DEVELOPMENT OF CHAIN OF PONDS

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Abstract

Processes underlying the formation of chains of ponds are identified and discussed in relation to changes to landscapes caused by farming. Management actions that promote the development of chains of ponds are identified, addressing the management of hill slopes as well as flats and stream lines. Examples are given for implementations by farmers.

Introduction

Chains of ponds systems have received considerable attention since several farmers raised near surface water tables and produced wetlands in previously dry land. The farmers are managing the systems to recreate conditions they considered existed prior to European settlement. The objective is to create meandering waterways and ponds that are coupled with the subsurface water in the surrounding land.

The premise behind this management is that clearing and grazing increased the surface runoff of water and decreased the capacity of soils to resist erosion. This created erosion gullies and scoured stream lines, thereby further increasing the drainage of water from the landscape. Eroded gullies and streams rapidly drain water and, because of the lowering of the level of the floor of the drainage channel, remove water from the soil as well the surface.

Well documented evidence exists of massive soil erosion following the introduction of agriculture, primarily grazing. There is similarly evidence to show that agriculture has increased soil compaction and reduced the levels of soil organic matter. However, there is limited information on the net changes to the hydrology. Observations show how natural vegetation, pastures, crops, and plantations now use water but there are no observations of how the systems previously functioned.

While there are no detailed observations of changes to hydrology with European agriculture there are general observations that provide insights. Surface runoff is generally considered to have increased. Moreover, the seasonal patterns of stream flow have changed in some regions. Stream flows in SE Australia have changed from being markedly winter dominant to having a pronounced summer component. Such a change is a consequence of an increased contribution to stream flows by surface runoff.

The lack of a reliable reference has led some to question the appropriateness of the management practices used to develop chains of ponds. The two main criticisms relate to water harvesting and dryland salinity. The chains of ponds are considered to harvest water that is the property of the State, and the officially applied ‘rising groundwater’ model has dryland salinity being caused by groundwater coming closer to the soil surface. The management practices are seen by some as being potentially environmentally damaging in reducing stream flows and increasing dryland salinity.

Many of the management practices used to create chains of ponds focus on streams with the management actions directly producing the desired outcomes. In effect, engineering activities are used to raise stream levels and construct ponds. However, chains of ponds are a consequence of what occurs in the entire landscape. While chains of ponds intimately interact with the adjacent flat land it is land upslope that supplies most of the water, and water delivered in the wrong way from the slopes can destroy chains of ponds. In terms of landscape function the chains of ponds are primarily a response or outcome of changes in the landscape rather than being the cause.

To understand the reasons for the changes involved in developing chains of ponds, and to devise the most appropriate management, it is necessary to understand the relationship between the chains of ponds and the hydrology of the remainder of the landscape. Such understanding is also required to address concerns about adverse environmental impacts. This paper examines the relationship between the chains of ponds and the landscape using information from implementations by farmers as well as scientific research.

The Basic Soil Landscape

The development of a basic soil landscape involves the weathering of rock on hills with the weathered material being eroded and deposited on flats (Fig. 1). Development of the soils depends on the relative rates of weathering, erosion and deposition and, while these vary with the nature of the parent rock material, climate, and terrain, the generalised situation identified in Fig. 1 is common.

The significance of this pattern for nutrients is that the nutrient supply derives from the weathering of material on the hills. While the depositional soils on the flats may become most fertile their fertility derives from the deposition of material eroded from upslope areas.

The significance of this pattern for the surficial hydrology relates to the vertical stratification of soil materials. Gravity is the prime force causing water to flow in saturated soils thus the tendency is for water to drain vertically down. However, the layering of materials in soil profiles typically produces preferred pathways for water flow. The surface soil, or A horizon, generally has the least resistance to water flow. Following the path of least resistance most water tends to flow laterally in the surface soil perched on top of the relatively impermeable subsoil.

The generalised relative resistances to flow from the lowest to the highest are:

- Surface (runoff)
- A horizon[1] in erosional areas
- B horizon in erosional areas (weathering materials)
- A horizon in depositional areas.
- B horizon in depositional areas
- C and D horizons[2]

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[1] Soil profiles generally develop vertical stratification associated with patterns of accumulation and leaching of materials. The basic layers are the A horizon or top soil, which tends to be leached, and the B horizon or subsoil. The A horizon often has two distinct layers, the surface A1 (surface soil) where organic matter tends to accumulate and the A2 below. The B horizon accumulates materials leached from the A horizon.

This pattern is illustrated by seepage of water to the surface at the transition between erosional and depositional soils at the break of slope. Water flowing laterally through the top soil in erosional areas comes to the surface where it strikes depositional materials having a higher resistance to flow.

The relative water flows along different paths depend on the gravitational and water potential gradients and resistances to flow. With impermeable soils a large proportion of rainfall usually flows from the landscape as surface run off. With permeable soils most rainfall is absorbed into the soil and runoff is then restricted to periods of very high intensity rainfall and when the soil profile becomes saturated.

The basic physical processes associated with the above generalisations always apply, but the realised outcomes vary due to structural unconformities in the soil and underlying materials. In Fig. 1 the soil is represented as layers of homogeneous porous material (vertically stratified but laterally homogeneous) and this assumption is typically applied when modeling soil processes. However, soils can be highly non-homogeneous due to the development of cracks and the death of plant roots producing channels for water flow. Moreover, rocks develop fractures providing preferred pathways for water flow through the underlying materials.

The significance of such channels can be illustrated by contrasting the drainage of water from soils that are horizontally homogeneous or contain vertical fractures such as cracks. With a homogeneous soil water tends only to drain when the entire soil profile becomes saturated. The soil functions like a bucket in not loosing water until it becomes full, except that soils then drain from the bottom as well as the top. However, in non-homogeneous soils water drains along cracks and other channels even when the entire profile is not saturated. Non-homogeneous soils are much leakier than homogeneous soils.

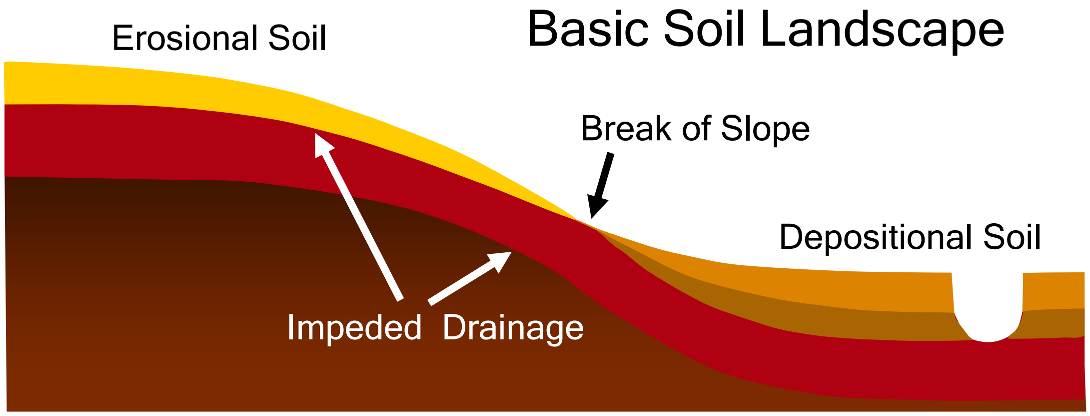

Fig. 1 Schematic representation of a basic soil landscape. Vertical exaggeration 100:1

The chemical composition of water draining from homogeneous media is effectively in equilibrium with the bulk of the medium. That is, the salinity of the drainage water is the same as the water remaining in the soil. This does not apply with non-homogeneous media, at least in the short term, as the water flowing along cracks does not have sufficient time to

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[2] The C and D horizons represent the layer immediately beneath the subsoil. The designation C applies where the soil derives from that material (erosional soil). The designation D applies where the soil and underlying materials are derived from different geological materials, as commonly applies with depositional soils.

equilibrate with the water in the remainder of the soil. Water draining from the soil then has lower salinity than the water remaining in the soil.

The differences between the hydrology of homogeneous and non-homogeneous soils have a marked effect on the functioning of the landscape. While such differences can naturally occur, as with sandy soils tending to be homogeneous and clay soils non-homogeneous, they can also be generated and accentuated by land use. The structure of soils depends strongly on the accumulation of organic matter where agriculture typically reduces the levels of soil organic matter. The loss of soil organic matter increases compaction and reduces the structural unconformities, aeration, and the ability of soils to adsorb water and nutrients. The reduction of organic matter is of paramount importance in Australia because most soils are derived from highly weathered materials that no longer possess mineral characteristics needed to produce soils highly favourable for plants.

The general situation identified in the introduction of compacted soils increasing the surface runoff is associated with land use increasing the homogeneity of the soil. The main effects are summarised in Table 1.

Table 1. Contrasts in the functioning of systems with compacted homogeneous soils and those with friable non-homogeneous soils.

	Friable, non-homogeneous soil	**Compacted homogeneous soil**
1	High water infiltration / low runoff	Poor water infiltration / high runoff
2	Good aeration	Poor aeration
3	Soils are leaky (frequent drainage through the profile)	Soils are non-leaky (drainage tends only to occur when soils become saturated)
4	Drainage water has lower salinity than the soil water	Drainage water in equilibrium with the soil water

The prime consequences of these changes for landscape function are:

1. The increased surface runoff accelerates erosion, often removing solid materials such as clay and organic matter from the landscape. The system looses water, which is almost invariably a limiting resource, and it also looses nutrients. Moreover, the development of erosion gullies produces a positive feedback that promotes such losses. Additionally, water draining into streams is highly episodic and has high velocity and turbidity, all of which disadvantage aquatic systems.
2. Soil aeration is essential for plant roots and soil microbes. This is of consequence for plant growth as soil microbes recycle organic matter and extract most of the nutrients from the soil minerals. They also produce the long lived organic matter that improves the soil structure.
3. Drainage of water through the profile represents a loss to the vegetation where it occurs. However, some of this water is used by plants lower in the landscape. Moreover, percolation through the soil produces stream flows with low velocity and turbidity, and with high duration, where these characteristics benefit aquatic systems.
4. While water is lost from the landscape regardless of its condition the loss through drainage minimises the loss of nutrients. Water loss through surface runoff produces high nutrient losses whereas nutrient losses are low where water is lost through drainage in a non-homogeneous soil.

Some of the interrelationships between these effects can be illustrated by reference to dryland salinity. Water draining from leaky soils has low salinity. Moreover, the water tends to drain into streams so any salts are removed from the system. Water draining through compacted soils accumulates salt and, because the vertical drainage is highly restricted, this water tends to drain laterally and come to the surface lower in the landscape. With evaporation the accumulation of saline water produces saline soils.

The above contrasts key differences in the functioning of ‘natural’ and impacted systems. However, in practice the differences are usually of degree rather than kind. It is only with catastrophic system failure that adverse extremes prevail, but this has occurred during periods of massive erosion. The issue for land management is how to return the system to something like its natural function, particularly since the adverse changes produce a positive feedback that tends to retain the system in a degraded state.

The Role of Plants

A soil represents a dynamic system that develops in relation to the climate and vegetation. The prime effects of vegetation relate to the modification of the soil environment by changes to the hydrology and temperature, the provision of organic matter, and the promotion of soil micro-organisms. While farming has mechanically damaged soils through practices such as ploughing, the main land use impacts have been caused by disruptions to processes involving interactions between vegetation and soil microbes.

A favourable soil has good aeration, good retention of water and nutrients, and functions as a non-homogeneous porous medium. These characteristics are promoted by the accumulation of organic matter as it increases the average aggregate size, greatly increases the stability of aggregates in water, and increases the ability of the soil to store (adsorb) water and nutrients. While vegetation is the primary source of the organic matter it is microbes that convert it into forms that provide these benefits. Microbes produce organic compounds that are resistant to microbial breakdown and these compounds help produce a soil environment favourable to plants and microbes.

Additional benefits from plants arise from shading of the soil and plant roots increasing the level of non-homogeneity. The death of plant roots produces channels that provide preferred pathways for water flow. Shading reduces soil temperatures and hence the rate of breakdown of soil organic matter.

The development of soil organic matter represents the balance between production and breakdown where the rate of breakdown increases more than two fold for each 10 degree C increase in temperature. Soil exposure greatly increases the rate of loss of soil organic matter. Ploughing further increases the rate of loss by increasing the aeration.

The general relationships between soil microbes and vegetation are identified above whereby plants provide food for microbes and the microbes produce a soil environment favourable for plant roots. However, the relationships go much further. Plants cannot derive nitrogen from the air and rely on microbes fixing gaseous nitrogen and recycling it through organic matter. Similarly, plants by themselves cannot extract all required nutrients from rock minerals and depend on their extraction by microbes. The relationships are often symbiotic to the extent that plants directly provide microbes with food. The relationship can involve protection for plant roots against pathogens as well as the provision of nutrients.

Two separate aspects of the relationships between microbes and plants relate to recycling nutrients and the provision of new nutrients. Nitrogen fixation by bacteria and blue-green algae represents a new source of nutrients, as does the extraction of nutrients from soil minerals by microbes. However, most microbial activity involves recycling nutrients by breaking down organic matter produced by plants.

Minerals in subsoils are less weathered than in the surface, and additional minerals accumulate through leaching from the surface. These minerals are difficult for microbes to access due to the generally inhospitable environment by way of poor aeration and limited food (energy source). Plants promote microbial activity in subsoils by increasing aeration and providing organic matter. This relationship is most developed in symbiotic associations where fungi live in the cortex of plant roots as well as the soil, as with arbuscular fungi. Plants place microbes in environments where they could not otherwise exist and where the microbial activity benefits the plants.

The long term consequences of plant roots not being able to access the subsoil or B horizon are illustrated by the development of vegetation on parts of coastal sand dunes that effectively do not receive accession of nutrients from elsewhere. At the peak of its development the vegetation is a tall dense eucalypt forest, but the vegetation begins to decline as the top soil looses its capacity to supply new nutrients and plants become unable to access nutrients accumulated in the B horizon (Walker et al. 1981[3]). Nutrients that are inevitably leached from the top soil increasingly become inaccessible to plants as the depth of the B horizon gradually increases due to leaching. When the B horizon is at a depth of 10m the vegetation has degraded to a low sparse shrubland.

Plants and hydrology

Nutrients are essential for life but so too is water. All of the chemical reactions essential for life occur in aqueous solution so water is a prime driver or control in the system.

Plants grow by fixing energy from the sun into complex carbon compounds. The overriding constraint is that the accession of atmospheric CO_2 essential for photosynthesis inevitably results in plants loosing water. While plants tend to optimise their water loss in relation to CO_2 gained (they are not profligate users of water) they need a source of water to replace that lost when acquiring CO_2.

For most plants the soil acts as a buffer store for water in supplying water during periods without rain. The soil water store is highly dynamic with intermittent input via rain and a diurnal pattern of continuous water extraction by plants. The rate of extraction varies with a number of factors including the characteristics of the vegetation, the dryness of the atmosphere, temperature, insolation, and the level of soil water availability.

The general situation is that most exchange of soil water by way of input and output occurs in the top soil. The use of water by plants generally prevents the entire soil profile from becoming saturated and this strongly limits the leaching of nutrients. The development of the soil profile reflects this pattern of water use with clay and ions being leached from the A horizon and accumulating in the subsoil. The development of soil profiles is primarily a consequence of the patterns of water infiltration into the soil and its extraction by plants. The main modification to the pattern produced by the infiltration and extraction of water arises from the accumulation of organic matter in the surface soil (A1 horizon).

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[3] Walker, J., Thompson, C. H., Fergus, I. F. and Tunstall, B. R. (1981). Plant succession and soil development in coastal dunes of subtropical eastern Australia. In *Forest Succession Concepts and Applications*, pp 107, 131. Eds. D. E. West, H. H. Shugart and D. B. Botkin. Springer-Verlag, New York.

Given the temporal patterns and variations in rainfall plants can seldom prevent the entire soil profile from becoming saturated at some time[4]. As most drainage occurs when soil profiles are saturated there is always some potential for nutrients to be leached. In winter rainfall areas subsoils are generally saturated each year due to the low potential evaporation, and this also occurs in the seasonal climate of northern Australia where rainfall exceeds the potential evaporation over summer.

Percolation of water soil depends on the structural characteristics of the soil and underlying materials as well as the climate and vegetation. In appreciable areas of Australia there is effectively no percolation under native vegetation, crops or pastures because of the depth of clay. These deep sedimentary formations are effectively sealed. Conversely, in fractured areas there is always percolation of water and this is regarded as the most common situation.

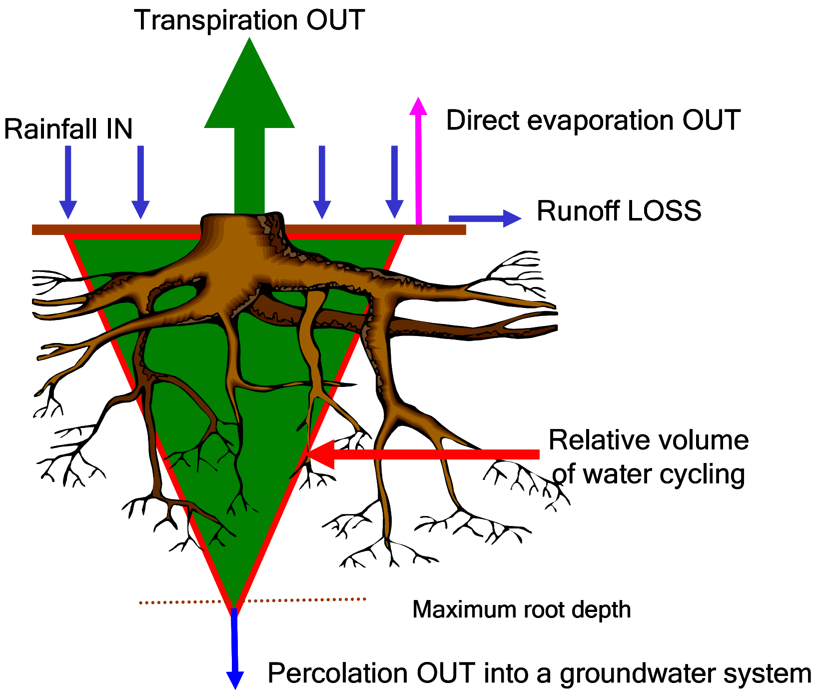

Fig. 2 Schematic representation of water accessions, losses and storage in soils. The relative volume of water recycling reflects the relative contribution to water storage of soil at different depths.

The Consequences for Chains of Ponds

Chains of ponds represent systems that are fed through subsurface as well as surface flows. Dams constructed along a gully do not represent a chain of ponds system. Managing for chains of ponds involves addressing subsurface as well as surface water flows.

The basic requirements in developing chains of ponds are to slow the rate at which water drains from the system and to raise the level of the most surficial groundwater system. Most simply this involves filling in all incised gullies but this is impractical because of the very

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[4] Plant roots develop to utilise soil water hence their level of development reflects the environment. Root development tends to optimise rather than maximise water use hence there will always be periods when water infiltrates below the rooting depth of plants.

large volumes of material that have been eroded. The efforts have therefore been directed at placing structures at intervals along streams that restrict but do no block water flow. The restrictions to flow spread water across the flats during periods of high surface runoff and tend to maintain groundwater levels within the root zone. The benefits include the effective elimination of erosion, increased plant growth, and maintenance of wetlands. Spreading runoff across flats greatly reduces mass movement of solid materials from the landscape.

The term coined for this raising of water levels is hydrolation. The objective is to increase the duration or residence time of water in the landscape and to raise the water to a level where it is accessible to the biota. Access by the biota, animals as well as plants, develops the functionality of the system and returns it to something like its prior natural state.

Hydrolation in streams is achieved using structures that slow but do not block the flow. This can be achieved ‘naturally’ using logs and branches, particularly where the branches take root and grow, as with willows. The root growth of willows helps stabilise the stream bank and hence increases the effectiveness of the structure. Constructed barriers perform best where they incorporate emergent aquatic plants to control the permeability and produce a self sustaining barrier.

Focussing on streams alone restricts the extent of the chains of ponds to a narrow drainage line. While chains of ponds were usually restricted to stream lines some landscapes naturally have wetlands in elevated areas. The most unusual occur in the sand dunes of Stradbroke Island and other coastal sand dunes where lakes and wetlands are perched in dunes. The water is perched on old B soil horizons where sand is cemented by organic matter and aluminium and ion oxides.

Elevated chains of ponds can occur in any system provided the rainfall and catchments are sufficient and the subsoil structure produces lateral flow of water. However, the generalised soil landscape in Fig. 1 identifies that chains of ponds are most readily developed in the depositional parts of a landscape. New chains of ponds isolated from stream lines can be formed by accessing subsurface water flows on flats. Ponds established remote from streams will usually be linked to the streams through subsurface flows. The ponds represent transient storages rather than dams.

Knowledge of subsurface structure is invariably limited and usually insufficient to allow accurate definition of the location and nature of subsurface aquifers. Trial and error is usually required to identify the location and depth of aquifers, noting that several groundwater systems can occur in the same paddock. The characteristics of the systems can differ markedly, particularly if one is surficial and responds rapidly to rainfall and the other is fed by deeper systems. Knowledge and experience are useful.

Management of slopes

The prime requirement is to reduce surface runoff and increase percolation into surficial aquifers as these aquifers feed the chains of ponds. Moreover, the water storage and resistance to flow associated with subsurface drainage increases the duration of recharge to the ponds.

Percolation through soils is increased by improving soil structure, largely by increasing the level of soil organic matter but also by having deep rooted plants. Direct intervention can also be used, as with the Wallace plough. This breaks compacted layers and, when sequentially applied at increasing depths, increases the development of organic matter deep in the soil profile. The ploughing and development of organic matter at depth increase the leakiness of the soil and hence increase percolation into groundwater systems.

The Keyline system linked with the Wallace plough can be used to counter the effect of erosion gullies accelerating the loss of water from the landscape. Ploughing with the Keyline system counters the natural patterns of surface drainage and directs water flows to spurs rather than gullies, thereby increasing the infiltration of water into the soil and reducing surface runoff.

Indensation

The above was written prior to the identification of indensation but with an appreciation of circumstances where neither rainfall nor any other known source of water could account for the water needed to sustain the existing vegetation. From a general appreciation of plant water relations the vegetation existing in many situations was much greater than should have occurred with the known available water.

The above considerations were written on the assumption that vegetation was gaining water in some unknown way hence the conclusions remain valid when indensation is taken into account. However, knowledge of indensation changes the emphasis, and such changes will continue with development of knowledge.

The occurrence of indensation means that vegetation can contribute water to groundwaters and streams. While vegetation uses water the leakage associated with non homogeneous soils can increase percolation from soils. This drainage from the soil profile is greatly promoted by the development of soil organic matter through the symbiotic relationships between plants and microbes, and the production of channels for water flow by the growth and decay of plant roots.

With indensation all vegetation can provide water to groundwater systems. Vegetation across the entire landscape can potentially contributes water to chains of ponds similarly to accessions of water from rainfall. The contributions of water to groundwater systems by indensation and rainfall are complementary. Developing the groundwater systems involves developing the vegetation and soil profiles across the entire landscape.

With indensation vegetation can be seen as directly hydrating the landscape. However, it can also have an indirect effect by increasing the humidity of the air through transpiration, and by seeding clouds through ‘transpiration’ of bacteria such as Aerobacter spp. The direct effects are localised within a catchment while indirect effects are regional.

Salinity and Water Harvesting Issues

The general consideration is that developing chains of ponds returns the system to something like its natural condition. It would therefore be expected to be environmentally beneficial. However, anything that modifies the surficial hydrology has a potential to impact on salinity and stream flows, and impacts can potentially be adverse as well as beneficial.

The above considerations identify that impacts on salinity would be expected to be beneficial, and this has been demonstrated by Whittington (Paulin, 2002[5]). It also occurred with the Natural Sequence Farming in the Hunter Valley. This does not mean that a combination of circumstances cannot produce an adverse impact but it does identify that beneficial changes are to be expected and adverse changes to salinity should be rare.

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[5] Paulin, S. (2002). Why salt? Harry Whittington, OAM and WISALTS: Community Science in Action. Indian Ocean Books, Perth. 63 pp.

Chains of ponds increase the growth of vegetation by increasing the amount of water and its period of availability. To a first approximation this would be expected to increase the water use by plants and therefore decrease flows to streams. While this may arise it did not occur in the one detailed study observed to date (Bell et al. 2001[6]). In a degraded grassland 20% of rainfall was lost through surface runoff and none from drainage. In grassland with improved soil structure there was no surface runoff but 20% of rainfall was lost through drainage. Increased plant production was achieved without increased water use.

This situation is difficult to explain with prior knowledge as drainage arose despite the development of increases in the capacity for transpiration and soil water storage. The failure of the vegetation to use the increased recharge to soil water would have arisen from the soil becoming leaky through improvements in structure rather than environmental limitations to evaporation. In the location investigated by Bell et al. the potential for evaporation is seldom limiting. The increased growth may have arisen through increased water use efficiency associated with the improved fertility and soil environment for plant roots. However, the magnitude of change observed by Bell et al. is considerably greater than would be expected.

With prior knowledge the drainage from the improved soil by way of percolation should not have occurred. However, the drainage accords with accession to soil water by plants through indensation and an increase in leakiness of the soil due to the development of soil structure and non homogeneity.

Some Realised Examples

The best documented system for water management in dryland farming is the Yeomans Keyline System[7], but this focuses on water management rather than the development of chains of ponds. Its relevance to chains of ponds relates to the provision of a practical method of reducing runoff and increasing infiltration, and the maintenance of a cover of green vegetation. It provides a means of managing slopes to increase plant production there while also increasing the percolation of water to the chains of ponds. It provides a practical means of rapidly restoring degraded lands.

The Whittington Interceptor Bank technology (Paulin 2002) represents another historic success whereby productivity was restored by increasing the infiltration of water into soils in upslope areas. The successional development of land degradation on the landholding over a period of twenty years involved:

- Loss of fertility and plant production across the entire property.
- A fresh water creek drying up and becoming filled with sand.
- Development of waterlogged saline areas on the flats.
- Severe gully erosion along the creek line

The Whittington technology remediated all of these adverse impacts. While the interceptor banks are not as elegant as the Keyline system they were effective. Again this technology was

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

[7] Yeomans, P. A. (1958) The challenge of landscape: The development and practices of keyline. Keyline, Sydney, NSW.

Yeomans, P. A. (1978) Water for every farm using the Keyline approach. Murray Books, Ultimo, NSW.

Yeomans, K. (2002) Water for every farm: Yeomans Keyline plan (2nd ed.) Keyline designs, Southport, Qld.

not directed at producing chains of ponds but the interceptor banks did restore flow to a stream that had gone dry.

Critical aspects of the Whittington results are that:

- Dryland salinity was remediated by increasing the infiltration of water on the slopes.
- The water flow to streams associated with this percolation had low salinity.
- Increased productivity and amelioration of dryland salinity were associated with an increase in soil organic matter.
- The occurrence of dryland salinity was not associated with any groundwater system and therefore not associated with 'rising groundwater'.

The Natural Sequence Farming (NSF) of Peter Andrews incorporates a number of elements but the focus is on modifying patterns of water flow in streams and flats. It has yet to be fully documented but has been well publicised on television, several books have been published, and a review was conducted for the Australian Government by CSIRO [8].

The important elements of NSF are:

1. Structuring streams to reduce flow velocities and raise water levels so as to provide subsurface irrigation on flats.
2. Diverting stream flows into channels to provide subsurface irrigation.
3. Maintaining a good vegetative cover.
4. Mulching organic mater to improve soil structure.
5. Maintaining a diversity of plants that includes deep rooted species.
6. Using structures in streams that provide Flow Form patterns of water flow.

Soil salinity is not an issue in most coastal areas because rainfall leaches the salt, but parts of the Hunter Valley have saline soils despite the rainfall because of the high salt content of some marine sedimentary formations. Reducing the soil salinity depends on leaching and is achieved by improving the soil structure. Organic matter provides marked structural improvements to soils that promote the leaching of salt as well as enhancing the nutrient and water status for plants. Application of NSF ameliorated soil salinity.

There is no known direct 'scientific' evidence for the significance of deep rooted species in providing new nutrients in farming systems as it is difficult to identify the sources of all nutrients taken up by plants[9]. However, the occurrence of deep rooted 'weeds' in pastures was a key element in the development of NSF directed at improving the performance of racehorses. As NSF achieved this goal it appears that the mixture of species did provide nutritional benefits where these could derive through the provision of limiting micronutrients from subsoils.

The identification of Flow Forms with water movement is similar to nutrient acquisition in lacking direct scientific support. However, Flow Form structures have been empirically shown to provide production and health benefits with plants and animals. Gains of around 20% are typical. Producing Flow Form patterns in streams could be as important as reducing the flow

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[8] CSIRO Land and Water 2002. Expert Panel Report "The Natural Farming Sequence" Tarwyn Park, Upper Bylong Valley, New South Wales. Available on http://www.clw.csiro.au/publications/consultancy/2002/Tarywyn_Park_Upper_Bylong_Valley.pdf

[9] The paper by Walker et al. 1981provides 'scientific' evidence of the significance of subsoil nutrients for native vegetation but requires interpretation, hence the evidence is indirect. Also, it does not differentiate between new and recycled nutrients.

velocities, noting that Flow Form patterns naturally occur in many streams. Appropriately constructed flow form structures condition water by developing the appropriate phase.

Another example has been implemented by Peter Marshall near Braidwood. Peter Marshall purchased highly degraded land to provide a realistic demonstration of the benefits of a natural approach to farming. Aspects of the implementation include:

- Hydrolation using restrictions to flow in the stream line, thereby promoting the flooding of flats during periods of high surface runoff.
- Producing ponds in flats away from the stream by excavating into underlying aquifers.
- Increasing water infiltration into soils on slopes by breaking compacted layers using a Wallace plough. Successive ploughing at increasing depths is used to increase the organic matter at depth.
- Control of weeds such as broom bush and blackberries using scheduled grazing by goats.
- Agroforestry to provide deep rooted plants and to control shrubby weeds such a broombush.
- Growing plants for specific purposes, such as bamboo to provide silica as a drench.
- Introduction of casuarinas to fix nitrogen and stabilise stream banks.

The goats preferentially graze areas where the blackberries have been knocked down indicating enhanced plant nutrition compared to the adjacent grassy pasture.

All examples involve an ecological approach to land use that addresses the functioning of the entire system. They demonstrate that sustainable and profitable systems can be developed where the management promotes the natural system function rather than attempting to override it.

Conclusions

Chains of ponds may be developed in some locations by focusing on streams but the best outcomes are achieved where management addresses the slopes as well as flats. Indeed, recreating the pre 1770 form of chain of ponds depends on establishing a good cover of vegetation across the entire landscape.

The potential to develop chains of ponds depends on the climate, particularly rainfall, and the landscape, but they can be developed in considerable areas of Australian agricultural lands that are currently degraded. Moreover, many of the management principles involved have general applicability and can be used to improve production and environmental outcomes even where ponds cannot be developed. That is, the benefits of plants in hydrating the landscape can arise without the development of surface ponds, and this is the situation across inland Australia in areas where grazing has not significantly damaged the native vegetation.