Managing Dryland Salinity in the 21st Century - An Integrated Salinity Management Approach

by

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MANAGING SALINITY IN THE 21ST CENTURY - AN INTEGRATED APPROACH

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INTRODUCTION

The causes and extent of dryland salinisation of agricultural soils and water resources in Australia have been well established scientifically and generally understood by rural land managers. The fundamental impacts of converting forest, woodland and heath to arable agriculture include:

- rooting depth of vegetation changed from deep (>2 m) to shallow (<2 m)
- a reduced availability of profile storage capacity for infiltrating water;
- increased rate of aquifer recharge beneath the agriculturally developed part of the landscape;
- an increase in the quantity, duration and velocity of surface runoff;
- the change in the quantity and seasonality of actual evaporation, and its spatial distribution within the landscape; and
- the degradation of the soil resource in its various forms - soil compaction, soil structural decline, soil acidity, soil salinity, waterlogging, wind and water erosion, nutrient deficiency, and decline in soil biota.

Managing salinisation of the land resources involves managing all these impacts. Soil salinisation is probably the most visible of the various forms of soil degradation.

The indicators of the process of land salinisation develop immediately following the land use change and progress through:

1. development of an aquifer shown by the elevation of the water level (hydraulic head) in an existing deep and generally saline aquifer, or the creation of a new aquifer;
2. an increase in the mass of salt discharged from the catchment measured as an increasing output/input ratio (O/I) for salt in streamflow ;
3. the presence of areas of saline seepage (groundwater discharge) and saline soil; and
4. poor growth and death of vegetation due to both excess water and increasing salt concentration in the soil.

Unfortunately, there may be 15 to 50 years between stage 1 and the impact of salinisation on production at stage 4. Application of control measures do not need to wait till stage 3 and 4 appear.

The desire to control the development of areas of saline soils reached a critical state in the 1980's with the emergence of community and catchment land care groups. Despite the actions taken over the ensuing 20 years, the current level of saline groundwater discharge and the continuing spread of salinised land remain as major concerns for farmers and water resource managers. The extent of saline land is shown in Table 1 including the prediction of the potential area at hydrological equilibrium.

Table 1: Estimate of the existing and potential area of salinised land in Australia

State	Saline Land (1996) ha	Saline Land (1998/2000) ha	Potential Area ha
Western Australia	1,804,000	4,363,000	8,800,000
New South Wales	120,000	181,000	1,300,000
Victoria	120,000	670,000	3,110,000
South Australia	402,000	390,000	600,000
Queensland	10,000	not assessed	3,100,000
Tasmania/Nth.Territory	18,000	54,000	90,000
TOTAL	2,474,000	5,658,000	17,000,000

Source: Australian Dryland Salinity Assessment, National Land and Water Resources Audit, 2000

The trend of increasing salinity in rivers is a significant and direct consequence of the continuing salinisation process occurring in both dryland and irrigated agricultural systems. The major examples are seen in the declining water quality trends in the Murray-Darling Basin and the loss of over 50% of the divertible surface water resources in the south-west of Australia. The increase in stream salinity for a selection of catchments is given in Table 2.

Salinisation has its causes within the whole landscape consequently the focus for management needs to be at the catchment scale. Despite a recognition since the early 1980's that managing salinisation required an integrated catchment management (ICM) approach, there has been almost exclusive focus on trees as the solution to the problem. For at least 20 years there has been a persistent message giving to land managers, landcare groups, politicians, the community and funding bodies by well intentioned individuals, groups and national organisations that "trees are the solution to the salinity problem". The large investment in planting trees, mostly to stop groundwater discharge in or adjacent to saline areas, has had minimal effect for basic technological reasons. Where plantings have survived, the impact has been simply to hide the unacceptable appearance of saline areas in valleys and seepage zones. Few land managers have claimed success with tree planting programmes in dealing with the salinity problem.

Table 2: Increase in stream salinity for non-irrigated catchment attributed to dryland salinisation within the catchments.

River Catchment	Annual Salinity Increase mg/L/year	Mean Stream Salinity ha
Lachlan River (Forbes) (NSW)	3	250
Collie River - (Wellington Dam) (WA)	11	730
Billabong Creek (Walbundrie) (NSW)	36	780
Denmark River (WA)	25	890
Avoca River (Vic)	84	1740
Blackwood River (Bridgetown) (WA)	52	2192
Williams River (WA)	95	2425
Hotham River WA)	89	3711

Period for increase estimate >20 years Mean is for at least 5 years of recent record

This paper aims to show that salinisation control requires recognition of the range of factors operating at the catchment scale which need to be managed. The salinisation process involves a set of complex interactions requiring the integration of all components of a pragmatic and economic management system at the catchment scale to control the movement of excess water and salt.

The salinisation process has its impact on agricultural production, stream water quality and its use, the natural ecosystems of streams and landscapes, public infrastructure (roads, bridges, urban amenities), and private and community buildings in rural urban areas and on farms. The management of the problem has both potential on-farm and off-farm benefits which need to be included in any cost-benefit analysis of management options. These analyses need to include a suite of factors in addition to the value of the land and the restored agriculture production.

BASIC REQUIREMENTS OF SALINISATION

There are 3 basic requirements for salinisation of soil and streamflow to occur:

1. **a storage of salt in the soil.** This mass of salt has a range of 50 to 5000 tonne/ha for a rainfall of 1400 to 320 mm respectively.
2. **a supply of water** to mobilise the salt. The leakage to groundwater recharge beneath agricultural crops and pastures ranges from 4 to 10% of rainfall.
3. **a mechanism by which the salt is re-distributed** to locations in the landscape, including rivers, where it can cause damage. The hydrogeology of the regolith provides the structures for transmission of water from recharge area to discharge area, including the presences of geological structures which modify the direction of flow.

Rehabilitation necessitates that only one of these 3 requirements be eliminated, though where management is able to only partially control one requirement, then achievement of the remaining control must be found within another one of the requirements. The removal of the stored salt would take 100's to 1000's of years even at the current enhanced rates. There is no practical reality in removing the store of salt. Rather there is significance in avoiding the creation of conditions which could mobilise known concentrations of salt in the regolith. Of the other 2 requirements, the logical approach for long-term control is to cut off the supply of water (preventing excess groundwater recharge) since this would manage the cause of the problem. The recharge control focuses on the appropriate manipulation of vegetation type, its distribution and rooting depth. Since the hydrogeology of a catchment identifies the mechanism for water to move in the groundwater system, tapping into the hydrogeological structures, for example, with artificial drainage, aims to intercept the process of salt redistribution. Both of these approaches are discussed in more detail in this paper. Rehabilitation could be expected to include the application of a variety of both biological and engineering options within a social and economic framework.

HISTORIC MANAGEMENT SCENARIOS

The classic approaches using vegetation have included:

- doing nothing! This has variations since farm management practices are not static with specific changes determined normally by factors other than salinity control (eg. market forces)
- controlling excess recharge using perennial vegetation systems. The recommendations have many variations including planting trees on a % of the catchment, developing agroforestry systems, inclusion of perennial pasture plants in crop rotation systems, placing strips or blocks of trees upslope of areas of saline discharge to intercept the groundwater flow, and planting trees in high recharge areas.
- using "best management practice" (BMP) for agricultural activities. This includes the vegetative control of excess recharge especially applying agroforestry systems such as alley farming, and whole farm water management systems.
- controlling seepage in discharge areas using shallow and deep drains to remove excess surface and near surface water. Planting of salt tolerant trees and use of salty tolerant pastures for grazing has been applied in saline land across southern Australia.

Revegetation with trees and perennial plants

Seeking recharge control

Biological methods have been the primary focus of management strategies since the 1960's. Although few perennial plants have been used, there has been reduction in recharge measured for perennial pastures, specifically lucerne, and also for tree plantations and other woody vegetation (eg. oil mallee). Unfortunately there have been many modelling studies of perennial vegetation distribution in which the calculations assume that trees have unlimited access to water in aquifers in both space and time. This has led to proposals for using bands or strips of trees in an agroforestry system across the landscape to act as biological drains intercepting groundwater flow toward discharge areas. Few studies have been rigorous enough to determine how much of the observed fall in the groundwater level is due to actual withdrawal by vegetation of water from the aquifer, withdrawal from within the capillary zone above, and/or what is the result of natural drainage when recharge has been eliminated. Basically, trees and other woody perennials reduce recharge only where they are planted and to a distance of approximately 10 m beyond the edge of the tree belt or plantation.

The objective of establishing recharge control by catchment scale revegetation techniques is sound in principle since it seeks to manage the cause of the salinity problem and recognises that salinisation is basically a groundwater problem. The difficulty lies in applying the principle and in the capability of economically viable agricultural vegetation systems to mimic the hydrology of the native vegetation.

There have been advocates who propose that putting trees back onto a proportion (from 10% to 30%) of the cleared land in a catchment is sufficient to control the excess recharge. This concept was first put forward in 1976 but one of the essential requirements, the phreatophytic capability of the trees, has been assumed but never demonstrated for *Eucalyptus sp.* in general. The known exception is the river red gum (*E. camaldulensis)*, and then only where the groundwater salinity is not excessive. There are good examples of catchments in which 30% (Upper Kent Catchment, WA) and greater (75% for Bingham River Catchment, WA) of the area retains remnant vegetation but this has not prevented salinisation of soils and water resources. The excess recharge in the area of agricultural activity is not accessible to trees located elsewhere in the catchment.

Using the approach of planting trees in the areas of high recharge under agriculture has been attractive. However, an example of the inadequacy of this simple approach is shown in Figure 1 for a 100 ha catchment with 10 ha of saline land within which an estimated 2,400 m^3/year (240 mm/year) is being discharged from the aquifer. If the high recharge area of 10 ha (10% of the catchment) has excess recharge of 120 mm/year, re-forestation of the area would eliminate this 1,200 m^3 of water otherwise received by the aquifer preventing its flow to the discharge area. If the remainder of the catchment (80 ha) has an average excess recharge of only 15 mm/year, this is equivalent to adding 1,200 m^3 of water to the aquifer which will flow to the saline discharge area. Consequently, the 10 ha of re-forestation will only manage half of the water causing the area of saline discharge.

Unit	Area	Groundwater
A	10ha	Discharge (240mm) with permanent waterlogging = 2,400 m^3 water
B	10ha	High Recharge (120mm) Total volume of water = 1,200 m^3
C	80ha	Seasonal recharge (leakage) below agriculture (15mm). Vol = 1,200 m^3
Discharge [2400] balanced by Recharge {1200+1200}		

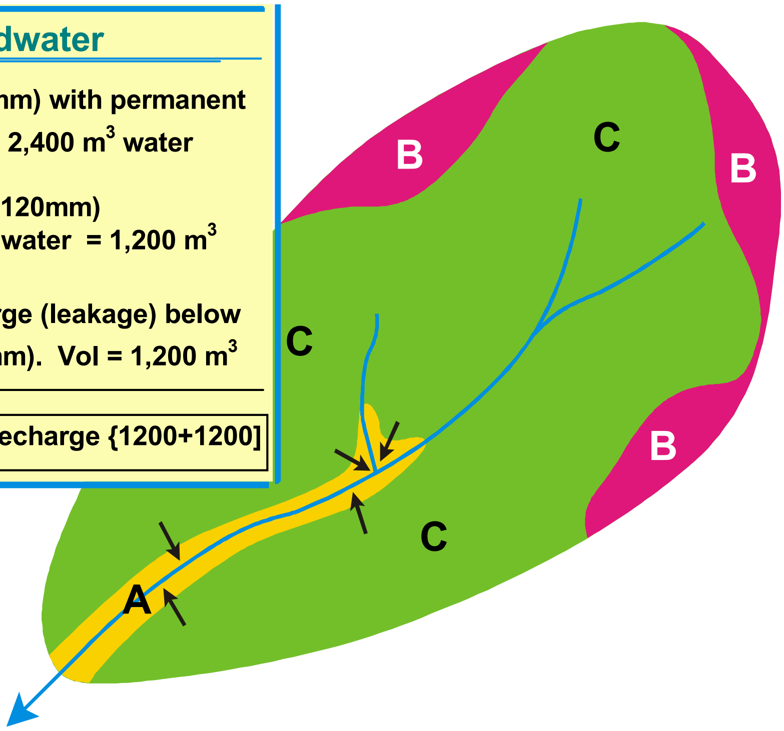

Figure 1 Assessing the implications of re-vegetation of areas of different recharge amount.

There has been a persistent message given to land managers by well intentioned individuals, groups and national organisations that “trees are the solution to the salinity problem”. Consequently, there has been a large investment in planting trees usually within the saline and adjacent areas for the purpose of using the excess water where it would otherwise discharge at the soil surface. Where these plantings have survived, the impact has been simply to hide the unacceptable appearance of saline areas in valleys and seepage zones. Few land managers have claimed success with tree planting programmes in dealing with the salinity problem, at best, finding some control in the area and/or rate of expansion of saline areas, or achieving an aesthetic benefit.

Evaluation of success with recharge control

The scientific examination of revegetation strategies over the last decade has concluded that the full management of excess recharge at the catchment scale could only be guaranteed through replacement of 70 to 90% of the original type of vegetation to the landscape. This is obviously not a socially or economically acceptable proposition.

Basically, the established agricultural systems all “leak” and, therefore, only a partial control of excess recharge could be expected for the current, economically-acceptable, agricultural vegetation strategies. The anticipation in the 1970’s of managing salinisation solely through biological control of excess recharge has not been realised, requiring more recognition that complementary control measures will be needed to achieve even the cessation of the continuing expansion of saline areas. While there is excess leakage of water from the root zone at the catchment scale, even using “best management practice”, water will flow with minimum loss to discharge at the soil surface in the natural drainage lines of the catchment (often flat valleys) and upslope of hydrogeological barriers. The result is waterlogging and salt accumulation, with some of the discharge becoming baseflow to a stream.

Response time for recharge control

Even if adequate vegetation was established to reduce the recharge to aquifers to pre-clearing quantities, there would be a lag time between getting the vegetation in place and the cessation of seepage to saline areas. Re-afforestation would require 4 to 7 years before full transpiration potential was achieved. The subsequent decay curve for natural drainage of accumulated groundwater is exponential, and includes a length factor for the distance between recharge and discharge areas. It is known that salinisation takes of order 15 to 50 years to develop after clearing. This time period should be seen as the most optimistic estimate of the time for the impact of an instantaneous, whole of catchment re-forestation system to show an effect on seepage. A natural drainage analysis would show a much longer time for the exponential decrease in seepage to an acceptable rate.

Neglected issues in salinity management

A number of issues have been neglected in the pursuit of the biological solution.

1. **Development of engineering solutions involving artificial drainage systems.**

Managing the mechanism which mobilises salt in catchments is the second basic requirement for the control of salinisation. For over 40 years there has been resistance to exploring opportunities to use artificial drainage because of the cost and the problem of effluent disposal. If these are the two principal factors delaying progress toward adding drainage to the options for controlling salinisation, then these factors require a concerted effort in research and development, in innovative solutions and a redefined focus to achieve effective results. Limitations in the understanding of the hydrogeology in agricultural landscapes, particularly the sedimentary stratigraphy often found in salinised broad flat valleys and the presence of transmissive aquifers in non-sedimentary systems, has constrained the possible application of drainage methods in reducing the hydraulic head in saline land.

Removing the hydraulic head causing groundwater discharge (to >2 m below soil surface) is acknowledged as managing the effect and not the cause, but has implications for the short-term need to prevent further spread of salinisation. However, in the situation where the available management of the cause is either ineffective or can only be identified as a partial long-term solution, managing the groundwater discharge will be essential in both the short and long-term.

2. **Reducing the consequences of all forms of soil degradation at the catchment scale that limit root growth and plant production.**

Determining the area of land affected by any one of the sub-surface soil degradation problems has not received anywhere near the effort given to determining the area of visual saline land. These soil degradation issues include soil compaction, soil structural decline, soil acidity, waterlogging, erosion, nutrient deficiency, and decline in soil biota. By virtue of their individual or combined impact on rooting depth alone, these issues affect water use and plant production and must be acknowledged as contributing to excess recharge, and hence the salinisation process. Most farmers have recognised wind velocity as a significant problem which affects plant growth and crop yield.

Waterlogging is extensive in duplex soils. It is not confined to flat valley sites but known to occur in all landscape positions. The hydrograph data for waterlogged soils shows that the direction for flow of the major volume of accumulated water is vertically downward. For broad-acre agriculture waterlogging may be the principal mechanism for excess recharge. With soil compaction, soil structure decline and soil acidity, root depth would be restricted, contributing to a reduced availability of profile storage capacity for infiltrating water, and excess recharge.

Managing these soil degradation problems must be recognised as having high significance in managing excess groundwater recharge at the whole catchment scale. Application of what is already known in the management of these problems must be seen as having a wider implication than simply managing the individual degradation problem.

3. **Economic capacity and equity factors to support landcare activities.**

Currently, most farmers do not have the economic capacity at the current commodity prices to undertake landcare activities at anywhere near the scale required. Support may include tax incentives, local government rate relief for land declared non-productive, realistic subsidies for landcare works, and negotiation of trade agreements which achieve acceptable commodity prices. Rehabilitation of saline land to full production needs to achieve acceptable cost/benefit ratio.

There is more recognition required of the equity issues which are involved with landcare. All the factors which help determine the private and public benefits which any landcare activity promotes require both identification and quantification. For example, there is a significant public benefit in the recharge minimisation by land managers high in the catchment in addition to the private benefit of improved production. Even though a farmer may never have salinised land, his actions to assist the management of excess recharge in the catchment deserve a financial subsidy for their public benefit.

Assistance in making provision for landcare activities may be enhanced by the incentive of carbon credits which could be specifically allocated to farm managers in their application of agro-forestry systems such as alley farming, oil mallee production etc.

4. **Community responsibility to assist resource management**

The development of agriculture by extensive clearing of land in the last 50+ years was promoted by government because of the benefits to be received by the whole community in economic, social and political terms. The salinity problem is a legacy of the development of the agricultural economy and should be accepted as the responsibility of the whole community. The salinisation of land and water resources has its source at the catchment scale. The land manager who owns the saline land rarely has the management control over the remainder of the catchment in which his property exists. On behalf of the community, government has a responsibility to provide the economic, social and political support needed to manage salinisation as was provided in loans and tax incentives for the original land development. In some management activities, government could be the appropriate provider of the necessary infra-structure. Benefits to the whole community, such as improved water quality in rivers and streams, have to be included in cost:benefit analyses.

5. **Need to re-invent agriculture within the Australian landscape, soils and climate.**

Successful management of salinisation will include the urgent need to re-invent agricultural landscapes to suit Australian landscapes, soils and climate. Included in the suite of practices will need to be the strategic use and sound management of productive vegetation on non-saline and saline soils. Permanent woody vegetation will be included for its ability to limit recharge where it is located, to provide shelter for stock and downwind vegetation, and for aesthetic value and restoration of habitat for fauna which control pests. New agricultural practices, and new crops and pastures, need to be developed and applied to eliminate causes of land degradation problems.

6. **Market requirements based on accreditation to environmental standards.**

The future acceptability of our farm products on world markets will be gauged by audits measured against environment management standards including the judgement of the adverse impacts, such as salinity, and sustainability of agricultural management practices. Environmental management systems which will require compliance with standards such as ISO14001 are being developed to provide guidance to land managers in modifying practices.

COMPONENTS OF INTEGRATED SALINITY MANAGEMENT

Integrated salinity management is basically the application of integrated catchment management to the problem of salinisation. This is not a new concept, but rather the recognition that the general application of ICM principles has not been achieved in the last 25 years. There is no single, simple management practice or methodology which will prevent or reduce the impact of the salinisation process in all situations which is acceptable economically, socially and scientifically.

The management of salinisation will involve the application of a diversity of management practices for which the sum total of the reduced recharge will eventually constrain groundwater discharge (seepage) to a manageable quantity of water and salt in acceptable locations in the landscape. The methods will include both biological and engineering components of water management applied strategically in both space and time within the various landscape units, including the saline areas, and based on their integration to achieve the total catchment response. Effective management is not a simple short-term exercise.

The pre-European ecosystem had an element of salinisation within it as seen in the natural salt lakes in lower rainfall woodland or heath regions and the small, often brackish, discharge areas in high rainfall forested regions. Studies in uncleared catchments in locations of 500 mm and higher rainfall have shown that salt content was at equilibrium (input equals output) prior to agricultural development. In the present agricultural system the achievable task will establish realistically how to manage a landscape which contains an acceptable proportion of salinisation of land and water resources rather than having an unrealistic expectation of managing to eliminate all salinisation. This has been identified as achieving conditional sustainability in farming systems.

The primary components required for integrated salinity management are:

1. Control of all the soil and land degradation problems which affect root activity;
2. Manage surface runoff to prevent inundation and waterlogging of areas prone to salinisation.
3. Integrate appropriate engineering and biological management methods for the reduction of excess recharge and groundwater discharge in agricultural landscapes; and

4. Re-invent agricultural practices and production systems to fit within the soil, plant and climatic conditions relevant to Australian landscapes.

Components of an Integrated Salinity Management Approach

1. Whole Catchment Approach

The focus for management must be at the whole catchment scale achieving the desired effect by the sum of the correction to contributing parts of the recharge system across the catchment. Since at least 70% of a catchment will be productive land there is a large proportion of any catchment where the type and distribution of agriculturally productive vegetation systems needs to be selected to minimise the leakage of water passed the root zone.

The distribution of vegetation using an agro-forestry approach (eg alley farming, parkland) at the catchment scale provides additional benefits in shelter for soil, crops, pastures stock and fauna (relevant to pest control) which enhances both production and water use. Agro-forestry and engineering works such as banks and drains can be combined to minimise cost and provide a complementary effect on surface and sub-surface water management.

Community co-operation is essential for effective control since the source of saline discharge is the whole catchment. Economic incentives are just as essential for those managing parts of the catchment where salinisation is not a problem as for those managing areas where production is affected by saline land. The farm planning process requires co-operation between adjacent land owners especially with surface water management, nature conservation corridors and wind erosion control.

2. Adoption of productive agricultural ecosystems

An understanding of the ecosystem concept is required to provide both productive crops and pastures and effective management of the landscape hydrology (the eco-hydrological approach). These agricultural systems are the economic engine which allows the rural industry to exist and survive. Nevertheless, the necessary changes must be environmentally, socially and economically sustainable, and include the adoption of practices which achieve rehabilitation and long-term control of the soil degradation issues referred to earlier in this paper.

Some of the practices which would be expected to be adopted in agricultural ecosystems include:

- the use of a perennial in rotation/phase cropping;
- adoption of an agro-forestry system, such as alley farming, nature conservation areas, tree belts, and associated eco-systems;
- establishing shelter from wind for crops and pastures to limit stress on plants and encourage greater water use;
- adoption of cultivation practices which enhance good soil structure and encourage soil biota;
- monitoring soil nutritional capacity for suitability to cropping or pasture programme;
- management of vegetation and soil to prevent degradation.

A much wider selection of options will need to be developed to provide the appropriate eco-system for the range of soil-landscape units used for even broad-acre agriculture.

3. Inclusion of engineering practices for water management

Surface water management to prevent erosion, flooding and waterlogging is an essential component of farm planning. There must be recognition by managers that surface water runoff is an asset of high quality water capable of innovative use. The minimum requirement is to prevent runoff causing waterlogging in the lower, often quite flat and salinised parts of the landscape. This waterlogging provides a connection between shallow groundwater and the soil surface, and also diminishes good plant growth in the valley areas where salinity risk is high. The control of this cause of valley waterlogging has often allowed cropping activities to proceed using the less salt-sensitive species (eg barley).

If runoff water is not collected and stored in dams, the discharge of excess surface runoff can be safely routed to a stream using a grassed waterway. Although there are factors such as distance between drains which limit their effectiveness, management of perched water associated with waterlogging in the landscape may benefit from drains. There is an increasing awareness of the complementary aspects of banks for surface water control, drains for perched water drainage and strips of trees in agroforestry systems.

Saline soils are almost always supplied by saline water which comes from an aquifer at depth driven by a hydraulic head (piezometric water level) close to or above the soil surface. The aquifer might be classified by the water supply industry as of medium or low yield and low transmissivity. However, the hydrogeological conditions may be quite adequate to convey the recharge from the agricultural soils to lower topographic positions where convergence produces a vertical flow path forcing water to the soil surface. Rising water tables are observed in aquifers across extensive areas of agricultural landscapes because the horizontal transmission of water is less than the vertical input of water via recharge. (Hence the "leaking bath-tub" concept for the dryland salinisation process.)

The type and design of appropriate groundwater drainage systems to control saline discharge can only be determined when the details are known of the hydrogeology of the whole depth of the soil profile (termed the regolith) in the landscape. In south-west Australia studies have concluded that the dominant source of salt for saline discharge is in flow from the deeper aquifers, either in sedimentary stratigraphy of broad saline valleys or in the saprolite gritty layer immediately above, and derived from, the basement granitic rock. The dominant source of water has often been found to be in the near surface perched aquifers, causing confusion in proposing drainage needs for salinity control.

Artificial drainage to control saline discharge requires techniques which will lower the hydraulic head of the saline aquifer >2 m below the soil surface. Studies have shown that, for "de-watered" profiles, natural rainfall is adequate to leach out the accumulated salt from the surface soils in less than 10 years provided any near-surface compacted or dispersed layer is kept fractured by cultivation.

Historically, the potential use of artificial drainage (ditches, pumping bores, siphons etc. to control saline groundwater discharge has been constrained by issues such as:

- cost of installation, operation and maintenance;
- low hydraulic conductivity in the near-surface soil profile - absence of conductive aquifers;
- loss of land to open drains;
- blockage by iron precipitates and bacteria;
- limitations in understanding by contractors and land managers of hydrogeology; and
- environmentally acceptable disposal of drainage effluent.

Options for disposal of effluent include:

- discharge to creeks and rivers (currently not permissible in WA by government regulation);
- channelling to evaporation basins located within the saline lands, or in adjacent land;
- saline water conveyed to the ocean via a canal or pipe;
- use of saline water for industrial process purposes involving transport by canal or pipe.

A novel proposal has been put forward to convey drainage effluent from agricultural areas in several river catchments in south-west WA (eg Upper Blackwood River catchment) by gravity canal to the ocean. By appropriate routing of the canal from the Upper Blackwood saline effluent could be received from other catchments en route, such as the East and West Branches of the Collie River.

The transportation by pipe and canal of saline water to the ocean was proposed and evaluated in the 1980's for the disposal of effluent generated by artificial drainage and saline tributary stream flow in the lower reaches of the River Murray (Murray-Darling Drainage Basin). It was not considered cost effective amongst a range of associated issues, with evaporation basins selected as the preferred disposal system. It is relevant to identify that the River Murray and its tributaries, like most other rivers in the world, show a progressive increase in water salinity as they flow from high rainfall/runoff areas in their upper reaches through lower rainfall areas to the ocean. Hydrogeologically, the lower reaches of the River Murray are the natural drainage canal for the regional groundwater systems of the Murray Basin.

By contrast, in the south-west of Australia, many rivers have their upper reaches in the inland lower rainfall areas of the wheatbelt. The river salinity level is highest in these regions feed by saline aquifers. As the river passes through the higher rainfall/runoff zones in the western or southern parts of catchments, the salinity decreases as the flow volume increases closer to the ocean. For many of these rivers putting the enhanced saline flows from the up-stream regions into a canal for transfer to the ocean would substantially reduce the major source of salt for the river and therefore lowering the salinity in the down-stream flow. The quality of water in a number of river systems (eg Collie, Blackwood, Kalgan, Kent, Denmark) could benefit from diversion of upstream saline inflows sourced in the groundwater discharge of the saline areas.

Land managers in many areas of south-west Australia have demonstrated clearly that, despite the difficulties of complying with the statutory requirements to obtain a licence to dispose of effluent, they are willing to consider drainage as a management option for their saline land. The disposal of effluent is the major practical and environmental issue for achieving drainage of saline land.

4. Economic and Social Components of Sustainable Agriculture

Sustainable farming includes the economic capacity to be able to manage the land resource to ensure that it is not degraded. The agricultural industry cannot be expected to move into the extensive landcare and integrated salinity management practices required without the associated financial factors being favourable. Even willingness to undertake appropriate landcare activities is not enough if the economic climate does not provide the financial resources to take the necessary management steps. Social factors are primarily related to the co-operation and collaboration required to achieve whole catchment concepts. Integrated catchment management includes the acceptance by the whole community (city and rural) that they have a basic dependence on rural production and a responsibility for the impact this production has on the environment. Without these aspects being properly addressed there will be little movement forward by simply identifying the appropriate technological solutions.

A recent economic study of a catchment scale drainage and effluent disposal to the ocean for the Upper Blackwood Catchment has indicated that the principle factor in making integrated management schemes cost effective (say BCR of ≥1.5) is in the rehabilitation of the area of saline discharge back to full agricultural production within 5 to 7 years. An appropriately designed drainage system for hydraulic head reduction in the saline discharge areas, including catchment scale surface water control, has the potential in the short-term necessary to achieve this result. Social factors need to be supported to achieve the long-term management of excess recharge using part of the economic benefit.

CONCLUSIONS:

The major concern of the farming community regarding salinisation of farmland is that the area of useful land being salinised continues to increase. The expectations of control and rehabilitation have not been realised as we move into the 21st century.

Two significant predictions have been publicised since the beginning of 1999, and identified as having relevance nationally, viz.:

1. Without appropriate management, there will be a 3-fold increase in the area of salinised soils in dryland agriculture regions before equilibrium conditions establish sometime in the latter half of the 21st century.
2. To achieve effective control of excess recharge, extensive areas of arable land, estimated to be from 70 to 90% in any catchment, will need to be revegetated with deep-rooted (>2 m) plants (particularly woody plants) of economic value. This is supported by the scientific evidence that trees will only prevent recharge where they are located and do not have the assumed status of "biological drains". This prediction should not be surprising given the observation that, despite intense promotion of tree planting programs over the last 20 years, the anticipated control of saline discharge has not achieved almost universally.

Neither of these predictions are acceptable socially, economically or politically. The response within the rural community has been one of new uncertainty, and even pessimism, as land managers seek clarification from those who have made these predictions and some who have proposed that farmers need to "learn to live with the problem".

The approach to salinity management for more than 2 decades has been focussed on using vegetation types and distribution patterns to eliminate the supply of water (drainage below the root zone of plants) which causes the mobilisation of salt in catchments. As this approach has been found, at best, to be only partially effective in managing excess recharge within the current agricultural systems, additional and alternative management activities are required. As stated in the introduction, although rehabilitation of salinisation necessitates that only one of the 3 basic requirements needs to be eliminated, where management is able to only partially control one requirement, then achievement of the remaining control must be found within another one of the requirements. Consequently, while agricultural practices and vegetation distribution systems are still being developed to achieve better recharge control, there is need to be creative and constructive in enhancing the discharge of the excess water and salt before it accumulates at the soil surface. At best, salt tolerant pastures have been found to vegetate saline land, but not prevent salinisation.

Managing the mechanism which mobilises salt in catchments is the second basic requirement for the control of salinisation. For over 40 years there has been resistance to exploring opportunities to use artificial drainage because of the cost and the problem of effluent disposal. If these are the two principal factors delaying progress toward adding drainage to the options for controlling salinisation, then these factors require a concerted effort in research, innovative thinking and a redefined focus to achieve effective results.

A significant component of achieving integrated recharge control, and reducing the area of salinisation, will be to eliminate at the catchment scale the consequences of all forms of soil degradation that limit root growth, plant production and water use. These degradation issues (soil compaction, soil structural decline, soil acidity, soil salinity, waterlogging, wind and water erosion, nutrient deficiency, and decline in soil biota) must be acknowledged for their impact on the problem of excess recharge. Application of what is already known in the management of these problems must be seen as having a wider implication than simply managing the individual degradation problem.

A holistic ecosystem approach to rehabilitation of landscapes, including saline areas and sub-surface soil degradation, and the assessment of applicability of a variety of biological and engineering management options, needs to be established within a social, economic and whole-catchment framework. This is not a new concept. Integrated catchment management is not new, but its principles have been largely ignored in attempts at application. The reasons for the failure of ICM to achieve its objective need to be established and managed. Salinisation has to be acknowledged as the result of a complex set of interactions within a catchment scale ecosystem. This factor needs to be recognised by the many well meaning groups and individuals offering numerous single factor solutions. A much more holistic approach is necessary for a problem in which partial recharge control and substantial rehabilitation of degraded land are achievable objectives.

The fact that many land managers have been installing drains and pumping bores of various types is an indication that they are determined to work at potential management options despite discouragement due to cost estimates, government regulations, and previous lack of success with tree planting. In many cases, driven by sheer frustration, managers have acted outside the law which, in WA, requires a licence to discharge drainage effluent into any water course. Given the response time of decades for the impact of biological techniques on recharge to effect discharge control, applying short-term engineering options to enhance groundwater discharge is essential to contain the current increasing area of land becoming salinised. Innovative solutions are needed to assist developing engineering options particularly in the disposal of drainage effluent water. In the Blackwood River Catchment (WA) and the Kent River Catchment effluent disposal via a canal to the ocean is technically feasible.

The changes in farming systems necessary to achieve acceptable recharge control strategies requires the re-invention of the agricultural system to make it suitable to Australian landscapes, soils and climate. The definition of the ecosystem behaviour of the natural Australian landscapes existing prior to agricultural development provides the biophysical and ecohydrological limits to which landscapes can be manipulated. These data form the technological basis to determine what is possible or feasible among the plethora of ideas and strategies for control of the salinisation process.

The development of agriculture by extensive clearing of land in the last 50 years was promoted by government because of the benefits to be received by the whole community in economic, social and political terms. The salinity problem is a legacy of the development of the agricultural economy and should be accepted as the responsibility of the whole community. There is an increasing recognition of the equity aspects in achieving land management. The acceptance of the importance of conservation of natural diversity has seen requests for greater areas of farm land dedicated to native vegetation. However, the economic benefit to land managers is so limited (eg. these areas would be removed from grazing use) that they could argue for a scheme to re-purchase the land needed to establish conservation reserves. On behalf of the community, government has a responsibility to provide the economic, social and political support needed to manage salinisation.

An independent Working Group who reported to the Prime Minister's Science, Engineering and Innovation Council in 1998 stated that they believed "that the lack of capacity to innovate has been the greatest failing in the salinity issue. While there is more to be done scientifically, many of the existing ideas are still not being used as widely as they need to be." Integrated catchment management is an existing system which requires application of all its principles to achieve integrated salinity management. Management of salinisation will involve the application of a suite of biological and engineering options which, collectively, will achieve both a reduction in recharge across the range of landscape management units in a catchment and constrain groundwater discharge (seepage) to a manageable quantity of water in acceptable locations in the catchment. Whilst logic has compelled the substantial attempt at control by revegetation strategies over the last 20 years, practicality dictates that engineering solutions must be as thoroughly examined and field tested to complement the revegetation programs to achieve sustainability of Australia's land and water resources. In additional it will be critical that there is a greater acceptance of the financial support required from the community through government to overcome the existing economic constraints farmers experience in the application of appropriate land management practices.

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