

# Chapter 3 – Salinity and hydrology management

## Managing salinity by managing groundwater balance

A discharge area can be managed by increasing the outflow of groundwater from the catchment until outflow exceeds recharge. However, increasing outflow simply by increasing evaporation and transpiration in the discharge area may not be sustainable in the long term. This is because salt remains and is redistributed to the soil surface or within the root zone. Vegetation in the area will die unless it is able to cope with the more saline conditions. Both the water and salt balances need to be considered because water is the transport mechanism for salt.

Evaporation from surface soil is an energy-efficient means of removing free water since the actual evaporation rate often exceeds the actual transpiration rate of vegetation (particularly if the vegetation is affected by waterlogging or salt) and may approximate potential evaporation rates.

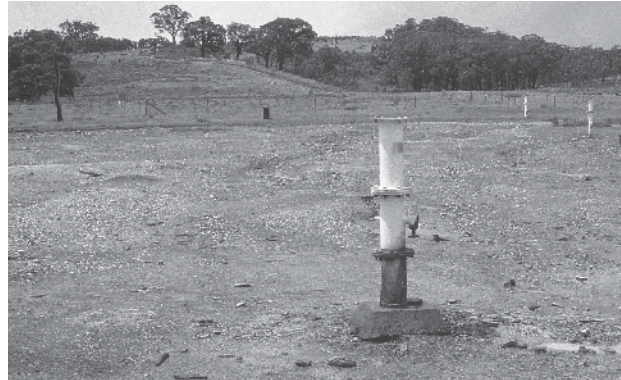
Talsma (1963) determined the critical depth of watertables at which groundwater supply equalled the daily evaporation rate for several soils. The results for a medium clay and a loam are shown in Table 4.

**Table 4. Watertable depths at which upward water movement from the watertable equals daily class A pan evaporation rate for two soils (after Talsma 1963).**

Soil type	Depth to watertable (m) for daily evaporation rate (mm/d)					
	1	2	4	5	8	10
Medium clay	1.3	0.9	0.6	0.5	0.4	0.4
Loam	2.0	1.6	1.3	1.2	1.1	1.0

Watertables have to be shallower in heavier clay soils and under conditions of higher daily evaporation rates (for example, in summer) before maximum capillary rise and salting will occur. Surface mulching can reduce the evaporation rate considerably.

Experience in Queensland, where daily evaporation rates generally exceed 5 mm/d, suggests that watertables need to be within one metre of the soil surface for a considerable part of the year for serious surface soil salting to develop.



**Figure 21. A de-watering bore located within a groundwater discharge area near Yass, New South Wales.**

## Managing soil salinity by managing leaching fraction

Accumulated salts can be periodically flushed from the soil profile by seasonal rains or by regular or specific applications of irrigation water. Leaching fraction is the term given to the portion of applied water that is required to drain through the root zone to maintain soil salinity at acceptable concentrations. USSL (1954) used the term leaching requirement and expressed it in terms of the steady state mass balance model discussed earlier:

$$LR = \frac{c_i}{c_o} = \frac{Q_o}{Q_i} \dots \dots \dots 3$$

where

- LR is leaching requirement
- $Q_i$  is quantity of water entering the soil (usually expressed as depth)
- $Q_o$  is quantity of water draining below the root zone
- $c_i$  is concentration of water entering the soil (usually expressed as electrical conductivity)
- $c_o$  is concentration of water draining below the root zone (salinity of deep drainage Dd).

This calculation has proved popular for long-term equilibrium situations, although it is strictly only correct where no precipitation of salts or ion exchange occurs within the root zone.

Under dryland conditions,  $Q_i$  can be readily measured as rainfall and  $C_i$  as rainfall salt concentration. Assuming  $C_o$  of the drainage water is in equilibrium with the salt concentration of the soil matrix at a water content approaching field capacity,  $Q_o$  can be estimated.

Since it is difficult to determine the amount of water draining below the root zone, an estimate of drainage is usually obtained by relating salt concentration at depth to the concentration of the input water (rainfall and irrigation water) weighted for volume of input. In symbolic terms:

$$\text{Rainfall weighted } c_i = \frac{Q_o c_r + Q_{iw} c_{iw}}{Q_i + Q_{iw}} \dots\dots\dots 4$$

where

- $Q_r$  is quantity of input water due to rainfall
- $Q_{iw}$  is quantity of input water due to irrigation
- $c_r$  is concentration of input water due to rainfall
- $c_{iw}$  is concentration of input water due to irrigation.

This approach assumes that the soil salt content at the bottom of the root zone reflects the concentration of water draining below the root zone. Deep drainage and salt balance in a particular soil are influenced by vegetation, rainfall, evaporation, landscape position and soil properties such as infiltration rate, available water storage capacity and texture.

Table 5 highlights the range of leaching fraction values encountered for various soils under rainfall.

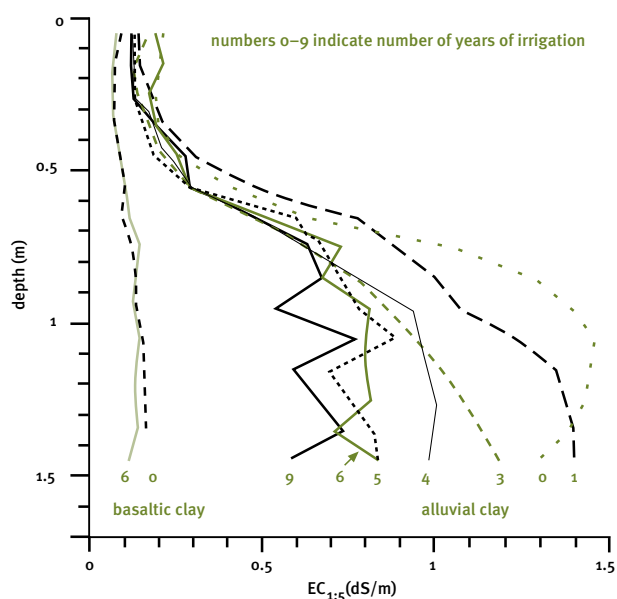
However, both the salinity **and the sodicity** of applied water affect soil stability, dispersibility and permeability (discussed in the following section).

**Table 5. Rough guide to how leaching fraction varies with soil properties (from Yo & Shaw 1990).**

Soil texture	Assumed LF	Range
sand	0.4	0.3–0.6
loam	1.15	0.1–0.3
light clay	0.15	0.05–0.2
heavy clay	0.1	0.05–0.2
clay soils with heavy clay subsoils or very poor structure with poor subsoil wetting	0.05	0.002–0.1

When soils are irrigated with good quality (low salinity/sodicity) water, the amount of rainfall is effectively increased. This increases leaching, and over a period of time a new salt content equilibrium will be established in the soil. Irrigation with good quality water can result in significant removal of salts from the soil profile, as was seen in the Emerald Irrigation Area (Figure 22). A new equilibrium is established when the final soil salt concentration is balanced by the amount of water available and the sodicity of the soil.

**Figure 22. Changes in soil salinity of two soils with years under irrigation in the Emerald Irrigation Area (data courtesy of Don Yule).**



The impact of irrigating with saline and moderately sodic waters on a clay soil in the Lockyer Valley is shown in Figure 23.

Many irrigation water quality guidelines promote managing soil leaching by varying the amount of water applied. This works well with permeable soils. However, in slowly permeable soils (for example, 1 to 10 mm/d), soil properties and sodicity are the dominant controls on leaching rates and reduce the effectiveness of irrigation water management. In clay soils, leaching is strongly influenced by the salt concentration and sodicity of the irrigation water. (Calculating leaching fraction using simple empirical relationships is covered in **Leaching fraction** page 32.)

This problem is obvious with any high-sodium water during and following rainfall because the salt in the surface layers is washed out by rainfall, leading to dispersion and crusting. Very low salinity water almost always results in water infiltration problems, regardless of the proportion of sodium ions in the water (Ayers & Westcot 1985). Assessing irrigation water quality with soil properties and behaviour is the best way to avoid these problems.

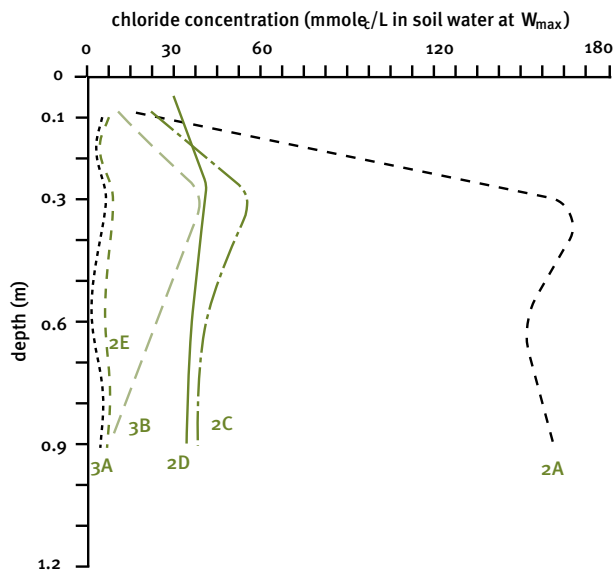
## Soil stability and sodicity

The mineralogical structure and behaviour of clay minerals have been described in a range of textbooks such as van Olphen (1977) and Bolt (1979).

Ion substitution in the clay mineral lattice creates a negative charge on the clay mineral, which attracts cations to the mineral surfaces.

Figure 23. Changes in salt content A) and exchangeable sodium percentage B) profiles under irrigation for the Tenthill soils in the Lockyer Valley (Shaw et al. 1987).

**A) salt content**



**Irrigation water** (key to Figure 23)

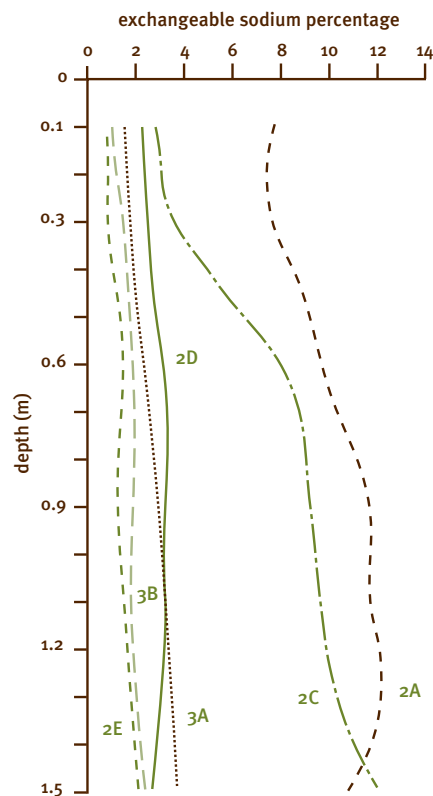
Soil texture	Assumed LF	Chloride mmolec/L	EC ds/m	SAR
3A	nil	nil	nil	nil
2E	nil	nil	nil	nil
3B	30	26	1.6	1.2
2D	9	13	2.0	1.3
2C	5/22	9.8	3.5	2.0
2A	45	55	7.4	6.8

\*changed water quality sites 3A & 2E are non-irrigated sites

These cations, called exchangeable cations, balance the negative charge of the clay mineral. The properties of the layer of adsorbed cations are determined by the nature of the clay mineral (particularly surface charge density and surface area) and the composition and concentration of the surrounding solution. For example, a high proportion of sodium in the soil solution will result in a high relative proportion of sodium among the exchangeable cations. These characteristics of cations, mineral and surrounding solution determine clay behaviour.

The attractive forces between clay particles are strongest when the exchangeable cations are mostly calcium and weakest when the exchangeable cations are mostly sodium. This is because the cation layer for the divalent calcium cations is smaller, making the distance between the clay particles smaller. This is the main factor contributing to the stability of calcium-dominated clays (Quirk & Murray 1991).

**B) exchangeable sodium percentage**



The balance between the attractive and repulsive forces between clay particles determines the degree to which a soil will swell or disperse when it is wetted. Swelling is promoted by repulsive forces associated with hydration. If the layer of cations is thick and diffuse (for instance, a cation layer dominated by sodium cations), the greater repulsion between clay particles will result in increased particle separation and dispersion.

Montmorillonite-dominated clays are more stable than clays dominated by other clay minerals. This is because montmorillonite clay minerals attract divalent ions such as calcium ( $\text{Ca}^{2+}$ ) and magnesium ( $\text{Mg}^{2+}$ ) in preference to monovalent ions such as sodium ( $\text{Na}^+$ ) and potassium ( $\text{K}^+$ ). In contrast, illite minerals display no ionic preference.

Several researchers have identified a non-uniform mixing of divalent and monovalent cations on montmorillonite. For example, Shainberg et al. (1980) considered the affinity of the internal surfaces of montmorillonite for  $\text{Ca}^{2+}$  to be between two and 15 times greater than the affinity of the external surfaces. Thus in low to moderate  $\text{Na}^+$  concentration solutions, only the outside layers of montmorillonite clay minerals will be affected by sodium, contributing to the greater stability of montmorillonite or cracking clay soils.

Aggregates may slake and/or disperse on wetting. Slaking is the macroscopic breakdown of an unsaturated aggregate on immersion; dispersion is the process of part of an aggregate going into suspension (Emerson 1968).

The behaviour of clay minerals with sodium has been described by a mechanical model and a physico-chemical model (Olsen & Mesri 1970). In the mechanical model, clay behaviour is not very responsive to salt concentration; this is because the clay is based on the interaction of particle shape, particle friction and the geometric arrangement of particles. In the physico-chemical model, salt concentration and ESP cause major changes in clay behaviour.

The mechanical model describes the behaviour of kaolinite clays fairly closely because kaolinite crystals are large and not particularly responsive to salt concentration. On the other hand, the physico-chemical model better describes the behaviour of montmorillonite clay minerals because these minerals are responsive to the physico-chemical nature of the medium. Illite clay minerals are intermediate in behaviour.

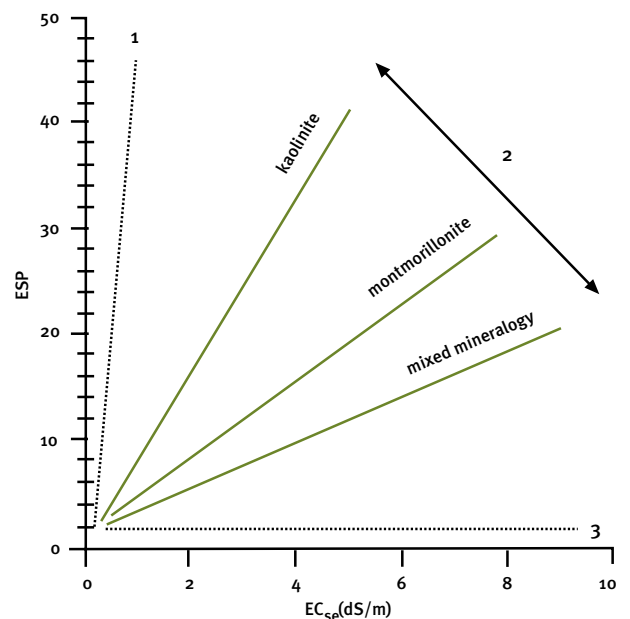
Mixtures of clay minerals are most sensitive to exchangeable sodium. Arora and Coleman (1979) found that the order of clay mineral susceptibility to dispersion in sodium bicarbonate solutions was illite (most) > vermiculite > montmorillonite > kaolinite (least).

Rengasamy and Olsson (1991) represented (in diagrammatic form) the stages and force strengths of slaking, dispersion and flocculation of aggregates under wetting and drying. The mechanisms suggested by Rengasamy and Olsson involve wetting air dry aggregates such that the repulsive forces generated by wetting result in slaking. In a calcium-dominated clay, attractive forces dominate within the micro-aggregates, resulting in greater stability. As the particles continue to wet, sodium-dominated systems will demonstrate spontaneous dispersion due to the repulsive forces in the exchangeable cation layer. A point is reached where the repulsive and attractive forces are balanced. If the salt concentration of the surrounding solution is raised, flocculation will occur. The point at which soil just flocculates can be termed the *threshold value*; this is the balance between repulsive and attractive forces such that the soil remains stable and not dispersed.

If external energy is applied (mechanical dispersion), the clays will disperse when the strength of the repulsive forces exceeds the strength of the attractive forces. Because these processes affect soil structure, they also affect hydraulic conductivity.

The threshold values can be idealised into three regions as shown in Figure 24. Line 1 is almost parallel to the Y axis and shows a very limited effect of an increasing proportion of sodium ions adsorbed onto the clay mineral surfaces (ESP) on salinity (EC). Such soils respond to the mechanical effects of bonding and cementing of clays in soils with low clay contents, rather than to physico-chemical effects. Typical of this response would be the behaviour of kaolinitic soils associated with large amounts of iron oxides and the behaviour of acid clay soils with aluminium as the dominant exchangeable cation.

Figure 24. A conceptual framework of soil response to ESP and EC<sub>se</sub> (Shaw 1996). (The lines are described in the text.)



In region 2 (the intermediate region in Figure 24), the soils respond to an increase in ESP with an increase in EC. This is the region of true physico-chemical response and is typical of many soils. Kaolinite is least sensitive to the physico-chemical response, whereas illite and mixed mineralogy soils are most sensitive to sodium. Montmorillonite-dominated soils that can restructure on wetting and drying are intermediate in sensitivity to ESP as assessed by EC (Shaw 1996).

Line 3 represents the other boundary of the physico-chemical soil response. The pattern of line 3 would only occur in soils with no cation exchange capacity and thus no ability to increase ESP, and with no effective leaching below the root zone. In such soils, soil dispersibility is not likely to increase and EC is likely to increase. This would not occur in normal field soils.

When irrigation waters with a high proportion of sodium ions compared with other cations are added to soil (high SAR, described in ***Sodicity in soils and waters*** page 37), sodium displaces other cations on the clay mineral exchange sites. This increase in the sodicity of the soil generally results in soil dispersion with consequent soil surface sealing, crusting, erosion, poor water entry and poor seedbeds.

Ham et al. (1993) reported problems with low salinity, low sodicity irrigation waters in the Burdekin Irrigation Area on silty soils prone to surface dispersion. The effects were attributed to insufficient salts to maintain soil flocculation in the soil surface. This is commonly reported worldwide with low salt content irrigation waters.