SUSTAINABLE MANAGEMENT OF LAND DEGRADATION: THE EXAMPLE OF SECONDARY, DRYLAND SALINITY IN SOUTH-WESTERN AUSTRALIA

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INTRODUCTION

Worldwide, population growth is placing growing pressures on the land. Traditional, mostly sustainable farming systems developed in conjunction or integrated with native vegetation, are being or have been replaced by commercialised agriculture. Modern agriculture is often large-scale, mechanised, and reliant on agricultural chemicals and hybrid crops grown in monocultural systems. Land degradation — which has been defined as 'alterations to all aspects of the biophysical environment by human actions to the detriment of vegetation, soils, landforms, water, ecosystems and human well-being' (Conacher and Conacher, 2001, 364) — is one outcome. It has been described as Australia's number one environmental problem (Diamond, 2004).

The International Geographical Union's (IGU) Study Group on Erosion and Desertification in Regions of Mediterranean-type Climate initially focussed on land degradation *processes*, with a strong geomorphic emphasis (reflecting the background of most of the Study Group's members). However, it soon became apparent that research into land degradation needs to be more broadly based. This realisation is reflected in the chapter headings of Parts II and III of the main publication which arose from the work of the Study Group (Conacher and Sala, 1998). Part II's chapters identified the main problems of land degradation in the Mediterranean world, their historical origins, the causes of the problems and some of the broader ecological, social and implications. Part III then considered a range of solutions to the problems, including farming practices and, more broadly, economic, social, agency and policy changes required to enable such changes to be made.

The IGU's Commission on Land Degradation and Desertification (COMLAND) developed from the Study Group in 1996, but with its focus on the entire globe. The breadth of the work carried out by its members has continued. This, too, is reflected in the contents of a major publication of the Commission (Conacher, 2001). The five Parts of that book deal with: land degradation processes; the effects of land-use practices and land-use change; interactions between society and land degradation; the rehabilitation of degraded land, and government policies in relation to land degradation. More recently, at a meeting of COMLAND's Steering Committee in Iceland in 2003, it was agreed that there needs to be an even greater emphasis on management.

Accordingly, this paper considers some of the issues associated with managing land degradation. Discussions with numerous people in many places have made it clear that sustainable land management is highly complex. A sound understanding is required of what the precise objectives of land management are and what methods can be used to achieve those objectives. It is particularly important to develop an integrated approach: problems must not be tackled on a one by one basis, in isolation from one another. Questions of scale are also important: what are the most appropriate spatial units for implementing solutions? In turn this raises the question; who is or should be responsible for planning, for implementing the solutions on the ground, and for reviewing their effectiveness?

These issues are brought into focus by considering the land degradation problem of secondary soil and water salinisation in the Western Australian wheatbelt. The paper first briefly outlines the nature and causes of the problem and then considers two popular management solutions. The shortcomings of these solutions illustrate some of the complexities of sustainable land management.

The secondary salinity problem

Salinisation refers to the hyper-concentration in soils and water of naturally-occurring soluble salts, usually chlorides, sulfates and carbonates, and the accumulation of artificial nutrients associated with fertilisers and pesticides. In the former instance the causes of the salt concentrations are hydrological changes resulting from either irrigation or the replacement of natural vegetation with introduced crops and pastures (secondary salinisation). In contrast, primary salinity refers to areas or water bodies which were naturally saline, such as saline playas in more arid areas or coastal marshes (that is, not caused by human actions).

The salinity of water bodies illustrates some of the complexities associated with identifying and measuring land degradation. The extent or degree to which water salinity is a problem depends on the use to which the water is to be put. The World Health Organisation has a standard for human consumption of 500 mg l^{-1} total soluble salts (TSS), and a 'maximum permissible limit' of 1500 mg l^{-1}. However, water used to manufacture steel or paper needs to have a TSS content of less than 200 mg l^{-1}.

An important issue is that the salinity of flowing water varies considerably not only seasonally but also over short periods of time. After a long, dry period concentrations will be relatively high. During or shortly after a rainstorm event, flow increases and salt concentrations drop dramatically, within minutes. Assuming there is no further rain, salt concentrations then increase gradually as the discharge decreases (George and Conacher, 1993a). Averages, even flow-weighted averages, are not very meaningful; and data obtained from an 'at a point', single water sample are virtually worthless. Similar comments apply to other water-soluble pollutants.

The question of the extent to which salinity is a problem also involves the susceptibility of animals and plants to various salt concentrations. The tolerance of animals to salt concentrations depends on their age and the nature of the available feed. For example, adult sheep can tolerate salt concentrations of 13 000 mg l^{-1} in their drinking water(Craig, 1963), whereas if they are fed on green grass they can handle concentrations of up to 18 000 mg l^{-1} (Callinan and Webster, 1971). Younger animals are more susceptible than adults, as are ewes in milk compared with dry ewes.

The susceptibility of plants to salinity is also complex. One measure refers to the salinity of irrigation water (Callinan and Webster, 1971): but the effect then depends on the method used (flood, spray or drip irrigation), its duration and, crucially, how well the soil is drained. It also depends on the stage of the plant's growth, as its susceptibility to salinity is much greater when germinating than when it has reached maturity. A different measure is the salt concentration of a soil-water extract from the root zone of the plant (for example, 'approximate values, from saturated soil extracts, during the period of rapid plant growth and maturation, at which 50% yield reductions can be expected': Carter, 1975). The two measures are not directly comparable and the latter is more precise. It is also more difficult to obtain.

Salinity caused by dryland agriculture in Australia

In Australia, the first accounts of the development of dryland salinity problems came from Western Australia and Victoria late in the 19th century, not long after the natural woodland vegetation was cleared for agriculture by the European settlers. One hundred years later, more than 2.4 Mha of agricultural land in Australia had been rendered unproductive due to increased concentrations of soluble salts in the soils (Conacher and Conacher, 2000, Ch. 3). All States have areas of secondary, dryland soil salinity. Western Australia is the worst affected, with more than 1.8 Mha in 1996. This is predicted to increase to over 6 Mha ‘by equilibrium’ (that is, when groundwater tables have stopped rising): the equivalent national prediction exceeds 12 Mha. Increased salinity of water in streams, rivers, lakes, wetlands, wells and water supply dams is an associated, serious problem. In the southwest of Western Australia, all major rivers have their headwaters in the agricultural areas and are now unfit for human consumption, even though all were fresh before the development of agriculture.

Fundamentally, the problem in dryland (‘rainfed’) agricultural areas is caused by the replacement of indigenous vegetation with introduced crops and pastures. In Australia, the native vegetation is usually a woodland association. The plants have deep root systems which enable them to draw on subsoil moisture for the entire year, sometimes from considerable depths (>20 m). In contrast, the introduced agricultural species have shallow root systems and they grow only during spring and early summer. Thus less water is transpired by the agricultural plants than by the native vegetation, resulting in the accumulation of water in the soil.

There have been various studies into the extent of this imbalance, particularly in the south west of Western Australia. In general terms, in areas with mean annual rainfalls of around 300–400 mm, the amount of ‘excess’ water in the landscape after clearing is only of the order of 6–15 mm yr^{-1}, which infiltrates to groundwater. Because valley-floor gradients in the ancient landscape of the semi-arid, Western Australian wheatbelt are very gentle, and hydraulic conductivities of the deep, intensely weathered (kaolinised) ‘lateritic’ soil materials are very low (as little as 0.009 m day^{-1}), the rate at which the saline groundwaters drain from catchments is only 0.05–0.3 mm yr^{-1}. Thus, since clearing of the native vegetation, more water is entering the groundwater systems than is able to drain from them. As a result, groundwater tables in the Western Australian wheatbelt are rising at rates of between 0.02 and 0.3 m yr^{-1} in areas receiving less than 350 mm of rain a year, to 0.15–1.5 m yr^{-1} in areas with more than 500 mm of annual rainfall (George and Conacher, 1993b).

The saline groundwater (with salt concentrations up to three times that of seawater) accumulates to within the capillary fringe of the soil surface, water is evaporated and soluble salts are left behind, to concentrate in the soil and at the surface. Saline groundwater also emerges at the surface as saline seeps, which then contribute salts to adjacent streams. Mixing of the deeper, saline groundwaters with near-surface, relatively-fresh water in perched aquifers is common (Conacher and Conacher, 2000, Ch. 3).

Consequences include loss of soil structure and fertility, increased erosion by water and wind on the bare, salt-affected surfaces, waterlogging, reduced agricultural productivity, salinisation of streams, rivers and lakes, and severe degradation of natural habitats. Additionally, many farm houses and towns in Australia were built adjacent to (then) fresh streams and rivers. Unfortunately, these low-lying areas have been amongst the first to be affected by waterlogging and increased salinity. As a result, many farm houses and their adjacent building complexes have had to be abandoned, and some 80 rural towns in Australia are being affected by rising, saline groundwater tables or the development of perched water tables. Mortar and bricks fret and crumble, roads are pot-holed, railways buckle, power and telephone poles corrode, playing fields and home gardens become dust(mud)bowls, and the basements of hotels and other large buildings are filling with salty water.

The complexity of management solutions

Clearing of natural vegetation in areas potentially subject to secondary, dryland salinity could be prevented. Legislation to control clearing in most parts of Australia has been introduced, but its enforcement leaves much to be desired — largely for social, economic and political reasons. In most agriculturally-suitable areas, however, the land has already been cleared.

Revegetation

An apparently obvious solution to the problem is to replant landscapes with vegetation which will transpire as much or more water as that previously transpired by the native (cleared) vegetation. But the new plants must also provide an income for the farmer. Empirical evidence indicates that some 80% of catchments upslope from salt-affected areas would need to be replanted. (Early estimates, derived from mathematical modelling, were that only 10% would be needed. This was soon recognised as being totally inadequate: many salt-affected areas already had much more than 10% of their catchments still under native vegetation.)

Extensive tree planting schemes are being undertaken on previously-agricultural land, usually with the introduced Tasmanian Blue Gum (*Eucalyptus globulus*). The plantations have been introduced primarily to supply the resource for an export woodchip industry. Much of the planting is in relatively high rainfall areas which are not severely salt-affected, and the shallow-rooted (albeit high-transpiring) trees are having only minor effects on regional groundwater aquifers. Relatively small saline seeps can and do respond to management, but the extensive, salinised valley floors which characterise much of the wheatbelt are a much more difficult proposition. With the partial exception of the Denmark river catchment (Lothian and Conacher, in press), the plantation schemes are unlikely to solve the salinity problem. Moreover, they will not return the land to its previous agricultural productivity.

Tonts *et al*. (2001) identified a range of socio-economic as well as biophysical environmental consequences of the extensive tree-planting schemes. They found that employment and economic benefits were largely restricted to larger urban centres. Elsewhere, the plantation industry is not replacing the economic activity and employment previously generated by agriculture. Moreover, the plantation industry appeared to be accelerating the process of rural population decline in some areas, with many adverse social and economic implications. The industry was also reported to be: impacting adversely on local roads; increasing land values; affecting irrigation entitlements to groundwater, and causing concern to adjacent farmers through the aerial spraying of pesticides to control insects. There was a view that local communities are 'dying', and a commonly expressed criticism was that the farm plantation industry 'is dominated by "faceless corporations" with little or no commitment to the rural areas in which they operate'. It seems that none of the social and economic implications was investigated before the large-scale tree planting program was introduced.

In addition to the foregoing socio-economic consequences, actual and potential biophysical problems identified by Tonts *et al*. (2001) included:

1. destruction of remnant vegetation and wildlife habitats;
2. destruction of conservation works on farms turned over to plantations;
3. impact of chemical sprays on water courses;
4. increased fire risk (exacerbated by reduced fire-fighting personnel);
5. hydrological and environmental implications of the draw-down of groundwater tables;
6. the lack of biodiversity associated with single species plantations;
7. a lack of weed control;
8. soil erosion following harvest;
9. excessive shading of neighbouring fields, and

10. water and nutrient depletion from adjacent soils.

Deep drainage

Deep (2+ m) drainage to lower groundwater tables is another alternative which is currently being implemented by many farmers, albeit without official sanction (Deep Drainage Taskforce, 2000). As with tree plantations a number of problems is associated with this solution.

First, it is technically not a feasible proposition in many locations, due to the low gradients of the valleys and low hydraulic conductivities of the ubiquitous, deeply- and intensely-weathered, kaolinised, soil materials. Drainage (or pumping) of groundwater from locations underlain by sediments and other more porous materials will be more successful.

Second, it is costly, especially if the farmer also raises sheep (as many wheatbelt farmers do). Drains in grazing areas need to be installed with slotted pipes and backfilled with gravel and sand, to avoid sheep losses. Maintenance becomes more complex.

Third, deep drainage does not deal with numerous other problems of land degradation in the region. These problems include soil acidification, accelerated erosion by wind and water, loss of soil structure, reduced soil fertility, the introduction and spread of environmental and agricultural weeds, and loss of biodiversity. Some are more serious than the widely publicised salinity problem, depending on the criteria used to assess the severity and importance of land degradation (area affected; number of people affected; social consequences; economic costs, and ecological implications).

Fourth, as with the tree plantations discussed above, solutions to one problem may generate new ones. An obvious difficulty concerns the disposal of the highly saline (and often acidic, with pH <3 in some places) groundwaters. Some farmers simply terminate their drains uncaringly at the farm boundary, depositing the drainage water on to their neighbour's property. Most drain the water into nearby stream channels. These in turn sometimes lead to ecologically-valuable wetlands, with disastrous consequences. Some drain groundwater into nearby salt lakes, with the possible effect of recharging saline, regional groundwater aquifers. This, of course, counters the objective of the drainage exercise. And farms located in public water supply catchments have obvious difficulties.

And fifth, it follows that regional-scale, social, economic and technical implications need to be assessed.

Non-adoption of preventative or remedial measures

There are many other possible management solutions (some are presented in GRDC, 2001), of which only two have been discussed here. Other measures include valley-side interceptor banks or drains, groundwater pumping or siphoning, raised beds, cropping with deep-rooted alfalfa, relocating towns and infrastructure, and replacing salinised dams. Some are being implemented as a matter of necessity.

A major problem has been and is the lack of political will to take effective preventative or remedial actions. In Western Australia, reputable scientific, government researchers had demonstrated the nature and causes of the secondary salinity problem, and warned against further clearing for agriculture, in the 1920s and again in the 1950s. The warnings were not heeded. Large-scale clearing of native vegetation continues in Queensland. Decades of boards, committees and agreements in the Murray-Darling Basin (which extends over parts of Queensland, New South Wales, Victoria, South Australia and the Australian Capital Territory: Murray-Darling Basin Commission, 1993; Breckwoldt *et al*., 2004), clearing bans in South Australia, and the State Salinity Strategy in Western Australia (Government of WA, 1996), have failed to halt the inexorable spread of soil and water salinity problems across the nation.

Pannell (2000) considered that lack of awareness is not the main factor responsible for the slow or non-adoption of remedial measures. Rather, he argued, the major factors are related to the economic costs and benefits of current treatment options, the difficulties of testing the options, long time-scales, externalities, and social issues. A specific study by Kington and Smettem (2000) found that existing catchment management policies (regulatory, co-operative and market-driven) have inherent implementation problems and are inadequate for the purpose. They suggested that perhaps no policy approach, even if fully implemented, would abate the salinity problem. They asked, therefore, whether it would not be more appropriate to develop policy strategies aimed at minimising the inevitable social and environmental impacts, and therefore extend current policy beyond its almost exclusive focus on dryland salinity management.

Integrated, sustainable management solutions

The need for integrated solutions to the problems of land degradation and desertification more generally has been stressed for many years. The main reasons have been indicated in the above case study. Namely,

1. there is usually more than one means of dealing with a problem;
2. a focus on one problem means that other existing ones go untreated and may be exacerbated;
3. solutions to one problem may generate new, unanticipated problems, and
4. the problems themselves may include social and economic elements which are not amenable to technical, engineering or biological remedies.

Delimiting management areas

If integrated solutions are to be implemented, an important question concerns the delimitation of the area or region in which the solutions are to be applied. In Australia, Land Conservation Districts have been delimited on the basis of two (usually unstated) criteria; a common set of land degradation problems, and a degree of 'community of interest' in the district. Catchments (also referred to as watersheds or drainage basins) are often used for this purpose (Soil and Land Conservation Council, n.d. (ca. 1991), Chs. 5 and 7). But not all land degradation problems relate to water movements. Bioregions are sometimes advocated, and are appropriate for problems relating to biodiversity, ecological processes and perhaps the introduction and spread of exotic plants and animals, pests and diseases. But physically-based regions rarely if ever coincide with communities, or with administrative or statistical areas. Since local governments often have planning responsibilities within a region their boundaries must be taken into account; and since economic, demographic and social data are often needed, the spatial units in which such data are collected (for example by the country's census bureau) also need to be considered.

It has been suggested that natural, economic and social criteria should all be used to select and delimit regions in relation to integrated management objectives. A planning and management region's boundary should be the external one of all the boundaries drawn on the basis of the criteria — a maximalist not a minimalist approach.

Implementing sustainable solutions

The final questions are: How can we ensure that planned solutions are implemented? And who is responsible for developing and implementing the plans?

For the purposes of this discussion it is assumed that government is supporting moves to combat land degradation and desertification. To achieve that, some form of planning and subsequent implementation of the plan is required. FAO's (Food and Agriculture Organization of the United Nations) *Guidelines for land-use planning*, first published in 1993, or modifications thereof, would be particularly appropriate for this purpose. There are ten steps in the *Guidelines*: 1. establish goals and terms of reference; 2. organise the work; 3. analyse the problems; 4. identify opportunities for change; 5. evaluate land suitability for the options; 6. appraise the alternatives; 7. choose the 'best' options; 8. prepare the land use plan; 9. implement the plan, and 10. monitor and revise the plan.

It is crucial that stakeholders are involved throughout the process, or the plan will fail. 'Stakeholders' are defined by FAO and UNEP (1999, 19–20) as 'anyone or any institution who has interests in, or is affected by, an issue or activity or transaction, and therefore has a natural right to participate in decision-making relating to it'. They are characterised as:

1. those having, needing or seeking control of or access to a resource;
2. those who are affected by the use of resources by others, and
3. those wishing to influence the decisions of others on the use of resources, for scientific, ethical or conservationist reasons, including the decision-makers and policy-makers.

Strategies whereby the objectives (Step 1 of FAO's *Guidelines*) can be implemented are likely to include changes in land use or land-use practices (Step 4) and an evaluation of various options (Steps 5 and 6). That evaluation should include economic and social assessments, including marketing and provision of infrastructure, land suitability evaluation, and possibly environmental impact assessments. The evaluations should be detailed. More specific *action plans* whereby the strategies can be implemented are then drawn up (Steps 7, 8 and 9). In doing so, the following questions need to be asked and answered in relation to each action: **what, who, when, where, how** and **why**?

1. *What* needs to be done? The actions need to be specified in precise terms. For example, 'riparian vegetation will be restored, using local species, along the banks of stream X covering the width of the flood plain on both sides of the stream, from location Y to location

Z' (place names, river crossings, grid references). Measurable and achievable targets need to be set. Benchmarks need to be established and measured. *What* data will be required for ongoing monitoring and later auditing? Which soil, vegetative, social and economic properties need to be measured. Spatial and temporal sampling strategies need to be specified. *What* new local government or other regulations, or possibly legislation, are needed to implement the plan? *What* will it cost? (Not only the above but all the other actions included below must be costed as accurately as possible.)

2. *Who* will actually do the work described under 'What' above? Landholders? A local community group? Local government? A government agency? A contractor? *Who* employs the contractor? The answers must be specific and be provided only with the agreement of the people involved. Memoranda of understanding and partnership agreements are two tools which can be used to formalize cooperative agreements.

Additionally, *who* owns the land on which the work is to be done? If the owner is not responsible for doing the work, then their written permission must be obtained. Owners could be private landholders, leaseholders, an indigenous community, companies, local governments or government agencies in which land is vested. Questions of legal responsibility and insurance must also be resolved at this stage.

And *who* will provide the necessary funds?

3. *When* will the work be done? Again this must be specified with the full agreement of the people responsible for doing the work. Sequences and timelines need to be established if the work involves various stages. The answers to this question also involve identifying *when* the measurable targets specified under 'what' above are to be achieved. *Temporal* sampling designs for monitoring programs need to be specified. Determining the latter meaningfully is crucial for certain properties (such as water quality) which will vary over very short periods of time during individual rainfall events, or for short-term variations in economic data, seasonally-varying crop and animal characteristics, and longer-term demographic and other social data.

4. *Where* exactly will the work be carried out (in the above example this is already specified under 'what?'). Additionally, there are hierarchies of scales at which work will or can be

done. One example is from land facet to land unit, land system and region. Another example is from a specific site (a groundwater pump, perhaps), to a paddock or field (changed cropping practices or crops), a farm (a change from individual to company ownership, or new suppliers of farm inputs or outlets of produce), farming system (changing to irrigation), catchment (a catchment-wide tree-planting strategy to improve water quality) and region (designing a protected area strategy to preserve biodiversity for the region as a whole).

5. It is essential to establish exactly *how* each piece of work will be done. What *methods* will be used for the planting example discussed under 'what' above? What machinery will be used or will it be done by hand? How many people will be involved? Have they all agreed to participate? *How* will weeds be controlled — by herbicides or hand pulling? What are the implications and costs of different methods? Will the plants need to be watered? Will fertilizers be needed, if so what kind, how much, how often and how will they be applied?

It will be appreciated that unless the *how* questions are answered in detail then costings cannot be done, and it would be difficult to answer many of the other questions, especially *who*, and also *when*, as well. Note that the *how* questions must also be answered in detail for measuring and monitoring methods; indeed for all actions.

6. The *why* question applies to every action and indeed every question. Fundamentally, the question is: does the action contribute to achieving the objectives of the plan? If not, then that action should be abandoned.

A FINAL COMMENT

This paper has focussed on the largely intractable problem of secondary salinity as a specific example of the management issues associated with devising and implementing sustainable solutions to the problem of land degradation. Secondary salinity occurs throughout the world, usually in association with irrigation or dryland agriculture. But salinity (and waterlogging) is only one, highly visible, manifestation of severely disrupted ecosystems. Other manifestations include loss of soil fertility, reduced soil structure, increasing soil acidity, increased erosion by water and wind, accumulation of chemical residues in soils and water, and loss of biodiversity and wildlife habitat. These problems result in decreased agricultural production and offsite environmental problems such as eutrophication of water bodies, the accumulation of chemical residues in food, and species extinctions.

The ecosystems have been disrupted by agricultural practices. In a world with burgeoning populations and therefore increasing demands on increasingly scarce good land from which to produce more food and fibre, this is not good news. Yet in many places (for example around the Mediterranean Basin), agricultural and pastoral land has been abandoned. We have to learn to farm much more cleverly and more intensively on the relatively small areas of good land, and maintain the world's biodiversity on the remaining, extensive areas with low actual and potential agricultural productivity. Agriculture must be part of the solution and not seen solely as a cause of the problems of land degradation.

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