# Salinity Is Natural

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## WHAT IS SALINITY?

Salts are the product of an acid and base and hence include a wide range of compounds. The salts achieving highest concentrations in soils are common or sea salt (NaCl), lime ($CaCO_3$) and gypsum ($CaSO_4$). However, salts containing potassium, sulphur, nitrogen phosphorus and other elements are common and essential for plant growth. Salts of some elements, such as boron, can be toxic to plants at low concentrations. The occurrence of salts is ubiquitous hence salinity is generally only recognised where the level or type of salt has a deleterious effect.

High levels of soil salinity can be natural and in parts of Australia salinity was once more widespread than today. The current concern relates to changes that threaten the continuation of established land use. The prime issues are the decline in production of agricultural systems, rapid changes to native vegetation, and increases in stream salinity.

The damaging effects of salinity mainly arise through a decline in soil structure associated with dispersion of clay due to displacement of bi and trivalent ions by monovalent cations, osmotic reduction in the availability of water to plants, and specific ion toxicity. These effects are usually linked. Bivalent cations such as calcium improve soil structure, and the associated improvement in drainage and limited solubility ensure that calcium is rarely responsible for adverse salinity effects. The salinity changes currently of consequence primarily relate to sodium chloride, hence the issue is generally sodicity rather than salinity.

Sodium chloride can derived from many sources. Fundamentally it derives from the weathering of rocks, and the old weathered mantle over most of Australia provides many opportunities for the extensive accumulation of salts. However, the solubility of sodium chloride has resulted in large quantities of this salt accumulating in the oceans, whence some is redistributed through changes in sea levels and/or atmospheric transfer.

Many geological formations used for agriculture have marine origins, as with sedimentary rocks, lakes, and coastal dunes. The materials comprising the formations often contain high levels of salts and this has been increased through atmospheric accession. Some of this accession has been highly beneficial, as with the aeolian deposition of calcium across large tracts of south eastern Australia, but the slow, continuing accession of sodium chloride has been detrimental in many areas.

The geological origins of salt means that an understanding of the development of systems is the starting point in addressing salinity. However, the high solubility of sodium chloride makes it highly mobile, and the patterns of water movement strongly influence expressions of salinity. There is a need to understand factors controlling the movement of salt within systems where this is inextricably linked with the movement of water.

## WHAT CHANGES SALINITY?

Most rainfall in Australia is evaporated where it falls as the potential evaporation is generally much higher than rainfall. Consequently, most water that infiltrates into soils is extracted through plant roots and evaporated to the atmosphere. This infiltration down the soil profile with extraction by roots tends to leach salt down the profile and hence helps reduce salinity in the surface soil while increasing the salinity of subsoils.

The other components of water movement are surface run-off and lateral and vertical subsurface drainage through the soil. Surface run-off of water is common but only deleteriously affects salinity where it feeds evaporation pans or basins such as Lake Eyre. Surface runoff is generally beneficial in reducing salinity levels in streams.

Lateral and vertical sub-surface drainage are the main components influencing the development soil salinity but these do not occur in some systems. Some areas of marine sediments do not exhibit significant vertical or lateral sub-surface water movement because of the thickness and impermeability of the clay. These systems can contain high levels of sodium chloride in the subsoil, where this helps seal the system, and the salt can only become detrimental through upward movement in the profile.

Other systems similarly have ‘sealed bottoms’ because of the thickness an impermeability of underlying clay, but lateral sub-surface movement of water occurs due to gradients in elevation. This lateral movement results in accumulation of salt in accession areas where the level of expression of salinity depends on the magnitude of the accession relative to the local water balance. Apparent changes are often small in natural systems because events producing lateral seepage are infrequent compared with the in-situ cycling of water at the accession site. The natural tendency for the movement of salt down the soil profile largely neutralises the effects of the accession of salt from elsewhere.

This natural control on soil salinity is weakened where there is disruption of the water balance pattern through actions such as clearing and grazing. Clearing, grazing and farming can result in lateral accession having a prominent effect where once it did not, and this can produce significant salinisation. The reduction in vegetation reduces the local extraction of water and hence increases accessions to lower parts of the landscape. Reduction in vegetation at the accession site reduces the extent to which the local water cycle can reduce surface soil salinity through leaching.

Vertical sub-surface drainage of water removes salt from a site and can therefore be locally beneficial. Indeed, maintenance of low salinity in sub-soils depends on leaching from the profile with drainage into underground aquifers and/or streams. However, extensive negative effects can occur where the water seeps to the surface elsewhere (lateral movement), or where the system is confined. The water cannot drain from a confined system hence any accession is manifest as a rise in ground water levels, where this rise can bring salt to the surface.

The model officially promoted as the general model for dryland salinity is based on a confined or semi-confined aquifer and a rise in groundwater, where this is only one of the mechanisms for the development of salinity. The reasons for its popularity are obscure but appear to relate to an apparent simplicity and the applicability of the model to several significant irrigation areas. However, the model has limited relevance to extensive areas of dryland farming if only because they lack a definable groundwater system. Salinity research activities that have not been reported include the installation of piezometers in a system where there was no ground water, a situation that should have been known from prior observations.

The most significant mechanisms for salinity changes associated with land use relate to vertical drainage and lateral movement, with seepage occurring at lower areas of landscapes. Land use can affect these mechanisms by reducing on-site water use, but it also affects it through changes to the physical structure of the system. For a given hydraulic gradient most water flows along the path of least resistance. Variations in the permeability of systems are therefore of particular consequence.

Soil compaction is the most widespread consequence of agricultural development in Australia, and is likely the most significant factor affecting production. The magnitude of compaction is evidenced by comments in explorers dairies as to the permeability of soils that are now impermeable, and by comparisons between forested and cleared areas. Part of this compaction is mechanical, as with ploughing and trampling by livestock, but most is likely associated with the loss of organic matter. The development of a permeable structure in most Australian soils depends strongly on the levels of organic matter.

Organic matter affects permeability in several ways. The chemical fraction binds with clay minerals to produce friable aggregates, and hence acts similarly to bivalent cations such as calcium. The coarse fraction has direct mechanical effects, with old root channels becoming pathways for the movement of water as the roots decay. This preferred drainage along channels continues until they become clogged by clay.

The lowering of permeability associated with the loss of organic matter affects salinity in several ways. The loss of preferred pathways reduces vertical drainage, and hence increases lateral seepage. Additionally, it alters the salinity of the drainage/seepage water. Water flowing through preferred channels has much lower salinity than would be predicted from measurements of soil salt content because the movement of salt from the bulk soil to the drainage channel is slow. Removing preferred channels means that water flows more uniformly through the soil, hence the salinity levels of the percolating water tend to more closely relate to the soil salt content.

The implication of these considerations is that, while the physics of water and salt movement are reasonably well known, application is limited by knowledge of the structure of the systems. Reliable predictions require knowledge of the fine and coarse structures and the chemical compositions. The coarse structures include geological formations, preferred paths for water movement such as fractures and prior streams, and blockages to flow such as large rock masses and thick clay layers. The fine structures relate to horizontal and vertical variations in the soil profile, and changes to this imparted by factors such as vegetation.

The information requirements to develop an understanding of the system necessary for the evaluation of salinity risk involve significant scaling issues. Detailed site-specific information on soils and land use is needed, as this determines the local water balance. However, regional information is additionally required to ensure that site considerations are evaluated within an appropriate context.

## GAINING THE REQUISITE INFORMATION

Considerable existing information is applicable to the issue, such as climatic records and geology maps, but the available information is always inadequate. For example, the error in rainfall estimates is often of higher magnitude than the subsurface drainage and this limits the reliability of water balance modeling. Moreover, soil landscape maps assume that the effects of interest are dominated by surface topography hence their application to addressing salinity can result in erroneous conclusions.  There is generally a requirement to obtain new information that more directly addresses the salinity issue.

Technological developments provide opportunities for gaining necessary information but there is no single technology that directly provides an answer.  This partly arises because there is no means of directly measuring soil salt composition and levels across regions, but it is mainly due to the temporal nature of the issue.  Salinisation is a process that involves a transition from one equilibrium towards another, and there are lags in the expression of salinity that depend on factors such as patterns of rainfall and the rate of clogging of old root channels.  The development of information has therefore focused on identifying the structural aspects of the systems that affect the movement of water and salt.

Apart from boreholes, the data available to define subsurface structure are largely geophysical, represented by magnetics, electro-magnetics, and gamma radiation emissions (radiometrics). Surface information is provided by elevation (surface topography), and remotely sensed imagery such as photography, digital optical imagery, and radar.

## Surface Data

Surface information can be used to infer sub-surface structure, as with identification of lineaments and paleo drainage systems.  Radar and optical satellite imagery have directly identified paleo drainage and other structures where observations are little affected by vegetative cover, but most applications in Australia involve the interpretation of land cover and lithology.  Lithological information obtained from optical satellite and airborne imagery identifies the surface distribution of materials, and hence aids the understanding of the mode of development of the system.

Optical satellite imagery provides the most cost-effective means of monitoring land cover and land use, with the archival record dating from 1972.  It can readily be used to map extreme expressions of salinity, such as the development of salt pans, but has most value in identifying areas at risk of salinity.  Drainage and salinity patterns identified in the imagery from variations in the condition and type of vegetative cover are evaluated through field observation.

Surface topography is used to predict surface flows, but application to sub-surface flows is limited by the assumption that sub-surface flows follow the surface topography.  It can be particularly valuable where high resolution data are available but application without careful evaluation of the system can produce erroneous conclusions.  Combining elevation information with land cover information derived from satellite imagery improves the applicability of the results.

## Sub-surface Data

### Magnetics

The subsurface data vary considerably in resolution and scale.  Magnetics record variations in the earths magnetic field and provide information on deep underlying structures.  They are useful for identifying the overall regional constraints, as with identifying major blockages to flow, but they do not provide the near surface information needed to address water balance.

### Electro-magnetics

Airborne electro-magnetics (EM) provide more detail on sub-surface structure than the magnetics and can provide near surface information. Ground measurements can provide information for soils. EM measures the strength of an electromagnetic field induced in the earths surface. The signal is strongly influenced water and clay contents and well as other magnetically susceptible compounds as well as salt.

The dependence of the EM measurement on several factors increases the complexity of the interpretation, particularly in Australia where lateritic materials often dominate the measurement. Field observations from boreholes are required to help discriminate between the effects of at least three factors and this can involve considerable expense because of the effective depth of the measurement (nominally 0.9, 1.8, and 6 m for the common ground units, and around 50 m for airborne data).

The depth of airborne EM measurement has benefits in investigating underlying structures but application is limited in addressing the part of the hydrological cycle that primarily determines the occurrence of salinity.

### Gamma Radiation (radiometrics)

The radiometric signal mainly reflects the nature of the parent material and its alteration through the various aspects of weathering. The signal mainly derives from around the surface 30cm of soil but the development of the signal depends on the characteristics of the entire soil profile. As soils are primarily a product of parent material and weathering, the radiometrics identify spatial patterns of variation in soils

The radiometrics can be variously processed and interpreted depending on the requirement. Analyses most applicable to salinity identify patterns of soils and structural features that could act as preferred pathways or barriers to the movement of water. The preferred pathways identified are generally lineaments that reflect underlying fractures, but they can also be old stream lines (paleo-drainage).

The ability to identify lineaments in the radiometrics illustrates that, while the signal derives from the near surface, it is affected by underlying structures. Statistically the signal correlates best with observations from the A2 and B2 soil horizons and hence is useful for identifying patterns of subsoil salinity significant for land use.

There is no reason to expect a simple correlation between the intensity of the radiometric signal and any soil property because a given signal can arise for different reasons. However, different materials have characteristic radio-nuclide compositions and radiometric patterns identify spatial patterns of variations in soils. Multi-variate analysis can be used to establish these relationships, and field sampling to identify the associated soil properties. The field sampling must separate the effects of parent material and weathering to be reliable.

With appropriate analysis of the radiometric data, and an appropriate field sampling strategy, soil maps can be produced where all the soil categories mapped are statistically different. Implementation of the methodology therefore automatically tests the reliability of the mapped results. Also, by field measurement of soil properties rather than soil types, maps can readily be produced that identify features of particular interest, such as the occurrence of areas with high sub-soil salinity.

The main advantage of the radiometrics is that they provide detailed information on the properties of the land surface needed to identify the main factors influencing the hydrology and salinity. When combined with other information, such as land cover and land use derived from satellite imagery, it allows interpretation of the relative significance of factors in determining outcomes, and therefore provides a rational basis for determining risk.

The radiometrics provide further advantages through the ability to address a range of scales. Detailed information is provided at the paddock level, where this is needed to address the local hydrology. The regional coverage of the radiometrics, and the ability to identify the structure of the system, ensures that the local circumstances are interpreted within an appropriate context. Moreover, in allowing the identification of cause, the information supports the implementation of appropriate remedial actions. It not only identifies risk but has direct management application.