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Expert Panel Report:

The "Natural Farming Sequence"

Tarwyn Park
Upper Bylong Valley
New South Wales

A report prepared for the Honourable John Anderson MP, Deputy Prime Minister of Australia

July 2002

Executive Summary

In response to a request from the Honourable John Anderson MP, Deputy Prime Minister of Australia, CSIRO Land and Water formed an "Expert Panel" to assess the "Natural Farming Sequence" (NFS) as implemented at Tarwyn Park in the upper Bylong valley, New South Wales. The panel included expertise in hydrogeology, surface water hydrology, fluvial geomorphology, biogeochemistry, dryland salinity, landscape ecology, agricultural systems and agricultural economics. The panel made its assessment on the basis of professional interpretations of verbal and written descriptions of NFS, and an inspection of Tarwyn Park on 23 May 2002. The lack of quantitative data and the limited resources for the study precluded quantitative assessment.

NFS can be viewed as an agricultural approach based on understanding landscape and biological processes and implementing practices compatible with these processes to achieve sustainability. The panel endorses this general approach, but notes that the achievability and the cost-effectiveness of such an approach depends upon the landscape and the farm enterprise. The panel only assessed NFS as implemented as Tarwyn Park, and comments on the applicability of the particular practices used at Tarwyn Park in other landscape settings. The practices required for the application of NFS in other settings have not been demonstrated or documented, and so cannot be assessed.

The panel believes that NFS is a successful and sustainable farming system for the current enterprise at Tarwyn Park, where it has led to substantial agronomic and environmental improvements on the property. Central to the implementation of NFS at Tarwyn Park is the manipulation of the hydrologic regime, that has increased aquifer water storage providing effective sub-surface pasture irrigation. This has substantially increased pasture productivity, and avoids the evaporative water losses that occur with surface irrigation.

Small structures have been used to spread stream flows out across the floodplain and to dam the stream channel at several locations. This has reduced the velocities of stream flow and floodplain flow, reduced channel incision and soil erosion, and leading to sedimentation in the stream channel and on the floodplain. The deposition in the incised stream channel has been sufficient to recreate a "chain of ponds" system, colonised by dense stands of reeds.

The evaporation and evapo-transpiration losses associated with the more natural stream system are higher than for the previous degraded incised channel. The reductions in floodplain evaporation are probably largely offset by increases in channel evaporation and evapo-transpiration, and there is little evidence to indicate substantial changes in the total streamflow downstream. However, where channels are incised and surface irrigation of the floodplain is not used, implementation of NFS would reduce total streamflow volumes, returning them closer to natural. Importantly, the manipulation of the hydrologic regime together with changed land management on the flanking saline soils, is likely to have reduced the export of salt from the property.

Increases in floodplain pasture productivity have been achieved primarily as a result of changes to the hydrologic regime, but enhanced by various non-structural management measures that promote soil structure and nutrient status. Because the current enterprise exports little agricultural biomass, the system at Tarwyn Park is sustainable with very low inputs of chemical fertiliser. Important to this sustainability is the effective internal nutrient cycling that NFS achieves. Sustainability of NFS at Tarwyn Park is enhanced by the elevated water flows and sediment and nutrient loads that are currently received from upstream as a result of catchment disturbance and conventional agricultural practices. The increases in pasture productivity appear to translate into increases in economic productivity, and hence the relatively small financial investments required by NFS implementation are likely to have substantially increased the profitability and market value of the property.

NFS has done little to address issues of native biodiversity and landscape ecology at Tarwyn Park. There is low species diversity in the riparian and stream plant communities, and a near absence of remnant native trees on the farmed hillslopes. These plant communities are therefore expected to provide little habitat for birds and other terrestrial fauna.

The suite of practices implemented for NFS at Tarwyn Park are only appropriate for local groundwater systems (recharge and discharge areas within a few kilometres of each other) dominated by fresh groundwater in porous floodplain sediments. The occurrence of these groundwater systems has been mapped across Australia by the National Land and Water Resources Audit. In addition, this suite of practices is only appropriate in floodplain systems that are confined by valley walls, and that prior to European settlement were characterised by a “chain of ponds” stream rather than an incised channel. The panel indicates which of these practices may be applicable in other settings. Full application of NFS in other settings would require different suites of practices yet to be determined, some of which would require management at scales far greater than the property-scale. For example, in regional groundwater systems application of NFS would require management of recharge areas that extend far beyond the property-scale, and therefore beyond the direct control of single property managers.

The panel notes that the level of productivity achievable on a property under NFS is not independent of the management of upstream properties. NFS moves stream flow, and sediment and nutrient loads leaving a property closer to the natural condition, hence implementation on one property would reduce the productivity of sustainable implementation downstream. However, it is the opinion of the panel that a scenario of more widespread application of the NFS practices used at Tarwyn Park–within the compatible areas identified–would most likely represent a more environmentally appropriate and sustainable form of grazed pasture agriculture than that which is currently typical in such environments.

Introduction

In March 2002 the Honourable John Anderson MP, Deputy Prime Minister of Australia, requested that CSIRO undertake an "Expert Panel" assessment of the "Natural Farming Sequence" (NFS) implemented by Mr Peter Andrews on the property Tarwyn Park, in the Upper Bylong valley, New South Wales. This report documents the panel's assessment.

The terms of reference for the Expert Panel assessment were as follows:

1. Describe the NFS as implemented at Tarwyn Park
2. Determine the environmental and agricultural issues that the NFS addresses
3. Describe the changes that occurred at Tarwyn Park as a result of the implementation of the NFS on the basis of professional judgement, and existing data and documents
4. Consider the extent to which NFS could be implemented elsewhere, with similar results to those achieved at Tarwyn Park.

CSIRO assembled the following panel of experts to undertake the assessment:

1. Dr William Young (panel leader), CSIRO Land and Water–fluvial geomorphology, surface water hydrology, biogeochemistry
2. Mr Ray Evans, Salient Solutions–hydrogeology, dryland salinity
3. Dr Jon Olley, CSIRO Land and Water–fluvial geomorphology, biogeochemistry
4. Mr Nick Milham, NSW Agriculture–agricultural economics
5. Professor Alistar Robertson, Charles Sturt University–landscape ecology, biogeochemistry
6. Dr Chris Smith, CSIRO Land and Water–agricultural systems.

Resourcing of the Expert Panel was limited to five days of panel members' time which allowed:

1. familiarisation with existing documents
2. inspection of Tarwyn Park with explanations of NFS by Mr Andrews
3. panel workshop to discuss NFS and consider its potential wider applicability
4. writing of Expert Panel assessment report.

As the panel only visited Tarwyn Park, the assessment of NFS is limited to its implementation at Tarwyn Park. In the panel's opinion, most of the reports of prior scientific studies are of poor quality. Because of this, and the resource restraints placed on the panel, the assessments are qualitative, based on professional interpretation of observations made at Tarwyn Park. Furthermore, it should be noted that very little data to describe conditions at Tarwyn Park before the implementation of NFS exist, and the panel did not have the opportunity to view comparable properties in the region–with or without NFS.

Expert Panel Description of NFS at Tarwyn Park

Tarwyn Park is a 1,190 hectare property in the Upper Bylong valley in the headwaters of the Hunter River catchment, New South Wales. It is operated as a thoroughbred horse stud. The majority of the property is a floodplain (280 metres above sea level) consisting of 10–15 metres of Quaternary alluvial sands and gravels underlaid by the sandstones, shales and conglomerates of the Singleton coal measures, and surrounded by massive sandstone escarpments rising to over 600 metres above sea level.

Mr and Mrs Andrews purchased Tarwyn Park in 1973. Mr Andrews asserts that at that time, Tarwyn Park was characterised by an incised stream channel, surface salting on parts of the floodplain, degraded soils, and "monoculture" pasture of low productivity. Floodplain pastures were spray irrigated with water pumped from shallow groundwater. To address these issues Mr Andrews developed a mental model of how the landscape (hillslopes, floodplain and river channel) would have appeared and functioned prior to European settlement of the catchment, using historic flow and vegetation cover information. He sought to understand the key hydrologic and biogeochemical processes that drive the system, and through process of trial and error over many years, he manipulated these processes to restore important aspects of system function. He has not sought to return the landscape to its former condition, but rather to restore natural processes to the extent necessary to enable a productive farming system. He has labelled this approach to agriculture by understanding and working within the constraints of hydrologic and biogeochemical processes as the Natural Farming Sequence (NFS).

The implementation of NFS at Tarwyn Park is manifested as a combination of structural and non-structural management measures that have altered the water, salt (major ions – calcium, magnesium, sodium, chloride, alkalinity, sulphate)[1], and nutrient (carbon, nitrogen and phosphorus) balances of the property, and that have increased farm productivity. The structural measures include:

- grade-control structures in the stream line
- contour banks on the floodplain and at the hillslope-floodplain break of slope
- contour channels diverting water away from the stream line.

These structural measures serve to increase the residence time of water on the property by diverting floodwaters from the stream to the floodplain and hence increasing shallow aquifer recharge, and by decreasing water velocities in the channel and on the floodplain. This hydrologic manipulation at Tarwyn Park has been possible because the groundwater system is contained within the coarse alluvial material of the floodplain and is bounded below by bedrock. This allows substantial recharge, limits deep drainage, and allows maintenance of high water tables across the floodplain (Figure 1).

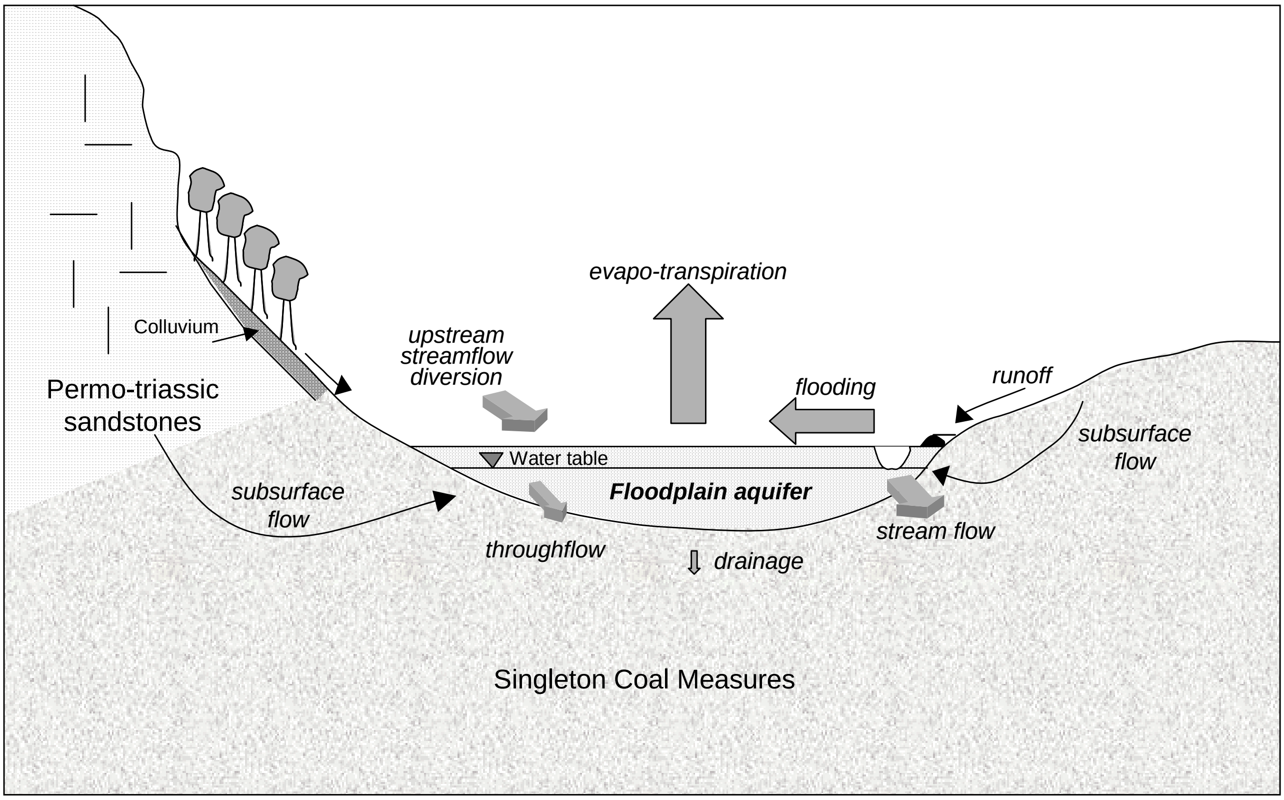

Figure 1. Cross-section of floodplain and surrounding geologic units. The relative magnitude of water fluxes in the overall water balance are indicated approximately by the size of the arrows.

The older rocks that underlie the floodplain and form the hills and rises are composed of two main rock types–the Permo-Triassic sandstones of the higher hills and escarpments, and the inter-bedded shales, sandstones and coals of the underlying Singleton Coal Measures. Both these rock units are fractured and will transmit groundwater. However, under natural conditions, the contribution of groundwater to the floodplain environment would be small compared with the volume of water moving longitudinally down the floodplain. The Singleton Coal Measures have a very high salt content, and when weathered, produce clays that are

[1] There is some confusion regarding the use of the term "salts". In discussions with Mr Andrews about the NFS system, it became evident that all salts were grouped under the one term, and that discussion of the role of salt movement was clouded by alternate reference to the labile salts versus the nutrient salts. This report has adopted the terminology of salt as the major elements generally found as dissolved components of water (namely, calcium, magnesium, sodium, chloride, sulphate and those associated with alkalinity) and nutrients as those salts that are used in the process of plant production (namely nitrogen, carbon and phosphorous). It is acknowledged that some of the former salts are used by plants, but the panel believes the distinction introduced is more relevant to the discussions of broader natural resource management.

expansive and dispersive. In areas where land use has increased the water flux moving through them, very high salt fluxes have resulted. These salt fluxes are usually manifest as salinity outbreaks at the junction of the floodplain and the flanking lower slopes. In terms of the overall salt budget for the valley, disturbed Singleton Coal Measures would be the dominant salt source.

The contour banks introduced under NFS at the hillslope-floodplain break of slope collect surface and sub-surface drainage from the hillslopes. They are clay-lined to minimise infiltration, have no surface flow outlet, and so collected water is either lost by evaporation or flushed out by high floods. These structures therefore prevent most salt from the hillslopes (either from overland flow or from shallow seepage) reaching the floodplain aquifer. However, this salt is only stored temporarily in these ponds, and will be periodically flushed by floods and transported downstream.

These hydrologic changes have caused increased sedimentation both in the stream lines and on the floodplain. The sedimentation in the stream line has led to the recreation of a "chain of ponds" (*sensu* Eyles, 1977) with substantial growth of aquatic macrophytes. These hydrologic changes, and particularly the way in which the stream water is allowed to artificially recharge the floodplain aquifer, have ensured that root zone salt build-up from evapo-transpirational processes is minimal, with the majority of salts either flushed vertically downward into the lower parts of the aquifer or moved laterally further down the floodplain. A crucial factor that seems to be promoting sustainability in the instance of Tarwyn Park is the very low salinity of the stream water that is being used as the feed water for the artificial recharge. As a consequence, there is a large assimilative capacity for salt storage in the floodplain system.

The non-structural measures include:

- avoidance of surface (typically spray) irrigation
- avoidance of herbicide use
- minimal use of chemical fertilisers (small amounts are used for lucerne crops)
- avoidance of ploughing on the hillslopes
- avoidance of storing water in dams on areas underlain by the Singleton Coal Measures
- minimisation of cultivation on the floodplain
- redistribution of nutrients (in the forms of animal excreta, harvested aquatic plant mulch and horse stable wastes) to the head of the floodplain and onto hillslopes
- a grazing regime managed to promote a succession of pasture species from a dominance of less palatable annual broad-leaf species to a dominance of more palatable perennial grasses.

These non-structural measures serve to increase pasture productivity, increase soil organic carbon levels, and increase the residence times of nutrients on the property. The improved ground cover and minimal cultivation helps minimise soil erosion, avoids soils compaction and maintains soil structure. While the non-structural measures do appear to have increased pasture productivity, it is the alterations to the water balance that have been achieved that are most important for the increased productivity. It is a combination of the non-structural measures on the Singleton Coal Measures and the structural measures on the floodplain that are most important in achieving a low salt flux from the system as a whole.

Environmental and Agricultural Issues Addressed by NFS

Although Mr Andrews began works at Tarwyn Park to address low productivity and a perceived dryland salinity problem, the more complete NFS as now implemented addresses a far wider range of issues. The panel believes the following major issues are addressed by NFS at Tarwyn Park:

- low floodplain productivity
- elevated salt export
- salt intrusion into the root zone of floodplain soils
- channel erosion
- hillslope erosion
- low functional diversity of pastures
- poor nutrient retention in plant-soil system
- unnatural surface–groundwater hydrology.

Changes at Tarwyn Park as a Result of NFS

There is little data to describe the current water, salt, and nutrient balances of Tarwyn Park, and no data to describe levels of productivity. Furthermore, there are no data to describe conditions at Tarwyn Park before the implementation of NFS. Our assessments of the changes that have occurred at Tarwyn Park are therefore qualitative, based on observation and our interpretation of the verbal and written descriptions of changes due to NFS with which we were provided. These changes are summarised below in terms of material balances (water, salt, sediment, and nutrients), productivity, landscape biodiversity, and farm economics.

Water Balance
Relative to the situation that existed when Mr and Mrs Andrews purchased Tarwyn Park (incised channel and spray irrigation of floodplain pastures), NFS has increased the volume of water stored in the floodplain aquifer and decreased the direct evaporation of water from the floodplain surface. Evapo-transpiration by floodplain pasture is probably similar to pre-NFS. The decreases in floodplain evaporation are probably largely offset by increases in direct evaporation from the reinstated "chain of ponds", and by evapo-transpiration of the re-established stream vegetation. Consequently, the total volume of stream flow leaving the property is unlikely to have changed greatly, although Mr Andrews asserts that downstream flows have increased. Although stream flows are unlikely to have changed greatly, there will be an increase in the volume of groundwater leaving the property by sub-surface flow once a new groundwater equilibrium is reached. Overall the changes to the water balance appear to have moved the system closer to what the natural condition is expected to have been. It should be noted that where channels have incised but where surface irrigation is not used or is minor, stream flows are higher than natural as there is little water storage and little direct evaporation or evapo-transpiration. Implementing NFS as applied at Tarwyn Park in these situations would reduce downstream stream flow.

As a result of the increased aquifer storage, water-tables are generally within capillary reach of the pasture root zone, thus providing effective sub-surface irrigation. The aquifer recharge has been achieved by spreading flood flows out across the floodplain, by slowing the velocity of floodplain flows, and by diverting in-channel flows down contour channels to "irrigate" floodplains. While a previous study estimated a gross water balance for Tarwyn Park, this was based on a poorly conceived conceptual model, several untested assumptions and few data. Improved data and quantitative modelling of the current and prior water balances would be required for a more reliable and accurate description of the changes that have occurred to the water balance.

NFS has also reduced the amount of structural disturbance on the lower hillslopes flanking the floodplain, which results in lower deep drainage fluxes under these soils. This is accomplished via a program of organic enrichment of the soils that leads to greater plant productivity (and hence evapo-transpiration). Whether this has reduced deep drainage to pre-development levels is unknown.

Salt Balance
Changes in the salt (major ions) balance of Tarwyn Park have been effected by the changes in the water balance described above, as well as to the reduction in disturbance to the major salt store. On the floodplain, the current hydrologic regime keeps salt flushed from the pasture root zone, and increases the long-term store of salt in water deeper in the floodplain aquifer. The increase in watertable levels on the floodplain will establish a new base level for seepages from the adjacent hills. In the short term, this will decrease the salt flux from these surrounding sources, but will have little effect in the long term. The critical aspect of NFS in relation to the decreased salt fluxes from the surrounding Singleton Coal Measures is the reduction in deep drainage on the hillslopes, rather than the blocking effect of the increased water levels on the floodplain. It is likely that the salt concentrations in streamflow have been reduced, and even allowing for an increased salt load coming from groundwater baseflow, the total salt loads entering the Bylong River downstream are likely to have been reduced. However, both the long-term change in salt concentration in floodplain groundwater (and its contribution to the overall salt balance via its impact on baseflow in the stream) and the long-term change in the gross salt balance for the property are unquantified. The time required for the system to reach a new equilibrium (where salt inflows equal salt outflows) is unknown, but is expected to be the order of decades. In terms of salinity management for Tarwyn Park, the current operation of NFS is therefore probably sustainable for several decades. Further long-term reduction in salt loads leaving the property could

probably be achieved by planting deep-rooted vegetation on the hillslopes[2] to increase evapo-transpiration in these areas and reduce surface and sub-surface runoff to the floodplain.

Sediment Balance
Erosion in the catchment upstream of Tarwyn Park delivers a substantial sediment (and associated nutrient) load to the property, mainly during flood events. The majority of this incoming sediment load appears to be deposited on the property and there is no evidence of substantial erosion on the property. Deposition is achieved by reducing the hydraulic grade along the stream line, reducing flow velocities on the floodplain, maintaining vegetative cover in the channel, on the floodplain and on the hillslopes, avoiding cultivation of the hillslopes, minimising cultivation of the floodplain, and creating and managing a lightly grazed riparian paddock. At present therefore, Tarwyn Park appears to be a net sink for sediment. Over time (all other things being equal), the available sediment stores will fill and an equilibrium will be reached where sediment inflows equal sediment outflows. While the recreation of a chain of ponds along the stream line suggests that a substantial proportion of the channel store has already been filled, the floodplain store can be expected to continue to accumulate sediment for at least several decades and maybe many hundreds of years at current rates of deposition.

Nutrient Balance
The net deposition of sediment at Tarwyn Park also indicates an accumulation of sediment-associated nutrients, particularly phosphorus and organic carbon. In addition the reduction in streamflow leaving the property suggests a reduction in the loss of nutrients in dissolved forms. The pasture management that is in place is expected to have increased the stores of organic carbon in the soil, particularly through the mulching of less palatable perennial plants. Soil nitrogen stores are also likely to have increased through increased nitrogen fixation. Productive exports from the property that represent nutrient “losses” are limited to the sale of cattle, and minor increases in horse biomass through agistment. Overall, nutrient retention on the property appears to be high – nutrient inputs and outputs are low, and nutrient recycling appears to be effective. Small amounts of phosphorus fertiliser are currently used for lucerne fodder crops. The change in the hydrologic regime can be expected to have increased the release of mineral phosphorus from the soil through the more frequent cycles of soil wetting and drying. Phosphorus chemically desorbs from clay particles during the anoxic conditions of a saturated soil, and is solubilized by microbial activity during the oxic conditions of an unsaturated soil. In the longer term, the system should be fully sustainable in terms of nitrogen and carbon. However, as phosphorus is ultimately sourced from the weathering of catchment geology, even low rates of phosphorus export from the farm system will in the long term probably amount to a net loss. At present, however, as a net sink for sediment, the system is most probably also a net sink for phosphorus. In any case, the soils at Tarwyn Park are rich alluvial soils with a large store of phosphorus, and even in the absence of continued deposition, could probably be ‘mined’ for decades before phosphorus availability would limit pasture production.

Productivity
Productivity – as measured by net primary productivity – appears to have been increased on average and reduced in variability at Tarwyn Park as a result of improved provision of water to the pasture root zone, and as a result of management that maintains or improves soil nutrient status. By encouraging the growth of both annual and perennial plant species (including legumes) in early successional stages of the pasture, year-round growth is achieved and larger amounts of atmospheric carbon and nitrogen are fixed into plant biomass. While various aspects of NFS maintain or improve soil nutrient status, pasture growth on these rich alluvial soils is unlikely to have ever been limited by nutrient availability. Nor is the ability of the plants to convert atmospheric carbon into plant biomass limited by available energy (sunlight). Rather, it is moisture availability that will limit production. The changes in the hydrologic regime are therefore critical to the increased productivity. In spite of the substantial increases, productivity is probably substantially less than the maximum possible, as moisture availability while increased, is still partially controlled by the vagaries of the climate. Nonetheless, the energy costs involved in pumped, surface irrigation would offset the benefits

[2] Some trials of lucerne have been undertaken on the hillslopes underlaid by the Singleton Coal Measures. However, these trials were under irrigation and the end result was an increase in the amount of salt leaving the system. As well, it is generally accepted in the area that cultivation of these highly reactive soils for pasture establishment is a very risky undertaking. There appears to be resistance to trialling of dryland, deep-rooted pastures in these environments.

gained in extra production. Given the long-term sustainability of the changes to the hydrologic regime, the panel believes the increased production at Tarwyn Park is also sustainable in the long term.

Landscape Biodiversity
While the implementation of NFS at Tarwyn Park has increased the functional diversity of plant species within the pasture, biodiversity has not been increased on the property. The number of native plant species on the property is low, with all plant communities – floodplains, hillslopes, stream channel, and riparian zone – characterised by moderate to low species diversity. The pasture communities are the most diverse, although native species diversity and abundance in the pasture is very low. Because of the dominance of broad-leaf annuals in the pasture mix at certain times, it is likely that there is a significant export of the seeds of these species (for example, Paterson's curse (*Echium plantagineum*) and thistles (*Centaurea* spp.)) to downstream properties. To downstream landholders pursuing more conventional agriculture, this is undesirable.

The stream channel plant communities are dominated by the native common reed (*Phragmites australis*) and the invasive native rush cumbungi (*Typha* spp.). Both species grow vigorously especially in slow, nutrient-rich water. Although a native plant, cumbungi is sometimes viewed as a weed, as in some situations it will displace native emergent plants and sedges, reducing a diverse stream or billabong community to a near-monoculture. While the stream vegetation probably provides habitat for a range of native water birds, it is unlikely to support a high species or function diversity of aquatic invertebrates and fish.

The riparian vegetation is dominated by a canopy of exotic willows (*Salix* spp.) and native river oak (*Casuarina cunninghamania*), very little understorey, and a mix of native and exotic grasses as ground cover. There is an absence of trees on the hillslopes adjacent to the floodplain, although native eucalypts dominate the forest up the steeper slopes towards the escarpments. The lack of trees implies poor habitat on the property for birds and other terrestrial fauna.

Farm Economics
It is the panel's opinion that in terms of biomass production, Tarwyn Park is more productive under NFS than previously. This translates into better ongoing economic productivity. By enabling a large subsurface water store for plant growth, NFS increases forage yields and evens out much of the variation in productivity caused by streamflow variation. Pasture yield and reliability on Tarwyn Park under NFS is probably close to, but not equal to, that of irrigated enterprises in the local area, and is achieved without the financial costs of surface irrigation. Anecdotal evidence given to the panel indicated that in the 2001-02 season, the "dryland" lucerne paddock on Tarwyn Park yielded around twice the product harvested from equivalent dryland lucerne activities in the area.

The start-up costs for NFS are largely associated with the construction of the rock weirs and contour banks, and as these are all low-height, simple structures, the costs are relatively low (asserted to be similar to the cost of a single cultivation of the productive area, that is, of the order of tens of thousands of dollars). The maintenance costs associated with these structures are very low. The favourable economics of NFS are also partly due to the negligible annual input costs: no pumping costs for irrigation, no pesticide or herbicide costs, and minimal fertiliser and seed costs.

The current farm business has unknown annual veterinary and specialised feed costs, but these costs are disregarded in this assessment as they are unrelated to whether or not NFS is practiced. At present the fencing infrastructure on the property is in poor condition. Investment is this infrastructure would enable greater control over the grazing regime, and hence an improved ability to manage overall productivity.

The current levels of productivity are determined by the hydrologic regime, nutrient availability, and grazing management. The first two of these factors could be affected by the implementation of NFS on upstream properties as discussed below. The productivity of the property under NFS is therefore not independent of the farming systems used upstream.

The panel believes that, all other things being equal, the increases in productivity and the improvement in a range of environmental conditions resulting from the implementation of NFS at Tarwyn Park, are likely to have substantially increased the overall profitability of the enterprise and hence the market value of the property.

Wider Applicability of the "Natural Farming Sequence"

The panel concluded that NFS is currently an effective and sustainable farming system for Tarwyn Park. In principle the general NFS approach has widespread applicability–however, the management practices required and the costs involved will differ between landscapes and farm enterprises. As the practices required to implement NFS in different settings have not been demonstrated or documented, it is not possible to assess the achievability or effectiveness of more general NFS application. In considering the wider applicability of NFS, the panel has therefore interpreted its brief to mean an assessment of the wider applicability of the practices implemented at Tarwyn Park. For this assessment it is important to firstly understand the landscape and farming enterprise attributes required for successful implementation of these practices, and secondly, to consider the dependence of the farm operation on the flows of water, salt, sediment and nutrients it receives from upstream.

It is the opinion of the panel that suite of Tarwyn Park practices can only work for local groundwater flow systems where the water balance is dominated by fresh groundwater held in highly transmissive floodplain sediments. Local groundwater systems are those which have recharge and discharge areas within a few kilometres of each other. They tend to occur in individual sub-catchments in areas of higher relief such as foothills to ranges (Coram *et al.*, 2002). The manipulation of the surface–sub-surface hydrologic regime is the core of NFS, and this is not possible at low cost, or at a local level (on-farm) for systems other than local groundwater systems. The distribution of local groundwater systems in Australia has recently been mapped by the National Land and Water Resources Audit (see Coram *et al.*, 2002). The sediments of the floodplains must be relatively coarse (sands and gravel) throughout their thickness to ensure the high transmissivity required for high recharge rates. The sediments must also be sufficiently deep to allow substantial subsurface water storage. The valley and floodplain topography must be such that it is possible to move the majority of the stream flow out onto the floodplain. The salinity of the groundwater in the floodplain sediments must also be low. Furthermore, the salt sources must be discrete such that those areas of highest salt mass can be effectively quarantined from the water cycle that is operating on the floodplains.

In addition to the hydrogeologic setting, the suite of Tarwyn Park management measures are only suitable in fluvially confined floodplain systems that prior to disturbance were characterised by a "chain of ponds" stream system. In systems that previously had incised channels, stream energies would be sufficiently high to preclude the stability and effectiveness of low-cost grade control structures. Some of the practices used at Tarwyn Park are appropriate in other fluvial settings, and these are summarised in Table 1.

The implementation of NFS at Tarwyn Park is a low input, low output agronomic system, but with high productivity and effective internal nutrient cycling. The effective internal nutrient cycling makes the system sustainable in the medium to long term, but because of the low inputs, it is necessary that the soil has a high initial nutrient status. This is especially true for phosphorus that, unlike nitrogen and carbon, cannot be captured from the atmosphere by plants. In the case of Tarwyn Park, the net deposition of sediment from incoming stream flow currently provides a phosphorus supply, but this is small relative to the store of phosphorus already in the rich floodplain soils.

The primary income generation at Tarwyn Park is agistment of thoroughbred horses. It is likely that NFS would also be successful for other livestock grazing operations (sheep and cattle), although the greater rate of nutrient export as livestock biomass would make these enterprises less sustainable in the long term without additional nutrient inputs. NFS as currently described would not be sustainable for cropping systems where the export of nutrients as plant biomass is high. Such enterprises would require greater use of chemical fertilisers, or need to accept lower productivity (per hectare) in the longer term (as is the case for many organic farming enterprises). In addition, either herbicides or cultivation would be required to control weeds. Key elements of NFS–in particular the manipulation of the hydrologic regime–would however, be advantageous for many cropping systems.

The implementation of NFS has altered the water, sediment, salt and nutrient balances of Tarwyn Park. These balances however, are partly determined by the inputs the property receives from the Bylong River upstream. The volumes of water and loads of sediment, salt, and nutrients delivered to Tarwyn Park from upstream are all likely to be elevated above pre-European settlement amounts (assuming little surface irrigation occurs upstream). Tarwyn Park benefits from the increased volumes of water and loads of sediment and nutrients, and provides an environmental service by acting as at least a medium-term store for a proportion of the salt load it receives from upstream. It is the panel's view that implementation of NFS higher up the Bylong River catchment would reduce these inputs to Tarwyn Park. With reduced flow and nutrient inputs from upstream, sustainable productivity on Tarwyn Park would be lower. In addition, with less incoming water, the ability to store salt would most probably be reduced. Thus if the properties upstream implemented NFS, there would be a negative impact on Tarwyn Park. Similarly, implementing NFS on Tarwyn Park has reduced sediment and nutrient loads downstream of the property. These changes are believed to be towards the pre-European condition, nonetheless from a downstream agricultural perspective they could be viewed as detrimental.

Although the net result of wider application of the practices employed at Tarwyn Park (in appropriate hydrogeologic and fluvial settings) is even more uncertain than their effectiveness at Tarwyn Park, it is the opinion of the panel that such a scenario would most likely represent a more environmentally appropriate and sustainable form of grazed pasture agriculture than that which is currently typical in such environments. However, it is also the opinion of the panel that wider application of these practices would, because of reduced fluxes of water, sediment and nutrients through catchments, mean lower productivity, and less effective control of salt export from the landscape, than is currently the case at Tarwyn Park.

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Table 1: Matrix indicating which practices employed at Tarwyn Park are applicable in different fluvial settings. The Tarwyn Park setting is indicated by the shading.

	Water balance control	Erosion control	Salt export control	Productivity control	Nutrient retention control	Pasture functional diversity control
Headwater streams		•stream grade control structures •ground cover				•encourage broad-leaf annuals •avoid herbicide use
Confined floodplains – naturally chain of ponds	•floodwater diversion •aquifer recharge and storage •hillslope runoff trapping	•stream and floodplain grade control structures •contour collection and diversion channels •ground cover	•aquifer salt storage •reduction in hillslope salt delivery	•effected by water and nutrient management	•mulching •nutrient redistribution	•encourage broad-leaf annuals •avoid herbicide use
Confined floodplains – naturally incised channel	•hillslope runoff trapping	•floodplain grade control structures •contour collection and diversion channels •ground cover	•reduction in hillslope salt delivery		•mulching •nutrient redistribution	•encourage broad-leaf annuals •avoid herbicide use
Unconfined floodplains		•floodplain grade control structures •ground cover			•mulching •nutrient redistribution	•encourage broad-leaf annuals •avoid herbicide use