# A SOIL STRUCTURAL DEGRADATION MODEL FOR DRYLAND SALINITY

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June 2006

## Abstract

The applicability of rising groundwater model for dryland salinity is examined by way of applications where it can't apply, observed salinity outcomes discordant with the model and the physical invalidity of usual representations of the model. A hypothesis involving dryland salinity being caused by soil structural degradation is discussed by way of the impacts of land use on soils, observed salinity outcomes, and the ability to reverse the adverse salinity. The implications are discussed by way of the general degradation of the system that leads to the localised salinity impacts and the appropriate remedial actions.

## Introduction

The Channel 9 Sunday Program presentation Salt Solution (28 May 2006) provided an alternative perspective on salinity to the views promoted by government scientists and agencies. The program identified that predictions based on the established view that dryland salinity arises through tree clearing increasing groundwater flows, the rising groundwater model (RGM), have not come to fruition. Alarmist predictions from the government research organisations and agencies have been wrong.

Differing explanations have been given as to why the predictions were wrong. The establishment line is that the rising groundwater model is right but predictions were degraded by factors such as inadequate data and political interference. However, farmers and independent scientists have for some time suggested that the RGM is inapplicable with some identifying the primary case of dryland salinity as being soil degradation.

The proposition in Salt Solution was that an open debate is required to examine the alternative hypothesis given that:

- Predictions based on the RGM have not come to fruition, and to a large extent are being abandoned.
- That beneficial outcomes achieved by farmers are achieved in ways that are discordant with the RGM.
- An alternate model has been proposed that is consistent with the results achieved by farmers.
- Remedial actions being implemented by some farmers are much more cost effective than current actions based on the RGM.

Given these circumstances the proposition made in the Channel 9 program Salt Solution is sound in identifying a need to consider alternatives.

Public responses to the Channel 9 program Salt Solution included the comment that '*Unfortunately it is extremely difficult to understand what the causal mechanism in the theory really is.'* in referring to an alternate hypothesis for the development of dryland salinity than used in the RGM. While detailed mechanisms for dryland salinity arising through soil degradation and limitations of the RGM have previously been given there is evidently a need for further consideration of the alternate model. That requirement is addressed here.

Material on the ERIC web site (Tunstall 2001, 2004a, 2005a) provides considerable detail on the mechanisms involved, as do the papers by Jones (2000a, 2000b, 2001). The ERIC site also presents many examples of dryland salinity that do not accord with the RGM (Anon. a, b, 2006, Tunstall 2004b). Such material is referenced here and further consideration of mechanisms is provided.

## Limitations of the Rising Groundwater Model

The RGM has been the establishment reference for addressing dryland salinity in Australia since the mid 1970s to the extent of becoming the official model for dryland salinity. From about 1990 onwards research and remediation activities have only been funded where they accorded with the model.

The hypothesis underpinning the RGM evidently originated in the 1920s but has evolved over time. The RGM has meant different things to different people and representations differ considerably. The confusion partly arises because of poor definitions and partly because most representations are physically invalid. However, it also arises through changes in the representation of the model to account for observed discrepancies.

The only commonality in the different representations of the RGM is that dryland salinity is said to arise through tree clearing increasing water accessions into some form of groundwater system. Adverse salinity occurs where the groundwater discharges or comes close to the soil surface. A recent qualification is the use of the more general term perennial vegetation instead of trees. The essential requirement is for the original native vegetation to have a greater capacity to use water than the replacement agricultural vegetation.

The RGM represents a direct application of salinity considerations with irrigation. ‘Excess’ water applications with irrigation can increase the drainage of water into groundwater systems. With dryland salinity the ‘excess’ water is attributed to agricultural vegetation using less water than the prior native vegetation. The suggested difference in water use is usually ascribed to native plants being deep rooted perennials and crop plants having shallow roots and often being annuals.

The main uncertainties in representations of the RGM are the nature of the groundwater system and the source of the salt. The version of the RGM used in the 1980s had the groundwater system occurring beneath the soil and the salt[1] deriving from stores beneath the soil on plains. However, it is rarely clear whether the ‘rising’ groundwater represents water that moves vertically upwards, as can occur with confined aquifers, or water that simply fails to drain. Even with irrigation salinity where the water table rises the water usually does not, the water simply fails to drain. The mechanisms for salt movement differ greatly between water rising and failing to drain.

A recent description of the RGM additionally has salinity occurring through drainage at the break of slope where the salt and water flows only occur in the soil. There is then no need for a groundwater system beneath the soil or for salt stores beneath the soil on the plains. The RGM has variants that encompass very different circumstances.

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[1] The term salt is used generically to encompass all soluble salts. More detailed considerations would address the salt composition and the implications of salts such as NaCl strongly dissociating and therefore being present in soils as the ions $Na^+$ and $Cl^-$ rather than the compound NaCl. NaCl is of prime consequence because of its abundance, high solubility, and the dispersion of clay by sodium.

The exceptions to the rising groundwater hypothesis take three forms:

- Where the RGM has been applied to produce predictions in circumstances where the basic constraints cannot apply.
- Where observed occurrences are discordant with the RGM.
- Where the model is physically unsound.

The first two situations are addressed in a note on the ERIC web site (Anon. a) that provides examples of the inapplicability of the RGM for dryland salinity including the Meandarra and Talwood examples discussed below. The Meandarra site is identified as having the highest of 5 levels of salinity hazard and the Talwood site is level 4[2].

Inappropriate application is best illustrated by the salinity hazard mapping for the Queensland part of the Murray Darling Basin that encompasses Meandarra and Talwood. The mapping is based on the RGM in invoking groundwater flows within landscapes.

A brigalow study near Meandarra involved almost 3 years of monthly neutron moisture meter measurements of soil water content in native vegetation in an essentially natural condition (Tunstall & Connor 1981). During a wet period some gilgais contained water for several months and soil in the depressions became a slurry to a depth of around 0.5m. While the semi-arid forest effectively became a wetland with aquatic plants such as the water fern nardoo (*Marsilia sp.*), and crustaceans such as the back swimming shrimp *Anostracus anostracus,* there was no groundwater recharge and no groundwater system.

The relative distribution of salt under gilgai mounds and depressions[3] evidences the extent of lateral movement of salt in the system (Fig. 1). As the gilgais are roughly 10m in diameter the maximum distance for the lateral movement of salt is around 5m. Applying a model invoking landscape scale movement of salt and water in such a system is inapplicable as there is no surface runoff and effectively no lateral subsurface drainage. Invoking a rising groundwater system is similarly inapplicable as there is no groundwater system. High levels of salt exist and under particular circumstances they may degrade agriculture but not through rising groundwater or groundwater flows.

The same groundwater constraints apply in the Talwood example as there is no groundwater system remotely close to the surface. The soil is underlain by a thick layer of kalonitic clay. However, there is surficial movement of water and salt with accumulation in accession areas. Results for brigalow at Talwood (Fig. 2) are for an accession area and the poplar box sites were immediately adjacent up a low slope. Lateral movement of water and salt occurs in the landscape but the flows are along the surface and in the soil and not within any groundwater system. Peak soil salt levels in accession areas are higher than at Meandarra (Fig. 2) but again a salinity hazard cannot occur through rising groundwater. The RGM has been used to produce predictions where the model cannot apply.

Exceptions to observed occurrences negate the rising groundwater model as being general. Examples given on the ERIC web site include Dicks Creek near Yass in NSW, an airfield

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[2] Considerable diversity in opinion exists as to the difference between salinity hazard and risk. The logical differentiation is that hazard is categorical, in that it exists or it does not, but it does not have a level. An electrical hazard exists whether the power voltage is 240 or 10,000V as both can kill. Risk assesses the potential for damage and the probability of it occurring and is a continuous variable. The risk of electrocution is much greater when working with 10,000V than 240V. A hazard map should not present levels of hazard.

[3] The surface topography of gilgaied soils resembles a battlefield completely covered by bomb craters. The depth of the depressions varies from a few centimetres to over two metres depending on the swell shrink characteristics and likely also depth of the soil. The lateral dimension of the depressions varies but is usually around 10 metres.

drain in central coastal Queensland and Whittington in Western Australia. Dicks Creek has been presented as a classic example of the rising groundwater model and there is a peizometer in the photograph given on the ERIC web site (Anon. a). However, the example identifies that the patterns of salinity are associated with surficial flows. Moreover, results obtained by ERIC (Tunstall et al. 2001) and Dr Geoff Taylor from the Uni. of NSW independently identified the occurrences of salinity in the area as being associated with geological unconformities[4].

The influence of geology is also illustrated by the results for ERIC soil mapping at Cootamundra (Trethewey and Gourlay 2001, Tunstall 2004b) where there is a linear occurrence of salinity associated with a geological fault that runs for around 100km and cuts across the Lauchlan and Murrumbidgee drainage basins. A subset from the regional map identifies salinity arising at the break of slope, along a fault line, and through drainage onto flats (Fig. 3a). Another subset identifies where flows along a fault line caused damage to a highway (Fig 3b). Such occurrences are associated with water accessions but not a rising groundwater system[5].

ERIC extrapolated the salinity mapping results for Cootamundra to the neighbouring Temora Shire and Fig. 4 compares the results with those obtained for a landholding using an EM31 by Dr John Angus of CSIRO Plant Industry. The results are not identical as would be expected given the different depths of the measurements. However, the ERIC results identified where salinity most affected crops and infrastructure such as roads, and more clearly identified the flow pathways including one that had not previously been identified. This pathway was of particular consequence in being the main source of salt affecting the paddock. The regional ERIC mapping using airborne gamma radiation data provided greater detail than the local EM mapping even though the results were extrapolated from an adjacent shire.

The airfield example identified in the note Anon (2006) is noteworthy because of the continuation of saline drainage in the airfield drain when a freshwater spring broke out in the airfield around 50m distant. The grass airfield was a natural flat and was un-constructed apart from the removal of trees and the construction of an initially shallow V drain. While there is an underlying semi-confined groundwater system that is at least sometimes under pressure it does not affect the salinity outcomes in the soil. The salinity arose from surficial lateral drainage through the soil along the surface of the B horizon and was visually obvious. The example is also noteworthy as the salinity arises from the parent material, an old fine-grained marine sediment, rather than atmospheric accessions.

The Whittington example (Paulin 2002) is most comprehensive and is summarised in the ERIC paper Common Assumptions on the Process of Dryland Salinity (Anon. 2006). While soils became saturated and saline on the flats a network of piezometers identified that this was not associated with rising groundwater. According to Whittington it arose through surficial lateral flow on compacted subsoil and he remediated it by preventing such flow. The salinity did not arise through groundwater flows bringing salt from stores beneath the flats to the surface as required by the RGM. Moreover, the adverse salinity was remediated by increasing rather than reducing the infiltration of water in soils on the hills and slopes and it occurred without any change in the form of vegetation.

It is now suggested that putting trees back can be damaging rather than beneficial and both the adverse and beneficial effects of trees are attributed to high water use. It is not clear how high

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[4] ERIC results involved mapping using optical satellite imagery and airborne radiometrics. The results of Dr Geoff Taylor derived from numerical analysis of hyper-spectral airborne imagery and field observations.

[5] While accessions on flats could be associated with rising groundwater the simplest explanation is that they arise through surficial lateral flow. When two explanations can apply the simplest one prevails.

water use can be both beneficial and detrimental to the same outcome in dryland salinity. Indeed, the occurrence of this situation completely negates the RGM as high water use by the pre-existing vegetation being beneficial is central to all versions. The illogicality may be an artifact of the use of stream salinity as a measure of dryland salinity but that is unlikely. If the outcome was good under trees before they were removed it should be good under trees when they are returned if the mechanism relates simply to high water use. The best test of cause is the ability to reverse the outcomes and the RGM has failed that test.

The key issue with the RGM relates to the source of salt and is most simply illustrated by the one-dimensional groundwater model for dryland salinity. Adverse salinity is identified as occurring because a water table comes sufficiently close to the surface for water to move upwards through the soil by capillary forces. The upward movement of water is identified as transporting salt from stores beneath the soil into the soil. The rise in the water table is attributed to reduced water use by vegetation increasing the percolation of water through the soil.

The natural condition illustrated using a bucket model (Fig. 5a) has water accessions through rainfall, and losses through transpiration by plants, evaporation from the soil surface and percolation into a groundwater system (Fig. 6). However, there are also losses through drainage from the groundwater system as, if there were not, the water table would naturally be at a level where it affects the soil.

The effect of reducing the water use by vegetation is illustrated by identifying increased input via rainfall as the effects are the same and also occur with irrigation. The RGM depends on increased percolation of water through the soil into a groundwater system. The situation in Fig. 5b is similar to Fig. 5a except that the water table rises through reduced transpiration by plants, and there is increased evaporation from the soil surface and increased drainage from the groundwater system. Increased drainage from the groundwater system would normally occur because of the increase in the hydraulic head associated with the rise in the water table.

The general patterns of water infiltration into the soil (Fig. 6) identify that most of the input of water seldom penetrates below the surface soil because of the water use by vegetation. The depth of penetration of rainfall events is limited by plants drying the soil between events. Typically only around one third of the rainfall infiltrates through the A horizon into the B horizon.

The cycle of input by rainfall in the top and extraction of water from throughout the soil by plant roots produces a net downward flow of water in the soil illustrated by the relative volume of water recycling (Fig. 6). The width of the triangle reflects the relative magnitude of the downward flow of water from rainfall[6]. This cycle naturally leaches salts and clay from the surface soil into the subsoil.

An upward flow of water occurs in the surface soil due to evaporation from the soil surface. This reduces the net downward flow of water near the surface and the soil salinity is generally higher at the soil surface than at 20 cm (Fig. 8). However, while evaporation from the soil reduces the net downward flow the net flow direction is still strongly down.

The RGM has upward flow of water from a groundwater system bringing salt into the soil from stores lying below. While salt can move through moist soils by diffusion the flow of salt is effectively determined by the net direction of water flow and, in the natural system, this is down (Fig. 5a, Fig. 6).

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[6] The use of a triangle is indicative only but it is a realistic representation. The realised pattern depends on the temporal patterns of rainfall and potential evaporation and the characteristics of the vegetation and soils.

With the rise in the water table it is suggested that water can move vertically upwards into the soil through capillary forces but this water has previously flowed down through capillary and gravitational forces. The situation is the same as at the soil surface whereby any upward flow is less than the downward flow. The upward flow reduces the magnitude of the net downward flow but the net flow direction of water and salt for the situation in Fig. 5b is the same as in Fig. 5a and is down (Fig. 7c).

The only means for the level of soil salinity to increase through an upward flow from a water table into the soil in this one dimensional system is for the upward flow to have appreciably higher salinity than the downward flow. However, the water moves up from the top of the water table and therefore does not flow through any salt store where it can gain additional salt. A very small amount of drainage from the groundwater system, which is almost inevitable, would negate the possibility of the salinity of water increasing through the diffusion of salt. There is therefore no physical basis for the suggestion that any vertical flow of water from a water table into the soil due to an elevated water table can increase the level of salt in the soil.

The physical invalidity of the one-dimensional rising groundwater model also applies with two dimensional representations involving hill slopes. With the landscape or hill slope model water draining from the slopes can transport salt from the slopes to the plains. However, with unconfined aquifers, it cannot bring salt into the soil on the plains from any salt stores underlying the plains. Salt accessions in soils on the plains can derive from soils and other upslope material but not from beneath the soil on the plains. Soils on the plains can become saline due to water moving up through capillary action but the salt derives from upslope.

Any form of the RGM that identifies increased soil salinity occurring through subsoil salt rising against a gravitational gradient is physically unsound except for confined and semi-confined aquifers. The issue with such aquifers is that they exist because there is a barrier preventing the flow of water between the soil and the aquifer. Only under particular circumstances can such a groundwater system affect the soil and these are uncommon and localised. The situation has arisen at Virginia Plains in South Australia but that occurrence was associated with a number of factors and involved water accessions from multiple sources including irrigation.

## An alternate model

The commonality with all of the above examples is that the adverse salinity arises through surficial lateral flow of water with the salt deriving from the soil. The issue is not whether the rising groundwater model is applicable as it is not. The issues relate to how the adverse situations differ from the pre-existing natural system by way of patterns of soil water flows and the salinity of the water.

The best indication on water flows is given by Whittington and he identified compacted, structurally degraded soil as the cause. He also identified how the water flows changed with improvements in the soil. The water losses in the degraded system were by surface runoff and surficial lateral flow on top of a compacted soil layer, and by drainage vertically through the soil (percolation) when the soil was improved. The soil was improved by preventing water loss through surface runoff and surficial drainage. The retention of water and nutrients promoted the development of soil organic matter which commenced in the interception banks and gradually progressed upslope.

The changes in the patterns of soil water flow with improvement in soil structure observed by Whittington in Western Australia have also been observed in a research study by Bell et al.

(2001) in southern coastal Queensland. In the degraded soil 20% of rainfall was lost through surface runoff. When the soil was improved by building the levels of organic matter 20% of rainfall was still lost but by drainage through the soil (percolation) rather than by surface runoff.

The conclusion is that soil degradation decreases the percolation of water through soils and increases the surface runoff and surficial lateral flows where the surficial flows are mainly on the top of the B horizon. There is nothing new or unusual in these suggestions and the increased runoff accords with observations of the post European settlement expansion of brigalow by Herbert reported by Isbell (1962). This phenomenon has been observed in several locations by Tunstall and is often associated with the expansion of gilgaied soils[7]. There has been widespread increase in surface runoff of water due to land use impacts and there also appears to have been increased lateral flow in the surface soil.

The conclusion that land use impacts have resulted in less water infiltrating into soils is consistent with the widespread soil erosion that has occurred over most of Australia. In systems such as poplar box this reduces the effective rainfall in runoff areas and hence represents desertification. Tunstall attributes the shrub encroachments in the poplar box system to such desertification: the change in vegetation effectively represents an easterly movement of shrub woodlands into areas naturally occupied by grassy woodlands.

While water is redistributed in such landscapes not all finds its way to rivers because of the flat terrain. Much of the redistributed water and salt accumulates on flats, hence the expansion of brigalow and the associated gilgaied soils. As water use by brigalow enhances the development of gilgais it enhances the availability of water to the plant community by reducing surface runoff. The plants help develop soil conditions that are beneficial to them which they also do with the fixation of nitrogen through mychorrhiza.

The brigalow example evidences a situation where the pattern of soil water use by vegetation limits the negative effects of the salt accessions. Salt tends to be leached from the surface soil and accumulate in the subsoil due to the water use by plants. With more permeable soils the salt could be leached from the soil. The realised effect of salt accessions depends on the vegetation and soil at the accession site as well as the level of salt accessions and the climate.

The development of adverse salinity with surficial redistribution of water and accumulation on flats can depend on enhanced concentrations of salt in the drainage water as well as increased water accessions. The actions of Whittington were designed to keep salts in the soil as he correctly identified the leaching associated with the development of dryland salinity as causing a loss of nutrients. The issue is how soil degradation alters the salinity of water draining through it.

A number of papers give insights into controls on the salinity of water draining through soils but those of Peck (1973) and Blackmore (1978) are apposite. Peck identified that the salinity of water draining through soils was not in equilibrium with the salinity of the soil. Water was flowing along preferred pathways hence the salinity of percolating water was lower than would be predicted from the soil salinity. Blackmore identified a complementary mechanism

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[7] An explanation has the development of the gilgaied formation in clay soils arising from salt altering the water retention of soils such that high saline parts remain moister than low saline parts. Cracking in the dry therefore preferentially occurs in low saline parts. The preferential infiltration of water into cracks further reduces the salinity in low saline parts and increases the salinity in high saline parts. The outcome is lateral spatial variation in salinity related to the gilgai formations (Fig. 1). The process starts with water preferentially entering cracks. (Note: This mechanism does not explain gilgai formations on coarse textured soils (Tunstall 2005c).)

whereby clay soil aggregates adsorb salt. The salinity of water draining through a column of clay aggregates was lower than in the applied water.

The conclusions are that salt losses in drainage water are enhanced by reductions in the adsorption capacity of soils and the loss of the preferred pathways for water flow. Loosing preferred pathways increases the residence time of the water in the soil by decreasing the flow rate. Loosing preferred pathways makes the soil more homogeneous (uniform) where this increases the proximity of water flows to salt. Both effects serve to increases the uptake of salt by the water. These effects combine with the loss of adsorption capacity associated with the loss of organic matter which reduces the ability of the soil to store salts. All effects of soil structural degradation tend to increase the salinity of drainage water.

An additional effect not normally linked with salinity is the reduction in cation exchange capacity with reduction in pH (Tunstall 2005a). Soil acidification is pronounced and widespread under agriculture and hence has the potential to significantly increase the leaching of salts. The acidification would compound the effects of structural degradation[8].

The next issue is how does the soil structural degradation arise? Surface soil compaction is usually identified as being associated with impacts by the hooves of livestock and vehicle movements and subsoil compaction by ploughing. However, soil compaction can arise simply through the denudation of the soil. Higher soil temperatures and reduced input of plant material result in the depletion of soil organic matter. This compaction is promoted by disturbances that increase soil aeration, such as ploughing, as they increase the rate of breakdown of organic matter.

A decline in organic matter in agricultural soils is general throughout the world even though it is not inevitable. In Australia 75% of agricultural soils are identified in the National Land and Resources Audit (NLWRA) as having levels of organic matter less than 1.75% when the desirable levels are 2 to 4%. The low levels of organic matter are of particular consequence for many if not most Australian soils because of the highly weathered nature of the minerals that comprise the non-organic part of the soil. The soil structure effectively depends on the accumulation of soil organic matter.

Soil organic matter is directly beneficial in providing food for microbes that supply nutrients to plants. It is also directly beneficial as a reservoir for water and nutrients due to its high adsorptive capacity. However, its main physical effects are catalytic in beneficially affecting a number of soil properties important in retaining water and salts and promoting plant growth. The main effects on soil structure are an increase in aggregation and a large increase in the water stability of the aggregates. This improves the permeability of the soil to air and water and its resilience to impact. It increases the infiltration of water and reduces the loss of water through direct evaporation from the soil surface. The nature of the effects and their significance for dryland salinity are addressed by Tunstall (2005a).

The alternate hypothesis has dryland salinity arising through soil structural degradation reducing preferred pathways for the flow of water through soils. This decreases the percolation of water through the soil and increases the surface and surficial lateral flow and the salinity of the flow. Even if soil water flows are regarded as groundwater flows[9] this hypothesis differs from all versions of the rising groundwater model in that:

- It does not depend on changes to water use by vegetation.

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[8] This paragraph is an addition made in August 1960.

[9] Soil water flows and groundwater flows are modelled separately because the driver for groundwater flows, the hydraulic gradient due to gravity, is a very small component of the forces controlling soil water flows.

- It is associated with a decrease rather than increase in percolation of water through the soil.

It also differs from most representations of the RGM as the salt derives from the soil rather than stores beneath the soil.

While the soil degradation model does not depend on changes to water use the outcomes will be affected by changes in water accessions similarly to as suggested for the RGM. The mechanism depends on soils becoming saturated and is promoted by a Mediterranean climate (Tunstall 2004a). It is therefore not possible to distinguish between the applicability of the two hypotheses by developing empirical correlations with factors such as groundwater levels.

The above discussion on soil structure relates to fine structures associated with organic matter, clay peds and the like but the same considerations apply to larger structures such as old root channels. Indeed, old root channels can be highly significant as their large size and continuity result in highly preferred pathways for water flow. The maintenance of old root channels by not ploughing can be highly beneficial.

Preferred flow pathways are also important at landscape scales as illustrated by the results for Yass and Cootamundra in NSW. The basic considerations are that water preferentially flows along the path of least resistance and salt accumulates where the flow of water is blocked. The blockage may be a change in permeability associated with a change in geological formation, a change in soil permeability at the break of slope, or may simply arise through a loss of hydraulic gradient as occurs with the accumulation of salt on flats.

The above discussion invokes surficial lateral flows of water and this appears to be common. However, situations can arise where soil salinity levels increase without such accessions. The example on tree killing and grazing in poplar box (Fig. 7) evidences the significance of the patterns of soil water extraction by plants and the infiltration of rainfall. Adverse salinity can arise insitu through soil structural degradation as the degradation affects plant development and hence the patterns of soil water infiltration and extraction.

## What proof for the soil degradation model for dryland salinity?

The soil degradation hypothesis was developed around observations as well as theoretical considerations hence it accords with those observations. However, the best test is given by the ability to remediate adverse salinity by improving the soil structure, particularly by increasing the levels of soil organic mater. This was done by Whittington. It has also been done by other farmers with the most striking example being that of Seis (www.winona.net.au) where crops are direct drilled into native grasses. No fertiliser or ploughing is used.

There are also examples where adverse soil salinity has been remediated using the Wallace plough / Ecoplow, as with the Yeomans Keyline system. This is a more elegant way of retaining and redistributing water within the landscape than the Interceptor Banks of Whittington and has the advantage of more rapidly eliminating hard pans. However, in the long term the ploughing is only effective where it increases soil organic matter which, once the soil health has been restored, should involve little or no ploughing.

Local remediations have also been achieved by increasing the percolation of water through soils by applying gypsum (Amelioration of Salinity, Lockyer Valley, Queensland. Source:ABC news online, Transcript of AM broadcast of 9 April 2002-04-10) and by the use of water conditioners (e.g. Carefree, www.carefree.com.au). The production of beneficial effects by these treatments is associated with improvements in soil structure. The occurrence of beneficial effects with the Carefree and other similar conditioners is contrary to the RGM as the increased water accessions should exacerbate the adverse salinity. However, in reducing salinity through leaching the water conditioners have a potential to exacerbate salinity elsewhere as with all irrigation.

## Implications

Dryland salinity is a symptom of desertification which involves dehydration of the landscape. However, the soil degradation that causes the dehydration it is also associated with a loss of nutrients. Salts that were beneficial when distributed throughout the landscape are being concentrated in localised situations where they can cause damage. While the focus has been on the damage caused by the accumulation of salts the loss of nutrients from throughout the landscape is likely of greater consequence. This applies to conservation as well as production. Fertility is important for wildlife and native vegetation just as it is for livestock and crops.

The ironic aspect is that with dryland salinity the salt accumulations are associated with the accumulation of water but the water is of little use. Water is a limiting resource but the land use activities are transforming an appreciable amount into a form that cannot be beneficially used and can even cause damage.

The long term implications of the nutrient losses are illustrated by the development and decline of vegetation on sand dunes at Cooloola in southern coastal Queensland (Walker et al. 1981) where the background successional theory is given by Tunstall (1978). Vegetation development on the nutrient deficient sand depends on microbes extracting and recycling nutrients with plants limiting their loss by using water and providing a nutrient store. The vegetation develops from grassland into a tall forest but begins to decline when the accession of nutrients from the sand cannot replace the losses. The period of decline is much longer than the build up.

The Australian environment is characterised by low rainfall and nutrient deficient soils with most systems naturally being in slow decline because nutrient losses exceed the gains. These limitations have been accentuated by the land use such that we have taken a large step down the decline. The issues include how to step back up, and how large a step can we take?

### For stream flows

The above addresses the land but has implications for streams. The basic thrust of salinity remediation is to use water where it falls where this reduces the potential for water flow into streams. A common characteristic of all situations where soils have been improved is that dams tend to become dry due to the greatly reduced surface runoff. Surface runoff increased due to soil degradation and remediating the degradation reduces the surface runoff. Remediating the soil would be of concern to many if it produces a significant reduction in stream flows.

The few observations of the hydrological outcomes indicate that improving the soil structure increases percolation while reducing surface runoff. Bell et al. (2001) provide definitive results that accord with general observations of the return of stream flow by Whittington and the development of springs with cell grazing. The percolating water is identified as being good quality which is to be expected where the soil adsorbs salts and retains clay and organic matter. It is additionally beneficial compared to surface runoff through its slower accessions to streams and extended persistence. The uncertainties relate to the potential quantity and frequency of percolation.

Models based on homogeneous soils have percolation being infrequent because the entire soil profile must become saturated before percolation occurs. However, with preferred pathways for water flow percolation can occur without the entire soil profile being saturated. Improving the soil structure has the potential to increase the frequency as well as amount of water percolating through soils but with current knowledge the magnitude of effects is essentially unknown. As we have no observations of the hydrology of the system prior to 1770 we are now dependent on the conduct of research to resolve such issues. Remediating soils could be beneficial to stream flows but we currently don't have the knowledge to make a reliable assessment of what the realised outcomes might be.

## Remediations

The appropriate remedial procedures are largely identified in the examples used to illustrate the reversal of adverse salinity. The basics are minimise soil disturbance and maintain a cover of ground layer vegetation. The embellishments identified above include the removal of hard pans using ploughs that minimise disruption to the soil profile, such as the Ecoplow (www.ecofarming.com.au). As demonstrated by Yeomans (Yeomans 1958, 2002), such ploughs can also be used to reduce the surface and surficial drainage of water from the system.

The remediations should be applied across the landscape and not just on saline sites. While they can be effective on saline sites most gains will be obtained by improving the soil elsewhere because of the much larger areas involved as well as their impact on the saline sites. As the remediations provide production as well as environmental benefits such an approach is practical and sustainable.

The remediations are designed to increase the levels of soil organic matter but the effects depend on the form as well as amount of organic matter. Plant roots supply the bulk of the organic matter that provides the energy to drive the soil microbial processes and so are important in death as well as life. They can also be important when decomposed as they leave cavities along which water can rapidly flow.

The soil organic matter of most consequence for soil structure is produced by microbes where the importance derives from its form and longevity. Humic compounds and the protein glomalin are of most consequence. Additional to producing these compounds microbes supply nutrients to plants thorough processes such as fixation of atmospheric nitrogen and the recycling of nutrients in organic matter, as with nitrogen mineralisation. Microbes are central to the development of the soil hence the use of the term soil health. A healthy soil has a viable and active biology that involves diverse microbial populations but can develop to include larger life forms such as worms and other invertebrates.

To be effective the remediations must be directed at developing the plant – microbe association to produce a biologically active soil. Many examples of partial solutions exist, as with the inoculation of legumes. However, options are available that introduce millions of forms of selected microbes rather than just a few where this delivers greater benefits. Moreover, small applications of organic substrate and minerals in appropriate forms can greatly promote biological development. Numerous options exist that can be tailored to economic as well as the biophysical constraints but these have effectively yet to be explored. In large part this is the mission of Healthy Soils Australia (www.healthysoils.com.au).

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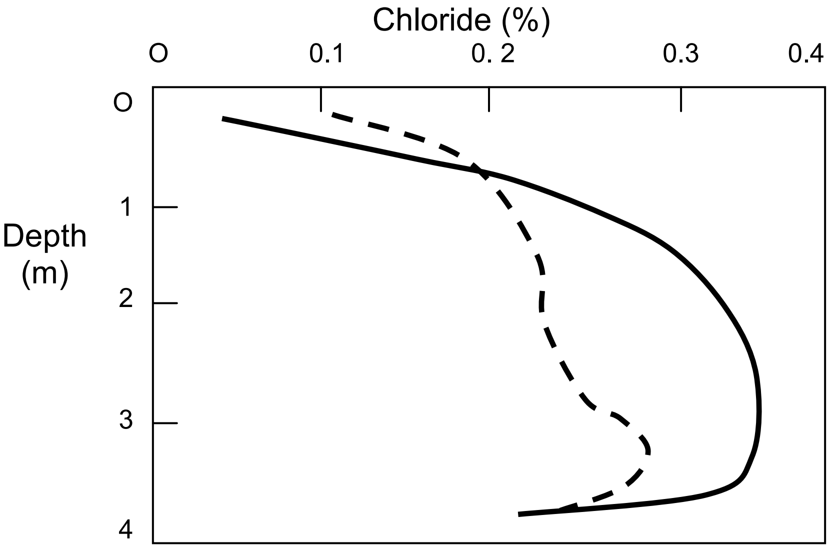


**Fig. 1** Soil chloride under mounds and depressions for gilgaied soil in a brigalow community, Meandarra From Tunstall & Connor (1981).

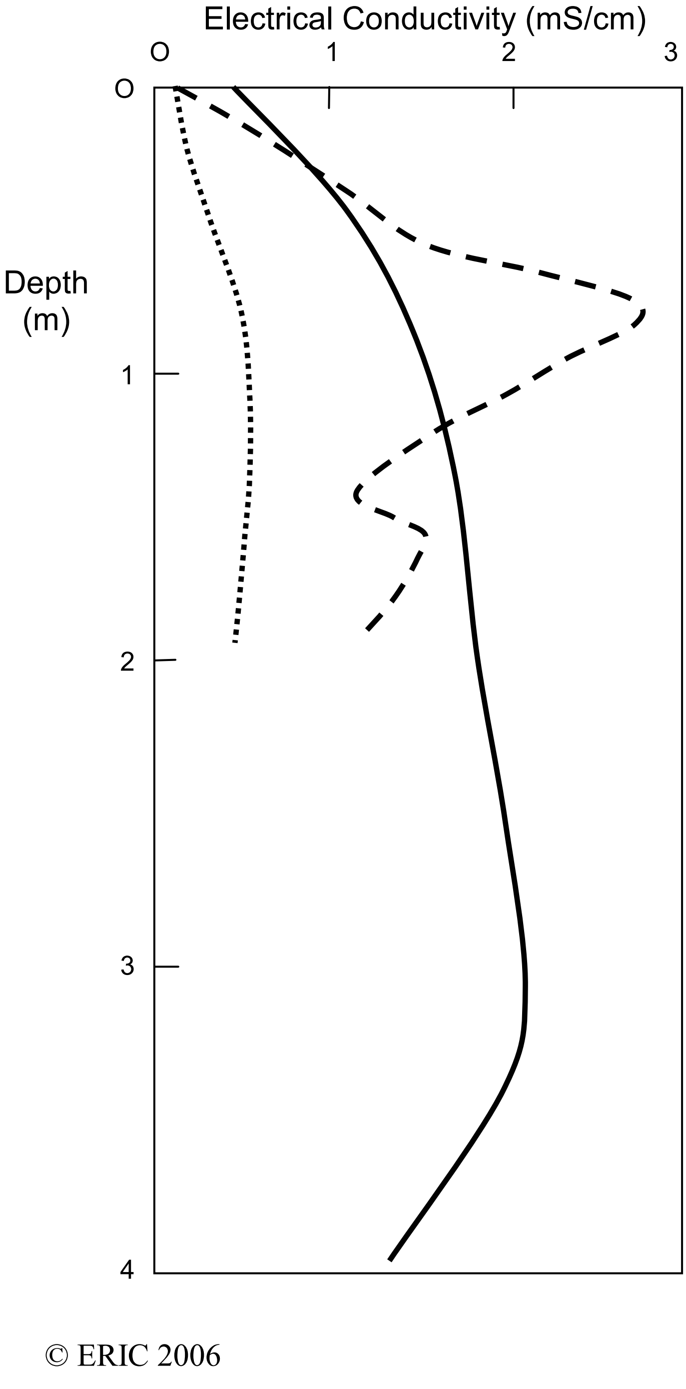


**Fig 2.** Soil salinity (1:5 Soil:water) for brigalow at Meandarra and brigalow and poplar box communities at Talwood.
From Tunstall & Walker (1975) and Tunstall & Connor (1981).

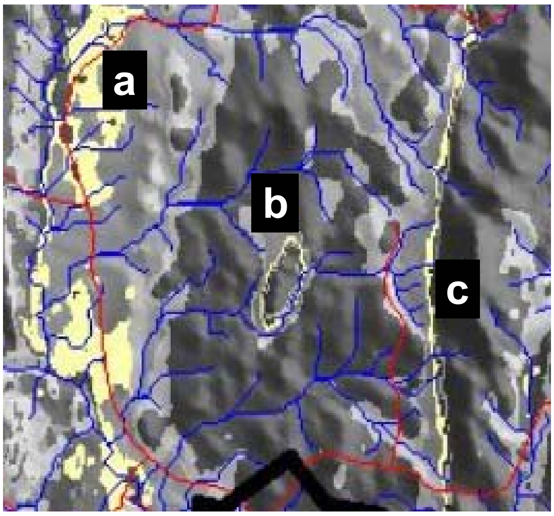


**Fig. 3a** Patterns of salt flow and accumulation in the Cootamundra Shire.

a Along flats and streams
b Break of slope around hills
c Along fractures and fault lines

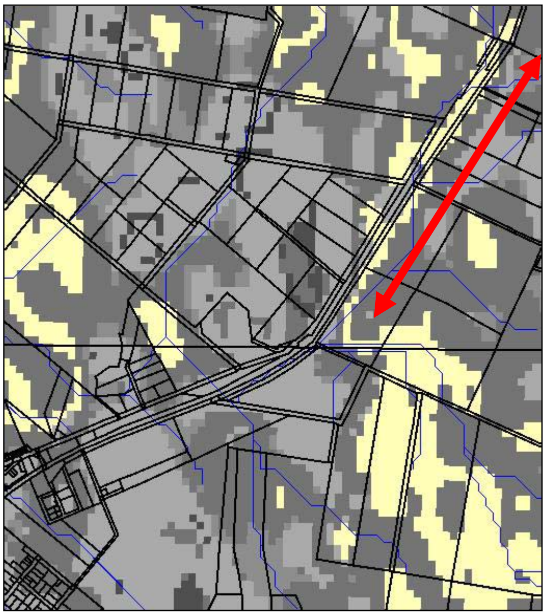


**Fig. 3b** Section of the Olympic Highway subject to annual repairs (associated with a salinity pathway).

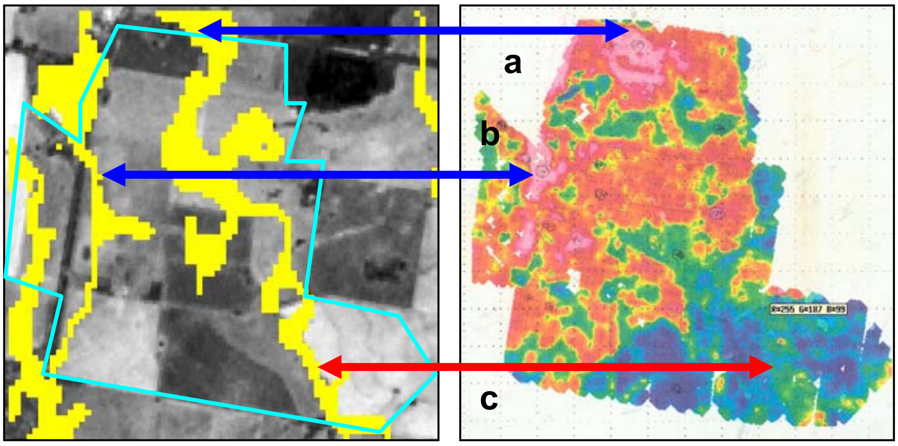


**Fig. 4**

Comparison of salinity results extrapolated from Cootamundra and EM31 results for a landholding near Temora. Blue arrows link previously known saline areas.

**Fig. 5** One dimensional rising groundwater model. Natural system having a groundwater system identified by a water table (a), and the same situation with increased water accessions (b).

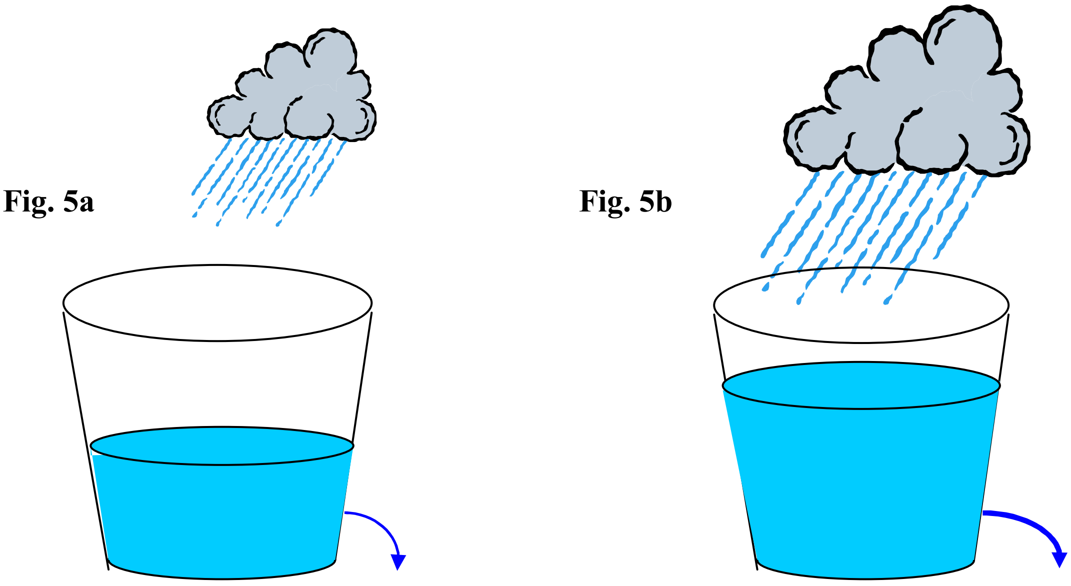


**Fig. 5a**

**Fig. 5b**

**Fig. 6** Patterns of water infiltration into soils. The relative volume of water recycling illustrates the relative amount of water infiltrating to different depths in the soil.

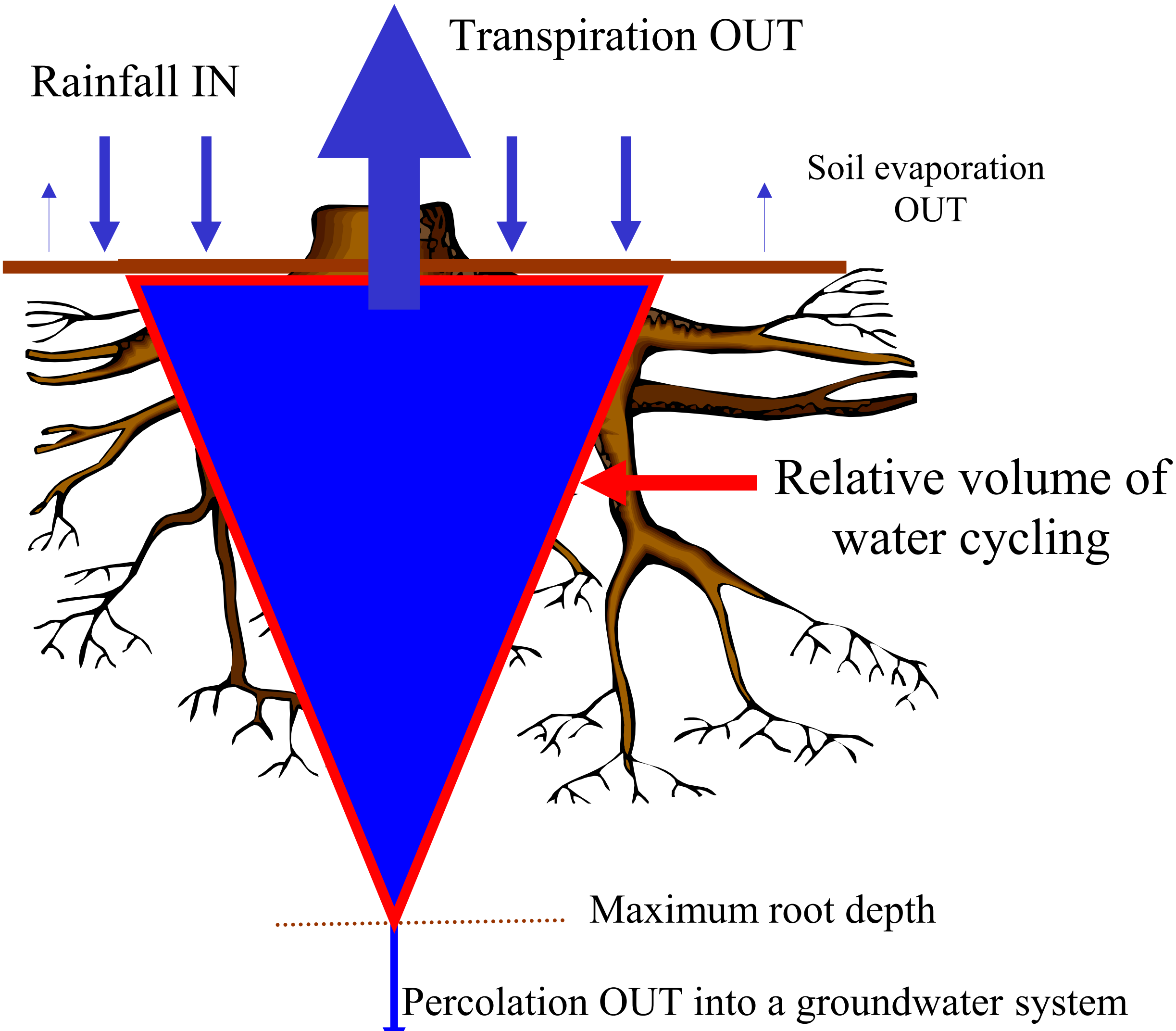
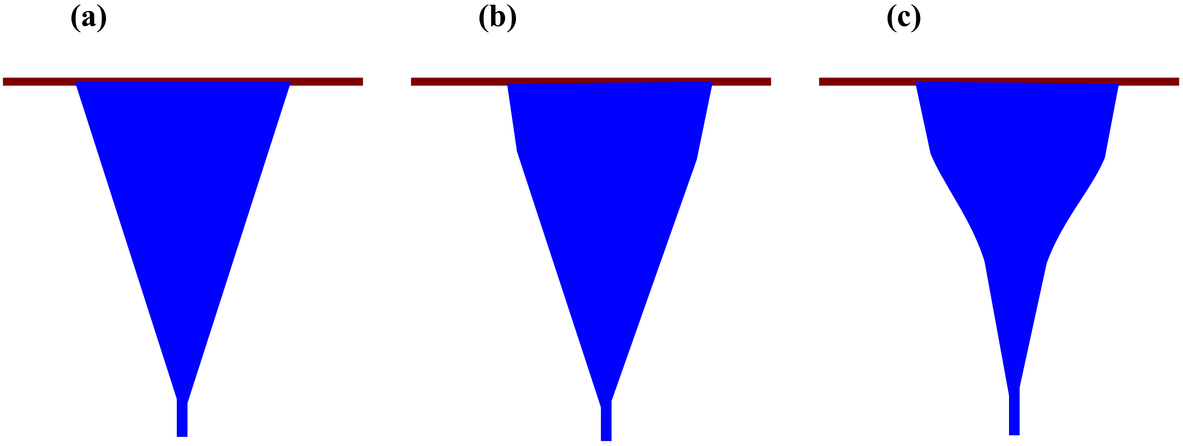


**Fig. 7** Schematic representations of the relative amount of downward flow of water in soil for a one dimensional system. (a) Rainfall penetration. (b) Net flow with evaporation from the soil surface. (c) Net flow with evaporation from the soil surface and upward flow from a water table.



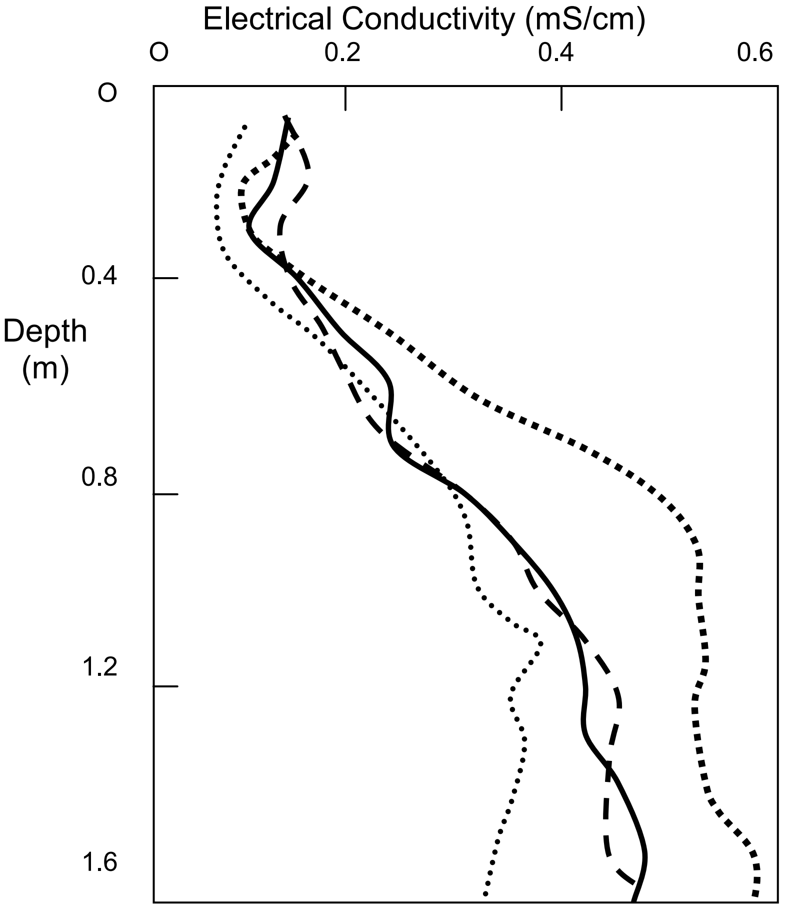


**Fig. 8** Soil Electrical Conductivity (1:5, soil :water) for poplar box subject to the treatments of tree killing and grazing. The reference condition is trees alive, grazed. Measurements were obtained 8 years after the treatments were applied / initiated. From Tunstall & Walker (1975).