

Documenting the concepts of the 'Ecosystems Farm Management' approach

Colin D. Walker

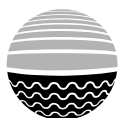


Documenting the concepts of the ‘Ecosystems Farm Management’ approach

A farmer innovation report to Land & Water Australia and the Land Management Society

Colin D. Walker

Geo & Hydro Environmental Management Pty Ltd



Land & Water

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This project was managed by the Land Management Society Inc. (LMS), and thus bears the Project Number LMS1. The Principal Investigator of the project was David Chambers of the LMS.

The volunteered time of David Chambers and his family in their commitment to the work of the LMS and particularly in this project, is gratefully acknowledged. The support of Rita Watkins in collecting and supplying bird observation data reported herein is also gratefully acknowledged. Ron and Suzanne Watkins have supplied considerable support and information on the history and observations on their remarkable property and our thanks go to them for this support, and for their tireless efforts and commitment to good farming.

This report will be promoted through a synopsis in the form of a brochure for use by the Land Management Society Inc. in field days on Payneham Vale, the property under study. Further copies of this report will be placed in several libraries and portions used in articles in the Land Management Society Inc. Newsletter. Copies will be made available through the Society in electronic form.

Abstract

This report considers the biophysical condition of the landscape of a prominent farming household in operating and developing their property, Payneham Vale. The property has been substantially renovated to improve its resource conservation, and this report reflects on the success of these renovations. The report is in the circumstances of developing salinity, and over the difficult climatic conditions of 2000–2001. It can be considered as a case study on a relevant impact on the rural community. As well as documenting the renovations, the report describes the property conditions over a diverse spectrum of landscape health indicators that are applicable to farms. These indicators are reviewed in general terms through the Overview of investigations section, with specific research highlights pointed out, and in more complete treatment in a set of technical appendices.

Following initial observations in the 1980s of saline groundwater discharge into dams and riparian vegetation of Payneham Vale, investigations found that groundwater beneath the fringes of the watercourse was semi-confined. Significant hydrostatic pressure in groundwater was found in several locations along the main watercourse through the property and persisted. It could be readily interpreted as discharge, responding to upslope recharge. After reflection, modifications to the land surfaces on the slopes of this valley were made in an attempt to control recharge. These modifications sought to rapidly control the movement of surface and subsurface water and to then securely store it. The property was modified over the 1980s with channels and banks built on the ‘keyline’ principle, conveying surface water towards the head of the catchment, with several major dams. The banks have been supported by four-row tree plantings along their downslope side, so that the subsoil of the drain channels has remained dry. The established tree belts have intercepted recharge from these drain channels.

Vegetation growth on the channel tree-belts of the property has been successful in modifying the microclimate and ecosystem activity levels as well as the hydrology of the landscape. The weather conditions suit grazing and outdoor work. In several tree belts, the

biomass includes a fence-line row of tagasaste (tree lucerne). This species provides a perennial feed source for stock, with a contribution to nitrogen nutrition. Bird populations are abundant and diverse, with both nectivorous and insectivorous species.

Fresh water capture and storage has created a growth path for production on the property, addressing the water limitations of biomass production of rainfed, broadacre farming. The stored water has allowed the establishment of dedicated reticulation of secure production areas, and plant water use by perennials clearly contributes significantly more to the catchment water balance and biomass production than under the previous, more cleared conditions.

Remaining broadacre cropland areas have distinct, near contour boundaries that delineate tillage to the same ‘on-contour’ pattern and thus contribute to soil conservation. The use of crop rotations into canola and lupins gives improvements in endogenous crop nutrition and avoids pest problems.

As a farming system, the property combines several interesting ideas to achieve a better fit into the Australian landscape and climate. It receives wide interest and frequent farm tours are conducted. Significant international and national awards have recognised its value as a contribution to environmental protection. For farm operators examining alternative approaches to farming, the Payneham Vale case represents a ‘re-tuning’ of cropland management. That is, conventional broadacre cropping and grazing remain the dominant land uses, rather than more radical changes of land use — for example, to aquaculture or complete agroforestry — as attempts to address water-balance issues. The approach is growing, with a further 70 properties in Western Australia also taking on this mode of operation over the last decade — in many cases, it is now over eight years since their renovations were initiated. Undoubtedly, there is a great opportunity to learn more in review of these properties and their successes as these advances in landscape management progress to their mature visions.

Introduction

Over the past 10 years, the warnings of early commentators have come to be widely acknowledged by current land managers — these commentators (who typically reported in the 1920s) considered that there were risk signs of widespread land degradation in Australia through salinity.

There is now a corollary of the recognition that these warnings were correct. This corollary is that it is necessary to re-design Australian farming which has proven unsuitable for the prevailing landscape systems. Several farming systems have been devised which

demonstrate considerable promise. Of these, the popular ‘ecosystem farm management’ system devised by Ron Watkins, and implemented on his own property, Payneham Vale (Figure 1), has been applied to approximately 70 farms. The system has been recognised by a United Nations Environment Programme (UNEP) Global 500 award for contributions to dryland farming. This project reviews the application of the ecosystem farm management system. It is a distinctive project in that it reviews a farm management system that has both developed inside the industry consultancy sector **and** received UNEP recognition.

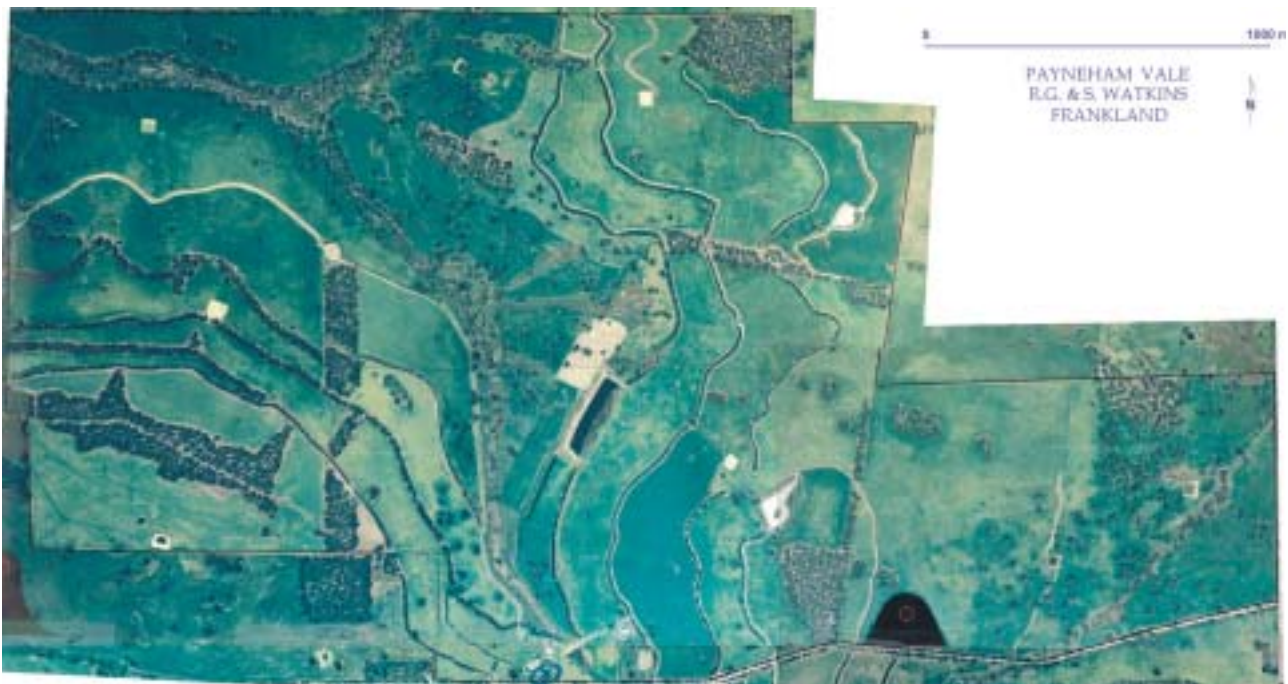


Figure 1. Image of Payneham Vale (October 1996). The Payneham Vale property is located on the headwaters of a tributary of the Frankland River in Western Australia. Drainage of the tributary generally proceeds to the north-west of the property, falling from divides at up to 310 m AHD (Australian height datum) to around 245 m in the creek channel in the north-west. The homestead, marked in blue near the bottom centre, is at around 285 m and located on Haynesdale Road at the lower centre of the image. The surface drainage from the property has been controlled with a series of banked channels. The channels have graded falls of around 1-in-300, usually leading water to the south-east corner of the catchment. They also have tree belts on their downslope side; these usually consist of four rows of trees across a 12 m width.

Key to obtaining information for managing the farming system is the farm ecosystem. For example, resident, deep-rooted trees can indicate to the farmer when the levels of salts in soil and groundwater are changing. Their canopies are thin and leaf tips burn off. Abundance and vigour of weed species can indicate inadequate consumption of moisture and nitrogen fertiliser. A crop with proliferating weeds may have root disease(s). The farmer regularly observes other aspects of the soil conditions, the behaviour of water, the health of the remnant vegetation, and the behaviour of organisms in the farm environment. These are interpreted in terms of the condition/health of the soil and water in the farm landscape.

This project sought to explore and verify the linkages between the hydrology and the condition of the indicator features that are read by the farmer in an ecosystem farm management location. Other workers reporting on this area, notably in *Indicators of catchment health* (Walker and Reuter 1996), have taken a more technical or “conventional science” approach to this subject. Also, it is widely recognised that processes in groundwater are often cryptic and difficult to monitor, and that deep-rooted vegetation provides an opportunity to do so, albeit through a biological entity’s experiences with it.

Such exercises will lead into overall activities that will allow the monitoring of the sustainability of farming systems (Dalal *et al.* 1999; Sparrow *et al.* 2000). These authors extrapolate from indicators of production, catchment, or ecosystem viability to suggest specific indicators that amount to a framework approach, intended for standard adoption in monitoring programs. It is one contention that information may already exist within the collected observations by agencies and private organisations that can substitute for this framework monitoring. Further, it should be noted that the successful

International Standards Organization (ISO) 14000 environmental standard is an open standard. The significance of this open nature is that the managers of a production unit select the appropriate monitoring for their unit, and auditors then advise whether this spectrum of monitoring achieves operational control of the externalities flowing from the unit. This approach leaves the monitoring choice up to the individuals closest to the process(es) being monitored. They are often at the best vantage point to judge which portions of the environment’s resources are under threat.

In formulating their key indicators, Walker and Reuter (1996) generated a list of 29 parameters of which only a few (macroinvertebrates and the soil cotton test) have a close relationship to aspects of the ecosystem. Also, their approach is suited to more expensive technologies, and draws on the resources of remote-sensing technologies, for example. Some such indicators may be very useful for industry management at the agency level, but may not diffuse to the farmer in a timely flow and in an effective form on which a confident management decision may be based.

The indicators used in the current project were identified from ‘what was available’ to the farmer — these included air temperature and rainfall, soil nutrients, groundwater levels and quality, surface water quality, bird counts and species, and vegetation condition. Data collection along lines advocated by the Land Management Society had been undertaken on the Payneham Vale property for some years, and these additional data are reported. As further evidence of the farm’s success, additional meteorological observations and investigations of the hydrological conditions of the landscape have been reported. Perhaps key to the property’s success is the ongoing intensification of its land uses, and this is also briefly summarised.

Overview of investigations

The main objectives of the project were to:

- conduct hydrological studies of an ecosystem farm management location for a 12-month period
- evaluate and record the system's benefits to hydrology and other performance results achieved and/or achievable
- define the basics of the hydrological linkages to the various parameters of the ecosystem
- present the findings and data that will demonstrate sufficient integrity and potential to warrant expanded assessment of the system's principles by natural resource managers in the agricultural sector.

These objectives were met by identifying 'indicator' parameters (particularly in remnant vegetation) that have clear relationships to the natural resources used by both production and the indigenous ecosystems' remnants. Healthy settings of such key indicators will generally relate to high biomass production rates in both the farming production systems and the indigenous ecosystem.

The project investigations began with the collection and analysis of extensive sets of local data on the property. Aerial images of the property were scanned and a farm plan of the property prepared. Topography and fencing were particularly documented. Initial examinations of the Payneham Vale property and its images indicated that extensive tree belts dominate the property landscape. In contrast to surrounding farmland, where some isolated remnants remain, the tree belts link remnant vegetation. Such an increase in contiguous area is known to increase the capacity of native fauna species to forage and generally move in secure habitat, and increases their prospects (Zanette *et al.* 2000).

The several, long tree belts laid out across the property have developed as a repository for nature, as an interception tool for recharge in the slopes across the property, and as a stabilising structure to the drains that actively drain profile water from the farmland. These processes appear to be very successful — for example, several monitoring bores were installed in the slopes that

were expected to fill for a metre or so of saturated profile, but no watertable has appeared in them. (Several other monitoring bores have intercepted groundwater.) Other effects of the tree belts have been recognised over the years and provide some remarkable records. In particular, the tree growth rates and bird numbers and species in the tree belts are clear indicators of the health of the farm ecosystem.

Datasets of air temperature maxima and minima have been collected on the Payneham Vale property since May 1996. In this project, air temperature, radiation, humidity, wind speed and other environmental conditions were recorded via a weather station. This was to extend the long-term temperature data, to provide an indication of long-term water balance, and to comment on the success of dams (see, for example, potential evapotranspiration, Figure 2, which clearly is linked to air temperature, as indicated by seasonal variation). Regional weather datasets and those from the property suggest that the temperature ranges and maxima may have moderated with the effects of the maturing perennial vegetation. The daily range of air temperature is less than 12°C while the average temperature is a mild 15.6°C; the farm is clearly a relatively comfortable environment in comparison to many Australian farms, although much of this can be attributed to location rather than the farming system. The tree-belt system across the farm probably does moderate the environment, using soil moisture to cool down air. Intensifying the weather data collection has placed it in a form suitable for comparison with other regional weather observation sites, so that further analysis on the moderation of weather is possible (see Appendix 2).

In reviewing the data already collected on the property, it became apparent that the farming system must allow the farm to become a comfortable zone for the inhabitants of the farm. The focus on the tree-belt effects is further brought to light in the lambing yields, where increases of 60–90% have been reported. These data illustrate how the tree systems serve to provide shade and relief from extreme microclimate, from strong direct sun, from high winds, from driving rain, and so on. After all of the

economic considerations affecting the return on farming have been dealt with, the farm must remain a pleasant and satisfactory working environment. Elevated summer temperatures characteristically drive farmers indoors and away from their activities, as well as moving stock into shade.

As with many farms, local rainfall records have been diligently collected on the Payneham Vale property. The average rainfall is around 590 mm/year \pm a standard deviation of 68 mm. On average, 470 mm (\pm 76 mm) of this rain falls in April–October, the water usage season of annual crops. The calendar year 2000 was a little unkind in this respect, providing a total rainfall of 595 mm, but only 397 mm in the April–October window. Such years are handicapped with substantial summer rains, which can recharge significant proportions of the rain events into the groundwater, eventually exacerbating salinity down-catchment. However, on Payneham Vale, approximately 11 km of drains and floodways conduct excess water into dams. These grade-drains have been cut into the duplex profile of the valley slopes so that much of the water is conveyed in a clay channel on the subsoil. These drains remove water from profiles in the central valley of the property, organising and carrying water through up to 35 m of fall. The net effect on profile hydrology is to ‘dry out’ upslope recharge areas; there is a shorter period for surface water to recharge through to the watertable. It is an effect in contrast with the increase in water storage duration on the upper section of a catchment achieved by contour banks.

Groundwater-monitoring bores were installed, with collection of soil profile materials on several locations around the property. Soil moisture profiles were obtained on recovered profiles (see Figure A1.8, Appendix 1), and demonstrated the point mentioned earlier concerning the dryness of the subsoil zone. The new monitoring bores supplement an original set that was established in 1996. Groundwater depths have been periodically monitored in the established bores and show a typical late-summer decline and late-winter rise. The hydraulic conductivity of most of the monitoring bores has been examined by ‘slug’

tests. The data indicate permeable profile materials along the creek bed, where fractured bedrock features may dominate the groundwater behaviour (see Appendix 1).

The soil profiles were also studied for salinity and pH. Soil salinity appears to be an infrequent problem among the sampled locations, however one unexpected location — the Old Irrigation Paddock — showed some subsoil salinity which may be attributed to the history of irrigation with water collected from the drain system (see Figure A1.8). Rains early in the winter wet season are regularly rinsing surface salt from the landscape, and such water fills dams and taints the irrigation water. The Old Irrigation Paddock is currently just cut for hay, although its closeness and drop in elevation from the contour dam would continue to make it a good site for irrigation.

Among the collected data are some 20 years of surface-water samples from the Part Clearing sampling point on the main valley creek (see Figure A3.4, Appendix 3). The analyses of the salinity of the Part Clearing creek water very neatly demonstrate the elevated salinity of early season water. It is suggested that allowing the drainage water to bypass the collection dams until 1 July each year will ensure fresh irrigation water for the following summer. In comparison to a regional surface-water dataset, the Part Clearing data suggest that, if anything, the Payneham Vale Creek has better water quality than the other nearby watercourses. Some drainage data were collected to examine rainfall–run-off relationships (see Figure A3.3, Appendix 3).

Soil nutrient status on Payneham Vale does not appear to have suffered from the renovation of the farming system. A long-term dataset of soil nutrient analyses was collated. Some 33 sets of varied analyses on soils have been consolidated to records. The soils of the property can be characterised as young and relatively fertile. The soil analysis dataset is eclectic: the data are related to specific cropping projects and are not good indicators of long-term trends, partly because of technical variations. With the intensification of production on specific areas of the

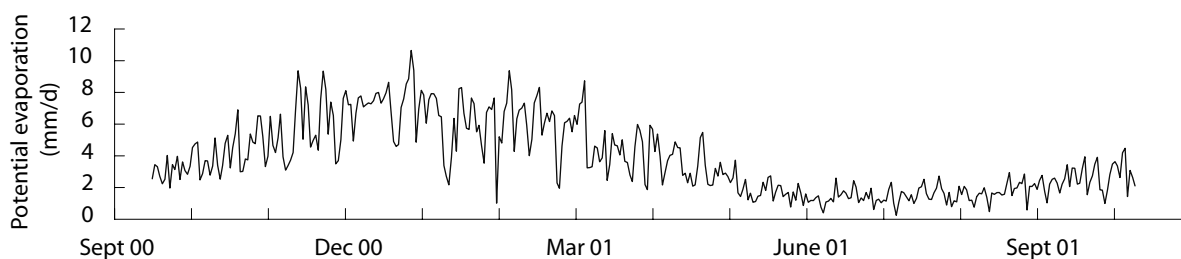


Figure 2. Potential evapotranspiration estimated from weather data recorded by an on-farm weather station. With a summer maximum of evaporation, the green perennial and deep-rooted vegetation has the capacity to remove substantial amounts of water, and will simultaneously draw salts to the considerable depth when the groundwater has been drawn down. Strategically, this is a relevant tool in recharge areas — particularly after these areas are minimised in their extent by the use of drains.

property that follows from irrigation, soil analyses will remain an information flow necessary for good crop management and will improve future management. Further soil samples were collected from five selected paddocks of the property, these being mostly irrigable paddocks. These were studied to see if there was any further evidence of salinity and to follow the nutrition levels of the property soils. Additional data collected on texture, acidity and other properties of the soil profile (Appendix 1) and earthworm counts (Appendix 4) have also been analysed.

Discussion of the condition of the landscape often turns to systematic landscape photography. An extensive photographic library exists with the Watkins of their property developments, and additional photographs were taken during current project work. The photographic library was reviewed with the idea of replicating several of these to establish photo-points. Such points can be quickly used to periodically obtain images that show the evolution of the landscape. Given that the first tree belts were planted in 1984, the Watkins have seen substantial changes to their treescape: many trees are now approaching an age and canopy architecture resembling mature bush (Appendix 5).

Bird numbers in four of the property's tree belts were counted in September 2000 and May 2001, extending a longer data collection which began in 1989 (Figure 3). The bird population was recognised to be seasonal in counts that had been carried out over this period. The tree belts have provided a valuable and popular habitat for birds. Bird-banding studies continue to be undertaken on the property. The study has shown a high level of

biodiversity in the different species of birds present on the farm. Some 81 bird species have been observed on the property (Appendix 4), of which between 30–50 might typically be sighted in any one season. These numbers compare favourably to those reported by Kitchener *et al.* (1982) for bird species diversity in Western Australian wheatbelt reserves. Further, there is some suggestion that the mixture of species is continuing to change, as opportunities for other species to succeed arise.

The many birds on the property are suggested, in anecdotal evidence by observant visiting farmers, to contribute to the stability and success of the property's farming system. High levels of birds, particularly insectivores, are identified as allowing the cultivation of organic crops. The highlight of this is successful crops of broadacre canola without the use of insecticides on Payneham Vale. Organic canola was grown for eight successive years over the period to 2000. The attractive idea of 'cropping without chemical inputs' may not be limited to broadacre crops, and it must be recognised that certain aspects of the tree belts may be assisting the process. The high density of field-edge habitat on cropland is recognised elsewhere to affect the success of birds (Best *et al.* 2001). Significantly, the tree belts make extensive use of a fringing line of tagasaste (tree lucerne). This vigorous tree provides the dominant nitrogen source in the ecosystem when a leguminous crop is not in rotation, and this may draw insects towards the tree belts as a food source. Further, wind transport of mobile mature insects frequently deposits them into the windshadow zone close to the tree belts, and foraging of mature insects and their eggs and larvae appear to be successful niches for birds.

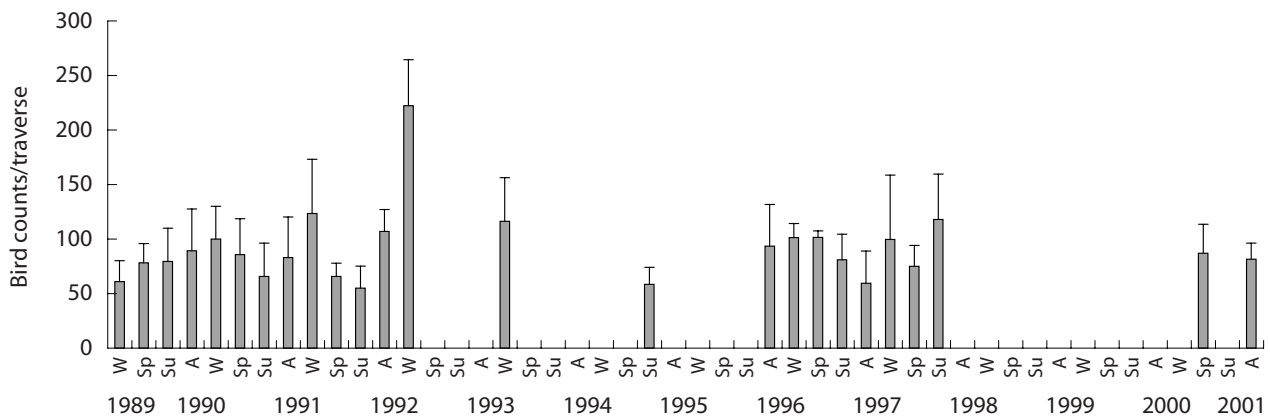


Figure 3. Summed bird counts in quarterly observation traverses along each of four tree belts on Payneham Vale. Error bars indicate standard deviations on the four traverses in one season. The X-axis indicates the seasons (W = winter, Sp = spring, Su = summer, A = autumn) of each successive year (across top). Absence of a column indicates that the traverses were not undertaken in that season. Note that the winter traverses have been notably higher than most other seasons. The counting technique ignores the many birds that do not generally use the tree belt, but might be visible in the paddock — this includes large numbers of swallows and tree martins, among other birds. This was because the project originally sought to document the role of the tree belts in attracting birdlife. Many insectivores are present in the farm bird list (see Appendix 4). Rita Watkins, whose support is gratefully acknowledged, collected all traverse data except the last two seasons. Beryl Walker collected the last two seasons.

Water management

Of the 540 ha area of the Payneham Vale property, the central valley occupies around 440 ha, to the down-catchment boundary. From the rainfall data, it can be inferred that there will be a volume of 2600 ML of rain on the central valley annually. Of this, a drainage volume within a range of 380–500 ML (13–20%) might be reasonably expected to run off this high-gradient, upper-catchment surface, based on drainage estimates. This is to be compared with surface storage of around 70 ML, the majority of which is in two dams (Figure 1; Table A3.2, Appendix 3).

Using water in irrigated horticulture helps support its harvesting. In the annual cycle of the farming system (Figure 4), the active input of water is seen as allowing

the operation of the system for longer portions of the year, with more reliable production of higher value crops, in a more balanced landscape hydrology.

Water is, in fact, seen as the most limiting of the resources depicted in Figure 4. The situation of occasional oversupply of water is worth analysing: it creates a hazard in crop establishment and flood peaks in the watercourse, as well as erosive loss of topsoil. Not only does this situation suggest lowering the gradient of drainage (a feature of keyline channels), but also that shifting the availability of water to other times wins in both conditions/times: both when flooding and waterlogging would prevail and in the normal conditions of water shortages.

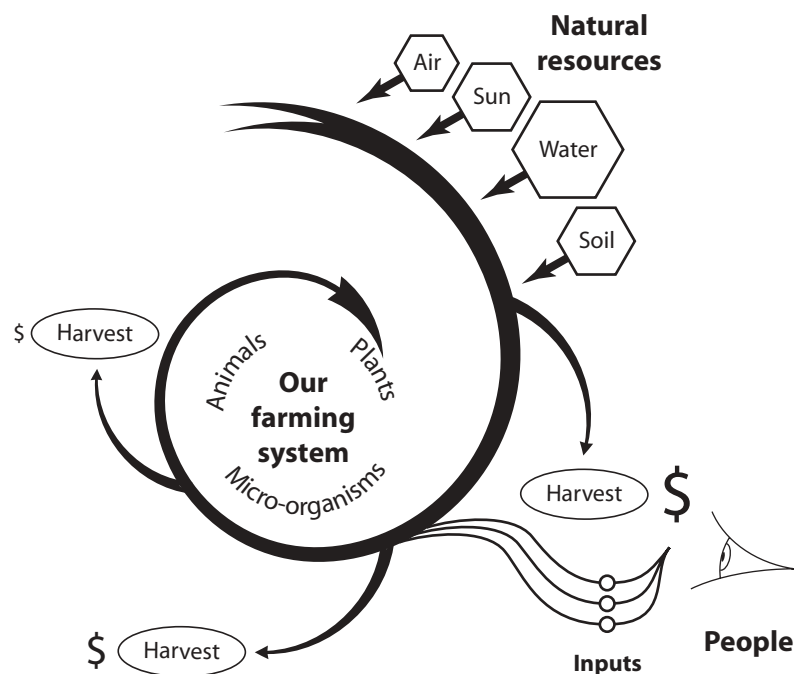


Figure 4. A farming system involves a cyclical process with contributions from eight resources (air, sun, water, soil, plants, animals, micro-organisms, people) for successful operation. In the ecosystem farm management concept, people apply interventions to guide the system, with control over water (the resource most out of balance) most critical to success.

Conclusions

Towards the ends described earlier, water from the large dams seen on the east side of the central valley has been used for horticultural blocks to the west, mostly across the valley (Figure 1). Some of this activity has taken place since 1997, so is not in place in Figure 1.

Indicators of the environmental sustainability of the Payneham Vale farming system have been selected and justified. Establishment of the success of the property through the indicators is clear but somewhat limited: only one property was examined and comparisons against benchmarks in the literature and background agency data were the main means by which interpretations could be drawn. The indicators and their characteristics, detailed in the appendixes, are summarised in Table 1.

Indicators *per se* are nothing new (Lefroy and Hobbs 1992), but it is important to choose indicators that are relevant and that efficiently indicate appropriate management. In this case, all the indicators give some insight (or education) to the property manager. The insight is into particularly cryptic or complex processes taking place in the farming environment (intangibles; Table 1) but some drawbacks remain (issues; Table 1). Extension of this process to other properties will further demonstrate that it has merit, and lead into developments of environmental management systems. Our understanding of the 'relevant-efficient indicator', as advanced in this study, must be regarded as preliminary.

Table 1. Indicators used to examine farming system viability on the Payneham Vale property.

Indicator	Investigated by	Observed	Intangibles	Issues
Vegetation growth	Photo-points	Plant communities have grown rapidly	Failures identify groundwater trouble spots	Cohorts in life cycles
Groundwater accession	Monitoring bores and profile textures	Geological structures provide locally confining barriers/aquifers	Understanding of resource balance	Drainage, water balance
Stream water properties	Quality, flow	Stream water is less saline than that in regional streams	Education in management techniques	Seasonally unavailable
Bird biodiversity	Traverse counts	Bird population rich in rare/declining passerines; insect control appears significant	Capacity to regulate pests and recycle nutrients	Seasonally varying
Soil nutrients	Analysis of spectrum of nutrients	Soil nutrients appear adequate	Assists in plant production	Cost, insensitivity
Microclimate	Weather station	Moderation of extreme temperature may be developing	Production measures, quality of life	High technology

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from an artesian source. Alluvial transport across fractured bedrock can seal over the weathering fracture area with fines, leading to a confined condition. Several such discharging monitoring bores are also present on Payneham Vale (Figure A6.1, Appendix 6): these are the bores numbered 1, 2 and 4 (4A and 4B are a piezometer pair). These all lie along the main creek line of Payneham Vale. The QUESTEM™ survey identifies a major feature trending from SW to NE on the alignment of the main creek line that may explain these discharges (Figure A1.1). If this is the case, then the construction of dams over bedrock fractures may risk recharge and pressurisation of the fracture.

Literature from agency studies of regional land sciences provides a wide-ranging set of references on soil properties, landform systems and drainage characteristics of the region (Fedowsian and Greenham 1992; Bartle *et al.* 2000). The landscape is an undulating surface (Figure A1.2) with elevation varying from just over 310 m to around 240 m.

The success of the grade-drains and dams in capturing and removing surface water relates to the prevalence of subsoil material with lower hydraulic conductivity than the surface solum. The consequence of this arrangement is that infiltrating water typically moves laterally downslope in the subsoil, a widely occurring behaviour. This has been demonstrated by texture analysis of surface and subsurface materials (Figure A1.3). The literature on infiltration rates of such materials suggests that the

average two samples vary in their rate of infiltration, being between 100- to 1000-fold slower at the deeper level (McCuen *et al.* 1981). A substantial amount of water is therefore leaving profiles by going sideward into drains — a process commonly referred to as throughflow or seepage.

The success of the grade-drains and dams in capturing and removing surface water was also examined by the analysis of water content in further profile samples (Figure A1.4). Dry subsoil material below 1 m depth was the proposed criterion when drilling was done in September 2000. Although there was some suggestion that subsoil material was drier, there was by no means a consistent pattern, and would require further study.

The profile materials available during the drilling program were examined to see if there was evidence of subsoil salinity developing. Electrical conductivity of 1:5 soil:water extracts was analysed for each of the profile samples (Figure A1.5). Three locations (RRS = Rocky Ridge South, OIP = Old Irrigation Paddock, and LJCEF = Lower Jonas Creek Electric Fence) were observed to have evidence of subsoil salinity (see Figure A6.1, Appendix 6). The salinity at RRS is a known outbreak associated with the geological structure discussed above. OIP may be a related phenomenon, but may have also become salinised in the course of irrigating lucerne over several years. LJCEF is on the flank of the main creek line, with a remnant of native vegetation around it. It may be considered a relatively undisturbed site, with the



Figure A1.2 Ortho-drape of the aerial photograph of the property over the local topographic surface. North is to the top left corner, as a diagonal across the image. Bear in mind that the surface on which the photograph has been draped has an exaggerated vertical scale compared to the horizontal scale. As with many properties, a resource protection strategy of leaving vegetation on high ground and along creek lines has been practised during early clearing. Revegetation has mostly introduced the narrow belts of trees below the grade-drains. These are seen meandering around the landscape, approximately on the valley contours. A central, salinised area (to the NE of the cream-tinted dry paddock) can be seen to be a convergence of flow from the SE and E in the middle of the property.

salinity below 2 m (Figure A1.5) reflecting the capacity of native vegetation to keep this hazard under control.

Another property of the subsoil material that was of concern was its acidity. With the abundance of dolerite in the landscape, it was quite plausible that the solum would become hostile, with acidic groundwater rising from zones with oxidation of pyrites usually associated with the dolerite intrusions. Two locations (CP = Centre Paddock and LJCOD = Lower Jonas Creek Orchid Dam; see Figure A6.1) were observed to have a $\text{pH}_{\text{CaCl}_2}$ of around 4 at around 1.5 m depth (Figure A1.6). Two further locations trend towards similar acidity at around 3 m depth. Such conditions may be a hazard for production of certain perennials.

The long-term discharge of saline water through profiles tends to convert clays in the permeable material from calcium clays to sodium clays. This soil property is known as sodicity. It is a soil condition that can be investigated by examining the change in acidity of a soil:water slurry when a small aliquot of soluble calcium is added, a technique discussed by McArthur (1991). A sodic clay will be more alkaline in such conditions, because the sodium ions displaced into solution create a stronger base. Only one sample (RRS = Rocky Ridge South) reaches this condition (Figure A1.7). This response is clearly due to a localised groundwater discharge, also evident as a barley grass-fringed bare patch adjacent to this monitoring bore (Figure A1.8).

The RRS outbreak is very gradually developing — located approximately 100 m up-slope from the first saline outbreak on the property. In winter, the area shown here remained bare, with a further ‘halo’ of fewer capeweed flowers for approximately 10 m either side of the bare area, which has an abrupt boundary of good vegetative growth. Treatment with gypsum to deal with the sodicity effects is anticipated to improve this problem patch.

Soil fertility had been periodically analysed on the property on an as-needed basis, driven largely by major cropping programs. Over the interval for which soil nutrient analyses were available in the farm records, production has become more intensified, with the arrival of available irrigation water from the installed drainage network. The obvious task is to put the water to a suitable and productive use in an irrigated form of cropping, in which the plant water supply is well scheduled against the evaporative demands. In this context, it has become more critical to identify and satisfy any nutrient deficiencies as, ideally, the normally limiting water shortages that the crop plants would face do not arise. Faster-growing plants require higher levels of nutrients to develop biomass.

The nutrient analysis data are extensive, but comparisons are somewhat difficult to make, given that the analyses were carried out by different laboratories using varying

techniques for specific nutrients and it was difficult to identify the sampled areas. However, the range of analyses performed, the overall observations, and reasons for conducting the analyses are summarised in Table A1.1. Agronomic advice has sometimes focused on particular issues in plant nutrition in the last couple of decades.

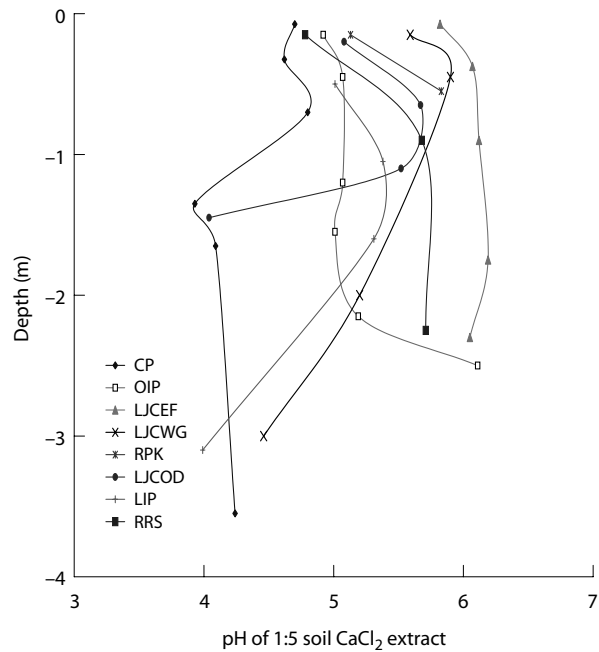


Figure A1.6 Acidity analyses of profile samples collected during installation of a set of eight monitoring bores on the Payneham Vale property.

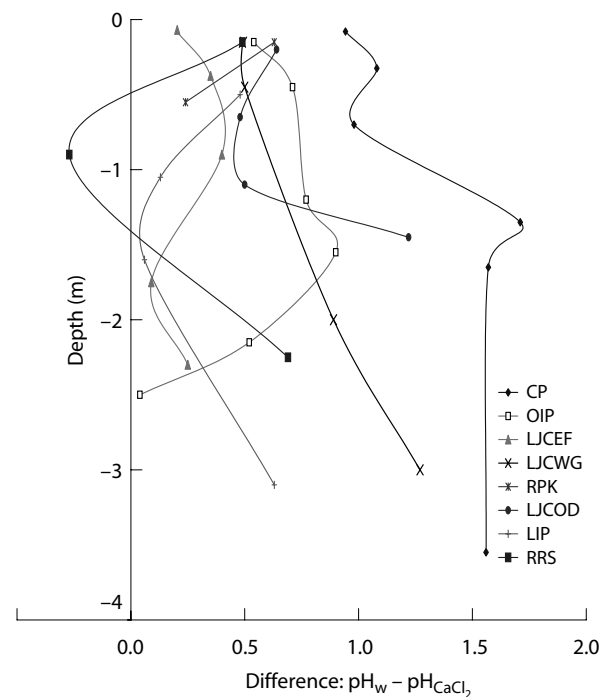


Figure A1.7 Difference of $\text{pH}_w - \text{pH}_{\text{CaCl}_2}$ analyses of profile samples collected during installation of a set of eight monitoring bores on the Payneham Vale property.

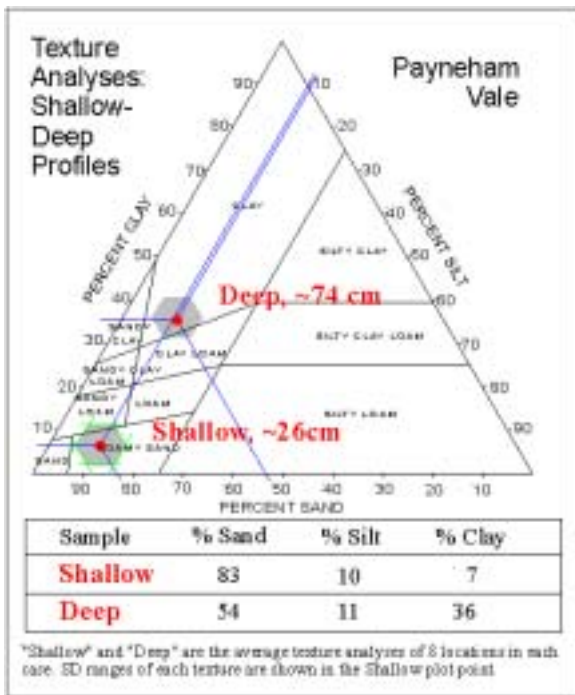


Figure A1.3 Texture analyses of paired surface and subsurface samples collected during installation of a set of eight monitoring bores on the Payneham Vale property. Tabulated data show the mean proportions of sand, silt, and clay plotted in the texture triangle. The standard deviation ranges of the two groups of data are depicted graphically, forming hexagons. It can be seen that the two groups of samples from deep and shallow depths are significantly different in their textures.



Figure A1.8 The Rocky Ridge South bore is monitoring the development of this saline outbreak, here fringed with barley grass.

Certain issues, such as loss of residual phosphorus on soils rich in reactive iron, became better extended into the farming community as analysis service laboratories became aware of these trends and have routinely provided data.

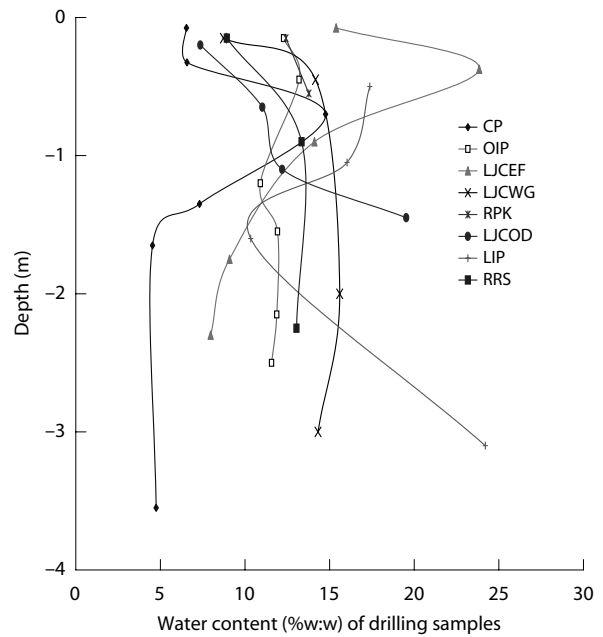


Figure A1.4 Gravimetric water content of samples collected during installation of a set of eight monitoring bores on the Payneham Vale property.

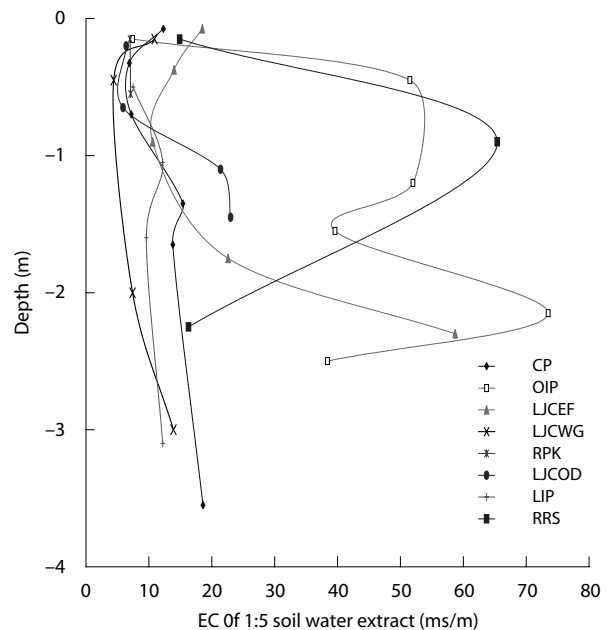


Figure A1.5 Electrical conductance analyses of profile samples collected during installation of a set of eight monitoring bores on the Payneham Vale property.

Phosphorus and nitrogen are the two nutrients whose status has generally been of most concern (Table A1.1). The phosphorus issue is to be expected in the context of the iron-rich laterite and dolerite-derived substrates of the area. The antagonism of reactive iron to plant phosphate nutrition is well known. The relatively youth of much of the property's soils over primary mineral rocks points to a strategically good situation with respect to nutrients such

as the trace elements, sulfur, potassium and alkali earth minerals.

Given that the farm operation has moved into an organic approach to farming, the option to use high-analysis nitrogen–phosphorus fertiliser is not available. The capacity of organic matter to mineralise and release these to the growing crop plant has become important. This capacity would be clearly supported by occasional green manure crops, and lupin crops are also used to replenish nitrogen. Another approach to maintaining fertility is to use organic manures, such as those available from the peri-urban composting facilities available in Australia. The analysis in Table A1.2 is of a composted manure used on the property in irrigated vegetable production areas (areas 1–6, Figure A6.1, Appendix 6). It can be seen to supply modest amounts of the major nutrients of concern, nitrogen and phosphorus, but it should be noted that the ‘slow release’ nature of such a fertiliser makes plant

utilisation of such nutrients quite efficient. One additional risk with such manures is that of relocation of weed species, and management of weeds has become a management concern.

A further issue is the suggestion that some areas of irrigated cropland are starting to develop salinity. This may be due to the geological structures influencing the basement hydrology, but may be exacerbated by over-irrigation or by irregular drainage of irrigation water.

In terms of combating the salinity issues, the intensification of production has shifted input stresses on the farming system away from there being a concern about water imbalance. Rather, management now focuses on issues of a spectrum of nutrient requirements, the weed problem mentioned above, and a water-handling (and perhaps quality) issue. Such issues are present in many intensified farming systems.

Table A1.1 Number and nature of soil analyses on the Payneham Vale property.

Year	No. of analyses	Issues of concern	Analysed	Observations
1978	3	Fertility of newly cleared ground, nutrient rundown	Organic N, P, K, Ca, Mg, Fe, Mn, Cu, Zn, Mo, Co, Na, pH _w	No clear deficiencies, higher fertility in land near homestead; high iron in the analyses
1982	3	Nutrient rundown, availability of P	As for 1978, plus available P, S	Available P for pasture was marginal; high iron in the analyses
1983	1	As above	As for 1982	A further paddock was similar to the 1982 analyses
1984	2	Nutrient requirements of irrigated plants	NO ₃ , available P, K, S, Ca, Mg, Fe, Mn, Cu, Zn, Na, TSS, pH _w	Subsoil salinity and infertility observed in the Old Irrigation Paddock (OIP); higher S in its subsoil
1988	25	Tie-up of P on iron minerals, mineralisable OM	NO ₃ , NH ₄ , available P, K, reactive Fe, pH _w , organic C	Some low N status but good OM levels; high reactive Fe and marginal P
1993	2	Lucerne and oats	pH _w , organic C	Good conditions
1998	5	Lucerne, olives and broadacre production areas	Organic N, P, K, S, Ca, Mg, Fe, Mn, Cu, Zn, B, Na, pH _w , OM	Marginal P, S, B; very good OM
1999	5	Setting up irrigated vegetable areas, two broadacre crops	As for 1998	Low N for vegetables; good OM
2000	6	Irrigated vegetable production areas	As for 1998, omitting Na, B	Low N, marginal K
2001	28	Sustainability: samples for analysis taken from areas 1–8 shown in Figure A6.1, Appendix 6)	Organic N, Total (P, K, S, Ca, Mg, Fe, Mn, Cu, Zn), pH _w , electrical conductivity, organic C	Adequate nutrient status generally observed; demonstrated substantial mineralisable trace nutrient reserves; salts accumulated in old irrigation area

Note: B = boron, C = carbon, Ca = calcium, Co = cobalt, Cu = copper, Fe = iron, K = potassium, Mg = magnesium, Mn = manganese, Mo = molybdenum, N = nitrogen, Na = sodium, NH₄ = ammonium, NO₃ = nitrate, OM = organic matter, P = phosphorus, S = sulfur, TSS = total soluble salts, Zn = zinc.

Table A1.2 Nutrient analysis of organic compost used on the Payneham Vale property, September 1999.

Analyte	Concentration	Analyte	Concentration	Analyte	Concentration
Nitrogen	1.6–1.9%	Sulfur	0.7%	Zinc	700–900 ppm
Phosphorus	0.8–0.9%	Iron	0.4–0.5%	Copper	100–200 ppm
Potassium	0.8–1.2%	Magnesium	300 ppm	Boron	40 ppm
Calcium	6%	Manganese	300 ppm		

Appendix 2

The farm microclimate

The Payneham Vale property enjoys a semi-arid Mediterranean climate with dry, moderately hot summers and cool, wet winters. As discussed in the Overview of investigations (main report), some conjecture has arisen as to whether the tree belts installed have moderated the weather conditions on the property. Comparisons of the recorded weather observations to those of the Frankland Vineyards and Rocky Gully weather stations were undertaken to consider this hypothesis. This comparison does not adequately address the capacity of a mobile organism to seek cover from exposure to wind, sun, or rain in the protection of the tree belts (Figure A2.1).



Figure A2.1 Weather-station monitoring the micro-climate conditions in a tree-belt location on the Payneham Vale property undertaken in this project. Wind speeds in this protected location were around five-fold lower than at a Bureau of Meteorology location in the Rocky Gully townsite (Table A2.1). Obviously, protection from exposure is a preference of many domestic and native species. This weather station also logs groundwater levels in a bore installed alongside it.

Long-term data that extend beyond annual cycles can be used to benchmark various environmental parameters. This has assisted in interpreting the climatic effects of the tree-belt system on the Payneham Vale property. As well as weather, comparisons to other locations with long-

term data have been undertaken in understanding trends in the surface water quality and stream behaviour and groundwater levels (Figure A2.2).

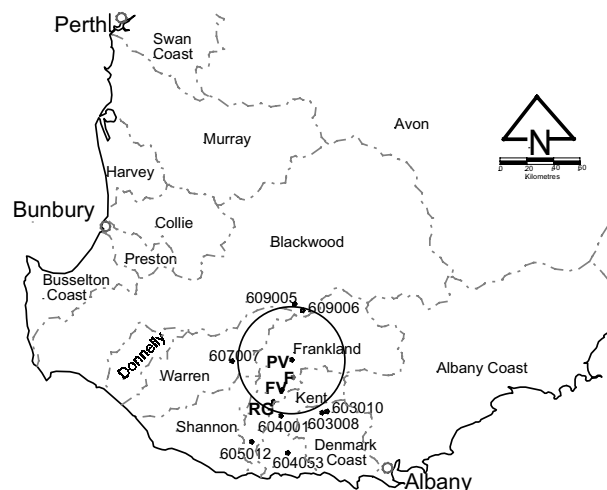


Figure A2.2 Location map of the Payneham Vale (PV) property in relation to catchments and monitoring locations used in this project. Frankland (F) is the nearest townsite, but has no monitoring data. Weather data (rainfall, wind, air temperature maxima and minima) were obtained from Frankland Vineyard (FV) and Rocky Gully (RG) from the Bureau of Meteorology. Rainfall, stream-water quality, and river level (stage) were obtained from several sites indicated by their designated numbers of the Water & Rivers Commission. Catchments names are given, with catchment boundaries indicated as dashed lines. A study of groundwater levels in the Kent River catchment by CSIRO was also used. The circle centred on Payneham Vale shows that much of the nearby data sources are around or a little under 40 km away.

Maximum temperatures at Payneham Vale have been both substantially hotter and substantially colder than at Rocky Gully (Figure A2.3) although, on average, Payneham Vale is just slightly warmer (Table A2.1). There are occasional periods of several days when atmospheric conditions at the two locations are clearly different and maximum temperatures may be more than 12°C different — a significant value in that this is often

the order of the full range of the daily temperatures. Minimum temperatures at the two locations differ only slightly. The net effect in temperature range is that Rocky Gully has a slightly smaller average daily range — an effect that could be attributed to more maritime influence (Figure A2.2).

The difference in maximum temperatures between the two locations can clearly reach to greater amplitude in summer (Figure A2.3).

The tree belts on the Payneham Vale property were installed over the late 1980s and early 1990s, and it was conjectured that their growth and development would moderate climatic conditions. This may be the case with air temperature. That is, over the period of time studied, mid-1996 to 2000, the maximum daily air temperatures at Payneham Vale may have moderated slightly in comparison with those at Rocky Gully. The ratio of average daily air-temperature maxima between the two locations was, on average, around 5.5% higher. When the ratio was smoothed by averaging over 5-day intervals, and analysed by regression against time, it was found that the ratio had declined by nearly 0.4% per year, a trend that was not statistically significant (probability = 10.8%). Further work would be needed to clarify if this drift in microclimate is accurately observed herein and is driven by the revegetation activities. With minimum temperatures at the two locations similar and relatively static, these temperature ranges would show a similar behaviour to the maximum temperatures.

Daily temperature range is regarded as an important agricultural climate parameter. Sombroek *et al.* (1982) pointed out that temperature range can be used to indicate the geographical range of farming systems. They devised a sequence of nine temperature zones (Table A2.2) within which Payneham Vale and Rocky Gully fall into zone 2: a very comfortable zone for many crops.

The annual rainfall at Payneham Vale over the previous 20 years has averaged 590 mm. In comparison, the estimated potential evapotranspiration is around 1140 mm (Table A2.3), summing the monthly estimates of potential evapotranspiration from Wang *et al.* (2001). The ratio of rainfall to potential evapotranspiration indicates a moisture availability index of 52%. Such an index indicates a relatively mild level of evaporative demand on annual plants and winter-growing annuals, fitting into zone 3 (50–65%) of the 7-zone system of Sombroek *et al.* (1982; Table A2.2).

However, it must be recognised that seasons outside of these zones can occur. The year to 30 September 2001 had a potential ET of 1411 mm (Figure 2, main report) and rainfall of 431 mm. This gives a moisture availability of 31%, which is in zone 5 (Table A2.2). This is typical of a semi-arid, broadacre cropping zone, and it is not surprising to receive reports of good crops on Payneham Vale, but the outlook for summer vegetables was poor for 2001, because of low water stores in the dams on the property.

Table A2.1 Air temperature and wind data for Payneham Vale and Rocky Gully. Uniformly collected measures of air temperature at these two locations were available from mid-1996 to 2000. Temperature data are the average of approximately four years of complete records for this interval. Wind speed data were recorded on Payneham Vale for only a 12-month period in this project and at a different location on the property, where the weather station installed also served duties in logging the groundwater level (Figure A2.1).

Location	Average daily maximum (°C)	Average daily minimum (°C)	Average daily range (°C)	Average temperature (°C)	Average wind speed (km/h)
Payneham Vale	21.1	9.4	11.7	15.6	2.85
Rocky Gully	20.4	9.5	11.1	15.9	15.90

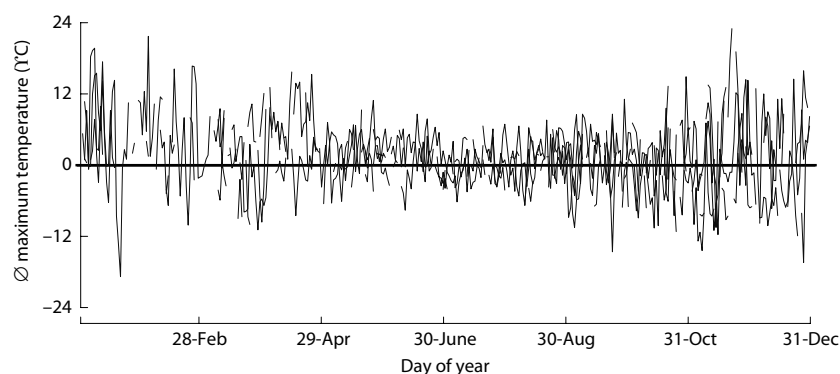


Figure A2.3 Differences in maximum air temperature between Payneham Vale and Rocky Gully. Data from mid-1996 to 2000 were consolidated to a single annual cycle to indicate the hourglass ‘envelope’ of range found with this comparison.

Table A2.2 Agro-climatic zones of temperature range and moisture availability (from Sombroek *et al.* 1982). Agro-climatic zones are described as specific combinations of moisture availability and temperature range.

Temperature zone	1	2	3	4	5	6	7	8	9
Temperature range (°C)	<10	10–12	12–14	14–16	16–18	18–20	20–22	22–24	24–30
Moisture availability zone	1	2	3	4	5	6	7		
Moisture availability range (%)	>85	65–80	50–65	40–50	25–40	15–25	<15		

Table A2.3 Evapotranspiration (ET) estimates for the Payneham Vale region (from Wang *et al.* 2001). Actual evapotranspiration may be used as a rough indication of the return of rainfall to the atmosphere, allowing estimation of runoff, storage and recharge components by difference. Point potential evapotranspiration estimates evaporation loss from small, free water surfaces such as dams, and may be used to identify leakage problems and to consider available irrigation water after the expected losses over summer. Average annual data are as follows: actual ET: 520 mm, potential ET: 1140 mm, and point potential ET: 1560 mm

Month	Actual ET (mm)	Potential ET (mm)	Point potential ET (mm)	Month	Actual ET (mm)	Potential ET (mm)	Point potential ET (mm)
January	54	168	230	July	31	43	46
February	42	128	184	August	39	41	65
March	33	103	160	September	49	83	110
April	32	66	110	October	56	122	140
May	32	50	70	November	60	140	172
June	28	40	52	December	60	167	220

Appendix 3

Hydrological studies

Initially, the Payneham Vale property had inadequate monitoring of its water resources to develop much interpretation of the water balance of the location, or decide on the 'healthy' or 'troubled' status of various areas of vegetation. Monitoring needed to be developed for both surface water and groundwater resources. As described elsewhere in this report, there were recognised zones of salinity outbreak and further concerns about older remnant vegetation. Developing monitoring to characterise the associated water conditions would provide a basis for understanding the prognosis of these problems. This project has largely focused on providing and monitoring a more extensive network of groundwater-monitoring points

and examining the surface-water salinity and flow rates in the main creek line.

Monitoring bores were installed to complement an earlier set. Their locations and codes are shown in Figure A6.1, Appendix 6. Over the project, all monitoring bores have been regularly measured for water depth (Figure A3.1), and acidity and salinity (Table A3.1).

The calendar year 2001 was unusually dry, and water levels declined over the course of the 12 months of the study period (Figures A3.1 and A3.2). The mid-year low point in groundwater levels in 2001, depicted in more

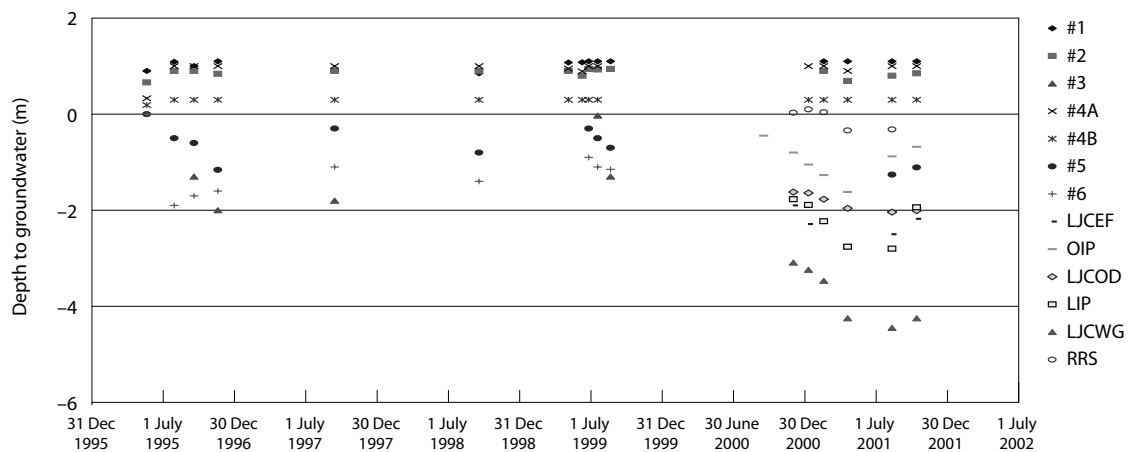


Figure A3.1 Groundwater levels in monitoring bores installed on the Payneham Vale property. Bores were installed in 1996 and 2000. This figure includes data for the major bores only; some three further were dry for most of the study period. Measures are with reference to the local ground surface as zero.

Table A3.1 Groundwater quality in monitoring bores on the Payneham Vale property. Data are averages of 5–15 separate measurements over period shown in Figure A3.1. Monitoring bore numbers/codes refer to those given in Figure A6.1, Appendix 6. An electrical conductivity (EC) of 1800 mS/m (18000 mS/cm) corresponds to around 10 g salt/L.

Monitoring bore	#1	#2	#3	#4A	#4B	#5	#6	LJCEF	OIP	LJCOD	LIP	LJCWG	RRS
Average EC (mS/m)	1487	1765	82	1830	1820	64	88	1435	1271	985	112	928	840
Average pH	6.14	6.21	6.19	5.95	5.61	6.45	6.37	6.00	6.38	5.04	5.47	5.23	4.46

detailed monitoring of the Old Irrigation Paddock bore (Figure A3.2), appears to have rapidly responded to local rainfall. A similar, prompt mid-year jump from such a low point in the annual cycle of groundwater was observed in several bores continuously monitored over the dry sequence of years of 1994 to 1996 by Bartle *et al.* (2000) in studies in the neighbouring Kent River catchment.

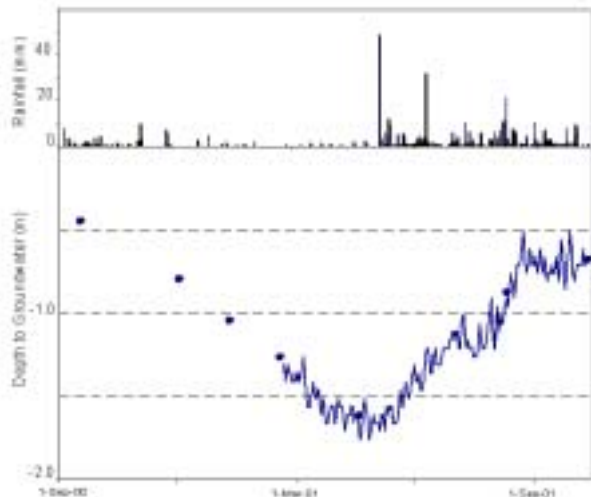


Figure A3.2 Groundwater levels in the Old Irrigation Paddock (OIP) monitoring bore. Rainfall data are from a weather station adjacent to the monitoring bore. This figure is a composite of manual measurements and continual logging (from mid-February 2001) of the one bore hole (OIP).

Several of the bores initially installed in 1996 were along the valley creek line. These bores (numbers 1, 2, 4A and 4B) continue to almost always have water right to the top of the casing (and consequently they have positive depth readings in Figure A3.1). They demonstrate that pressurised, confined groundwater exists at their relatively shallow depths right along the watercourse. The groundwater in these holes is the most saline on the property (Table A3.1). The Rocky Ridge South monitoring bore (Figure A1.8), installed some distance from the watercourse in 2000, also transiently showed a positive groundwater pressure (Figure A3.1), but declined in a

similar pattern to groundwater in the other holes after February 2001. Fractures in the basement geology have been discussed earlier, and could lead to this condition.

In comparison to other studies in the wheatbelt of Western Australia, the groundwater of the Payneham Vale property is not particularly saline. Similarly moderate salinity has been reported by Bartle *et al.* (2000) and others examining groundwater in nearby regions. Rather, the hydrological connectivity and associated salinity simply present a hazard through relentless groundwater pressure continually discharging (or importing) salt to an evaporating surface where it can concentrate over time. Further, the groundwater of Payneham Vale is not particularly acidic (Table A3.1), although the presence of pyrite-rich basement rock, usually associated with dolerite intrusions, has been indicated earlier (Figure A1.1).

Thus, the concentration of salts into shallow soil profiles or right onto surfaces presents the major challenge for management. Investigation of profiles, such as those shown in Figures A1.5 and A1.7, identifies areas that are accumulating salt. A further means of identifying salinity would be to find elevated salt concentrations in run-off and through-flow or seepage. Such water collects in the extensive network of dams on the Payneham Vale property (Table A3.2).

The collection of water has been organised to minimise the local recharge that would exacerbate the discharge from the fractures along the main creek line. Given that the main geological risk appears to lie in the head of the valley, it places an acute test on the design of a keyline approach to surface drainage. As discussed earlier (Water management, main report), the total water storage available for retention of flow in the main valley of the Payneham Vale property is approximately 70 ML — the major portion of this being in two dams, the Contour Dam and the High Dam. These two dams are located on the eastern flank of the valley, where it is to be hoped they are above any water seepage that could carry in salts, and they are away from the risk area, but still serve to delay surface water drainage according to the keyline principle (Figure A6.2, Appendix 6). The individual catchment collection areas of these two dams comprise approximately 147 ha

Table A3.2 Surface water storage in dams in the main valley of the Payneham Vale property (see Figure A6.2, Appendix 6 for dam locations).

Dam	Name/location	Capacity (ML)	Dam	Name/location	Capacity (ML)
A	Contour Dam	30	G	Back Paddock East Dam	1
B	High Dam	25	H	Back Paddock West Dam	1.5
C	Transport Dam	1	I	Upper Jonas Creek Dam	1.5
D	House Dam	5	J	Lower Jonas Creek Dam	1
E	Uphouse Dam	1	K	Orchid Dam	1
F	Max's Dam	2	L	Part Clearing Dam	0.8

for the Contour Dam and 35 ha for the High Dam. Part of the latter lies in the catchment of the north-east-draining creek arising south of Haynesdale Road and draining across Dennis's paddock. Dennis's paddock is the eastern-most portion of the Payneham Vale property. It is the section where the north-south extent of the property reduces to around half. Its significance is that there was only a minimal water retention system put across it and there has been little attempt to improve it further. It has a separate surface-water drainage line to the main creek across the property: the latter goes to the north-west while Dennis's paddock drains to the north-east. Capture of the water from both sides of the ridge has improved the efficiency of the dams and protects the lower area in Dennis's paddock from wetter conditions. It may also remove some recharge that would end up progressing into the main valley through the bedrock fracture discussed earlier. The landscape to the south-east of the property is an elevated laterite-bedded plateau rising to over 330 m, and capped with coarse white sands, reminiscent of a Goonaping land surface. This surface is likely to have considerable recharge. Approximately 1 km to the south-east of the head of the valley at Payneham Vale, the land elevation drops back below 320 m and recharge in this area could not plausibly flow northwards given the grade to the south. However further fractures are known (Anderson 1994). It is thus a little unclear as to what differences exist between the surface catchment and aquifer catchment feeding water into the creek line of Payneham Vale.

To examine the nature and quantities of seepage flow in the creek, its flow was measured at a convenient point in the head of the main creek line from mid-August to mid-October (Figure A3.3). The hydrograph shows that around six rain-laden weather systems passed in this period. At such a time, the flow in the creek line would normally benefit from improved run-off yield with the

property profiles near full, as suggested by Figure A3.2 for the Old Irrigation Paddock location. Integrating the depicted flows gave water yields of between 18 ML and 46 ML for the individual events. Assuming full run-off and uniform rainfalls (as indicated in Figure A3.2), effective catchment areas of 50–74 ha are indicated. This area (perhaps coincidentally) fits the portion of the catchment that has no collecting dam (Figure A6.2, Appendix 6). It remains to be examined whether this effective catchment area is constituted by the indicated area without dams on Figure A6.2 and further study will help resolve this. Some additional techniques such as tracers may improve our insight.

One tracer that was examined in the period of flow measurement above was salinity. This was measured as steady levels of around 1200 mS/m (or 12000 µS/cm). Even during the relatively large rain event of 28 September to 1 October, salinity levels in surface water declined by only 15%. This broadly indicates that most stream water is entering the creek channel via through-flow or seepage migration where it is collecting salts such as those depicted in profiles in Figure A1.5. Thus, the baseflow water quality was consistently around 7 g salt/L, with only slightly fresher conditions when rain events came through the flume. A similar situation has been recognised in the functioning of the property drains, in that their water-harvesting is mostly of seepage water that has infiltrated and collected on the relatively less permeable subsoil and then flows sideways. In practical terms, this water is of little horticultural value.

Fortunately, such poor water so late in the season is rare (Figure A3.4). The long-term salinity of the surface water in the Payneham Vale creek was compared to the Water & Rivers data for the region. Figure A3.4 compares surface-water salinity observations at the Part Clearing Paddock Creek site on Payneham Vale with four external locations

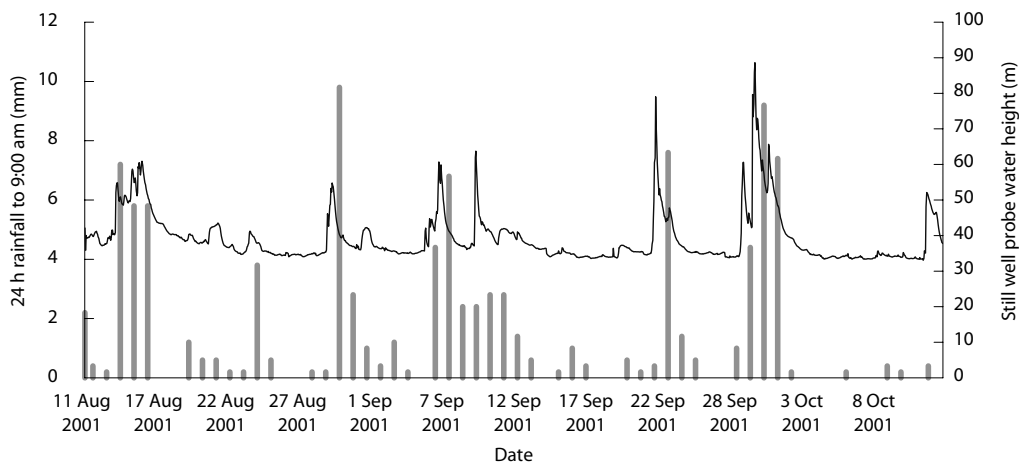


Figure A3.3 Stage height trace and recorded rainfall. Note that the nearby aquifer was basically full over this period (see Figure A3.2) and would be steadily discharging seepage.

for which there exist substantial records. These are in all directions from Payneham Vale (Figure A2.2).

It should be highlighted that there have been relatively low salinity levels in the Payneham Vale creek water in comparison to the four other locations. Comparisons with other sites must be undertaken with a view to recognising minor variations in rainfall or catchment clearing that might lead to differences, and rainfall across these loca-

tions has been collated as part of this study (Table A3.3). Rainfall differences do not appear to be particularly significant overall. It is interesting to note several periods when the Part Clearing Paddock creek water appears to be substantially fresher than elsewhere in the late 1980s — such as in comparison to 607007, and in the early 1990s — such as in comparison with 604001 (Figure A3.4). Such effects could possibly be attributed to the impact of the installed drains and tree belts.

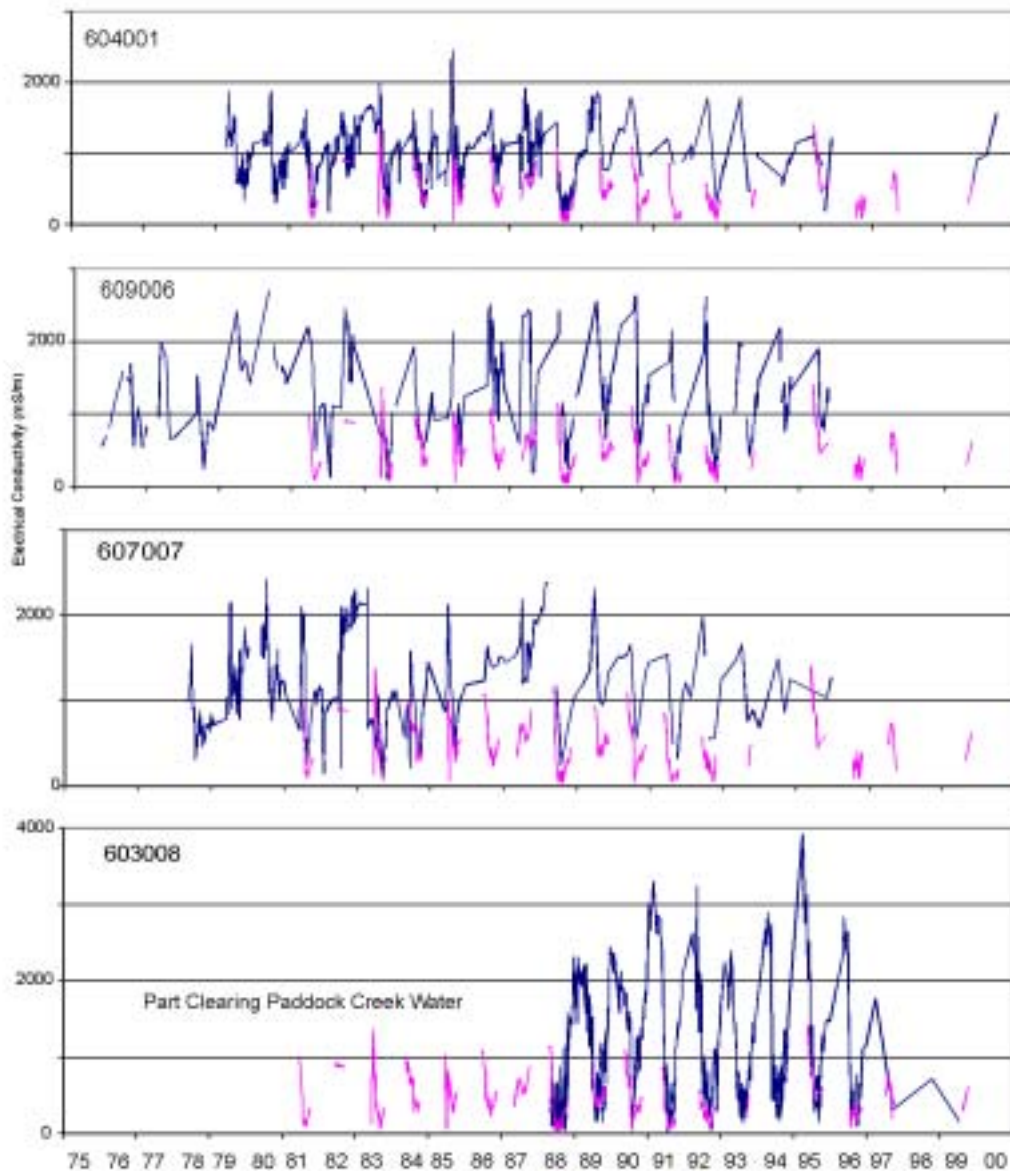


Figure A3.4 Comparison of the salinity of four regional creeks (dark blue) with that at the Part Clearing sample point of Payneham Vale creek (magenta, replicated in each of four traces). The four Waters & Rivers locations 603008, 607007, 604001 and 609006 are shown in Figure A2.2.

Table A3.3 Comparison of monthly rainfall (mm) at Payneham Vale and two other locations—two stream-monitoring locations reported in Figure A3.4 and shown in Figure A2.2.

Payneham Vale	Monthly aggregates												Summations	
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual	Apr-Oct
1980	0	54.5	3.5	58.5	38	81	70	75	42	81.5	18.5	16.5	539	446
1981	0	6.5	10.5	54.5	71	83	108.5	68	48.5	28.5	33	13	525	462
1982	141	17	23	3	29	77.5	56.5	58	30.5	22.5	35	13	506	277
1983	0	39.5	12.5	50.5	33.5	132	109	91.5	82	26.5	45	19.5	641.5	525
1984	3	7.5	19	22.5	100	74.5	56.5	97.5	70	27.5	77	18	573	448.5
1985	20	46.5	9.5	83	40.5	46.5	79.5	123.5	38	45	33.5	16.5	582	456
1986	3.5	67	26	3	46	85	82	84.5	93.5	41.5	18.5	1.5	552	435.5
1987	4	0	25	105.5	79.5	46.5	67.5	35	29	24.5	59.5	21	497	387.5
1988	10	0	29.5	26	155.5	189.35	95.7	91.3	64.5	27.5	20	25	734.4	649.8
1989	62.5	52	2.5	41.5	57.5	44.5	105	66.5	45.5	71	44.5	7.5	600.5	431.5
1990	43	24	15	63.5	43	62.5	143.5	42	52	50.5	33	7.5	579.5	457
1991	10	20	6	22.5	76	92.5	112	96.5	72	29.5	63.5	30.5	631	501
1992	0	25	21.5	27	92.5	105.5	73.5	103.5	74	34.5	79	17	653	510.5
1993	0	15.5	80.5	27	102	40	108	86	62	71	46	10.5	648.5	496
1994	0	3	2	11.5	117.5	60.5	85.75	71.5	55	48	16	0	470.8	449.7
1995	3	14	3	16	72	82.5	112	66	58	64	36.5	35	562	470.5
1996	2.5	0	11.5	11	41.5	107.75	158.5	82.5	138.5	58	17	62.5	691.2	597.7
1997	6	57.5	15	6.5	74.5	69	82.5	82	82	28	26	4.5	533.5	424.5
1998	1.5	0	97	51	66	86	56.5	129	93	34.5	12	30	656.5	516
1999	3.5	0	27.5	3	127	126	82	73.5	63	62.5	28	40	636	537
2000	87.5	3	74	24.5	33.5	68	130.5	83	44.9	12.8	27.2	6.6	595.5	397.2
												Average	590.8	470.3
												S.D.	67.9	76.6

Table A3.3 (cont'd) Comparison of monthly rainfall (mm) at Payneham Vale and two other locations—two stream-monitoring locations reported in Figure A3.4 and shown in Figure A2.2.

607007	Monthly aggregates												Summations		
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual	Apr-Oct	
1978				6.7	92.5	120.1	122.1	37.3	120.4	12.8	17.8	20.8			
1979	34.9	21.6	14.1	31.3	54.3	69.2	80.1	63.2	62.4	53.5	45.4	10.2	540.2	414.0	
1980	1.2	27.6	4.3	65.4	36.9	76.5	96.2	87.0	12.3	61.2	42.4	12.2	523.1	435.4	
1981	0.9	0.0	14.6	71.5	66.1	109.1	117.3	96.5	51.8	25.3	82.1	21.7	656.9	537.5	
1982	110.6	16.3	8.5	12.0	27.6	54.0	67.8	43.6	48.3	32.8	19.4	8.9	449.7	286.0	
1983	3.6	33.8	15.2	5.4	45.8	0.0	68.2	102.4	109.3	9.3	25.4	28.2	446.5	340.3	
1984	0.8	14.7	11.3	20.0	113.4	78.4	52.2	100.1	68.0	23.1	75.2	15.9	573.1	455.2	
1985	110.6	16.3	8.5	12.0	27.6	54.0	67.8	43.6	48.3	32.8	19.4	8.9	449.7	286.0	
1986	3.6	33.8	15.2	5.4	45.8	0.0	68.2	102.4	109.3	9.3	25.4	28.2	446.5	340.3	
1987	0.8	14.7	11.1	14.0	119.3	75.9	54.9	100.1	67.8	23.0	75.3	16.1	573.1	455.1	
1988	22.6	8.0	17.8	80.6	63.0	85.7	55.2	134.9	41.5	31.9	39.4	9.5	590.1	492.8	
1989	3.6	33.8	15.2	5.4	45.8	0.0	68.2	102.4	109.3	9.3	25.4	28.2	446.5	340.3	
1990	0.8	14.7	11.1	14.0	119.3	75.9	54.9	100.1	67.8	23.0	75.3	16.1	573.1	455.1	
1991	22.6	8.0	17.8	80.4	63.3	59.9	80.6	134.5	41.9	32.1	34.2	14.7	590.1	492.8	
1992	3.1	47.2	24.0	4.2	58.3	59.5	79.3	72.2	53.2	49.8	13.0	1.1	464.7	376.3	
1993	0.8	14.7	11.1	14.0	119.3	75.9	54.9	100.1	67.8	23.0	75.3	16.1	573.1	455.1	
1994	22.6	8.0	17.8	80.4	63.3	59.9	80.6	134.5	41.9	32.1	34.2	14.7	590.1	492.8	
1995	3.1	47.2	24.0	4.2	58.1	58.1	79.6	73.4	51.4	51.5	5.0	9.1	464.7	376.3	
1996	4.4	0.0	29.6	91.5	44.4	44.7	97.1	42.7	37.2	43.6	39.0	13.9	488.0	401.2	
1997	22.6	8.0	17.8	80.4	63.3	59.9	80.6	134.5	41.9	32.1	34.2	14.7	590.1	492.8	
1998	3.1	47.2	24.0	4.2	58.1	58.1	79.6	73.4	51.4	51.5	5.0	9.1	464.7	376.3	
1999	4.4	0.0	29.6	84.9	51.0	44.6	90.2	49.7	37.2	30.6	51.4	14.5	488.0	388.2	
2000	6.0	2.2	15.0	24.9	122.3	203.2	101.5	108.8	66.9	38.6	21.4	5.7	716.4	666.1	
												Average	531.3	425.8	
												S.D.	78.4	90.0	

Table A3.3 (cont'd) Comparison of monthly rainfall (mm) at Payneham Vale and two other locations—two stream-monitoring locations reported in Figure A3.4 and shown in Figure A2.2.

604001	Monthly aggregates												Summations		
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual	Apr-Oct	
1979									95.6	66.4	90.4	12.4	264.8	162.0	
1980	7.7	25.3	9.8	82.5	40.6	84.3	118.4	94.2	63.4	92.2	57.8	9.4	685.6	575.6	
1981	5.4	4.7	18.1	56.3	96.2	149.0	127.8	120.7	67.5	25.6	48.1	0.2	719.7	643.1	
1982	107.5	21.9	41.5	12.9	41.2	88.9	39.4	53.0	51.9	26.7	43.2	14.5	542.5	314.0	
1983	5.8	41.9	14.1	20.7	72.9	93.5	101.0	135.1	79.0	47.4	49.0	26.8	687.2	549.6	
1984	1.6	20.1	20.7	28.8	127.4	97.9	99.3	151.2	74.6	31.8	87.5	19.5	760.5	611.1	
1985	107.5	21.9	41.5	12.9	41.2	88.9	39.4	53.0	51.9	26.7	43.2	14.5	542.5	314.0	
1986	5.8	41.9	14.1	20.7	72.9	93.5	101.0	135.1	79.0	47.4	49.0	26.8	687.2	549.6	
1987	1.6	20.1	20.7	28.5	127.7	97.6	96.4	150.8	74.3	30.0	91.8	20.7	760.1	605.3	
1988	18.7	9.7	7.0	70.1	57.6	110.1	76.5	161.7	80.7	50.1	43.7	15.9	701.6	606.7	
1989	5.8	41.9	14.1	20.7	72.9	93.5	101.0	135.1	79.0	47.4	49.0	26.8	687.2	549.6	
1990	1.6	20.1	20.7	28.5	127.7	97.6	96.4	150.8	74.3	30.0	91.8	20.7	760.1	605.3	
1991	18.7	8.3	8.3	70.0	57.5	95.3	91.4	161.8	80.7	50.1	38.2	21.3	701.5	606.7	
1992	1.6	51.8	28.9	13.5	79.6	65.3	127.9	74.9	73.5	61.1	17.9	7.1	603.0	495.8	
1993	1.6	20.1	20.7	28.5	127.7	97.6	96.4	150.8	74.3	30.0	91.8	20.7	760.1	605.3	
1994	18.7	8.3	8.3	70.0	57.5	95.3	91.4	161.8	80.7	50.1	38.2	21.3	701.5	606.7	
1995	1.6	51.8	28.7	13.8	79.6	65.3	121.5	81.1	73.7	61.1	17.7	6.7	602.4	496.0	
1996	6.9	1.2	34.7	127.8	93.9	46.5	122.1	61.8	41.4	64.3	54.1	18.1	672.7	557.8	
1997	18.7	8.3	8.3	70.0	57.5	95.3	91.4	161.8	80.7	50.1	38.2	21.3	701.5	606.7	
1998	1.6	51.8	28.7	13.8	79.6	65.3	121.5	81.1	73.7	61.1	17.7	6.7	602.4	496.0	
1999	6.9	1.2	30.2	126.7	99.5	45.8	121.9	59.6	44.7	43.1	75.3	17.8	672.5	541.2	
2000	12.1	1.5	36.3	25.3	244.7	168.4	107.6	128.7	102.8	69.2	36.1	16.0	948.5	846.5	
												Average	690.5	561.1	
												S.D	88.0	109.7	

Appendix 4

Ecosystem studies

The good condition of the ecosystem of the Payneham Vale property has been indicated to the author in a number of testimonial statements concerning the relative performance of crops, of improved lambing rates and of avoidance of pestilence. While these indications appear acceptable, further questions arise as to what aspect(s) of the property ecosystem might be extracted through this study as indicators of ‘good health’ for use in other Australian properties. As introduced earlier, the diversity and number of bird species on the property have been considered as such indicators. This section will focus further on bird numbers and attempt to expand on the significance of the property’s bird population, particularly in terms of its role in the sustainable operation of the property’s farming system. Tree-growth observations by photography also serve in such a role and are discussed. Data on the earthworm population were collected in a further ecological study on the property, and were revised over the course of the project, but have not been explored further in the field. The earthworm population might equally well serve as an ecological indicator of property health, particularly if tillage impacts are of concern in individual situations.

Bird numbers were counted in four tree belts across the property. Individual season-to-season changes (Figure 3, main report) suggested an annual cycle, with a slight maximum in total bird numbers over winter, and this can be demonstrated statistically by consolidating and comparing the data for each season (Figure A4.1). Significant differences also existed between the four tree belts (Table A4.1). Small linear variations in the lengths of these belts appear to account for a major proportion of the variations in bird numbers in each belt, although probably not all of the differences.

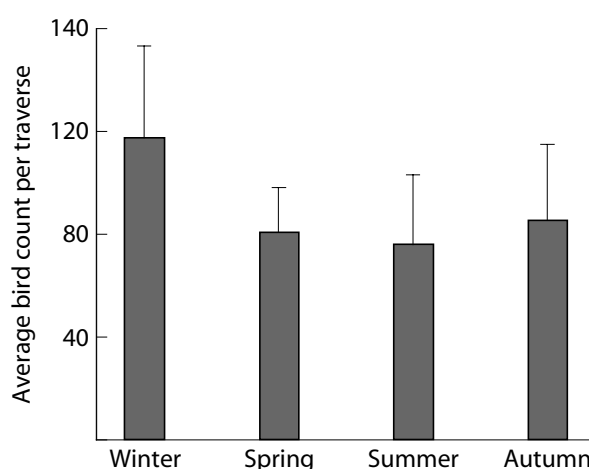


Figure A4.1 Annual cycle in bird numbers in the Payneham Vale tree belts. Data are the averages (error bars = standard deviation) of four tree belts visited on six separate occasions (spring, summer, autumn) or seven separate occasions (winter) from 1989 to 2001. An analysis of variance of all bird count data found that:

- bird numbers differed significantly between seasons ($P = 0.00034$)
- bird numbers differed significantly between tree belts ($P = 0.01950$)
- there was no interactive effect of these two factors (seasons and tree belts) numbers of birds present ($P = 0.8400$).

The two sets of four transects collected in the last two observing seasons (Spring 2000 and Autumn 2001) had bird diversities of 45 and 34 observed species, respectively. Since 1989, some 81 species have been observed in the tree-belt surveys (Table A4.2). Considering the work of Kitchener *et al.* (1980, 1982), this regular 35–45 level of avian vertebrate biodiversity

Table A4.1 Comparison of tree-belt length and average bird numbers for each of the four tree belts used in the bird study.

Tree belt no.	1	2	3	4
Length (m)	2540	2316	2127	2119
Average bird no.	102.4	97.6	91.6	71.3

would suggest that the tree belts are supporting an ecosystem of similar complexity to that supported by a wheatbelt remnant of 50 to 100 ha. The physical extent of the revegetated tree belts is much smaller, being 12 m wide by the overall length of 9102 m, indicated above, or about 10.9 ha. However, they connect to several large remnants within the Payneham Vale property. There is in total around 25 ha of revegetated, tree-filled land and 79 ha of remnant bushland on the property. It is thus clear that the bird species diversity observed is partly due to these many species of birds successfully using the tree belts to move around and through the property.

Authors such as Rosenzweig (1995) point out that an indicator of the successful development of stable ecosystems is the flow of food (that is, energy and nutrients) to higher trophic levels. In common with other types of vertebrate species, food flow through birds appears to be a process linked to biodiversity. Effectively, a common observation is that a certain ratio of predator to victim species appears in species lists. It would appear that a diversity of smaller species that can be caught becomes attractive to the higher predators, and these then frequent the ecosystem. The current location certainly has higher predators in the species list, as well as many nectivores and insectivores on lower trophic levels. This will mean that species that are or become skilled at using cover to avoid being caught will become more abundant. Best *et al.* (2001) points out the importance of cover for bird use in crop fields in the United States of America. Many species appeared to use the field edge as a significant habitat, and species were more abundant with wooded block-cover or strip-cover. The field-edge habitat has certainly increased on Payneham Vale with the introduction of tree belts; there being around 37 km of such edge, measured using a geographical information system (GIS). The foraging by birds from tree cover to capture food from crop and pasture was frequently observed during the counting surveys. Smaller species such as robins would venture out to feed and return directly to cover (Zanette *et al.* 2000). Bigger birds, such as the magpie lark and larger, would usually spend more extended periods foraging in crop or pasture and then rest in cover.

Newbey (1999) described a broader study of many surveys of birds on farms and in road verges in Western Australia. This study drew from Saunders and Ingram (1995) to recognise three status levels for birds, relating to whether their abundance was (1) INCREASING in numbers or range, (2) NOT CHANGING in numbers or range (or insufficiently studied to tell), or (3) DECREASING in numbers or range. In the study, there were 732 surveys carried out on 108 farms and 1147 surveys on 161 road verges. On analysis, some 91 species of status 3 bird species were recorded in an overall total of 179 bird species (Newbey 1999), a proportion of close

to 50%. In a similar proportion, some 41 of the 81 species observed on the Payneham Vale property are status 3 bird species (Table A4.2). However, a greater proportion of rare or declining species of passerine (perching) birds have been present on Payneham Vale. Of the 28 status 3 passerine species, some 20 have been recorded on Payneham Vale — over 70%. This high proportion of the passerines suggests that the tree belts are providing a comparatively good habitat for these species of conservation interest. It is suggested that direct feeding inside the reticular network of tree-belt habitat and feeding in the field-edge habitat are successful niches for birds on the property, with food shortage a major pressure in small fragments (Zanette *et al.* 2000).

Bradshaw (2001) relates observations that bird life on rural properties is providing insect control for the property's biological systems. The actual biomass flow through the bird community as food can be considerable, and represents an acceleration of the nutrient cycling of the ecosystem as well as a control of insect pests. Rough estimates of the biomass in the bird population on the Payneham Vale tree belts were used to estimate their food requirements and the insect biomass harvested. Length data on bird species are widely available. The weights of individual birds of each species were estimated using guides providing both weight and length and developing a regression relationship from known species for those where only length data were available (Serventy and Whittell 1976; Saunders and Ingram 1995; Simpson and Day 1999). Investigations concerning the nature of biomass consumed by birds from sparse literature were also attempted, but it was concluded that a comprehensive level of information across the range of species would not be available. It is, however, recognised that birds require a significant proportion of their biomass as food, particularly in the smaller species.

Ignoring the aquatic and predatory birds in Table A4.2, but retaining the omnivores such as the magpie and raven, the estimated biomass of all other birds (9338 individuals seen in the 100 surveys) was summed. The average bird mass was around 98 g. This is roughly equivalent to a small magpie lark or stubble quail in size. Such a bird might consume around 12% of its body weight daily. Only four tree belts, 10.9 ha, of a larger area of around 104 ha of tree-covered surfaces on the property have been counted. Scaling up the observed bird population to this full area of vegetation on the Payneham Vale property, it is estimated that the full property bird biomass of around 350 kg would require around 42 kg of food per day. Examining the species distribution, perhaps 60% or 25 kg/day of this is drawn from the cropland-remnant fringe. Over a year, this is 9 t of food, or a little over 2.2 g/m² of clear land on the property if spread out uniformly.

Table A4.2 Bird species observed in tree belts on the Payneham Vale property. Identification and counts were carried out by experienced bird observers using techniques described by Watkins (1998). Those marked * are status 3 species (ie. considered to be decreasing in numbers or range; see text for further information).

Species	No. observed	Species	No. observed	Species	No. observed
Stubble quail	17	Western gerygone*	172	Regent parrot*	36
Musk duck	1	Inland thornbill*	88	Western rosella*	333
Australian shelduck	151	Western thornbill	36	Australian ringneck	1462
Australian wood duck	296	Yellow-rumped thornbill*	508	Red-capped parrot*	121
Pacific black duck	61	Red wattlebird*	142	Elegant parrot	60
Grey teal	52	Singing honeyeater	286	Horsfield's bronze-cuckoo*	1
Chestnut teal	1	Yellow-plumed honeyeater*	49	Shining bronze-cuckoo*	12
Hardhead	2	White-plumed honeyeater	11	Laughing kookaburra	59
Australian grebe	3	Brown-headed honeyeater*	61	Rufous treecreeper*	24
Little pied cormorant*	3	White-naped honeyeater*	196	Splendid wren*	449
Pied cormorant	4	Brown honeyeater*	1401	Restless flycatcher*	11
Little black cormorant	1	New Holland honeyeater	18	Magpie lark	935
Great cormorant	11	Western spinebill*	2	Grey fantail	174
White-faced heron*	15	White-fronted chat	4	Willie wagtail	116
Black-shouldered kite	8	Scarlet robin*	95	Black-faced cuckoo-shrike	15
Brown goshawk	1	Red-capped robin*	4	White-winged triller*	1
Wedge-tailed eagle	9	Western yellow robin*	9	Dusky woodswallow	7
Brown falcon*	2	White-browed babbler*	6	Australian magpie	445
Australian hobby*	3	Varied sitella*	51	Australian raven	278
Peregrine falcon	1	Golden whistler*	76	Richard's pipit	22
Nankeen kestrel*	1	Rufous whistler*	27	Welcome swallow	14
Eurasian coot	1	Grey shrike-thrush*	29	Tree martin*	308
Little button-quail	2	Common bronzewing*	172	Rufous songlark*	8
Painted button-quail*	2	Crested pigeon	22	Brown songlark	41
Black-fronted dotterel*	11	Red-tailed black cockatoo	13	Silvereye*	775
Spotted pardalote*	7	Short-billed black cockatoo*	25		
Striated pardalote*	72	Galah	3		
White-browed scrub-wren*	5	Purple-crowned lorikeet*	68	Total observations	10024

This would not initially appear to have a major impact on the insect population, but it must also be considered that it would return around a tonne of nitrogen to the soil as bird manure during the year. However, bird foraging is not uniformly distributed, with 50% of this food drawn from the linear 37 km of cropland-remnant fringe, foraging pressure of around 12 g/m² would be applied on (say) 10 m bands.

Thus, insects that migrate towards more extensively gleaned areas to breed or feed would come under foraging pressure, particularly within the tree canopies themselves. In such situations, insect species would suffer predation on egg masses, on hatching juveniles, and on adults seeking mates, creating a 'fire break' effect protecting the crop from the introduction and multiplication of its insect pests. Other aspects of the tree-belt landscape also suited the foraging of insects by

birds. It was very noticeable that large populations of tree martins and some welcome swallows would, particularly in the late afternoon and into the evening, soar in the updraughts created by the tree belts while foraging for insects rising off the paddocks (Figure A4.2). The relatively calm air conditions allowed accurate aerobatics in the characteristic insect foraging of these bird species. This foraging pressure on the insects rising in the air column over the paddocks has not been completely considered above, as relatively few of these individuals were added to the tree-belt surveys in comparison to their numbers that could be casually observed.

The consequences for mixing agriculture and conservation are significant. In a Swedish study, Chiverton (1999) reports that leaving crop margins unsprayed for the benefit of native birds (partridges and pheasants) was of great advantage to these birds. Areas of

greater human impact in partly cleared tropical forest ecosystem were found to have fewer insectivorous bird species (Canaday 1996). Insectivorous bird species returned to isolated fragments of Amazonian forest following regeneration of the forest when specific tree genera, only viably regenerating if burning was not practised after logging, were able to bridge across felled areas (Stouffer and Bierregaard 1995).



Figure A4.2 Tree martins collecting insects in the early evening. Difficult to photograph, but close inspection of the original photograph suggested that there are around 20 birds in the sky in this image. One perhaps inconsistent indicator that resulted was bird lime on vehicle window and bonnets.

The vegetation in the best position to enjoy the protection of the guild of birds foraging for insects is in fact the trees and shrubs in the remnants and tree belts

themselves. These trees have several of the smaller active species such as the pardalotes, honeyeaters, thornbills, fantails and wrens surveying their surfaces for food sources. The health and growth of the vegetation in tree belts can be considered as demonstrating the functioning of the ecosystem. Watkins (1998) pointed out the rapid growth rates of trees in the tree belts in an earlier, extensive discussion of the birds on Payneham Vale. Trees planted in 1985 to 1987 were around 2.5–9 m tall in 1989, when bird observations commenced, and had grown to 9–14 m by 1998. An inspection of a small tree-belt section of some 40 individual *Eucalyptus globulus* trees by the New Zealand Forest Research Institute (1996) found that these had in nine years grown to a mean diameter at breast height of 203 mm.

This rapid growth of trees has also been documented through periodic photography, as shown in Appendix 5. Photography has provided a quick and convenient means of illustrating the impact of the tree belts on microclimate and the successful connection of bird cover to the open production areas of the property. Characterising the habitat present in understorey is particularly difficult to a lay person, and photography has been adopted as the best means of demonstrating the successful development of this aspect of the fenced tree belts. Sequential return to particular photo-points also delivers further observations such as the decline in canopy of individual mature trees, of locations where saline discharge continues to dominate, or that particular species are successfully flowering at particular points in time.

The capacity of landscape rehabilitation projects to install plant communities capable of regenerating themselves is of great concern to those looking for sustainability indicators. This is of particular concern in the context of the worsening soil conditions for germination and recruitment of new individual plants that is associated with soil salinity. This study has demonstrated that there is adequate evidence that the applied revegetation projects will go ahead into succession and further conservation roles while in other ways supporting the production processes on the Payneham Vale property. This future evolution will no doubt hold a few surprises because of the complexity of ecosystems and the fact that their developmental processes are competitive and environmentally sensitive.

Appendix 5

Photographic comparisons



Figure A5.1 (above) Development of revegetation protecting the main watercourse. On the Payneham Vale property, protection of the watercourse has largely been through the growth of new plantings. Older, mature trees, such as the one at top right, that showed thinning canopies in August 1991 have continued to decline, and died in the next few years. Other examples of declining trees are a tree to the left of the dead forked tree, itself right of centre, and a further tree seen over the vehicles, somewhat obscured in the later image by the vigorous growth of the fenced trees.



Figure A5.2 (above and left) Series of four photographs taken while standing on the bank of the House Dam and looking north, showing the development of vegetation and consequent protection of the watercourse. The House Dam is dam D in Figure A6.2, Appendix 6. (Photo credits: 1991–1994, Watkins; 2001, GHEM.)

Appendix 6

Farm maps

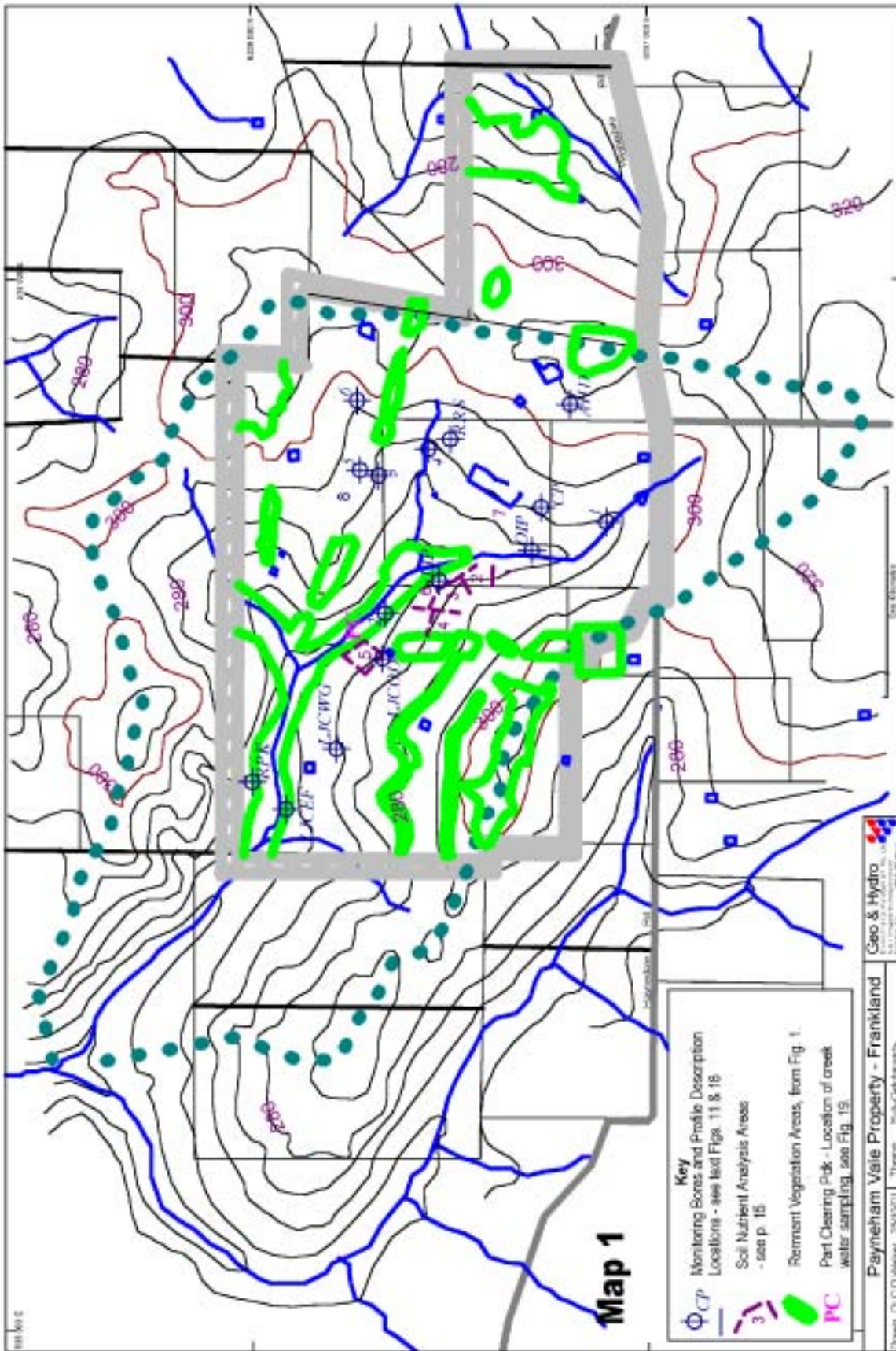


Figure A6.1 Map of Payneham Vale property showing monitoring bores and profile description locations, soil nutrient analysis areas, remnant vegetation areas and part clearing paddock.

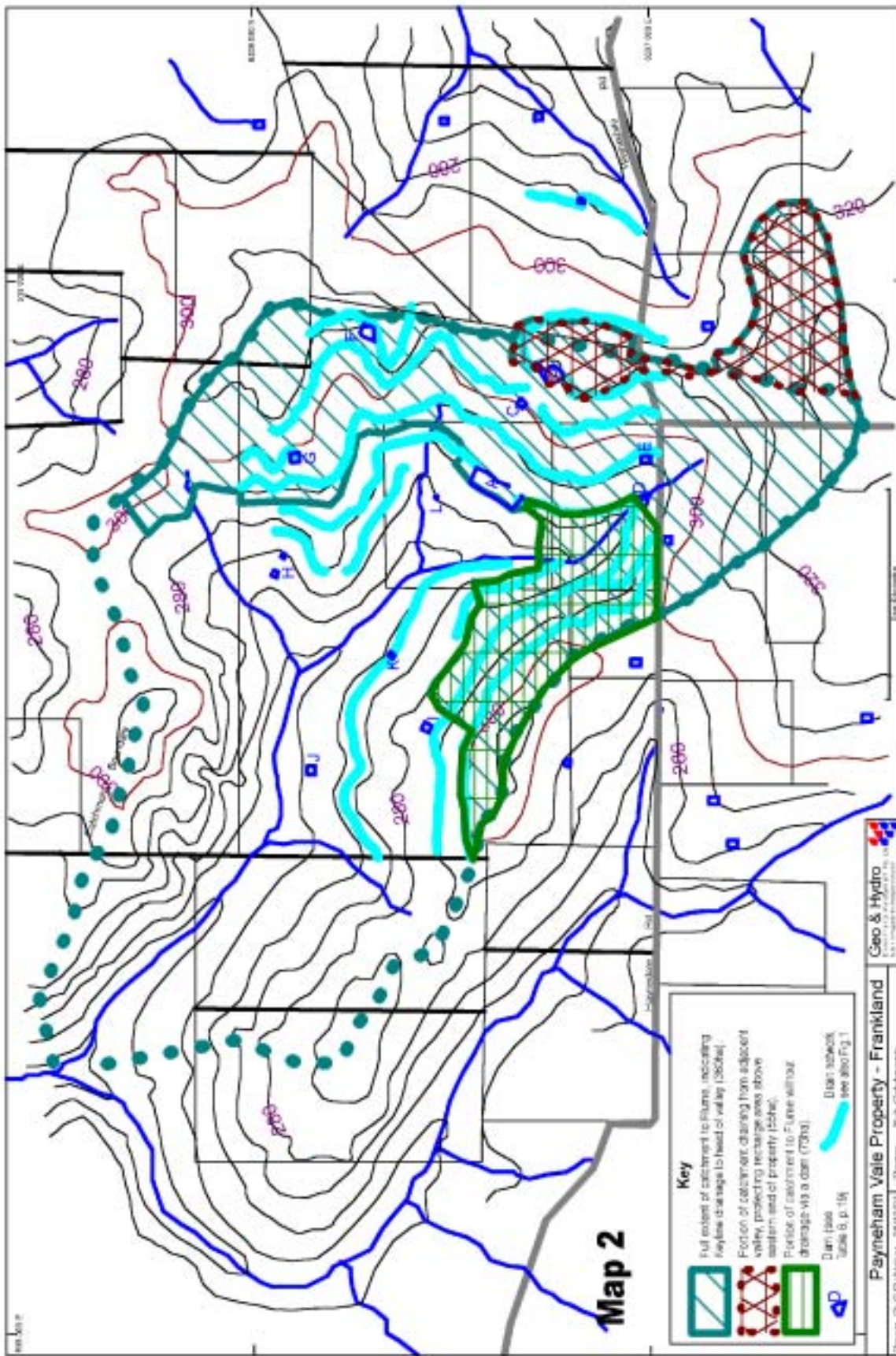


Figure A6.2 Map of Payneham Vale property showing drainage lines and features.

Titles in this series

Opportunities to breed/select/bioengineer plant species to control deep drainage and nutrient leakage

Biotechnology (GMO) issues and research priorities in natural resource management

Mapping regional metabolism. A decision-support tool for natural resource management

Documenting the concepts of the 'Ecosystems Farm Management' approach

Exploring future landscapes: a conceptual framework for planned change

Review of farmer initiated innovative farming systems

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