Sustainable water and energy management in Australia's farming landscapes

W. J. Hurditch
The Fifth Estate, Australia

Abstract

Australia's ancient geology, continental isolation and long, stable biophysical evolution have produced a unique and biodiverse flora and fauna complex, and well-balanced mechanisms for handling water, nutrients and organic production in its landscapes. When humans arrived more than 40,000 years ago, Australia's water, nutrient and energy systems were essentially self-sustaining. Western agricultural methods have since uncoupled parts of the innate productivity system that had long sustained these natural landscape functions. Many Australian farming and grazing businesses are today challenged from unreliable rainfall, declining soil health and rising debt. New landscape management approaches are now emerging. Some involve rehydration to reinstate Australia's natural biophysical landscape functions and processes, and can deliver both ecosystem resilience and profitability to farming enterprises. Benefits of landscape rehydration for farmers include greater water reliability, improved soil organic content and reduced reliance on high-cost artificial inputs. It also assists in mitigating climate change, as vegetated, rehydrated landscapes dissipate incoming solar thermal energy via the plant-driven photosynthetic process and the daily water cycle. This feature, until now little recognised in mainstream climate change discussions, adds a major dimension to this opportunity for the world's landscapes.
Keywords: Australia, salinity, rehydration, fertility, sustainable farming, soil.

1 Introduction

Globally the deterioration of landscape productivity is a rising concern. This is particularly so with the heightened food security challenge in the context of a world population that the United Nations predicts will exceed nine billion by 2030 [1]. Following the remarkable agricultural productivity gains of the first *Green*

WIT Transactions on Ecology and The Environment, Vol 200, © 2015 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/WS150281

Revolution, into the 1970s, staple food production is today again being outstripped by population growth in critical places around the world. Examples are India and Nigeria, whose populations will likely overtake those of China and the United States, respectively, before 2030.

At the same time, the planet's available arable land base is shrinking, both in real terms and on a *per capita* basis [2]. As well as land losses to urban sprawl and infrastructure, physical land degradation today affects around 38 per cent of the world's agricultural soils [3]. Desertification, an extreme form of land degradation, increasingly impairs agriculture and prospects for dependent livelihoods around the world. It is estimated that within 15 years, up to 2.4 billion people may experience periods of intense water scarcity, displacing more than a quarter of them [4]. Clearly, loss of access to reliable water impacts farming yields. Where water is an increasingly limiting factor of production, food supply from formerly reliable sources cannot be expected to be sustained.

Nations considered to be developed are not immune from the insidious effects of land degradation. Australia, the subject of this paper, is a case in point. Today, Australia's food and fibre industries operate at varying levels of intensity across some 475 million hectares of grazing, cropping and intensive agricultural land. However in significant parts of these landscapes rates of water-driven soil erosion currently exceed soil formation rates by factors of hundreds and, in some cases, thousands. Acidification now affects around half of Australia's agriculturally productive soils, and is increasing in severity [5].

Land degradation and its consequent impacts on landscape productivity around the world are not new problems to science, agricultural practice, technology and policy. Recent decades have seen myriad national and global institutions and programs established to address it. Some have advocated ecosystem-based approaches to tackling land degradation, with many recognising the impact of climate change as another layer of complexity that adds to the urgency of the situation [4].

Ecosystem-based approaches acknowledge that answers to our sustainable landscape productivity conundrum may be found in the fundamental ecological and biophysical landscape functions that have operated, in concert, within nature for millions of years. These functions include nutrient and energy cycling, periodic flood events, evapotranspirational water cycles, chemical fluxes within biodiverse plant and animal assemblages, and organic matter accretion. But despite the increasing global attention to the value of an ecologically-integrated landscape approach, there are only a small number of peer-reviewed reports of how such an approach can be applied commercially and at scale [6].

Evidence assembled from studies of a range of farming approaches in Australia, Oceania, and parts of Asia and Europe [7–10], reinforces the utility and elegance of adopting an ecological approach to address the land degradation problem. Understanding and applying such management principles and approaches more widely can help address our increasingly urgent and global food and fibre production challenge, while helping moderate climate warming.

2 Australia's ancient landscape ecology and impacts of European settlement

Australia's biophysical landscape processes have evolved continuously in relative geological stability over millions of years. Gentle stream gradients and the scarcity of large waterfalls are examples of biophysical stability in much of Australia's land mass. Persistent plate-driven displacement of northern Australia's land surface could also be a contributor to some of Australia's benign landscape features [11].

Across wide areas of Australia, including around the now arid Lake Eyre Basin, rainforests and other moist ecological assemblages thrived in past climatic times [12]. Inland-flowing rivers brought fresh water, sediment and nutrients from the margins of the continent to the centre. As late as 45,000 BP freshwater mega-lakes in the Lake Eyre Basin persisted, until a long climatic drying phase reduced their area [13]. Even today, one can witness this "inland wetland" phenomenon in places like the still extensive Macquarie Marshes [14] and the inland floodplain of the Lachlan River [15]. Australia's coastal-flowing rivers tended to originate in short, confined valley systems and end in extensive dune-bound lakes and wetlands, with only occasional outflows to the ocean. Remnant examples today include the NSW Great Lakes system and the lakes of the Murray River mouth in South Australia [16].

It can be thus be argued that Australia's ancient landscapes were essentially self-irrigating, balanced ecological systems that maintained their functions in the face of climate extremes by tightly cycling nutrients, water and organic-bound energy. High primary productivity rates in parts of pre-European Australia were possible because of elegant nutrient and water conservation mechanisms that had evolved with the landscape's physical form and its unique biota.

Important conservative features of this landscape were based on step-diffusion processes [7], and included natural dissipative and buffering flow line structures variously termed "chain-of-ponds", "pool-riffle sequences", "in-stream wetlands" [17] and "swampy meadows" [18]. On a regional scale extensive anastomosing channel systems operated to capture and disperse water and sediment across broad inland floodplains [19]. These mechanisms served to buffer stream and overland flow energy, trap and aggrade the residues of successive landscape erosion and flood events, and build organic matter within the zones of peak biological production. Remnants of these phenomena can still be observed today, albeit in diminished scale and frequency.

Long before Europeans arrived, Indigenous Australians had brought about profound changes to the Australian landscape through, for example, their hunting of megafauna and a widespread use of fire [20, 21], perhaps even tipping the continent towards desertification [22]. However, common with other ancient cultures in the Asia-Pacific region, in some case dating before 5,000 BP, some groups of Australian Aborigines appeared to show a deep functional understanding of water and fertility movement and its consequences for biological productivity. Evidence includes a class of aboriginal artworks known as *Water Dreaming*, which depict the essential features of the chain-of-ponds structure and adjacent landforms. When overlaid with modern geomorphologic models, this suggests an ancient grasp of the essential physiognomic form for riparian sustainability [7]. This appreciation of holistic landscape function seems to have since been lost to much modern land and water management thinking.

From as early as a few decades following European colonisation of Australia, settlers started applying then-conventional Northern Hemisphere agricultural and pastoral practices, draining wetlands (pejoratively termed "bogs"), and dismantling the chain-of-ponds and swampy meadow forms [23]. This triggered progressive and serious landscape deterioration, including stream channel incision and widening, bed and bank erosion and general floodplain degradation. High stream flow velocities brought increased rates of sediment transport. Other impacts included the rapid run-down of surface water between high rainfall events, and high water salinity [24]. Most impacts can be attributed to human-induced *geomorphic* rather than climatic-change factors. Ironically, during the same 19th Century pioneering period, some of the new-Australian pastoralists recorded high primary productivity rates for their livestock and wheat. However it has since been recognised that such impressive productivity was largely the gift of free access to the millennia of stored fertility in the Australian landscape complex [23].

It has been estimated that, since 1788 when the first western-style farm was established by Englishmen around Sydney Cove, Australia's soils may have lost up to 80 per cent of their organic carbon content [25].

In common with many traditionally significant agricultural economies, the decline in broadscale soil condition and farm productivity in Australia has gathered pace to the present day [2]. Its deleterious effects on farmland production have been masked and moderated through successive technological advances in crop and animal genetics, widespread application of fertilisers, pest and disease management and targeted water infrastructure investments. But despite the promise of a technologically-driven second *Green Revolution*, the biophysical capacity of Australia's landscapes to regulate their natural water and nutrient resources has been severely compromised. Ripl [26] characterises the inexorable downward spiral of landscape productivity in the following way: "…In terms of food production, self-organising landscape processes are replaced by agricultural practices oriented towards net output. Vegetation cover has been cleared, sub-surface water tables have been depleted and organic soil layers mineralised. The feedback control process of the water table through plant evapotranspiration has been interrupted. Thus, a short-term net productivity is gained at the cost of long-term landscape ageing…".

Whether this is an irreversible trend is the crucial question now facing landscape managers, farmers, rural communities and policy-makers alike.

3 Innovations for landscape regeneration

3.1 Rethinking landscape management along ecological lines

A reappraisal is currently underway within Australia's modern farming context of the significance for sustainable landscape management of the fundamental biophysical processes that have operated for millennia [27]. A growing number of case studies is demonstrating that, by working *with*, rather than against, the linked functional processes that sustained the Australian landscape prior to European settlement, productive farming, cropping and pastoral enterprises can be supported without degrading the system. It is thereby feasible to recover a version of landscape stability for our present age.

This approach is consistent with key ecological principles: accumulating, self-organising, building and localised cycling of nutrients, energy (carbon) and water. It recognises that plant-dominated landscapes can work against the degrading and essentially one-way forces of drainage and material export that characterise so much of 21st Century agriculture in Australia and elsewhere.

Hydrologically, this process involves the reconnection of stream waters with their adjacent alluvial groundwater systems, promoting a form of natural irrigation. This entails the use of subsidiary water courses and flow-slowing structures within streams to recreate sequential, stepped wetlands and high-productivity riparian vegetation zones. The resulting re-connection of surface and alluvial water flows converts degraded watershed landscapes from a "drainage mode" to a "natural storage mode", with streamside floodplains effectively becoming grass-covered water reservoirs. Importantly, the permanent, water-filled stream channel exhibits perched features – that is, becoming raised (by sometimes as much as 12 metres) above the alluvial floodplain itself – producing a hydrostatic head of fresh water that effectively prevents saline water intruding from the surrounding hillslopes [21]. Given the significant productivity impacts of salinization of Australian soils, this feature has major implications for restoration of saline catchments.

Plants, as the natural drivers of terrestrial energy capture and distribution via photosynthesis and organic cycling, in their many and biodiverse forms, are an indispensable part of this process of restoring healthy landscape function. As well as providing an effectively zero-cost means of organic matter production, plants act as essential pioneer repair instruments by colonising the various niche habitats for nutrient and further biological aggradation.

3.2 The *Natural Farming Sequence*

The *Natural Farming Sequence* (or, in some publications, *Natural Sequence Farming*) is a term coined by the Australian natural scientist Peter Andrews. Andrews has, for the past 40 years, been observing and interpreting the landscape rehydration process, and was awarded the Order of Australia Medal in 2011 for service to conservation and the environment through the development and promotion of sustainable farming practices [28]. He conceives the "sequence" of a sustainable landscape function in the Australian context as follows: "…In Europe, the sequence by which the landscape operates is seasonal. In Australia, the sequence is not nearly so regular and it is not determined by seasons. The basic factors that control this landscape are the carbon-processing green surface area of plants and the water cycle, operating together in an interrelated sequence of processes. The event that sets the sequence in motion is rain. The key principle is re-coupling of the carbon cycle with the hydrological cycle, which together have the capacity to promote landscape fertility, on the one hand, and to moderate climatic extremes through evaporation, on the other…" [29].

There are six underlying tenets and processes for the renovation of landscapes for sustainable farm productivity, as applied under the *Natural Farming Sequence* approach comprise (Table 1).

Table 1: Six underlying tenets and processes in the *Natural Farming Sequence.*

1. **Centrality of local, daily water cycling**
   The repetitive, rapid cycling of water through evapotranspiration by intact vegetation (the "daily water cycle") supplies constant recycled water for ecosystem processes, while acting to limit fertility (nutrient and carbon) losses from the soil profile, thus arresting soil degradation [26, 30]. This is the only water a plant can receive that does not move environmental capital.
2. **Landscape cooling**
   The dissipation of incoming solar energy through evapotranspiration and condensation of dew plays a significant role in buffering diurnal temperature extremes and moderating landscape and atmospheric warming [8].
3. **Functional role for biodiversity**
   The proactive retention and recruitment of biodiverse flora and fauna in the landscape enhances ecosystem function by, *inter alia*, maximising leaf area index, promoting niche occupation for fertility build-up from the soil profile and from water-borne detritus, rapid nutrient recycling and repair of impoverished soil [31].
4. **Salinity management**
   The reinstatement and maintenance of a surficial "lens" of fresh groundwater, under positive hydrostatic pressure, prevents saline ingress [32]. Active accession of soil organic matter also ameliorates existing surface soil salinity [33, 34].
5. **Streamflow energy buffering and alluvial water recharge**
   Installation of low-cost kinetic energy dissipaters and sediment traps ("leaky weirs") acts to harness stream flood and fresh events for streambed rebuilding, re-establishment of chain of ponds configurations, and watering of floodplains [9, 35, 36].
6. **Active production and redistribution of organic matter**
   Recycling of organic matter (carbon/energy and the associated nutrients) in landscapes is typically interrupted under human management by loss of natural herbivores and export of surplus site primary productivity as crops, forage, etc. Hence landscapes under active management for production typically require interventions that redistribute biomass from lower to upper slopes including careful grazing management [21, 28].

Advocates and practitioners of *Natural Farming Sequence* interventions highlight the importance of adopting an *integrated* ('holistic') approach to harnessing these vegetated landscape functions, as distinct from working in a *reductionist* fashion. Attaining sustainably productive landscapes will therefore not principally be delivered through hydrology alone, nor through pedology, nor biodiversity management, but through a careful optimisation of all these domains within the farming complex [37].

4 Case studies of Australian farm landscape rehydration

Recent years have seen a growing awareness and promotion amongst decision-makers of the elements and promise of the *Natural Farming Sequence* in Australia and other parts of the world. This includes scientific investigations of the efficacy of these practices in reversing the impacts of land degradation and of implementing cost-effective sustainable landscape management (Table 2).

Table 2: Examples of Australian landscape rehydration projects and benefits.

*Tarwyn P*ark, Upper Bylong, NSW (32°26'56.6"S 150°08'59.1"E)
• Significant reduction in stream and floodplain salinity, and reversal of valley salinisation; low dissolved salts indicating reduced export of site’s nutrient capital [38]. • Increased pasture productivity and substantial agronomic and environmental improvements on the farm, with increased aquifer storage providing effective subsurface pasture irrigation; reduced velocities of stream and floodplain flow velocity, reducing channel incision and soil erosion; recreation of a "chain of ponds" system, colonised by dense reed beds; a sustainable farming system with very low inputs of chemical fertiliser through the effective internal cycling of nutrients [32]. • Major (positive) changes to soil chemical and biological properties [39].
Baramul, Widden Valley, NSW (32°33'09.2"S 150°21'35.3"E)
• Considerably greater residual stream pool depths in cease-to-flow periods, with pool water storage volumes quadrupled, and an increase in aquatic habitat [40]; enhanced stream bench development, with channel narrowing, accelerated by active recruitment of in-stream rheophytes such as *Casuarina cunninghamiana* [41]; enhanced localised channel-floodplain hydrological connectivity in coarse-grained sediments - important for restoring hyporheic function [24]. • Indicated improvements in soil organic matter levels & cation-exchange capacity [42].
Mulloon Creek, via Bungendore, NSW (35°16'32.6"S 149°34'10.8"E)
• Progress on a series of research projects on 10,000 hectares of the Lower Mulloon watershed to reinstate alluvial hydration and to implement other sustainable farming practices [43]. • Significant reversal of channel and floodplain incision; reinstatement of chain-of-ponds system. • Evidence that the project is “banking” water during higher flows and maintaining higher low flows when the weather is dry. • Costs of flow-slowing installations assessed in terms of farm return [36].
Spring Creek, via West Wyalong, NSW (33°38'20.8"S 147°23'01.2"E)
• Spring Creek was originally chain-of-ponds and swampy meadow complex. The installation of rock weirs and other intervention structures is designed to arrest channel incision and to functionally reconnect Spring Creek and its floodplain [44]. • The work has resulted in enhanced sediment aggradation, extending to up to 100m above installed in-steam weirs; overland flow dissipation in vegetated riparian zone with reduced lateral stream bank erosion [45].

Table 2: Continued.

Jillamatong, via Braidwood, NSW (35°27'47.4"S 149°45'47.8"E)
• Following reinstatement of chain-of-ponds systems and other landscape rehydration interventions, farm productivity and profitability significantly improved; soil organic matter increased by several orders of magnitude; greater local recycling of nutrients; significant biodiversity improvements. Case Study #7 [10].
Gunningrah, Bombala, NSW (36°47'58.5"S 149°06'23.6"E)
• By constructing "leaky weirs", implementing cell grazing and fencing out stock from highly degraded riparian areas, dependency on rainfall *per se* was reduced through more effectively management of water flowing *through* the landscape; pasture growing periods have increased and there is greater continuity of streamflow within and downstream of the farm. Case Study #8 [10].
Tallawang, Willow Tree, NSW (31°45'39.6"S 150°21'12.9"E)
• Intervention works comprising weirs, swales and contour banks were undertaken to manage erosion, soil compaction, impoverished pastures and severely eroded drainage lines; Cell grazing was established for pasture management. • Overall landscape hydrology has improved, with more water now retained in the landscape for plant and stock availability; soil organic matter levels and vegetation cover have increased. Case Study #10 [10].
Gumlu, Rocky Ponds Creek, via Bowen, Qld (19°50'31"S 147°37'39"E)
• Flow-retarding structures enabled a complete halt to the pumping of bore water and recharging of aquifers; a 75% reduction in salinity; improved productive land capacity; a 70% reduction in needed water supply. • Approx 85% reduction in pesticide use; 20% reduction in use of artificial fertiliser; 30% reduction in herbicide use with significantly reduced runoff onto the Great Barrier Reef. • The Gumlu property is now drought proof for up to two years with salinity levels continuing to decline [46].
Mulwarree River catchment area, via Goulburn, NSW (34°49'37"S 149°40'15"E)
• Reinstatement, through various interventions, of chain-of-ponds features across multiple farming properties in the catchment area. • Establishment of biodiverse vegetation for land repair and grazing management. • Use of composted urban/municipal waste as a soil amendment [47].

There is a diversity of experiences of, and outcomes from, implementation of the principles of the *Natural Farming Sequence* in the above case studies. All warrant further technical evaluation of the long-term benefits of such interventions for enhancement of farm productivity and profitability. However there is already an emerging consensus amongst Australian landscape scientists and managers that the holistic *Natural Farming Sequence* approach can offer a low-cost, productive alternative to conventional high-input agricultural practices [9].

5 Landscape rehydration and climate moderation

In addition to enhanced benefits for productivity and ecological integrity of landscapes from rehydration interventions, there is evidence that mesic landscapes contribute to climate stability [8, 26, 30]. Two principal processes are in play, one at regional scale and one operating more locally.

At the regional scale forested landscapes contiguous with coastlines are thought responsible for “pumping” maritime moisture-laden air onto the land through evapotranspirational flux [22, 48]. It appears that complex natural forests with high leaf-area index will deliver the most precipitation via this ‘biotic pump’ mechanism, while sparser savannas will deliver the least [49]. Productive farming landscapes, including those rejuvenated by the types of interventions described earlier, which include extensive belts of upper slope closed-canopy forest, can be expected to have the potential to also contribute in this way.

The second, and perhaps more far-reaching, implication of rehydrated vegetated landscapes for climate moderation is their contribution to dissipation of incoming solar energy through the daily water cycle [8]. This cooling value of rehydrated landscapes, until now little acknowledged in mainstream climate science discussions, can be shown to be a far more significant contributor to climate moderation than sequestration of carbon dioxide [30]. Such a recognition adds a significant dimension to the opportunities landscape rehydration offer for Australia’s and the world’s farming future.

6 Conclusions

Researchers in parts of Europe have sought to apply the science of landscape rehydration to policy reform for management of farming, nature conservation and urban lands [50]. Mainstream Australian thinking and policy on integrated farm and landscape management still lags behind. However where a landscape rehydration management approach has been adopted in Australia it has delivered greater water reliability to farmers, improved soil organic content and reduced reliance on high-cost chemical inputs. The collateral benefits of biodiversity protection, reduced bushfire impacts, and buffering the impacts of climate extremes add significant weight to the urgency of progressing this opportunity.

The wider, informed adoption of interventions aimed at producing sustainable rehydrated farming landscapes, matched by priority legislative, promotional and market support, would provide a sound, low-cost basis for reversing landscape degradation across Australia and around the globe.

References

[1] United Nations, *World Population Prospects: The 2012 Revision*. New York, 2013. Online esa.un.org/wpp.
[2] Cribb, J., *The Coming Famine – The global food crisis and what we can do to avoid it.* CSIRO Publishing, Melbourne, 2010.
[3] United Nations Environment Programme, *Assessing Global Land Use: Balancing Consumption with Sustainable Supply*. Report of the Working Group on Land and Soils of the International Resource Panel. Nairobi, 2014.
[4] United Nations Convention to Combat Desertification, *Desertification – The Invisible Frontline,* Second Edition, Bonn, 2014. Online www.unccd.int.

[5] State of the Environment Committee, *Australia state of the environment 2011 report*. Independent report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities, 2011.

[6] Cifor, *Interactive Map of Landscape Approaches to Land Management*. Outcomes Statement from Global Landscapes Forum, Lima, Peru, 6–7 December, 2014. Online www.cifor.org/landscape-map.

[7] Tane, H., Restoring Watershed Systems by converting to Natural Sequence Farming. *Proc. first Natural Sequence Farming Workshop, Natural Sequence Farming – Defining the Science and the Practice*, eds. Hazell, P. & Norris, D., Bungendore NSW, Australia, 2006.

[8] Kravcík, M., Pokorný, J., Kohutiar, J., Kovác, M. & Tóth, E., *Water for the Recovery of the Climate – A New Water Paradigm*. Krupa Print, 2007.

[9] Williams, J., The principles of Natural Sequence Farming. *Int. J. Water* **5(4)**, pp. 396–400, 2010.

[10] Soils for Life, *Innovations for Regenerative Landscape Management – Case studies of regenerative land management in practice*. Outcomes Australia, Soils for Life Program. 2012. Online www.soilsforlife.org.au.

[11] Quigley, M., Clark, D. & Sandiford, M., Tectonic geomorphology of Australia. *Australian Landscapes,* eds. Bishop, P. & Pillans, B., Geological Society, London, Special Publications, **346** pp. 243–265, 2010.

[12] Habeck-Fardy, A. & Nanson, G. C., Environmental character and history of the Lake Eyre Basin, one seventh of the Australian continent. *Earth-Sci. Rev.*, **132** pp. 39–66, 2014.

[13] Cohen, T.J., Nanson, G.C., Jansen, J.D., Jones, B.G., Jacobs, Z., Larsen, J.R., May, J.-H., Treble, P., Price, D.M. & Smith, A.M., Late Quaternary mega-lakes fed by the northern and southern river systems of central Australia: Varying moisture sources and increased continental aridity. *Palaeogeog., Palaeoclimatol., Palaeoecol.,* **356/357**, pp. 89–108, 2012.

[14] Hogendyk, G., The Macquarie Marshes – an ecological history. *Inst. Pub. Affairs. Occas. Pap.*, Sept, 2007.

[15] O'Brien, P.E. & Burne, R.Y., The Great Cumbung Swamp – terminus of the low-gradient Lachlan River, Eastern Australia. *AGSO J. Aust. Geol. & Geophys.*, **15(2)**, pp. 223–233, 1994.

[16] Fluin, J., Haynes, D. & Tibby, J., *An Environmental History of the Lower Lakes and the Coorong*. A report prepared for the South Australian Department for Environment and Heritage, Adelaide, 2009.

[17] Zierholz, C., Prosser, I.P., Fogarty, P.J. & Rustomji, P., In-stream wetlands and their significance for channel filling and the catchment sediment budget, Jugiong Creek, New South Wales, *Geomorphology* **38**, pp. 221–235, 2001.

[18] Mactaggart, B.G., Bauer, J. & Goldney, D.C., When History May Lead us Astray: using historical documents to reconstruct swampy meadows/chains of ponds in the New South Wales Central Tablelands, Australia. *Aust. Geog.* **38(2)**, pp. 233–252, 2007.

[19] Knighton, A.D. & Nanson, G.C., Waterhole form and process in the anastomosing channel system of Cooper Creek, Australia. *Geomorphology*, **35**, pp. 101–117, 2000.
[20] Rule, S., Brook, B.W., Haberle, S.G., Turney, C.S.M., Kershaw, A.P., & Johnson, C.N., The Aftermath of Megafaunal Extinction: Ecosystem Transformation in Pleistocene Australia. *Science* **335**, pp. 1483–1486, 2012.
[21] Andrews, P., *Back from the Brink: How Australia's Landscape Can Be Saved*, ABC Books, Sydney, 2006.
[22] Macarieva, A.M. & Gorshkov, V.G., Biotic pump of atmospheric moisture as driver of the hydrological cycle on land. *Hydrol. Earth Syst. Sc.* **11**, pp. 1013–1033, 2007.
[23] Scott, A., Water erosion in the Murray-Darling Basin: Learning from the past, *CSIRO Land and Water Technical Report* **43/01**, Canberra, 2001.
[24] Keene, A.F., Bush, R.T. & Erskine, W.D., Connectivity of stream water and alluvial ground water around restoration works in an incised sand-bed stream, *Proc. 5th Aust. Stream Manage. Conf. Australian rivers: making a difference.* Charles Sturt University, Thurgoona, NSW, 2007.
[25] Jones, C.E., *Our soils, our future. Australian Soil Carbon Accreditation Scheme*, Armidale, NSW, 2008. Online www.amazingcarbon.com
[26] Ripl, W., Losing fertile matter to the sea: How landscape entropy affects climate. *Int. J. Water* **5(4)**, pp. 353–364, 2010.
[27] Williams, J. & Gascoigne, H., Redesign of plant production systems for Australian landscapes, *Proc. 11th Aust. Agron. Conf.*, Geelong, Vic., 2003.
[28] Andrews, P., *Beyond the Brink: Peter Andrews' radical vision for a sustainable Australian landscape*, ABC Books, Sydney, 2008.
[29] Norris, D. & Andrews, P., Re-coupling the carbon and water cycles by Natural Sequence farming. *Int. J. Water* **5(4)**, pp. 386–395, 2010.
[30] Eiseltová1, M., Pokorný, J., Hesslerová, P. & Ripl, W., Evapotranspiration – A Driving Force in Landscape Sustainability, *Evapotranspiration, Remote Sensing and Modelling*, ed. A. Irmak, InTech, 2012. Online www.intechopen.com.
[31] Cardinale, B.J., Matulich, K.L., Hooper, D.U., Byrnes, J.E., Duffy, E., Gamfeldt, L., Balvanera, P., O'Connor, M.I., & Gonzalez, A., The Functional Role of Producer Diversity in Ecosystems. *Amer. J. Bot.* **98(3)**, pp. 572–592, 2011.
[32] CSIRO, *Expert Panel Report: The "Natural Farming Sequence". Tarwyn Park, Upper Bylong Valley, New South Wales*, CSIRO Land & Water, Canberra, 2002.
[33] Tunstall, B., Dryland Salinity Implications of Interactions Between Clay, Organic Matter, Salt and Water in Soils. *ERIC Research Papers*, Canberra, 2005. Online www.eric.com.au/html/papers_salinity.php.
[34] Bann, G.R. & Field, J.B., Dryland Salinisation in Southeastern Australia: Processes, Fallacies and Sustainable Natural Resource Management, *Int. J. Environ., Cultural, Econ. & Social Sustainability* **3(2)**, pp. 155–163, 2007.
[35] Bush, R., Keene, A., Erskine, W., Sullivan, L., White, I., Bowman, G., Bowling, L., Cheetham, M. & Somerville, P., *Restoring hydrological*

connectivity of surface and ground waters: Biogeochemical processes and environmental benefits for river landscapes, Report of ARC Linkage research program, Widden Valley, NSW, Southern Cross Uni., Australia, 2010.
[36] Dobes, L., Nathan, A.C., Weber, B., Bennett, J.A. & Ogilvy, S.B., Streambed and flood-plain rehabilitation at Mulloon Creek, Australia: a financial and economic perspective. *The Rangeland Journal* **35(3)**, pp. 339–348, 2013.
[37] Stapper, M., *Soil Fertility Management: Towards Sustainable Farming Systems and Landscapes*. CSIRO Sustainability Network, Update 61E, 2006.
[38] Anderson, P., *A hydrogeological investigation of the Natural Farming Sequence applied in the Bylong Valley at Tarwyn Park Property*. M.Sc. Thesis. National Centre for Groundwater Management, Uni. Technology, Sydney. 130 pp., 1997.
[39] Weber, N. & Field, J., The influence of Natural Sequence Farming stream rehabilitation on upper catchment floodplain soil properties, Hunter Valley, NSW, Australia. *19th World Congress of Soil Science, Soil Solutions for a Changing World*, August, Brisbane, 2010.
[40] Keene, A.F., Bush, R.T., Cheetham, M.D., & Erskine, W.D., Pool-riffle reformation and bed armouring induced by structures and riparian revegetation that sequester sand, Proc. of symposium: Sediment Dynamics in Changing Environments, Christchurch, N.Z. *IAHS Publication* **325**, pp. 576−583, 2008.
[41] Erskine, W.D., Chalmers, A., Keene, A., Cheetham, M., & Bush, R., Role of a rheophyte in bench development on a sand-bed river in southeast Australia. *Earth Surf. Process. Landforms* **34**, pp. 941-953, 2009.
[42] Rogers, G. & Bauer, B., Preliminary Investigation of effects of Natural Sequence Farming (NSF) on soil organic matter levels and nutrient uptake at Baramul. *Proc. first Natural Sequence Farming Workshop, Natural Sequence Farming – Defining the Science and the Practice*, eds. Hazell, P. & Norris, D., Bungendore NSW, Australia, 2006.
[43] Mulloon Institute. Research Report Summaries. 2014. Online www.themullooninstitute.org/research/current-research-projects.
[44] Johnston, D. & Carnegie, M., *Natural Sequence Farming: Catalyst for riparian restoration in semi-arid Australia - Project planning & implementation*. Lake Cowal Foundation Report, 2008.
[45] Streeton, N.A., Greene, R.S.B, Marchiori, K., Tongway, D.J. & Carnegie, M.D., Rehabilitation of an incised ephemeral stream in central New South Wales, Australia: identification of incision causes, rehabilitation techniques and channel response. *The Rangeland J.* **35**, pp. 71–83, 2013.
[46] The Natural Edge Project. *Water Transformed: Sustainable Water Solutions for Climate Change Adaptation,* 2009. Online www.naturaledgeproject.net
[47] McKay, J., A case study in land and water regeneration to reduce the impact of climate change by soil bio-sequestration of atmospheric carbon. *Interdi. Environm. Rev.* **11(2)**, pp. 224–235, 2010.

[48] Sheil, D. & Murdiyarso, D., How forests attract rain: an examination of a new hypothesis. *Bioscience* **59(4)**, pp. 341–347, 2009.
[49] Macarieva, A.M, & Gorshkov, V.G., The biotic pump: condensation, atmospheric dynamics and climate. *Int. J. Water* **5(4)**, pp. 365–385, 2010.
[50] Ripl, W. & Hildmann, C., Dissolved load transported by rivers as an indicator of landscape sustainability. *Ecol. Eng.* **14**, pp. 373–387, 2000.