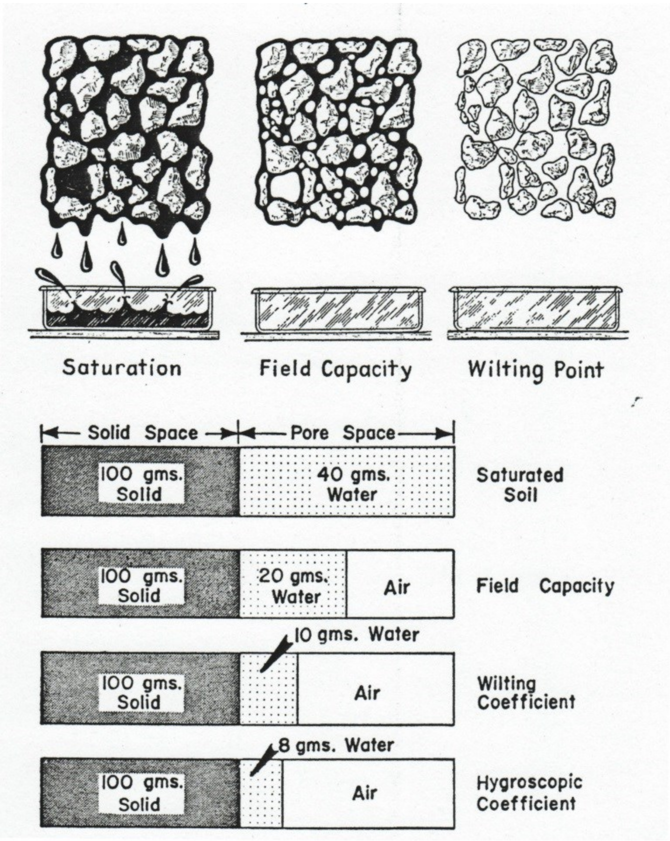
WATER IN THE SOIL

Behaviour, Storage and Movement in the Soil

Robert van de Graaff, PhD
Van de Graaff & Associates P/L

Soil is hydrophilic – It attracts water to its surface very strongly (as well as into its voids by capillarity)



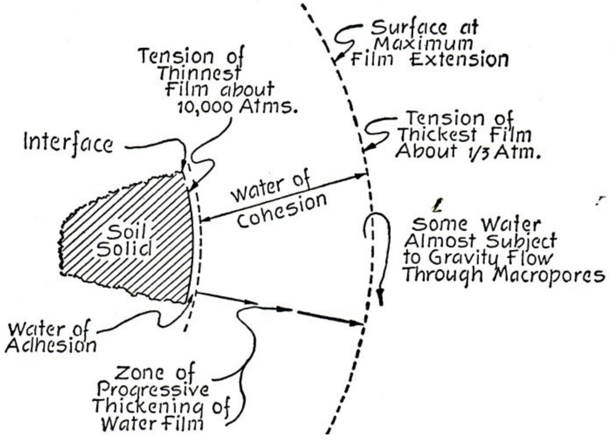


*Figure 7:2. Diagramatic representation of the progressive thickening of a water film in a macropore and the corresponding decline in the tension at which the surface molecules are held. While an increment of water can be extracted easily from the surface of a thick film, a similar removal from a thin film is much more difficult. Soil water is held in two ways—*adhesion *and* cohesion.

Capillary forces control water in the soil

Strength of the capillary suction is expressed as the height of the water being drawn up above a reference surface

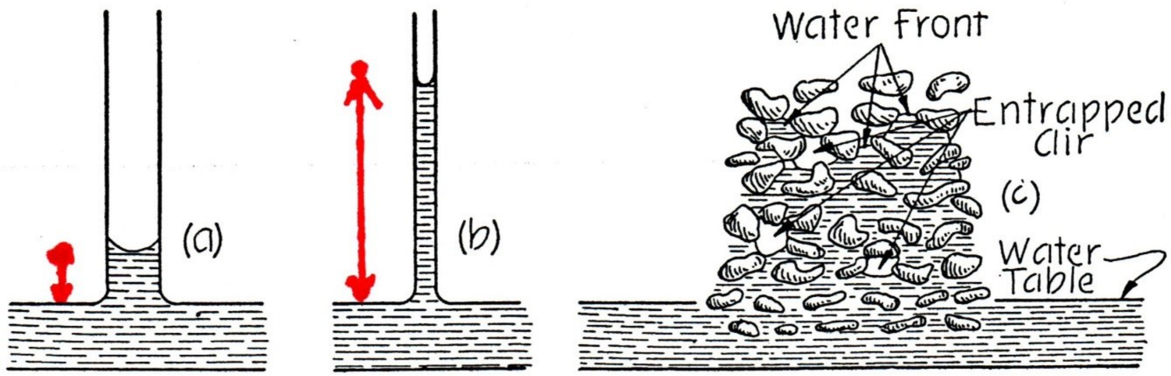
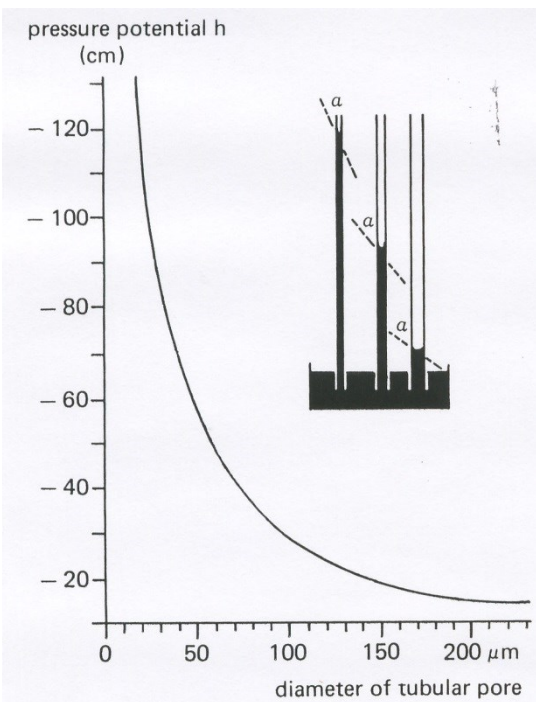


***Figure 7:10.** The upward capillary movement from a water table, (a) in a large glass capillary tube, (b) in a small capillary tube, and (c) in a soil column. Note the higher rise in the small capillary tube and the greater curvature of film. While the mechanism is the same in both the tubes and in the soil, the adjustment is extremely irregular in the latter due to the tortuous nature of the channels, their variability in size, and the presence of entrapped air.*

Units of Strength of capillary forces
(cm above reference surface, or atmospheres of pressure)



[5] *A Table of Pressure Equivalents*

Height of a Unit Column of Water in Centimeters	*Atmospheres (Bars) of Pressure Approximate*
1	1 / 1000
10	1 / 100
100	1 / 10
346	1 / 3
1,000	1
10,000	10
15,849	15
31,623	31
100,000	100
1,000,000	1,000
10,000,000	10,000

[6] For further information consult L. D. Baver, *Soil Physics* (New York: Wiley, 1956), pp. 224–47.

Capillary force expressed logarithmically as pF so as to have small numbers

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[6] For further information consult L. D. Baver, *Soil Physics* (New York: Wiley, 1956), pp. 224–47.

- pF = log of height water column (cm)
- a. Water pressure = 100 cm → pF = log(100) = log(10^2) = 2
- b. water pressure = 1000 cm → pF = log (1000) = log(10^3) = 3
- Etc. etc.
-

Conversions to various units

Table 1 **Conversions of head in cm to other units used for expressing pressure or suction (negative pressure)**

Head (length of water column)	kPa	pF	bar	Psi*)
80 cm	8	1.9	0.000,08	1.160
100 cm	9.8	2	0.098	1.421
300 cm	29.4	2.47	0.294	4.264
407.9 cm	40	2.61	0.4	5.801
815.8 cm	80	2.92	0.8	11.603
15,000 cm	1471	4.2	14.71	213.35

*) pounds per square inch

Positive pressure vs negative pressure

- When water is drawn upwards into a capillary it is due to the negative pressure or suction exerted on it by the capillary
- There is no positive pressure pushing it upwards from the bottom of the capillary
- Instead of talking about **suction** we normally speak about **tension**
- To draw water out of a capillary one needs to apply a suction greater than that produced by the capillary
- As the capillaries become narrower the water they hold is under greater tension: **Soil Moisture Tension**

Soil moisture tension and equivalent soil pore diameter

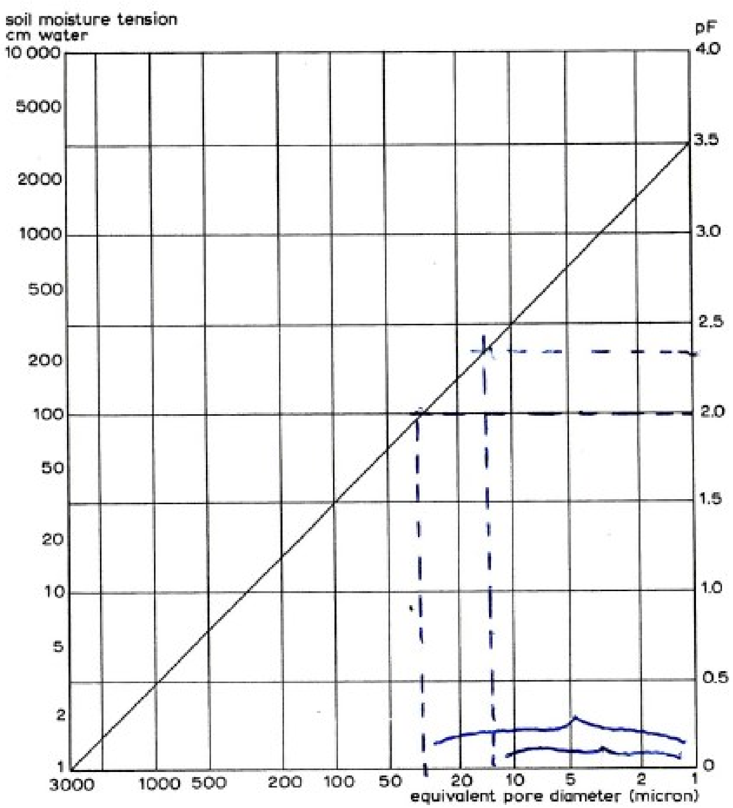


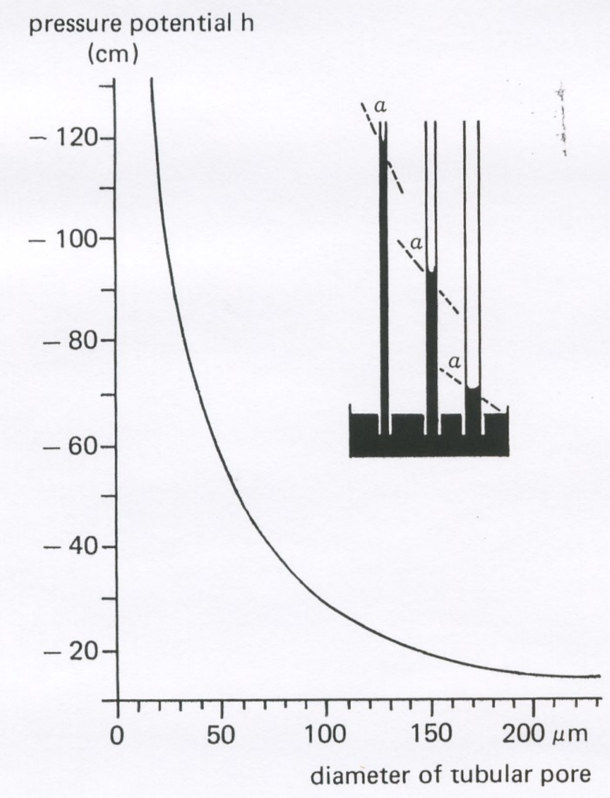
Fig.2. Relation between soil moisture tension and equivalent pore diameter (for water at 20 °C)

- Field Capacity of soil equates to that water that fills all pores smaller than ≈ 30 micron (= pF 2.0)
- As the soil dries out, the remaining water is progressively only in the smaller pores
- The plants have to "work" harder to get it out
- At pF = 4.2, the soil may still have water, but the plants will irreversibly wilt and die.

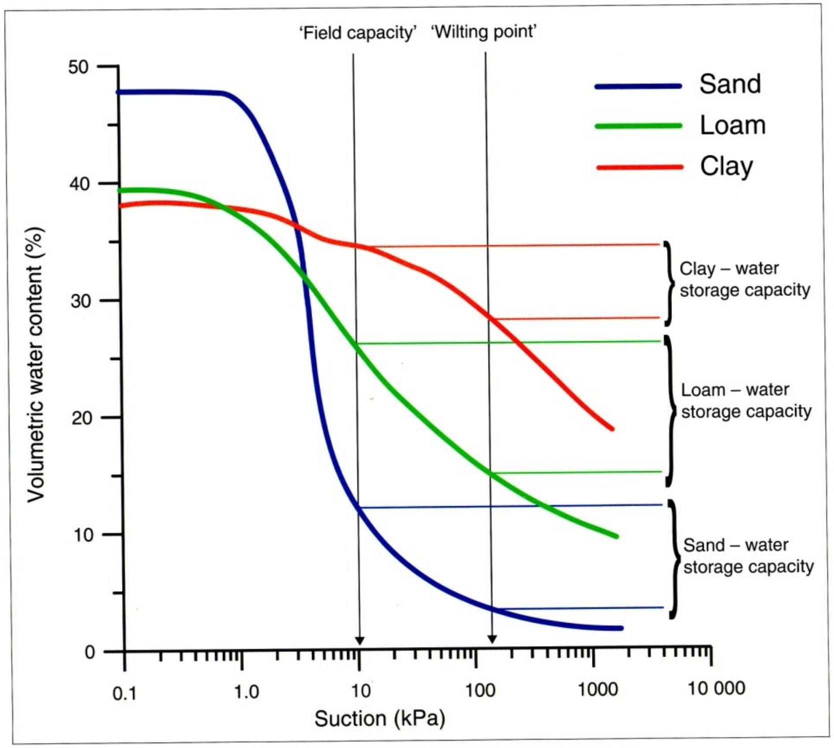
How is water held in soils?

All soil pores act as capillaries

A pore with a diameter of 20μm exerts enough suction to pull water up 1.2 m



Sand contains mostly large pores so these can only be full at low suction; clay has predominantly smaller pores so clays have much of its pores full of water at a wide range of suction



Effects of capillary suction

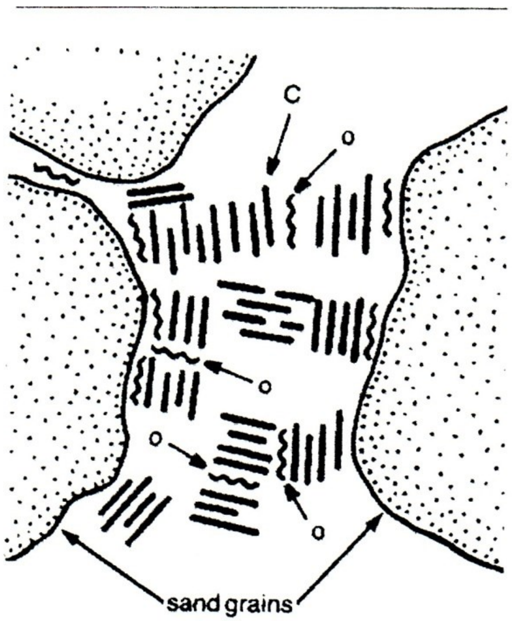
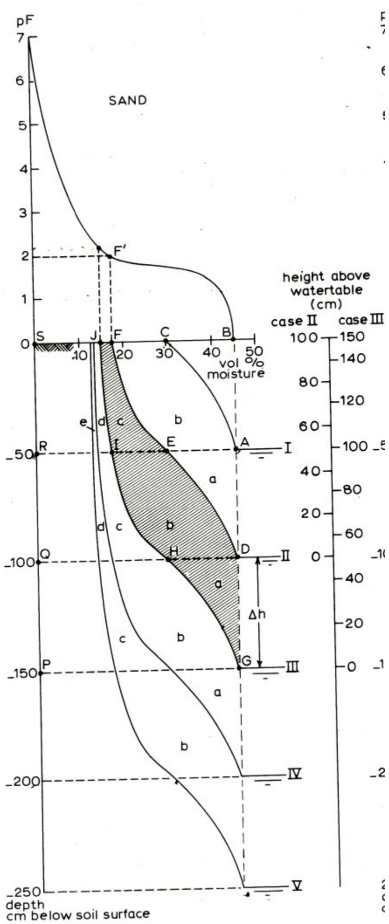


FIGURE 8.3
Soil crumbs are probably held together in this way. O = organic matter, C = clay mineral particles. *After* W W Emerson *J. Soil Sci.* 10: 235, 1959

- In soil that contains sands. Silts, clays and organic matter, when it dries out the capillary suction compresses the soil particles:
- A. the soil shrinks
- B. soil pores become narrower
- The higher the clay content the higher the shrinkage
- Cultivated soils that wet and dry repeatedly become denser by the repeated shrinking and re-arrangement of soil particles

Effects of shallow water table on water storage



Bemm River camping ground

- Yabby mounds all over the surface of the disposal field
- A single rainstorm of 25 mm causes the water table to rise to the surface
- With the water table so close, there is almost no water storage space in the soil between the water table and the surface

Capillarity and upward water movement
extent and rate #1

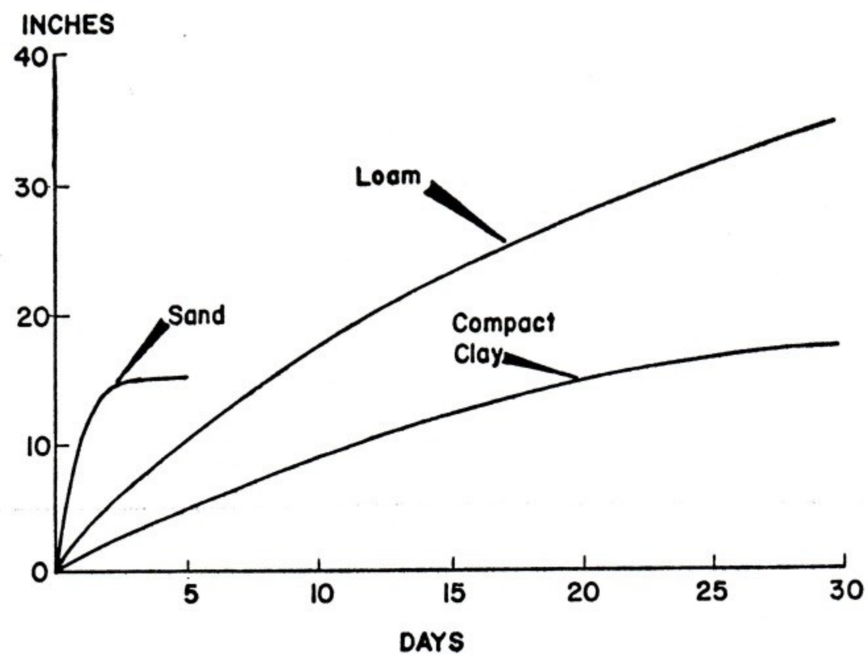


Figure 7:11. *Upward movement of moisture from a water table through soils of different textures and structures. Note the very rapid rise in the sand, but the moderate height attained. Apparently, the pores of the loam are more favorable for movement than are those in the compact clay. The rate of movement is thus seen to be of greater significance than the total height.*

Capillarity and water movement (upward and lateral)

extent and rate #2

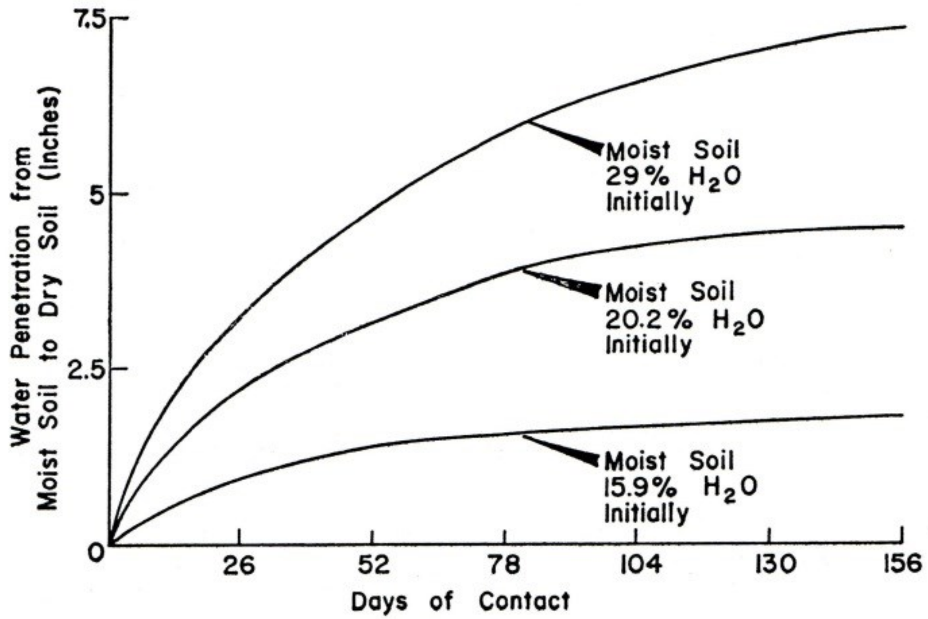


Figure 7:13. Curves showing the rate of water movement from a moist soil at three moisture levels to a drier one. The higher the water content of the moist soil, the greater will be the tension gradient and the more rapid will be the delivery. Water adjustment between two slightly moist soils at about the same water content will be exceedingly slow. (After Gardner and Widtsoe.)

Water movement from moist/wet soil to drier soil

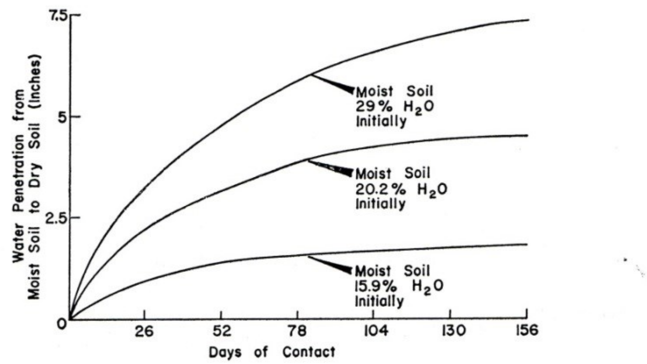
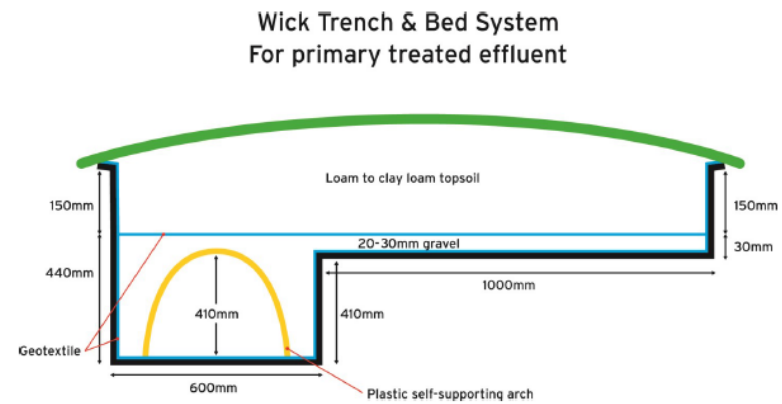


Figure 7:13. Curves showing the rate of water movement from a moist soil at three moisture levels to a drier one. The higher the water content of the moist soil, the greater will be the tension gradient and the more rapid will be the delivery. Water adjustment between two slightly moist soils at about the same water content will be exceedingly slow. (After Gardner and Widtsoe.)

- Wicking trench & bed system – Are we sure it works? Has anyone measured it?



Darcy’s Law (1856)

- Seepage velocity, V, of water through a soil with hydraulic conductivity, Ksat, under a gradient, i, equals:
- $$Q = K\,(\Delta h/L)\,A$$
-
- where
- Q = the rate of flow through the sample (volume/time, for example litres/minute)
- Δh = delta h the head loss L (length, for example metres)
- L = the length of the sample (length, for example metres)
- A = cross-sectional area of the tube holding the sample (area, for example m^2)
- K = proportionality constant, depending on the nature of the sand and the fluid (water in our case), (length/time, for example metres per day)

Let's apply Darcy's Law to lateral seepage of effluent.

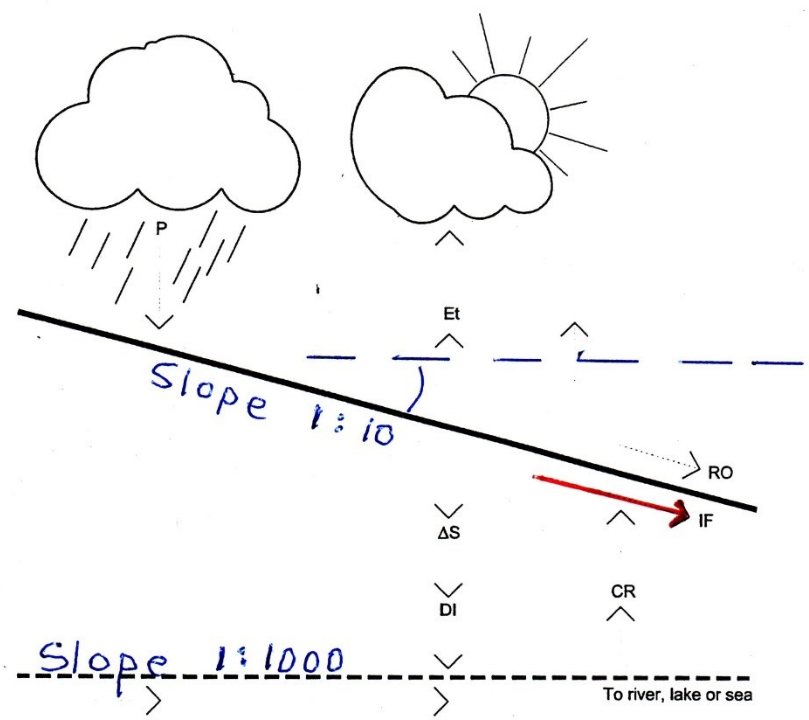


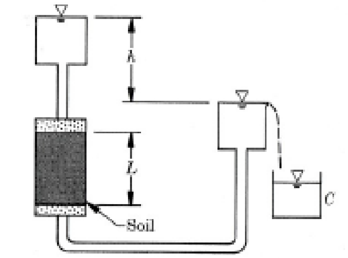
FIGURE 4.2C1 THE NATURAL WATER BALANCE OF LAND

- 1. Seepage through upper soil: Assume Ksat of soil = 0.5 m/day. Slope gradient is 0.1, thus seepage velocity is:
- V = 0.1 x 0.5 = 0.05 m/day
- To travel 1 m takes 20 days

- 2. Groundwater flow.
- Usually gradients are very small
- Even in pure sand with Ksat of 10m/day:
- V = 0.001 x 10 = 0.01 m/day
- Travel time for 1 m = 100 days

Measuring soil hydraulic conductivity in the lab

Figure 4. Laboratory method for measuring hydraulic conductivity under constant head



The soil sample sits in the cylinder and water flows through it due to the water being subjected to a hydraulic head, i.e. the water in the top container is situated higher than the level of the container where it flows out.

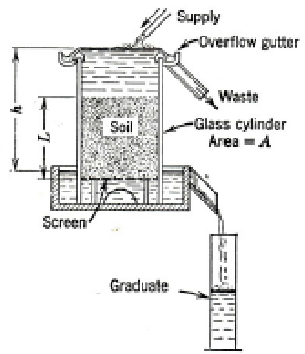
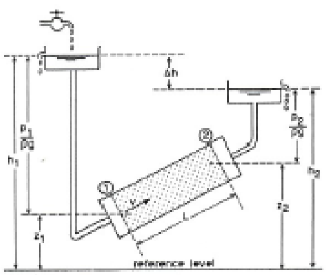
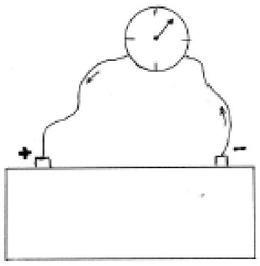


FIG. 6·3 Constant-head permeameter.

Just a variation in the set up shown to the left.

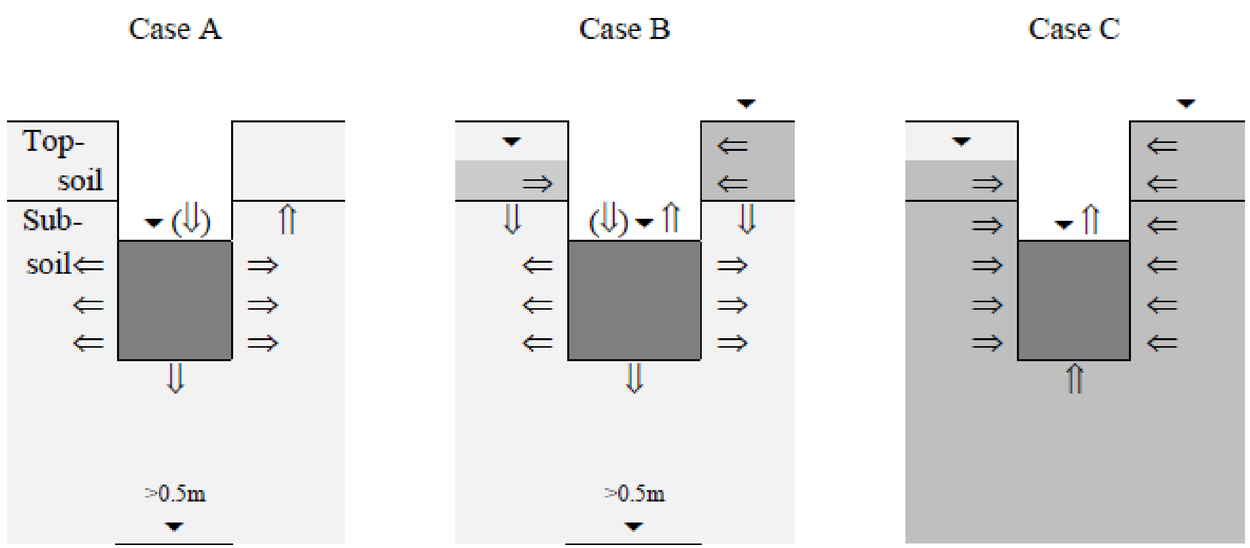


Another variation in the set up. It makes no difference whether the container with soil is angled or upright. The water still has to traverse a fixed length of pathway.



Electricity flows through a conductive metal wire also because the current is "pushed" by a potential (voltage) difference between the two electrodes of the battery.

Soil moisture conditions and their possible seasonal variations as they affect *soil permeability and soil percolation tests in the field*: Only Case A is suitable for the test



⇐ ⇒ ⇑ ⇓	Directions of water flow (⇓) Applies only to the falling head percolation test. The water level in the hole stays at the pre-set level in a constant head permeability test.
▼	Indicating position of the free water surface (water table).
	Dry or moist but not saturated soil.
	Saturated soil.
	Water in the test hole.

Case studies of LCA practice

- 1. Consultant sets up percolation tests and notes water is spontaneously running into the hole from the soil. He cannot get the added water to percolate away. Conclusion: “The soil is impermeable” [Yet water can clearly be seen to be moving but in the wrong direction!!]
- 2. Consultant sets up percolation tests and notes water from the soil is spontaneously running into the hole, goes away, comes back next day. Now the holes are full. Checks with EHO who tells him onsite systems work well. Conclusion: “we must come back some other time to repeat the tests”. [Surely there was no need to check with the EHO]
- 3. Consultant sets up percolation test immediately next to full farm dam and obtains zero percolation rates. Conclusion: “the soil is impermeable”. [Probable reason the soil was already saturated]
- 4. The Regulator (EPA) used to advise that consultants must do the percolation tests when the soils are at their wettest. Conclusion: Even the regulator didn’t understand water in the soil.

How does water flow through soil? Saturated flow

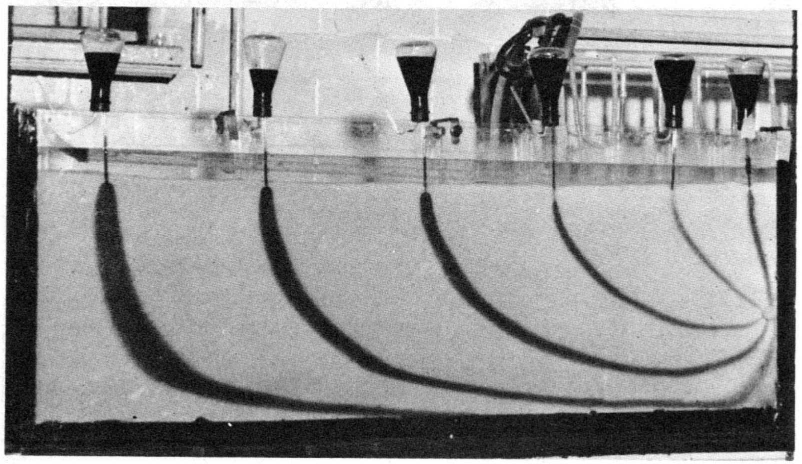


Figure 9:4. Demonstration of the saturated flow patterns of water toward a drainage tile. The water, containing a colored dye, was added to the surface of the saturated soil and drainage was allowed through the simulated drainage tile shown by the arrow on the extreme right. (Photo courtesy G. S. Taylor, Ohio State University.)

- Saturated flow controlled by flow lines through a uniform medium
- Flow velocity is controlled by hydraulic gradient which is non-uniform here & hydraulic conductivity Ksat which is uniform
- Hydraulic gradient equals difference in water table height divided by flow path length

(explain)

Hydraulic conductivity affected by soil structure, chemistry (sodicity) and gypsum amendments

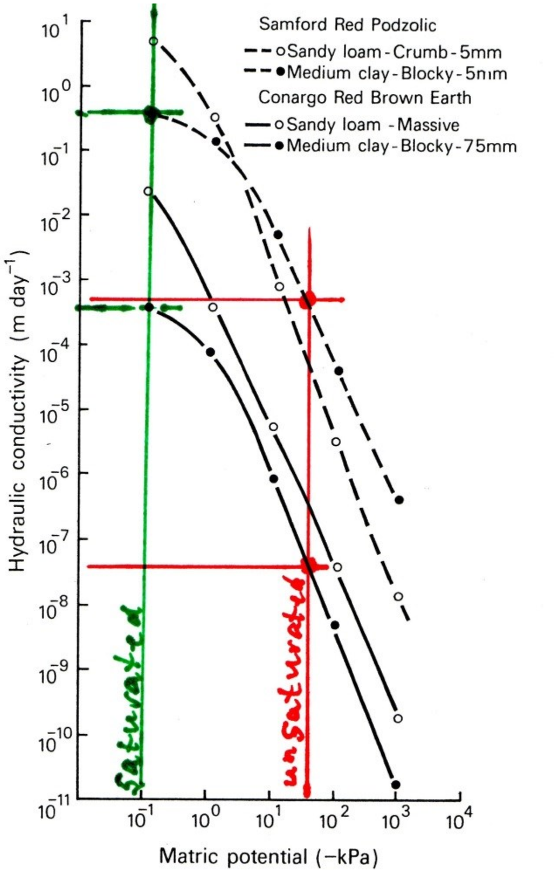


Fig. 32.12. Hydraulic conductivity–matric potential relationship illustrating the influence of structure at similar textures for two important Australian soils. (Based on data from Prebble 1970*b*, Bridge 1968.)

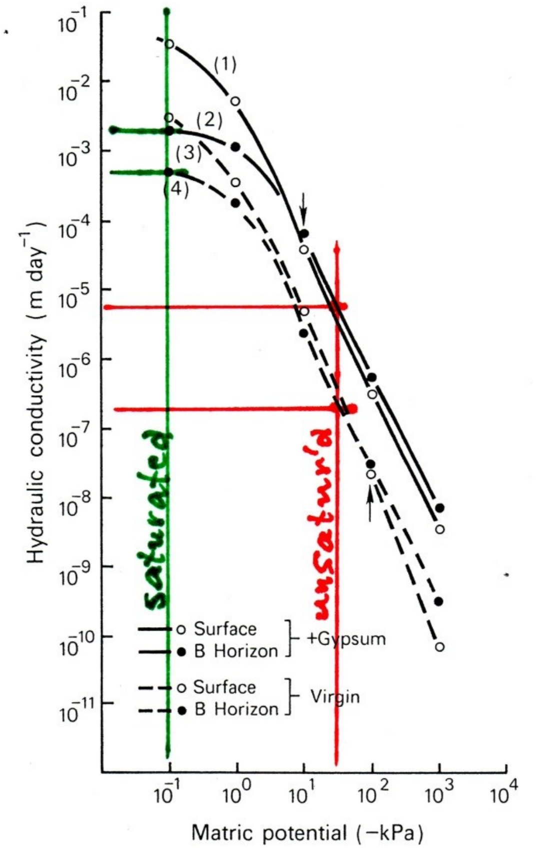


Fig. 32.13. Effect of gypsum and structural stability on the hydraulic conductivity–matric potential relationship for Billabong grey cracking clay. (Johnston 1952; Bridge 1968.)

Using AS/NZS 1547:2012 to predict permeability and loading rate

- Clay soil profile on basalt at Deer Park
- "Oh what a beautiful structure…!!" ☺
- Soil Category 6a with indicative Ksat of 0.6-0.05 m/day
- Actually Ksat ≈ 0.002 m/day ☹
- Highly sodic clay subsoil
- Highly dispersive
- High pH ≈ 9.5

Using AS/NZS 1547:2012 to predict permeability and loading rate

- Clay loam to light clay soil profile on volcanic rock in forest near Warburton

- "Oh what a beautiful structure..!" ☺

- Actual Ksat ≈ 0.2 m/day
- Non-sodic, non-dispersive, acidic profile, pH ≈ 5.8

Range of variation of Ksat & Kunsat

How many tests are needed to obtain a “representative” value?

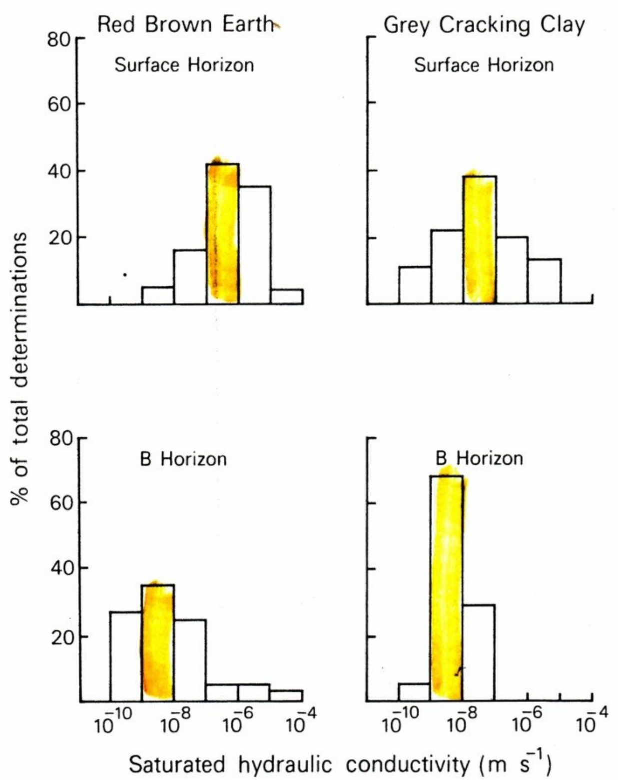


Fig. 32.14. Variability of saturated hydraulic conductivity for two important Australian soils. (Redrawn from Bridge 1968.)

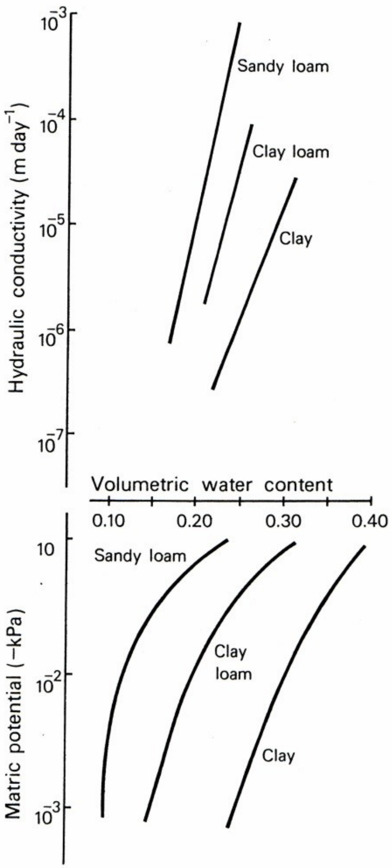
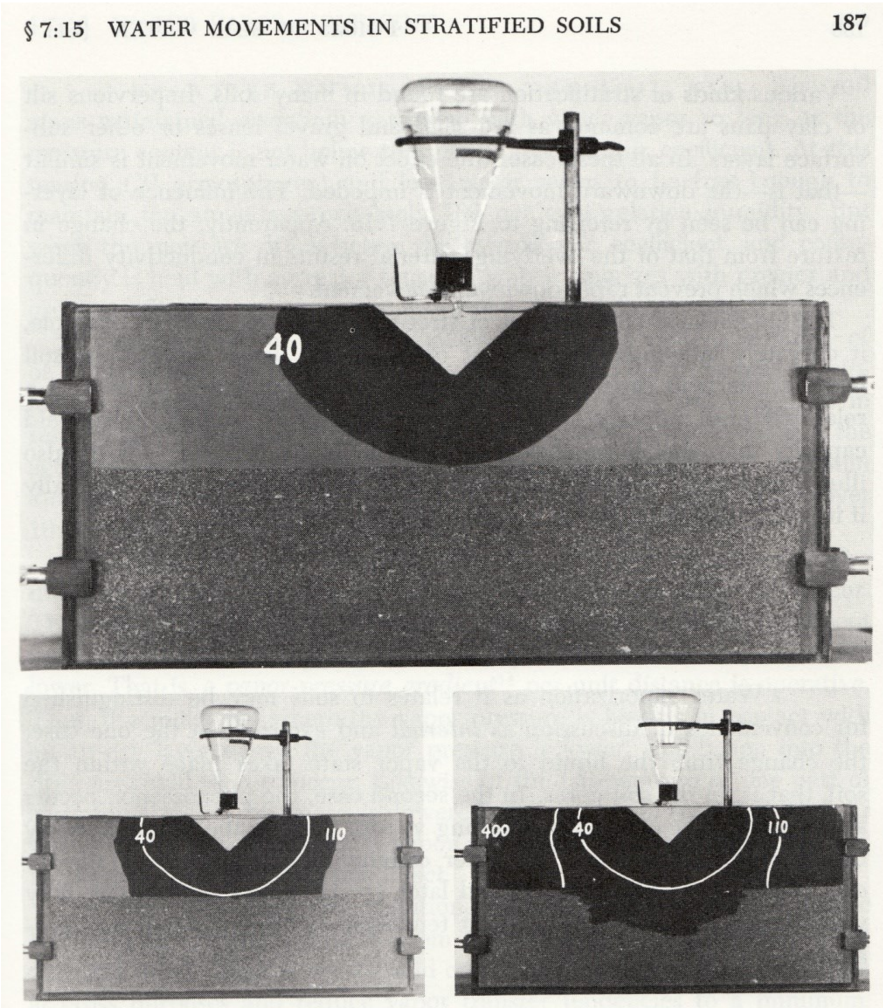


Fig. 32.10. Unsaturated hydraulic conductivity and matric potential as function of volumetric water content for clay, clay loam and sandy loam soil textures. (Data redrawn from Rose *et al.* 1965.)

How does water flow through soil? Unsaturated flow



- **Unsaturated flow controlled by size of capillaries (soil pores)**
- Upper soil layer in picture is loam with fine pores having stronger capillary suction than lower layer of sand with bigger pores
- Only when loam layer is saturated and suction there drops to low level can water enter the sand below

Practical uses of capillary theory - Irrigation

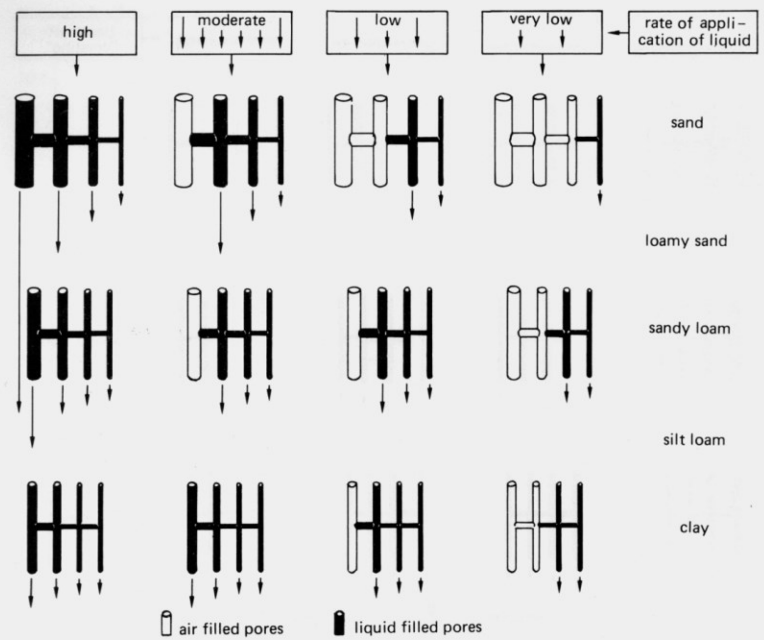


Fig. 18. Schematic diagram showing the effect of decreasing the rate of application of liquid on the rate of percolation through three "soil materials".

Schematic of pore sizes for different soil textures

1. Irrigating a sand with much water in a short time causes much water to be lost as the many large pores drain quickly; irrigating slowly forces only the small pores to let water through, keeping the water in the soil much longer
2. Irrigating a clay soil with much water could result in runoff, but irrigating at a moderate rate fills all the pores but these drain more slowly, keeping the water in the soil

Applying theory to improved effluent treatment - Controlling the application rate

Figure 4 Virus penetrates soil to greater depths and is reduced at a lesser rate, when the water moves through the soil at greater velocity.

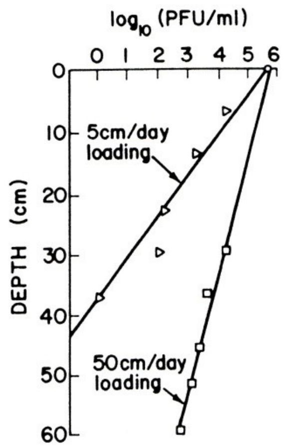


Figure 15. Penetration of poliovirus into packed sand columns at room temperature (Green and Cliver, 1974).

Figure 5 Slower seepage flow also leads to better retention and purification of bacteria.

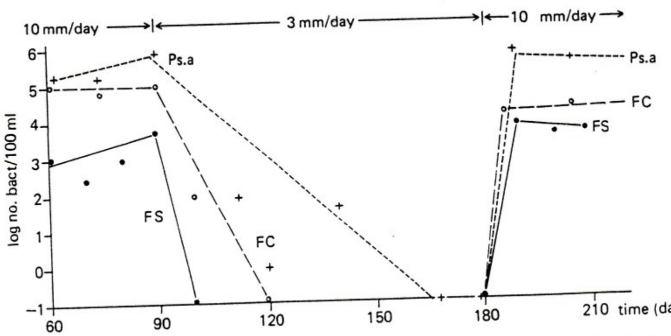
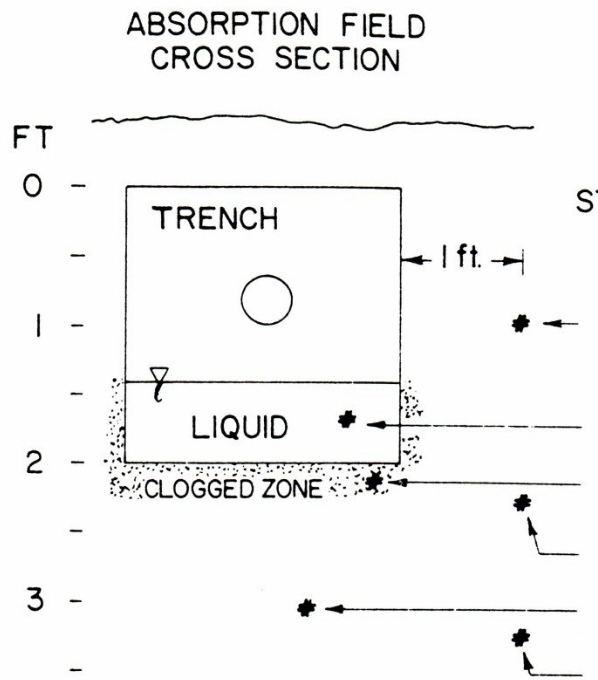


Fig. 31. Concentration of pathogenic bacteria as a function of the flow regime in large 55 cm long undisturbed columns of a prismatic silt loam. FS = Fecal Streptococcus, FC = Fecal Coliform, Ps.a = Pseudomonas aeruginosa. The lower dosing rate induces flow through rather than around the peds and results in better purification (Modified from ZIEBELL et al., 1975).

Reduction of faecal bacteria with distance of travel

Figure 6 Reduction of faecal bacteria counts with distance of travel around an effluent absorption trench.



BACTERIA/100 ml OR PER 100 g OF SOIL

FECAL STREPTO-COCCI	FECAL COLI-FORMS	TOTAL COLI-FORMS	TOTAL BACTERIA x 10^7
< 200	< 200	<600	0 6
160,000	1,900,000	5,700,000	3.0
54,000	4,000,000	23,000,000	4,400
<200	17,000	23,000	6 7
< 200	< 200	< 600	3.7
< 200	700	1,800	2.8

Figure C-7. Cross-section of an absorption field in Plainfield loamy sand with typical bacterial counts at various locations (Ziebell, *et al.*, 1975b).

Irrigating effluent from a trench

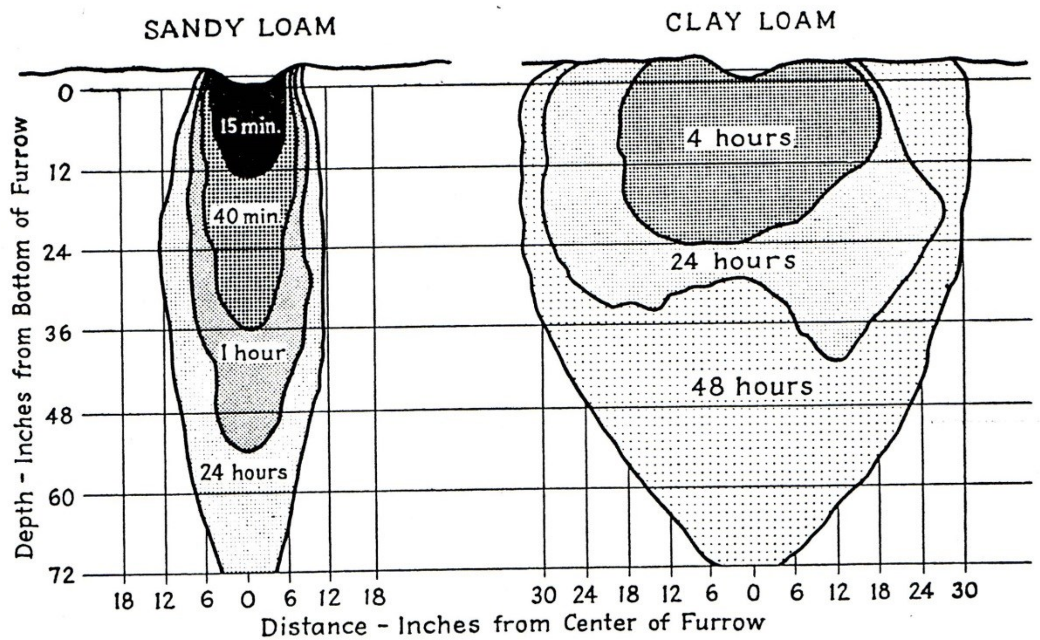


Figure 7:12. Comparative rates of irrigation water movement into a sandy loam (left) and a clay loam (right). Note the much more rapid rate of movement in the sand, especially in a downward direction. (Redrawn from J. J. Coony and J. E. Pehrson, Avocado Irrigation, *Calif. Agric. Ext. Leaflet 50, 1955.)*

Applying theory to monitoring an effluent trench and deriving safe long-term absorption rates

(Brouwer, J. 1982 – PhD thesis "Septic tank effluent absorption systems near Melbourne – Land Capability and Design", La Trobe University)

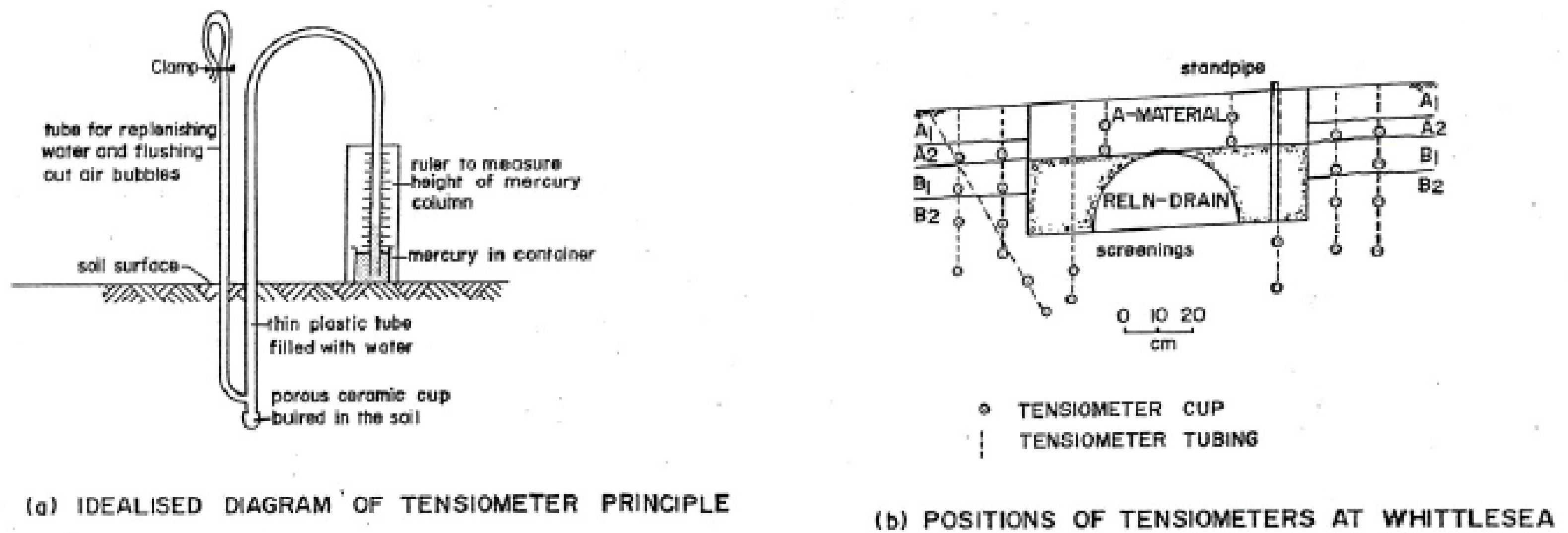


Figure 1 Diagram of the tensiometer principle and tensiometer positions around a trench at North Whittlesea.

Response of saturated surface (water table) to high rainfalls and dry periods

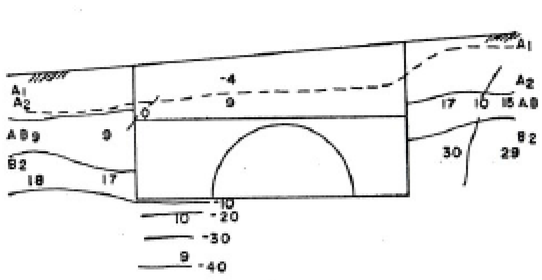


Fig. 3·2·6 A. ISOPOTENTIAL LINES AT NORTH WHITTLESEA ON 7 AUGUST 1978, DURING A WET PERIOD. (OLD TRENCH SYSTEM, LOWER TRENCH)

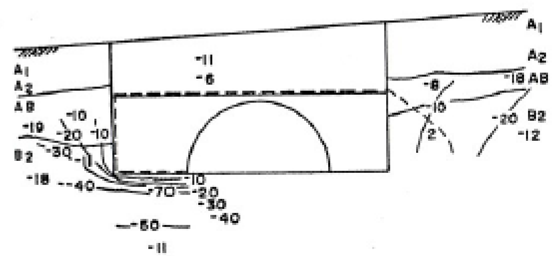


Fig. 3·2·6 B. ISOPOTENTIAL LINES AT NORTH WHITTLESEA ON 3 AUGUST 1978, DURING A DRY PERIOD. (OLD TRENCH SYSTEM, LOWER TRENCH)

Figure 3 Iso-potential lines and local perched water tables at North Whittlesea during a very wet period (left, 7 August 1978) and an earlier dry period in mid-winter (right, 3 August 1978). Note the rapid response of the water table in the trench and the surrounding soil to high rainfalls. The spacing of iso-potential lines below the trench also shows increased vertical drainage during the wet period compared to the dry period, which is a compensating factor.

Waterlogging does not necessarily lead to failure
In waterlogged soil GRAVITY pulls water downwards

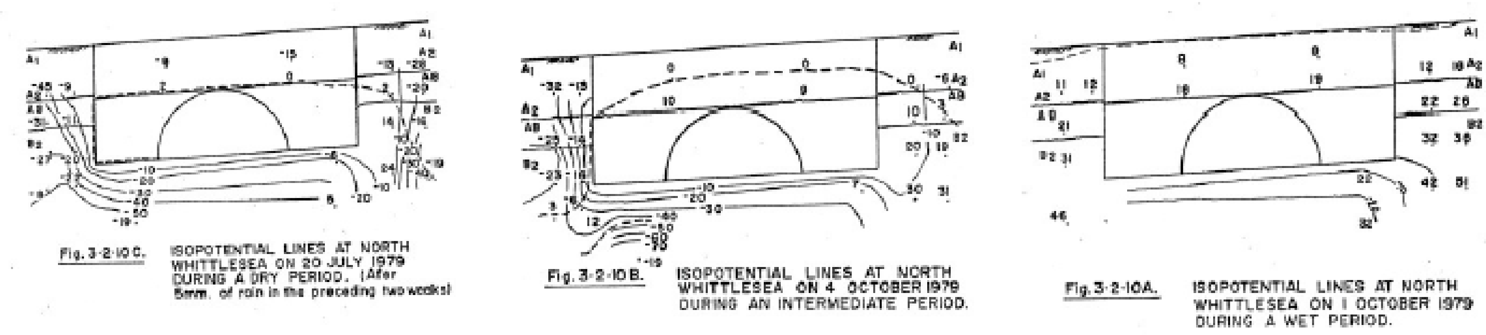


Figure 4 Iso-potential lines and local perched water tables around an absorption trench and a control site at North Whittlesea during 20 July 1979, a dry period (left), 4 October 1979, an intermediate period (middle) and 1 October 1979, a wet period (right).

Behaviour of trench under intermittent waterlogging

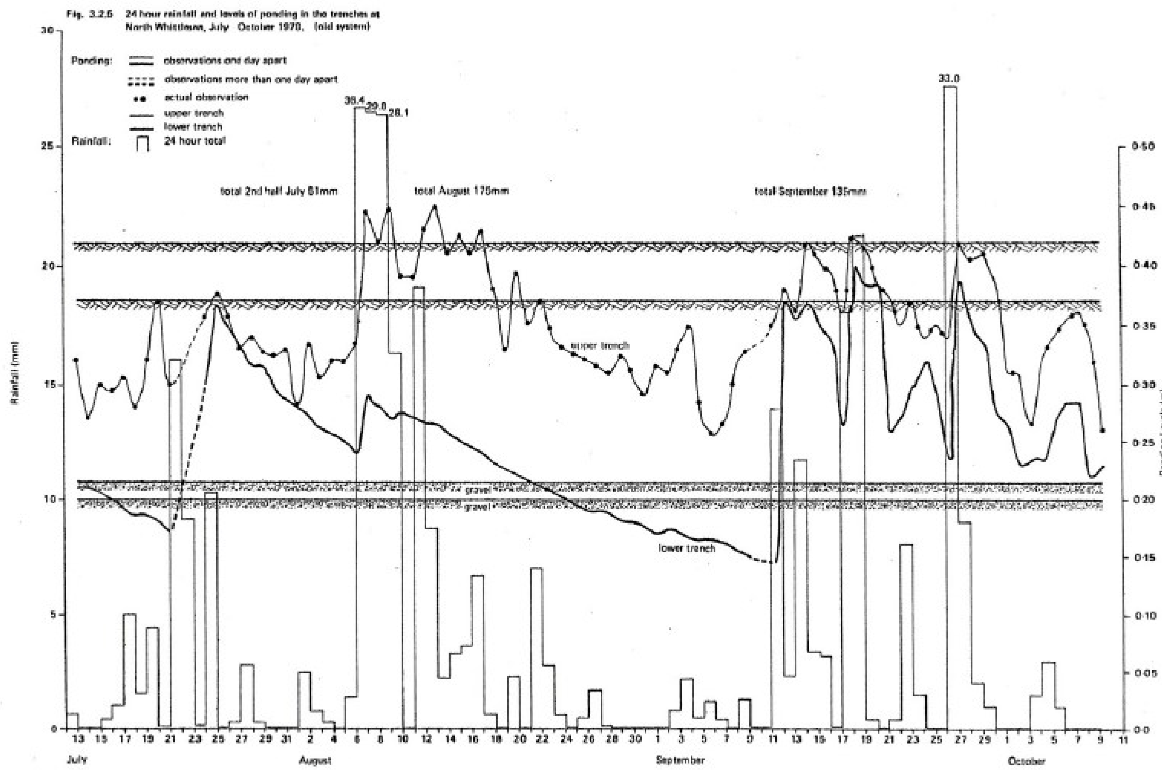


Figure 2 24 Hour rainfall and levels of ponding of effluent in the trenches (old system) at North Whittlesea, from July to October 1978. Note the response of ponding level to rainfall events and the lower ponding levels in the lower trench. The position of the top of the gravel backfill and the topsoil cover are indicated in the diagram.

Water movement in a saturated soil

- Saturation → capillary suction in the soil = 0
  - (Matric potential = 0)

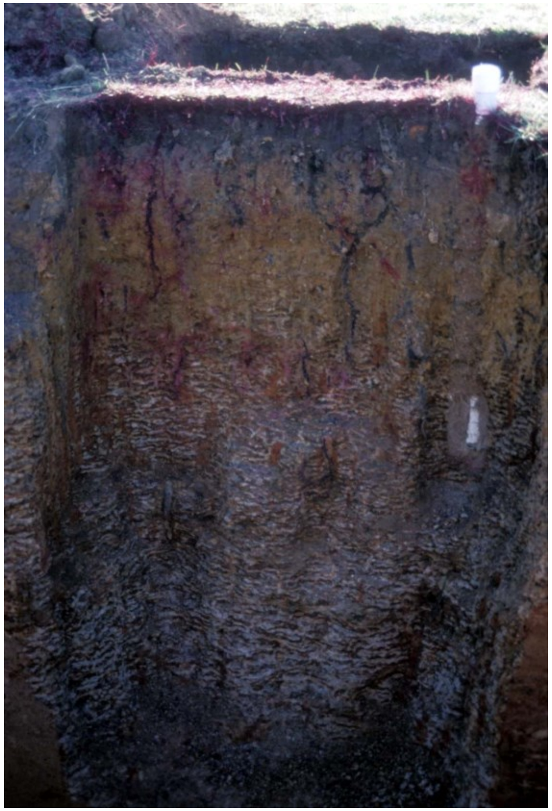
- Gravity is the only force acting on the soil water

- Effluent in the soil must move vertically down, as fast as soil Ksat allows

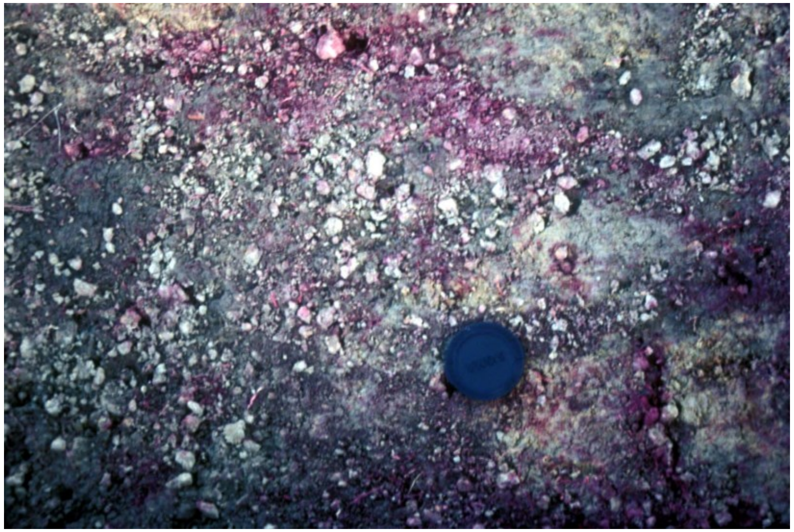
- Rainfall arriving at the soil surface must flow off sideways or pond on the surface

How does deep percolation occur in a living soil?
There are preferred pathways that assist spreading

Tracing flow with fluorescent purple dye – vertical flow



Horizontal flow at the interface between topsoil and subsoil



Grey water use for residential gardens as promoted by EPA

2.2 Greywater diversion in sewered and unsewered areas

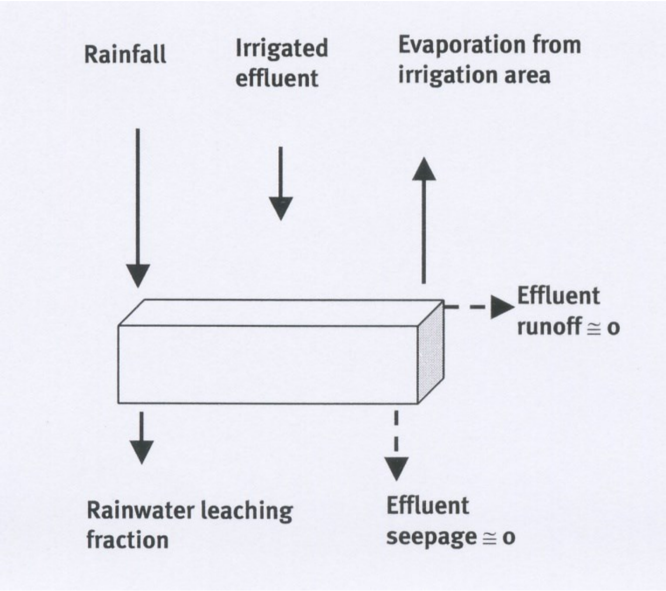
In urban areas the sewerage system is the preferred way to handle household wastewater, including greywater. If households in sewered areas are interested in utilising greywater on their own property they should install an approved system to collect and treat greywater, and store and irrigate the resulting effluent in accordance with Section 3.

Guiding Principles

1. No grey water must ever percolate down to groundwater table;
2. During any season when rainfall is enough for plant water needs, **DO NOT IRRIGATE BUT STORE** grey water in winter storage tank **or discharge to sewer**
3. Stored grey water is irrigated next season

Grey water use for residential gardens as <u>*formerly*</u> visualised by EPA

Principle illustrated by diagram



Allowable leaching?

Each drop of water that percolates downwards from a grey water irrigated garden ought to be from Rain and not from the grey water

<u>Is this physically realistic?</u>

Can effluent, once in the soil, stay there while rain water passes?

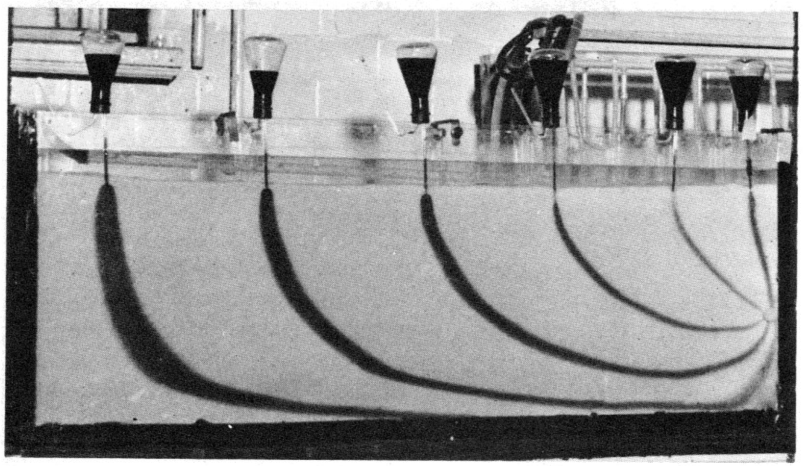


Figure 9:4. Demonstration of the saturated flow patterns of water toward a drainage tile. The water, containing a colored dye, was added to the surface of the saturated soil and drainage was allowed through the simulated drainage tile shown by the arrow on the extreme right. (Photo courtesy G. S. Taylor, Ohio State University.)

- Remember? Once a drop of water is in the streamline it cannot allow other drops to overtake it.
  It is like water in a hose
- *But then we must have some leaching to avoid salt build up*

Grey water re-use in urban areas

Calculation of size of grey water storage tanks for 'typical' areas in Victoria from EPA guideline [perhaps not in force today?]

EPA 168 "Guidelines for wastewater irrigation" also based on zero leaching of wastewater

Table 1: Indicative irrigation area and winter storage requirements for sites in Victoria

Location	Assume flow = 1000 litres/day		Assume flow = 500 litres/day	
	Area (m^2)	***Storage (m^3)***	***Area (m^2)***	***Storage (m^3)***
Marysville	1800	280	900	140
Welshpool/Yarram	1500	260	750	130
South-East Melbourne	1200	240	600	120
Wodonga	1000	240	500	120
Bendigo	810	220	400	110
Werribee	730	220	360	110
Horsham	360	180	180	90
Mildura	260	120	130	60

What do these winter storage tank sizes mean in real life?

- This tank of 220 m^3 is what you need in your garden if you have a 3-bedroom house around the Bendigo area but would be 20m^3 short of what is required around the south eastern areas of Melbourne

Water retention and soil texture

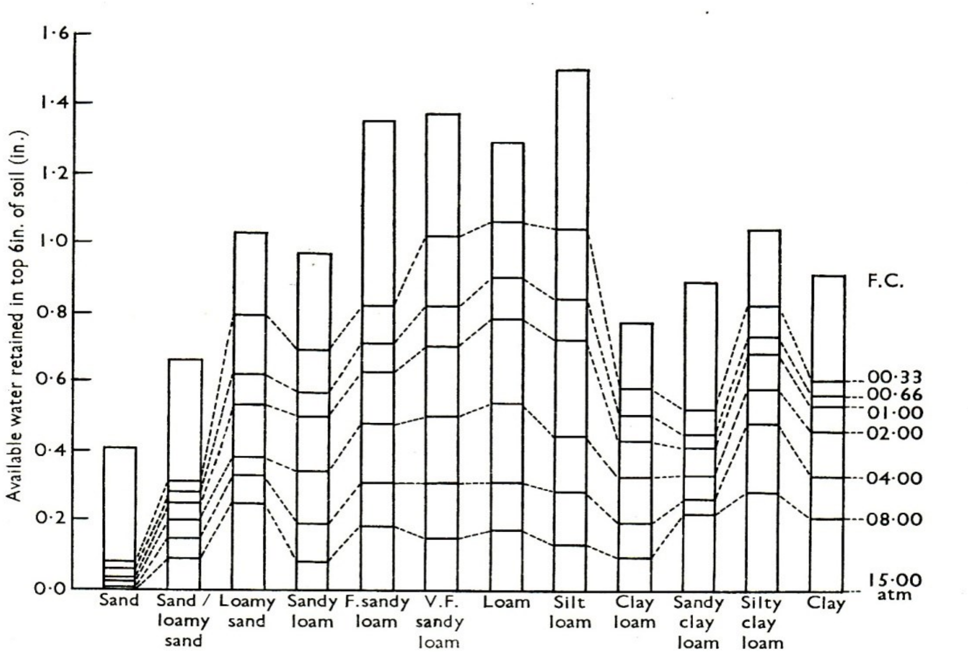


Fig.7. Water retention characteristics summarized for the different textural classes. (Salter and Williams, 1965)

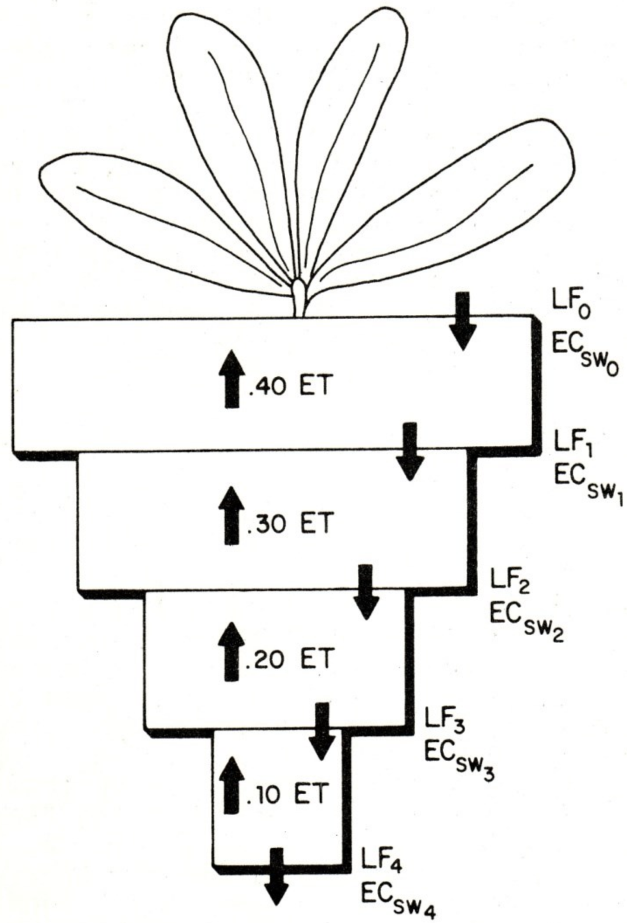
- The loams and silt loams have the best water holding capacities
- Most garden soils sold in Melbourne are very sandy

How is water taken up by plants?

Especially important under irriaation

- ET = evapo-transpiration = plant water use
- LF = leaching fraction
- EC = electrical conductivity of the water (i.e. its salinity)

Example: if applied water had a salinity of 1000 mg/L and 95% of the water was evapo-transpired, the water at the base of the root zone would contain 20,000 mg/L of salt. Can the roots survive in that area?



Develop a water and salt balance!

- Make sure the dispersal field is loaded to ensure some net leaching to remove added salts
- Treat the soil with gypsum (calcium sulphate) to assist the removal of excess sodium (Na)
- Carry out a soil chemical analysis to use as a starting condition so that trends in soil chemistry over time can be determined

Make sure the soil always is well supplied with soluble calcium from gypsum (note typical wastewater composition)

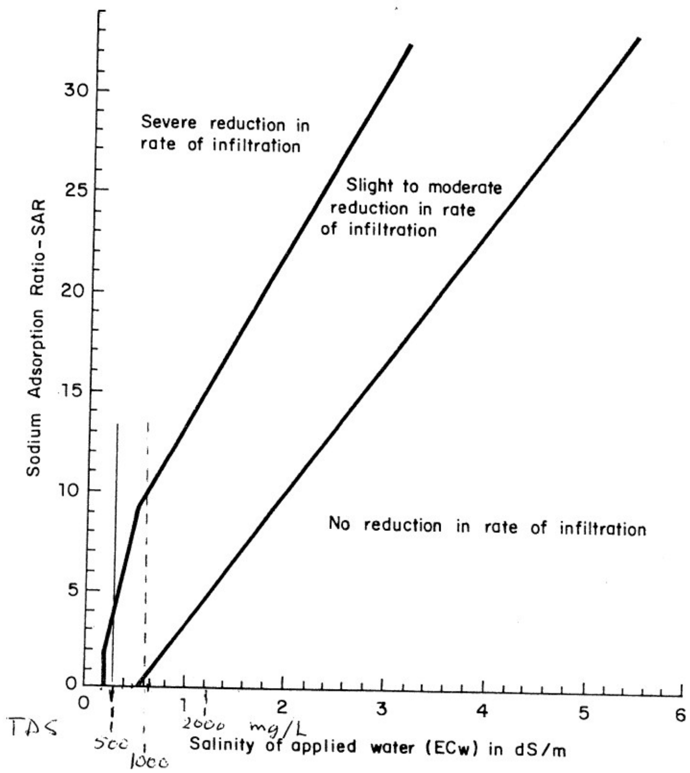


Fig. 21 Relative rate of water infiltration as affected by salinity and sodium adsorption ratio (Adapted from Rhoades 1977; and Oster and Schroer 1979)

Parameter	Unit	Level
Total Dissolved Solids	mg/L	420
Sodium Absorption Rate (SAR)	$(mmolc/L)^{0.5}$	6.5
Nitrogen (Total)	mg/L	19.4
Phosphorus (Total)	mg/L	9.8
Calcium	mg/L	10
Magnesium	mg/L	5
Sodium	mg/L	102
Chlorine (Total)	mg/L	3.8
pH		7.3

Final remarks

- Do not carry out an LCA on the basis of intuition
- Understand the fundamentals of how water behaves in the soil – the basics are not difficult
- Understand how soil reacts to water and salts – know your basic chemistry
- Learn how to interpret the soil you come across and how it is related to local geology and geomorphology