WHAT HAS SOIL GOT TO DO WITH WATER?

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The Leeper connection
Geoffrey Leeper was described by Peter Ryan in an article in The Age in 1986, several years after his death, as ‘one of Australia’s most distinguished and useful citizens’. Not having known Leeper, but having heard much about him, especially through the medium of this Memorial Lecture series, I am sure that Leeper would have some trenchant comments to make about the current political and public debate on water.

Interestingly enough, although past lectures have dwelt on Leeper’s undoubted contributions to soil science, little has been said about his involvement with water. Back in 1972, after Leeper had retired from Melbourne University, he met a visiting group from the US Army Corps of Engineers, a powerful US government agency with responsibility to manage water in all its many conditions and situations. The group had come to Melbourne to learn more about the sewage farm at Werribee, and they approached Leeper because of his knowledge of the fate of heavy metals in soil. Leeper was subsequently invited to Washington DC to advise on the fate of heavy metals in sewage that was applied to land, and to advise on the management of land-based sewage systems in Wisconsin and New Jersey. Arising out of this work, Leeper wrote the book ‘Managing Heavy Metals on Land’. So in presenting this lecture ‘What has Soil Got to Do with Water?’ I am carrying on a tradition that Leeper started in making the connection between soil and water on the land.

Introduction
There is no doubt that public awareness of issues to do with water quality and quantity has been rising steadily for at least a decade, reaching an acute level in the past few years of drought on the eastern half of the continent. After many years of benign neglect of these issues by Federal and State governments, there is now a plethora of public education notices about saving water, together with financial inducements to install water-saving devices, and penalties for not observing water restrictions.

The city-based media finally decided to make water, and the lack of it, or its mismanagement, a newsworthy topic. First, early in 2002, the Murdoch Press launched some of their long-suffering reporters on flimsy boats into unfamiliar waters on the campaign ‘Saving the Murray’. Quickly The Age in Melbourne responded with emotive headlines such as ‘One last chance to save the Murray (30 October 2002) and ‘Our Water Crisis – a special series’, which started in April 2003 and continued in one form or another, trading doom and gloom predictions with The Australian newspaper through the remainder of this year.
The media campaign and political lobbying were given a further fillip early in 2003 with the emergence of the Wentworth Group of senior scientists, led by Professor Peter Cullen, formerly Director of the CRC for Freshwater Ecology, and containing high-profile commentators such as Dr Tim Flannery (of *Future Eaters* notoriety) and Dr Mike Young, a CSIRO economist-cum-policy analyst. In the second half of 2003, there was an avalanche of conferences and symposia on water.

In November 2003, I attended the 28th International Symposium on Hydrology and Water Resources, organized by Engineers Australia and entitled simply ‘About Water’. At that symposium, Don Blackmore, then CEO of the Murray-Darling Basin Commission (MDBC), the biggest water provider in the land, gave an address on water and the concept of managed sustainability. At another conference organized by the Academy of Science and Technological Engineering in Melbourne, entitled ‘The Water Dilemma’, Graham Harris of the CSIRO Flagships program spoke of the concept of ‘adaptive sustainability’ (meaning learning to manage as you go). I shall return to these concepts later in this lecture. But at this stage I can say that my impression from these conferences, and from many newspaper articles and radio programs, such as ABC Four Corners ‘Sold down the River’, is that the debate suffers from two major deficiencies.

1. Too much attention is paid to managing flows in rivers, and apportioning water between irrigators and the environment, and

2. Too little attention is paid to resolving the paradox that there is too much water of poor quality in many parts of the Australian landscape, but insufficient water of good quality in others.

This observation leads me to the substance of my lecture, which I summarize as follows.

**Objective of the lecture**

I may have created an impression of doom and gloom from my Introduction. Certainly, that is what many of the media reports tend to do. But I do not want to perpetuate that impression – I want to leave you with a blueprint for progress and a message of hope.

With this overall aim in mind, my specific objectives are:

(i) to inform you of the basic interactions between soil and water in the landscape, and how these interactions affect the flow of water to underground reserves (groundwater) and to streams and rivers;

(ii) to argue that socio-economic analyses should be done on a whole-of-catchment basis, to determine the costs and benefits of changes in land use and management designed to achieve desirable biophysical outcomes, and

(iii) to convince you that significant progress in solving our national water problems will only be made when we study soil-vegetation-water systems holistically in relation to climate, and its variability, and community needs, which need to be identified.
The importance of soil properties and pathways of water movement

Soil is remarkably variable as seen in the following few examples of soil profiles. For example, profiles with a marked textural change from sandy loam A horizon to impermeable clay B horizon are common in the higher rainfall areas of eastern Australia (Fig. 1a). These soils, which are called ‘duplex soils’, are frequently poorly drained, especially if the subsoil clay is sodic. However, soils of alluvial origin are often of coarse texture with many pebbles and are freely drained (Fig. 1b). Other soils, such as Vertisols, swell when wet and shrink to produce wide and deep cracks when dry (Fig. 2a), which means they can absorb much water when dry but have low infiltration rates when wet. When cultivated, many Australian soils deteriorate in their structure such that the surface ‘puddles’ when wet and sets hard when dry, which affects the soil’s ability to accept water (Fig. 2b). Thus, inherent soil properties and soil management markedly influence how a particular soil responds to water.

Depending on soil properties, vegetation type and rainfall (and irrigation), the pathway of water movement in soil can be complex. The major pathways for water in a duplex soil are illustrated in Fig. 3.
Fig. 2a

Surface of a sodic soil after rain

Fig. 2b

Surface of a sodic soil after rain

Fig. 3

Water pathways in a ‘duplex’ soil

- Rainfall
- Evapotranspiration
- Surface runoff
- Subsurface flow
- Deep drainage (potential recharge to groundwater)

A horizon - sandy loam
B horizon - clay

Root zone
Managed sustainability – is this achievable?
In a recent paper in Asian Agri-History, Professor Lindsay Falvey (Falvey 2003) argued that the relevance of principles often espoused for sustainable agriculture – maintenance of the natural resource assets – pivots on the motivation behind protection of the resource. If the motive is primarily to maintain a system of competitive, profit-based agriculture, conflict between objectives is bound to arise, because each act of environmental modification can have unforeseen effects, which adversely affect some other part of the ‘natural system’.

The history of water use in Australia, and in the Murray-Darling Basin in particular, is a classical example of chain of events in which conflicting objectives have led to unforeseen changes that have adversely affected both production and the resource base. One might call this the ‘managed unsustainability’ paradigm.

First, some 100 to 200 years ago, settlers were encouraged by governments to clear the land, plant crops and export the products. The money earned was pumped back into rural communities, and so large areas of the interior became more closely settled (displacing the indigenous occupants in the process, but that is another story). As well as land clearing, irrigation was especially encouraged in northern Victoria and southern NSW.

However, over much of the settled area, large scale clearing of native woodlands and scrub led to changes in the regional hydrology and increased recharge to groundwater. The Mallee region of northwest Victoria and eastern South Australia is an unfortunate example of this process. As watertables rose, subterranean stores of salt were mobilized, and when this saline groundwater rose to within 1-2 m of the soil surface, ‘dryland salinization’ appeared.

Dryland salinization was not new in the Australian landscape, but the concern has been that over the past century it has increased in extent as a result of extensive land clearing, and will continue to do so. The current extent of dryland salinity in the Murray-Darling Basin is shown in Fig. 4. Irrigation has also contributed to rising watertables and salinization, but irrigated agriculture occupies only about 4% of crop and pasture land, with the remaining 96% being under dryland agriculture.
Recognizing the problem of increasing dryland salinity, government agencies and environmental groups have in recent years advocated extensive tree plantings. The catchcry ‘plant a tree’ rose to a national chorus in the 1990s. Based on large-scale modelling of the Murray-Darling Basin, CSIRO advocated that to reverse current salinity trends, between one-third and one-half of the Basin should be planted to trees. Farmer organizations were outraged, because farm forestry is generally not profitable, especially in the short term.

However, there were substantial tax advantages for investing in plantation forestry, and forestry companies calculated they could make money from plantations of trees such as blue gums and sugar gums, provided they could grow them on fertile soils, under high rainfall, and reasonably close to a timber or paper mill. So large areas of good agricultural land has been taken out of agriculture and put under plantation trees.

Now scientists, such as those in the CRC for Catchment Hydrology (Vertessy et al. 2003), are saying that this change in land use, especially where it has occurred in the upper parts of important river catchments in the Murray-Darling, will seriously reduce water yields in these catchments, so exacerbating the problems of water availability in the Basin.

Thus, through the 200 year history of agriculture in Australia, one can trace the unforeseen consequences of actions, driven by the profit motive, which have caused repercussions elsewhere in the ecosystem.
At this point, it is appropriate to say something about water availability in the Murray-Darling Basin and lead into some recent research with which I have been associated, that offers guidance as to how we might collectively ameliorate the problems of water quality and quantity.

The Murray-Darling River - what are the real numbers?

Pre-development, the median annual flow in the Murray-Darling was 13900 GL. At present, some 75% of this water is extracted for irrigation. However, an audit of the Basin’s water supplies in the early 1990s revealed that if all the entitlements to extract water were activated, the demand for water would be comparable to the median annual flow – the river system would run dry (Fig. 5). Thus, the MDBC imposed a cap on further development at 1993-94 levels of development (Keyworth 2002). The rate of actual extraction has only now begun to slow; indeed, Queensland, admittedly a small user compared to NSW and Victoria, has only now (2003) signed off on the cap.

Fig. 5

[Graph: Average Natural Flow to Sea]

Much attention is now being directed to the state of health of the river ecosystem – aquatic and terrestrial, and much engineering effort directed at understanding river hydraulics to determine the appropriate environmental flows to achieve specific biophysical objectives. The Council of Australian Governments (COAG) recently endorsed a plan – the First Step - to ‘recover’ up to 500 GL per year during the next 5 years, starting on 1 July 2004 (now deferred), and targeting iconic sites such as the Barmah, Koondrook-Perricoota and Gunbower Forests near Echuca, the Chowilla flood plain near Mildura, the Murray mouth and Coorong Lakes, and the Murray Channel.
The water will be recovered through a matrix of options, with a focus on on-farm initiatives, efficiency gains, infrastructure improvements and rationalisation, market based approaches, and purchase of water from willing sellers, rather than by way of compulsory acquisition. Previously, COAG, in launching a National Water Initiative to address the problem of over-allocation of water in the M-D system, had agreed to allocate $500 million over 5 years. Even if one assumes that all of this money will be used to purchase water for the environment (which it will not), one can calculate that the assumed cost of water purchased for the environment could be as low as $200 per ML. I suggest this is a gross undervaluation – first for the practical reason that permanent sales of water rights in the irrigation areas have already reached as high as $1400 per ML, so why should irrigators sell water to government for much less; and secondly because $200 per ML seems to be a very low value to set for the ‘environmental benefit’ of this water. Remember that the economic value of tourism in the Basin is now $5 billion a year, which is almost half the value of agricultural production.

So, rather than focusing primarily on current rivers flows and arguing about how these should be divided up (more equitably?), let us look at a whole-of-catchment strategy that could on the one hand substantially increase flows of good quality water to the rivers, and on the other substantially reduce water percolating to saline groundwater and essentially being wasted. In doing so, we will need to apply knowledge of catchment hydrology and the interaction between climate, soil and vegetation in determining how much water is available and where it goes.

Note that 13,900 GL of stream discharge from a catchment of 1.1 million square km amounts to an average of 13 mm of runoff (surface and subsurface) annually. Even more revealing, an increase in the average runoff in the Basin of 2 mm per year (effectively about 1 mm after evaporation and seepage losses in the rivers) would provide and extra 1,100 GL water. Compare this amount with the ‘Living Murray’ recommendation of an additional 1500 GL per year, considered essential to maintain a healthy river, and we can clearly where our planning priorities should lie.

**A case history – the Sustainable Grazing Systems (SGS) program**

SGS was a Meat and Livestock Australia program supported by State agencies and universities that focused on more profitable and more sustainable grazing systems in the high rainfall zone (>600 mm) of southern Australia. SGS involved cooperation between meat and wool producers and resource scientists from 1997 to 2002. A National Experiment (NE) was established with 10 main Sites extending from Albany in WA to Tamworth in NSW.

If we examine the water balance for an ecosystem in southern Australia, we find that surplus water is generated mainly in winter, when rainfall $P$ is high and evapotranspiration $ET$ very low. Thus, when the soil is wet, the difference between $P$ and $ET$ gives the surplus water that is lost as runoff and deep drainage (see Fig. 3). The ratio of drainage $D$ to $D$ plus runoff $R$ is called the partition ratio (PR).
In the NE, long term weather data (1971-2001) for the main Sites were used to determine the probability of a winter surplus of water occurring at an individual Site, and the average size (in mm) of that surplus. These data showed marked differences between Sites in the size of the winter surplus (mainly a climatic effect), but a consistent trend for the surplus to decrease with increasing perenniality of the pasture and culminating in zero average surplus for plantation blue gums, as shown in Fig. 6.

A soil-water-plant-animal process model (the SGS Pasture Model – Johnson et al. 2003) was used to simulate water losses on different soil types under different pastures (perennial vs annual species) and different grazing managements. Results reported by White et al. (2003) showed the importance of the rooting depth of grasses in minimizing deep drainage (Fig. 7). Further, the partitioning of surplus water between deep drainage and runoff was strongly influenced by soil type, irrespective of the Site climate. Sodosols with impermeable subsoils allowed only 40-50% of the surplus water to go to deep drainage, whereas deep sandy soils with no subsoil impediments to water flow directed almost 100% of the surplus to deep drainage.

Fig. 6
Conclusions from SGS

1. Changing from annual pasture species (e.g. annual ryegrass) to perennials (phalaris, kikuyu) decreased winter surplus water by 40-50% (39-97 mm).

2. Only plantation trees gave complete control of deep drainage, and hence control of potential recharge to groundwater.

3. Spaced trees (red gums) up to 14 per ha saved 44 mm of water relative to a phalaris pasture, but this is a high density of mature trees to have in a productive pasture. Remnant tree densities of 2-3 per ha (the norm on cleared hills in the MDB) have an insignificant effect on hydrology.

4. Soil type interacted with climate and pasture type to have a major effect on the winter surplus.

5. Soil type had a major effect on the partitioning of surplus water between runoff and deep drainage.

6. Strategies to manage water in complex landscapes must be holistic, encompassing economic, social and environmental goals.

An example of a holistic approach to better water management
A holistic approach should start with spatially referenced biophysical data that is used to
determine the optimal pattern of land use for specific water management outcomes. The
land use options then need to be subjected to a critical economic analysis to determine the
costs and benefits of change for both public land (the community) and private
landholders.

Using the knowledge gained from the SGS program, supported by other research results
from other sites in southern Australia, how can we plan more strategically to improve
both the quality and quantity of water available in the Murray-Darling Basin?

Given the twin aims of:
(a) decreasing recharge to groundwater that exacerbates dryland salinity, and
(b) increasing runoff that supplies good quality water to streams,
we can use a hydrologic model in a spatial (Geographic Information System) framework
to assign cropping, dryland pastures and plantation trees to land areas, taking account of
1. Local climate
2. Hydrology (including the distribution of salt stores and saline seeps)
3. Slope and soil type (soil depth and profile form)
4. Soil fertility (e.g. soil pH)
5. Pasture species (perennial vs annual), and
proximity to streams.

Take, for example, the Goulburn-Broken (GB) catchment in Victoria (Fig. 8), part of the
Murray-Darling Basin.

Fig. 8
Lindsay Trapnell of Benalla and I did a preliminary analysis for the GB catchment and estimated that between 88 and 449 GL of water could be ‘saved’ (diverted from groundwater) if 20-100% of the available area was re-vegetated. We also believe that more water could be diverted to streams if well-managed perennial pasture replaced trees in some areas. Note, the GB catchment occupies less than 2% of the total MDB and supplies 11% of the runoff. Thus, if this approach were applied to other catchments in the better-watered parts of the MDB, the overall impact on water availability and quality could be huge.

However, the most important aspect of the preliminary modelling we did was the economic/financial analysis of land use changes (Trapnell 2002) to show
(a) revenue changes  
(b) cost incurred  
(c) other gains and losses that can be given a dollar value  
(d) analysis of extra risk, and  
(e) non-monetary considerations.

What about climate change?

The possibility of climate change over the next 25 years adds an additional level of complexity to planning for better water management, especially in southern Australia. The consensus outcome of global-systems modelling by CSIRO suggests there will be 20-130 mm less water available in soil-plant systems in southern Australia by 2030 and that the seasonal distribution of the rainfall will change. These changes will probably exacerbate water supply problems in most areas, especially in the Murray-Darling, so that a contingency factor needs to be built into all water supply models that are based on catchment water balances.

Final conclusions and recommendations

The extreme variability of rainfall and river flows in southern Australia (ranging from drought to floods) was the prime motivation for our previous attempts to regulate river flows by engineering – using dams, diversions, channeling and locks. However, now and in the future, as much attention should be focused on the controls for generating surplus water in catchments as on the regulation of river flows.

Management of water should be on a whole-of-catchment basis (crossing State boundaries where necessary), but individual landholders, Catchment Management Authorities and local authorities need to have realistic financial analyses of the consequences of change.

Individuals make decisions for a multiplicity of reasons, not all of which are related to economics. Lifestyle choices are also important. Thus, the social consequences of change for individuals and communities need to be taken into account.
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References


