WHAT MODEL FOR DRYLAND SALINITY?

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INTRODUCTION

Salinity currently has the highest priority of all environmental issues and this is reflected in the allocation of funds by the Commonwealth Government. However, the reasons for this prominence are not readily apparent from an analysis of the impacts of land use. Other factors such as soil acidity have a much greater economic impact while for the conservation of biota the salinity effects are minor compared to clearing and introduced weeds and pests.

Concerns for salinity in streams have resulted in salinity levels being set without any knowledge of their levels prior to the introduction of European agriculture. The proscribed levels reflect the use of rivers to transport irrigation and drinking water and there has been little regard to their natural function in draining the land. Attempts to retain salt on land to lower stream salinity serve to promote land degradation as is currently occurring with major irrigation areas being sinks for salt from rivers. Such accumulation of salt has historically been the reason for the eventual demise of irrigation areas around the world.

There are some obvious illogicalities in the current approach to salinity and there is no single reason that can readily be identified for salinity receiving the highest environmental priority. One can only conclude that it arises from a number of contributing reasons such as the salinity of Murray River water used to supply Adelaide, the often dramatic visual effect of salinity, the loss of productive agricultural land, threats to biodiversity, and the suggestion that dryland salinity is caused by tree clearing. This latter suggestion has been used by conservationists to support their view that there should be no clearing of native vegetation.

The suggested causal effect of tree clearing is linked with the acceptance of the rising groundwater model which has been presented as the general and official model for dryland salinity. Tree clearing on hills is said to increase the percolation to groundwater under the hills with the adverse salinity occurring through this water rising to the surface at a distant point on the plains. The salt in the rising groundwater is said to derive from subsurface salt stores on the plains.

Development of this model was based on observations that the water table ‘rises’ in the sense of coming closer to the surface. However, it is rarely clear whether discussions relate to water failing to drain as opposed to water being forced vertically upwards. Suggestions that one can stand there and literally watch the water rise do not resolve this issue nor does the use of the more explicit reference to an increase in the piezometric head[1]. Piezometers measure the hydraulic head but do not identify the source of the water except where a network is used to infer patterns of water flow below the root zone from pressure gradients.

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[1] Piezometers measure the pressure of water at particular depths by the height of the water column in installed pipes. In highly permeable systems the height of water in the pipe is the same as the height of the water table and is the same for all depths of installation of the piezometers. In confined and semi-confined aquifers the water can be under pressure so that the height of water in the pipe is well above the water table and sometimes even the soil surface. This is reflected in the height of water rising slowly in new holes bored into the ground. The initial height of water in a new borehole is the height of the water table. The equilibrium height closer to the soil surface gives the piezometric head (water pressure) at the bottom of the hole.

Many representations of the rising groundwater model defy physics as water can only move vertically upward in confined or semi-confined aquifers and these are by no means general. Even with such systems there is the logical difficulty that for water to be able to move upwards on the plains it must also be able to percolate down. The plains were the first to be cleared and there should logically be increased percolation on the plains which could leach salt down. This is quite apart from tree clearing not necessarily increasing percolation into a groundwater system. Depending on soils and climate tree clearing can reduce such percolation.

While the rising groundwater model has been promoted as the official model for dryland salinity there has been considerable dissent because the model cannot account for a large number of observed situations. This dissent has been widespread in coming from farmers, agency field personnel, and independent scientists.

Acceptance of the rising groundwater model arose from its promotion by those now generally identified as hydro-geologists. In the mid 1970's the Commonwealth Government cut all land survey by CSIRO and the now Geoscience Australia (GA) as such activities were identified as being a State responsibility. Around the same time the Government identified the research priority as being salinity instead of water. Having lost their reason for existing the commonwealth geologists used the rising groundwater model to justify their involvement in dryland salinity. Control was exercised by advice to Government that dryland salinity was associated with rising groundwater and therefore a geological problem associated with underground aquifers.

Significant consequences of geologists specifying the mechanism for dryland salinity include the application of the highly simplistic notion that tree removal increases groundwater recharge and a failure to consider effects of either climate or the changes to soils caused by land use. Application of the rising groundwater model effectively ignores the soil and plant water balance where this is the prime determinant of the flows of water and salt. Moreover, it is this surficial water balance that is directly impacted by land use. Groundwater systems are not directly impacted by land use and hence cannot be causal in dryland salinity.

These considerations are addressed in more detail in a paper[2] that concludes that dryland salinity is primarily caused by soil structural decline arising mainly from a loss of organic matter. The same conclusion was reached by Christine Jones[3] who examined ecological changes associated with historical changes to the use of land. When examined comprehensively and objectively salinity is a symptom of land degradation and is usually not the cause. A focus on salinity is therefore unlikely to provide much benefit and this has been the experience over the past 25 years.

This paper develops considerations originally presented in a web discussion on alternate models for dryland salinity. The focus is on models for the mechanism for the development of dryland salinity and hence on surficial hydrology. However, expressions of dryland salinity depend strongly on geology by way of the nature of the material and subsurface structure. Adverse salinity is often associated with saline marine sediments while geological structures control the patterns of subsurface water flows.

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[2] Tunstall, B. R. (2001). Scenario for Dryland Salinity

[3] Jones, C. E. (2000). The great Australian salinity debate Part 1:Controlling the salinisation processes. Holistic Management Aust. Quarterly Newsletter, July 2000.
Jones, C. E. (2000). The great Australian salinity debate Part 2: why the recharge:discharge model is fundamentally flawed. Stipa Native Grasses Newsletter 14, 6-11
Jones, C. E. (2001). The great Australian salinity debate Part 3: Soil organic matter: past lessons for future learning. Stipa Native Grasses Newsletter 15, 4-9

Context

Logic

A summary of the position of Einstein is that while his model of the universe was better than given by Newton a better solution would be provided in the future. The best now will not be the best in the future.

This consideration can be alternatively expressed as identifying that there is no absolute truth or correct answer. Even if a correct answer exists the issue arises as to how it can be recognised.

Popper addressed this latter consideration by suggesting that science depends on testing with any failure resulting in rejection. This is equivalent to implementing a process of continuous improvement by using monitoring and reporting against specified objectives to evaluate performance.

Popper also suggested that testing could only be conducted on parts of a system and not on an entire complex system. While this consideration is difficult to discuss without becoming involved in semantics, it is of particular consequence when addressing complex systems such as arise with dryland salinity.

The concern of Popper about testing whole systems may have arisen from consideration of evolution where knowledge of the process does not allow prediction of the outcome. Popper regarded reliable prediction as a necessary outcome for laws in science and recognised that, while this could be achieved for parts of systems, it could never be achieved for many complex systems if only because of uncertainties as to future conditions.

These issues are central to the evaluation of hypotheses as to how dryland salinity arises and predictions of what any future changes may be. The considerations identify the invalidity of the proposition that any model can be absolutely correct hence the recognition of an official model is inappropriate. The administrative requirement in addressing salinity is for a process that takes account of the reality that any model will contain deficiencies hence the need for a feedback process incorporating monitoring and reporting against defined objectives to allow for a continuous improvement in performance.

The considerations also identify that only one negation or exception is needed to refute a model as being general. Many exceptions have been identified to the rising groundwater model hence it cannot be general. This has been recognised in the June 2004 House of Representatives Standing Committee on Science and Innovation report on *Science overcoming salinity: Coordinating and extending the science to address the nation's salinity problem*[4].

The issue of an ability to test conclusions for a complex system is particularly relevant to the use of models in predicting salinity outcomes. A model can readily be developed to characterise a particular system but this does not identify its applicability elsewhere. Moreover, refining a model to provide a correct answer for a complex system in no way validates any components of the model. The ability to provide an empirical prediction does not validate the applicability of assumptions or processes used in a model. Any presentation of results from complex models as representing reality is irrational.

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[4] Available on http://www.aph.gov.au/house/committee/scin/salinity/report.htm

Definitions

Much of the confusion with dryland salinity appears to have arisen from different perceptions as to what constitutes basic elements of the discussion such as dryland salinity, groundwater and rising groundwater. In the Land and Water Audit[5] groundwater has been defined as *All free water below the surface in the layers of the Earth's crust*. With this definition there is no groundwater as none of the water is completely free because of the inevitable occurrence of salts.

If groundwater is regarded as any water with zero matric potential then it is axiomatic that dryland salinity arises through changes to the groundwater as all salt effectively moves in solution. With this definition resolution of the issue of how dryland salinity arises derives through definition. This pointless situation has arisen because of a failure to differentiate between parts of the system that have very different functional characteristics. It does not discriminate between water accessible to plants that can be evaporated to the atmosphere and water that drains through the ground into some form of aquifer or groundwater system.

Different forms of numerical models are used to address surficial hydrology and groundwater systems because of differences in the processes and in the relative significance of different processes. Groundwater flows are modeled from the hydraulic head and can often be reasonably simulated as steady state systems using linear functions. Conversely, the surficial hydrology is highly transient and many responses are markedly non-linear. The hydraulic head is effectively insignificant compared to other forces controlling water flows in soils unless they are saturated (matric potential close to zero) but it is always the dominant force controlling groundwater flows.

The term dryland salinity was originally used to differentiate it from salinity associated with irrigated agriculture and now also from urban salinity. As irrigated agriculture and urban development are land uses, dryland salinity logically arises through the impact of dryland agriculture. However, primary and secondary dryland salinity have been recognised where these relate to natural and land use induced salinity respectively. If dryland salinity is associated with dryland agriculture by definition there cannot be primary dryland salinity.

Primary and secondary can have different connotations. The second may follow the first or the first be more important than the second. Neither of these appears to apply with its application to dryland salinity. Natural and land use induced salinity exhibit a similarly wide range of impact, and land use induced salinity can arise where previously there was none.

The term primary is used to identify soils that derive from the underlying parent material where this distinguishes them from soils having other forms of development, as with alluvial deposition. Reference to a primary soil provides useful information on the process of its formation. However, the processes involved in dryland salinity associated with land use are the same as in natural systems. There is no basic physical difference between primary and secondary salinity.

As the salinity change with land use is one of degree rather than kind it can be difficult to discriminate between what is natural and what is land use induced. The lack of a clear distinction in the processes means that the issue could be discussed at considerable length but that there would be little benefit in doing so. Logically there can be natural salinity and salinity associated with dryland agriculture but not primary dryland salinity.

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[5] Australian Dryland Salinity Assessment 2000. National Land & Water Resources Audit. Land & Water Australia, Canberra http://audit.ea.gov.au/ANRA/atlas_home.cfm

Salinity Models

The analysis here is largely restricted to addressing the soil as dryland salinity is taken as being the development of adverse salinity associated with dryland agriculture. Dryland agriculture effectively only impacts the soil and vegetation, and the adverse impacts of salinity on agriculture are mediated through the soil. Dryland salinity is caused by changes to the soil and vegetation and the adverse impacts arise from changes to the soil impacting on vegetation.

While the soil must be causal other parts of the system that influence patterns of water flow can also affect outcomes. These are considered under expressions of dryland salinity rather than with the causal model.

A General Model

Soil salinity can arise where water containing salt accumulates through impeded drainage and salt is concentrated through evaporation. The requirements are accession of salt in water and impedance to drainage so that the water is lost through evaporation. These requirements can occur insitu provided the rainfall is less than the evaporation.

Soil operates as a sponge in holding water against gravity and hence impedes drainage[6]. The effective magnitude of the impedance depends on the volume of water that can be evaporated relative to the input where this depends on the physical properties of the soil, particularly its water storage capacity, and the characteristics of the vegetation and climate.

An excess of water input over evaporation results in drainage of water from the soil either over the surface, laterally through the soil, or down into a groundwater system. Drainage through the soil tends to reduce the insitu soil salinity. Surface runoff decreases the effective rainfall but otherwise has no effect on the insitu soil salinity.

Drainage water contains more salt than rainfall and significantly increases salt accessions where it accumulates. However, the constraints for the development of salinity remain the same as for accessions through rainfall. There must be impedance to drainage so that the water accessions are lost through evaporation. As the soil must store the combined water from rainfall and lateral accession the rainfall must be considerably less than the evaporation for salt to accumulate.

These constraints can be used to identify areas susceptible to the development of saline soils. Compared to coarse soil textures, fine soil textures increase the effective impedance by their higher capacity to store water and to directly evaporate water from the soil surface to the atmosphere. Rainfall should be considerably less than the potential evaporation. However, enhanced accessions of salt through lateral drainage only arise where there is drainage and this primarily occurs when the soil profile becomes saturated. A Mediterranean climate whereby soils saturate over winter and become dry over summer is therefore highly conducive to the development of soil salinity. The areas of Australia most subject to dryland salinity have a Mediterranean climate.

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[6] Soil is effectively a buffer store for water that allows vegetation to survive during periods without rain. Its main hydrological characteristics, apart from the way water flows and is available to plants, are losses in getting water into it, leakage out the bottom and overflow from the top and bottom (lateral flows ignored). Overflow drainage from the bottom and leakage primarily affect salinity. The separation of overflow drainage from leakage is somewhat arbitrary but this differentiation is useful when addressing changes in hydrology with changes to the vegetation and soils.

Dryland salinity can be regarded as occurring where broad acre agriculture produces soil salinity or increases the severity and/or extent of soil salinity. Most expressions are associated with lateral movement of water through or under the soil but this is not essential as salt can move towards the surface due to insitu changes in the soil hydrology. Soil compaction can reduce water inputs by increasing surface runoff and changes to the vegetation can further modify the patterns of soil water penetration and extraction. Reduced input and reduced water extraction by vegetation can result in salt in the subsoil gradually moving closer to the surface.

The expressions of dryland salinity generally regarded as being of most consequence are associated with an increased accession of water through lateral flow. The increased accession mainly arises because of a decrease in the effective impedance of the soil in areas of higher elevation. Factors that can increase this accession are therefore increased rainfall, reduced runoff, and a reduction in the effective soil water storage capacity as determined by changes to soil properties and the potential for water use by vegetation.

The increased surface runoff through soil compaction directly reduces the potential for drainage but can indirectly increase this potential. Increased surface runoff reduces the development of vegetation and so decreases the potential to evaporate water during wet periods when drainage occurs.

The reduced capacity of vegetation to evaporate water arises through its degradation by impacts such as grazing or replacement of perennials with annuals. The reduced capacity of the soil to store water mainly arises through the loss of organic matter and the associated compaction.

The significance of these changes in drainage depends on the amount of salt in the accession water and the characteristics of the reception site. Low salinity accessions generally have little impact other than to increase the susceptibility to waterlogging. The accession of large volumes of water can produce drainage and hence decrease soil salinity even where the accessions have appreciable salinity. High salinity accessions that cannot drain produce the greatest increases in soil salinity. The realised outcome depends on the characteristics of the accession site as well as the nature of the accessions.

Subsoils affect the development and expression of soil salinity where they contribute salt and/or impede or promote drainage. A complete blockage to drainage in accession areas makes the development of soil salinity inevitable, as with Lake Eyre.

Maintaining drainage of water through the soil is the only means of preventing the development of soil salinity and this occurs naturally in high rainfall areas. At least one soil web site in the USA correctly states that soil salinity can readily be fixed by providing drainage. It depends on increasing the percolation of water through the soil. However, increasing percolation is difficult without irrigation in low rainfall areas, particularly with duplex soils, and may effectively be impossible in some situations due to geological and/or topographic constraints.

The above considerations lead into the paper Scenario for Dryland Salinity which goes into greater detail on changes to soil structure.   Soil structural decline is primarily associated with loss of organic matter which reduces the capacity of the soil to store water and produces compaction. However, the reduced storage capacity does not necessarily produce increased percolation into a groundwater system. The structural decline decreases the preferred pathways for water flow, such as cracks, voids and root channels and forces the water to flow thorough the bulk soil matrix. This greatly decreases the flow rate and increases the uptake of soil salt into the water. The main outcome appears to be an increase in lateral surficial flow of more saline water than occurred naturally and this causes adverse salinity where it accumulates. The accessions of sodium in such water provide a positive feedback by further decreasing the permeability of the soils and hence drainage.

With this mechanism adverse salinity can arise without any change to the water balance as it can be produced by changes to the salinity of drainage water. However, most occurrences of dryland salinity would be expected to additionally be associated with changes to the partitioning of water flows. The main practical consequence is that a focus on vegetation in remediation, as with planting trees, will be of limited benefit. The benefits of different remediations are best evaluated by way of their effects in improving the soil. With Australian soils in particular the benefits are best reflected in structural improvements associated with the levels of accumulation of organic matter as this reflects the development of the biology and hence health of soils.

Expressions of Dryland Salinity

Expressions of dryland salinity depend on the structural controls. Most represent accumulation in lower lying areas through drainage along an elevation gradient but the drainage can be over the surface, and/or through the soil, the subsoil and underlying aquifers. Water flow in these pathways is not mutually exclusive and all can affect an outcome.

The relative magnitude of the flows along different pathways depends on the relative resistances and these can be affected by land use. Surface runoff increases because of the increased resistance to flow in the soil. An increase in the resistance to flow through the B horizon will decrease percolation below the root zone and increase lateral flow through the surface soil. There can be considerable difficulty in determining the significance of the different flow pathways for expressions of salinity.

Water moving in subsoils and underlying aquifers must come to the surface to affect soil salinity and this can arise in several ways. The relative resistances to flow can result in water coming to the surface at unconformities, such as the break of slope or boundaries between different geological materials, and in lakes. Surface aquifers can fill where the drainage is inadequate resulting in the water table coming closer to the surface. In confined or semi-confined aquifers water can be forced vertically upwards where the subsurface drainage cannot accommodate the increased flow.

The transport of salt to the soil is markedly different between confined / semi-confined aquifers and the other situations. With confined and semi-confined aquifers the net vertical mass flow of water in the soil can be up but it is down in the other situations, lakes excepted. This greatly increases the capacity to transport salt to the soil and produces a distinct soil salinity profile.

Salinity expressions are often related to surface topography due to the topographic controls on drainage and soil development. However, structural controls such as geological fractures, dykes and unconformities can modify these patterns and these controls can operate across catchments and basins. I have interpreted 5 forms of expression in one region, and have observed patches of surficial salt accumulations associated with lateral water flow through the soil occurring alongside accumulations associated with seepage from a semi-confined aquifer. There are many different forms of expression of dryland salinity and having one form of expression does not preclude the occurrence of others.

There are many other forms of development of soil salinity associated with land use, as when flow pathways are cut by channels or blocked by constructions. One adverse situation on an alluvial plain assigned by some solely to irrigation has water accessions at the impacted site deriving from distant hills, urban settlement and possibly also salt evaporation pans as well as by rainfall and irrigation. The pans additionally block drainage. Some drains installed to protect crops at an impacted site effectively remained dry while others carried large volumes of water. There can be large regional diversity and high local spatial variability.

The structural controls on water and salt flows influence remedial actions. Greatest benefit will arise where an entire system can be fully remediated but the level of benefit from an action can vary considerably depending on where it is applied. The greatest part of the potential benefit may come from localised actions hence knowledge of the structural controls can be used to maximise returns from expenditure of the invariably limited resources.

Prediction

Assuming knowledge of the processes is adequate the level of prediction depends on the ability to provide detailed information on the structural characteristics of the system that determine outcomes.

Hydrological Modeling

Hydrological models are used to predict changes in the distribution of soil salt associated with changes in land use. The main study that tested the applicability of such models is the Representative Basins Project. This had the objective of quantifying Australia's surface water resources by developing models of gauged catchments and applying them to un-gauged catchments.

The main result from this project arose from an initiative of a geographer, Peter Laut. Statistical models were used to relate catchment inputs to outputs using spatially detailed characterisation of catchment characteristics such as vegetation and slope. The models demonstrated that each catchment preformed in a predictable fashion (outputs could be reasonably predicted from inputs) but the relationship between the controlling factors and catchment performance varied between catchments. Each catchment had its individual characteristics and the performance of a catchment could not be predicted from knowledge of its physical characteristics. Each catchment requires calibration and the results from one catchment cannot be transferred to another using current knowledge of catchment characteristics and physical processes

I ran a catchment study designed to use catchment outflows to evaluate the impact of land uses such as fire and off-road vehicle movements. It involved 15 gauged catchments ranging from 2 to 10ha in size, all located together on a single geological formation and selected to be similar in relation to vegetation and soils. Outflows of water and salt were monitored at 10 or 20 minute intervals in undisturbed catchments containing native vegetation in essentially pristine condition.

Six years of calibration data were used to relate water outflows to inputs using a five parameter model run to identify the global optimum for each catchment. Each catchment performed in a very consistent and hence predictable fashion but some physically similar catchments performed very differently while some physically dissimilar catchments effectively had the same response characteristics. The key conclusion was that results for any catchment could not be reliably transferred elsewhere given the current level of knowledge. As with the large catchments the results from very small catchments were site specific and observations on one area cannot be reliably extrapolated elsewhere.

The above studies test the ability to apply existing knowledge to new situations to obtain a reliable prediction of the outcomes. They identify that for water this ability is limited. It is much more limited for salt because of uncertainties between the linkages between water and salt movements.

Conclusions from results for salinity are the same as for the hydrological studies identified above. Catchments tend to perform in predictable way and hence can be empirically calibrated[7] but the results cannot be reliably extrapolated elsewhere. Results can be applicable to the circumstances under which they were developed but cannot be reliably extrapolated to new situations.

Developments have been directed at using more mechanistic models to establish the input-output relationships in the expectation that this will improve the reliability. However, this expectation has not been tested and the results from the catchment studies that have tested this capability indicate that it cannot be achieved with current levels of knowledge and understanding.

While our understanding of processes is incomplete the limited ability to predict outcomes likely mainly derives from an inability to provide necessary information on the structural characteristics of the system that determine outcomes. Examination of the 15 small catchments after obtaining the results indicated that some of the discrepancies likely arose because of differences between the effective catchments for surface and subsurface flows. The lateral directions of flow need not be the same for the subsurface as for the surface. This is compounded in large catchments by structural features such as fractures and fault lines providing preferred pathways for flows that need not be characterised in any of the measurements.

Process

A paper from my thesis[8] addressed the effect of salt on water availability in soils and concluded there is an amount of soil water that is effectively solute free making the osmotic effect of salt greater than currently calculated for dry soils. The amount of such bound water can be estimated by the temperature increase associated with the addition of water to dry soil. This soil heat of hydration (Soil HoH) represents the release of energy with the dissociation of hydrogen bonds when water adsorbs to the surface of materials such as clays and organic matter.

Early studies used the Soil HoH to characterise the change in specific energy of water in clays with change in water content. My recent observations identify that Soil HoH depends more on the level of organic mater than the type of clay. Moreover, salinity (Na) decreases the amount of bound water in clay and organic matter and the effect is reversible.

The significance of this effect of salt on bound water will only be determined through further research but it is likely associated with a reduced capacity to store water. It is mentioned here to illustrate that our knowledge of processes important in addressing soil salinity is by no means complete.

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[7] Peck, A. J. (1973). Chloride balance of some farmed and forested catchments in southwestern Australia. Water Resour. Res. 9: 648,57

[8] Tunstall, B. R. (1973). Interrelationships Between Salt Content, Water Content and Water Potential in an Expansive Clay Soil. In PhD Thesis: Water relations of a brigalow community. Botany Dept, Uni. Of Qld.

Way Forward

The classic line that more research is needed is a truism. The issue is where might progress best be made. Should it be more of the same or involve an attempt to develop knowledge and understanding?

The above discussion represents a compilation of information and experience over a long period. This involved extensive field experience across Australia as well as the development of methods for developing spatially detailed information on natural resources. The combining of remote sensing and ground observations in the development of information represents application of new technology to land survey and hence is a development of the highly effective Land System approach developed by Chris Christian.

The complete package developed by Christian, that became the CSIRO Division of Land Research, used detailed agronomic studies to examine and apply information obtained from regional surveys. This requirement for testing applicability was addressed by me through the company Environmental Research & Information Consortium Pty Ltd (ERIC). Results had to be relevant and applicable to those on the land. Benefit can only be derived through such application and the evaluation by others provides a much greater range of testing than can be implemented in scientific studies. The scope of testing is important when addressing complex systems that exhibit high diversity.

The capacity to develop information on natural resources was primarily directed at land management in military training areas and investigation of the factors controlling the distribution of native vegetation. Land use activities in military training areas encompass most impacts associated with normal land use, such as clearing, grazing and fire, but include some exotic activities such a live fire battle runs and bombing. The requirement to address native vegetation necessitated a focus on providing information that could be used to examine process.

The methods developed are directly relevant to dryland salinity as they address the initial requirement to efficiently obtain observations to determine what likely is occurring in particular systems where these insights provide a rational basis for actions and further observations. They allow examination of a system to determine what is likely occurring rather than having to rely on application of a model having uncertain applicability.

In developing the paper Scenario for Dryland Salinity it became apparent that there were key deficiencies in knowledge, hence the use of the phrase ‘it appears that’. These deficiencies remain. The main issue relates to the partitioning and movement of water in the surficial water balance and the effects on this on the movement of salt. Work by Bell et al.[9] shows that percolation to a groundwater system can be improved by improving the soil structure and in his situation the improvements did not change the water use by vegetation. While these results are explainable in terms of preferred pathways for water flow they are contrary to the basic precepts invoked in application of the rising groundwater model. Current knowledge is grossly deficient, particularly as it has generally been applied.

To my mind an essential next step in developing understanding is to obtain more information on the changes in soil hydrology associated with land use. One difficulty lies in finding systems that have not been impacted by land use that can be compared with the impacted state. The exclusion of grazing is at least as important as the trees remaining intact. Another relates

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[9] Bell, M. J., Bridge, B. J., Harch, G. R., Want, P. S., Orange, D. N. and Connolly, R.D. (2001) Soil structure affects water balance of Ferrosol cropping systems. Proceedings of a GRDC conference, Kingaroy (www.regional.org.au/au/asa/2001/3/b/bell.htm)

to the effort required to obtain a useful temporal average of water balance for an adequate number of sites.

Soil profiles contain information on hydrology as the profile development reflects the patterns of water infiltration and extraction. The development of soil profiles is directly linked to patterns of water flow as determined by climate, vegetation, and the nature of the soil material. The VERY limited observations I have obtained to date identify that some profiles indicate increased leaching under agriculture but most did not. However, all agricultural profiles had a marked decline in organic matter with soil compaction reducing the depth of some surface profiles by one third. The loss of soil organic matter with dryland agriculture is pronounced and ubiquitous despite modeling in the Land and Water Audit[10] suggesting the opposite. The effect of the loss of soil organic mater is dramatically characterised by the Soil HoH measurement.

It appears that observations of soil profiles can provide considerable useful information on changes to surficial hydrology but the limited occurrence of intact, undisturbed sites in agricultural areas limits opportunities for sampling paired sites. The best that may be achieved could be the identification of the interrelationships between soil properties and rainfall in determining the impacts of agriculture on soil properties and percolation through the soil. The issue then is the development of the mapped soils information needed for application.

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[10] Results for changes to carbon and nitrogen with agriculture are located on http://audit.ea.gov.au/ANRA/land/land_frame.cfm?region_type=AUS&region_code=AUS&info=farmgate