Dealing with Salinity in Wheatbelt Valleys

Processes, Prospects and Practical Options

Foreword

In mid-2001 more than 220 people attended the **"Dealing with Salinity in Wheatbelt Valleys: Processes, Prospects and Practical Options"** Conference in Merredin, Western Australia. The strength of interest at the conference was a reflection of the level of concern for the future of the previously productive and valuable valley floors due to the increasing risk from rising water tables and salinity damage. It is not only good agricultural land, but also rural towns, biodiversity, water resources, private and public assets that are threatened.

The aim of the conference was to develop a Shared Vision for the future of Wheatbelt valleys based on a clear view of what is occuring in the landscape (from the field trips), a sound understanding of the processes involved and the options available (from the presented papers) and on negotiated outcomes considering economic, social and environmental factors (from the workshop). In effect, it was a conference that bought together many people with widely differing opinions about managing salinity but with the common intent of a better future for our wheatbelt landscapes.

The conference is already recognised as an important benchmark for salinity management. It coincided with a Ministerial Taskforce Review initiated by the WA State Government. Some of the changes that have occurred since this time include:

- The establishment of a Natural Resource Management Council,
- New initiatives to better understand possible future landscape scenarios
- Research and assessment of engineering options for salinity control,
- Increased emphasis on the productive use of saline resources, and
- Trial of the Salinity Investment Framework for prioritising public resources in the Avon Catchment.

The papers presented on the second day of the conference were considered by many to have been the best ever presented on salinity in Western Australia. They have been recently reviewed and provide an important set of statements about salinity in the Wheatbelt. They include a review of relevant information, a range of research findings, some case studies and speculation about future options.

(cont.)

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The Workshop held on the third day produced a wide range of comments for the five themes of discussion. While the process may not have achieved the expectations of some participants for new practical options, it did deliver a draft Shared Vision based on the workshop themes. The general intent of this vision has been adopted by many groups and new salinity management initiatives. It has influenced the way that many people view salinity in the landscape and is leading us towards commonly sought management goals.

Information from the workshop has been available on the conference website (www.avonicm.org.au/avonicm/wbeltvalleys) however there have been quite a few enquiries for the proceedings to be available in a different format. As a result the conference Management Committee decided to make the proceedings available to all participants on a CD-ROM assuming wide availability of suitable technology to access the information in this format.

The proceedings of this important conference are the result of those who attended, those who presented, those who organised and those who sponsored or contributed in other ways. The efforts of the Organising Committee (listed below) and members of the R&D Technical Committee are gratefully acknowledged.

Dr Don McFarlane
Conference Convenor
Chairman, WA Salinity Research and Development Technical Committee
October 2002

Wheatbelt Valley Floors Organising Committee:
Don McFarlane (Chair)
Barbara Morrell (Chair, Avon Catchment Council)
Viv Read (Executive Officer)
Liz Yunken (Media)
Tom Hatton (CSIRO)
Richard George (Dept of Agriculture WA)
Doug Abrecht (Dept of Agriculture WA)
Greg Keighery (CALM, UWA)
John Sutton (WRC).

1 Day one: Monday 30th July. Field trip

The buses will depart from Perth, Northam and Merredin. Departure arrangements will be provided upon registration.

Stop 1. Coles Farm.
Landscape overview showing the confluence of the Yilgarn and Lockhart tributaries. Discussion about plant communities (*Rob Lambeck* and *Greg Keighery*), surface hydrology and flooding (*John Ruprecht* and *Rosemary Nott*) and use of satellite images (*Peter Caccetta*).

Stop 2. Doodlakine Tavern.
Presentation of predictive modelling (*Tom Hatton* and *Richard George*) and the community response to salinity risk in the Wallatin Creek Catchment (*Mike McFarlane*).

Stop 3. Baandee Lakes.
Playa (salt lake) ecosystems and new industry opportunities (*Mark Coleman* and *Jasper Trendell*).

Stop 4. Belka Valley.
Engineering options to manage water. Discussion of drainage options, flood control structures and salinity in the Belka Valley (*Richard George, John Flockhart* and *Kevin Lyons*).

Stop 5. Merredin.
Managing town-site salinity (*Mal Harper, Jay Matta* and *Richard George*).

Response to the day.

Evening: BBQ (or winter equivalent).

2 Day two: Tuesday 31st July. Conference Cummins Theatre, Merredin

8 - 8.30am Collect conference information.

Chair: Roger Payne, CEO Water and Rivers Commission

8.30 - 9am Opening of the Conference **Hon. Judy Edwards,** *Minister for the Environment and Heritage, and Water Resources.*

Situation Statements

9 - 9.30am Between a rock and a hard place – the geology, physiography and regional significance of Wheatbelt Valleys (*Phil Commander*).

9.30 - 10am Dryland salinity – appreciating and creating history (*Fionnuala Frost*).

10 - 10.30am Why the valleys are valuable and vulnerable - the ecology of Wheatbelt Valleys and threats to their survival (*Greg Keighery*).

10.30 - 11.00am *Morning Tea*

Chair: David Singe, Director, Wheatbelt Development Commission

11 - 11.30am Counting the costs – economic aspects of Wheatbelt Valleys (*David Pannell*).

11.30 - 12pm Watching the rivers flow – climate trends, surface hydrology and flooding associated with Wheatbelt Valleys (*John Ruprecht* and *Tom Hatton*).

12 - 12.30pm The hidden menace - groundwater hydrology, playas (salt lakes) and commercial options for salinity in Wheatbelt Valleys (*Richard George* and *Mark Coleman*).

12.30 - 1.30pm *Lunch*

Chair: David Hartley, Executive Director, SRD, Agriculture Western Australia

1.30 - 2.15pm **Guest speaker.** Making a virtue out of a necessity. Marketing new opportunities for rural communities into a globalised society (*Ann Macbeth*).

2.15 - 2.45pm Fitting perennials into an annual world (*John Bartle* and *Bill Porter*).

2.45 - 3.15pm Drainage options and their use in WA Wheatbelt landscapes (*Riasat Ali* and *Neil Coles*).

3.15 - 3.45pm **Response and comments.**

3.45 - 4.15pm *Afternoon tea*

Case Studies

Chair: Keiran McNamara, A/Director, Sustainable Forests Management, CALM

4.15 - 4.35pm Ecologically Sustainable Development: The Lake Chinocup Story (*Barbara Morrell*).

4.35 - 4.55pm Toolibin Lake and catchment (*Ken Wallace*).

4.55 - 5.15pm Profitable sustainable saltland pastures – GET REAL (*Michael Lloyd*).

5.15 - 5.35pm Engineering options – Belka Valley (*Kevin Jones*).

5.35 - 5.55pm Perennialising agriculture (*Bill Fraser*).

6.00pm Close

7.30pm Conference dinner. **Speaker: *Kevin Goss***, MDBC

3 Day three: Wednesday 1st August. Workshop "Designing the Future"

8.30 - 10.30am

"Setting the Future Scene"
(*convened by Ann Macbeth).*

- Salinity Threat Review: a synopsis of what to expect (*Bob Nulsen*).
- An Integrated Management Future (*Ted Lefroy*).
- Multiple choices in a salinised landscape (*Ed Barrett-Lennard*).
- A Socially Acceptable Future (*Sue Middleton*).

10.30 - 11.00am *Morning Tea*

11.00 - 12.30pm **Action Workshop**

A. Managing water for optimal outcomes

B. Managing for biodiversity

C. The economic use of valley resources

D. Managing public assets

12.30 - 1.30pm *Lunch*

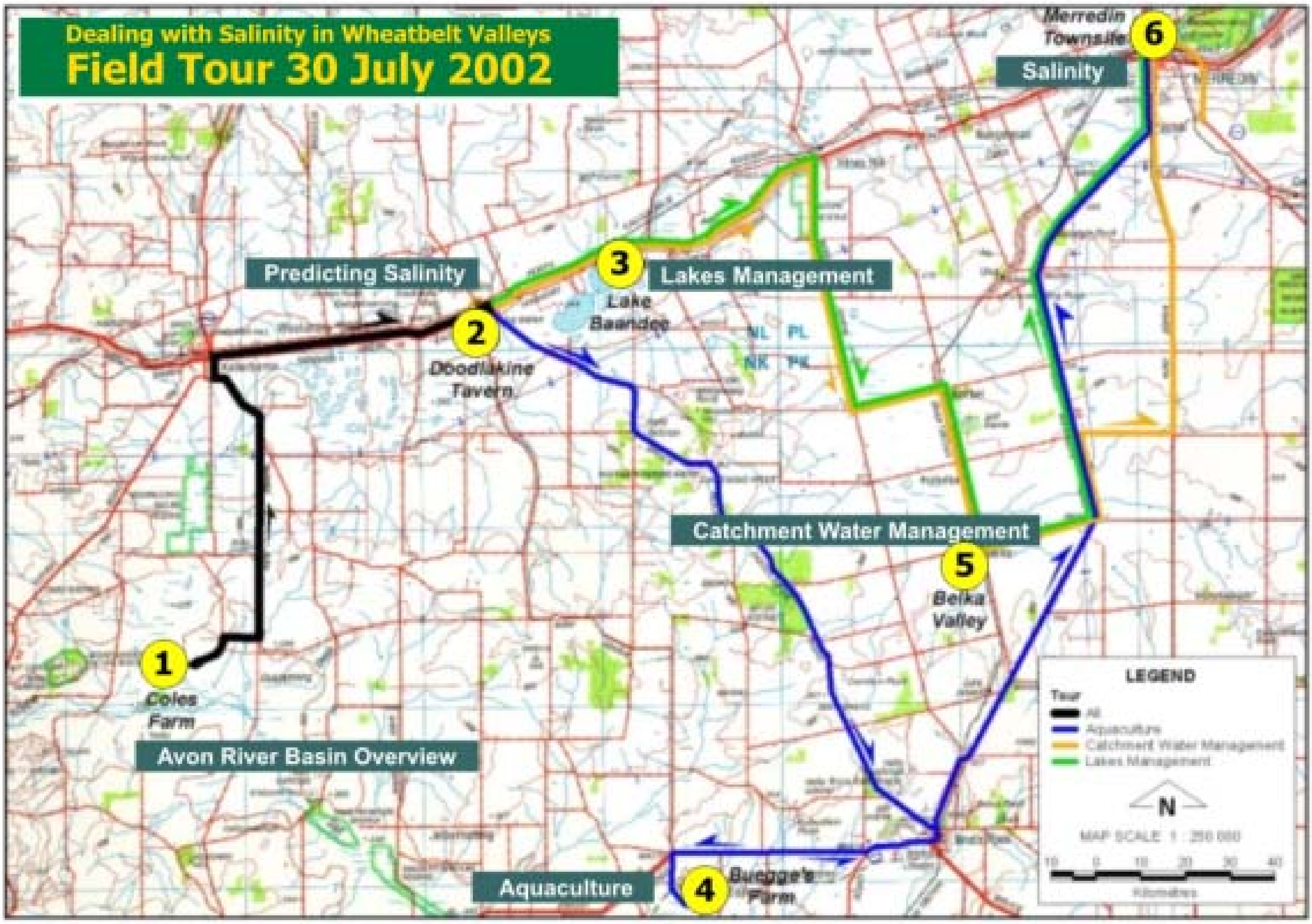
1.30 - 2.30pm **Action Workshop** (continued)

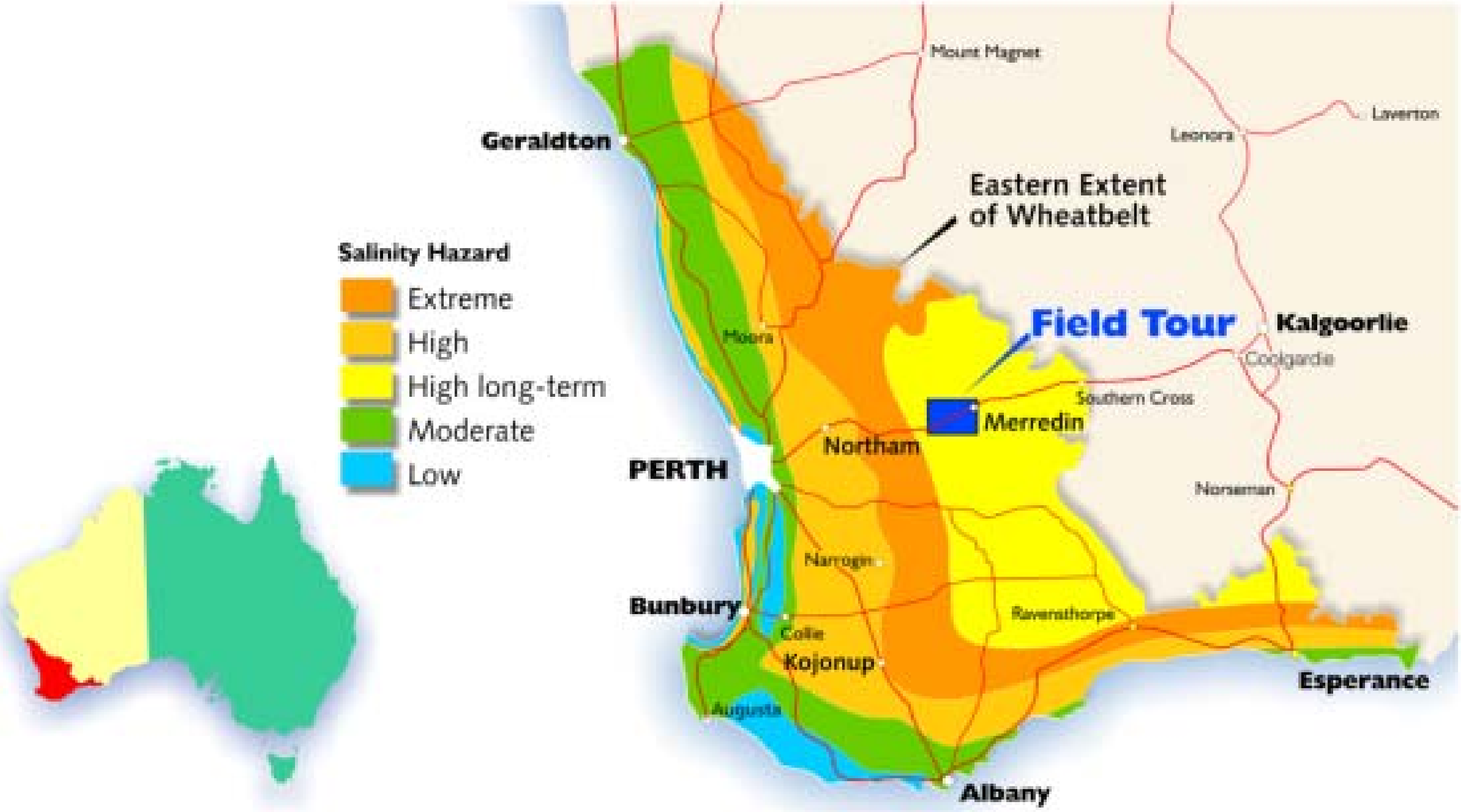
2.30 - 4.00pm **Plenary Session**

4.00 - 4.30pm Summary of workshop outcomes and directions (*Alex Campbell, Chairman of State Salinity Council*).

4.30 - 4.40pm **Close** (*Don McFarlane, Conference Convenor*).

program





BACK QUIT NEXT

Papers

Dealing with Salinity in Wheatbelt Valleys

Processes, Prospects and Practical Options

Papers presented at the field tour/conference/workshop

DRAINAGE OPTIONS AND THEIR USE IN WHEATBELT LANDSCAPES IN WA

Riasat Ali[1] and Neil Coles[2]

ABSTRACT

Effective management of waterlogging and soil salinity is one of the biggest challenges faced by the farming community in the dryland agricultural areas (known as the Wheatbelt) of Western Australia (WA). Many individual farmers, as well as State and local government agencies, have trialled and adopted various drainage methods in an effort to manage salinity. However, only a few large-scale systems have been evaluated on a formal scientific basis for different locations and landscapes in the Wheatbelt. The lack of formal evaluation of engineering options at variable scales has generated intense discussions and at times conflicting interpretation regarding effectiveness of engineering solutions for salinity management.

Evaluation of drainage options at catchment and regional scales is required to assess the economic, social and environmental impacts of using such options in managing salinity in the Wheatbelt. A number of research studies currently underway in the Wheatbelt address some of these issues. The design, construction and maintenance criteria need to be addressed to ensure that appropriate decisions are made regarding planning and implementation of such schemes. Actual drain design evaluations are required which may help minimise silt deposition and maintenance costs and enhance efficiency. The level of effectiveness required for the economic viability of a particular option is a real determinant for making implementation decisions. The adverse or positive impacts of drainage on downstream farmers, wetlands, waterways and natural reserves need to be addressed. Only after thorough assessment is it possible to draft meaningful guidelines, regulations and other related legislation. Without effective guidelines that have been scientifically, economically and environmentally assessed, it is unlikely that the real benefits offered by the appropriate use of drainage will be realised.

INTRODUCTION

The natural water balance of agricultural catchments in the Wheatbelt of WA has changed due to the clearing of native vegetation to allow the development of broadacre farming. Most of the State's commercial broadacre farms are located in the dryland agricultural region of WA, which is defined as farmland that receives less than 600 mm average annual rainfall (Coles *et al.* 2000). Reduced evapotranspiration and increased contributions to shallow and deep groundwater occurred as a direct consequence of clearing (Allison and Hughes 1983). The replacement of deep-rooted native vegetation with predominately shallow-rooted annual crops and pastures has exacerbated the impact of clearing on relatively fragile landscapes of the Wheatbelt.

The remobilisation of salts, stored within the regolith as a result of rising water tables and the development of localised perched systems, has resulted in extensive areas of the wheatbelt being affected by seasonal waterlogging and secondary salinity (McFarlane *et al*. 1992). The scale of this problem has grown each year after clearing, which began with the initial colonisation of WA. By 1996, nearly 90% of the dryland agricultural landscape was cleared. The subtle changes this brought about were first noticed and documented by Wood (1924) in his seminal paper on salt discharge increase following clearing. To date some 1.8 Mha has since been impacted in the Wheatbelt by primary or secondary salinity (Ferdowsian *et al.* 1997).

Management of salinity and other soil degradation issues is a complex problem with almost two-thirds of the agricultural land in this region comprised of duplex soils, the remainder being a mixture of deep sands (i.e. sand plain) and heavy clays. Thus salinity and soil management in this region is one of the

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biggest challenges faced by farmers. Already many relatively small-scale farm enterprises in the Wheatbelt are finding it difficult to remain viable under the impacts of salinity, associated land degradation problems and commodity prices, and are on the verge of collapse. Amalgamation of farm properties is likely to increase, reducing the viability of rural communities as families leave the district. The problem of soil salinity and waterlogging threatens both the productive agricultural land and the rural infrastructure (rural towns, roads, rail etc.) that supports it.

Over the past 25 years, most of the research has been focused on quantifying the problem and finding agronomic and biophysical solutions for the remediation and management of salinity. The adoption rates of these recommendations within the dryland agricultural areas has been limited and has not been of sufficient scale to significantly impact upon the hydrology of catchments. There is a limited amount of literature on engineering approaches generally, and deep drainage specifically, as an approach to manage dryland salinity. The thrust of the research, on a global scale, has been aimed at irrigated drainage or wetlands drainage and associated salinity issues as opposed to the large-scale drainage of dryland agricultural areas affected by rising shallow saline groundwater tables. The drainage management techniques have been developed and applied extensively only for irrigated agriculture where there has generally been a high return on investment.

Revegetation strategies have been successful only at limited locations in the Wheatbelt. Farmers are now starting to employ engineering options as part of the on-farm soil and water management system (Coles *et al.* 1999) and revisit the designs and methods adopted in the past. The relatively rapid spread of salinity or saline affected lands in the last 20 years has refocused attention on the use of large-scale deep drainage to manage rising saline groundwater and perched aquifer systems. In recent years farmers in the Wheatbelt have started to re-evaluate the use of engineering options implemented during the late 1970's and early 1980's for the management of salinity and other water related degradation problems. This includes the use of earthworks (banks, surface drains etc.), deep drainage and groundwater pumping (including relief wells and siphons). The main aim of this paper is to assess drainage of valley floors in the Wheatbelt as a tool to manage salinity, highlight possible directions for further research into drainage and other integrated catchment management options.

HISTORY

Three main strategies are used in the wheatbelt for the management of saline groundwater. These include deep drains, pumping and relief wells. Other engineering options such as grade banks or interceptor drains are used at site-specific locations to manage surface or subsurface water. Large-scale deep drainage was initiated in the late 1970's in the Moora district (Coles *et al.* 1999) and was responsible for the popularisation of this method for salinity management. This led to the widespread construction of deep drains across the Wheatbelt with up to 29 sites being monitored and assessed in the localities near West Wubin-Watheroo region in the north, Narrogin-Wickpin area in the central region and near Esperance on the south coast. The initial results of these trials were reviewed by Nulsen (1983), who concluded that: "*theoretical studies followed by field verification should be undertaken to clarify the role of both underground and surface drainage*". This statement remains valid today with only limited projects being instigated to apply drainage theory and to assess the results of the implementation of large field trials at catchment scales.

Drains now exist in almost every catchment in the Wheatbelt and total some hundreds of kilometres in length, but are generally scattered, isolated and without extensive regional linkages. More farmers now see drainage as a viable alternative to re-vegetation strategies and the availability of information on the effectiveness, placement and design of drains is becoming critical. With the increased level of drainage, adequately designed and maintained regional drainage is likely to become necessary in order for drainage, and thus water management strategies, to be more effective.

PERFORMANCE

Many engineering options including deep open drains have been adopted in the wheatbelt of WA in the past decades. Some form of evaluation has been carried out on a few of them. In most cases individual farmers have carried out the performance evaluation by monitoring some parameters of their interest. State and local government agencies have also been increasingly involved in the evaluation of engineering options, particularly deep drainage and pumping. However, as is often the case, each evaluator may have a different scale for measuring the effectiveness of a particular drainage system and a different system for measuring success. For example, if after constructing a drain, an individual farmer is able to grow a crop in otherwise unworkable lands, he would conclude that the drain is working effectively. However, another measure of success could be the effective lowering of the water table irrespective of whether or not a crop is able to survive.

According to Speed & Simons (1992), a drain is termed ineffective if it does not lower the water table significantly and at a notable distance from that drain. Anecdotal evidence from various sites in the wheatbelt suggest that many drains in the wheatbelt valleys did not impact on the water table (*per se*) but had significant impacts on the period for which the areas were waterlogged and rate at which surface runoff was removed (Coles *et al.* 1999). A drainage option may be termed as effective if it enables the land to economically grow crops on a sustainable basis (irrespective of its impacts on the water table). Deep drainage is often not seen as a preferred tool to manage salinity, as it does not address the root cause, i.e. recharge. It is expensive, not always effective and has high risk factors associated with on-site and downstream impacts (Drainage Taskforce 2000). However, as recent studies have suggested, re-vegetation strategies are likely to have only localised impacts in the near future (George *et al.*1999) with long term benefits for areas affected by regional groundwater systems to accrue over 100 years or more (Hatton & Nulsen 1999; Pannell 2001), drainage is more often than not seen as the 'quick fix' to the immediate salinity problem.

Past Research on Drainage

The research-based assessment of deep drainage in WA was instigated in the late seventies. Deep drainage, as a method for treating salt land, was assessed by Bettenay (1978) at farm scale level at the Yalanbee research station and by George (1985; 1991) in the Moora district. These investigations concluded that severely degraded land will take many years to reclaim - if at all - and that marginal or recently degraded land should be targeted for drainage. Three issues were identified as being critical to the success of drainage: (1) an assessment of the most likely impacts of a drain on the shallow and deeper groundwater table; (2) the disposal of drainage water, which may be highly saline; and (3) cost/benefit including construction, maintenance and return on investment. The first two are site specific whilst the third is likely to depend on personal choice and perceived net benefit. Despite problems such as relatively flat landscapes in the wheatbelt, deep drains are increasingly seen as a viable option in this region (Luke 2000).

Cox & McFarlane (1995) evaluated inverse seepage interceptor and other shallow drains in a number of sub-catchments at Mt Barker and Narrogin. The spacing of these drains varied between 70 and 140 m. They concluded that the drains helped in reducing waterlogging immediately downslope in 18 of the 21 transects in which the problem of waterlogging was present. There were similar reductions in waterlogging at both Narrogin and Mt Barker during wet years. Another drainage study at Bulyee (Berhane 1999) assessed that the shallow drains (less than 1.8 m), constructed on the lower slope and in valley near the break of slope in heavy clay soils, had no measured effects on salinity and a limited impact on waterlogging. Some leaching occurred in the upper perched system (20-40 cm bgl) but it was difficult to determine if salts were being removed from the deeper profiles. It was difficult to attribute the apparent changes in soil salinity and salt distribution to the construction of drain. These drains did not have any appreciable impacts on shallow water table and it was concluded that water in the drain was derived from surface runoff and subsurface flow from the perched aquifer system or via preferential pathways (Berhane 1999).

Coles *et al.* (1999) reviewed the efficacy of deep open drains in the wheatbelt. Their appraisal was based mainly on existing hydrological investigations and interpretations and anecdotal evidence from landholders. This review suggested that deep drains might reduce waterlogging and improve leaching and plant survival at distances greater than those predicted by drainage theory. They were of the view that improvements in the yields (recounted by farmers at some sites) were due to amelioration of waterlogging, the management of surface runoff and changes in the behaviour of water storage in the unsaturated zones. The location of the drains was considered an important factor, with drains constructed at the break of slope appearing to have a greater impact because of their location at the point of stronger upward flow. They concluded that a careful evaluation of the feasibility of drainage is required for each location and placement in the landscape was as critical a factor as design in determining the effectiveness of a particular drain.

Only limited in-depth scientific studies have been completed on drainage of dryland areas of WA. Large-scale drainage designs need to be evaluated at the catchment scale to ensure that the effectiveness and impacts of these systems are fully understood. Current studies on drainage address some of these issues. Guidelines, drafted after proper design evaluations, will help minimise sedimentation, erosion, maintenance costs and increase drain efficiency. Similarly positive or adverse impacts of drains on downstream farmers, wetlands, streams, and environment need to be addressed. However, the integration of surface water management strategies with other management options (e.g. trees, alternate-farming systems) are viewed as a vital part of the catchment planning process to reduce episodic and localised recharge and to manage catchment discharge.

Drainage Research in WA

Apart from some unpublished studies in the Moora District, most - if not all - of the evaluations of deep open drains, carried out in the wheatbelt in the past, were short-term, informal (occasional/unplanned), and based on monitoring of minimal parameters. Whereas to scientifically evaluate the impact of drains on crops, hydrology, soil root zone salinity etc. at farm, sub-catchment and catchment scale levels, long-term monitoring is required. Several large-scale drainage studies that address some of these issues are underway in the Wheatbelt (Narembeen, Jibberding, Beacon River and Dumbleyung). At Narembeen and Dumbleyung, similar parameters are being monitored to evaluate the performance of deep drains at farm and sub-catchment scale levels. Whereas a feasibility study of regional drainage is underway at Beacon River. A brief outline of the parameters being monitored and some of the initial results will be presented here from the Narembeen research project. The main aim of the Narembeen research project is to evaluate the impact of drains on crop productivity and environment at farm and sub-catchment scale level (Figure 1).

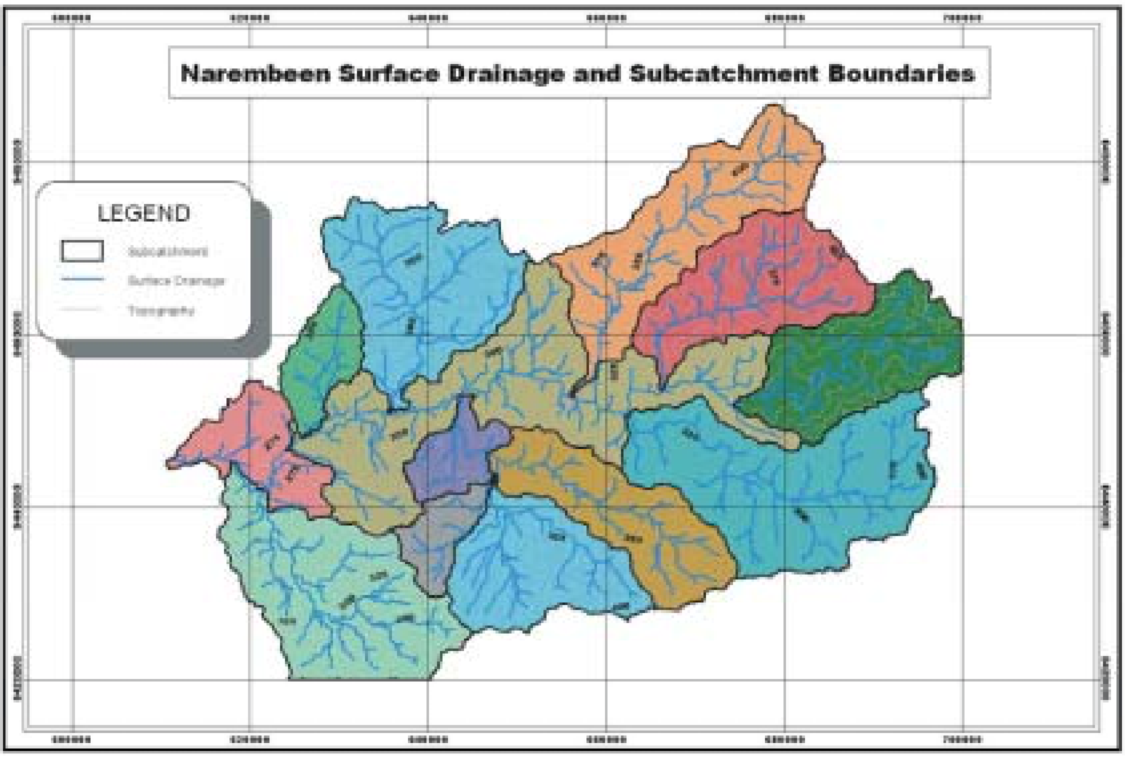

Figure 1: Wakeman sub-catchment and surface drainage boundaries (Narembeen)

Several sites that reflect the major representative landscapes evident at the sub-catchment level in the Wheatbelt were chosen. Drains with various design types and drain ages were selected and instrumented last year to evaluate the impact of drains on crops, shallow and deep groundwater, soil root zone salinity, regional hydrology and the environment. Similarly several sites were selected and instrumented in areas where the drains will be constructed in the near future. The monitoring of instrumented sites started last year and will continue for the duration of the project (approximately five years) in order to collate a long-term comprehensive suite of data on drainage performance. At this relatively early stage in the project only preliminary data and limited evaluation are available; however, trends in shallow and deep piezometers at various transects and sites, quality of water flowing in various drains, and water and salt outflow rate from the sub-catchment will be discussed.

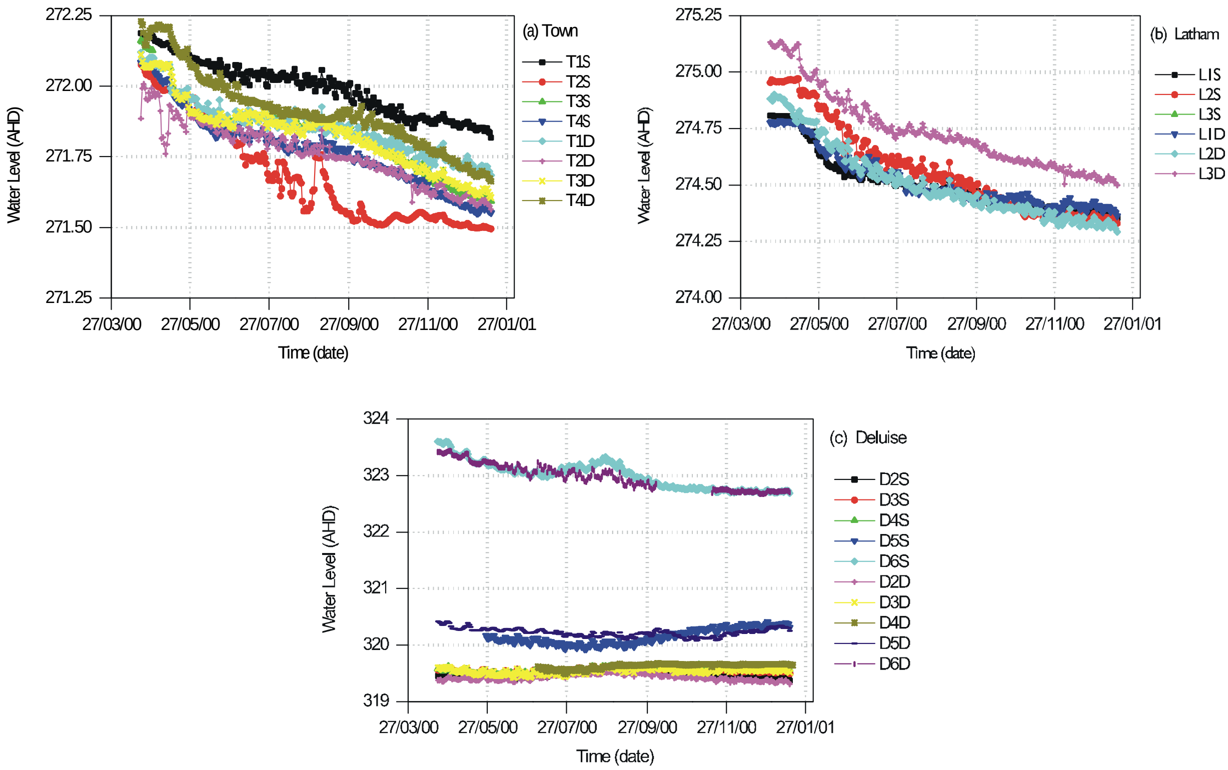

Figure 2: Temporal variation of water levels in shallow and deep piezometers at (a) town, (b) Latham and (c) Deluise sites (Wakeman sub-catchment, Narembeen).

Figures 2(a), (b) and (c) illustrate the temporal variation of shallow and deep water levels in piezometers at various sites with a water table decline evident at all sites except Deluise. The decline, although significant, may be related to a natural balancing of the system following an extreme episodic recharge event that occurred in January 2000. Continued monitoring over a longer time period will enable the impact of drainage on the system to be evaluated. Preferential flow, through lenses of porous material, was observed at various sites through visual observation and dye tests (Figure 3). This may explain the ability of seemingly low conductivity soils being able to transmit larger quantities of water than theory would suggest as summarised by Nulsen *et al*. (1986) and Berhane (1999) and may have contributed to the lowering of the water tables. There were rising trends in both shallow and deep water levels at the Deluise site (Figure 2(c)).

Figure 3: Lenses of porous material in clayey soil at Deluise site (Narembeen)

The drain at this site is not connected to the local natural creek line and therefore acts as an evaporation ditch. Rising water tables over time are expected under these conditions. The quality of water flowing in the drains declined as it moved towards the downstream end of the sub-catchment. The quality of water flowing in the drain at Pini was relatively fresher as compared to that flowing through the town of Narembeen. This is not an unexpected trend (Figure 4). The deterioration in the drain water quality at the Deluise site was considered to occur as a result of evaporation of water in the drain due to its isolation and role as a containment structure. Water flow and salt loads discharged from the main drain passing through the town of Narembeen varied between 10 and 15 ML/day and between 400 and 600 Tons/day respectively for the period of record (Figure 5). The rate of discharge and salt load changed drastically during and after the occurrence of significant rainfall events. The contributing area surrounding the drain is yet to be determined, and no valid conclusions can be drawn from these initial data as yet.

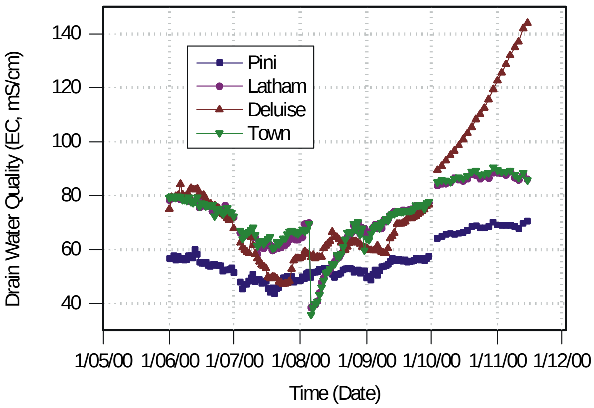

Figure 4: Temporal variation of water quality during 2000 in selected drains (Narembeen)

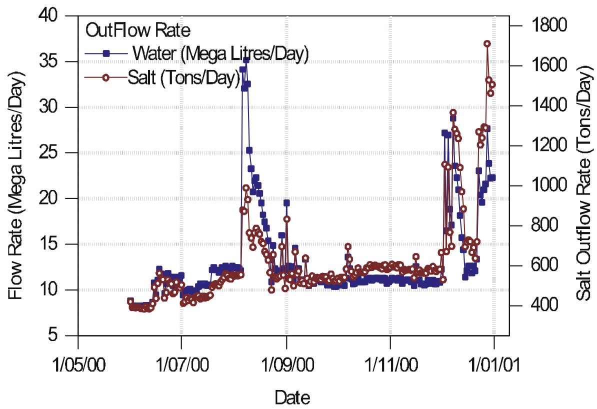

Figure 5: Temporal variation of flow and salt outflow from a main drain in the town of Narembeen (Wakeman sub-catchment)

Drainage Design, Construction and Maintenance

The design, placement and maintenance of drains are critical issues that should be considered in conjunction with environmental impacts. In general, the majority of deep drains constructed in the Wheatbelt are designed on the basis that they do not allow the entry of surface runoff. That is why only base flow is usually considered in the design of these drains. But due to poor protection against its entry, the surface runoff usually enters into these drains as a result of significant rainfall events. Velocities generated within these drains during heavy rains result in the undercutting of the drain slopes and washing of eroded material into the drains. This causes sedimentation and a drastic reduction in their effectiveness. Additionally, at locations where drains cross roads, the culverts are usually required. These are designed on the basis that the drains are for groundwater or baseflow only and, therefore, are incapable of managing excess surface runoff. This often causes extensive damage to both the drain and the road. Spoil bank slumping into the drains is another major cause of sedimentation (Figure 6).

Appropriate design and placement of the drain and spoil banks can minimise the amount of runoff entering the drain and reduce erosion. Drain embankments/spoil banks, shape, landscape location, compaction, angle of repose, soil type, gradient, velocity and carrying capacity are some of the factors that must be considered at the planning and design phase. The drain slope is another important design parameter as it determines the drain's stability and is likely to vary according to soil type based on light (sandy) to heavy (clayey) soils and it is considered best practice to determine the natural angle of rest for each location.

FUTURE DIRECTIONS

While there are a myriad of views about drainage and its effectiveness, there remains a limited amount of scientific research directed at the long-term effectiveness of such drains at local and catchment scales. Study sites like those at Narembeen and Dumbleyung are being designed and managed to answer the long-term questions about drainage efficiency; however, it may be some time (5-10 years) before there are adequate data to make informed decisions concerning deep drainage. Optimal management strategies can be recommended and applied only after the impacts of such strategies have been evaluated. However, it is incumbent on the researchers and organisations involved in these projects to ensure that data are passed on to the public, landholders and contractors in a timely manner to ensure that only appropriate practices are adopted and continued.

Figure 6: A main drain silted up due to spoil bank slumping and erosion

Other engineering options should also be considered and evaluated as part of an integrated approach to water management in wheatbelt landscapes. These include surface water control structures and groundwater pumping. For example, windmill/solar pumping may be considered as previous long-term windmill experiments have shown that under the right conditions pumping rates of 15-30 m^3/day can be achieved. In the experimental catchments examined, this resulted in a reduction of water levels by up to 2 m at radial distances of more than 1 km after several years of pumping (Salama *et al*. 1994).

A revised approach to water management, involving the use of earthworks to manage surface and shallow sub-surface water and re-distribute that water more evenly within the catchment, is being considered as a tool for recharge management. The methods proposed deal with managing: (1) surface water from upper and middle catchment into dams or discharge areas in lower catchment; (2) recharge in the upper catchment; and (3) the impact of waterlogging and salinity in broad valley floors. (Coles & Ali 2000). An integrated approach to catchment planning and water management in the landscape that includes re-vegetation options and farming systems is viewed as one of the most important aspects of salinity management.

CONCLUSIONS

Effective management of soil salinity and waterlogging is one of the biggest challenges currently faced by farmers in the Wheatbelt of WA. Agronomic manipulations have had only limited success and require long time frames and large areas to be managed under these systems. Engineering solutions have been increasingly seen as viable for the management of waterlogging and soil salinity in the Wheatbelt. Many farmers have constructed drains at various locations and landscapes in the Wheatbelt. However, there is a lack of formal evaluation of deep drainage which has made it difficult for agencies to provide a formalised set of guidelines for their construction, placement and effectiveness.

Only limited in-depth scientific studies have been completed on drainage of dryland areas of Western Australia. Large-scale drainage designs need to be evaluated at the catchment scale to ensure that the effectiveness and impacts of these systems are fully understood. Current studies on drainage address some of these issues. Guidelines, drafted after proper design evaluations, will help minimise sedimentation, erosion, maintenance costs and increase drain efficiency. Similarly positive or adverse impacts of drains on downstream farmers, wetlands, streams and environment need to be addressed. However, the integration of surface water management strategies with other management options (e.g. trees, alternate-farming systems) are viewed as a vital part of the catchment planning

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THE GEOLOGY, PHYSIOGRAPHY AND SOILS OF WHEATBELT VALLEYS

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ABSTRACT

Wheatbelt valleys lie in an ancient landscape in which drainage is largely internal and characterised by discontinuous chains of salt lakes. The crystalline rocks, eroded to a plateau maybe some hundreds of millions of years ago, preserve remnants of river systems originating when Australia was joined to Antarctica. These rocks, now deeply weathered beneath the valleys, are incised by old river courses (palaeochannels). The palaeochannels are infilled with up to 60 m of sediments either of Eocene (c 43 million years) or Pliocene (c 5 My) age, and lie within flat bottomed valley floors. The widened out valleys contain up to 20 m of more recent sediments, and soils of colluvial, alluvial, lacustrine and aeolian origin. Digital elevation models derived from the Land Monitor program now give the opportunity to map surface drainage pathways and areas of inundation in detail, and integrate with soils and radiometric data. The flat valley floors, and lack of either surface or subsurface drainage, present a challenge for water management.

INTRODUCTION

Wheatbelt valleys are now the focus of considerable attention from a water management perspective. The flat-bottomed, largely internally-draining valleys which form a significant proportion of the Wheatbelt were settled and cleared early as they are highly productive. However, the valley floors are subject to waterlogging, rising water tables and dryland salinity, with the likely soil structure decline, loss of productive farmland, and threat to native vegetation in reserves and infrastructure.

The southwest of Western Australia has some unique geological and physiographic features which have a bearing on the land use management in the valleys. The region has not only some of the oldest rocks in the world, but also one of its more ancient landscapes. The valleys, now occupied by discontinuous chains of salt lakes, are parts of palaeodrainage systems tens of millions of years old.

Modelling of hydrological processes in wheatbelt valleys has emphasised the importance of understanding the slope of the land surface in order to control surface water, allow drainage, and model groundwater table rise. The distinction between management of valley floors and uplands requires a definition of valleys, which is made possible by the availability of accurate digital terrain models (DEM) derived from the Land Monitor Project.

The purpose of this paper is to provide a brief background to the geology, physiography and soils of wheatbelt valleys, with a comprehensive and up to date bibliography of previous work. Details of palaeochannel sediments are discussed in some depth as this information is not collated elsewhere. It is convenient in this review to cover the whole of the southwest part of WA, while focussing on the valleys in the Wheatbelt Region which are contained within the zone of ancient drainage (Figure 1).

PREVIOUS WORK

The Darling Plateau had been recognised as a peneplain by Woolnough (1918) and Jutson (1934), who also distinguished an old plateau (the hills) and a new plateau (the valleys). The valleys were studied in detail by Bettenay (1962) who mapped the ancient drainage system, and by Bettenay *et al.* (1964) from the point of view of salinity. Detailed geomorphic descriptions of the landforms in the south west were made by Bettenay & Mulcahy (1972), Mulcahy & Bettenay (1972), Mulcahy (1973), and by Finkl & Churchward (1973), who put forward the concept of

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etch plains – the formation of the landscape from deeply weathered regolith. More recent authors have concentrated on specific aspects of landscape e.g. Twidale (1994); Glassford & Semeniuk (1995); Twidale & Bourne (1998); and Beard (1999) has recently made a comprehensive analysis of the drainage history.

Figure 1: Drainage pattern in the southwest of Western Australia

The impetus to understanding the bedrock geology was the systematic geological mapping carried out in the 1970s, together with isotopic age dating (Geological Survey 1990). The Cainozoic (younger than 65 million years old) geology of the sediments overlying the bedrock is less well known. Quilty (1974) reviewed the Tertiary stratigraphy, and Wilde & Backhouse (1977) described the existence of outcropping Tertiary (Eocene) sediments in the Darling Range area. The ancient drainages, termed palaeodrainages, were mapped and described by van de Graaff *et al.* (1977), but only in the last ten years have Eocene or Pliocene sediments been described from palaeochannels in wheatbelt valleys away from the south coast (Waterhouse *et al.* 1995; Salama 1997; De Silva 1999; Yesertener *et al.* 2000). These investigations in the Wheatbelt and adjacent areas followed the recognition of an integrated Eocene drainage system in the Eastern Goldfields (Kern & Commander 1993; Clarke 1994b). The palynological dating (from pollen) is hindered by lack of subsurface samples; as the groundwater in the region is almost invariably saline, there has been little deep drilling for water supply, and only some exploration for coal and kaolin. Only in the last ten years also have the full thickness of Quaternary sediments and regolith in the valleys been described in detail (e.g. George & Frantom 1990a,b,c; George, 1992; Salama *et al*. 1993) as part of land salinisation studies.

Wyrwoll (1988) has commented on the inordinate length of time during which the geomorphology has developed, but the acceptance that the landscape itself is of great antiquity is comparatively recent (Twidale 1998), a theme popularised by White (2000).

Definition of the valleys in a systematic way throughout the Wheatbelt has only been possible since the completion of the 1:2,500,000 geological mapping in the 1970s (Commander 1989, Fig. 1), through soils mapping and, since 2000, by remotely sensed digital elevation modelling carried out under the Land Monitor Project (Caccetta 1999a,b).

BASEMENT GEOLOGY

The southwest of Western Australia is divided into two major tectonic units: the Archaean (pre-2500 million years) Yilgarn Craton, and the Proterozoic (2500-600 My) Albany-Fraser Orogen. The evolution of the crystalline bedrock in these provinces is summarised in Table 1 from Geological Survey (1990).

Table 1: Geological timescale of basement rocks

Tectonic unit	Age range (millions of years)	Rock unit	Event
	550-750	Boyagin Dyke Swarm Muggamugga Dyke Swarm	Intrusion of dolerite dykes NW trending NE trending
Pinjarra Orogen	1000-1300	Moora and Yandanooka Groups	Deposition of dolomite, basalt, sandstone, siltstone
	1150		Metamorphism of Stirling Range Formation
Albany Fraser Orogen	1100-1300	Biranup and Nornalup Complexes	Metamorphism and granite intrusions
	1200-1800	Gnowangerup dyke swarm	EW trending dolerite dykes
	2400	Widgiemooltha dyke suite	EW trending dolerite dykes
Yilgarn Craton	2600-2700	Granite	Granite intrusions, metamorphism and folding
	2700-2900	Greenstone	Sediments and volcanic lava
	3000-3300	Western Gneiss	Metamorphism, sedimentation
	4500	Formation of the Earth	

The oldest rocks are remnants of early sedimentary crust thought to have been deposited around 3300 million years (My) and metamorphosed around 3000 My into what is now the Western Gneiss (Figure 2). A period of sedimentation and eruption of volcanic lava followed between 2900 and 2700 My, culminating in the intrusion of granite plutons, with folding and metamorphism of the sedimentary and volcanic rocks, the remnants of which are known as greenstone belts. Two major phases of dolerite dyke intrusions at 2400 My and 1800 My or later completed the crystalline bedrock distribution that we observe today in the Yilgarn Craton (Figure 3).

On the southern and south eastern margins of the craton, renewed orogenic activity around 1300 to 1100 My metamorphosed sediments (such as the Stirling Range Formation), whose age is currently unknown, and formed the Biranup and Nornalup gneiss and migmatite complexes. Further sedimentation took place on the western margin of the craton with deposition of the 2 km thick Moora and 5 km thick Yandanooka Groups. All these rocks were then further intruded by dolerite dykes between 750 and 550 My.

The basement rocks are generally exposed only in the hills, but isolated outcrops occur sporadically within the valleys. The crystalline basement is now mostly weathered to clay or clayey sand beneath the valleys to depths of generally 40 m below the surface, but exceeding 70 m in the vicinity of palaeochannels.

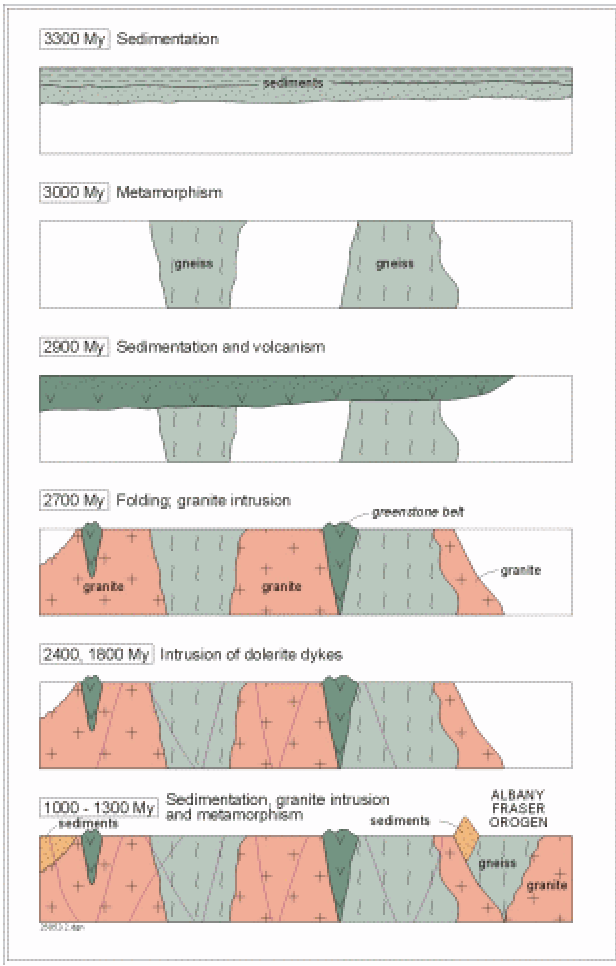

Figure 2: Diagrammatic sections illustrating the geological evolution of the basement rocks (age in millions of years, My)

EROSION, DRAINAGE AND SEDIMENTATION

Peneplanation

Erosion of the Archaean crystalline basement in the north east of the Yilgarn Craton to a subdued peneplain (the present Darling Plateau) certainly took place in the Middle Proterozoic, as evidenced by the exhumation of the unconformity beneath flat lying 1800 My old sediments. The unconformity being exhumed is a peneplain with slightly elevated greenstone belts, remarkably similar to the granite-greenstone topography of today's north east Yilgarn Craton.

In the south west of the Yilgarn Craton there may have been significant uplift and erosion during the Late Proterozoic. This is demonstrated by the higher grade metamorphic rocks at the surface, and by folding and faulting in the Albany-Fraser Orogen, and of the Moora and Yandanooka Groups.

The whole region was glaciated during the Carboniferous-Early Permian (about 280 My) when a continental ice sheet covering Gondwana (Figure 4), likely to have been 3-5 km thick, moving to the NNW, planed off the pre-existing land surface. Possibly, valleys would have been created beneath the ice sheet from melt waters (P E Playford, *pers. comm*. 2001), which may also have trended NNW. These valleys may have filled with glacial till and outwash gravels, as in the Collie, Wilga and Boyup Basins. In the extreme south west, there must have been a significant coverage of sand and coal measures immediately following glaciation, evidenced by the sediments now preserved only in the coal basins and in the Perth Basin to the west (Figure 3).

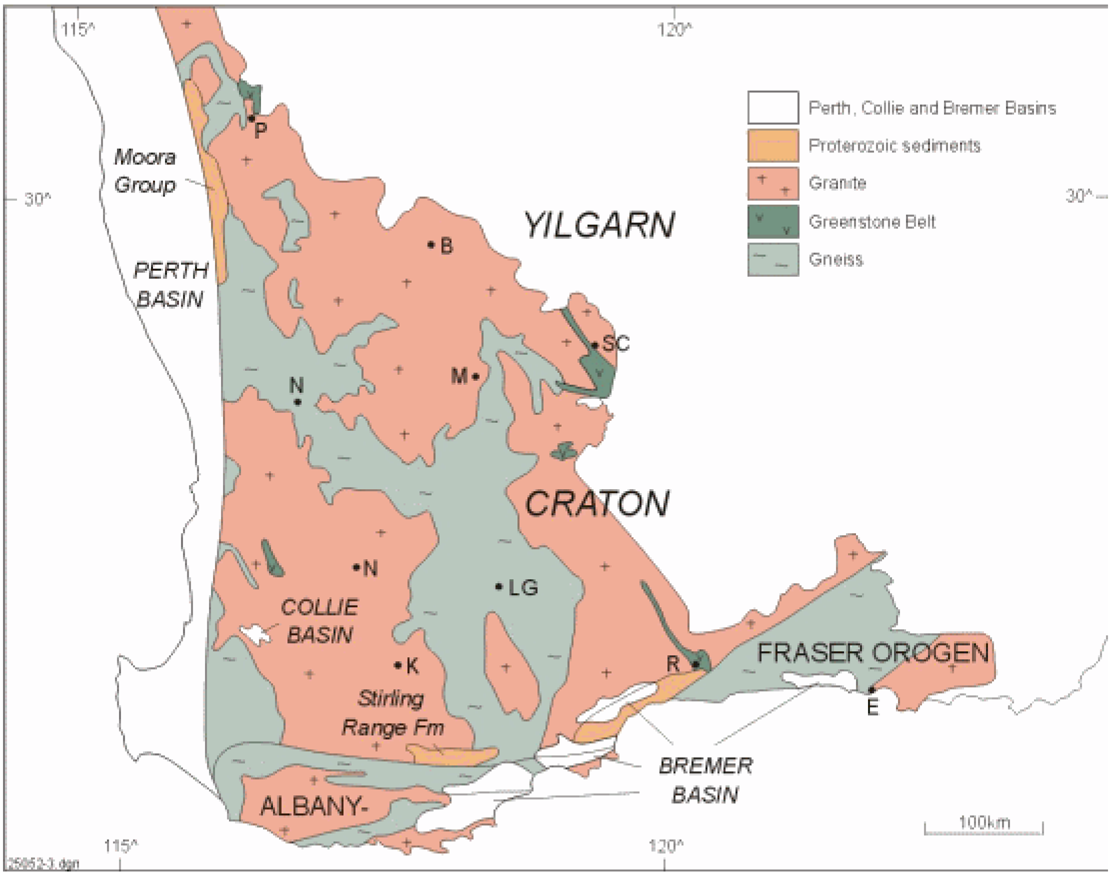

Figure 3: Solid geology of the Agricultural Area (after Myers and Hocking 1998)

Finkl & Fairbridge (1979) have suggested that peneplanation of the Yilgarn Craton was completed in the Proterozoic, and that denudation rates were minimal ever since. They argued for a western source for the Permian-Cretaceous Perth Basin sediments (Fairbridge & Finkl, 1978), though this was challenged by van de Graaff (1981) who argued for removal of some 500 m of rock from the Yilgarn Craton since the Jurassic. However, it has recently been found that the Archaean provides only a minor source of detrital zircons to Quaternary mineral sand deposits in the Perth Basin (Sircombe & Freeman 1999). This strongly implies a western source for Perth Basin sediments from Proterozoic rocks, and supports the suggestion of minimal erosion of the Yilgarn Craton at least since the Jurassic/Cretaceous. Thus the landscape appears to have been moderately stable since the age of the dinosaurs.

Most authors now agree that peneplanation was complete by the end of the Createceous. Twidale (1994) postulates that the ‘new plateau’ of Jutson (1934) in the eastern Yilgarn must also be of Eocene age, on the basis of the Eocene sediments there, and that the ‘older plateau’ is even older.

Drainage

The oldest drainage systems now preserved are likely to be in the zone of ancient drainage (Figure 1) containing the Pingrup, Lockhart and Camm valleys, between the median and the central watersheds, recently recognised by Beard (1998; 1999). The region may have been traversed by palaeoriver systems draining Antarctica when the continents were joined (Figure 4), and Beard (1999) has suggested that these rivers may have originally drained southwards (Figure 5), following the opening of a seaway between Australia and Antarctica in the Jurassic 150 million years ago (Table 2). It may be significant that these valleys follow the NNW structural trend in the basement rocks.

Figure 4: Reconstruction of Gondwana (GSWA 1990)

These palaeodrainages are analogous with the Eastern Goldfields where an integrated palaeodrainage system, at least in existence by the start of the Middle Eocene (50 My) has palaeochannels infilled with mid to late Eocene sediments (Kern & Commander 1993; Clarke, 1994b). These palaeodrainages, however, cross the geological structure and direction appears determined by drainage to the Eucla Basin. No age dating has apparently been carried out on the palaeochannel sediments in the zone of ancient drainage (Yilgarn System of Beard 1999), though they have been correlated with the Eocene Bremer Basin sediments (Dodson 1999).

Westward draining Eocene sediment-filled valleys (Figure 5) have been identified in the current Blackwood and Beaufort catchment (Waterhouse *et al.* 1995) and in the North Stirlings (Appleyard 1994), Mobrup catchment (Hundi *et al.* 2000) and at Wilgarup near Manjimup (Thorpe 1994). However, farther north, Eocene sediments have been identified only in dissected uplands (eg Westdale, Brookton), so the drainage pattern is currently unknown. The Perth Canyon, infilled onshore with Palaeocene (65-55 My) sediments (Davidson 1995), and correlated with the Avon palaeochannel (Salama 1997) indicates the presence of a large westward flowing river system, but no sediments of that age are preserved on the Darling Plateau.

The existence of Eocene sediments in palaeochannels confirms a minimum age for these palaeodrainages of about 45 My, Early Cretaceous sediments preserved only in the Collie basin (Nakina Formation) could have been much more extensive, but cannot be linked with current drainage systems. Twidale (1994) postulated a Gondwana landscape of low relief, with low domes rising from duricrusted plains in the southwest Yilgarn Craton, which could be similar to other pre-Cretaceous land surfaces currently being exhumed elsewhere in Gondwana.

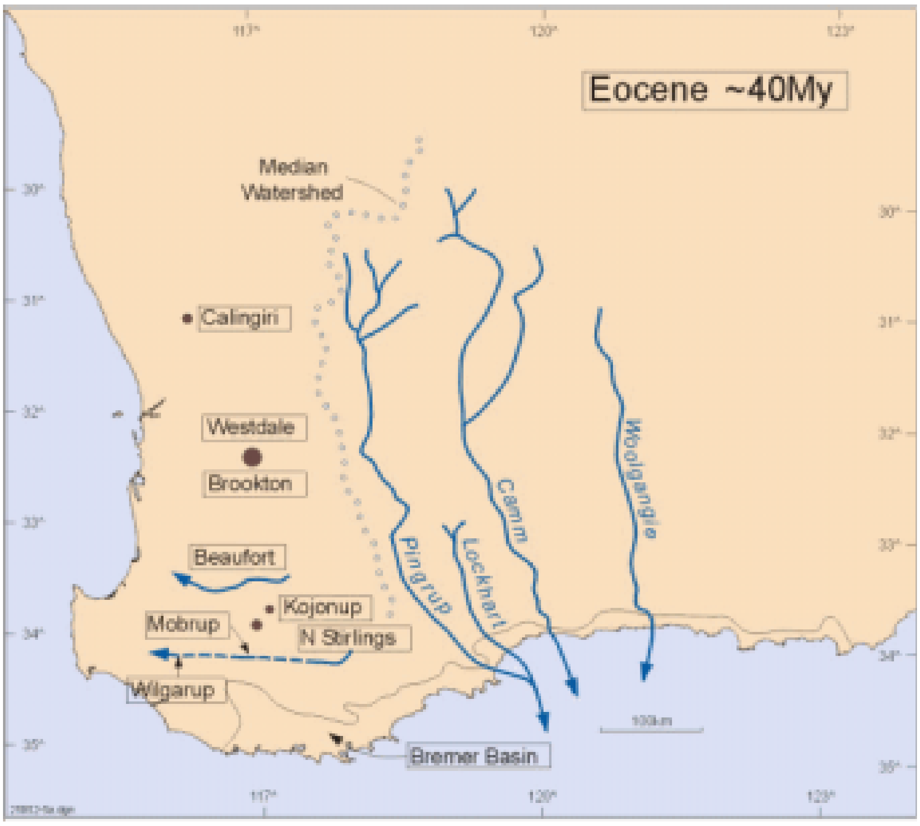

Figure 5: Eocene sediment localities and possible drainage pattern (after Beard 1999)

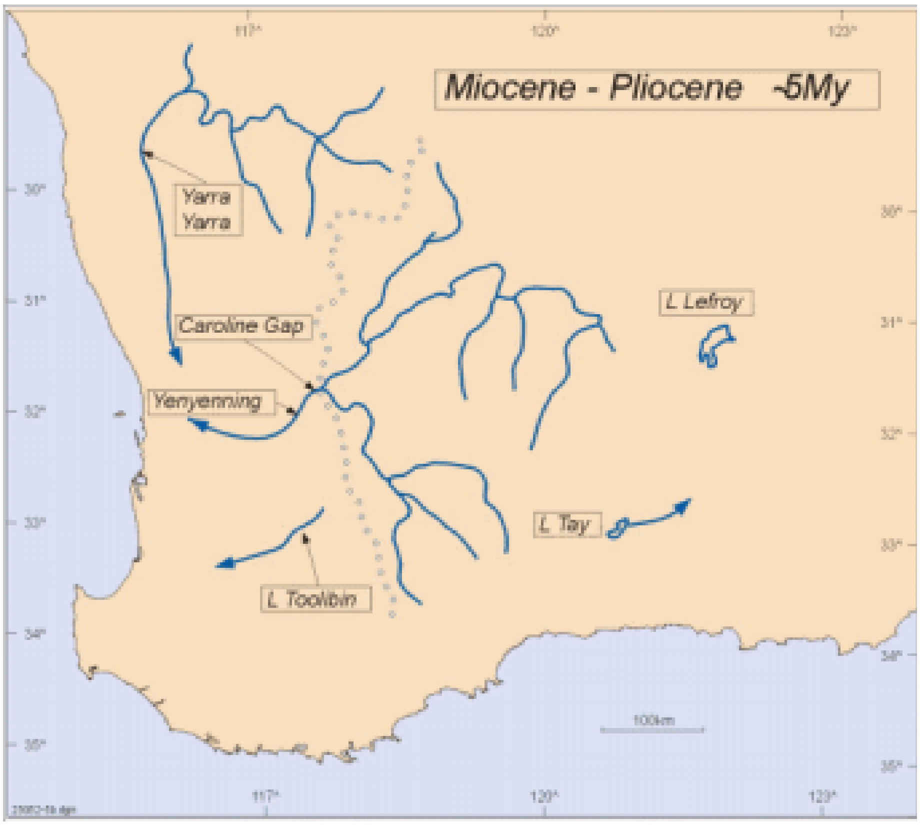

Figure 6: Late Miocene-Pliocene sediment localities and drainage pattern

Table 2: Evolution of the western part of the Australian continent (modified after Middleton 1991)

Age (millions of years)	Event
0-2	Quaternary – Late Pliocene sediments across wheatbelt valleys
5-2	Late Miocene - Early Pliocene sediments in palaeochannels
?	Uplift and rejuvenation of Darling Range, west of Meckering Line
25-11	Miocene chemogenic sediments in Eucla and Perth Basins
38-25	Main period of lateritisation in Oligocene?
43	Final separation of Australia from Antarctica
50-38	Eocene Bremer Basin and palaeochannel sediments
50	Rejuvenation of rifting with Antarctica
105	Spreading ceased along south coast– deposition of Late Cretaceous sediments in the offshore Bremer Basin
119	Opening of rift with Antarctica
	Separation of India, and widening of Perth Basin
150	Beginning of separation from Antarctica
280	Glaciation
280	Formation of Perth Basin

Separation of Antarctica after 43 My (Table 2) was accompanied by uplift along the Ravensthorpe Ramp (Cope 1975), about the Jarrahwood Axis, with the likely development of short incised south flowing streams. At this stage the Camm, Lockhart and Pingrup valleys may have been beheaded, or reversed. The westward trend of the North Stirlings-Mobrup-Wilgarup drainages was dissected, and the Beaufort Palaeoriver (Waterhouse *et al.* 1995) diverted south.

In the north, uplift of the craton, with tilting to the south, reduced the erosive power of north flowing drainages. Beard (1999) concluded that the Lockhart/Camm/Yilgarn Rivers were captured at Caroline Gap, the one prominent gap in the median watershed. While it is attractive to consider that this expanded catchment may be associated with the cutting of the Perth Canyon, and Kings Park Shale (Salama 1997), the presence of Pliocene sediments in the palaeochannel downstream of Yenyenning (Figure 6), and the dissection of high level Eocene sediments in the Darling Range suggests a post-Eocene capture.

By the Late Miocene-Early Pliocene there appears to have been substantial modification of the Eocene drainage pattern by uplift along the Darling Range, with dissection of lateritised bedrock and Eocene sediments. The Meckering Line marks the eastern extent of this rejuvenation, west of which current river valleys are generally youthful and incised (Mulcahy 1973). This line of rejuvenation also partly coincidesd with the South West Seismic Zone (Beard 1999). Unlike the Eocene drainages, river systems in the Pliocene may have been able to cut more easily through deeply weathered crystalline bedrock (saprolite).

Continued uplift of the whole continent to the north (Beard 1998) has contributed to the internal drainage and development of salt lakes in the north flowing valleys. The south tilt is evident from diversion of rivers to the south, such as the capture of Beaufort by the Blackwood at Duranillin, the south diversion of the Yarra Yarra Palaeodrainage (Figure 6) through the Moore-Brockman valleys, as well as the south coast rivers off the Ravensthorpe Ramp (the area of rejuvenated drainage along the south coast, Figure 1).

Sedimentation

Lack of widespread coarse land derived sediments in surrounding basins (Perth, Bremer, Eucla) after the Early Cretaceous (120 My) suggests that erosion of the Darling Plateau had been essentially completed by then. Rejuvenation after the late Cretaceous is indicated by the Palaeocene age Kings Park Shale filled Perth Canyon, implying that a precursor to the Yilgarn River – Avon Palaeodrainage existed at that time through the Darling Range.

Eocene Sediments occur both in palaeochannels (e.g. Waterhouse *et al.* 1995), and as dissected remnants on drainage divides (Wilde & Backhouse 1977).

The Eocene sediments have been lateritised and deep weathered. There is no unanimity on the date of laterite formation and Twidale (1994) noted that the age of the high plain surface and duricrust of Darling Range is controversial. van de Graaff *et al.* (1977) suggested an Oligocene (38-25 My) age on the basis that Eocene sediments are lateritised on the margins of the Eucla Basin, whereas Miocene (25-5 My) sediments were not, and a Late-Oligocene to Early Miocene date was supported by Schmidt & Embleton (1976) from palaeomagnetic work on laterite in the Perth Basin. Bird & Chivas (1993) also suggested a post mid-Tertiary age for deep weathering in Western Australia, based on oxygen isotope values in two samples of clay. A post-Eocene age for weathering is indicated by the deeper regolith paralleling Eocene infilled palaeochannels (Kern & Commander 1993). However, recent work (Pate *et al.* in press) suggests that laterite may have been forming continuously since the late Cretaceous, associated with iron fixing in the root zone of Proteaceae.

The time period of Oligocene-Middle Miocene (38-11 My) is not represented by sediments on the craton. The presence of Early – Middle Miocene carbonates in the Eucla and Perth Basins suggests a lack of erosion and sediment transport from the craton, consistent with deep weathering on the Darling Plateau (Finkl & Churchward 1973).

A later phase of sedimentation in palaeochannels appears to have taken place in the Late Miocene-Early Pliocene. Currently sediments of this age are known only from Yarra Yarra Lakes, Yenyenning, Lake Toolibin, Lake Tay and Lake Lefroy (Figure 6), though many areas are yet to be investigated.

It is not clear whether the valleys floors were incised by the Eocene and Pliocene palaeochannels or whether widening out of valleys took place subsequently. In places, as Twidale (1994) noted from the Eastern Goldfields, the valley floors may be of Eocene age, but valley widening may have been a continuing process. The mechanism for widening the valleys has not been extensively discussed by previous authors. Jutson (1934) illustrated sideways retreat of valley sides forming the new plateau from the remnants of the old plateau, and Finkl & Churchward (1973) discuss the processes of peneplanation and parallel scarp retreat.

The removal of stripped regolith has probably contributed both to the Pliocene palaeochannel sediments and to the surficial valley sediments (assumed to be Late Pliocene - Quaternary in age). Quaternary (< 1 My) aridity contributed to the development of salt lakes, and associated gypsum dunes and lunettes. The contribution of aeolian processes is discussed by Glassford & Semeniuk (1995) who propose a desert aeolian origin for much of the surficial material.

VALLEY SEDIMENTS

The valley sediments fall into two broad types, the thick (up to 70 m) Eocene, and Pliocene alluvial or lacustrine palaeochannel sediments, which occur in deeply incised narrow palaeochannels in the centres of the valleys, and the thinner (up to 20 m) Quaternary colluvial alluvial and lacustrine (salt lake) sediments which cover the full width of the valleys.

Permian sediments occur in valleys in the Eastern Goldfields and Pilbara, but do not seem to have been preserved in the Wheatbelt. Higher level Cretaceous and Eocene sediments also occur in the Darling Range. Palaeochannel sediments in the zone of ancient drainage have yet to be dated.

Cretaceous (130-120 My)

Cretaceous sediments have only been identified in the Collie Basin where the alluvial Nakina Formation is preserved as a thin covering on Permian coal measures (GSWA 1990). The sediments may have had a wider distribution, although alternatively they may be restricted to overlying Permian Collie Basin sediments, from which they may be derived.

Middle – Late Eocene (50-38 My)

Eocene sediments are preserved as high level remnants in the Darling Range, and in palaeochannels. To the south, the Eocene palaeochannel sediments become more or less continuous with the Plantagenet Group (42-38 My) in the Bremer Basin (GSWA 1990) where sand and lignite with basal gravel of the Werrilup Formation are overlain by siltsone and clay of the Pallinup Formation (formerly Pallinup Siltstone).

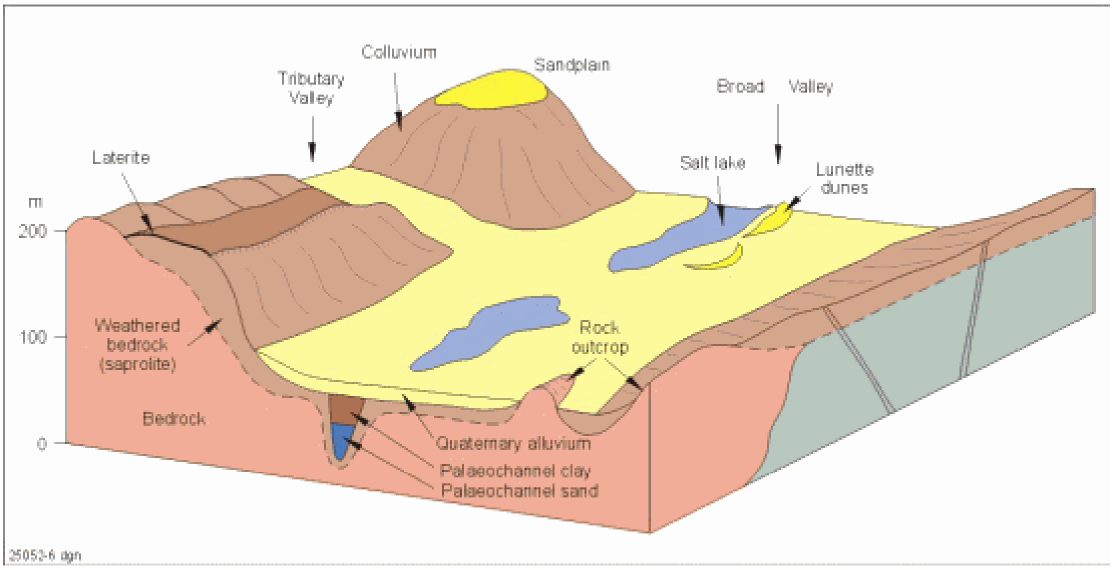

Figure 7: Block diagram showing schematic geology of a wheatbelt valley

North Stirlings (Appleyard 1994): This is the thickest and most extensive deposit of Eocene sediments away from the south coast Bremer Basin. There are 60 m of Eocene sands, lignites and clay, and this appears to continue westward to the Mobrup Catchment (Hundi *et al.* 2000). Farther west still, there is a remnant east-west trending palaeochannel preserved on the drainage divide between Donnelly and Wilgarup Rivers 12 km north of Manjimup (Thorpe 1994).

Beaufort (George *et al.* 1994; Waterhouse *et al.* 1995): This palaeochannel is 65 m thick in the Boscabel area, south of the current Beaufort River channel, and consists of basal sands and overlying clay with a degree of interbedding. The palaeochannel sands are about 1 km at their widest, whereas the overlying clays extend several kilometres across the valley floor.

Darling Range: High-level remnants are mainly preserved on drainage divides, e.g. Kojonup Sandstone, demonstrating younger (post Eocene) physiography west of the Meckering Line (Wilde & Backhouse 1977). A sequence of basal sand overlain by kaolinitic clay has been recently identified in a seemingly isolated high level basin 5 km north west of Brookton.

Oligocene - Middle Miocene (38-11 My)

As discussed above, there appears to have been no sedimentation on the Yilgarn Craton, other than those associated with lateritic duricrust.

Late Miocene - Pliocene (11-2 My)

Early Pliocene sediments on the Yilgarn Craton were first described from Lake Tay (Bint 1981), but remained isolated until discovery in the Yilgarn River valley at Yenyenning (Salama 1997). Subsequently, Pliocene palaeochannel sediments have also been identified at Lake Toolibin in the current Arthur River (de Silva 1999; Milne, 1998), and in the Yarra Yarra Lakes/Coonderoo palaeodrainage on the margin of the craton (Yesertener *et al.* 2000). Clarke (1993, 1994a) also documented shallow Late Miocene – Early Pliocene sediments from Lake Lefroy near Kambalda. The samples analysed from wheatbelt paleochannels are all from low in the profiles, and therefore suggest that all of the profile in each of these palaeochannels is Pliocene. By contrast, similar aged sediments in Lake Lefroy overlie Eocene sediments.

Yenyenning (Salama 1997): The sediments consist of greenish clay and sand with gravel and lignite, and are a maximum of 72 m thick.

Yarra Yarra Lakes (Yesertener *et al.* 2000): The sediments consist of clays and sands, with some calcrete development, and are a maximum of 30 m thick.

Lake Toolibin (de Silva 1999): Two bores contained Late Miocene-Early Pliocene flora from lignite layers (Milne 1998), within sand clay and silt. The sediments extend from 8-34 m and 12-31 m below surface.

Lake Tay (Bint 1981): These sediments extend to at least 39 m, and are described as predominantly clay.

Lakes Cowan and Lefroy (Clarke 1994a): These are described as up to 9 m of sandy silt and clay, with gypsum and carbonate, and interpreted to be deposited in an evaporitic environment similar to today.

Quaternary (<2 My)

The Quaternary is characterised by cyclic aridity, coinciding with glacial and interglacial periods. Periods of dune building are likely in a climate drier than today's current climate, but it is also likely that a wetter climate contributed to lakes and external run off. Silcrete horizons are evidence of past climatic changes through fluctuating water tables. Estimates of salt storage suggest that around 50 000 years is all that is required for salt to accumulate, implying cyclic periods of flushing have taken place. George & Coleman (this volume) suggest that salt lakes may have occupied an area 50% greater than today. Howevr, little research has been done on inland Quaternary climate in inland south western WA, and inferences drawn from studies in south eastern Australia may not be applicable.

Quaternary sediments are relatively thin, apparently ranging up to a maximum of about 20 m, though they are difficult to distinguish from Tertiary sediments and weathered basement (Figure 7), especially in rotary drill cuttings. The sediments are colluvial (slopewash), alluvial (water deposited), and in the centre of the valleys are characterised by aeolian and salt lake deposits, lunettes, and kopi dunes. Glassford & Semeniuk (1995) believe much of the valley fill sediments to be desert eolian in origin.

Bettenay & Hingston (1964) described some 10-20 m of sediments overlying weathered bedrock as clays and sandy clays. Similar descriptions are made by George & Frantom (1990 a,b,c) and George (1992) who investigated the valley sediments along traverses in the eastern Wheatbelt at Brennands, Merredin, Welbungin and Beacon River Catchments.

Salama *et al.* (1993) described relict channels, shallow sand seams which probably represent the last phase of alluvial sedimentation. These near surface features are also apparent on aerial electro-magnetic (AEM) surveys and radiometric data (see Figure19 below), and may be important in designing drainage works.

Characteristics of valley floors

In the zone of ancient drainage, the broad valleys are flat bottomed, and commonly range from 5 to 15 km wide. They contain large salt lakes, for instance Lake Grace North, which is 5 km wide, 17 km long and covers an area of about 75km^2.

Locally, there are outcrops of unweathered bedrock which protrude through the valley floor sediments, and the aeolian dunes are slightly elevated.

The upper parts of the wheatbelt valleys have a very low gradient in the direction of flow. Beard (1999) has measured a fall of 200 m in 525 km in the Yilgarn River, a grade of 0.38m/km, but in the Pingrup valley, between Lakes Grace and Chinocup, the gradient is only 0.037m/km. This contrasts with the gradient lower down the Avon of 0.58m/km between York and Beverley, and 1.9m/km through the Darling Range. Beard also quotes a gradient of 0.17m/km for the Coblinine River upstream of Lake Dumbleyung.

The broad valley floors are some 100 to 150 m below the level of the plateau surface, separated by comparatively steep valley sides (Figure 7).

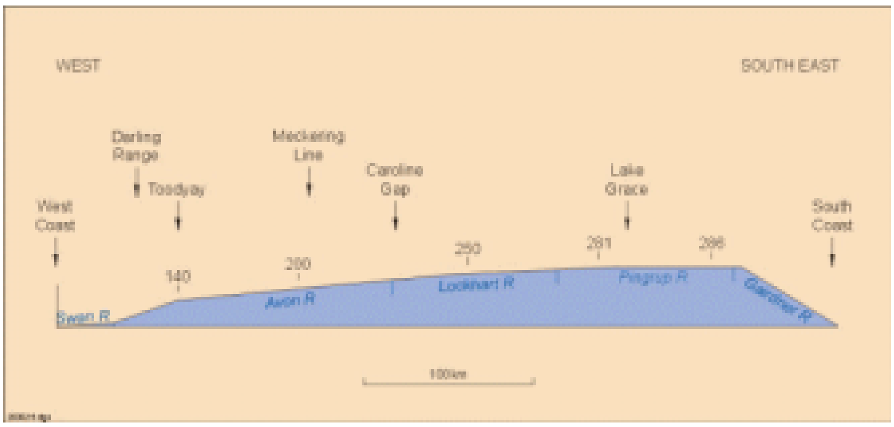

Figure 8: Physiographic profile along the Pingrup-Lockhart-Avon (after Beard 1999)

WHEATBELT VALLEY SOILS

General distribution of Soils

The Northern and Southern Zones of Ancient Drainage (Figure 9), as defined by the soil-landscape mapping conducted by the Western Australian Department of Agriculture, are characterised by a gently undulating plateau, wide divides, long gentle hillslopes, and broad valley floors 2 – 10 km wide which have been in-filled by alluvium and colluvium. Drainage is into chains of salt lakes on valley floors which are a remnant of an ancient drainage system that flows only in very wet years. The valley floors have very low gradients, often 1:500 or less. The western boundary of the zone is the Meckering Line (Mulcahy 1967, Moore 1998).

The Northern zone of Ancient Drainage is, in essence, characterised by yellow sandy earths on interfluves (Figure 10a) and red calcareous clays and loams in the valleys (Figure 10b). By contrast, the Southern zone of Ancient Drainage contains more Sandy Duplexes (Figure 10c).

The valley floors of the zones of ancient drainage have been simplified and divided into three broad landscape categories, idealised in Figure 11. The general distribution of each landscape category is discussed and described in terms of the Soil Groups of Western Australia (Schoknecht 1999) and the original soil series described in the several soil-landscape and soil mapping publications covering the Wheatbelt.

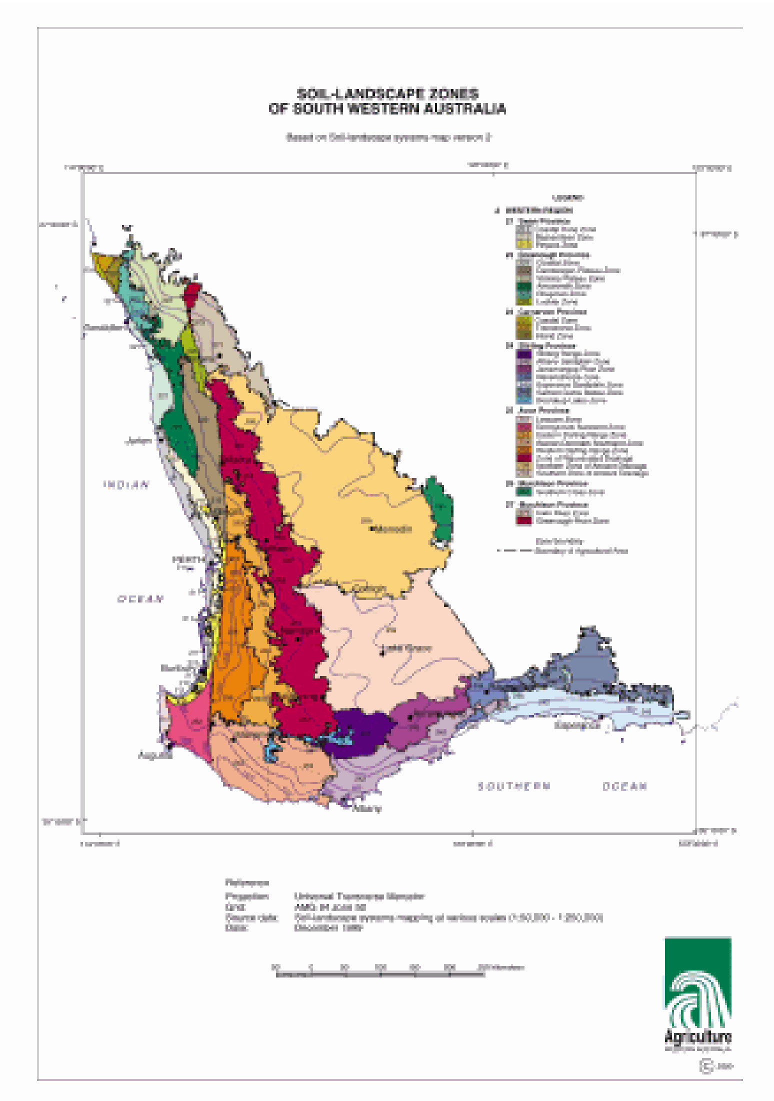

Figure 9: Soil-landscape zones of South Western Australia

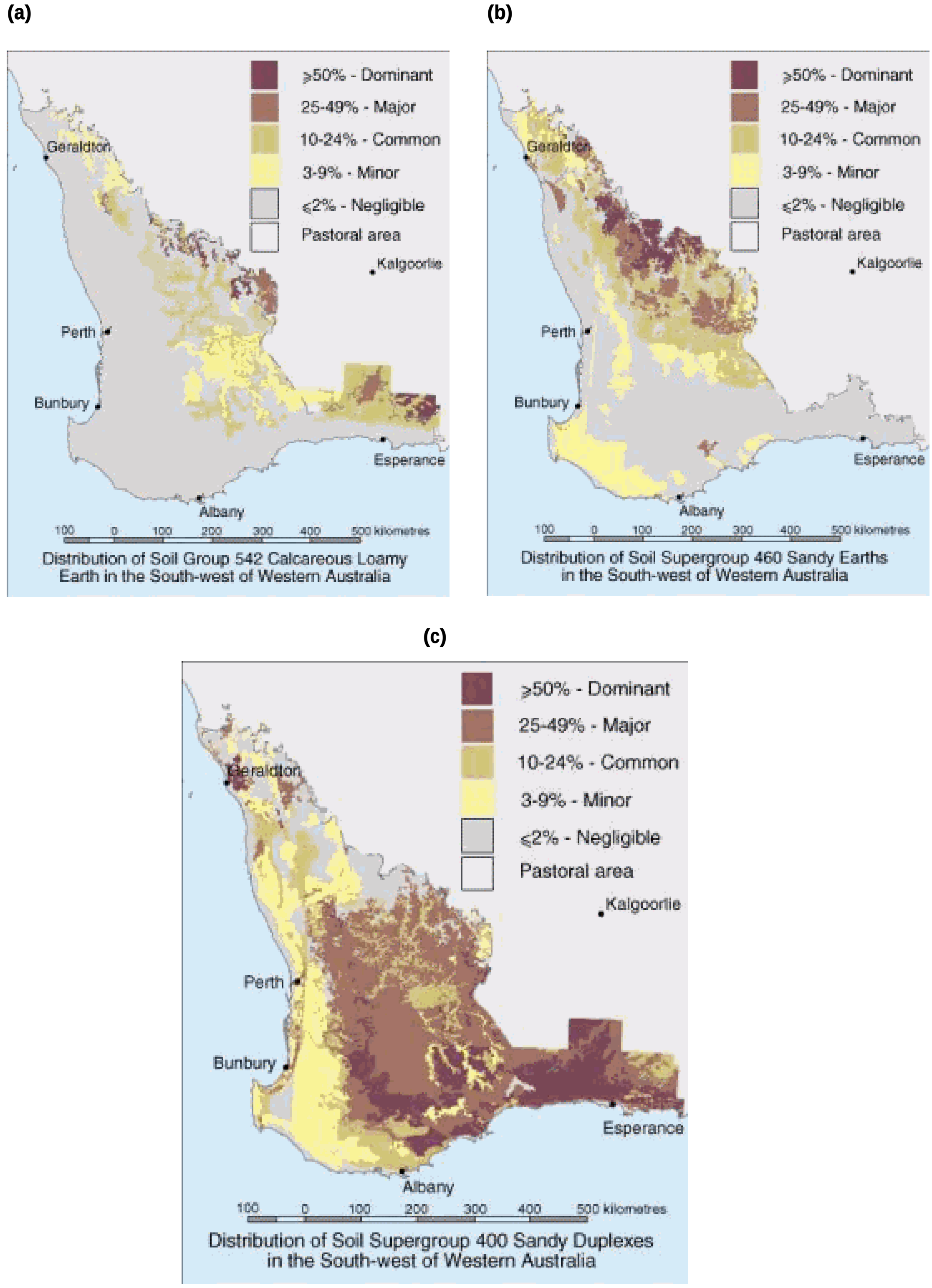

Figure 10: Distribution of selected soil groups

HYDRO-AEOLIAN LANDSCAPES

The hydro-aeolian "lakes and lunettes" landscape of the lower parts of the broad valleys has been formed by action of both wind and water. It is characterised by salt lakes and channels, source-bordering and relict lunettes and flat to undulating plains of clayey aeolian sediments sourced from salt lakes. This landscape corresponds to the Baandee and Nangeenan surfaces (Bettenay & Hingston 1961; Lantzke & Fulton 1993).

Salt lakes, playas and channels

The soils of the salt lakes are very variable, and have not been described in any detail across the zone. The lakes have shallow saline watertables, and may fill with surface water in wet years. The lakes are filled with fine and coarse alluvium, plus significant quantities of mobile salts. Sodium chloride is the dominant salt, but significant quantities of gypsum ($CaSO_4$) may also occur.

Soil groups: Salt lake soils, Saline wet soils

Vegetation: Usually bare of vegetation, with halophytic species such as samphire (*Halosarcia* spp.), saltbush (*Atriplex* spp.) and bluebush (*Maireana brevifolia*) on fringing areas.

Lunettes

Lunettes, composed of saline alluvium, occur on the lee side of the present or ancient salt lakes. The composition of the lunettes varies considerably, from gypsum, sand or even clays flocculated to sandy particle size by the saline conditions.

Soils: variable deposits of sands, clays and gypsum

Vegetation: Variable.

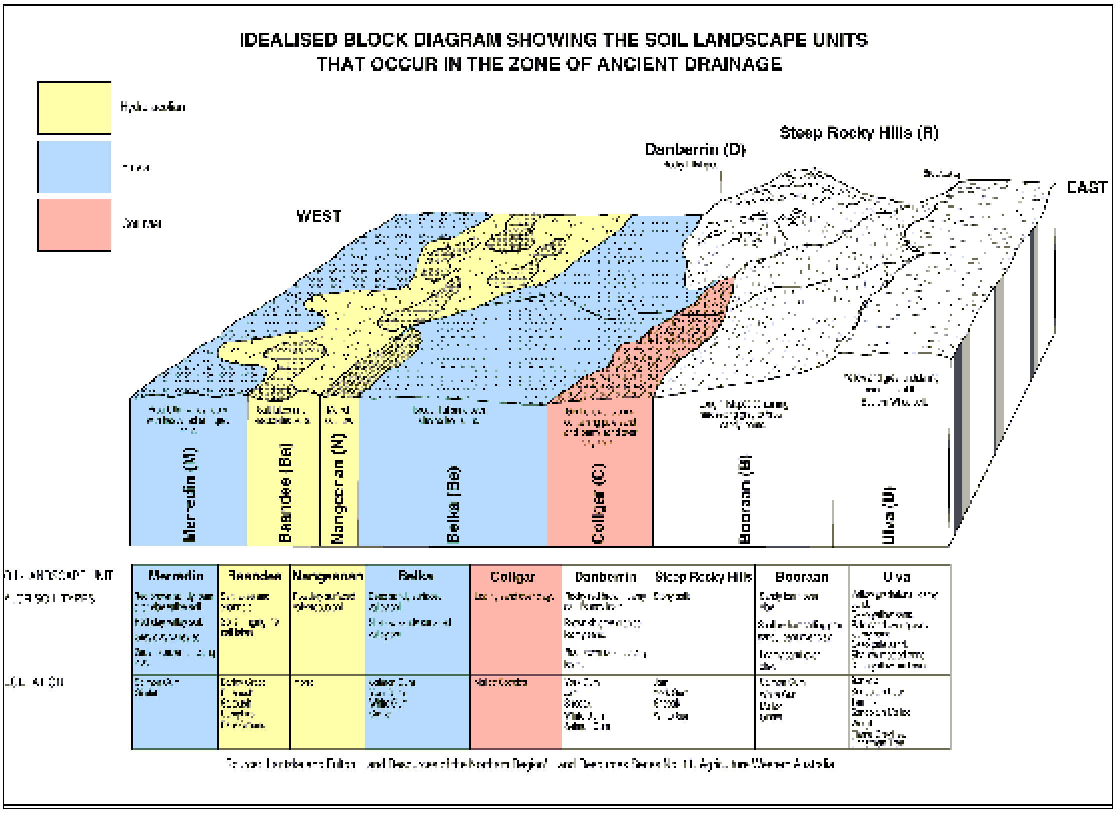

Figure 11: Block diagram showing soil-landscape units in wheatbelt valleys

Flat to gently undulating plains of clayey aeolian sediments derived from the lakes (parna)

These undulating plains are derived from fine textured and usually saline and calcareous dust derived from the salt lakes during dry periods (McArthur 1991). The soils are invariably brown to reddish brown, calcareous and often saline. Soils high in salt and carbonates at the surface have a fluffy or powdery surface condition. The soils are loamy to clayey at the surface, and clayey at depth.

Soils:

Brown calcareous loamy earths with powdery, calcareous surfaced soils, often saline (commonly referred to as Morrell soils).

Alkaline (and calcareous) red shallow loamy duplexes

Calcareous brown or reddish-brown non-cracking clays

Vegetation: Morrell (*Eucalyptus longicornis*) woodland dominant

FLUVIAL LANDSCAPES

The fluvial landscape of the broad, flat valleys of the Wheatbelt is derived from sediments moved and deposited by water.

Major valley floors in the eastern and northern areas are up to 3 km wide with gradients of 1:250 to 1:500. The soils in this area tend to be heavier textured, and more calcareous, with red or grey calcareous clays or loamy duplexes common. Crabholes (gilgais) sometimes occur.

The valley floors in the western and southern areas are of a similar width, but slightly steeper, with gradients of about 1:700 to 1:500. Natural drainage lines are ill defined, and old stream channels or sand seams mark the surface of this unit. Common soils are sandy duplexes, which are usually calcareous and alkaline at depth.

This landscape corresponds to the Merredin and Belka surfaces (Bettenay & Hingston 1961, Lantzke & Fulton 1993).

Soils in western and southern areas:

(Alkaline grey) shallow sandy duplexes

(Alkaline grey) deep sandy duplexes

Hard cracking clays

Saline wet soil

Soils in eastern and northern areas:

Calcareous loamy earths (neutral surface)

Alkaline red shallow loamy duplex

Hard cracking clay

Grey non-cracking clay

Red/brown non-cracking clay

Vegetation: Salmon gum (*Eucalyptus salmonphloia*) and gimlet (*Eucalyptus salubris*) woodland.

COLLUVIAL LANDSCAPES

A colluvial landscape of very gentle slopes fringing the broad alluvial plains occurs at heads of drainage lines and on the edge of the broad valleys. Sandy surfaced duplex “mallee soils” dominate. The depth of sand over the clays tending to increase with distance down the slope. This landscape corresponds to the Collgar surface (Bettenay and Hingston 1961, Lantzke 1993).

Soils:

Grey deep sandy duplex

Grey shallow sandy duplex

SOIL-LANDSCAPE EVOLUTION

Soil distribution in wheatbelt valleys broadly associates with the timing and degree of landscape rejuvenation and the inheritance of up slope materials (Jutson 1934; Mulcahy & Hingston 1961; NRAG mapping 2001). However, the notion that ancient lateritic soils are stripped away and replaced by non-lateritic soils derived from fresher crystalline basement may stem from the idea that laterite formed extensively on a pre-existing peneplain during hot humid interludes in the Tertiary (Jutson 1934; Butt & Zeegers 1992). Some subscribe to the idea that ferruginous horizons at and near regolith surfaces once developed in response to import of iron from underlying hydromorphic pallid zones by capillarity (Campbell 1917) or to seasonal rises in water tables (Prescott & Pendleton 1952). A modern refinement of these concepts is the relief inversion model of Pain & Ollier (1995). The essence is that lateritic mesas result from the prolonged erosion of resistant lateritic deposits that originally formed on valley flanks and its arguments hinging on the arrangement of lateritic components on mesa edges.

The problem is that lateritic bauxites and duricrusts are particularly common in incised systems towards the coast and laterites can develop on considerable slopes (Playford 1954; Mulcahy 1960). Furthermore existing valleys retain Tertiary sediments which clashes with the idea that laterites now on uplands formed in valleys during the Tertiary.

Verboom & Galloway (2000) and Pate *et al.* (2001) also point out that the relief inversion model cannot explain the remarkable regularity of the mesa edge effect, the circularity of mesa embayments and the development of a second front of duricrust formation in the fine pisolitic colluvium that is sometimes encountered.

The latter authors have offered a counter explanation that differs from conventional theories of old peneplain erosion or relief inversion while still in accordance with the concept that edge hardening and kaolinite preservation causes the landscape to evolve as surrounding superficial materials erode (Eggleton & Taylor 1998) and regolith materials dissolve (McFarlane 1995). This new hypothesis rests on evidence that laterites and related oligotrophic soils may have been partly derived biotically from soluble iron-rich complexes generated following secretion of low molecular weight organic acids by phosphate-absorbing specialised proteoid (cluster) roots of proteaceous plants. Gibbsitisation and induration may simply be a geochemical outcome of aggressive leaching following organic anion release by proteoid roots and concomitant mobilisation of ferric iron, and microbial precipitation where soil solutions bearing citrate-metal complexes would be attracted and concentrated. In addition, duricrust formation and bauxitisation may serve a biological function in countering headward incision and surface stripping of habitat soil and in certain situations combating Al toxicity.

We briefly examine competing claims of the above theories by considering a portion of the Avon valley system in the geophysics section below.

SOIL DEVELOPMENT

It is all very well talking about the broad geographical differences in wheatbelt valley soils or individual pedogenetic processes. Understanding how a multitude of poorly understood contemporaneous processes express themselves in soil morphology and distribution is another matter. It requires considerable field experience and intellectual sifting and disseminating that field wisdom then requires sweeping categorical statements and specific case studies as examples. To this end, we group soil forming mechanisms into three broad classes, and deal with each of these, in turn, below, before going on to newly acquired geophysical data and the pedogenetic insights and soil information that these data provide. The following statements and interpretations may of course have some fault, but at least the concepts can be tested or at least compared with the field experience of others.

Epimorphism

The genesis of a valley soil starts with epimorphism, that is the adjustment of near surface geological materials on the uplands to the superficial environment. Work on feldspars by Anand *et al.* (1985) and biotites by Gilkes & Suddiprakarn (1979) casts doubt on macro climate being the direct determinant of epimorphic change. These works show that controls over new mineral formation vary dramatically over extremely short distances, which might imply a role for micro-organisms and in this regard the emphasis may have to shift to bioclimate (see above). Indeed, understanding of rhizosphere chemistry is improving rapidly, to the extent that the importance of macro climate *per se* as a determinant of the World's soil zones is now openly questioned.

MOVEMENT OF SOIL MATERIALS

The detachment, transport, sorting and deposition of soil materials by the action of water and wind are also profoundly affected by the biosphere. Fauna are largely responsible for turning over soil materials and making them susceptible to rain and wind while vegetation has a mainly protective role. The combined action on the biomantle of rainsplash, slopewash and sediment rafting are collectively referred to as rainwash. The erosive power of a rainfall event is principally determined by kinetic energy delivered to the bare soil surface after it has become saturated and this obviously depends on vegetation cover at the time. Management practices which remove vegetation have of course contributed to accelerated erosion and caused deteriorating hydrologic conditions around the world. However, under more natural conditions, the protection afforded by vegetation, particularly in seasonally dry climates, varies from year to year and is periodically destroyed by fire.

The materials that leave the hill slopes are not representative of the soil as a whole. Soluble materials tend to enter groundwater systems while solid particles detached by rainsplash are entrained by sheet and rill flow and sorted down slope, often in quite complex ways with debris transported and organised into litter dams playing a major part (Paton *et al*.1995, Chapter 4). The big picture however is one in which solutes and suspended silts and clays move faster and further down slope than the rolling and saltating sands. The general model of soil formation on hillslopes thus involves epimorphism of bed rock to saprolite and saprolite to soil with the principal motivators of the latter being biochemical change in the rhizosphere, mining by fauna, mainly in the topsoil, clay eluviation (Chittlebrough 1992) and differential downslope movement of bioturbated topsoil by rain wash.

One outcome is a mobile, light textured, biomantle often expressing as a texture contrast soil. Reduced mobility on lower slopes, where the slope starts to wane, results in congestion and hence thickening of the mobile sandy layer. As deposition progresses, underlying soil starts to fall outside the influence of bioturbation, and clays coming in from upslope start to accumulate. In other words, there comes a point at which topsoil differentiation over-rides faunal mixing. Further down slope, old differentiation becomes buried by new differentiation and at this point we start to get a historical record of soil formation reflecting changes in surface hydrology, climate and vegetation (Figure 12). One thus encounters more and more colluvial/pedogenetic history in vertical sections as one progresses down waning cross valley slopes towards the oldest buried river channels.

The situation in flat-floored valleys is somewhat different. Their catchments are large enough to sustain planating flows that are tempered by the very low down valley gradients mentioned above. Indeed, the erosive power of contemporaneous flows may be so subtle and ineffective that their impact is more pedogenetic than topographic. In these situations, clay winnowing and sand saltation generates ‘rivers’ of deep sandy duplexes with shallow sandy and loamy duplexes on the ‘interfluves’.

HYDRO-AEOLIAN ACTIVITY

Hydro-aeolian activity is important whenever there is a plentiful supply of loose fine material and little vegetation. The latter condition was particularly evident during last episode of aridity (25000 – 13000 B.P.) (Bowler 1976) and is caused by rising and lateral flows of salt in lower parts of the landscape. The obvious expression of hydro-aeolian activity is the playa lake systems and associated depressions.

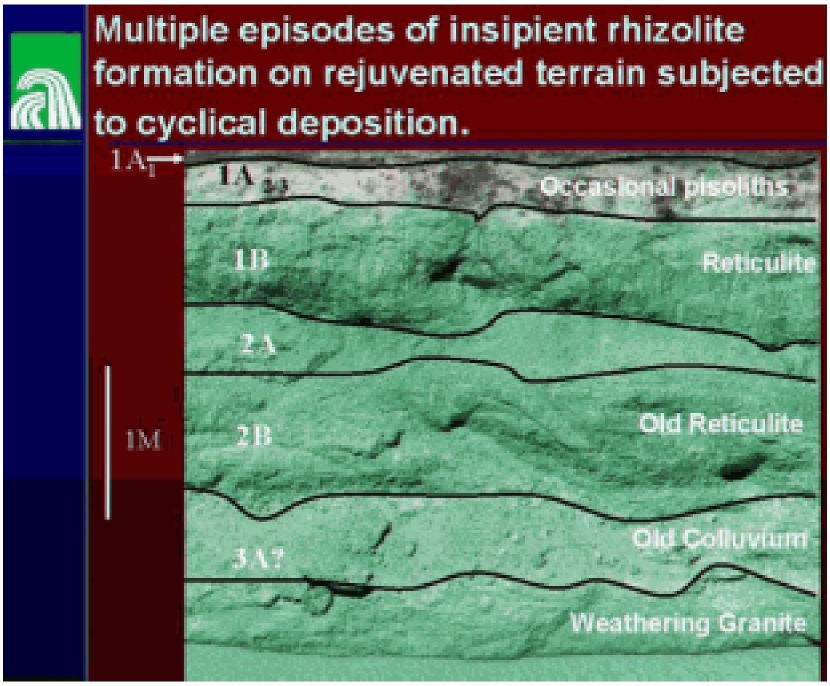

Figure 12: This profile, on a lower mid slope west of the town of Narrogin, records at least two cycles of soil formation in which iron and clay differentiation has been active with the most recent (uppermost) episode apparently contemporaneous. The sandy A-horizons appear intact and remain so 50 m down slope in two other exposures. They have similar sequences: red crystalline ferric oxides, principally hematite, can be seen along the margins of vertical root channels in horizon 1B, with their older, yellow hydrated counterparts in the buried 2B. Root channel precipitation does not extend into the sandy horizons below both B-horizons and so the contemporary process is limited to uppermost B-horizon. Contemporary precipitation tends to be confirmed by the observation of haematitic precipitates surrounding living Banksia roots.

Here, ground level winds entrained sand size particles (2.0 - 0.05 mm in diameter) which moved by rolling and saltation while finer particles moved in suspension after dislodgment by the saltating particles. The particles may themselves be quartz grains or aggregates of minerals detached from mud curls and salt/mud efflorescences. Lunettes on the south eastern side of playas betray old north westerly winds. Lunette composition depends on provenance which in turn depends on hydrologic regimes. In other words, playas producing loose quartz sand generate sandy lunettes while those producing pelleted clayey aggregates generate clayey lunettes. Finer particles blow and saltate out greater distances forming discontinuous sheets of parna (locally referred to as morrel soils) which may over print hillslope soils.

NEW GEOPHYSICAL PERSPECTIVES

At the end of the day, the above described pedogenetic processes have to be consistent with newly acquired data. Airborne geophysical mapping provides such data, offering pedologists a new and penetrating perspective of soil landscapes. Below we first briefly describe these techniques and then use them to examine the relationship between radiometric and elevation data and the occurrence of salts and soils in parts of the Avon, Lake Toolibin and Elashgin catchments.

DIGITAL ELEVATION MODELS (DEM)

A DEM is a digital representation of the earths' surface where, with the use of a computer, the elevation of a location on the ground (measured in Eastings and Northings, say) can easily be obtained by a simple click of a mouse button.

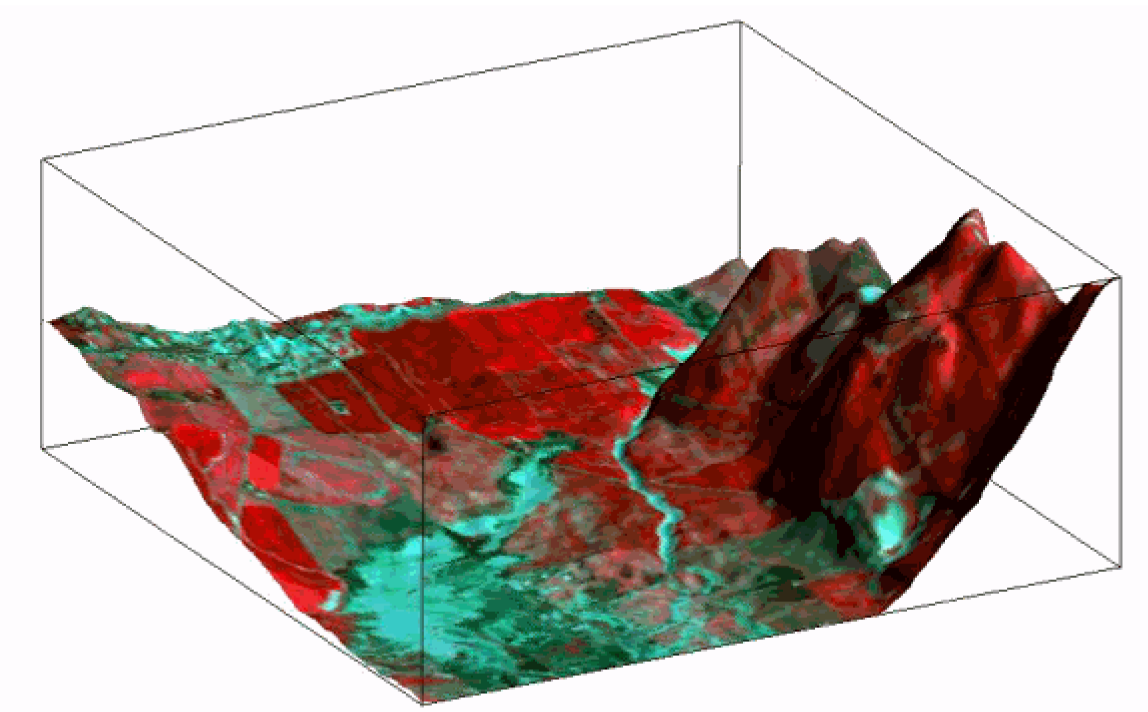

Figure 13: An example of landscape visualisation using Landsat TM

Figure 13 is an example of landscape visualisation using Landsat TM satellite information (visible and infrared) and digital elevation models. In this perspective view, the town of Merredin appears in the top left of the image as a blue/green colour. Paddocks with vigorous crop and pasture cover appear red, and saline areas in the lower left appear as hews of blue and green. Terrain has been exaggerated. From the figure we observe that the salinity is largely confined to the lower parts of the landscape.

DEMs may be combined with data such as Landsat TM, or aerial photography in digital form, to provide a powerful visualisation tool, an example of which is given in Figure 13. Further, computer algorithms and simulations may be applied to DEMs to produce estimates of land surface characteristics such as slope, curvature and sizes of catchment areas, which may be used in environmental assessments and risk analysis.

For the Western Australian Wheatbelt, the advent of relatively high-resolution DEMs (elevations accurate to 1-2 m sampled on a 10 m easting/northing grid) from the Land Monitor project, allows a great variety of variables to be accurately derived, e.g. Caccetta 1999b.

Here we outline an approach for extracting broad-valleys from DEMs:

A sample of digital elevation data generated by the Landmonitor project was used in the experiments. The data has an accuracy of approximately 1-2 m in elevation and is specified on a 10 m grid. The data were processed in a manner consistent with that currently being used for the salinity mapping component of the Land Monitor Project:

1. the data are smoothed to remove small discontinuities (Caccetta 1999a),
2. the data are resampled to 25 m, reducing the data volume and making the data consistent with landsat TM,
3. spurious depressions are filled to ensure surface flow (Caccetta 1999b),
4. an estimate of *upslope* area and *flowslope* is calculated, from which `flat' *flowpaths* are extracted,
5. the height above the nearest flat *flowpath* is derived,
6. all pixels having an elevation within 2 m of the nearest flat *flowpath* are classed as valley floors,
7. all remaining pixels are given a landform label based on stratifying the upslope area image into hilltops, ridges and upper slopes, upper valleys and lower valleys.

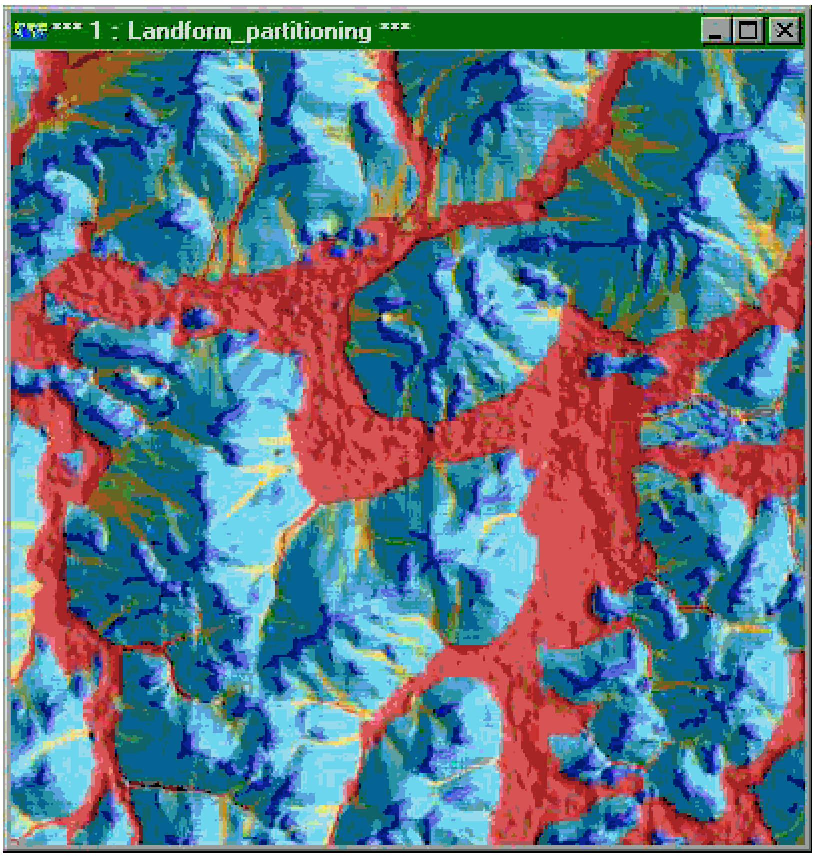

Figure 14: An example of a landform classification derived from a DEM. Hilltops are depicted as dark blue, ridges and upper slopes as cyan, upper valleys as green, lower valleys as orange and broad valleys as red. For visual purposes, the classification has been enhanced with sun shading

This process results in a landform classification having the following classes: hilltops, ridges and upper slopes, upper valleys, lower valleys, and broad valleys. An example of this partitioning is given in Figures 14 and 15. Here we note that the procedure may be applied with relative ease to extract broad valleys over large areas, and thus provides an accurate and consistent way of mapping valleys over large areas.

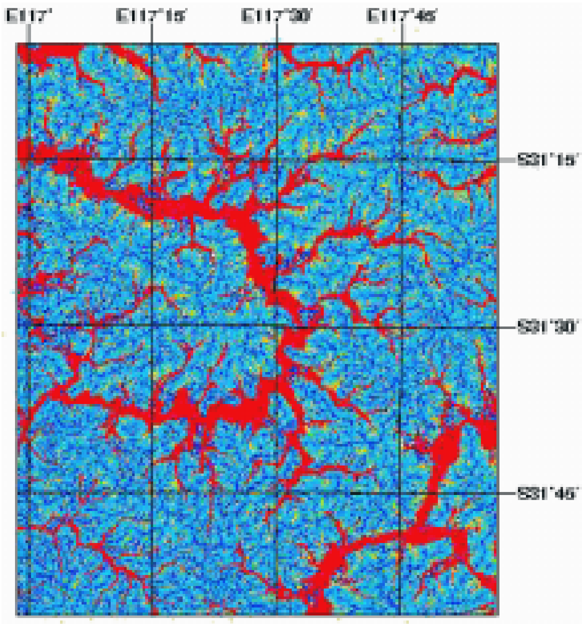

Figure 15: The landform partitioning may be applied over large areas to extract classes of interest. As in Figure 14, hilltops are depicted as dark blue, ridges and upper slopes as cyan, upper valleys as green, lower valleys as orange and broad valleys as red.

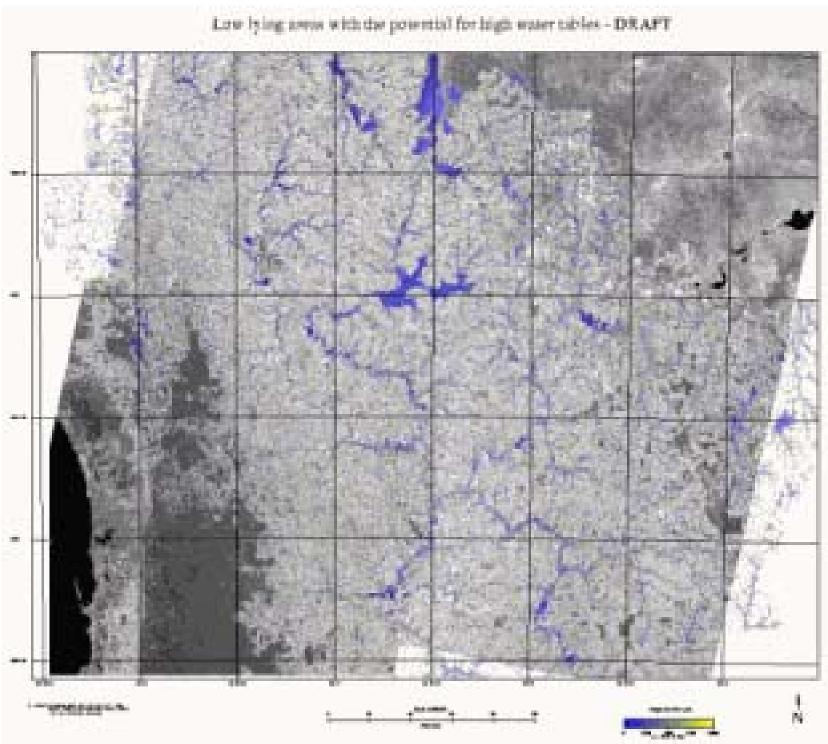

Figure 16: This figure depicts low lying areas with the potential for high water tables. In this figure areas with the potential for high water tables are coloured blue to yellow, as indicated by the colour bar in the figure. A grey-scale Landsat TM mosaic, along with a 1:100 000 map-sheet grid, is provided for reference. The region is approximately 400 x 400km, with the Swan River visible in the lower left

From the point of view of mapping and monitoring salinity, the landform partitioning provides strong prior evidence of which parts of the terrain are likely to be/become saline (the red and orange areas) and which parts are not (the blue areas) (Caccetta 1997; Hojsgaard *et al.* 1997). Observations from satellite imagery provide further information on the status of the land.

An extension to the above idea is to predict which of the valleys will experience high, saline water tables in the future, which serves as a tool for land management and planning. This concept forms the basis for Land Monitor salinity prediction, a preliminary result which is shown in Figure 16. Here we note that the DEM provides some morphological information (in practice about a dozen morphological variables are derived (Caccetta 1999b), and geological information is required to place the morphological information in context. The third piece of information required is expert knowledge, provided by Department of Agriculture hydrologists in this instance, presented as samples of areas that are likely to (and not to) go saline in the future. This information is used to form a relationship between terrain and potential salinity for each significant geological region (e.g. Evans *et al.* 1995; Evans & Caccetta 2000).

Giving Traditional Soil Mapping a New Perspective

As an example we return to the prediction by Pain & Ollier (1995) that rejuvenation exposes laterites that originally formed on valley flank, and the prediction by Verboom & Galloway (2000) that lateritisation requires leaching conditions and particular types of vegetation. These competing ideas might be tested by examining the association between rejuvenation and soil distribution in valleys on the margins of the Yilgarn block. We consider the tectonically affected areas near Brookton. Figure 17 gives the soil systems mapping of this area an exaggerated topographic context.

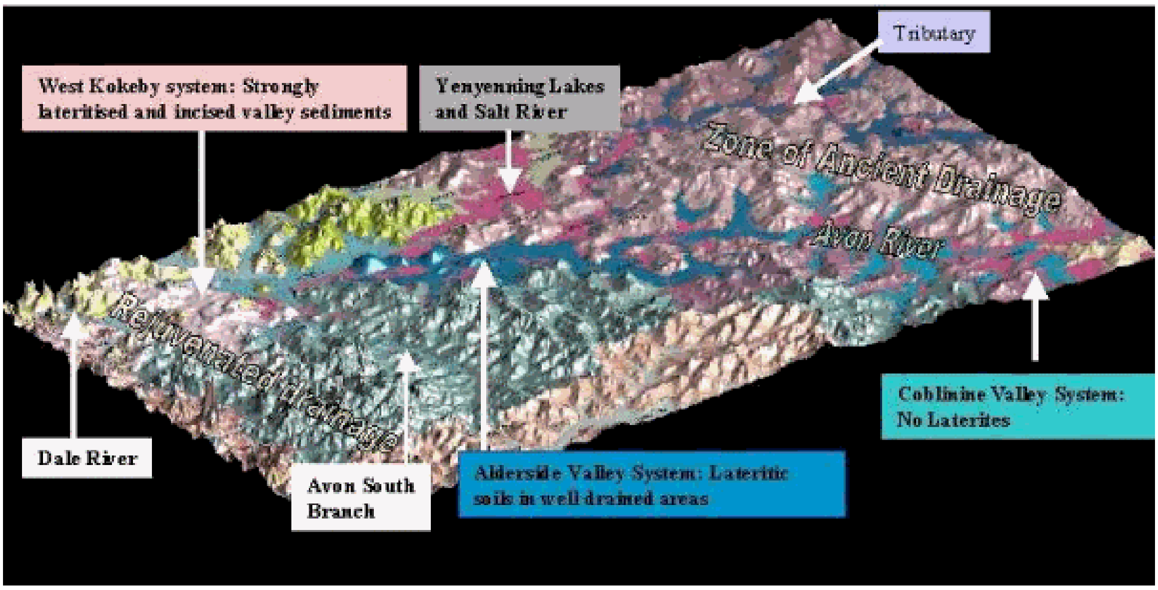

Figure 17: Soils mapping in the Avon River Valley, draped over DEM, viewed from the south

Salinity in the valleys is mapped by red and is used as a surrogate for down-channel gradient and drainage. For instance, the more sluggish the drainage, the more widespread the red. The usual scenario is increasing salinity down stream as seen in the tributary river running into the Avon from the east. In the case of the main Avon branch, salinity is much reduced in the rejuvenated lower reaches because of steeper down stream gradients.

Lantzke & Fulton's (1993) Kokeby system appears in the lower reaches as the light pink area towards the top left hand side of the image in the Zone of Rejuvenated Drainage. It is characterised by smooth rounded interfluves bearing proteaceous vegetation on lateritised palaeo-valley sediments. Of course, such occurrence favours both theories inasmuch as relief inversion is beginning where valley sediments become incised, drained and leached. However, further east, where rejuvenation is less substantial, flat valley sediments of the dark blue Alderside System are weakly lateritised and vegetated by Proteaceae. Conversely, lateritisation and associated Proteaceae are absent upstream in the light blue Coblinine System where salinity and sluggish drainage become dominant. The above hypotheses can of course be tested elsewhere but we leave that for now.

AIRBORNE GAMMA-RAY SPECTROMETRY (RADIOMETRICS)

This geophysical technique relies on an airborne instrument containing a thallium doped sodium iodide crystal. It measures the intensity and energy of gamma radiation emitted from naturally occurring radioactive isotopes of potassium (K), Bismuth (Bi) and Thallium (Tl). Emission peaks from isotopes of the last two elements are used to estimate the abundance of uranium (U) thorium (Th). Ninety percent of these emitted gamma-rays come from the top 30 - 45 cm of soil if it is dry and less than this if it is wet. An aircraft flying a series of transects at say 100 m spacings can thus map the abundance of the above elements if the data that it collects is geo-referenced. Since each element has its own peculiar soil chemistry and mobility, levels of radioactivity from each element, or combination of elements betray soil properties and geomorphic processes.

COMBINING DEM AND RADIOMETRIC DATA

We have already seen that relationship between topography and soil depends, in large measure, on the way in which water interacts with and moves over the surface and percolates downward. These interactions determine the outcome of rainwash and sub-aerial dissolution which of course depends on substrate and biological influences such as bioturbation, vegetative cover, exudates and bio-precipitates. Furthermore, soil landscape processes also reflect past macro and bioclimates. Not surprisingly relationships between topography and soils are not always straight-forward but certain associations stand out when radiometric images are draped over the DEMs.

In the image of Lake Toolibin Catchment (Figure 18), interfluve crests to the right (east) of the line A-B are of similar elevation to those in the western area but the main trunk valleys are longer and down stream gradients are less. This expresses itself in the landforms and soils. The irregularly undulating rocky hills to the left of the line A-B speak of active erosion and geological controls on interfluve topography. This usually goes hand in hand with exposed bedrock and weakly developed soils and, indeed, the east's geochemical inheritance is evidenced by higher concentrations of potassium (reds and pinks).

The smoothly undulating terrain to the right of the line A-B (Figure18) speaks of an old deeply weathered regolith. The soil materials are generally residual or colluvial and the radio element concentrations bear little resemblance to the underlying granites and gneisses. The top of the regolith is very leaky, K feldspars in the sand fraction have weathered away and clay minerals in these highly leached oligotrophic soils contain little K. However, chelatable metals such as uranium (blue) and thorium (green) concentrate to considerable degree in the biogenic ferricretes and emissions are strong where these soil materials are not blanketed by radiometrically barren quartz sand. Thick sand mantles (> 30cm) shows up as black.

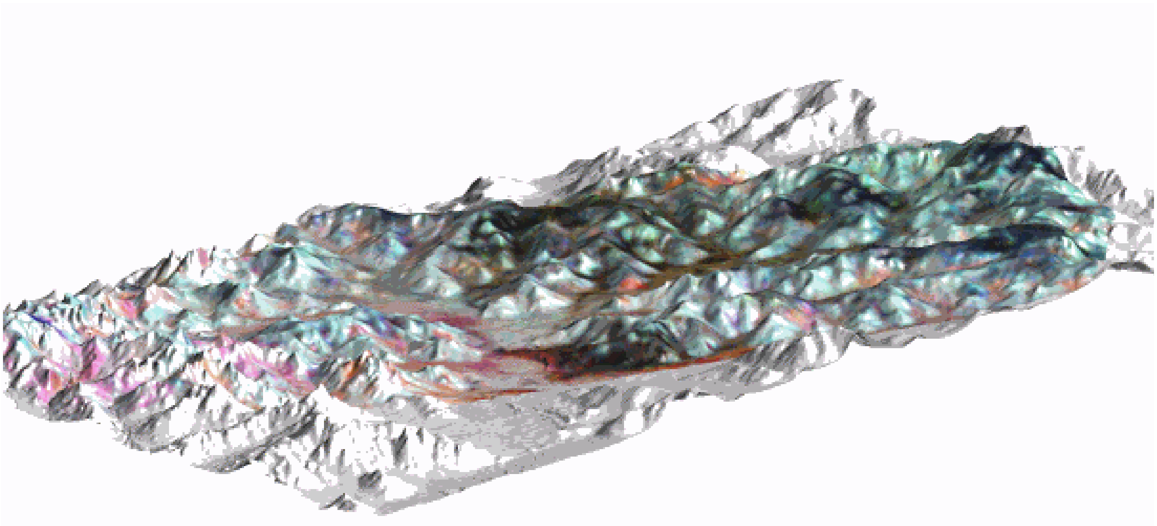

Figure 18: Ternary radiometric image of Lake Toolibin catchment draped over a sun-shaded DEM viewed from the south west

The alluvial materials that collect in the valleys reflect soil textures and provenance. The eastern valleys have inherited K deficient sands and clays from the uplands and these materials are differentiated according to fluvial and soil processes described above. Duplexes with deep sandy mantles (>30cm) develop in small braided channels and are only distinguishable on good contrast 1:25000 colour photos or high-resolution radiometrics. The duplex soils between these channels are comparable to over bank sediments as they receive slower flows and so accumulate more clay. This generates shallower sandy and loamy mantles on the 'interfluves'. More clayey K, Th and U material (pinkish-greenish white areas at lower ends of valleys) occur in zones where surface waters laden with clays accumulate. The ternary radiometric image shows very nicely how the valleys in the west have inherited K feldspars and K rich clays from shallow granitic soils on uplands vegetated by york gums, jams and casuarinas.

Evidence for contemporaneous formation of laterite is provided by radiometric images of smooth, upland south east of the Toolibin playa. The imagery in Figure 6 reveals a blanket of sand that blew out from the Toolibin playa in response to the wet season winds from the north-west. Such aeolian deposits are thought to have formed during the Pleistocene, but soil survey shows that the sands that deposited on the uplands have since differentiated to form various laterites, each vegetated by the characteristic Proteaceae community. To the north of this sand sheet one encounters a hydro-aeolian system with a clayey plume generated at about the same time. It is betrayed by the bright white radiometric signature (high in U, Th and K) and the perspective shows that it also encroaches upon upland. Soil profiles in these locations reveal lateritic profiles overprinted by calcareous red loamy parna.

HIGH RESOLUTION RADIOMETRICS

The radiometric data for Elashgin Catchment (Figure 19) reveals many of the processes referred to in the soil development section. As in the Toolibin area, Greeny-blue areas betray lateritic gravels (High U and Th and low K) and black areas show up the lateritic yellow sands. Granite outcrops (GO/C, pinkish white) emit strongly in the K window and moderately in the U and Th windows. Granitic soils are dominated by K emissions and show up as red.

The image unveils details of the downslope movement of the above soil materials to and along valley floors. Granitic colluvial fan deposits (GCF) differentiated as sandy duplexes, are evident on the waning southern slopes of the valley designated CGV. Associated finer materials (brighter whiter signature) can be seen beyond that, in the lowest positions towards the valleys northern margin. These soils are predominantly grey cracking and non-cracking clays. CVS locates another colluvial valley. In this case its sandy duplex soils have inherited K depleted materials from the adjacent lateritic uplands.

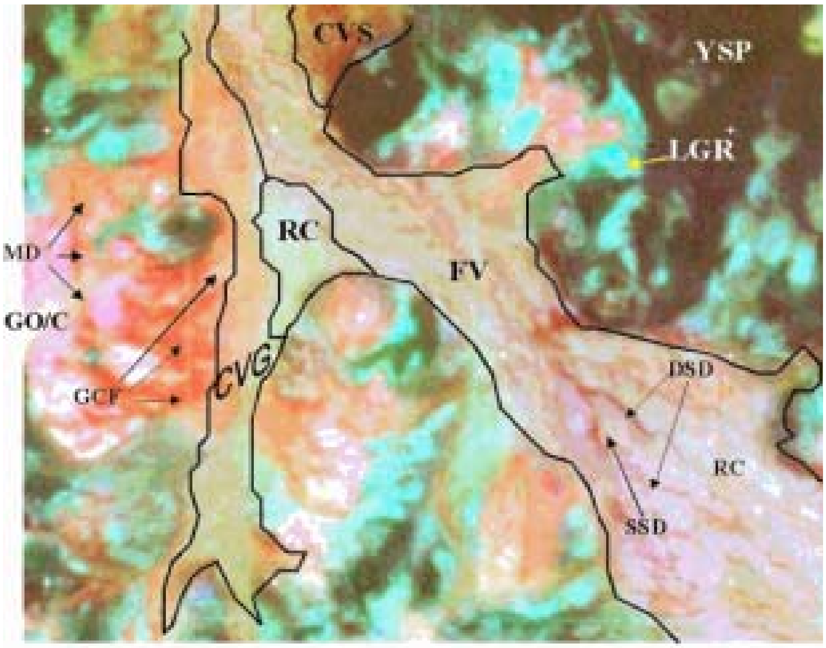

Figure 19: Ternary radiometric image of a portion of the Elashgin catchment. West is at the top, line spacings of 25 m and altitude approximately 20 m

Down valley migration also stands out in the flat trunk valley (FV) that has been planated by fluvial activity. In this, one encounters the 'rivers' of deep sandy duplexes (DSDs) referred to in the soil development section. An example of where shallow sandy and loamy duplexes occur on the 'interfluves' is designated by SSD. The bright white areas designated RC represent ferruginous loams and clays that tend to be removed from areas of active flow.

CONCLUSIONS

The landscape of the wheatbelt valleys is of considerable antiquity, originating at least some 50 million years ago, and modified since. The north flowing rivers in the zone of ancient drainage are broad and depositional in their upper reaches, which may reflect reversal of drainage direction. Valley floors are now flat, with very slight gradients.

Knowledge of the age of the palaeochannel sediments has emerged in the last decade with the recognition of two distinct phases of sedimentation, in the Eocene, and in the Late Miocene – Early Pliocene. Palaeochannel sediments, with their sandy basal layers, occupy only a small proportion of the broad valley floors. Elsewhere the valley sediments are composed mainly of sandy clay, overlying crystalline bedrock which is also weathered to form a sandy clay (saprolite).

Valley soils fall into three distinct landscape associations, a hydro-aeolian zone, a fluvial zone and a colluvial zone. The role of biochemical processes is being seen as increasingly important in soil formation. Combining digital elevation models with soil and radiometric data allows new insights into soil genesis and distribution.

The availability of digital elevation models allows an analysis of valley shape on a local scale, and a definition of valley forms using water accumulation models. This has the potential to greatly assist land and water management.

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APPRECIATING AND CREATING OUR HISTORY

Fionnuala Frost[1] and Don Burnside[2]

ABSTRACT

At this Conference, we will be reviewing and appreciating our history in the wheatbelt valleys. From that appreciation we will create the story as a basis for moving forward in addressing the obvious challenges posed by the new hydrology in these valleys.

In this paper, we argue that European settlement has always struggled to develop certainty from an uncertain landscape. However, this struggle has occurred within an environment of optimism, with a belief that good times are ahead. Over the last 170 years, in the wheatbelt valleys we have changed our land use from pastoral grazing associated with timber harvesting to an annual farming system that many in the World have looked at with envy. Three factors in this journey have been critical:

Government policy has driven most of our developments in the Wheatbelt, from the development of the railways, the encouragement of settlement of the land after the decline of the Goldfields in the 1920s and for soldier settlement after the First World War. After the shock of the Depression and WWII, the settlement process recommenced with the release of conditional purchase land and the development for agriculture of land previously considered infertile. Throughout this time, Government has continued to fund agricultural research, development and extension to support the people in that landscape. Productivity growth, particularly in the last 20 years, has been impressive.

This journey has been tough. Of the 10 decades since the land was first cleared, perhaps only two – the 1950s and 1960s – have been times of untroubled prosperity for all. People have coped with the difficulties of first settlements, the Depression, wartime shortages, rabbits, dry years and continually declining terms of trade. Many left with property amalgamations, and depopulation of small settlements has been a fact of life for over 80 years. But many stayed, building a legacy of resilience and an ability to adapt to changing circumstances. This leads to the third factor – that of a capacity for innovation. Adjustment, adaptation and evolution has always featured in these environments as individuals worked to maximise production from scarce rainfall, minimise the impact of pest and diseases and cope with changing circumstances.

Most of those responsible for creating agriculture in the wheatbelt valleys had come from non-agricultural backgrounds and so had to make it up as they went along. The culture of innovation has been significant in the development of the productive farming systems we see today.

These three factors – Government policy, a legacy of resilience and a culture of innovation – are the influences we believe will continue to shape the wheatbelt valleys.

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At the time of writing, Fionnuala Frost is a member of a Ministerial Task Force established to review salinity policy and management in Western Australia. This paper expresses the personal views of Fionnuala Frost and her co-author, not those of the Salinity Task Force.

INTRODUCTION

We begin with two quotes:

" *.....that the people here may flourish and develop the resources and turn the desert into the smiling plain, and build a great country and make it a worthy off shoot of the great Empire whence our fathers came.*" (Sir John Forrest 1892 as reported in Crowley 2000).

"In the 1920s the Western Australian Governments of the day had sought investment in order to settle farming families on the marginal lands of the Wheatbelt and the groups settlements of the South-West, with the aim of increasing and diversifying the State's productivity, as well as providing the farmers and their families with opportunities for betterment. These goals were hopelessly misguided because they were based on inadequate and over-hopeful estimates of agricultural capacity." (Bolton 1994, p.xi).

The history of European farming in the wheatbelt valleys neatly fits into the 20th Century, commencing with the land settlement schemes initiated by the first responsible State Government, which were continued with enthusiasm by subsequent Governments (as circumstances allowed) almost into the 1990s. Political leaders like Sir John Forrest created the structures for agricultural settlement that Governments led by Sir James Mitchell and Phillip Collier used to ensure that the wheatbelt valleys, by the late 1920s, looked like they do today. But at what cost? Commencing with the onset of the Depression in 1929, and lasting through to the early 1950s, wheatbelt agriculture struggled to support those directly dependent on it, let alone contribute to the greater good of the State's welfare in the manner predicted by the likes of Forrest and Mitchell (Snooks 1981).

The story of wheatbelt agriculture over the last 100 years has varied between these two poles of unbridled optimism and sober reflection as illustrated in the two quotes. The awareness of the likely impact of rising saline watertables in the wheatbelt valleys can be viewed as simply the latest and by no means the most difficult challenge facing the people who have lived and worked in these lands.

WHY FARM THE WHEATBELT VALLEYS?

Until the gold-rushes beginning in the 1880s, Western Australia was a small and poor component of the British Empire. In 1880, the European population of just under 30,000 survived on a subsistence agriculture with the main exports being wool and timber. The population was hardly growing and capital investment was very low (Appleyard 1981).

The pastoral phase

During the period from 1830 to 1890, Aboriginal occupancy of the wheatbelt valleys was replaced by sandalwood cutters and pastoralists. The former were successful, and sandalwood production for export grew rapidly. However, its exploitation peaked in 1848 as the stands of the timber were depleted in the more accessible areas (Statham 1981). Pastoralism in these areas was less successful, and most interest in pastoral development focused on the more grassy lands of the Kimberley, Pilbara and Murchison (Burvill 1979a) which were easier to develop for grazing and where water was more readily available than in the densely wooded lands east of the Avon Valley. The difficulty of obtaining quality underground water and problems with poisonous plants of the *Oxylobium* and *Gastrolobium* genera were further barriers to pastoral development. Overall, development of these areas for timber harvesting and pastoral grazing was not very successful (Appleyard 1981). The need to clear the land for crop production as a spur to economic development was recognised. However, until the gold rushes of the 1890s, the relatively impoverished State lacked both the labour and the ability to raise the capital needed to commence large-scale development.

From gold to agriculture

Western Australia experienced rapid growth between the late 1880s and World War I, as shown in Table 1. This period coincided with the granting of responsible government to the Colony in 1890, gold discoveries, first in the Kimberley and then in the Murchison and Goldfields, and the Federation of the colonies to form the Commonwealth of Australia.

The rapid expansion in population as a result of the gold discoveries, and the development of many new population centres in the remote part of the State stressed the Government's ability to provide services. The Government responded with extensive borrowing to fund necessary capital works, most notably the expansion of the very small existing railway network, the building of Fremantle Harbour and the development of the Goldfields Water Supply Scheme (properly called the 'Coolgardie Goldfields Water Scheme'). The level of borrowing was criticised by many, who felt that the State was exceeding its ability to service its commitments (Crowley 2000).

Table 1: Change in selected statistics – Western Australia (from Appleyard 1981; Snooks 1981)

Year	Population	Capital investment in railways ($)	Public capital formation for agriculture ($)	Gold exports ($)	Wheat exports ($)
1880	29,561	6,000	Nil	Nil	Nil
1890	48,502	15,000	Nil	173,328	Nil
1900	179,967	1,100,000	Nil	11,099,158	360
1910	276,832	2,138,000	480,000	9,137,736	406,326

An important reason for quickly equipping the State with the necessary infrastructure was to encourage this vastly increased population to stay in the State. At first this meant providing services to the Goldfields. However, after gold production peaked in 1903 and began to decline, the imperative shifted to attracting ex-goldminers to take up farming in the Wheatbelt, by providing a range of incentives. Building up agriculture to diversify the economy was the goal. The wheatbelt valleys with their modest but relatively sure rainfall, deep loamy soils and relatively easily cleared woodlands was to be the place, in the minds of the politicians, where the goal would be achieved.

The key instrument was the Homestead Act 1893, consolidated into the Land Act 1898. The approach, modelled on that used in the US to encourage settlement, allowed settlers to obtain small, but nominally free blocks, provided they showed proof of residence and commitment to develop the block for farming (Powell 1998). Governments borrowed funds to survey the land into blocks, with land classed on the basis of its vegetation as either 'first class', 'second class' or 'third class' land. The next stage was to finance families into farming – with funding support through the State's Agricultural Bank (now after a number of metamorphoses known as BankWest) provided to get the new landholder through the period of land clearing to the stage when crops would return income. Block sizes varied, but were normally a minimum of 500 acres granted, with most in the drier areas around 1,000 acres. All blocks needed to include substantial areas of 'first class' land (Burvill 1979b).

Results came quickly as shown in Tables 1 and 2. From exporting no wheat at all in 1890, the State grew to be a substantial exporter as early as 1910. Thereafter production grew very rapidly, although labour shortages during World War I slowed the rate of increase. The first class land – the open woodlands of the wheatbelt valleys – were relatively easy to clear (by axe at about 4 to 5 acres a week per man), and enterprising people quickly developed skills in clearing, burning, raking and rolling to hasten the process of establishment.

Table 2: Expansion in grain production 1890-1930 (Source: Burvill 1979b, p.43)

Year	Area of land cleared (m Ha)	Area of land seeded for grain (m Ha)	Wheat Production (m tonnes)
1890	0.05	0.014	0.013
1900	0.49	0.03	0.021
1910	2.1	0.24	0.16
1915	n.a.	0.70	0.50
1920	3.1	0.52	0.33
1930	5.6	1.60	1.46

Agricultural production was assisted greatly by the availability of machinery for seeding and harvesting that was suitable to Western Australian conditions, and the wheats being bred by William Farrer and others for Australian conditions combined with the use of superphosphate secured adequate yields. The first class land in the wheatbelt valleys was 'fertile' to the extent that only 'super' was required.

Expansion into the drier areas was supported by research and extension services – for instance, the Nangeenan Experimental Farm (now the Merredin Research Station) was established in 1906.

By the late 1920s, the policy of direct government intervention in financing of people into farming appeared to be working. There was a steady shift of people from the declining gold-mining industry into agriculture and the State was able to increase population and economic activity, mainly on the back of a booming wheat industry located principally in the wheatbelt valleys. Some development occurred on second class land, but no-one was able to contemplate extending agriculture into the third class lands – the light lands and sandplain between the valleys (Burvill 1979b). Until the 1950s the wheatbelt valleys carried dryland cropping in WA.

The railways

The development of railways and agriculture were closely intertwined. Both needed the other if they were to be viable. Already in the 1890s, the private sector had invested in two major railway-land development schemes.

The Great Southern Railway Company built the railway line from York to Albany and the Midland Railway Company built the line from Midland Junction to Geraldton. In both cases, the companies were rewarded with large land grants adjacent to the railways which they intended to sell for farming development. The Great Southern Railway received 3,000,000 acres, of which 250,000 acres had been sold by 1996. A similar area of land was granted to the Midland Railway Company (Crowley 2000). Although the railways were built, and much of the land settled, neither company was successful financially and both were eventually purchased by the State. However, the consequence was two additional arms of railways and associated agricultural development centred on Perth.

The pressure on Government from the landholders for railway development to service new agricultural settlements was high. Distance from the railway was an important constraint to development. In 1911, a Railway League formed with branches throughout the agricultural areas to confer with Government and particularly to plan for connecting lines and loop lines between the major axes. Examples of the latter built around that time include Merredin-Narrogin in 1909 and Corrigin-Brookton (Webb 1988).

One important consequence of the need to make the State's limited funds go as far as possible was the use of light rail construction on narrow gauge (3' 6") in areas where earthworks could be minimised. This tended to direct the railway lines through areas of gentlest grades – the wheatbelt valleys. These were also the areas that had suitable soils for the construction of earth tanks for the storage of rainfall run-off. Railways in the age of steam required a large number of people to service them. As a consequence, wherever the railways went, railway workers were located in towns and hamlets at frequent intervals, again mainly located in the wheatbelt valleys.

Salinity issues

Salinity in the settled wheatbelt valleys within the Avon, Blackwood and Moore river catchments was not an issue in the early years of the Century, although salinisation of the waterways was recognised, e.g. the Blackwood River became too brackish to drink in 1910. However, there are virtually no references to salinity impacting farming outcomes before the onset of a much more critical issue – the Depression.

There was an awareness in scientific circles of the possible problems of trying to farm saline soils. This resulted in the abandonment in the early 1930s of the '3,500 Farms Scheme'. This scheme to develop farms east of the Rabbit Proof Fence between Hyden and Salmon Gums was proposed in the late 1920s. As a result of investigation by Dr L J Hartley Teakle, the scheme was abandoned in part because of the risk of salinisation from the farming of the naturally saline soils. The decision to abandon the scheme was criticised strongly at the time, particularly by existing settlers in the adjacent Lakes District (Webb 1988). It appears, however, that the decision to abandon was mainly due to the onset of the Depression rather than to the predicted salt problems (Burvill 1979b).

WHEATBELT VALLEYS IN DIFFICULTIES

The Wheatbelt in 1929

Something of an early zenith was reached in 1929, the year of the State's Centenary. The proportion of the State's population living in these areas had hit a peak, which was never to be reached again. In absolute terms, some shires (see Table 3) never reached their pre-Depression populations again.

Table 3: Population trends in the Shire of Narembeen (Source: Bristow 1988, 191-192)

Year	Population
1925	2,100
1933	1,471
1947	977
1954	1,329
1961	1,558
1966	1,590
1971	1,384
1976	1,450
1981	1,330

The onset of the Depression

The most significant feature of the Depression for the wheatbelt valleys was the dramatic collapse in the price for the main product – wheat. In 1925/6, the price was $23 per tonne. This price declined each year to reach $8 per tonne in 1930/31 (Black 1981). In 1930, the Premier, Mr (later, Sir James) Mitchell was still looking to the wheat farmers for the solution, as demonstrated in his exhortation:

"...the world's food requirements are at once our opportunity and our danger – opportunity to people the country and reap a rich crop of annual wealth, danger because a hungry world is looking for ideal land on which to grow more food ……. To get the last acre selected and the whole of the cultivable land put to its fullest use is the aim of my party." (quoted in Black 1981, p.416).

The farmers responded. The crop of 53 million bushels (approximately 1.4 million tonnes) produced in 1930-31 was not exceeded until 1960 (see Tables 4 and 5).

The collapse of the wheat market shattered wheatbelt farmers and their communities. The low wheat prices did not allow the new farmers to service their debts for development and many were forced to leave empty-handed after less than 10 years farming. Hundreds of wheatbelt farmers abandoned their land in the 1930s. The Governments, which had done so much to get people 'on the land', had to provide further support to reconstruct the abandoned farms into larger units – up to 4,000 acres, which were then in the hands of the survivors, being those who had the resources to be able to stay. This process of Government adjustment and reconstruction was not completed until 1950 (Burvill 1979c).

Table 4: Trends in Wheatbelt production 1930-1950 (Source: Burvill 1979b, p.43)

Year	Area Cleared (m Ha)	Area sown for grain (m Ha)	Wheat Production (m tonnes)
1930	5.8	1.6	1.46
1940	6.4	1.06	0.57
1950	6.8	1.29	1.36

The collapse of the wheatbelt valley was a human disaster – a number of shire and other histories have stories of people being sold up and moved on with no reward after years of toil and after the promise of prosperity which induced them to these lands (e.g. Bristow 1988; Bolton 1994; Snooks 1981; Webb 1988). For the survivors, it was a time of struggle – coping with poor seasons in the mid 1930s, very low prices for wheat and the continuing need to service debts. Confidence in agriculture in general, and the value of wheat growing in particular declined severely as the wheatbelt valleys experienced hardship and genuine poverty (Bolton 1994).

Wartime stresses

The onset of World War II in 1939 simply added to the difficulties. Labour shortages for farming became acute and production levels and product prices were highly regulated. The cropping industry, which was trying to move from a dependence on horse power to fossil fuels was hampered by fuel shortages – with charcoal fired gas producers a common sight on tractors.

In summary the development of the wheatbelt valleys, commenced with such enthusiasm in the 1900s, stalled and struggled for two decades from 1930-1950 as shown in Table 4.

GOOD TIMES AT LAST – 1950 TO 1970

A combination of improving economic conditions in the World's trading nations, the fruits of the investment in science and technology, the removal of rabbits and a long run of generally favourable seasons gave the wheatbelt valleys probably their most untroubled, uncomplicated and confident two decades – the 1950s and 1960s. By that time agriculture in the Wheatbelt was breaking free from the wheatbelt valleys – with the move from the 'first class land' that had been the basis of the farming system to the 'second' and 'third class' land that had been rejected as unsuitable in the 1910s and 1920s. As Table 5 shows, the area cleared for farming and sown for grain more than doubled over the next two decades. It was during these two decades and into the early 1970s that most of the remaining second class land and virtually all of the available third class land was cleared for agricultural development.

Table 5: Trends in wheatbelt production 1950 to 1968 (Source: Burvill 1979b)

Year	Area Cleared for farming (m Ha)	Area sown for grain (m Ha)	Wheat Production (tonnes)
1950	6.8	1.29	1.36
1955	8.7	1.17	1.45
1960	10.4	1.63	1.74
1968	13.7	2.95	3.06

The value of science and technology

Australian agriculture dramatically expanded production based on new management skills, and new technologies, mainly derived from public investments in research and development. Between 1950 and 1990, a reduced number of farmers increased farm output by 250% (Goss *et al*. 1995). In this time, the number of farm establishments in Australia declined by about 25% (Barr & Cary 1992).

In WA, the focus of expansion shifted from the wheatbelt valleys to an intense and very rewarding period of research and development in learning how to farm the once ignored second and third class lands 'outside' the broad wheatbelt valleys. The demand for land for the settling of returned servicemen and surplus off-spring from wheatbelt valley farms was met through Government land development programs not dissimilar to that operating in the 1910s and 1920s, supported by publicly funded research in plant breeding, crop development, plant nutrition and farming systems development. The work was fostered by active Pasture Improvement Groups, Farm Management Groups and a large presence by research and extension officers from the Department of Agriculture (Burvill 1979c). The contribution made by Department of Agriculture officers to light-land development was commemorated in a plaque recording their work erected in Gnowangerup in 1963 (Underwood 1979).

This expansion in scale and productivity was hugely successful and a source of pride to farmers, political leaders and the general community. In all this, the wheatbelt valleys had ceased to be the only focus of attention - they were now just part of a much larger and more complete wheatbelt agriculture.

Agriculture and fossil fuels

The development of the wheatbelt farming systems coincided with the development of the fossil fuel-based economy (Halse 1979). Availability of cheap fuel, rapidly improving machinery development (largely stimulated by the needs of wartime production) and the relatively high labour costs in Australia directed Australian farmers into dryland farming systems that were reliant on high levels of technology, a high degree of mechanisation, and minimal labour inputs. Thus, as shown in Table 3, decreased population occurred as farmers focused on maximising productivity per unit of labour.

After the boom – the Wheatbelt in 1970

In summary, only when the good times came, in the 1950s and 1960s did the initial decision to settle the wheatbelt valleys reward sufficiently its proponents, financiers and landholders. By then, however, the State's economy was moving on – into a second period of dependence on mineral and hydrocarbon extraction and export that continues to this day. While the initial justification for settlement of the wheatbelt valleys was overtaken by these events, agriculture continued to grow in both production and productivity, albeit with a continuing decline in the number of farming establishments. The confidence developed in those years has resulted in some people holding a view of wheatbelt life in those years as being the desired 'normal state', when one could equally argue that they were really abnormally calm years in the 100 year history.

Salinity as an issue?

What was being said about salinity in the years of expansion? Very little it seems. Although the causes of dryland salinity or more properly secondary salinity were generally well known, it was never seen by the scientific community and most farmers as being of major concern for agriculture before 1980. By the mid 1970s, salt was recognised as a serious issue on some farms and occurring in small areas in many farms. The survey carried out in 1974 showed that less than 2% of cleared farmlands was affected (Burvill 1979d). The prevailing view was that:

'...*a major part of Western Australian farmlands, however, will never become unproductive because of salt. The 98% unaffected will, if properly farmed, sustain and increase rural production.'* (Burvill 1979d, p.104).

Throughout the 1950s and 1960s, the Department of Agriculture devoted some resources into developing productive uses for saline land principally using native species of saltbush (*Atriplex* species) and bluebush (*Maireana* species). This represented one of the few occasions in Australian agriculture when attempts were made to develop an economic value from native as opposed to exotic species.

Where other than purely agricultural values were at risk, however, Governments took prompt action. Increased salinisation of waterways recognised early in the 1900s eventually reached a point where further clearing in the catchments of the remaining fresh rivers posed a threat to irrigation systems and domestic supplies. Government instituted clearing controls (with compensation for those affected) in a number of south-west catchments in the 1970s in the face of considerable opposition by farmers in these areas. Elsewhere in the State, some further clearing of land for dryland farming occurred through the late 1970s and into the 1980s, mainly in marginal areas, although increased concern about secondary salinisation limited activity.

MORE SUCCESSES AND EMERGING DIFFICULTIES

Productivity increases in the 1980s and 1990s

By 1980, virtually all the land that could be used for agriculture in the Wheatbelt was cleared and farmed. Subsequent increases in production have come from dramatic increases in total factor productivity – measured as the ratio between outputs and inputs. Table 6 presents trends for productivity growth for the Central, Northern and Eastern Wheatbelt regions, compared to grain-growing regions in Southern Australia (i.e. grain-growing areas in SA, Victoria and southern New South Wales).

What Table 6 does not show is how the nation's grain industries have performed compared to other agricultural industries, or in relation to the whole economy. While the grain industries have achieved productivity gains of 3.5% per annum over the last 20 years, broadacre sheep farms have managed only 0.8%, with beef properties performing somewhat better at 1.6% productivity increase per annum (Knopke *et al.* 2000).

By the mid-1990s Australian agriculture contributed around 3% Gross Domestic Product (GDP), down from 15% in the 1950s. The rural sector's contribution to total exports had dropped from around 75% to 28% (Pollard 2001). The Central Wheatbelt in Western Australia contributed 23% of Western Australia's total wheat income ($411,970,000) in 1995/96 and 6% of the wool income ($39,435,000) (AgStats 1997). 1n 1996/97, about one tenth of Australian farm businesses were responsible for almost half of farm business turnover and cash operating surplus. This trend was mirrored in the Central Wheatbelt where in 1997 broadacre farms averaged 2,500 hectares. Property size was skewed to a large number of smaller operations – during this period it has been estimated that about 12% of the State's grain-growers produce about half the total crop.

The implication of these figures is that while in an overall sense, agriculture now contributes significantly less to Australia's overall GDP, the impact of the agricultural industry within the regions must not be underestimated. Agricultural income in 2001 remains very much the economic backbone of most rural centres and regions.

Table 6: Productivity trends in the dryland cropping industry – 1978/79 to 1998/99 (Source: Knopke *et al.* 2000)

Region	Percentage change per annum			
	Productivity	Outputs	Inputs	Number of crop farms
WA Eastern Wheatbelt	4.0	6.1	2.1	-6.4
WA Northern Wheatbelt	4.0	7.2	3.2	-0.5
WA Central Wheatbelt	3.1	3.8	0.7	-0.6
All WA farms	3.5	4.8	1.3	-1.9
All Southern farms (SA, Vic, S-NSW)	3.2	4.4	1.2	-1.9
All Northern farms (Qld, N-NSW)	3.0	4.4	1.4	- 4.1

The Eastern Wheatbelt in the 1990s

The data in Table 6 have particular relevance given the location of this Conference in the heart of the Eastern Wheatbelt, in that they show the impressive productivity gains posted by the grain industry in this region – as high as anywhere in the Australian grainbelt. The industry in the Eastern Wheatbelt has been robust over the last 5 years of the 20th Century – with farm cash incomes averaging $173,000, a rate of return on capital of 8.7%, which was higher than elsewhere in WA. Throughout the last 20 years, market forces have promoted structural adjustment, resulting in a relatively high loss of farms in this region – an annual loss of 6.4% or a halving of the number of farms in a 20 year period. The productivity gains have been driven by improved wheat yields averaging 3.8% improvement per annum, inclusion of lupins in the rotation, minimum till and no till farming, and better fertiliser use (Knopke *et al.* 2000). Professional services through private consultancies were well used by many farmers and a number of productivity groups emerged with enthusiastic involvement from farmers – notably TopCrop Groups, the Western Australian No Till Farmers Association, the South West Premium Wheat Growers and the Liebe Group.

A new look at salinity

While it was science and technology that made a noticeable impact in the profitability of agriculture and provided optimism and opportunity in agriculture, it was the environment that began to redefine the impact of farming on the landscape. This growing realisation of the potential impact of salinity also influenced the way in which rural communities and Government agencies would engage. A quote from Harry Whittington described the visual impact of salinisation of the valley floors.

'Very early in life, I came in contact with soil and water, saw the wonders, beauty and power of nature, watched the crystal clear creek which flowed gently throughout the year, change to a muddy, raging torrent in winter and a dry sand bed in the summer. Saw a flourishing orchard transformed to dry tree stumps, the evergreen verges of native lucerne on the flats change to waterlogged, bare, barren soil which in time was covered with small white crystals shining in the sun. This white substance was called sodium chloride – just common salt to me.' (Whittington 1975: 1).

During the 1970s and into the 1980s, a farmer-based movement led by Harry Whittington developed approaches and technologies to address what they saw as an issue not being properly tackled by Government or agricultural scientists. The relationship between the two camps was very strained through these years, but it is probably fair to say that farmer and Government awareness of emerging hydrological issues in the landscape was strongly stimulated by the debate and by the efforts of both farmers and scientists to come to terms with this emerging reality.

Their concerns were being justified as the evidence of increased secondary salinisation accumulated. Through the 1980s and into the

1990s, the wheatbelt valleys in particular began to show signs of secondary salinity suggesting that earlier estimates of 2% of the landscape affected by salinity might not be accurate. At the same time, people were starting to look beyond salinity simply as being a cause of a 'loss' of productive farmland. New words like 'biodiversity' and 'environmental values' began to be heard, and concern was being expressed about the impacts of rising saline groundwater on rural infrastructure such as roads, rail and towns – which as we have already observed are mainly located in the most vulnerable parts of the landscape - the wheatbelt valleys.

Building a basis for community action

At the same time as farmers, scientists and Governments were beginning to see secondary salinity as an issue that needed to be addressed in a more deliberate manner, structures to enable engagement around the issue were emerging. It was during the 1970s and 1980s that Governments responded to growing concerns about the state and trends in the natural resources used for agriculture throughout rural and regional Australia.

At the Commonwealth level, the release of the national soil conservation study in 1978 (Department of Environment, Housing and Community Development 1978) provided the basis for direct intervention by the Commonwealth into the management of land and water resources in the States – to be called initially the National Soil Conservation Program (NSCP), then the National Landcare Program (NLP), and culminating in the Natural Heritage Trust (NHT). The funds coming to WA from this source have grown from around $1m annually in the early 1980s to $30 million currently.

Actions in WA created an environment to handle these additional resources. Changes to the Soil and Land Conservation Act 1945, passed in 1982, allowed the Commissioner for Soil and Land Conservation to establish Soil Conservation District Committees (to be later known as the Land Conservation District Committees) who had a responsibility to help administer the Act and take pro-active action to prevent and repair land and water degradation. The growth in the number and activity of the LCDCs vastly exceeded expectations and the funds from the Commonwealth were an important source of resources for professional support and on-ground demonstrations.

One of the first regions to form an LCDC was the Yilgarn in 1983. The Yilgarn at the time had one of the highest lodgements of land clearing applications and the LCDC were aiming to maintain some control of these clearing applications. Members of the committee firmly held the view that local people were best positioned to make recommendations about land clearing. However, by this time it was not the valley floors that were under threat, rather the 'recharge sites', in particular the wodjil soils that were being cleared.

At the same time as the LCDCs were forming, catchment groups were also becoming established. The North Bodallin and the Beacon River Catchments were some of the first to become established under the National Soil Conservation Program. While valley floor salinity was an issue in both catchments, surface water management and erosion were also concerns.

Processes of community involvement and participation underpinned natural resource management planning and policy throughout the region during the 1990s. These processes were guided by policies developed under the Commonwealth Government's commitment to the Decade of Landcare, and the use of Telstra sale funds invested through the Natural Heritage Trust. In was during this time that Western Australia developed the State Salinity Action Plan 1996, which was founded on principles of farming system development, community involvement, catchment planning processes and hydrological research. While there remains considerable support and argument for community participation, the Decade of Landcare concluded on a note that this is only the beginning and other forms of salinity management must be developed (Mid-term NHT reviews 1999).

In this respect it was significant also that much of the additional funding for salinity management in WA was directed at the protection of public assets, with targeted investment into nature conservation and improved water quality in recovery catchments, and in protecting rural infrastructure through the Rural Towns Program.

Communities under pressure

In this time of greater awareness of the impact of agriculture on the natural resources, social trends continue to have a significant impact on the way in which valley floor salinity is viewed and managed.

At the beginning of the 20th Century Government policy, particularly the settlement schemes, aimed to shift people into the country. The beginning of the 21st Century sees the opposite, where farm economics and labour micro-economic reform are causing rural communities to become progressively smaller and farm size to become progressively bigger. The Eastern Wheatbelt reflects this trend to a greater degree than many rural areas (see Table 6). The median age of farmers in the 1996 census was 44 years, significantly higher than the 38 years in other industries. Between 1991 and 1996, the population in the Shire of Merredin declined by an estimated 2.5%, and many wheatbelt shires lost double this percentage (Haberkorn *et al.* 1999). ABS census data also show that the Central Wheatbelt region is one of the more severely affected in terms of population decline. The results also showed that more men (25.36%) have left the region than women (23.95%) between 1991 and 1996.

Paradoxically in view of the settlement policies promoted by Government in the early 1900s, reduced population in wheatbelt towns was occurring partly as a result of micro-economic reforms in labour management in Government organisations – such as the key transport and infrastructure providers. Another trend is the intra-regional population shifts from small settlements to so-called ‘sponge towns’ that are sufficiently large to retain and develop services.

Collectively, these trends imply that the load to sustain the agricultural industry is being shouldered by fewer and older people. The impact of these social trends in the Wheatbelt is important in the management of valley floor salinity. The most significant would be the declining scope and capacity for individuals to allocate funds to manage a problem that has very few known solutions, is substantial in its geographic size and complicated by its temporal scale. A second implication is the pressure on Governments to develop policy that assists in maintaining a focus on research and development in salinity and viable solutions and also support processes that will enable salinity to be addressed in an environment of continuing social change.

OUR STORY – WHAT DOES IT MEAN?

Our story could conclude on a morbid tone of decline and pessimism; however, there is in fact considerable optimism that should be drawn from the findings in this paper and it is these points of opportunity that bring this paper full circle. While there is concern for the direction of social trends in the rural regions, there is a growing awareness and appreciation of the impact of valley floor salinity on agriculture (National Land and Water Audit 2001) and an acknowledgment that ‘something needs to change’. Further, we have a robust and innovative agriculture with a capacity to make further productivity gains that can be used to address natural resource management needs. Finally, we have excellent traditions in developing technologies for difficult environments.

The qualities that have influenced the development of the Wheatbelt and have contributed, albeit unwittingly, to valley floor salinity will continue to influence change. These qualities of deliberate Government intervention, resilience to pressure and a capacity to innovate and adapt have each influenced the rate and type of community and industry development. Policy development will be guided by the fact that the people who live and work the valley floors, must live with and adapt to increasing salinity. In particular, the disconnect between a productive agriculture on the one hand and emerging natural resource issues needs to be removed. In this regard, Government policy must enable individuals and rural communities to develop strategies that help them to achieve their ‘visions’ for their rural landscape and rural community. The language and actions will be mainly about resilience - being the ability to cope with change.

Governments will also need to continue investment in research and development in order to develop viable and effective land use systems that can be productive in an environment of excess water. In the community, the qualities of resilience and a capacity to adapt and innovate will continue to support their involvement in salinity management. It is unlikely that the level of the pressures and challenges experienced in agriculture over the last one hundred years will change over coming decades. We can however learn from these experiences. Salinity may be regarded as a threat but it may also be seen as an opportunity for agriculture to redefine its vision, creating new industry opportunities that may lead to a resurgence in community and development throughout the Western Australian Wheatbelt.

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HIDDEN MENACE OR OPPORTUNITY – GROUNDWATER HYDROLOGY, PLAYAS AND COMMERCIAL OPTIONS FOR SALINITY IN WHEATBELT VALLEYS

Richard George[1] and Mark Coleman[2]

ABSTRACT

Wheatbelt valleys contain evidence of a long history of hydrologic and climatic change. In particular they contain ancient palaeodrainage systems comprising large volumes of saline groundwater. Prior to clearing, these palaeodrainages discharged small amounts of groundwater derived from episodic recharge on the hillslopes and *in situ* within valleys. However, as a result of significant increases in recharge following clearing, these palaeodrainages are now becoming saturated, and small natural discharge areas such as playas, which previously balanced recharge, are now too small to cope with increased surface and groundwater flows. Discharge areas are expanding and saline land is encroaching on farmland, threatening other assets such as towns, roads and remnant vegetation.

Today between 3 and 15% of the wheatbelt shires, and a higher percentage of valley floor farmland, is saline. A larger area of between 22 and 34% is likely to have shallow watertables with much of it being saline, if current trends in groundwater levels are maintained. In addition, few management options are available to reduce recharge, the area required for effective management is large (> 50%) and there remains considerable uncertainty as to the effectiveness and economics of discharge based options. Despite this uncertainty, farmers threatened by salinity have recognised that engineering options represent the most likely means of unilaterally managing salinity. Many also realise that discharge areas, saline or with a shallow watertable, are a complex mosaic of land with differing salinity levels and capabilities.

Given current levels of effectiveness of management options, added economic incentives for the use of wheatbelt valleys is required. These may be needed to both partially refund recovery of land where engineering options have been used or as a means to develop a new resource and associated industry. We believe that this incentive, should it exist, may potentially come from the longer-term development of the large (1000 GL/yr) and saline (> 30,000 mg/L) groundwater resources which lie beneath wheatbelt valleys. While aquaculture, salt harvesting, desalinisation and the production of solar energy are all possible, there remains a considerable economic gap to be filled before many of these new industries become reality and wheatbelt valleys change their current landuse and emphasis on reclamation for agriculture.

INTRODUCTION

Secondary salinisation of dryland agricultural farms in Western Australia has occurred as a result of the removal of perennial, deep-rooted native forests and woodlands over an area of some 200,000 km^2 and its replacement with predominantly shallow-rooted, annual crops and pastures (George *et al*. 1997). Additional recharge causes watertables to rise, dissolving salts stored within the regolith and root-zone of poorly tolerant agricultural crops. By 1996, 90% of the agricultural landscape had been cleared and shallow watertables and dryland salinity affected 18,000 km^2 of previously productive agricultural land (Ferdowsian *et al*. 1996). National Land and Water Resources Audit research indicated shallow watertables and salinity threatens at least two to three times this area unless appropriate management systems are developed and implemented quickly (Short & McConnell 2001).

Changes to the water balance also impact on infrastructure: towns, roads, pipelines, buried cables and rail networks. Already, 30 Shires in the region have begun to investigate salinity risk to rural towns and each are developing urban water management options (Pridham 2001). In addition, 50% of the region's divertible waters are saline and further losses are imminent. As a result of shallow watertables and expanding near-permanently wet areas in valleys, a

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two to four fold increase in flood volumes and changes in peak flow are predicted (Bowman & Ruprecht 2000).

Finally, the South-West of Western Australia is recognised as one of the ten megadiverse biological regions on the planet, containing over 12,000 native species of flora. In the Wheatbelt where native flora and fauna is only represented in small reserves, especially within valleys, as many as 450 extinctions may result from increased groundwater levels and salinity.

Minimising the current and potential menace posed by continued salinisation is dependent on our ability to develop both successful and economic management options and by finding productive uses for saline groundwater and land. This paper discusses the hydrologic factors responsible for the menace, reviews how wheatbelt valleys worked before clearing and how they have changed. It also explores some of the salinity predictions in the Central and Eastern Wheatbelt. Finally, it points towards some of the opportunities we have for the use of saline groundwater which may assist wheatbelt communities capitalise on the large scale environmental, social and political change which is forecast.

Hydrogeology of wheatbelt valleys

Archaean rocks of granitic composition intruded by Proterozoic mafic dykes underlie wheatbelt valleys. The crystalline basement has been deeply weathered and chemically leached during a period of relative stability (~100 Ma), resulting in a deeply weathered mantle which comprises the preserved saprolite (up to 50 m) and overlying sediments (usually less than 50 m). The saprolite consists of *in situ* and partially weathered material above the basement (saprock), then intensely weathered sandy clays (pallid colored), which are in turn overlain by mottled materials and the sandy soil layer. The saprolite is thickest on hillsides and within the lowerslopes.

In valleys, sedimentary sequences dominate the soil profile (George 1992a). At the base, particularly in association with trunk or palaeo-valleys, but also in some tributaries, occur sequences of coarse alluvial sediments which fine upwards into clay-rich materials (Salama 1997). In many palaeodrainages (typically < 270 m AHD in western areas) very fine-grained lacustrine (Eocene; lake or swamp) sediments occur (George *et al*. 1994; Clarke *et al*. 2000), and may in turn be overlain by indurated sands. Recently, drainage-inspired excavations have revealed iron and silica cemented horizons in the upper 3 m of the soil profile. These sequences are highly variable in vertical and spatial distribution.

Beard (1999) recently deliberated on the history and flow direction of wheatbelt palaeodrainages. Building on earlier work and together with experimental data obtained from drilling at many places (e.g. George 1992a; George *et al*. 1994; Salama 1997, George & Dogramaci 2000), a picture of the genesis and structure of wheatbelt valleys has been formed (see Commander *et al*., this volume).

Mapping the location of the deep, sandy palaeochannel sediments has not been undertaken in the Wheatbelt, except where drilling for minerals or airborne electromagnetic surveys have been undertaken (George 1999). However landform-mapping undertaken in the 1960's (Malcolm 1983), may provide a guide as to their general location. Bettenay and others recognised three principal valley forms in the Eastern Wheatbelt: the lower 'Baandee and Nangeenan' surfaces, which correspond to the playa and primary saline areas; the 'Belka surface' (sandy surface comprising braided streams); and the 'Merredin surface' (dominated by sandy clay loams, 'red' soils). The former was considered to overlay palaeodrainages, the second, is a more modern, fluvial depositional environment, while the latter was derived by sheet flow at lower velocities, hence depositing only fine-grained transported material (Bettenay *et al*. 1964). In this unit, colluvial sediments were expected and salinity risk was believed to be low.

Wheatbelt aquifers and their properties

In 1924, W.E. Wood identified the essential components of the Wheatbelt's groundwater hydrology, concluding that water movement was greatest in the lower layers of the weathered profile. This conclusion was modified by work by Bettenay *et al.* (1964) and Smith (1962) and later, by Peck *et al.* (1980) and Nulsen & Henschke (1981), although to this date, little reference had been made to sedimentary aquifers.

George (1992a) described in more detail the hydraulic properties of aquifers in the Wheatbelt. Three dominant types were recognised: a sandplain perched aquifer, a saprolite 'grit' aquifer (saprock) and a valley sedimentary aquifer (~20 m). George showed that the saturated hydraulic conductivity (K_{sat}) of the saprolite and sedimentary aquifers (~0.6 m/d) were about an order of magnitude higher than that of the pallid zone aquitard. George *et al.*

(1997) later refined the relationship between aquifers and salinity into ten models. They concluded that local-scaled regolith or saprock aquifers were dominant, although intermediate-scaled sedimentary systems were common in valleys. Clarke *et al.* (2000) showed that the K_{sat} of the saprock aquifer and intensely weathered aquitard was similar in western areas (Woolbelt). Clarke also found that in palaeo-valleys in the western areas, the lower sand-rich palaeochannel aquifer has a K_{sat} ~300 times higher (~3 m/d) than the lacustrine aquiclude (Clarke *et al,* 2000). These are similar to those found by Salama (1997; 3–6 m/d) in the Avon palaeochannel and George & Dogramaci (2000; 5 m/d) in the Toolibin palaeochannel.

Groundwater velocities are typically very low. Given typical hydraulic conductivities (0.5–5 m/day) and gradients (1:1000–1:10,000) for wheatbelt valley sediments, flow velocities in the deeper saprolite and sedimentary aquifers of about 0.1 m per year are considered likely. Under exceptional circumstances, in surface sediments, where there is a high permeability (> 1.0 m/day), and gradient (0.005), velocities may increase to 5 m/yr. For velocities of greater than this either the permeability must be very high (soil macropores) or the gradient increased by intervention (drainage or pumping).

Hydrology and salinity of wheatbelt valleys

The magnitude of recharge to wheatbelt valleys is not known with precision although several authors have attempted to estimate it. McFarlane *et al*. (1989) used hydrograph analysis to determine that recharge in valley sediments was at least as significant as that on hillslopes, recording rates of 35 mm/yr at Toolibin. George *et al*. (1991) in reviewing recharge processes from a range of wheatbelt sites agreed, and concluded that recharge occurred everywhere that discharge did not and that even in these areas, it could alternate between seasons. They further showed that episodic recharge is critical, a subject Lewis (2001) has comprehensively reviewed.

A range of techniques (chloride, water balance and hydrograph) was used to estimate the relative magnitude of recharge between catchments and landforms in wheatbelt valleys (George 1992b). He concluded that recharge from uncleared catchments was typically of the order of 0.05 mm/yr, while for the same catchments, recharge increased to be between 6 and 10 mm/yr. after clearing. Recharge was highest in upland (e.g. Danberrin and Ulva soil associations) and sandy surface valley soils (e.g. Colgar, Belka) and least in clay-rich soils (e.g. Merredin and Booraan surfaces).

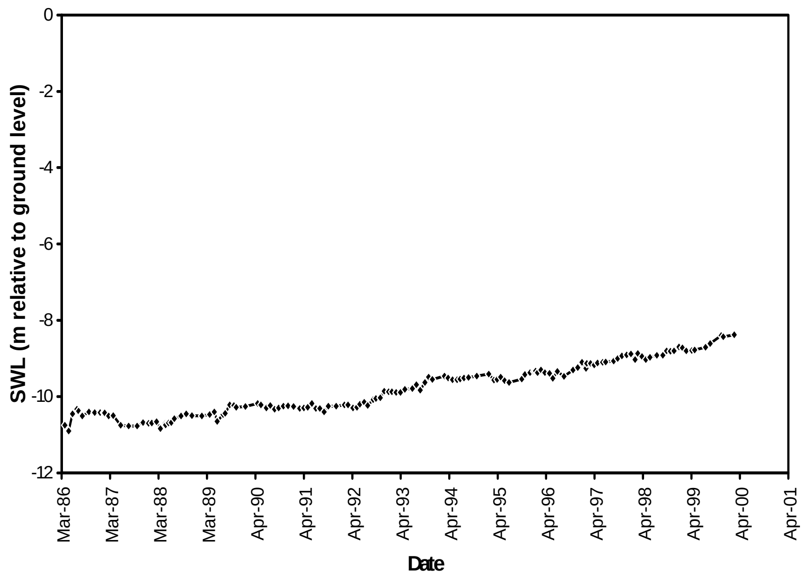
Recharge to valley sediments also takes place laterally, either directly from connected fluvial sequences of sediments or from depth, where groundwater from adjoining saprock and potentially fractured rock systems enters sedimentary aquifers (Salama *et al.* 1993; Salama 1997). The degree of interconnectedness has not been assessed in detail; however modelling at Toolibin (George & Dogramaci 2000) suggests saprock and palaeochannel aquifers, and at Merredin (Matta 2000) saprock and overlying sediments are both well connected and respond to pumping.

Groundwater discharge from valley sediments has also never been measured directly. In only one experiment known to the authors, Greenwood & Beresford (1980) used ventilated chambers to document the 'water use' (discharge) of bare soil near Kellerberrin. They measured rates of the order of 0.4 mm/d in summer (equated to 80 mm/yr) at a site where saltbush was growing. George (1992a) calculated potential discharge rates from piezometers (calculated vertical flux), concluding rates of between 50 and 230 mm/yr. Using a water balance approach, George (1992b) indicated that if the effective discharge rates were 80 mm/yr (~3% of pan evaporation rates), the entire recharge to the Wallatin Creek catchment (i.e. water added annually to the groundwater) could be lost from 12% (2880 ha) of the catchment.

Furthermore, from first principles, at equilibrium recharge will equal discharge and as catchment average recharge is about 20 mm/yr, and the potential discharge area is 20–30% of the landscape, average discharge rates will be no more than 100 mm, a number similar to that estimated above. This low flux rate has significant implications for salinity management, as we will discuss later.

The effect of the imbalance between recharge and discharge can be measured by monitoring trends in groundwater levels. In wheatbelt valleys, landholder groups and government, typically using shallow piezometers or observation wells, are monitoring trends in water levels. Short & McConnell (2001) documented trends in deep bores across the entire agricultural area. They concluded that where the watertable was within 2 m of the soil surface, there was often no trend (water levels neither rose nor fell from their 1–2 m position). However, where watertables were greater than 2–5 m below the soil surface, the vast majority of bores showed a rising trend.

At Toolibin and Merredin, typical of wheatbelt valley systems, watertables in saline areas have been relatively stable for some years (McFarlane *et al*. 1989; George 1999) although pressures may continue to rise if located near a palaeochannel (Figure 1). By contrast, valley bores located within tributaries with deep watertables are rising at about 0.15 to 0.3 m/yr, despite lower than average rainfalls during the past twenty years (Figure 1). This rate of rise is similar to that recorded in bores on hillslopes (Short & McConnell 2001).



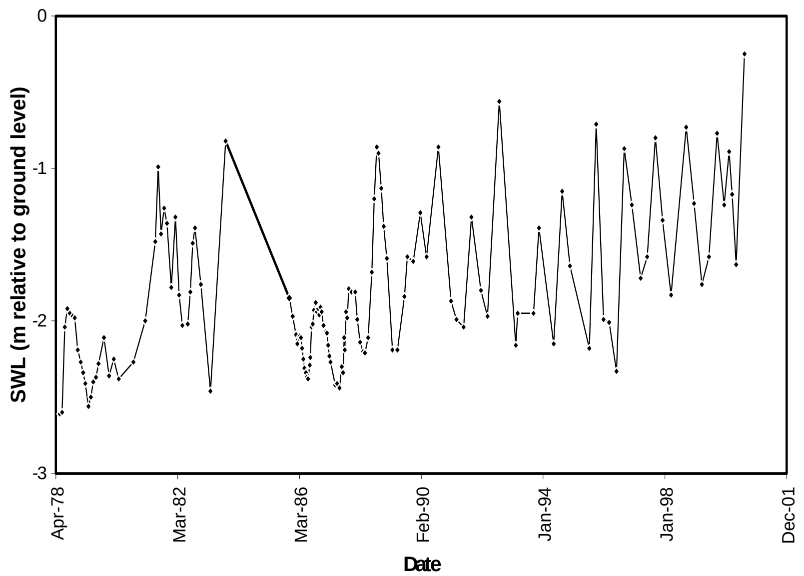


Figure 1: Two bores from wheatbelt valleys. Bore MD01 is a deep bore located in cleared farmland in the upper reaches of the Merredin valley. It has a typically deep watertable and shows a 2.5 m rise over the last 15 years (0.15 m/yr).By contrast, Bore 77 is located in valley sediments in the lower Toolibin catchment, within a 1000 ha remnant. This bore shows a small rise over the past 23 years (0.05 m/yr), despite a shallow watertable.

Salt stores and flux

McFarlane & George (1992) reviewed salt storage in two wheatbelt catchments (Table 1), concluding saltstore was directly linked to landscape type, showing ranges from as little as 247 T/ha in skeletal soils (Danberrin) to greater than 21,314 T/ha/TSS (Baandee; valley palaeodrainage channels). At present rates of deposition (~25 kg/ha/yr; Hingston & Gailitis 1976), stores of 1000 T/ha would require about 40,000 years to generate the measured load (McFarlane *et al*. 1993). These accumulation times are similar to those estimated by Teakle in 1937 (quoted in Malcolm 1983) for soils at Merredin.

In the Toolibin catchment, George (1999) documented similar average stores from airborne electromagnetics and drilling. In this catchment, a combined store of approximately 50 M Tonnes was postulated. At rates of input (30 kg/ha/yr), about 33,000 years of deposition would be required (assuming no loss).

Currently, the Toolibin gauging station measures an annual loss of about 2000 T/yr, interestingly equivalent to the annual input. In other words, even though 8% of the catchment is saline, there is currently no net loss. Again, we will discuss the implications later.

Groundwater chemistry of wheatbelt aquifers is predominately sodium chloride (NaCl), and maintains the same basic composition to that of seawater, reflecting its oceanic source (McArthur *et al*. 1989; Mazor & George 1992).

Table 1: Average total soluble salt stores (TSS) beneath a hectare of land above bedrock in typical Central (Wallatin Creek) and Eastern Wheatbelt (North Baandee) catchments (McFarlane & George 1992).

Landform (position)	Average TSS Storage above bedrock (t/ha)	Range (t/ha)	Number of profiles sampled	Average depth (m)
Danberrin (hilltop)	247	7 – 657	7	5.9
Ulva (sandy hillside)	289	139 – 422	5	19.7
Booraan (clayey hillside)	802	43 – 1,798	10	13.5
Colgar (sandy hillside)	1056	109 – 2,231	12	16.5
Belka (broad valley)	2571	44 – 6,206	14	20.4
Baandee (saline & playa)	13,533	5,752 – 21,314	2	51.0

Salinity and valley productivity

Nulsen (1981) describes experiments that indicate depth to watertable is a key determinant of crop growth in valleys, and is of greater predictive capacity than indicators species. His work showed that at a depth of 1.8 m, the yield of wheat was reduced significantly. Furthermore, Barrett-Lennard (1986) has shown that waterlogging compounds and increases the effects of salinity on crops. Barrett-Lennard (1986) used pot trials to show that at even relatively high salinity levels (6,000 mg/L) wheat was able to survive, but by stark comparison, pots that were waterlogged showed yield impacts with even fresh water.

The mosaic of salinity patterns in the landscape suggests there are other controls that influence the location of valley salinity. At a gross scale, the location and severity of discharge and salinity is controlled by both topography and geologic structures (Clarke *et al*. 2000) and discharge rate (George 1992a). At a local scale microtopography and soil type are most significant (Malcolm 1983). Local elevation has a strong influence since depth to watertable is least in depressions in the valley floor. In addition, soil types influence permeability and porosity and therefore salt flux (accumulation and leaching). Salinity may be permanent or intermittent, depending largely on waterlogging frequency and rainfall patterns (again influencing leaching and watertable rise).

What proportion of wheatbelt valleys is currently salt-affected?

Until the satellite-based 'Land Monitor' project is complete and all of the statistics are released (see below), no consistent and statewide means of determining *current salinity* (see definition below) has been available. Prior to this, assessments of regional salinity were compiled from assessments by farmers (who answered questions for each 5-yearly census) and scientists made estimates based on observed changes (e.g. water level trends and cropped area). The Australian Bureau of Statistics (ABS) information showed a high variability in wheatbelt shires, ranging for example in the Central and Eastern Wheatbelt from Tammin (9.26%) to Merredin (2.3%) (George 1990). These were considered to be an under-estimate of the real extent of salt-affected land.

In 1988, regional hydrologists of the WA Department of Agriculture estimated areas of salinity and trends across the state. Anon (1988) describes that in the Eastern Wheatbelt, where at that time no substantive evidence of groundwater rise existed (bores drilled in 1985 onwards had too short a record), salinity affected only 1.64% (based on ABS 1984 data) of the area and that potentially 10–20% was at risk. In 1994, with better catchment mapping and longer groundwater records, Ferdowsian *et al*. (1996) indicated as much as 9% of farmland was 'affected' by salinity to some degree (greater than 50% yield reduction). They concluded that salinity could potentially double and then double again (33%) before coming to equilibrium in approximately 50 to 200 years.

At the time of writing, Land Monitor data from the Kellerberrin, Perth, Newdegate and Bencubbin scenes are available for the central and Eastern Wheatbelt. Each scene represents over 1 M ha, and covers the area from Toodyay in the west, to Bullfinch (north-east), Ravensthorpe (south-east), including a southern boundary near Lake Grace, Kondinin, Quairading and Pingelly (Table 2). In this area, 'salinity' has been defined and mapped as land having 'consistent and low productivity due to shallow watertables'. It also includes many areas of primary salinity, but usually excludes heavy barley grass pastures, saline remnants and lakes (water) which have been identified by field checking. Field verified 'commission errors' (overestimates that include non-saline land) and 'omission errors' (underestimates of actual saline areas such as thick stands of barley grass and saltbush) are typically about 5% and 20% respectively. The process of ground truthing and statistical analysis has been described in more detail in each scene report which is available on the Land Monitor website (www.landmonitor.wa.gov.au/ – see Caccetta *et al*. 2000; Caccetta *et al*. 2000b; Caccetta & Beetson 2000; Dunne & Beetson 2000; Furby 2000).

Table 2: Land Monitor statistics of the area of land classified as having a low productivity attributed to salinity (includes primary salinity; excludes most barley grass, saltbush, and lakes). Each scene is based on statistics from different set of satellite data.

Scene/Shire	Shire Area Ha	Saline 1987–1991 Ha (%)	Saline 1995–1996 Ha (%)	Difference Ha (%)
Kellerberrin				
Merredin	329393	7537 (2.3)*	9138 (2.8)	1601 (0.5)
Bruce Rock	272516	11517 (4.2)	12608 (4.6)	1091 0.4)
Trayning	165196	6750 (4.1)	7577 (4.6)	827 (0.5)
Kellerberrin	191554	11580 (6.0)	11964 (6.2)	384 (0.2)
Tammin	110246	7492 (6.8)	84176 (7.6)	925 (0.8)
Bencubbin				
Koorda	283197	41255 (14.56)	42619(15.05)	1346 (0.47)
Dalwalinu	722135	83381 (11.5)	84412(11.69)	1031 (0.14)
Wongan-Ballidu	336518	34232 (10.17)	36587(10.87)	2355 (0.7)
Perth				
Cunderdin	186234	13032 (7.0)	13395 (7.2)	363 (0.2)
Northam	143127	2606 (1.8)	2732 (1.9)	126 (0.08)
York	213080	4537 (2.1)	4736 (2.2)	199 (0.09)
Beverly	237118	6296 (2.7)	6663 (2.8)	367 (0.15)
Chittering	121874	538 (0.4)	702 (0.6)	164 (0.13)
Toodyay	169285	832 (0.5)	917 (0.5)	85 (0.05)
Newdegate	1022162	63693 (6.2)	69507 (6.8)	5814 (0.57)

* Percentage of Shire area as defined by Land Monitor.

The Land Monitor data (Table 2) shows an increase in all shires, although the magnitude is highly variable (0.05 to 15%). The increase over the period 1987–1991 to 1995–1996 is about 0.5%. This equates to an annual increase of less than 0.1% (1% per decade). A comparison of the ABS statistics and Land Monitor data is not possible as methods differ too greatly. However it is worth noting that for the Kellerberrin Scene chosen for comparison (Table 3), salinity has both reduced and increased, depending on the shire and timeframe chosen.

Table 3: Comparison of saline area (1979, 1989, 1995) for five shires in the Kellerberrin Scene.

Shires	ABS (1979)	ABS (1989)*	Land Monitor 1989**	Land Monitor 1995**
Tammin	5692	9507 (9.26)	7492 (6.8)	8417 (7.6)
Trayning	1584	3155 (2.62)	6750 (4.1)	7577 (4.6)
Kellerberrin	4057	5568 (3.45)	11580 (6.0)	11964 (6.2)
Bruce Rock	5066	6960 (2.92)	11517 (4.2)	12609 (4.6)
Merredin	3443	5450 (1.98)	7537 (2.3)	9138 (2.8)

* Shire areas as reported by George (1990)
** Figures in brackets are percent change since 1979 census.

Table 4: Draft estimates of the area of land within the Kellerberrin 'Land Monitor' satellite image that have a high probability of having a shallow watertable at equilibrium if no salinity management is undertaken and current trends in groundwater levels continue. Data is reported in four classes (0.5–2.0 m) as height above the lowest point in the valley.

Shire	Upland Areas*	Shallow watertable with Height Above (ha)	*% Upland*	Height Above (ha)	Height Above (ha)	Height Above (ha)	Total (ha)	*% Total*
		0.5 m	*% 0.5*	1.0 m	1.5 m	2 m	All **(< 2m)	All
Merredin	232961	63359	*19*	14151	10491	8430	96431	*29.3*
Nungarin	63226	37023	*32*	7148	5035	3872	53078	*45.6*
Bruce Rock	180057	60193	*22*	14612	9952	7702	92459	*33.9*
Trayning	108191	39227	*24*	7709	5574	4493	57003	*34.5*
Kellerberrin	126368	43474	*23*	9637	6707	5366	65184	*34.0*
Corrigin	205923	35618	*13*	10923	8404	6943	61888	*23.1*
Tammin	72481	24384	*22*	6299	4060	3057	37800	*34.3*
Wyalkatchem	100608	44383	*28*	6347	4581	3623	58934	*36.9*
Quairading	136405	44878	*22*	10410	5859	4093	65240	*32.4*
Dowerin	124477	42869	*23*	8091	5951	4913	61824	*33.2*
	1350696	**435408**	***22.8***	**95327**	**66614**	**52492**	**649841**	***34***

* Includes areas with low probability of a shallow watertable
** Includes all areas with a higher probability of a shallow watertable; includes all currently saline land.
Based on local government boundaries provide by DOLA.

What proportion is at risk of salinisation?

Several methods have been used to *estimate* the likely future extent of *salinity*. Anon (1988) projected trends from the ABS data and also estimated the area of the valleys in the Wheatbelt to suggest a range of between 10 and 20%. Ferdowsian *et al*. (1996) used a range of methods, principally surveys, rate of watertable rise and landform type, and concluded that approximately 33% of the Wheatbelt landscape were at risk. In 2001, Short & McConnell used regional soils maps and groundwater trends to estimate the likely area of shallow watertables at equilibrium (~8 M ha). In 2001, as part of the Land Monitor project, estimates by regional hydrologists once again formed the basis of developing a means to predict areas that *at equilibrium exhibit a high probability of having a shallow watertable if hydrologic* *current trends continue*. The technique relies on derivatives from the high-resolution digital elevation models (called *height above* which is essentially topographically low areas in valleys) which have been compared with hydrologists' estimates. Four zones (< 0.5 m, 1.0 m, 1.5 m, 2.0 m) have been classified on the basis of height above areas of low elevation. While not *salinity risk* maps, the products allow a first approximation of the areas which are low in the landscape and which are likely to develop shallow watertables at equilibrium.

A preliminary estimate of the area with a high probability of having a shallow watertable at equilibrium was derived for the Kellerberrin satellite image (Table 4). The total area analysed is 2 M ha, covering 10 Shires. An area of 435,408 ha (22.8%) has been classified as at risk of future shallow watertables (< 0.5 m) and approximately 34% of the area is within 2.0 m. Shires with the greatest area predicted to have a shallow watertable are Wyalkatchem and Nungarin, while Corrigin and Merredin have the least. These estimates, which include all land that currently has a shallow watertable (primary salinity and dryland salinity), are similar to that derived by Ferdowsian *et al*. (1996). However by contrast, the new data allows a better estimate of areas at higher (0.5 m) and lower risk, within areas of a shallow watertable. More information at the paddock scale is required to further refine these indications of risk.

Given the nature of the groundwater systems and resultant dryland salinity, it is necessary to consider the natural landscape and what functions groundwater discharge landforms played in establishing a prior water balance and saline ecology before reviewing options for its management.

PLAYAS (SALT LAKES)

Palaeohydrology and changing hydrodynamics in wheatbelt valleys

Groundwater discharge and salinity are not new to Western Australia. For at least 0.7 M years, calcareous and saline soils have occurred in south-eastern and south-western Australia (Bowler *et al*. 1976). Reconstruction of the palaeohydrology of playas in north-western Victoria by Bowler *et al*. (1976) and Bowler & Teller (1986) over the past 80,000 years suggest that there have been at least four watertable maxima (36,000, 24,000, 6,000 and 1,000 yr BP) during this period. The pollen record also shows that during these climate phases the distribution of vegetation changed (Bowler *et al.* 1976). Combined pollen and geomorphic evidence shows that during periods of elevated watertable levels, salinity developed across land previously covered by perennial woody vegetation (Macumber 1978). In Western Australia, where the situation is less clear as few detailed studies have been conducted, radiocarbon dating by Bowler (1976) postulated a short-lived dune-building phase (15,000 to 20,000 BP) associated with major landscape aridity and potentially saline conditions.

Climate induced hydrologic change, particularly watertable and salinity fluctuations are also likely to have been responsible for the unique suite of landforms still recognisable in the wheatbelt valleys. Valley landforms such as playas, lunettes and widespread parnas are related to the redistribution of sediment, salt and water during arid periods (De Dekker 1988). Similarly, vegetation has adapted to and perhaps modified these patterns. At one extreme, playas are a very obvious form of discharge and may represent a window into the groundwater systems (e.g. salt lakes). At the other, they may be a marker reflecting the groundwater and salinity status of a previous climate and associated hydrological period.

At least five types of discharge landforms can be seen in the landscape: dry claypans, vegetated claypans, large salt lakes, isolated playas and salt lake 'fields' (called 'Boinkas' by Macumber 1991). Dry claypans and vegetated claypans are common in mid to upper catchment positions, particularly in the Eastern and Southern Wheatbelt, where they occur tens of kilometers from existing saline areas. They have been demonstrated to have a relatively deep and rising watertable (George *et al*. 1991) and in many but not all cases, represent markers of a previous climatic phase when watertables were higher.

Larger salt lakes and isolated playas are common and may have several forms. Large lakes such as Lake Brown and Lake Moore have extremely flat floors that evaporate surface and groundwater, depending on antecedent conditions. These lakes often give the appearance of being 'full' after light rain and soon after may be partially covered in halite efflorescence. Similarly, individual playas can also appear to have large volumes of storage in periods of high discharge and low evaporation, with some lakes appearing to empty and fill on a daily basis. In these playas, groundwater is strongly connected via the edge of the lake and respond to barometric and related affects.

Finally, large 'lake fields' or boinkas occur in the Eastern and South-Eastern Wheatbelt, where primary salinity or 'natural' groundwater discharge features are common. Lake chains such as Lake Grace and Lake King and 'lakes' areas north-east of Esperance are examples of these systems.

Playa formation remains subject to speculation; however there are common elements in most hypotheses. Playas occur in arid environments where groundwaters are shallow. They appear to be initiated at a point of impounded surface flow (such as could be due to differential compacting of sediments or geological barriers). They experience deflation following denudation (due to phases of aridity and salinisation), there remains a supply of sediment, regular inundation (prevents vegetation colonising the areas) and there is sufficient erosive capacity for its continued removal (particularly wind).

Killigrew & Gilkes (1974) reviewed the geomorphology of 600 Wheatbelt and Goldfields playas, most with an area of 0.05 km^2. They found that the orientation of the lakes varied from north to south within the Wheatbelt, that sediment moved in littoral currents and that playa features display equilibrium with contemporary fluvio-aeolian processes. In other words, given initiation, flooding frequencies shaped and orientated playas. However, Bowler (1976) and co-workers observed that the current size of lakes is much less than that which occurred previously. In Western Australia, most playas have characteristic lunette fields and strand lines of lakes, indicating that current lakes are perhaps only 50% the size they were at the onset of the last dune building phase (< 20,000 BP), e.g. Lake Toolibin and Taarblin (George & Dogramaci, 2000).

Groundwater discharge from playas takes place by passive mechanisms, e.g. evaporation. However in some lakes, groundwater flow can be observed as it issues from the aquifer around the circumference of the lake, especially from areas of highest adjacent gradient. Macumber (1991) identified that lakes in southern Australia, particularly larger systems, developed seepage faces that resulted from groundwaters being driven up salinity or 'density ramps' beneath the lake. He showed that the majority of evaporation occurred towards the floor of the lake and 'reflux' (density driven downward flux of brines to deep sediments) of brines occurred to the aquifer below.

Unfortunately, few playas have been studied in the Wheatbelt; however in the Goldfields several playas have been studied in the process of extracting minerals. Most of the information is the subject of 'commercial in confidence' reports but several publications have been made on palaeorivers and their potential impact on the playas. Examples of relevant articles are Turner *et al*. (1992), McArthur *et al*. (1989) Timms (1992) and the thesis by Johnson (2000). Unpublished work at Lake Carey, south of Laverton suggests that Lake Carey does not overlay palaeochannels, which are to the east of the main playa. An order of magnitude mass balance suggests that the hydrological interaction between the two is small and that the key components in the size and form of the playa are more to do with surface runoff and interactions with the superficial groundwater. The playa and its sediments (~100 metres to the basement) act as a sink or reservoir for salt. The salt load in the sediment of the playa was equivalent to 40,000 years of salt load from rainfall. This is a similar figure to what was calculated for wheatbelt environments. The goldfield playas tend to have a much higher island to surface area ratio than the wheatbelt playas with many of the islands formed by arid-phase sedimentary processes and maintained by current fluvial and aeolian events.

Playas offer an opportunity for the storage of episodic flood runoff and drainage waters. The impact on the groundwater hydrology of lakes and the surrounding landscape (salinity risk) has not been adequately studied. However comparative studies of small farm dams have shown that leakage (even if small) causes a groundwater mound to develop, reducing the hydraulic gradient and increasing groundwater discharge nearby. Full playas may also affect watertables in this way. However the impact will be lessened if the hydroperiod (inundation time and frequency) is short, the salinity is relatively low, waterlevels remain below the 'active discharge zone' surrounding the lake and surface water management mechanisms are in place (overflow, bypass and similar structures).

Ecology of playas

Until relatively recently, salt lakes and pans, salt marshes and coastal samphire flats have been perceived as undesirable places, full of mosquitoes, unsuitable for farming and only useful for rubbish or fill and associated housing sub-divisions. Encroaching salinisation is impacting natural remnants (George *et al*. 1995) and the degradation to naturally saline but highly variable ecosystems has also increased. With a shrinking conservation estate, these 'saline wetlands' are now beginning to be seen as more important vestiges of wheatbelt ecology, to be protected and preserved.

While not as diverse in flora and fauna as fresh water wetlands, saline wetlands are nevertheless parts of ecosystems, with life cycling according to the availability of water. For instance, crustal 'blisters' formed by algae on the surface of the Lake Minigwal playa (east of Kalgoorlie), provide shelter for millions of lake spiders, which in turn are prey for Dunnarts (*Sminthopsis sp.)* and salt lake lizards. Most of the macro and micro flora and fauna living in and around saline wetlands will only reproduce when the wetland water or surrounding soils reach the combination of salinity and temperature that trigger reproduction. In many species (of both flora and fauna) there is only a narrow 'window' when all factors are suitable.

As groundwater levels rise the water balance of wetlands change. An increased groundwater and surface flow will change the balance from the catchment into the wetland, resulting in a greater accumulation of salts. These changes will increase the time that the wetland is flooded causing the composition of plants growing at the wetlands to change or disappear altogether. Most plants have a very specific period of time for which they can be flooded before they suffer from root rot or chloride toxicity. This period of flooding that can be tolerated is termed 'hydroperiod'. The accumulation of salt in the wetland will raise the salinity of the water when the wetland is wet. This will also impact on the plant and animal composition as most organisms have a maximum salinity they can tolerate before dying of dehydration and a lesser salinity in which they can successfully reproduce. It is possible to have a scenario where a plant or animal can survive well but the life cycle is interrupted and recruitment does not occur. The brine shrimp is a good example where an animal requires a *low* salinity approaching 30,000 mg/L to reproduce but can tolerate quite high salinities as an adult (~150,000 mg/L). Brine shrimp also provides an example of where a shift in salinity is changing species composition in wheatbelt wetlands. Historically the brine shrimp genus of *Artemia* was rarely found in wheatbelt wetlands and the genus *Parartemia* was dominant. The difference was so marked that it was thought that Artemia were an introduced range of species. With salinisation of wetlands, *Artemia* are being found more often. It is known that *Artemia* can tolerate a higher salinity range than *Parartemia* and most likely have a better reproductive strategy for wetlands at a higher salinity and longer hydroperiod. It is speculated that these properties allow the *Artemia* to out-compete *Parartemia* in the current wheatbelt environment, whereas the previous salinity regime favoured *Parartemia*.

Most saline wetlands are poorly studied with many species of plant and animals lacking description in the scientific literature. These plants and animals have a role in conservation, and it is most likely that their environment will irreversibly change and species become extinct before that role is understood.

RESOURCE OPTIONS

This paper defines the term *resource* as a usable commodity. In this sense saline water is a potential resource and there are a number of encouraging options for its use. These options have been dealt with in a number of publications and reports such as Ahmed (2000) and PPK (2001) and an unpublished report to CALM (Actis 1999). This review does not cover uses of saline land; for this the reader is referred to the Opportunities Productive Use of Salinity Review (PPK 2001). In this paper we focus only on uses of saline groundwater (> 30,000 mg/L).

Groundwater in the wheatbelt valleys is the most recognisable hazard, but is a plentiful, if saline resource. Approximately 30% of the 15 M ha area of cleared farmland which lie inside the clearing line and within the 600 mm/yr rainfall isohyet, occurs within these valley systems. Given average recharge rates of 20 mm/yr and an area of 5 M ha, average annual recharge equates to a volume on 1,000 GL (1 Gigalitre is one billion litres and Sydney harbour contains 510 GL). If fresh, for example this would equate to approximately 1 megalitre (~1000 mm or one million litres per hectare), a volume able to be irrigated on 100,000 ha of land. By way of comparison, this is about ten times the volume used in the south-west irrigation area to irrigate perennial pastures.

In addition to the annual direct recharge, a supplementary volume could be mined from storage and induced lateral flow. Given a specific yield on 0.05, an additional 50 mm could be available from each metre of regolith from which the watertable was lowered, plus an unknown volume of lateral flow. This equates to another 100,000 GL of storage if the average regolith thickness is 40 m. Lateral flow is difficult to calculate. Using an estimate of 10 mm of recharge from the remaining area, 10 M ha, an equivalent volume of 1000 GL is assumed.

Given an average bore yield of 300 kL/day (0.1 GL/yr), typical of valley palaeodrainages (but not tributary valleys), and the estimates above, annual recharge supplying the valley aquifers could be negated by between 10,000 and 20,000 bores. If pumped, this volume of water would require an area of 1000 km^2 to be evaporated (if net evaporation was at a rate of 1000 mm/yr). To reduce the large amount of groundwater already in storage, many more wells would be required (perhaps 10-100 times the above number). If lower yielding wells (100 kL/day) were included in the calculations, as would be required given palaeodrainage sediments occupy a relatively small percentage of valleys, the number of wells required would again increase.

The salt resource available is dependent on finding suitable sites for extraction. Simplistically, with average groundwater salinities of the order of 50,000 mg/L (since palaeochannels contain the most saline groundwaters in wheatbelt valleys), removal of 1000 GL per annum would provide approximately 50 M tonnes of total salts per year or approximately 25 M tonnes of commercially available sodium chloride. This is twice the total sodium chloride production for Australia, and similar to the Nation's wheat harvest, both of which Western Australia produce the most.

Options for the use of water and salt

Most of the options for the use of saline water can be undertaken concurrently as there is usually considerable synergy between them. The types of activities that could use saline water include aquaculture, energy and mineral harvesting. The synergy is mainly sharing the large capital cost for the infrastructure (e.g. pumping bores) and technology needed, and providing short-term cash flow. The most capital-intensive step in using saline water is to accumulate the water at a common location in sufficient quantities to be useful. Once the water has been accumulated in a constructed basin or natural lake, it is a much more useful resource.

Aquaculture has the greatest potential for infrastructure cost recovery (Actis 1999). It generates a rapid return for a relatively small investment in capital and volume of water needed. Depending on the salinity of the water recovered from groundwater interception schemes, various finfish can be cultured such as trout through to the more salt tolerant fish such as *Barramundi*, *Bream* and *Snapper* (Lawrence 1996). As the saline water (brine) evaporates and in cases where the water is too saline for the above species, more salt tolerant species can be cultivated. These include brine shrimp (*Parartemia* and *Artemia* species) and algae such as *Dunaliella*, *Aphnothece* and *Spirulina*. Brine shrimp can be cultivated up to five times seawater concentration, while *Dunaliella* are best cultivated at halite saturation or five-time seawater for their *betacarotene* (Table 5). All of these species are being cultivated profitably around the world and several local examples exist. For most, the technology for growing and harvesting the species is known, if not immediately available.

For finfish culture the main constraint is that the water must have a low nutrient and metal concentration. The water requirements are relatively low and a viable venture can be built about a water flow of approximately 10 kL per day depending on water quality and fish species. Finfish aquaculture has the advantage of being able to be expanded in increments, allowing the operators to build in skill and experience. Also the relatively rapid return ensures a cash flow within months, assuming nothing goes wrong.

The problem with finfish culture is that like all agriculture ventures, it requires attention to the health and marketing of the animal. A number of health regulations must be observed. Finfish culture has a well-deserved reputation for financial disasters, as it is an intensive farming venture that requires a high level of husbandry and appropriate technical skills. Culturing of finfish does not remove saline water from the environment and the wastewater still needs to be disposed. The water that has been used for growing fish is often high in nutrients and possibly fish pathogens, and must be disposed of in an environmentally sound manner. The salinity range for culturing fish is relatively small and not many species can be grown profitably at salinities much greater than seawater.

In general, crustacea fall into a similar category as finfish with the exception of brine shrimp. This group of animals grows well in very high salinities, often with high metal concentrations, and of course, since they are plankton feeders, thrives on a high nutrient concentration as they eat the algae that utilise the nutrients. There is a lot of information on brine shrimp, which is a very profitable culture species at the moment because of the collapse of the natural harvest in America. The market is not small but quite specific with a large export component. For this reason it is seen to be vulnerable to marketing issues. There are several small-scale ventures in Australia.

Algae are another type of culturing that has been successful in Australia. *Dunaliella salina is* one success story with the Australian ventures providing a large part of the world market for beta-carotene. It is not a venture for the small producers, as it requires a large capital investment with support from

Table 5: Temperature and salinity parameters for a number of species of fish crustaceans and molluscs (modified from Lawrence 1996).

SPECIES	SALINITY (mg/L x 1000)	TEMPERATURE	REFERENCE
BRINE SHRIMP *Artemia salina/Parartemia sp.*	31–340	6–35	Persoone *et al*. (1980)
BARRAMUNDI *Lates calcarifer*	0–70	16–35	Shelley (1993);. Coleman (pers.com)
RED SNAPPER *Pagrus auratus*	16–60	13–28	Anon. (1995)
BLACK BREAM *Acanthopagrux butcheri*	3–60	8–33	Lenanton (1976); Sudmeyer *et al*. (1999)
GROUPER *Epinephelus tauvina*	23–45	18–31	Akatsu *et al*. (1983)
MARRON *Cherax tenuimanus*	0–6	0–30	Morrissy *et al*. (1990); Morrissy (1992)
MILK FISH *Chanos chanos*	0.5–158	25–36	Schuster (1960)
MULLET *Mugil cephalux*	0–75	3–35	Murashige *et al*. (1991); Walsh *et al*. (1991)
GIANT TIGER PRAWN *Penaeux monodon*	13–33	10–25	Tseng (1987)
RAINBOW TROUT *Oncorhynchus mykiss*	0–35	10–22	Sedgwick (1985); Bromage & Shepherd (1990)
TILAPIA *Oreochromis mossambicus*	0–60	8–42	Kueltz & Onke (1993)
YABBIES *Cherax albidus*	0–8	0–36	Morrissy & Cassells (1992); Mills & Geddes (1980)

specialised and experienced people. As for most micro algae ventures the difficulty is not growing the small plant but harvesting it and processing the fine chemicals that make them so valuable. The following (Table 6) is a list of potential algae species that could be cultured in saline water.

Most algae species require an extensive area for culturing with a high level of solar radiation. An extensive area also means that evaporation is high, so a large supply of relatively low salinity 'make up' water is needed to maintain the salinity of grow out ponds during high evaporation. This is not normally a problem for *Dunaliella salina* that is cultured in water up to 300,000 mg/L and where seawater concentration makeup water is often effective in maintaining a constant salinity in the grow out ponds. It is more of an issue with species cultured at lower salinities where an effective make up water needs to be approaching potable water standards to be useful. It is not practical to grow a species that can only tolerate a salinity of 50,000 mg/L when the only water available in large quantities is at 35,000 mg/L. Algae culture uses a large amount of water as the culture areas need to be in the hectare range or greater to be commercial. The commercial *Dunaliella salina* farms are several hundred hectares in size. The water used for algae culture needs a high concentration of nutrients and can tolerate a high concentration of metals, although some metals will tie up valuable nutrients.

Table 6: Salinity and market for various algae (Modified from Borowitzka 1997).

Alga	Product or Market	Salinity (mg/L)	Status
Microalga			
Dunaliella salina	Beta-carotene	>200,000	Commercial
Aphanothece halophytica	Polysaccharides, pigments	>200,000	R&D
Isochrysis, Tetraselmis, etc.	Aquaculture feed	~30,000	Produced in hatcheries
Spirulina platensis	Health food	~30,000	Commercial overseas
Porphyridium cruentum	Polysaccharides, pigments	~30,000	R&D
Macroalga			
Gracilaria spp.	Aquaculture feed	~30,000	Some overseas culture
Ulva spp.	Abalone feed	~30,000	Some overseas culture
Caulerpa spp.	Luxury food (Japan)	~30,000	Commercial overseas (Philippines)

Aquaculture may provide a useful cash flow and a means to use the water while it evaporates and the salts concentrate, but it does not remove salt from the environment. By contrast mineral extraction is the most effective method of removing salts. The term 'salts' is used deliberately because it is often overlooked that the saline water is made up of salts other than sodium chloride (halite) or common salt. Halite makes up over 50% of the salts in most brines but not all of this is recoverable. Other minerals include magnesium and potassium salts. Halite or common salt is best extracted by allowing the brine to evaporate to saturation (at near ten times seawater concentration). The saturated brine is then pumped or gravitates into specially prepared ponds. After the crystals of salt have formed they are then mechanically harvested and processed. Processing may include washing, drying and sorting before being bagged ready for sale. The remaining minerals such as the magnesium salts can then be extracted using a patented process such as SAL-PROC (Ahmed *et al*. 2000) or sold as a road base additive or dust suppressant. Additional products might include calcium chloride, magnesium hydroxide, gypsum and derivatives. Several small halite-based ventures have already been established in the Wheatbelt (e.g. Kalannie, Corrigin) and more are proposed.

Other aspects of using brine being researched include the generation of electricity from solar ponds (Ahmed *et al*. 2000) and desalinisation. Neither of these two concepts is new but methods of applying them are constantly been reviewed. For example several new desalinisation companies have recently been established, and cost of desalinisation of wheatbelt valley water has reduced to about $1 kilolitre (e.g. Merredin scheme) and $0.4 has been mooted as realistic given new processes.

In order for solar energy generation to be a successful option the following condition need to be satisfied (from PPK 2001):

- Local reliance on expensive fuels such as electricity, fuel oil or liquefied petroleum gas (LPG)
- Demand for heat in the 40–80 °C temperature range
- A sufficient supply of saline water and salt, preferably available locally
- Availability of relatively flat land on which to construct the solar pond
- Relatively high annual average solar radiation and evaporation
- Low wind (or investments in reducing turbulence).

The generation of heat requires a large pond with a salinity gradient from the top (ambient temperature; 20ºC) to bottom (60–90ºC). The salinity gradient is maintained by adding salt (brines; 300,000 mg/L) to the bottom layer and freshwater (normal salinity groundwater; say 30,000 mg/L) to the surface as it evaporates. It is difficult to maintain the salinity gradient under high wind and subsequent wave action. The brine must also remain clear and chemicals are needed to kill algae. The more saline bottom layer retains energy as heat during the day. The hot brine can be used to directly replace other heat sources or can be converted to electricity. Low-grade heat can be used in a number of applications to heat or chill items. One of the main advantages of solar ponds over other alternative energy systems is that there is a degree of energy storage intrinsic to the operation. That is energy generated during the day will be stored at least through the night. Compare this with wind or solar energy, which suffer from the vagaries of wind strength and diurnal light. It should also be possible to predict the energy production for a period in advance. Both of these points are important management considerations in the use and conservation of energy. In Australia, solar ponds operate in central Australia and a 0.3 ha experimental pond is being constructed in Victoria (Pyramid Hill).

There are advantages to match solar pond energy with desalinisation. Disposal of waste brine from a desalinisation unit can be used in the solar energy plant. It has been estimated that a ten-hectare solar energy salt pond will generate 200,000 KWh of low-grade energy ($130,000) per year in northern Victoria at a capital cost of $300,000 (Akbarzadeh & Earl 1992). The operating costs have not been stated but they would be significant and in the same magnitude as the energy replacement cost.

A comprehensive extraction scenario is possible and could be a profitable method of extracting and disposing groundwater in an environmentally sensitive way. The aquaculture would be the most profitable, at least in the short term, although significant time, money and effort would be needed to create a synergistic project. The reality is also that the mineral extraction processes require a massive input of brine to be profitable. For instance, profitable salt production would need an annual production of 15,000 tonnes (~750ML of seawater) or more. It is possible to be profitable with less production by targeting niche markets, but these markets are limited. Standard SAL-PROC processes require even more brine to generate a viable business and estimates place the brine supply for a viable production plant at more than 2,000 ML per annum. However SAP-PROC PSP plants, portable systems capable of extracting salts from brine stores, may provide a viable alternative for smaller pumping systems (e.g. rural towns). It is currently not known whether these small plants are profitable, but they do provide a useful method of removing salt in an environmentally sound way that may be cost neutral.

The transition from resource to product depends on the ability of the producer to convert the resource to another commodity. This is an important distinction as all too often a resource is described in favorable terms, when in reality producing a marketable product is much more difficult. For instance salt is readily produced using the lowest input of technology; it happens naturally on farmland after all. The marginal cost of salt from a medium size producer is about $A5–10 per tonne. Quality salt can be bought in bulk for less than $A60 per tonne. The market for salt is for a product that is over 99.9% pure and of a particular size. To achieve this purity the salt must be processed mechanically and the crystals must be very robust. Experience has shown that the larger purer crystals have the best chance of being commercially viable. Some processes generate a better chemical quality product such as some natural lakes and the SAL-PROC process, but the crystals still require cleaning and drying. Given these low values any cost or loss through processing can rapidly make a product non-commercial.

DISCUSSION

Salinity management

Both *in situ* rainfall and lateral flows from tributary sediments and hillslope aquifers recharge wheatbelt valleys. The relative mix and influence of these sources on the extent of salinity is both spatially and temporally variable. However it is apparent from several studies (McFarlane *et al*. 1989; George *et al*. 1991; Salama 1997) that farmers who principally manage recharge to valley sedimentary aquifers, have a chance of mitigating the *impacts* of salinity on their property by acting unilaterally.

Management options for salinity have recently been tested using numerical models (as field verification is extremely difficult and requires a longer-term commitment) and by review of existing field examples. George *et al*. (2001) showed from use of the Flowtube model that recharge reductions of greater than 50% were required to significantly alter the likely rate of watertable rise in most wheatbelt type (low gradient) catchments. In many examples however (e.g. alley and phase farming with a perennial such as lucerne) reductions of this magnitude only reduced the rate of rise, thereby buying time, but did not substantially reduce the potential risk. Of the options tested, only engineering provided significant *potential* long-term impacts for valleys. While large plantations within valleys may potentially create temporary reductions in the rate of watertable rise, high groundwater salinities and unfavorable soils represent significant limits to effectiveness of this option. The relative impact of a range of modelled treatments is summarised in Figure 2.

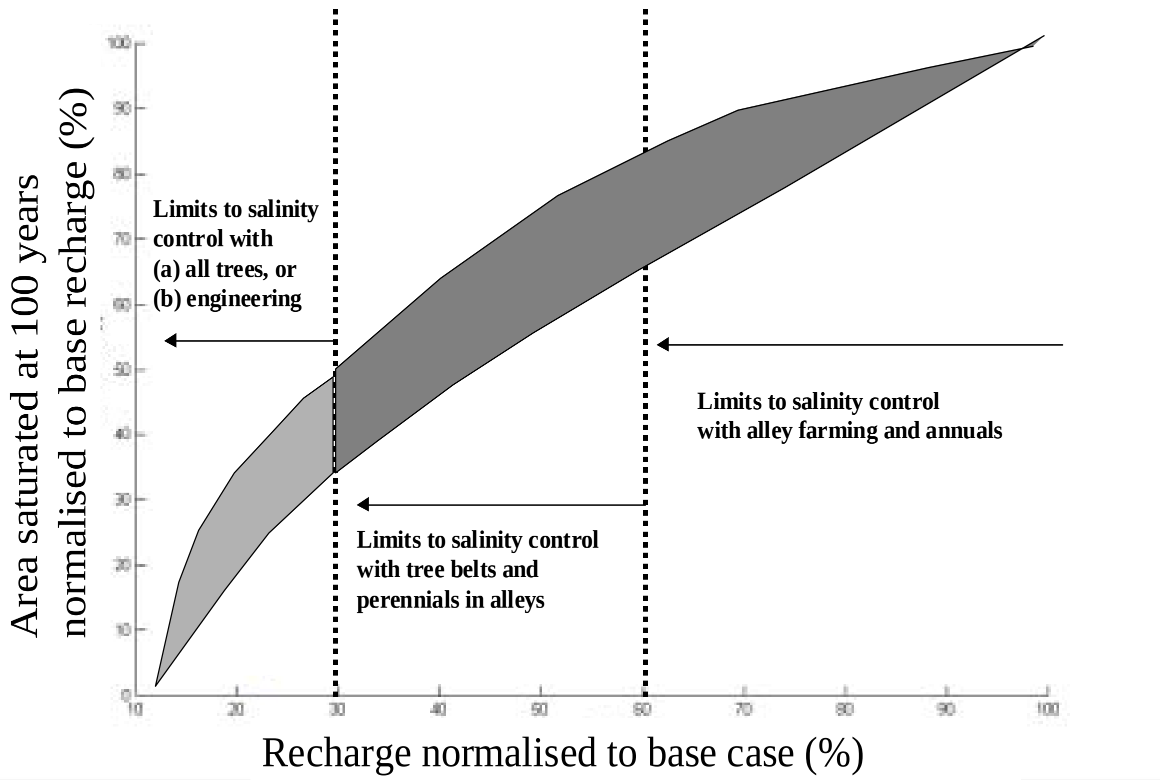


Figure 2: A range of eleven treatments modelled using Flowtube showed that for relatively large reductions in recharge, much less watertable control (% of the Flowtube saturated) and hence salinity management was gained (George *et al*. 2001). Farming systems which included annuals did not significantly reduce recharge, while modelled engineering or complete revegetation reduced the area with a shallow watertable the most. Alleys systems, which included phase farming systems with lucerne, were also effective.

Similarly (George *et al*. 1999) showed that monitored examples of revegetation had little or no impact on watertables until a substantial area of the groundwater catchment had been planted. Their impact in lower slopes and in larger aquifer systems (e.g. valley aquifers) was less than for hillside (local) aquifers.

Valley salinity and its management are therefore dependent on the relative mix of treatments adopted and the timeframe under consideration. Given recharge management options (see Porter *et al*., this volume) are unlikely to attain a scale or extent within the timeframes available, a parallel management approach focussed on valley recharge minimisation, increased discharge or re-evaluation of the saline resources, are required.

Recharge to valleys can be lessened by increased plant water use and surface water management; however to date, the impact of these actions of watertables has yet to be clearly documented. Despite this, many farmers have attempted waterlogging control in valleys using banks, drains and vegetation. Indications from these works shows that where groundwater levels are near equilibrium, and discharge is increased or maintained, plant responses (improved cover and species populations) can be expected if even modest watertable impacts are achieved. Examples of this included saltbush (see Lloyd, this volume) and earthworks (drains and banks). Best results occur if management is commenced prior to severe salinisation of the site.

However, the greatest impact (but highly variable) on watertables within wheatbelt valleys has been demonstrated by direct engineering intervention, where deep open drains and groundwater pumping has been used. Coles *et al*. (1999) have reviewed some of the field experiments known to date, while many examples are currently being documented or established, principally by farmers (see Ali & Coles, this volume). In general this work shows that drainage increases lateral flows and salt leaching lessens the impacts of waterlogging. While watertables reductions are highly variable (less than 100 m from the drains and of the order of 0.5 m depth), it is apparent that the response of plants to increased drainage is significant in *some* areas.

The effects of drainage can be further understood when seen in context with wheatbelt valley hydrogeology. As discussed above, valley soils act as both recharge and discharge areas, potentially changing state between seasons. In addition, the flux of groundwater in many cases is small (e.g. 80 mm/yr), and can be spatially variable, being subject to local topographic and soil (aquifer) controls. A high interannual variability in discharge rate and low catchment saltflux (e.g. Input:Output ratio of 1 for Toolibin is due to relatively deep watertables) leads to the conclusion that in flat valley areas, salt discharge to the drainage systems is likely to be lower than first thought and is probably driven largely by episodic events rather than annual losses. Only large flood events (when leaching occurs of stored salt in the unsaturated zone), and structures that enhance lateral flows (drainage) are likely to remove the salt from the soil profiles.

Furthermore, in the context of plant responses, the authors know of many cases where sea barley grass areas have been removed from cropping only to find that some years later, substantial barley crops have been harvested. This appears in spite of shallow watertables of less than 1–2 m. This situation appears after lower than average rainfall periods and is more common in the middle of valleys, downslope of valley constrictions and associated discharge areas and where sandy surfaced soils dominate.

Clearly, however, very large wheatbelt valleys maintain shallow watertables, high discharge rates and evaporative fluxes that prevent most plant growth. In these areas, especially at the break of slope (where discharge rates are greatest) or on soils that cannot be seasonally leached, salinity control requires direct intervention (engineering, saltland agronomy) or conservation.

Hydrology and salinity

Dryland salinity is a unique environmental issue, with significant ramifications. However despite having being acknowledged long ago (Wood 1924), it is only recently that salinity has become a major issue with large private and public investments being made in research, development and implementation. Determining appropriate research and development to salinity is also difficult, with a spectrum of opinion in terms of management outcomes promulgated (restore to pristine ecological functionality, restore for annual crops, or change to saltland uses). However, despite this, and after approximately twenty years of research and experimentation by wheatbelt farmers and scientists (following on from earlier work by Bettenay *et al*. 1964 and Smith 1962), we can make the following generalisations about the hydrology and salinity of wheatbelt valleys:

- We know hydrologic change following clearing has been substantial, but has precedent.
- We know sediments of differing permeability and salinity underlie wheatbelt valleys.
- We know some high yielding (0.1 GL/yr) palaeochannels exist, but not their exact location.
- We know watertables are rising at rates of 0.1–0.3 m/yr, especially in tributaries.
- We know dryland salinity is spreading at rates of about 0.3–1% year, especially in valleys.
- We know recharge has to be reduced by greater than 50% to reduce this rate of spread.
- We know without intervention watertables will come to within 2 m of most valley soils.
- We know recharge control options are not available at the scale required.
- We know discharge options exist, but their impact is uncertain and costs high.
- We know engineering-based options are worthy of consideration and further testing.
- We know there is significant variability (of type and responsiveness) within and between valleys.
- We know of many examples of failed salinity control, and only a few that 'worked'.

However we can also make some generalisations about uncertainties in our knowledge:

- We have little quantitative data on recharge rates and its spatial variability.

- We are uncertain what discharge capacity exists in playas and new saline landforms.
- We cannot accurately predict the extent of salinity at a paddock scale.
- We require accurate hydraulic properties (especially specific yield) for aquifers.
- We have too few commercially attractive options for its management.
- We are unsure what impacts recharge reductions will have on the timing and extent of salinity.
- We do not have enough simple tools to use to guide assessment and adoption of options.
- We do not know the best designs and impacts of engineering options in sufficient detail.
- We have between 10 and perhaps 200 years before hydrologic equilibrium!

Given our knowledge of the groundwater hydrology and of the response of management systems, then the impetus should be on the development of engineering systems to protect assets and potentially, parallel investment in commercial options for saline land and water. In the medium to longer term, revegetation and related commercial opportunities will also arise that help sustain production in the uplands and potentially reduce the rate of spread of salinity. Determining the balance of investment will be difficult. The following summary may assist in developing criteria for assessing uses of saline groundwaters.

Opportunities from saline groundwater resources

The opportunities for the use of saline groundwater are varied in their application, economics, practicality, environmental impact and ability to remove salt from the environment. Table 7 summarises the relevant facts about each generic opportunity. A note of caution is that the success or failure of a venture will hinge mainly on the ability of the producer to market their product, and this parameter cannot be tabulated.

It is unlikely in the short term that a sole venture will be profitable and provide a method of removing salt from the environment. For example the SAL-PROC process is a combination of halite and non-halite mineral extraction and could operate more effectively if combined with desalinisation and/or energy production. There is a good opportunity for combination of ventures but it is likely that some cross subsidy will be required for them to be developed together. Most of these opportunities are represented by commercial ventures in Australia but rarely do they co-develop. The reason for this is that the best geographical, commercial and social location for one venture may not coincide with a compatible venture. *Dunaliella* farming is a good example. Cognis Pty Ltd has operated a *Dunaliella* farm in a limited relationship with Pacific Salt Pty Ltd in Whyalla for several decades. On the other side of the spectrum, a north-western salt producer has actively opposed the development of a new *Dunaliella* farm near it for a number of years. Corporate attitudes vary, as do the reasons for commercial decisions. It is thought that for a synergistic development to occur in the Western Australian Wheatbelt, common facilities such as a bore field must be developed and a large area of land be available or acquired using common (public) funds. The salt removal process must be constructed first. Once this structure is in place it would then be possible to solicit interest in compatible and perhaps more profitable ventures as adjuncts to the main halite extraction plant.

Wheatbelt valleys are unique landscapes with unique challenges. However despite the title of menace under which salinity is portrayed, and can be for landholders in many valleys, there are opportunities for its management, and potentially, the longer-term development of natural resources within new business and market frameworks. Unlike toxic pollutants that threaten to destroy agriculture elsewhere, saline water and land is not in itself unmanageable, especially in an environment that has seen climate induced salinity come and go and to a community which is beginning to see new opportunities. We need to challenge ourselves to seek a combination of approaches that maximises agricultural and environmental benefits, while minimising the risks. We also need to note that at worst, salinity will only impact a maximum of about 30% of wheatbelt catchments. We therefore need to focus on maintaining the productivity of the remaining 70% as well as the key assets at risk. Salinity management of our wheatbelt valleys represents an opportunity to catalyse political, community and scientific endeavour, by developing a shared goal and delivering outcomes by implementing realistic salinity management options and protecting the resource base for agriculture.

Table 7: Summary of alternative water uses

Venture	Economy	Practicality	Salt Removal	Salinity (mg/L)	Comments
Finfish	Good	Good	None	Lower salinity than 50,000	Small scale
Dunaliella	Good	Good	None	High salinity	High capital cost an impediment
Aphanothece	Unknown	Good	None	150 ppm	R&D needed to determine productivity
Other micro algae	Unknown	Unknown	None	<50 ppm	Many small niche markets
Non-halite chemicals	Moderate	Good	Yes: 50%	350,000 plus	Still in development, high capital cost
Energy	Medium	Good	None	High salinity; 300,000	Beneficial, but high capital cost. Cost reducing with new technology.
Halite	Poor to medium	Good	Yes: 50%	320,000	Low value common product, high capital cost
Desalinisation	Medium	Good	None	Fresher is better	Energy intensive, high capital cost, significant market development in progress

[1]A high capital cost is where it is estimated that cash flow is greater than minus $500,000 before full production.

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WATCHING THE RIVERS FLOW: HYDROLOGY OF THE WHEATBELT

Tom Hatton[1] and John Ruprecht[2]

ABSTRACT

The surface hydrology of Western Australian wheatbelt catchments is characterised by low gradients, high potential salt loads, and high variability in flows. It is also distinctive in the variability of the actual catchment area contributing to flows at the outlet in any given year. The flood event of January 2000 is highlighted as an example of the mercurial behaviour of these systems, in that the runoff originated from areas a great distance from the outlet, linking many lakes systems on the way. The condition and trend of these catchments is described, in particular the trends and impacts of nutrients, salt and flooding. While strategic revegetation and improved farm practice have the potential to reduce sediment and nutrient yields, it is argued that only appropriate engineering can significantly reduce the impacts of stream salinisation and flood risk.

INTRODUCTION

The rivers of the West Australian Wheatbelt are distinctive from rivers elsewhere in a number of significant ways, and pose unique challenges to the people that live in that region and those that live downstream. In this paper, we review the natural characteristics of these systems, the changes they have undergone since settlement, and forecast their future condition. Against a background of the needs and trends in regional sociology and economics, we consider the options for river management open to us.

Physical Setting

The region under consideration drains large portions of the South West Drainage Division of Western Australia (Mulcahy & Bettenay 1972), and comprises the drainage basins of the Swan-Avon River, the Moore-Hill Rivers/Yarra-Yarra/Ninghan system (also known as the Monger System, *sensu* Beard 1999), and the Blackwood River (Figure 1). Drainage Basins with some similarities to these also include Frankland-Gordon River, Kent River, upper Pallinup, Gairdner, Fitzgerald, Lort and Young rivers.

By far, the largest portion of this region drains *via* the Avon River into and through the Swan system. This particular catchment is also significant in that its health most directly impacts most West Australians, in that it flows through the City of Perth. Note that this catchment is roughly the size of Tasmania (12 million ha). The bulk of this paper is devoted to a consideration of wheatbelt valley hydrology in this particular catchment, although examples are drawn from other catchments where relevant.

Climate

The first distinctive feature of these rivers is that mean annual rainfall is highest at or near their outlets to the sea (900–1,200 mm), and lowest in their uppermost headwaters (less than 350 mm) (Figure 2). The climate is typically Mediterranean, with cool wet winters and hot dry summers. However, summer rainfall does occur from north-west cloudbands and less frequently from tropical depressions. The summer events are typically the most extreme rainfall events. The potential evaporation is the reverse of the rainfall, with 800-1,200 mm mean annual evaporation near the coast and over 2,000 mm in the most inland parts of the catchment.

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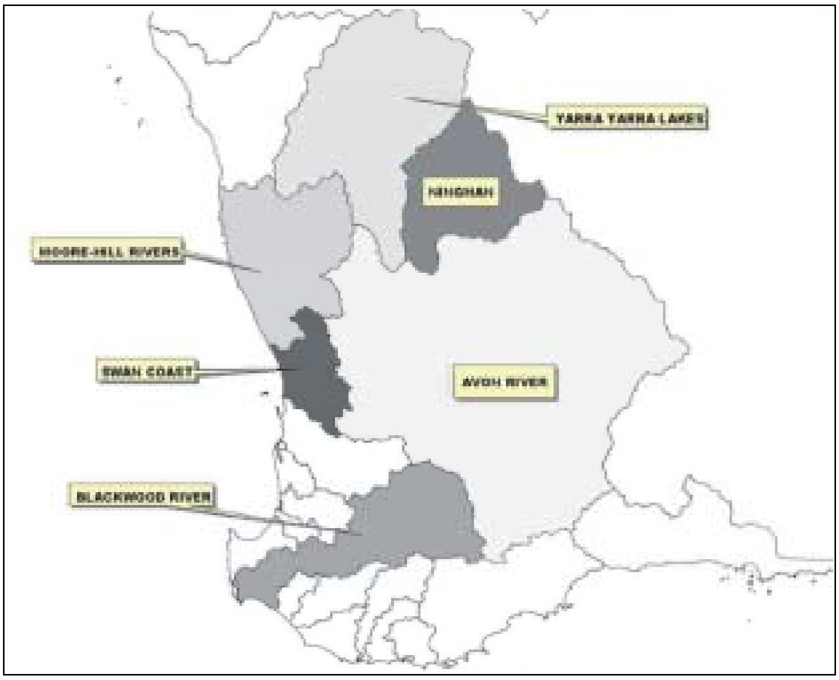

Figure 1: Drainage Basins of Western Australia strongly influenced by the surface hydrology of wheatbelt valleys. The Avon drains through to the Swan. The Ninghan basin potentially drains into the Yarra Yarra, which potentially flows through to the Moore River.

Figure 2: Mean annual rainfall isohyets for south-western Australia (from Pen 1999).

Since the mid 1970s annual rainfall for areas such as Narrogin have had below average conditions (Figure 3).

The number of wet years (Figure 4) has reduced significantly since the 1950s and since 1975 none has occurred for the Avon River. The number of wet years, defined as above the 1-in-10 year average recurrence interval has also reduced significantly in the last 50 years (Figure 4).

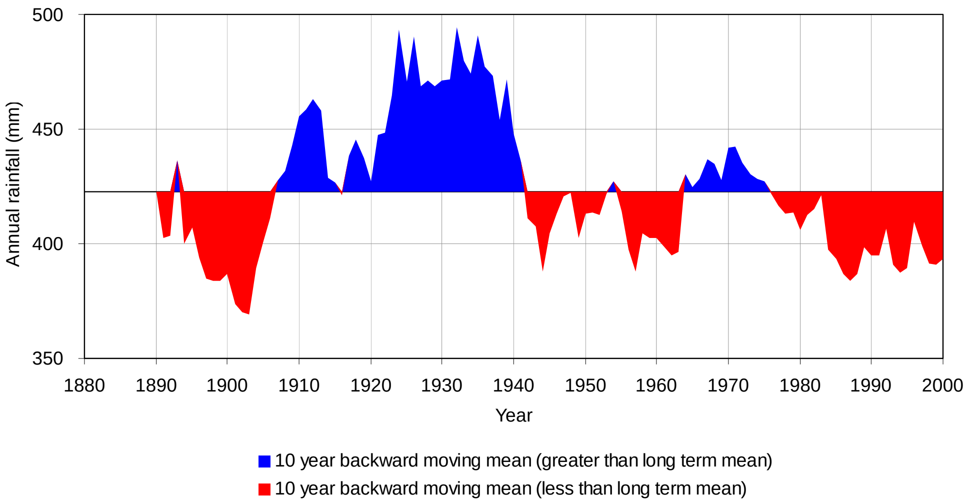

Figure 3: Decadal variability in rainfall for Narrogin Post Office.

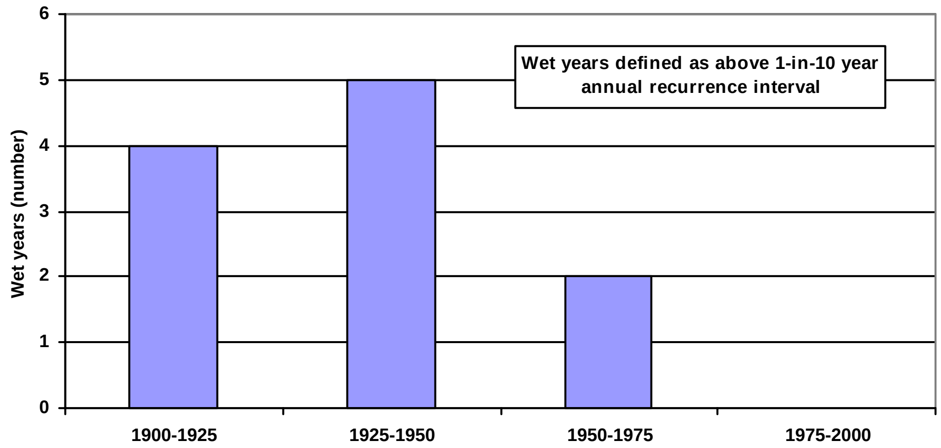

Figure 4: Wet years for the Narrogin Post Office in 25–year segments, based on annual rainfall.

The Drainage Network

The second distinctive feature of the Wheatbelt systems is the fact that their headwaters start out in an older landscape with remarkably low gradients, and the rivers do not steepen until they approach the younger parts of the system in the vicinity of the Meckering Line. The best and most recent treatments of the evolution of these rivers are in Salama (1994; 1997) and Beard (1999). The Lockhart-Pingrup River for instance, falls 51 m over 200 km (0.00026) from Lake Chinocup (near Pingrup) to the Caroline Gap; while the Yilgarn River to the Avon River at Toodyay falls 345 m over 420 km (0.00082), and then falls 140 m over only 90 km (0.0023) from Toodyay to the coast at Fremantle (Beard 1999). Salama (1997) and Beard (1999) estimated mean grades of 0.35 m km^{-1} and 0.38 m km^{-1} respectively for the Yilgarn River from head of channel to the confluence with the Avon. A key feature of this grade, however, is that it is interrupted by large, essentially flat playas that drop water from one to another when and if they overflow. Grades along the Lockhart and Pingrup rivers (the southern tributaries of Salt River) are very low (0.04 m/km and 0.24 m/km respectively), and from this Beard (1999) concluded that significant discharges are unlikely (however, see Flooding section below).

Unlike the valleys of most rivers, which usually broaden downstream, the valley of the Avon is wide near its source (77 km) and narrows to 5 km or less after Toodyay. These broad shallow valleys of the upper Avon are characteristic of the wheatbelt rivers.

The flatness of the bulk of the wheatbelt river systems leads to historic, and amusing, arguments regarding catchment boundaries, the putative connections between systems, and even which way water flows. It is essential to appreciate that these river systems do not all flow as one linked system except in the most extreme events. In the Blackwood catchment, the Coblinine River and Dongolocking Creek are two headwater streams draining to Lake Dumbleyung. This section of the river has very low grades, approximately 0.17 m/km. The combined drainage enters Lake Dumbleyung, which is a permanent salt lake that is said to have been dry before land clearing (Beard 1999). Since clearing, Lake Dumbleyung is thought to have overflowed into the Lower Blackwood only three times since the 1870s. The chains of (mostly dry) lakes form a series of local storages that in most years are not overtopped by the surface flows from upstream.

Commander *et al.* (2001, this proceedings) gives the geological history and background to the evolution of the wheatbelt systems, and George & Coleman (2001, this proceedings) provides a description of the hydrogeology with special reference to regolith salinity. The key feature of the latter issue is that the flat, inland portions of these catchments hold massive amounts of salt, accumulated as a result of atmospheric deposition of marine salts, low rainfall, the natural patterns of native vegetation water use, highly weathered regolith, and the low gradients described above.

Vegetation

The wheatbelt catchments were essentially completely vegetated by a diverse range of woody plant communities whose distribution was controlled by climate and soil type (Beard 1981). About 65% of the Avon catchment has been cleared for agriculture with most clearing taking place between 1940 and 1970. However, many catchments in the upper Avon and Blackwood rivers have cleared proportions ranging from 85 to 95%.

HYDROLOGY

In describing the hydrology of the wheatbelt catchments, it is important to realise that their hydrology is characterised by *high variability* and *nonstationarity*. The rivers of this region have higher variability of streamflow than others worldwide (McMahon *et al.* 1992), indicating a usually unpredictable climate from year to year and season to season (Table 1).

The smaller rivers may not flow for many years, then either a major summer event or a wet winter will lead to flow events. The larger rivers cease flowing in the wheatbelt regions during summer, except when extreme tropical cyclonic events or severe thunderstorm activities lead to heavy, intense summer rainfall. In "normal" years, winter rainfall is not enough to move water continuously through the catchment from the extreme eastern and southern boundaries to the coast.

Table 1: Comparison of hydrology statistics for Avon River tributaries.

Station No	River	Area (km^2)	Mean annual rainfall (mm)	Clearing (%)	Mean annual flow (ML)	Median annual flow (ML)	Mean annual runoff (mm)	CV
615012	Lockhart River	32,000	350	85	7,900	1,960	0.24	1.7
615015	Yilgarn River	56,000	300	50	6,500	890	0.12	2.1
615022	Yenyenning	92,000	340	70	12,980	87	0.1	1.4

Effect of clearing on runoff

The other key feature of the hydrology, *nonstationarity*, refers to the fact that the underlying hydrological processes in these systems are still undergoing profound but subtle changes as a result of historic clearing. These changes include increasing runoff source areas due to rising regional groundwater, soil acidification, and decadal climate variability. In the longer-term, climate change may lead to decreased winter rainfall, increased summer rainfall and possibly more extreme events. *The hydrological systems today are neither the same as they were on settlement nor as they will be into the future*. Median annual streamflow for many of the smaller catchments in the Wheatbelt would have been close to zero prior to settlement. For the Avon catchment the annual average streamflow prior to clearing was estimated to be 18% of the current water yield, approximately consistent with experimental results in Ruprecht & Schofield (1991) (Figure 5).

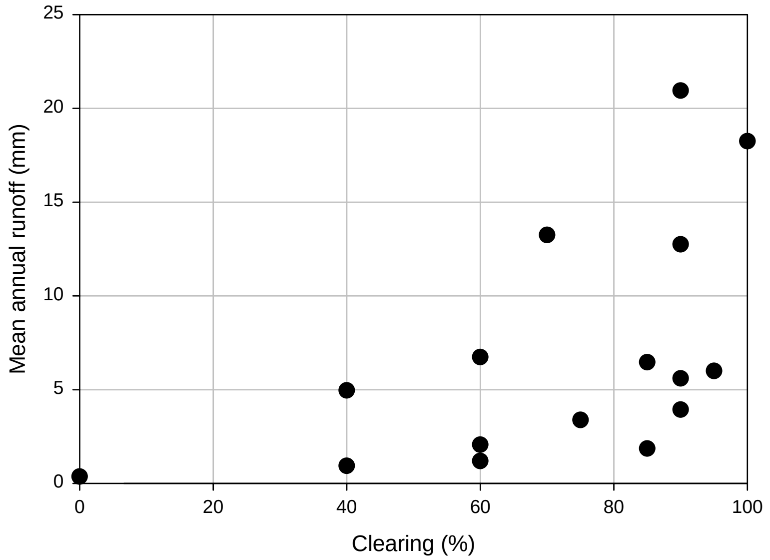

Figure 5: Mean annual runoff for wheatbelt rivers (mean annual rainfall less than 460 mm) as a function of clearing. As a percentage, the runoff equates to less than 5% and in most cases <1%.

The major change to the water balance (Table 2) is the reduced evaporation and interception in the agricultural catchment and increased runoff and recharge. Interestingly McFarlane *et al*. (1992) reported lower infiltration rates in four uncleared wheatbelt soils with an undisturbed surface crust compared with nearby cleared soils. They surmised that an organic crust caused local redistribution of surface water within uncleared areas. In addition, water repellency was reduced in a gravelly soil after clearing. Sharma *et al*. (1987) in jarrah forest soils found the impact of clearing for pasture led to a reduction in surface saturated hydraulic conductivities by an order of magnitude.

Table 2: Annual average water balance for a native vegetation and agricultural catchment north-east of Newdegate (Nulsen, unpublished data). All figures in mm.

Catchment landuse	Rainfall	Runoff	Evaporation	Interception	Recharge
Native vegetation	370	0	359	11	0
Agriculture	370	18	319	7	26

Very low runoff is observed from the smaller eastern wheatbelt catchments, ranging from 5% down to less than 1%. There is a clear relationship of increased runoff with increased level of clearing within the catchment (Figure 5). Mean annual runoff for small agricultural catchments increases slightly with a defined watercourse (Figure 6), and significantly with both a defined watercourse and interceptor drains.

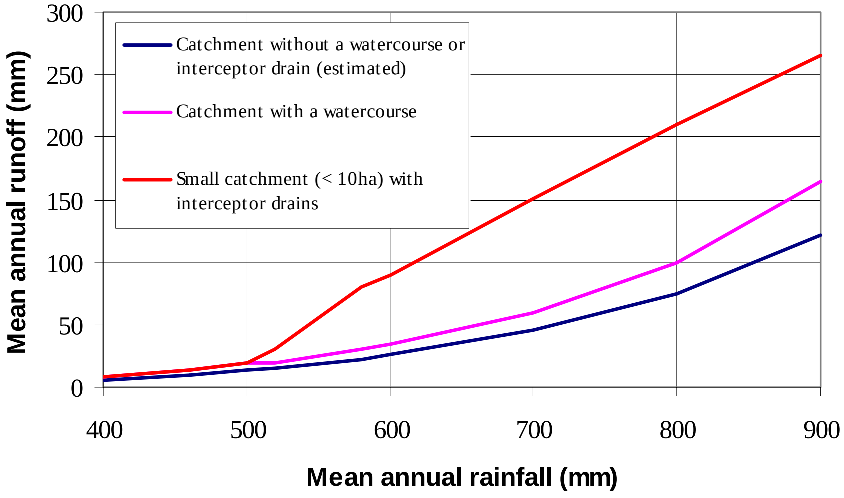

Figure 6: Runoff as function of rainfall for cleared catchments with a defined watercourse (adapted from McFarlane *et al*. 1995)

Some generalities of the present hydrological state can be made. In typical years, winter runoff is generated by a combination of shallow aquifer throughflow, saturation excess rainfall (particularly in the wetter regions near the coast) and some infiltration excess generation due to non-wetting soils and from soils with low hydraulic conductivity in cleared country. For instance, George & Conacher (1993) found that 37 percent of streamflow arose from saturation-excess overland flow, and 52 percent was from throughflow. These same authors found that saturation-excess overland flow still occurred, but with a much reduced variable source area and a longer lag following rain. They also report infiltration excess overland flow due to soil compaction and hydrophobicity (up to 70 percent of summer streamflow). Summer runoff can be generated by intense cyclonic events and is then dominated by infiltration excess processes. Much of the runoff that enters into the main channels is generated by rainfall directly on the valley floors themselves.

Infiltration-excess overland flow is considered an important mechanism in fine textured soils, surface sealing soils, non-wetting soils and surface compacted soils (McFarlane & Davies 1988). However, saturation-excess overland flow is considered more important in duplex soils, soils in groundwater discharge areas, and fine textured soils in valley flats (McFarlane & Davies 1988).

The amount of rainfall required to initiate runoff in the low rainfall wheatbelt catchments can be relatively high as shown in Figure 7. The Lake King catchment (86 km^2, 95% cleared, and mean annual rainfall of 320 mm) experiences many years of no flow, interspersed with either extreme summer events or a wet winter.

The rivers of the Wheatbelt show variable source areas at both small sub-catchment and larger river catchment scales. At the small sub-catchment scale the variable source is related to the saturation of the valley floor. The larger scale variable source area relates to the connection of the lake systems that is common in the Wheatbelt areas.

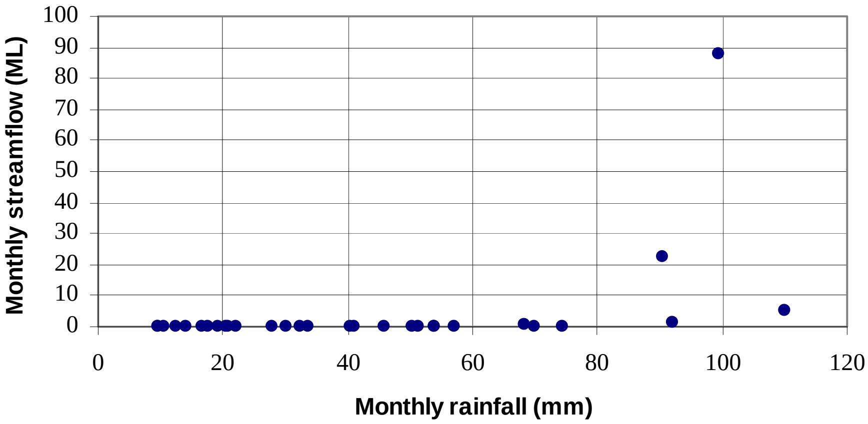

Figure 7: Monthly streamflow compared to monthly rainfall for Lake King catchment (Note that the rainfall required for significant runoff is over 80 mm).

Salinity

These catchments receive approximately 100-170 kg ha^{-1} yr^{-1} salt via atmospheric deposition near the coast, reducing to about 20 kg ha^{-1} yr^{-1} at their eastern edge (Hingston & Galaitis 1976). It is most likely that the catchments in the Wheatbelt were accumulating salt prior to clearing.

It is not known exactly how much of the land area was primary salinity (salinity existing prior to clearing), but it was probably less than 1%. The region currently has a salinised area of some 11%, and it is expected to increase to over 30% at groundwater recharge-discharge equilibrium (Ferdowsian *et al*. 1996). Many ephemeral freshwater lakes have salinised as a result, and runoff is now increasingly saline. For the Avon River system, while there can be much redistribution of salt within the upper reaches, most of the salt that reaches the ocean outlet in most years is sourced from between Yenyenning Lakes and Northam, and from the North Mortlock River (Viney & Sivapalan 2001). Sources to the east and south of these contribute only in extreme flooding events when the internal storages overflow (Pen 1999).

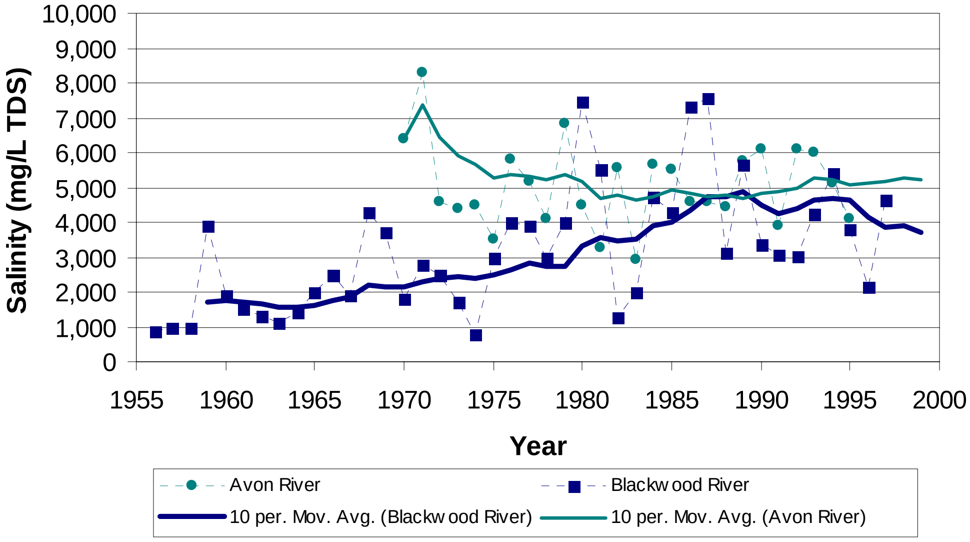

Figure 8: Flow-weighted annual stream salinity for the Blackwood (mostly cleared) and Avon rivers. The five-year moving mean trend is shown. Note the huge variation in salinity in the Blackwood River at Darradup. Avon data from Avon River at Walyunga.

The combination of variations due to rainfall (and its spatial distribution) and the internal storage or overflow of runoff leads to large variability in stream salinity from year to year (Figure 8). This can prove difficult for the estimation of trends and the detection and evaluation of mitigation efforts. However, it is clear that the salinity in the Blackwood river has risen from less than 2,000 mg L^{-1} to greater than 4,000 mg L^{-1} over the last 40 years.

The seasonal variability in salinity is also high, but salinity remains above saline (> 5,000 mg L^{-1} TDS) as shown in Figure 9 for the Coblinine River in the upper Blackwood River. There is usually an increased stream salinity in the early winter flows, followed by a significant freshening (to 2,500 mg L^{-1}) and then a recession to a higher salinity.

The average annual load export from the Avon River is 2,160 kT, compared to 1,040 kT for the Blackwood River (Table 3).

The delivery mechanisms for salt into streams vary. At a local scale, they can include shallow throughflow delivery (even when the ultimate origin of the salts is the deeper aquifer) and early wet season wash-off (George & Conacher 1993). At a regional scale, the occasional overflow of the major ephemeral lakes due to extreme rainfall events pulses salt already in the channel systems further downstream.

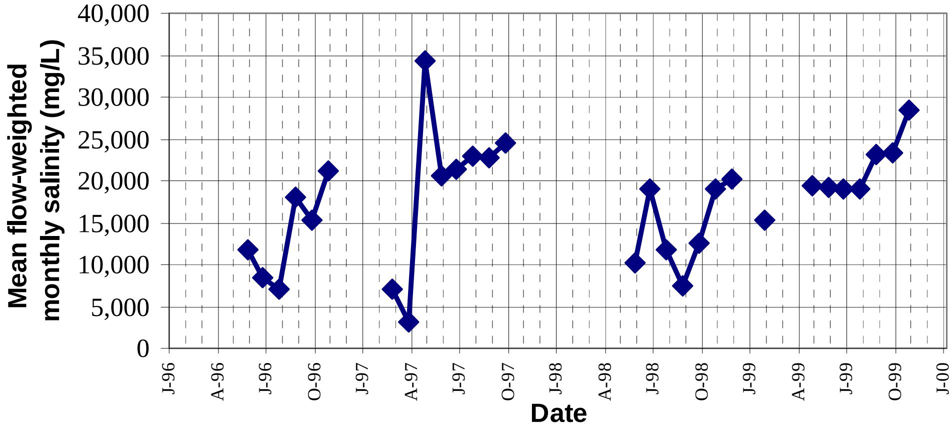

Figure 9: Flow-weighted monthly stream salinity for the Coblinine River, tributary of the Blackwood (mostly cleared)

Table 3: Summary salinity statistics for gauged rivers with significant wheatbelt catchment

River	Area (km^2)	Clearing (%)	Salinity[(1)] (mg/L)	Salt Load[(2)] (kT)	O/I[(3)]
Lockhart River	32,377	85	29,700	377	6
Yilgarn River	55,921	85	20,500	214	2
Avon River	119,000	65	5,200	2,160	10
Blackwood River	17,600	90	3,700	1,043	30
Lort River	2,800	60	23,700	109	9
Pallinup River	3,600	85	15,600	493	30

(1) Mean annual flow weighted salinity TDS mg/L; (2) Mean annual salt load TDS;
(3) Mean annual O/I, where O/I denotes salt load export from catchment divided by salt input from rainfall

The ratio of the salt outputs to inputs (O/I) is an important indicator of catchment salinity status. Prior to clearing of native vegetation, the catchments would have been accumulating salt with a O/I ratio of close to zero. After clearing, the large fluxes of water resulting from higher recharge and runoff increases groundwater discharge and, as such, increases salt load, leading to a salt O/I of greater than one. Smaller catchments within the Avon system have very high salt output to input ratios, such as Mooranoppin Creek with an O/I of 39 and Dale River with an O/I of 28.

Given the very high baseflow salinities (as an indicator of salt storage) for both the Lockhart and Yilgarn rivers, the leaching times or the time before most of the salt is leached from the catchment is of the order of 100,000 years. For catchments with lower salt storage and higher salt export the expected leaching times are much less.

Sediment and Nutrients

From the perspective of the outlet of the Avon, the chief sources of sediment lie along the Avon River in the region between Broun's and Dunbarton Bridge (Viney & Sivapalan 2001), suggesting in-stream processes of sediment mobilisation. The main area for phosphorous discharge is Ellen Brook, part of the Swan system, with other significant discharges from sub-catchments along the Avon between Julimar Brook and Broun's. These areas coincide with the westernmost (wettest) areas of the cleared agricultural country. It is important to note that these observations were for a period of 25 years with low mean annual rainfall and no serious flooding. These authors estimate that prior to clearing, the sediment, total phosphorous and total nitrogen loads in the Avon were only 4, 5.6 and 4 percent of rates for the period 1970–1994 respectively. In absolute terms, Viney & Sivapalan estimated that mean annual loads over this period for sediment, phosphorous and nitrogen were 55.2 kT, 0.077 kT and 0.563 kT respectively.

Flooding

Avon River Flooding

Much of what is characterised in terms of the sources and fluxes of water and materials out of wheatbelt catchments changes dramatically when large portions of these catchments are subject to extreme rainfall events, typically associated with tropical cyclones. Major flooding events of this type happened in parts of this region in 1926, 1930, 1945-46, 1958, 1963–64, 1974 and 2000. The annual floodflow in the Avon is presented in Figure 10.

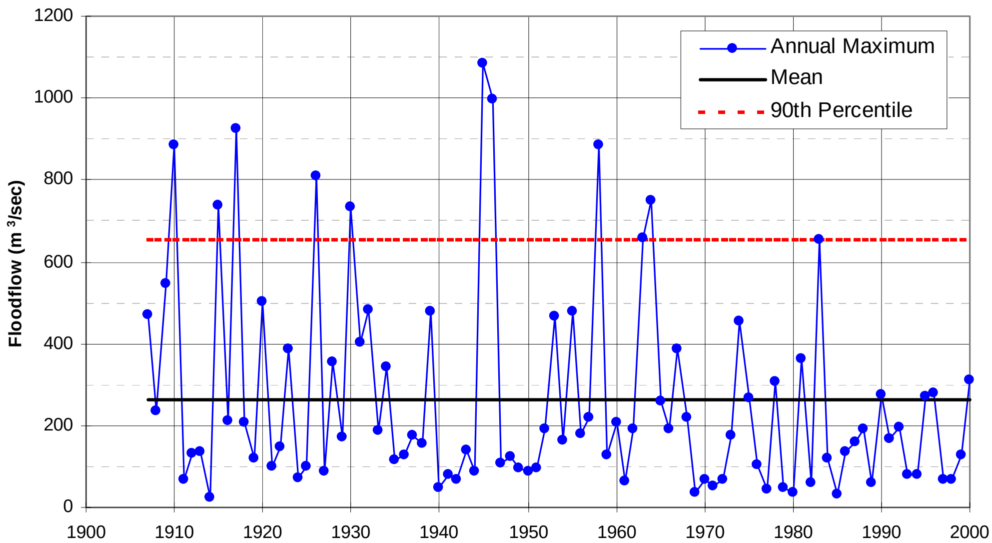

Figure 10: Annual floodflow for the Avon (at Walyunga), incorporating modelled floodflows from 1910 to 1969 and gauged data from 1970 onwards. Note the lack of floodflows above the 90th percentile in recent years. The 2000 event was only just above the mean annual flood, but was a significant summer event.

Following significant rainfall in the Avon River catchment on 21–22 January 2000 (remnants of Cyclone Steve), high river levels were experienced from Lake King to Perth. The rainfall was in excess of 100 mm in a large area from east of Hyden to Beverley, with the highest reading being 172 mm east of Corrigin. Much of the mainstream Avon River upstream of Northam and the Salt River upstream of Yenyenning had flows in excess of 150 m^3/s and below Northam in excess of 200 m^3/s. Peak flow in the Swan River at the Great Northern Highway was 312 m^3/s. The flood had an overall average recurrence interval (ARI) of 8 years (using all records since 1970), and an average recurrence interval of 20 years for summer events. Incorporating longer term modelling data the 2000 flood event for the Avon River was less than 5 year ARI. Devastating floods occurred along the Swan/Avon in 1862 and 1872, which are not included in this analysis.

The volume of water reaching the Swan River during the event was 270 GL (the approximate Swan-Canning estuary volume is 50 GL). Downstream tributaries of the Swan River like Ellen Brook and the Canning River had contributed almost nothing.

The Avon River carried 1,200 kT of salt, 800 T of nitrogen and 35 T of phosphorous from 23 January to 1 March 2000 (Muirden 2000). The flow-weighted salinity in the Avon at Walyunga averaged 4,500 mg/L TDS, total nitrogen 3.0 mg/L and total phosphorous 0.12 mg/L. The salinity of the Swan River at the Narrows Bridge reduced from its normal 24,000 mg/L TDS prior to the event to 4,400 mg/L at peak flow. The event is described in detail by Muirden (2000). Note that the salt load over these five weeks was almost equivalent to the mean annual load in more normal years estimated by Viney & Sivapalan (2001), and that it occurred in the “dry” season.

This event was the first time that the Lockhart sub-catchment had flowed significantly in summer for forty years; even during winter, this system does not usually generate any flows that reach the Avon. The consequences of this event to the Swan-Canning estuary were profound. High levels of nutrients (seven times the limit considered healthy for estuaries) combined with warm summer temperatures provided an ideal condition for algal growth. It is now believed that a strain of *Mycrocystis auriginosa* originating from stagnant pools of the Avon inoculated what became a catastrophic toxic algal bloom that closed the Swan River to the public for 12 days.

This event is significant in the present context in that the normal, average sources and fluxes into the Swan were overridden by material whose source was more from the upper catchment than usual, with magnitudes far in excess of normal loads as well as being rare. Tropical cyclones are expected in summer; however, they do not occur frequently and the magnitude rainfall experienced in March 2000 was very high. In such events, the system operates more as a typical catchment than elsewhere in the World. Such flooding events belie the common perception that the health of the Swan is largely disconnected from the processes in the Avon.

Wheatbelt flooding

Examples of flooding in wheatbelt areas include flooding in the Belka Valley (1963), Merredin (1978 and 1979) and Eastern Wheatbelt (1978). In 1963, flood waters over 2 km wide spread out over the lower parts of the Belka Valley, 30 km east of Bruce Rock. About 1,000 km^2 of the 1,700 km^2 catchment was considered to be at risk from flooding. Further flooding occurred in 1968 and 1978, when heavy rains in the lower parts of the valley washed away 48 km of levees.

The Merredin townsite experienced major flooding in 1978 and 1979. These floods caused extensive damage to Merredin and led to the evaluation of a number of flood mitigation options. The flood mitigation options included retarding basins, diversion and absorption banks. A diversion bank was eventually constructed along the northern town boundary to divert flow past the town.

Subsequent to a wet January and February in 1978, widespread flooding occurred following thunderstorms in late February in the area between Kellerberrin, Mukinbudin, Southern Cross and Hyden (Kratchler 1980). There has also been flooding experienced at Merredin (1978, 1979), Quairading (1983), Katanning and Narrembeen (1978, 2000).

Davies *et al*. (1988) examined the potential for retarding basins, levees, road crossings and drainage to reduce or increase peak flows (Table 4). Davies *et al*. (1988) concluded that most soil conservation structures and treatments only have a mitigating effect on small to moderate floods and are less effective in controlling major flood events. Retarding basins located on main drainage lines can be effective in controlling major floods. There were not considered to be any inexpensive control methods for major flooding in wheatbelt catchments.

Table 4: Results for treatment scenarios for three wheatbelt catchments (from Davies *et al*. 1988)

Study	Catchment area (km^2)	Treatment scenario and results
Cowcowing Creek Study	1,87.5	• 36 – 4 ML retarding basins reduced peak flow by 7% • 6,000 – 7,500 ML retarding basin downstream reduced peak flow by 63% • Absorption banks reduced peak flows by 34–42%
Beacon Catchment Study	1,375	• Levees can reduce floodplain storage and increase flood peaks downstream • Road crossing can cause substantial attenuation in flood peaks
West Nugadong Catchment Study	380	• Improved drainage increased flood peak for 1-in-10 year ARI by 10% • Road crossing led to far larger increases in flood depth than improved catchment drainage

Flooding and lakes systems of the Eastern Wheatbelt

The wheatbelt valleys east of the Meckering Line (Mulcahy 1967) commonly consist of chains of saline lakes and braided channels, bordered by floodplains 2–3 km wide. These old valley forms are susceptible to flooding and waterlogging. However these valleys as part of rivers, such as the Lockhart and Yilgarn river systems, have major flood storage that leads to major discontinuities in these watercourses. These lake systems, such as on the Lockhart and Yilgarn rivers, do not connect unless a major summer rainfall event or a prolonged and wet winter occurs. It is only then that the sediments separating the lakes are breached to connect the river system. However there are some parts of the Lockhart and Yilgarn river systems that appear to have a very low probability of connecting. These areas such as downstream of Job's Lake (near Beacon) and the Lake Ace – King system in the lower Yilgarn River system would be highly unlikely to have been breached in living memory. It is only with the changing land use that there is potential for these river systems to connect as a continuous waterway.

TRENDS AND CONCERNS

Salinity and Salt Loads

It is difficult to project the future salt loads and salinities of these rivers. Based on historic trends since clearing, it is likely that they have not yet peaked in either of these quantities. Given the fact that groundwater levels are generally still rising in the majority of the cleared country, and areas with high water tables are expected to treble in extent, one can expect increased salt loads and salinities. Our technical capacity to quantify these forecasts is quite limited.

Predictions for the Blackwood River indicate that further rises in salinity are possible (Figure 11). However there is significant uncertainty relating to the potential for Lake Dumbleyung to more regularly overflow and contribute significant salt load to the lower Blackwood River

Flood Risk

George & Conacher (1993) foreshadowed concerns over the long-term trends in flood risk due to the expanding groundwater discharge areas associated with valley salinisation. Bowman & Ruprecht (2000) developed a conceptual approach to the impact of land use change on flood risk, applied this conceptual model to a flood prediction model, and forecast the likely increase in peak flows in the Blackwood River under scenarios of increasing salinisation (Figure 12). Whilst this approach needs to be confirmed, these projections have profound implications to infrastructure risk and human safety along these rivers in the future.

These flood risks are not unique to the Blackwood River. The potential increased flood risk to towns like York, Beverley and Northam on the Avon is also significant. This could lead to significant increases in flood risk in areas within Perth, such as Bayswater, Bassendean and Guildford.

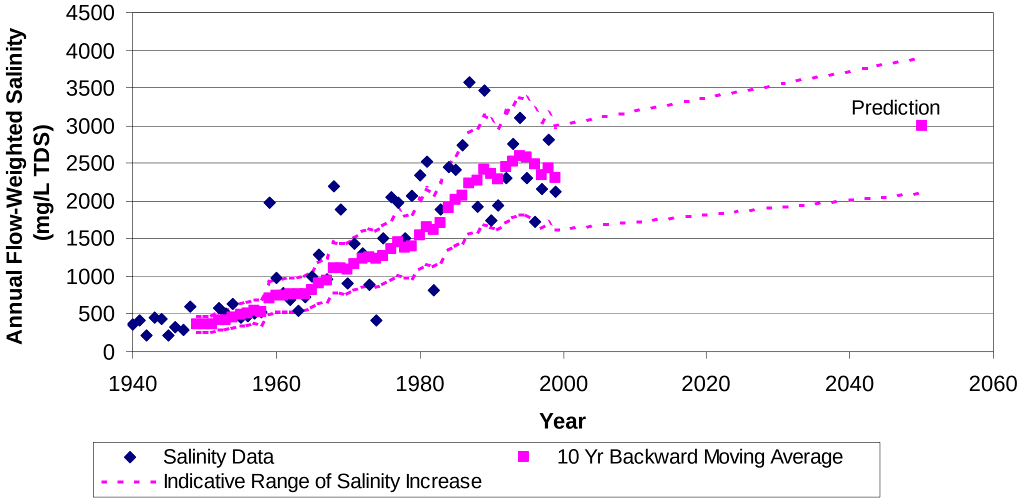

Figure 11: Salinity trend and prediction for Blackwood River at Darradup (adapted from Bowman & Ruprecht 2000).

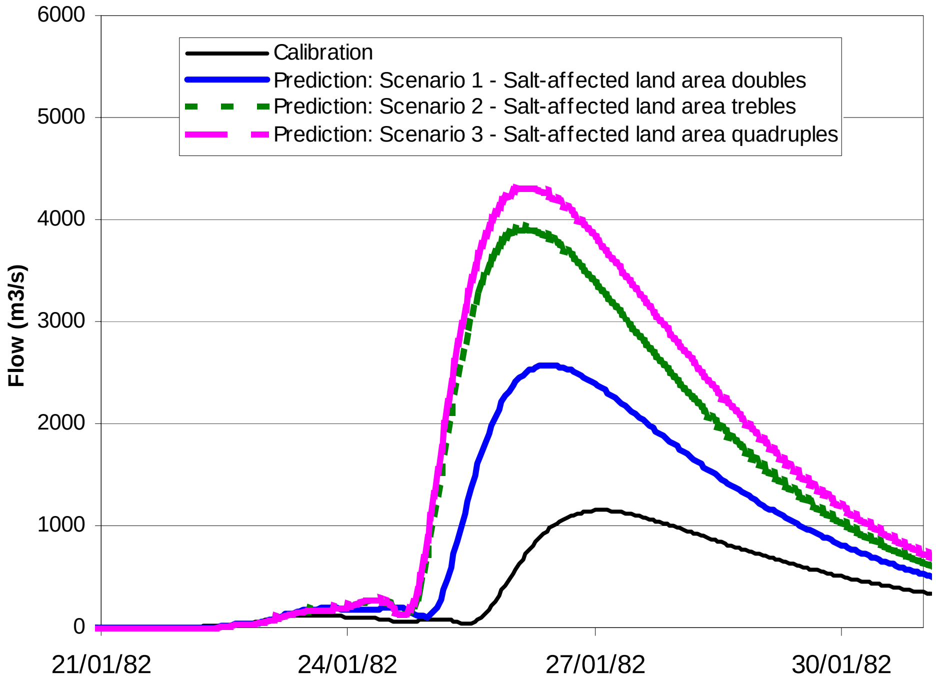

Figure 12: Predicted peak flows of the Blackwood River at Darradup with rainfall as recorded in January 1982 (Cyclone Bruno), under expanding source areas associated with rising regional watertables. The lower curve is the calibrated event as it happened under prevailing levels of groundwater discharge areas in 1982. That flood event had major impacts along the lower Blackwood to towns like Nannup. The three higher curves represent what may happen if groundwater discharge areas double, treble or quadruple.

THE FUTURE

In looking at the future of the wheatbelt catchments, it is not possible to divorce the health of the ecohydrological system from that of the communities that derive their living and wellbeing from these catchments. The Avon Basin, for instance, produces agriculture worth some $1.5 billion, and is home to 54,000 people. These rural stakeholders are affected by declining terms of trade for agricultural products, and the loss of people and services from rural communities. At the same time, growing environmental awareness regarding catchment health, and a growing intention to assert their values, translate to residents of Perth (1.3 million people) having a larger influence on natural resource management, including areas remote from Perth.

In any debate about wheatbelt catchment management, it is crucial that an objective picture regarding the future of the rivers be painted and understood by everyone. The rivers do not look like they once did, *nor will they look like they do now in the future*. The decisions we take must be considered in the context of the future state of these systems if we do nothing, not against the background of how they used to look or how they look now. Our technical ability to paint this picture is limited but must be developed.

As for what options are open to significantly improve the state of the wheatbelt catchments, it is useful to distinguish among the goals of reducing nutrient loads, salinity, flooding and inundation, and waterlogging. Each of these has a set of options that may be more or less feasible and attractive.

Viney & Sivapalan (2001) concluded on the basis of simulation modelling that strategic revegetation (of particular sub-catchments) had the potential to disproportionately reduce sediment and nutrient delivery to the Swan estuary, although these results would clearly not hold in the case of large flood events arising from the upper catchment. It is difficult to imagine revegetation at the scale of the Avon that could intercept nutrients and sediment on those occasions when summer rainfall inland leads to the kind of flows and loads observed in January 2000. It may be possible for new farming systems to reduce the inputs of agricultural fertilisers in large scale agriculture, but if the origin of most sediments delivered to the Swan estuary are remobilised from the river bed and banks from upstream, then the source of sediment and particulate phosphorous may in effect be inexhaustible.

The options for flood mitigation include revegetation of the variable source areas (i.e. saline discharge areas), increasing the storages along the chains of lakes, or widespread revegetation with trees. These options are not mutually exclusive, but the impediments to adoption of the latter are widely recognised. Lacking the development of commercially attractive tree crops with a product market that can sustain millions of hectares of production, it is unlikely to ever happen and will certainly not happen in the immediate future. Revegetation of discharge areas (e.g. with salt-tolerant vegetation) is more technically and economically feasible, but the effectiveness of this approach in mitigating flood risk is untested and is unlikely to dramatically mitigate risk, particularly in winter. The potential to create detention basins by raising the outlets of natural lakes and thus mitigate risk is higher, but also untested in practice. These basins may create a temporary impoundment, which releases water in times of “diluting high flows”, but not floodflows.

The increasing likelihood of flooding affects not only agricultural land, but has a major impact on infrastructure such as roads, railways and townsites. The potential economic value of protecting these assets is probably much higher than for agricultural land and as such there may be greater opportunity to look at multiple objectives of mitigating the impacts of floods on infrastructure and agricultural land.

The options for reducing inundation and waterlogging are similar to flood mitigation. However, the emphasis is more likely to be on surface water management, water harvesting, and engineering and vegetation options to increase discharge.

Hatton & Salama (1999) concluded that neither revegetation nor engineering was likely to recover the wheatbelt rivers from salinity. However, it is now widely recognised that engineering can be effective in reducing the impacts and extent of *land* salinisation on infrastructure and natural assets, as well as in keeping land under crops. It is also generally acknowledged that even if the long-term strategy is to revegetate, the immediate protection of land and assets can require engineering. Such practices are already being employed in places such as Lake Toolibin, where surface water diversions and groundwater pumping are beginning to protect the reserve ahead of intended revegetation in the surrounding catchment.

There is a lot of groundwater drainage being constructed in Western Australia's Wheatbelt, mainly on private land with private funds. The on-farm effectiveness of these engineering works varies, but to date has been subject only to modest research and development efforts to improve effectiveness and efficiency. There are serious concerns expressed by some downstream stakeholders regarding the negative impacts of disposal waters. There has been some evaluation of the flood mitigation options (Davies *et al*. 1988), but these studies have not looked at the impacts on biodiversity or nutrient flows. In the absence of the evaluation of these broader aspects, it is difficult to advance a serious debate on the winners and losers, and who pays, associated with engineering. It is worth noting that none of these catchments are water supply catchments, with the kinds of downstream constraints on water quality that complicate and inhibit drainage in catchments such as the Murray-Darling Basin.

There have been more recent initiatives that have started to address some of these issues. The development of water management strategies in the Lake Dumbleyung and Beacon River catchments, the implementation of a broad-scale trial pumping scheme in the east Collie, and research and investigations into deep drainage in the Narrembeen area are all examples of recent studies into engineering applications.

Given these recent initiatives, it is clear that we have an opportunity to design and optimise catchment-scale engineering that might bring the greatest collective benefit to those that have a share in the health of wheatbelt catchments. Landholders and government need to look at developing a framework that can work toward bringing about multiple benefits in terms of agriculture, flood mitigation and ecological values. A comprehensive vision for the management of flows and loads in these rivers, should we choose to further engineer them, is essential to deliver the best outcomes.

It is a cruel irony that we have salinity problems in these catchments precisely because they are in the process (in the most global sense) of *freshening*. More salt is coming out of the landscapes than is now going into them from the atmosphere, and if we take the longest possible view, at least the salinity and associated flooding will eventually (in thousands of years perhaps) self correct. But in the process, we will be leaving behind much of the natural and human heritage we value.

ACKNOWLEDGEMENTS

The authors would like to thank Neil Viney, Don McFarlane and Peter Muirden for their valuable comments on this paper. There are also many people who have contributed to the knowledge and understanding of salinity and hydrology of the south-west of Western Australia that has made this paper possible.

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WHY WHEATBELT VALLEYS ARE VALUABLE AND VULNERABLE: THE ECOLOGY OF WHEATBELT VALLEYS AND THREATS TO THEIR SURVIVAL

Greg Keighery, Stuart Halse and Norm McKenzie[1]

ABSTRACT

Five sections are presented: a brief background on the biodiversity survey of the Agricultural Zone, general results of the survey, the impact of rising groundwaters on biodiversity generally, and finally in wheatbelt valleys in particular. Questions are posed about what we can do to ameliorate and live with this changed landscape.

The survey has shown that the agricultural zone of Western Australia is more biodiverse in all groups surveyed than previously recognised.

Areas affected by secondary salinisation show major declines in vascular plant and animal biodiversity. Rich complex communities are replaced by a few succulents and weeds. Similarly major declines in diversity occur in animal communities where specialists are lost and/or replaced by generalist species.

Salinisation will cause further fragmentation, significant loss of plant communities that typify the Wheatbelt, and a major rise in the extinction rate of native plants, unless efforts are undertaken by the whole community to reverse current threats.

INTRODUCTION

This paper is developed in five sections: a brief background on the biodiversity survey of the Agricultural Zone of Western Australia (hereafter referred to as the Wheatbelt); general results of the survey; impact of rising groundwaters on biodiversity generally; wheatbelt valleys in particular and finally what can we do to ameliorate and/or live with this changed landscape.

At this stage it is important to note that this paper is based on the information collected over four years of survey in the Wheatbelt and other related published and unpublished reports. Over the next year (2002) the survey information will be collated and analysed and further reports prepared. As a consequence the information and interpretation presented in this paper is preliminary.

BACKGROUND TO BIODIVERSITY SURVEY

The Wheatbelt is central to temperate south-western Australia which is recognised internationally as a mega diverse area for flowering plants. Significant parts of six of the eight biogeographic zones recognised in south-western Australia (Thackway & Creswell 1995) are found in the Wheatbelt. These are the Geraldton Sandplains, Swan Coastal Plain, Avon-Wheatbelt, Jarrah Forest, Mallee and Esperance Sandplains zones.

The Western Australian Museum had surveyed the vegetation and vertebrate animals of 23 nature reserves of the Northern and Central Wheatbelt during the 1970s (reports are in Biological Survey of the Western Australian Wheatbelt, Records of the Western Australian Museum supplements 1–13). While these will form an essential baseline for those reserves, the Wheatbelt has had no previous comprehensive systematic survey of the distribution and diversity of the plants and animals of the region. Under the State Salinity Strategy, a four year field survey (1997–2000) was undertaken by the CALMScience Biological Survey Group with Greg Keighery as Project Leader.

The survey was structured under a series of themes. A large number of knowledgeable and experienced specialists in each of these areas, from a variety of institutions, are participating. This participation has allowed the survey to address the diversity of a wide variety of organisms at the species level. The themes and key participants are listed below:

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Terrestrial Communities

Flora:
Greg Keighery, Neil Gibson and Andrew Webb.

Fauna:
Vertebrates - Norm McKenzie, Allan Burbidge, Jim Rolfe and Bill Muir;
Invertebrates (CALM) - Paul Van Heurck, Nadine Guthrie, Lisa King and Bradley Durrant;
Invertebrates (WA Museum) - Julianne Waldock, Barabara York Main and Mark Harvey;
Frogs (UWA) - Dale Roberts.

Soils:
Trevor Stoneman

Wetland Communities

Flora:
Mike Lyons

Fauna:
Stuart Halse, Adrian Pinder, Jane McRae and Melita Pennifold (supported by many interstate and overseas specialists).

Detailed Wetland Monitoring

Jim Lane, Stuart Halse, Neil Gibson, Dave Cale, consultants from Edith Cowan University and Geohydro.

The biodiversity survey provides an overview of the distribution and conservation needs of the terrestrial and wetland biota of the Wheatbelt. Almost 2,000 sites have been established and scored, including over 300 terrestrial and over 200 wetland fauna/flora inventory sites that will be able to be used as monitoring sites into the future.

RESULTS OF THE BIODIVERSITY SURVEY

The general outcomes of the survey, up to this stage, are considered under each theme.

Terrestrial Communities

Flora

The Wheatbelt has an estimated vascular plant flora of circa 4,000 species, of which over 60% are confined (endemic) to the area. The region is the centre of species diversity for many of the species-rich groups (*Acacia*, *Dryandra*, *Eucalyptus*, *Grevillea* and *Verticordia*) that characterise the south-west of Western Australia.

This huge number of species, and the diverse range of plant communities in which they grow, were systematically sampled on public lands across the landscape in over 750 standard area plots of 10x10 metres (100 m^2). A series of these are associated with the 303 biodiversity sites (see Fauna below) while others were located independently of these sites. Approximately 200 sites have also been established on private and local government lands by members of the Wildflower Society of WA (Inc.) as part of the Bushland Plant Survey programme (Keighery 1994) and results are being incorporated into the overall study.

The biodiversity of the Wheatbelt is much higher than previously estimated. For example:

- Detailed surveys of the Lake Muir/Unicup reserves (Gibson & Keighery 2000) have documented a vascular flora of almost 1,000 species (considerably higher than Mount Lesueur, a larger area on the northern sandplain considered exceptionally diverse).

- The small areas of bushland in and around the Quairading townsite (part surveyed with community volunteers) has a vascular flora of over 500 species, including two completely new species and the largest populations of two critically endangered taxa (Keighery *et al.* 2001 and survey data).

- Plant species richness of equal area plots (100 m^2) ranges between 20 and over 90 species, equal to most areas of the northern and southern heathlands. The winter wet and summer dry (ephemeral) wetlands and heathlands plots are often equally species rich. Heaths are species rich in shrubs, whereas the other communities are species rich in perennial and annual herbs. While it is often assumed that heaths and granite rocks are 'the species rich communities', as found here and previously on the Swan Coastal Plain by Gibson *et al.* (1994) ephemeral wetlands have very high species richness. This is because they contain several groups of species that grow, flower, seed and die or become dormant during the year, i.e. one in autumn as the rains are filling the wetland, a winter group when the wetlands are full, another as the wetlands begin to dry in spring and a final group when the wetland is dry in early summer

- Three presumed extinct plants, and at least seven other previously unknown species have been collected and documented.

Naturally saline areas have major biodiversity values with a variety of plant communities and species confined to these specialised habitats. These areas, occupying the base of the broad valleys and representing the paeleodrainage lines, are widespread and of considerable age in the Wheatbelt. One indication of this specialised habitat is that at least 64 threatened and priority taxa are restricted to these areas. Several new taxa have been discovered during the survey. The plants and the communities they occur in are at major risk from rising water tables, altering the hydrological regime of these areas.

One of the outcomes of the plant survey is to identify native species of potential for revegetation. A database of species in naturally saline areas of the Wheatbelt (from plot and herbarium records) is being compiled.

The Wildflower Society of WA (Inc.) studies have already established that areas of privately owned bushland in good condition frequently contain communities and species of plants of regional significance, some of which are not represented in the conservation network (Gunness *et al.* 2000a & b; Gunness & Campbell 1998; Keighery *et al.* 2001)

Fauna

The sampling sites (3 x 50 metre long pit lines with 10 spider traps) are positioned on a minimally disturbed example of each of the 11 principal geomorphic units in the landscape, as well as on a salt-affected example of two of the units. Sites with natural vegetation have been chosen on typical examples of each unit, preferably within a conservation reserve. At the conclusion of the survey 303 terrestrial biodiversity (fauna and flora) sites have been selected and sampled for ground-dwelling arachnids (spiders and scorpions), some other invertebrates (carabid beetles, centipedes and millipedes) and small vertebrates (mammals, reptiles and frogs).

The study has dramatically increased available data on the distribution, status and habitats of small wheatbelt vertebrates and ground dwelling invertebrates. For example:

- The survey has collected over 50,000 ground dwelling invertebrates, making this the most comprehensive study of these organisms in Australia.
- In the first two years of sampling, 113 species of small ground-dwelling vertebrates (reptiles, mammals and frogs) were recorded, compared with previous Museum records of 130 species for the whole agricultural region. The sampling recorded an average of 9 species of vertebrate per quadrat. This is despite the known historical loss of 16 mammal species from the Wheatbelt.
- The first year's survey (less than a third of the study area) recorded 33 scorpions (previously 13 recorded for the entire Wheatbelt), 24 centipedes (previously 23 recorded) and 329 spiders (previously 128 recorded). Spiders have been sorted into 1,699 morpho-species for the Wheatbelt, suggesting a final tally of over 700 spider species. The sampling recorded 20-50 (average of 34) arachnid species per site.
- Although all vertebrates encountered can be assigned to described species, 60-70% of the arachnids were undescribed. At least 40% (210 of 500+ species) of the region's arachnids, and 25% (31 of 125 species) of its small ground-dwelling vertebrates, have distributions centred on the agricultural region or are endemic to it. Strong biogeographic patterns are apparent across the region in these faunas, and different communities of species occur on the different soil-types within survey areas (sands, clays, loams, saline floors etc).
- Biodiversity of terrestrial invertebrates is much higher than previously supposed for the Wheatbelt.

Soils

Bulked surface soil samples from each site are collected for chemical analysis and the soil profile is described and sampled for chemical analysis. At each of the 303 sites a description, sampling and chemical analysis of soil profiles was made. This will allow use of Agriculture WAs soil profile database (10,000 profiles across the Wheatbelt) to interpolate the biodiversity-pattern models CALM expects to derive from the biological survey during 2002 (see McKenzie *et al.* 2000 for an example). In conjunction with ANUCLIM data (McMahon *et al*. 1995), these will allow modelling of species' "environmental envelopes", including their salinity responses. This will enable predictions of what are the tolerances of a wide range of plants and animals to changes in soil chemistry due to salinity.

Wetland Communities

Two hundred and thirty two wetlands were chosen to cover the full range of wetland types within the study area (water quality, geographic spread, primary and secondary saline sites and wetland morphology).

Flora

Within the 232 wetlands sampled for aquatic invertebrates, about 750 sites (100 m^2 or less) were established to document the floristics of these wetlands. Preliminary results have uncovered numerous new records and major range extensions of rare and priority flora. Several new taxa of Samphires (*Halosarcia* species) and *Frankenia* species have been discovered.

The study is confirming the high floral values of naturally saline areas and regional floristic differences in the salt lake chains.

Fauna

Survey work to date in wheatbelt wetlands has collected about 1,000 invertebrate species, distributed in 139 families and 270 genera. About 50% appear to be described species and approximately 15% are only known from the Wheatbelt.

Provisional data suggests numerous species are restricted to naturally saline wetlands, mostly *Parartemia* (Brine Shrimps), *Coxiella* (snails), Ostracods and Copepods (Crustaceans). These form a significant endemic component in south-western Australia.

Aquatic invertebrates from fresh water habitats in the Wheatbelt have significantly higher salinity thresholds than members of the same groups in Eastern Australia (Halse *et al.* 2000). This suggests that these organisms have local adaptations to wetting and drying cycles (the pools become more saline as they dry) of the more seasonal wetlands of the Wheatbelt. As a consequence these species can tolerate higher salinity thresholds before they are lost from our wetlands.

South-western Australia has a highly rich and endemic aquatic fauna of microinvertebrates, especially Crustacea. This diversity may be of equal significance to the flowering plants on a world scale.

Of particular note, for wetland conservation, is that most freshwater wetlands in the Wheatbelt are on private lands.

Detailed Wetland Monitoring

This project was designed to analyse and report trends in salinity and depth in wetlands that have been monitored since 1978. Recordings of salinity, depth and nutrient status are made in a broad range of wetlands. In addition changes in floristic composition, tree health, waterbirds and aquatic invertebrates in 25 wetlands are monitored.

Vegetation transects (2-5 per wetland, 80 in total) have been established at all 25 wetlands. Reference photos have been taken on each transect. Aerial photos showing position of transects and biophysical boundaries have been captured on Geographical Information Systems and are also available on CD ROM with the reports. Over 6,000 trees have been tagged on the transects and vegetation profiles constructed for each transect. Three major reports on these transects have been prepared and are lodged in the CALM Library at Woodvale in Western Australia. Monitoring bores have been established adjacent to these transects at 20 wetlands. Waterbirds and invertebrates (macro- and micro-invertebrates) have been sampled at 23 wetlands to prepare baseline data and five have been resampled.

Monitoring of wetlands has shown that wetlands often have different values for waterbirds, invertebrates and vegetation. Biodiversity is comprised of many groups that respond differently to the environment. A single biotic indicator cannot be used to summarise the overall biodiversity value of a wetland.

Summary

The biological survey of the Wheatbelt has revealed that:

- The agricultural zone of Western Australia is more biodiverse in all groups surveyed than previously recognised.

- Despite widespread and intensive clearing there have been only minor losses at the species level (except for mammals). However, there has been extensive depletion of communities and genetic variation. This loss will increase to the species level over the next 100 years if current trends continue. Even with intensive management and intervention there will be further decline in most areas. We must carefully plan to minimise this impact and to maximise biodiversity values of these affected landscapes.

SALINITY IMPACTS ON BIODIVERSITY

Terrestrial Communities

Flora

Of the 4,000 species present in the Wheatbelt, over 1,500 occur low in the landscape, in riverine valleys, freshwater or primarily saline lands. Of these taxa an estimated 450 are endemic to the Wheatbelt. These taxa are in danger of extinction over the next 100 years as a consequence of rising saline groundwaters. Several hundred other species found only in lowland woodland, Mallee and *Melaleuca* shrubland sites, will be under threat in the longer term. Another 400-500 lowland taxa are centred on the Wheatbelt although not confined to it. These taxa are also under immediate threat of major genetic erosion from salinisation and hydrological changes.

Areas affected by secondary salinisation show significant declines in vascular plant biodiversity and loss of structural diversity. Rich complex communities are replaced by a few succulent shrubs and weeds.

Outside of the Wheatbelt hydrological changes threaten the diverse floras of naturally saline landscapes and areas of species rich heathland and ephemeral wetlands of the northern sandplains and Swan Coastal Plain. The karst communities, both subterranean and surface heaths, of the northern Swan Coastal Plain are threatened by flooding and perhaps increased impact of diseases from *Phytophthora* species.

Fauna

Approximately 25% (31 of 125 species) of its small ground-dwelling vertebrates (mammals, reptiles and frogs) have distributions centred on the Wheatbelt or are endemic to it. At least 40% (210 of 500+ species) of the region's terrestrial invertebrates have distributions centred on the Wheatbelt or are endemic to it.

A significant decline in the biodiversity of terrestrial invertebrates is apparent at secondarily saline quadrats (even partially affected), which have an average of 30% fewer species than their non-salinised counterparts. This loss is actually higher as localised specialists are replaced by "weedy" generalist species.

Wetland Communities

Flora

The impacts are greatest low in the landscape in and around all wetland types. However as the terrestrial and wetland plant communities intergrade specific comment is made under Flora in the section above.

Fauna

Birds

Of the 61 more common waterbird species in the south-west, only 16 prefer strongly saline (more than 20,000 mg/L) or hypersaline (more than 50,000 mg/L) conditions. Data from a 1981-85 survey of the south-west showed that an average of five waterbird species used hypersaline wetlands, compared with 20 in saline wetlands and 40 in fresh wetlands containing live trees and shrubs. Death of shrubs and trees in many wheatbelt wetlands due to salinity has caused a 50% decrease in the number of waterbird species using them. If the trend of increasing salinity continues, only 16 species, plus three or four species that use freshwater dams, will persist in the Wheatbelt out of an original waterbird fauna of more than 60 species.

Invertebrates

In a preliminary analysis of the first 700 species recorded, 253 species (45%) were restricted to fresh water with salinity less than 3,000 mg/L. However, 35 of the species occur on granite rock outcrops where salinity is unlikely to occur, leaving 218 species (39% of the fauna) that are vulnerable to increasing salinity. If all wetlands in the Wheatbelt became saline (more than 10,000 mg/L), most of these 218 species will disappear from the Wheatbelt, despite the fauna being more saline tolerant than in eastern Australia.

Species richness declines with salinity and the average number of invertebrate species present in fresh wetlands is about 50, in wetlands with salinity 20,000 mg/L about 25, in wetlands with salinity 50,000 mg/L about 12 and in wetlands with salinity greater than 100,000 mg/L about four. As a rule of thumb, doubling salinity halves the number of aquatic invertebrate species.

Caveats that must be attached to the above statements at this stage of the work are that probably not all wetlands will become saline, some species will persist in dams, and many species have ranges that extend outside the Wheatbelt.

Summary

The areas most immediately threatened by salinisation are the valley floors of the Wheatbelt. These areas affected by secondary salination show major declines in vascular plant and animal biodiversity. Rich complex communities are replaced by a few succulents and weeds. Similarly, major declines in diversity occur in animal communities where specialists are lost and/or replaced by generalist species.

Although dryland salinity is an Australian wide problem, information about the impact of hydrological change on biodiversity in Western Australia is more substantial than that of eastern Australia. For example, the Murray Darling Commission report on Salinity (Murray-Darling Basin Ministerial Council 1999) noted:

"No assessment has been made of the impact of dryland salinity on the biodiversity of the Murray-Darling Basin."

The challenge is what are we going to do with this new information? How to integrate these data into managing this changing landscape.

SALINITY IMPACTS ON WHEATBELT VALLEYS

We have already seen that the valley systems of the Wheatbelt contain a large component of the communities and species of the region threatened by salinisation. Since these areas are low in the landscape this is not surprising. In the final section on impacts we will consider the plant communities under threat from salinisation. These communities are the most readily understood and visible "management unit." They are the units for which all managers of lands can observe the visible signs of salinisation and can undertake intervention activities to maintain and monitor the results.

Non Saline Valley Floor Communities

A considerable diversity of tall woodlands of Wandoo (*E. wandoo*), Inland Wandoo (*E. capillosa*), Salmon Gum (*E. salmonophloia*), Red Morrell *(E. longicornis*), Black Morrell (*E. melanoxylon*) and Gimlet (*E. salubris*) once dominated the better drained heavy soils of the valley floors and slopes throughout the Wheatbelt. These woodlands generally extend into the adjacent pastoral regions. However, we know that the woodland understory varies across their range with rainfall and soil. These woodlands are now greatly fragmented but remain evocative of the area and are of considerable significance to our local and national heritage. The Wheatbelt will lose much of its local landscape character if they are lost.

In the south-east Wheatbelt there are woodlands of different composition, especially by dominant species (for example, *Eucalyptus ovularis*, *E. myriadena* and *E. flocktoniae*). In this area variable Mallee communities (*Eucalyptus platypus*, *E. celastroides*, *E. calycogona*, *E. cooperana*, *E. forrestiana* and *E. kessellii*) largely replace these woodlands on clays and calcareous clays and are being impacted by rising saline groundwaters.

There are also a number of possibly naturally rare woodlands, such as Lowland Brown Mallet (*E. astringens*) and Black Wandoo (*E. melanophitra*) that are also at risk.

Freshwater wetlands: (Creeks, Rivers, Lakes, Ephemeral wetlands)

Rivers in the incised western Wheatbelt are fringed by Flooded Gum (*Eucalyptus rudis*) communities and these are already greatly impacted by salinisation. Inland of these rivers, Flat Topped Yate woodlands (*E. occidentalis*) and its related Mallee form (*E. sporadica*) are dominant around small freshwater swamps and are also being impacted by salinisation and more frequent flooding.

The communities of lakes and ephemeral wetlands of the Wheatbelt contain an enormous diversity of plant communities depending on soil type and inundation, ranging from woodlands of *Melaleuca* species, through shrublands, heaths and sedgelands to aquatic herblands and are all under great threat. As an example Gibson and Keighery (2000) documented over 25 distinct wetland plant communities in the Muir – Unicup Recovery Catchment.

Rising groundwaters and drought are also causing stress of several of the major trees species of the western Wheatbelt such as Flooded Gum, Yate and Wandoo leading to increased insect and fungal attack.

Naturally Saline Habitats

These areas contain a diversity of Mallet (*Eucalyptus spathulata*), Mallee (including the oil Mallees, *E. suggrandis* and *E. vergrandis*), Woodland (*Casuarina obesa*, *Eucalyptus salicola*, *E. sargentii* and

E. kondinensis), shrubland, heath and herb communities that are at major risk from rising water tables. These areas probably contain the genetic biodiversity needed to find economic plants to revegetate the Wheatbelt for salinity control (e.g. the oil mallees, Broomebush (*Melaleuca uncinata*), saline adapted shrubs and bunch grasses).

The naturally saline areas of the Central/Western Wheatbelt are a priority for conservation because the threat of hydrological changes is more rapid and advanced in these areas. Although it could be argued that these areas are more resilient to change, the buffering effects are near exhaustion.

Summary

Salinity will impact on biodiversity of the Wheatbelt valleys at all levels of biodiversity - community, species and population in a wide variety of the organisms studied.

WHERE TO?

This section will briefly focus on how the biodiversity survey will aid aspects of tackling salinisation to protect biodiversity. The survey of the Wheatbelt will provide an overview of the patterning of many organisms across the region. It will enable the description and delineation of the areas with the most threatened communities and high levels of biodiversity. This will enable the selection of a further series of Biodiversity Recovery Catchments, in addition to the existing 6 recovery catchments, as outlined in the State Salinity Strategy.

The delineation of threatened species and communities will also be undertaken. A report on the conservation status of the vascular plants of the Wheatbelt is currently being prepared. Actions coordinated by CALMs Threatened Species and Communities Unit will target the most critically threatened communities and species for recovery actions.

The nature and degree of the impact on biodiversity at a site depends on a complex series of related hydrological factors. Crucially the time for impacts to develop fast in higher rainfall areas is a major determinant of options to protect remnant vegetation. How pervasive are the impacts in the valleys, depending on the effect of microtopographic relief? This still leads to increased fragmentation of remnants caused by salinity and these effects are still poorly understood. These areas of operational research need to be addressed in the future.

Clearly salinity is only one of the problems faced by biodiversity in the Wheatbelt. Broadscale clearing has led to fragmentation of remnants with all the attendant problems of edge effects, loss of genetic diversity, weeds, feral animals, losses of connectivity, disruption of ecological processes and unnatural disturbance regimes. Obviously to keep our marvellous and unique Wheatbelt plants and animals everyone needs to respect, value, appreciate and understand their local biodiversity. Hopefully the major outcome of the survey will be a major contribution to this process.

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PROFITABLE, SUSTAINABLE SALTLAND PASTURES? GET REAL!

Michael Lloyd[1]

INTRODUCTION

Saltland has received negative publicity over the last decade, mainly for two reasons. Firstly, research results of feeding trials in the early 1990s indicated that saltbush alone had little feed value. As a result, the media trumpeted that "saltbush is useless!" Secondly, doubt had been cast on the ability of saltbush and other halophytic perennials to use significant quantities of groundwater.

In 1997, a group of farmers and researchers formed the ***Saltland Pastures Association (Inc.)*** to demonstrate that, in a practical whole farm situation, saltland is a profitable sustainable resource which can be developed.

This paper details the experiences on one farm, "Bundilla", which is typical of the broad valley floors in the Wheatbelt of Western Australia. It discusses the options available in the late 1980s and gives reasons for a revegetation approach being taken. Information is provided on the types of revegetation, the production obtained and the environmental and other benefits achieved, to show the profitability and sustainability of saltland pastures. As well, it will briefly discuss further opportunities available for animal production from saltland, in both extensive and intensive production systems, and explore other productive uses of saltland and saline water.

"BUNDILLA" – AN EXAMPLE

"Bundilla" was originally selected in the early 1920s when the district was opened for settlement, but only a small area was cleared at that time. By the late 1950s, most of this had regrown. From 1960 to 1968, "Bundilla" was progressively cleared of most of the native perennial vegetation, with only non-arable areas (such as granite outcrops and a few small lakes) and shelter areas left uncleared. Typical of the broad valley floors in inland Western Australia, "Bundilla" has large areas of low-lying duplex soils. By the mid 1970s, salt began to appear in areas that, 15 years earlier, had grown above average wheat crops.

Over the next 15 years, increasing salinisation reduced the arable area on "Bundilla" from 1,800 Ha to fewer than 1,000 Ha.

It was clear that something had to be done. The traditional solution was to either sell to a neighbour or buy more land. For a variety of reasons (not the least of which was my stubborn nature), it was decided to stay and attempt to solve the problem, to try and get some production from the saltland.

OPTIONS

Three options were considered:

a) Drain or Pump

The drainage/pumping option was considered too expensive for the potential benefit. Together with the high cost was the fact that the very tight, water-holding clays may not transmit significant quantities of groundwater laterally. As one farmer put it: "If water will not flow laterally out of a dam into the surrounding soil, why would it flow out of the surrounding soil into a drain?" Difficulty in property management, increased fencing costs and aesthetics also played a part in the decision not to proceed with this option. Was it solving the problem, or just transferring it downstream for someone else to deal with? Legal implications also existed with the disposal of the saline groundwater. When enquiries were made in the late 1980s, it was discovered that there were a

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number of legal cases pending regarding the disposal of the groundwater from drains and pumps.

b) Plant Trees

Trees seemed to be an alternative, though advice received suggested that most would eventually die. An area of *Eucalyptus sargentii* was planted in 1989, and to date most have survived. Certainly they have lowered the water tables in the area and do provide shelter for stock. However, as these trees seem to have significant surface roots, there is nothing growing within 2 m of the base of the trees, although there is some extra production in the alleys away from the trees. Furthermore, there is no commercial production opportunity from these trees themselves; even though they look "nice". For "Bundilla" to remain a viable farming operation, this saltland had to become more productive.

c) Plant Saltbush

Saltbush seemed to be the answer. At the time it was considered to be good fodder with increased value for its "out of season" production and it would use groundwater. Reports from research at the University of Western Australia suggested that feed produced in autumn had up to 14 times the value of feed produced in the spring. Saltbush would provide shelter and be aesthetically pleasing. The WA Department of Agriculture had done significant work in developing saltbush. Researchers had scoured the world for different species to introduce into Western Australia. It seemed to be the perfect solution!

THE WAY FORWARD

After attending a field day in 1989 and seeing what could be done with saltbush, a machine was hired and a small area (17 Ha) was seeded. This area grew well. A direct seeding niche machine was purchased in 1990, and so the saga began. Now "Bundilla" has nearly 600 Ha of revegetated saltland upon which sheep are happily grazing. In fact, if it weren't for the saltbush, "Bundilla" would only be able to carry half the current number of sheep. The dry season in 2001 has demonstrated the value of saltbush, with normal sheep numbers being carried through the autumn/winter period. Apart from small areas of seedlings planted in 1989 and 1998, all saltbush has been direct seeded, using the niche-seeding machine. This machine rips, mounds and places a seed/mulch mixture every two metres in a niche formed on top of the mound. We normally expect well in excess of a 100% strike rate (i.e. more than one plant for every seed placement). There would be in excess of one million saltbush shrubs on "Bundilla".

Original species included *Atriplex amnicola, A. nummularia, A. lentiformis, A. undulata, A. semibaccata* and *Acacia saligna*. In the latter years, generally *Atriplex amnicola* (a low success rate when direct seeding) and *A. lentiformis* (short life span) have been eliminated. *A. semibaccata* is native to the region, and along with *Maireana brevifolia*, grows naturally and so is not included in the seed mix.

While the direct seeding/niche method of planting has not changed over the ensuing period, row spacings have varied. Originally, we planted the rows as close together as we could (remember that we thought it was good fodder!). We tried leaving gaps every 5 rows to correspond with boomspray widths, then extended the non-seeded areas and reduced the number of rows progressively until we have the present arrangement of two rows of saltbush with 9 metres between the double rows. There are plans in 2001 to establish a trial to determine the optimum alley width.

From 1991, *Paradana balansa,* tall wheat grass, and puccinellia were sown with the saltbush in each spring. However, these plants rely on a long wet season the following year to establish. Unfortunately, production was generally less than satisfactory and this has now been discontinued.

CHANGES

But how things have changed!

Following press reports of the Warren-Casson work in 1994 (Warren & Casson 1994), the role of saltbush had to be re-evaluated. If there was little fodder value in saltbush, why was it that we were grazing more sheep on the saline areas? Why did we have more wool? Why had the quality improved?

The answer appears to be twofold:

1) There was an increase in the understory fodder plants – sub clover, rye grass and capeweed returned to supplement the barley grass and native clover.

2) Pen trials suggested that the combination of saltbush and chaff increased feed intake over either saltbush or chaff individually.

In addition to this, recent tissue test of some of the saltbush suggests that the high digestibility and protein and the lower salt levels in some species may make a significant contribution to the fodder available to the sheep (Norman 2001). Research carried out in Spain in the early 1990s showed that sheep grazed on saltbush and barley straw gained in weight and condition (Correal & Sotomayor1996).

While we could see the changes happening with the return of the previous annual plants, the process was slow. There needed to be plants we could introduce to increase the amount of food available. The only plants then available (puccinellia, tall wheat grass and balansa and Persian clovers) were unsuitable for the lower rainfall areas. What we needed were plants that would tolerate some salinity and some waterlogging, but with a short enough growing season to survive and thrive in a low rainfall situation.

However, we were also seeing more changes:

- Monthly monitoring of two of the bores indicated saltbush was lowering the water table by about one metre. Another bore showed a dramatic fall in the water level following the wettest year on record.
- During a flood event in January 2000, the only areas to suffer water erosion were those not planted to saltbush.
- There is less wind erosion due to vegetation.
- Increased numbers of fauna are evident, including kangaroos and small birds.
- Improved aesthetics and increased farm value (Vigolo 2001).
- Improved wool value from sheep with a longer period in saltland pastures.

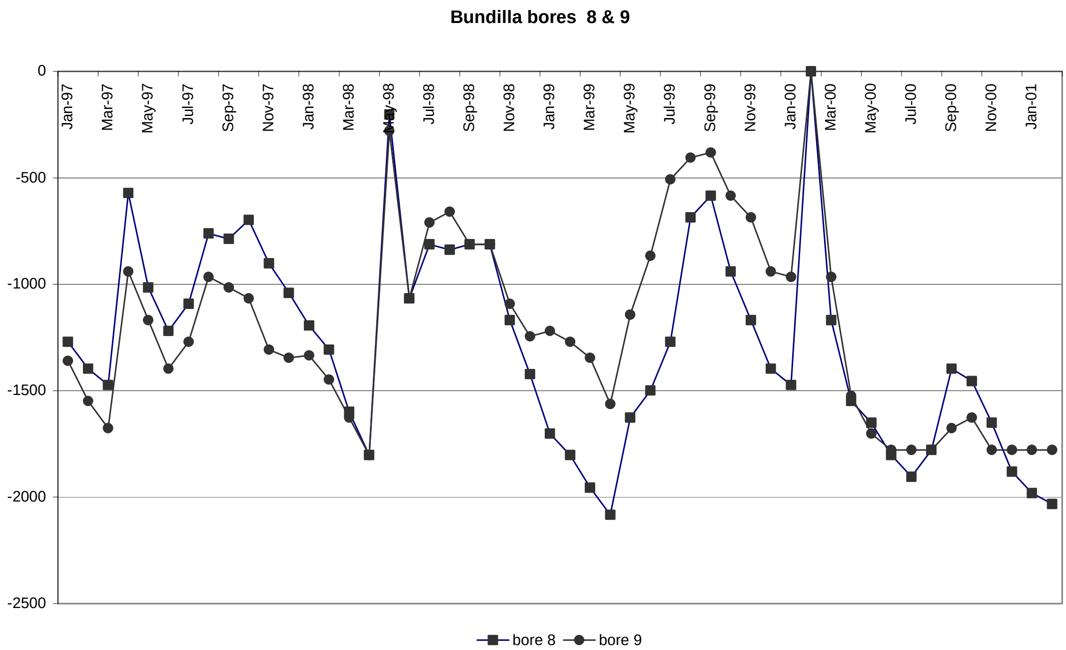

Figure 1: Relationship between two bores in the same area

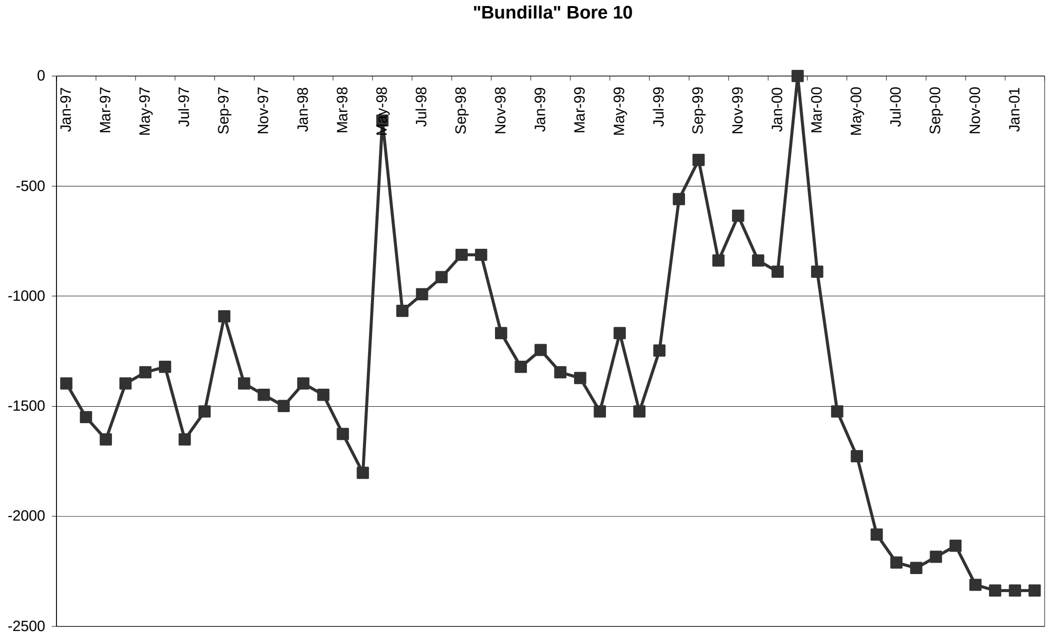

Figure 2: Effect of saltbush on the watertable at bore 10.

Figure 1 shows the relationship between two bores in the same area. Prior to August 1997, both bores were surrounded by annual (sparse barley grass) pasture. There was a difference of approximately 30 cm in the water levels between the two bores. Saltbush was seeded around bore 8 in August 1997. Within twelve months the relationship had changed with the water in bore 8 now lower than bore 9. This increased with the onset of summer, until a difference of 70 cm between the two bores was observed – a total turnaround of 1 m. In August 1999, saltbush was seeded around bore 9 and now the original differences observed prior to planting saltbush at either site are evident. However, since March 2001, both these bores have been dry.

Figure 2 shows the effect of saltbush on the watertable at bore 10. Saltbush was planted around this bore in August 1999. In the 13 months to the end of January 2000, Bundilla recorded twice its annual rainfall, culminating in the area being flooded in late January 2000. The watertable is now the lowest it has ever been, and in fact, for the last 6 months the hole has been dry at 2.3 m.

Table 1: Differences in wool value from sheep grazed for longer on saltland pastures

Mob	Wool cut	Micron	Yield	Price	Value per head
A	6.5Kg/hd	22.7	64.8%	375c/Kg	$24.38
B	6.5kg/hd	22.7	58.9%	342c/Kg	$23.59

Table 1 shows the difference in wool value from sheep grazed for longer on saltland pastures. Mob A grazed saltland pastures for 4 months from December to March following 8 months (April to November) on annual pastures. Mob B grazed saltland pastures only in December, being on annual pastures for the rest of the year. Both mobs were shorn in April. In addition, Mob B had supplementation of approximately $2.00 per head of lupins in February and March.

In February 2001, a benchmarking trial was commenced on "Bundilla", as part of the Animal Production from Saline Lands Initiative. Two hundred merino wethers were introduced to 25 hectares and have been grazed there since. Though the sheep had eaten all the meagre groundcover by mid-March and only had 2 Kg hay/hd/week to supplement the saltbush, they have maintained condition and gained weight slightly. The wool on some of the sheep was dye-banded and showed good growth of wool over the period from February to May.

As mentioned above, *Paradana balansa* was tried, but with a minimum rainfall requirement of 400 mm per annum, and "Bundilla" averaging around 330 mm, it was unrealistic to see this as the answer. We needed an annual pasture plant, preferably a legume, with salt and waterlogging tolerance that would be suited to the lower rainfall areas.

In 1998, 1 kg of a new selection of balansa *(frontier)* was obtained, and this showed promise. Growth in the first year was impressive, with subsequent years' growth also above expectations. One advantage seems to be the large amount of bulk it produces in late July when there is little other feed available. Subsequently, more of the balansa variety *frontier* has been planted. In conjunction with this, and with the evidence of the watertable drawdown by the saltbush, the rows of saltbush have been placed further apart to allow seeding machinery to move between the rows to plant the clover. Sheep have been grazed on these paddocks since February 2001.

Trials will be commenced in 2001 to determine actual water use by saltbush and distances that rows of saltbush can be placed apart and still obtain sufficient watertable drawdown and salt leaching to allow annual cereal crops and pastures to be grown successfully.

In spite of the limited growth of annuals, significant increases have been seen in sheep grazing days in some of the saltbush areas.

Table 2: Sheep grazing days on one 30 ha paddock over the summer of 1993/94. The area was direct seeded to saltbush in August 1991 and grazed lightly in autumn 1993.

Date in	Date out	Total days	Sheep numbers	Sheep days
02/11/93	06/11/93	5	1,300	6,500
06/11/93	13/11/93	7	2,000	14,000
03/01/94	07/01/94	5	650	3,250
08/01/94	11/02/94	35	500	17,500
12/02/94	05/03/94	22	200	4,400
06/04/94	11/04/94	6	660	3,960
12/04/94	17/04/94	6	1,220	7,320

56,930 sheep days @ 30 ha @ 365 days per year = 5.2 DSE/ha (annualised basis)

Table 3. Sheep grazing days in a 32 ha paddock grazed throughout 1999. The area was direct seeded to saltbush in August 1997. It had not been grazed until the sheep were introduced in January 1999.

Date in	Date out	Total days	Sheep numbers	Sheep days
04/01/99	11/01/99	8	450	3,600
11/01/99	08/03/99	56	386	21,616
08/03/99	16/03/99	9	365	2,385
17/03/99	11/04/99	19	480	9,120
01/05/99	06/05/99	6	545	3,270
06/05/99	14/05/99	8	586	4,688
07/06/99	20/06/99	14	375	5,250
21/06/99	01/07/99	11	455	5,005
01/07/99	15/07/99	17	300	5,100
31/07/99	14/08/99	15	300	4,500
16/09/99	26/09/99	11	1,052	11,572
09/11/99	18/11/99	10	465	4,950
19/11/99	22/12/99	34	527	17,918

99,874 sheep days @ 32 ha @ 365 days per year = 8.6 DSE/ha (annualised basis)

It can be seen from the details from "Bundilla" that saltbush, in conjunction with understory annuals and hay, can significantly increase the carrying capacity of saltland. It can also be seen that saltbush can significantly lower watertables.

ECONOMICS – IS IT WORTH IT?

But what of the economics? Is it worth it? From the work done on "Bundilla" and from the experience of other saltland farmers, the answer is undoubtedly "YES". In seasons of below-average winter annual feed production, the addition of hay enables sheep to be retained which otherwise would have to be sold, agisted or fed expensive supplements. All the saltbush is now direct seeded on "Bundilla" with our own seeding machine. Seed is harvested on the property.

Farmers' costs can be reduced significantly if they are prepared to do more of the work themselves. For instance, the retail cost of saltbush seed is around $50 per Kg, but we harvest our own. To get a true cost of establishment all costs need to be included. The actual cash cost for us to seed a hectare of saltbush is the cost of the spray ($10) and vermiculite ($14), a total of $24/ha. For this we would expect up to 2,000 plants per Ha. So much for it being too expensive. Where else could we more than treble production from an area of land with such a small additional cost?

Table 4 shows the relative cost of contractor versus farmer operated direct seeding. If the row spacings are increased with less rows of saltbush per hectare, the costs for both contractor and farmer-seeded will be reduced accordingly.

Table 4: Relative cost of contractor vs farmer-operated direct seeding

Activity	Farmer cost	Contract cost
Contract cost	0	150
Seed costs	4	Inc.
Vermiculite	14	Inc.
Machine hire	15	Inc.
Tractor value	6	6
Operator time	10	Inc.
Spray costs	15	15
TOTAL	64	171

While the cost per hectare is one thing, farmers will need to know that they can achieve economic returns from the saltland. Will there be enough money from the stock to pay for it? Our experience shows that these costs can be recouped in a short time frame.

On "Bundilla", we have been able to increase the stocking rate from under 2 DSE/Ha to more than 8 DSE/Ha without additional clovers. With the addition of balansa, this should increase further. If we assume a cost of $6.00 per head to run the 8 sheep per Ha, cut 6 Kg of wool per head at $3.00/Kg and the fertiliser cost is $20.00/ha, the total cost will be $68.00/ha for a return of $144.00/ha. A gross margin of $76.00/ha.

WHERE TO NOW?

So now we have seen that "Bundilla" has achieved increased profitability and sustainability in the productive use of saltland. Does it finish here? Can we sit back and relax?

No! We need to push on to make this increasing area of saltland more productive. We need to look at other industries that are themselves both profitable and sustainable.

What do we have?

THE FUTURE PASTURES AND THEIR ANIMALS?

Animal production from saline land will always be the "main show in town". Most will see this as sheep and cattle, with goats as perhaps another option. However, we should not be constrained by our current thinking. Are there other animals we can use to graze saltland pastures? What about our native animals? The kangaroos on "Bundilla" certainly enjoy the pasture. Is it possible to farm these and other native species?

In 1998, the *Saltland Pastures Association (Inc.)* proposed to the State Salinity Council that there are one million hectares of saltland in WA that could be revegetated with current knowledge and technology. This proposal was accepted by the Council and now forms part of the State Salinity Strategy released in April 2000. The proposal looks at the revegetation of one million hectares of salt-affected land with halophyte shrubs for fodder production, carbon sequestration and environmental improvement in the Wheatbelt of WA (Malcolm & Lloyd 2001). The Association received funds from the SSC under the 2000 Community Support Program to develop a Business Plan for the implementation of the project. The preparation of the Plan has been contracted to the Department of Agriculture, and is managed by a committee of the SPA.

Fodder production from saltland is well documented in this paper and other places (Barret-Lennard & Malcolm 1995). New plants, both annual and perennial, need to be developed to improve the profitability. There needs to be research into grazing strategies and overall management of the areas set aside for fodder production.

Discussions are continuing with the Australian Greenhouse Office to gain carbon credits for halophyte plantings. While this may be some way ahead, there are potentially significant financial gains to be made in this area.

The environmental aspects of the proposal should not be overlooked. While it is estimated that we could lose a large number of native species of both fauna and flora through the salinisation of the landscape, the revegetation of large areas of saltland will encourage the return of native plants and animals. Farmers will be encouraged to plant conservation areas within the One Million

Hectares project to provide wildlife corridors and havens for fauna.

AQUACULTURE AND OTHER SALINE WATER USES

Another area that requires mention is the "grazing" of fish in saline water, either pumped from the groundwater or surface water. Fisheries WA has developed the Outback Ocean project to grow rainbow trout during winter. While this may seem strange to some people, it is creating widespread interest amongst farmers who are looking to diversify their farm operation. What does the future hold for aquaculture? There are opportunities for both extensive and intensive aquaculture using saline water in Wheatbelt WA - opportunities in increased income for communities, increased employment in the fish processing and tourism potential.

The uses for saline water can be separated into use of the water itself and the processing of the water for salt. Apart from the fish production mentioned above there is potential for algae and brine shrimp production. In South Australia there is interest in trials the growth of an organism in saline water for the production of a petroleum – like product. There is also growing interest for generating electricity using the differential salt concentrations in a body of saline water.

In many areas, salt is used in swimming pools. There is an opportunity to market the salt from saline groundwater for its environmental benefits and even perhaps extract a premium for "Enviro-salt".

OTHER REVEGETATION OPPORTUNITIES

In addition to grazing animals on saltland pastures or in salt water, there are a number of other areas that can achieve production from saltland. These include other plants, and other products from water. As mentioned previously, the SPA project to revegetate one million hectares of saltland will largely rely on plants for animal production. However, there are other opportunities for profitable production from vegetation.

Seed Production

There will be a requirement for approximately 100 tonnes of seed each year for 10 years to achieve the aims of the One Million Hectares project. There is scope to develop this seed production enterprise into a significant export industry. Not only could the seed production be for woody perennials, but could also include grass and clover species developed for saltland.

Other Woody Products

CALM and CSIRO have identified several native tree species with some salt tolerance which are suited to a variety of end uses. High quality timber from eucalypts, firewood from a wide range of species, and brushwood fencing and cineole production from broombush are just a few. With more research, this list can be expanded. Of course, some of these will not grow well and be profitable in all saline sites, and will mainly be confined to the more moderately saline areas, but it really will be a "horses for courses" situation.

CONCLUSIONS

While there may be debate as to the amount of agricultural land that will become saline in the next few decades, there is no debate that the increase will be large. As a community, we cannot ignore the inevitable – that there will need to be changes in our attitude to saltland. This land can become very productive. The examples of some farmers in developing saltland pastures to graze animals are just the start of this change of attitude. We must all "think outside the box" and try to see where the future might lead us. Will we accept the challenge? Will we be prepared to change the way we farm both saline and non-saline land to make it more productive and more sustainable?

Saltland is Australia's fastest growing agricultural resource. What we do about it is our challenge. Are we prepared to change? The future is in our hands.

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THE CHINOCUP STORY

Barbara Morrell[1], Tom Hatton[2] and Peter Curry[3]

INTRODUCTION

The Lake Chinocup Catchment Resource Management Committee had its origins in 1996, when challenged by the Minister for the Environment at the time, Mr Peter Foss, to show community support for landcare within the Lake Chinocup Catchment. This was because, as a community, we were supporting the application from a member of our community to mine gypsum from the A-class Lake Chinocup Reserve. The community had to give guarantees to do landcare work in an effort to save the reserve from salinity. In exchange, gypsum would be able to be mined from the reserve. In 2000 mining commenced.

During the time that negotiations were occurring between the community, the mining proponent and the Government, much progress occurred on the local landcare front:

- The community drafted a Catchment Management Plan, with the assistance of the Departments of Agriculture, Conservation, Regional Development and Environmental Protection.
- Baseline data was collected, against which targets and milestones could be set.
- The mining proponent agreed to pay the community a royalty of 50 cents per tonne to be used to implement the Catchment Plan.
- An NHT grant was received to employ a Community Landcare Coordinator.
- An NHT grant was obtained by two of the sub-catchments to revegetate areas and protect remaining remnants.
- Two of the sub-catchments went through the Focus Catchment process with the Department of Agriculture.
- An NHT project to set up a bore monitoring program was implemented.
- The Committee became incorporated.
- Six hundred thousand trees were planted over a five year period.
- The Pingrup town was accepted in the Rural Towns program.
- Two thousand hectares of remnants were fenced.

You can see by the above list that the farmers living in the Lake Chinocup Catchment were very active in two ways, firstly through their own smaller catchment groups and secondly through the larger Lake Chinocup Catchment.

Unfortunately, while all of this activity was occurring, the level of salinity ***increased*** by two percent across the catchment.

DESCRIPTION OF THE LAKE CHINOCUP AREA

Location

The Lake Chinocup Catchment is located in the Shire of Kent and takes in approximately 60% of the land in the Shire. The area of the catchment is 3500 sq km, which includes many large Nature Reserves including the Lake Chinocup Reserve (19,825 ha) and part of the Lake Magenta Reserve (~94,000 ha).

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The population of the catchment is approximately two hundred people. It is a rural community reliant on agriculture. One town, Pingrup, is located within the catchment; seventy of the two hundred people live in the town. Pingrup was gazetted on 9 May 1924. Population trends during the last year show a 16% drop over that period.

The Lake Chinocup Catchment forms the headwaters of the Swan Avon River system in the zone of Ancient Drainage, in which run-off accumulates locally in terminal lakes (Figure 1). Overflow out of the catchment only occurs in exceptionally wet years. The area centres on the Lake Chinocup Reserve.

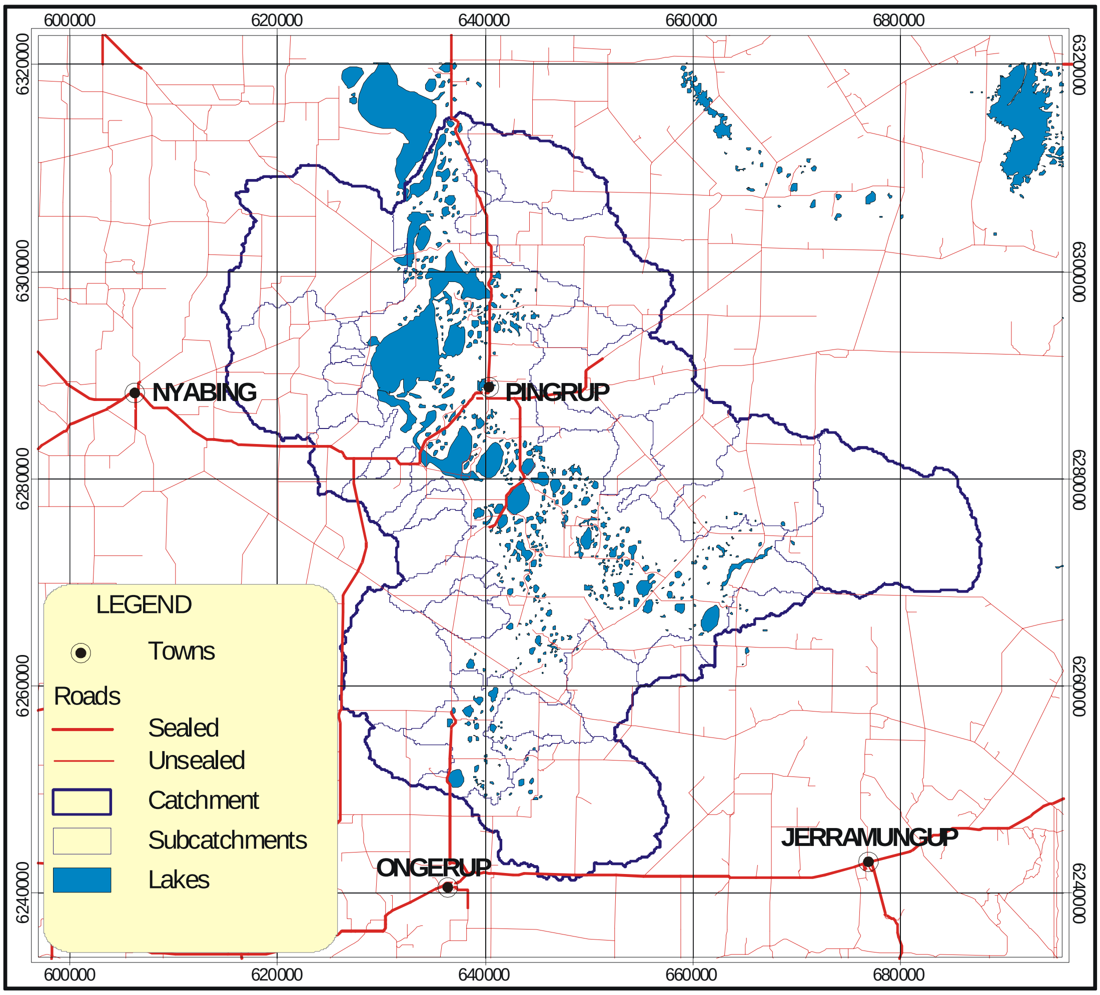

Figure 1: Location of the Lake Chinocup Catchment

Land Use

The major land use is cereal and sheep farming, with an emphasis on wheat and barley production. Crops such as canola, lupins and other pulse crops are increasing in area. Many farmers within the catchment are trialing high water using fodder crops such as lucerne, summer crops and Balansa clover. Farmers have also started to plant commercial tree crops such as oil mallees as well as other tree species for nature conservation.

Sheep are bred mainly for their wool with fewer concentrating on breeding fat lambs for the meat market. There are 60 farming families with property in the Lake Chinocup Catchment. Approximately 80,000 tonnes of wheat and 30,000 tonnes barley are produced annually. Wool production is at about 750,000 kg annually from 250,000 sheep.

Vegetation

The Pingrup district was originally covered in thick mallee scrub. It was developed (cleared for agriculture) in various stages, the oldest being approximately 85 years ago, while the newest is 25 years. Approximately 80% of the landscape has been cleared for agriculture. The remaining remnant vegetation is in the form of Conservation Commission controlled Reserves, vacant Crown land and Road Reserves, with approximately 10% remaining on farms.

Soils

The district consists of a large bank of salt lakes running from south to north with slightly undulating lands surrounding these lakes. Soils vary from very sandy to heavy clay; all however are relatively shallow soils over a clay base (Figure 2).

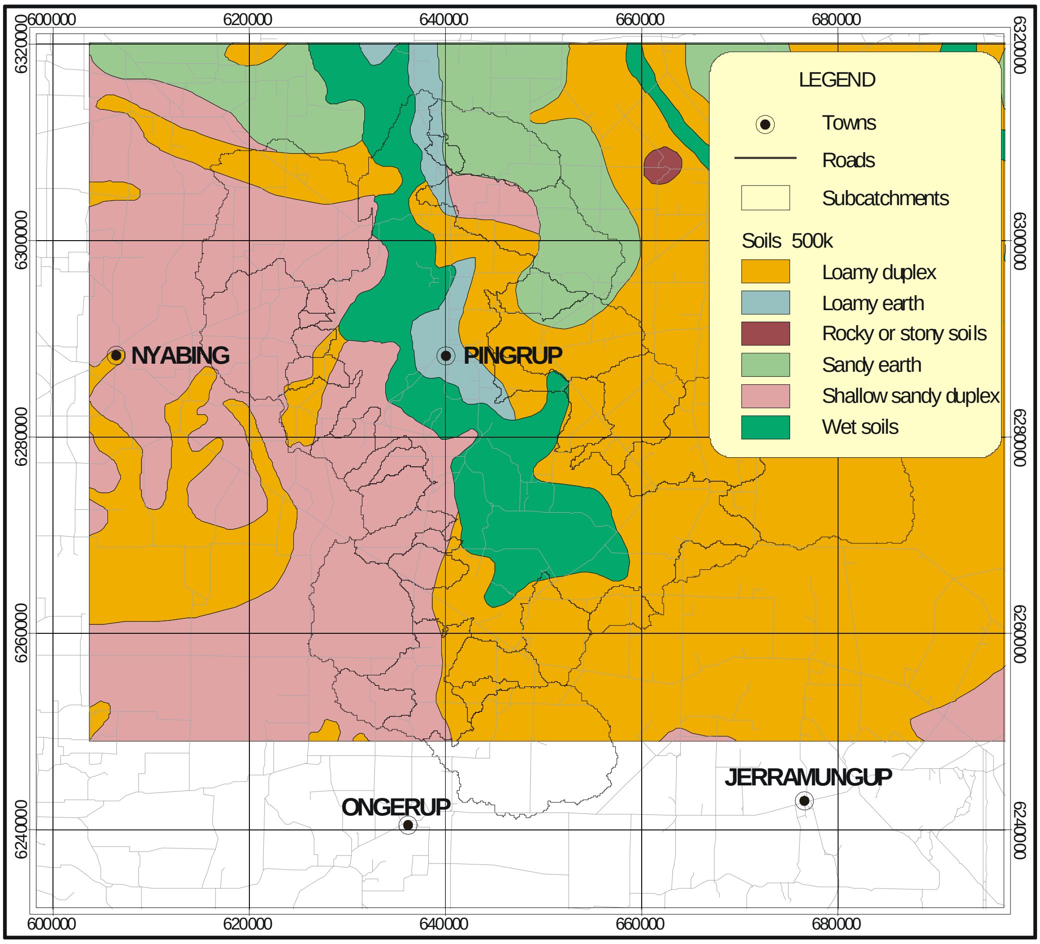

Figure 2: Lake Chinocup Soils Map

Hydrology of the Area

Detailed hydrological studies of the Pingrup town catchment through the Rural Towns Programme, and the Minelup Creek Catchment and Range Road Catchment through the Focus Catchment Process, have been completed.

A drilling project, which has placed piezometers and observation wells throughout the catchment, is in place. These were drilled in 1997 to 1998 and are NHT funded. Lewis & Nelson (1994) concluded the following about the area's hydrology:

- Average annual recharge under agriculture is in the order of 5–50 mm. Coarse textured soils probably contribute most recharge to the catchment aquifers, but some areas with finer textured soils are likely to be significant, even without waterlogging conditions.
- The water table is rising below many parts of the catchment at rates of about 10–30 cm/yr.
- Episodic recharge resulting from flood events may contribute most of the recharge occurring below some parts of the valley floor. Major summer storms may contribute a significant

proportion of the recharge, particularly on coarse textured soils.

- Before clearing, most groundwater discharge occurred by evaporation and transpiration from the playa zones, and this is probably still the case although the volume of water discharged through the vegetation has decreased. Groundwater discharge is also occurring in alluvial flats surrounding the lakes, through stringer sand deposits close to the lakes and through valley floors further away from the lakes, which have geological structures controlling discharge.

- Groundwater gradients are low and thus the impact of land treatment will be local rather than regional. For a regional impact the whole area must be appropriately managed.

- The vegetation in the lower areas of the Chinocup Reserve will, in time, be affected by the rising saline groundwater.

- Farm plans need to include a significant area of revegetation if the hydrological imbalance is to be addressed.

The principal landcare issues in the Lake Chinocup Catchment are:

- Declining condition of remnant vegetation
- Inefficient water use
- Poor drainage/ waterlogging
- Rising groundwater levels
- Flooding
- Salinity
- Inappropriate land management systems
- Wind and water erosion
- Soil structure/nutrient/biota decline
- Soil acidity
- Habitat loss, modification or fragmentation
- Loss of productivity

LANDCARE IN THE LAKE CHINOCUP CATCHMENT

The Nyabing-Pingrup LCDC was formed in 1989 and is made up of 14 sub-catchments; six of which make up the Lake Chinocup Catchment. Within the Lake Chinocup Catchment there were two Focus Catchments: Range Road and Minelup Creek.

A landcare coordinator was first employed in the Shire in 1995. He filled the position from 1995 to mid-1998. The second coordinator took over the role in September 1998. Our current coordinator began in October 2000. The Community Landcare Coordinator works with the community to help achieve sustainable farming systems and keep agriculture viable in the long term through maintaining and improving the sustainable productive capacity of the land and halting/preventing land degradation. As well as developing sustainable farming systems, emphasis is placed on protecting remnant vegetation and enhancing biodiversity. Much activity is financed by individual farmers as well as work done in catchment groups and externally funded works.

Landcare related activities in the Lake Chinocup Catchment include:

- Revegetation.
- Best Practice agricultural production methods.
- Protection and management of remnant vegetation and revegetated areas.
- High water using crops and pastures.
- Implementing, monitoring and revising the Lake Chinocup Catchment Plan.
- Funding.
- Monitoring.
- Establishment of baseline values for all key indicators.

BASELINE DATA ESTABLISHED IN JANUARY 1977

(54 farmers responded to the survey)

- **Revegetation and Remnants**

  – 306,540 trees were planted on 54 properties
  – 80% success rate
  – 30% of farmers planted for beautification
  – 30% planted for wind erosion
  – 30% for water table reductions
  – 15% for water erosion
  – 30% for shelter belts
  – 10% for wildlife corridors
  – Most farmers planted for several different reasons

– 3,477 ha of remnant vegetation or 33% on farms is fenced

- **Salt Affected Land**

– 3,069 ha which once grew cereal crops can no longer grow them.

- **Alternate Crops**

– 50% of farmers grew lupins.
– 20% grew lucerne.
– 4% grew tagasaste.
– 20% grew a pulse crop.
– 2% grew oil mallees.

- **Treatments Applied to Land**

– 4183 ha of land was treated with gypsum.
– 150 ha with lime.
– 1,588 ha with dolomite.

- **Piezometers and Observation Wells**

– 82 bore holes in place.
– No formal readings done until this survey.

- **Cropping and General**

– 48% of arable land was cropped in 1996.
– 8.6% of farmland was fenced to the contour.
– 10 farmers were successful in gaining a landcare grant.
– 27 farmers had formal farm plans.
– 3% of crop done conventionally.
– 41% minimum till.
– 28% direct drill.
– 28% no till.

- **Surface Water Control Infrastructure**

– 333 km contour banks.
– 136 km level banks.
– 273 km deep drains.
– 25 km w drains.
– 9 km other.

KEY RESULTS FROM SURVEY HELD IN 1999

(39 out of 76 farmers responded)

- **Revegetation and Remnants**

– 353,660 trees were planted, giving a total of 660,200 since 1994.
– 75% success rate.
– 40% planted for beautification.
– 50% for wind erosion.
– 55% for water table reduction.
– 40% for water erosion.
– 50% for shelter belts.
– 40% for wildlife corridors.
– Most farmers planted for more than one reason.
– 150 ha of direct drilling native vegetation was planted.
– 951 ha of remnant vegetation was fenced giving a total of 4,428 ha.

- **Salt Affected Land**

– A further 812 ha became too salt affected to grow crops, giving a total of 3881 ha.

- **Alternate Crops**

– 79% of farmers grew lupins.
– 28% grew lucerne.
– 8% grew sorghum.
– 23% tagasaste.
– 38% pulses
– 56% grew canola.
– 26% grew oil mallees.

- **Treatments Applied to Land**

– 26% of respondents used lime.
– 46% used gypsum.
– 13% used dolomite.

- **Piezometers and Observation Wells**

– 98 bore holes are in place.
– Readings are taken three times per year, with the results recorded at the Landcare Centre.

- **Cropping and General**

– 56% of arable land was cropped.
– 18% of farmland was fenced to the contour.
– 64% of respondents have successfully applied for landcare grants, or 25 farmers.
– 3% of crop is done conventionally.
– 50% use minimum till.
– 25% use direct drill.
– 40% use no till.

- **Surface Water Control Infrastructure**

– 360 km contour banks, giving a total of 690 km.
– 112 km of level banks, giving a total of 248 km.
– 53 km of deep drainage, giving a total of 320 km.
– 24 km of w drains, giving a total of 49 km.

COMMUNITY VIABILITY AND HEALTH

The community of Pingrup has suffered greatly due to conditions beyond their control. In 1998, two severe frosts occurred, reducing potentially record crops by approximately 60%. In 1999, a previously unheard of occurrence hit the community again.

Another three severe frosts repeated the devastation of 1998, with losses of up to 80% of potential yields lost. In 2000, drought reduced yields to an even lower level than the previous two frosts.

As a result of the three years of greatly reduced income, the average loss of equity was in the order of 10% per year, leaving the community in a very vulnerable position. The whole of the catchment falls within the declared Exceptional Circumstances area.

2001 is shaping up to be the driest on record. Currently, at the time of writing (early July) farmers are in one of the following positions: (1) no crop in the ground yet, (2) some or (3) all in the ground. It depends entirely on tillage methods as to the amount of seeding completed. No tillage or minimum tillage farmers have either all or some in, while traditional croppers have either some or none in. Some crops have emerged, with many now dying; some seed has malted in the ground, while much seed has not germinated due to the extremely dry conditions.

Much of the area is totally reliant on rainfall for all water requirements, and many landholders have been carting both house and stock water from off farm sources for many months. The worst affected areas for lacking water also coincide with the areas with the most salinity.

With a total community population of approximately 200, a loss of even one family is felt. In the last year and a half, eight families have left the district, with three more leaving at the end of the school year. It has meant a net loss of 23 to our community with a further sixteen leaving later in the year. If the dry conditions continue, and another crop failure occurs, many more families will be forced to either sell up, or move off their properties.

Without a vibrant, stable community, implementation of the Catchment Plan and other landcare works will cease. In other words, if there is no community, no one will be left to address the salinity issues.

Without any implementation of the Catchment Plan and other landcare works, much of the land that is not affected by salinity yet will be lost to production of cereal crops and traditional farming, as we know it.

Not only will the traditional farming land be lost to salinity, but large areas of the remaining remnants will also be lost. Current predictions show that if there are no changes to current agricultural practices, then more than 80% of remnants on farms are in danger as are more than 50% of those in Reserves, either Conservation Commission, Crown Land or Shire controlled.

It is vital therefore to keep our community as a functioning, vibrant concern, because without the community in place there is very little chance of tackling the declining biodiversity issues that face the region. Without people, there will be no fight to control salinity. Communities such as Pingrup will only survive to tackle these issues if they are able to be profitable. Without being able to make a living from farming or its associated industries, there will be no money available to do landcare work for the public's benefit. It is therefore in everyone's interest to ensure that communities like Pingrup survive.

It is vital that we realise that without people, no amount of new technology will be effective, as there will be no one left in rural areas to enact these new ways. Community survival should, therefore, be uppermost in the minds of our decision makers.

Terms of trade are not favourable for Australian farmers. We seem to be the only country playing on the "level playing field". Our major competitors are heavily subsidised by their governments, while we are not. This has made Australian farmers the most efficient in the world, but doesn't help us to survive, as the returns for our commodities barely cover the costs of production. Minor weather events, or events occurring somewhere in the world, threaten our viability. With major weather caused events, such has occurred in the last three years, and seemingly continuing this year, very few farmers are able to make a profit. This causes an exodus of families at the very worst, or a change to "survival mode" by the remaining farmers. Very little can be done in the landcare area, as all money is required to try to ensure survival in the short term, rather than looking after the environment on farmers own land, let alone that off farm.

Unfortunately, Pingrup is not unique in this regard. This situation is repeated right across the Wheatbelt.

THE DILEMMA: WHAT TO DO ABOUT IT?

Currently two thirds of farming families have some salinity on their properties. These range from a few hectares to an enormous 30% of previously arable cereal land now being non-productive. Twelve percent of the catchment is currently affected. This may seem a small amount, but when it is your farm that is affected, it can have major ramifications.

Scientists talk of up to 30% of the landscape generally being affected by salinity. Various figures are bandied around, but whatever figure is accurate, it means different things to different people.

Those fortunate enough to have land high in the catchment generally show little concern, as it is not their problem. They will never suffer much, if any, salinity on their properties. It is a problem of those neighbours lower in the landscape, not theirs. Landholders in the middle areas of the catchment are being forced to acknowledge that salinity may in fact be a problem for them, and not just those in the valley floors. This awakening is occurring due to "unexplained" areas of salt affected land suddenly appearing mid-slope, or running up gullies, for no apparent reason. Unfortunately, there are also farmers who through no fault of their own have land low in the catchment in valley floors. These farmers face salinity on a daily basis. If 30% of each catchment becomes saline then the likely scenario for these farmers is almost total loss of their arable land. Farming, as they know it today, will disappear.

This third sector of farmers is forced to accept the results caused not only by their excess water, but that of their upstream neighbours. This makes decision making all the more difficult for them.

The Lake Chinocup Catchment Committee began exploring reasons for this increased salinity. Frequently asked questions included:

- Is my salinity caused by my neighbour's water causing water table rises?
- Is my salinity due to waterlogging?
- Why is there suddenly an area of salinity appearing mid-slope?
- Will planting trees solve my salinity problem?
- Why can't I drain my groundwater off my farm?
- Are there farming systems currently available which will reverse my salinity?
- What can I do with my land that no longer sustains a cereal crop?
- How can I remain profitable?
- What is a sustainable system of farming?
- What percentage of my catchment, and my farm will go saline?
- What needs to be done to save the vegetation found in the Lake Chinocup Reserve?

Getting answers to our questions has always been difficult. When asked, often all we get is a lot of boot shuffling and evasive answers, as even the "experts" are not sure.

The Lake Chinocup Catchment Resource Management Committee asked CSIRO Land and Water, plus the Department of Environmental Protection and Murdoch University, to assist in answering some of these questions and give us a feel for what was happening within the catchment.

SALINITY RISK ASSESSMENT OF LAKE CHINOCUP CATCHMENT

In 2000, the Lake Chinocup Catchment commissioned an assessment of salinity risk under current and alternative land uses. The committee hoped to obtain:

- A clearer awareness of the hydrological processes we are dealing with in relation to our declared goal for managing rising water tables.
- The best available information on options for future salinity management strategies.
- A clearer indication regarding the timescale of likely salinisation and the windows of opportunity for remedial action to reduce salinity risk in particular areas of the catchment.
- A sounder basis on which to draw support for community planning and decision making towards agreed sub-catchment scale environmental management goals which may be needed in relation to saving the natural diversity assets at risk in the Lake Chinocup Nature Reserve, and other reserves, remnant bush, listed wetlands and the many significant environmental values in the catchment, and downstream of it.
- Advice on the extent and nature of any further priorities for obtaining groundwater monitoring data, or other lines of monitoring for environmental outcomes.

The report provided detailed descriptions of geology, surface drainage patterns, geomorphology and groundwater processes across the region. All available hydrological information was used to infer groundwater levels and flow lines. Due to the absence of adequate reduced water level data from existing bores, steady state water level maps were produced for the catchment using hydrogeomorphic principles (Salama *et al*. 1996b).

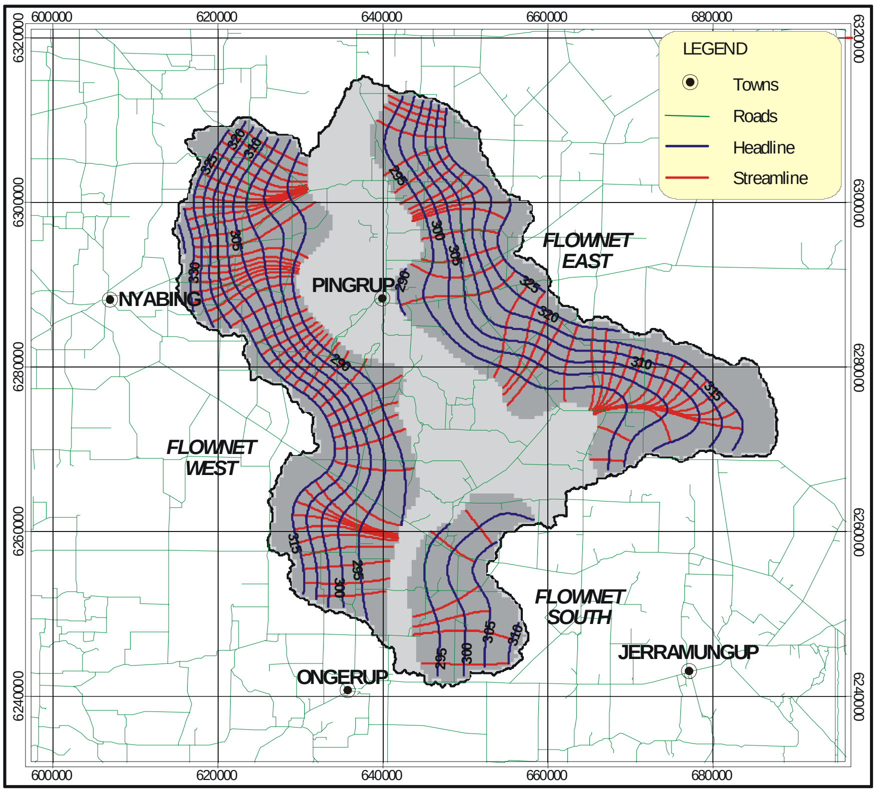

Figure 3: Groundwater Flownet

A simplified flownet (Salama *et al*. 1996a) (Figure 3) was constructed from the generated water level map. The flow net indicates that all the groundwater from the shallow and deep aquifers is discharging into the lake system. It also shows that the groundwater flow in the upper parts of the catchment discharges into the surface streams in confluent areas of the catchment. In the reserve sub-catchment, groundwater discharge is also taking place at the lower parts of the catchment due to the shallow basement in these areas. The map also showed that the general groundwater flow in the catchment is from the west and east towards the central parts of the lakes. The congested flow channels indicate major groundwater accumulation and discharge zones that highlight the hot spots in the catchment. The other important point to be taken into consideration is that most of these lakes, swamps and streams receive subsurface lateral flow from the interface between the shallow sandy topsoil layer and the low permeability clays characteristic of the duplex soils.

Numerical groundwater modelling (FLOWTUBE, Dawes *et al*. 2000) explored the catchment's groundwater behaviour during present and future conditions and its responses to land use changes. This modelling included sensitivity tests of the model parameters, for they were estimated with significant uncertainty. Predictive scenario modelling was performed from present conditions out 100 years for recharge rates of 10 mm, 20 mm, 40 mm and 60 mm for three flow tubes from three major sub-catchments and one flow tube representing 9 minor sub-catchments (Figure 4).

The sensitive analysis was conducted using a recharge value of 40 mm that was assumed to represent the average recharge taking place at the present time in this area. Recharge scenarios were performed with recharge equal to 10 mm, 20 mm, 40 mm and 60 mm per year. For these simulations, the values for hydraulic conductivity (0.5) and specific yield (0.1) were used. Calibrations indicated that the present day recharge is within the range of 30–40 mm. This was determined by comparing the model results with water level trends in other catchments in the area and water level patterns in drilled wells in the catchment. By increasing recharge to 60 mm the aquifer fills up more quickly and the final groundwater head is closer to the surface in most areas and above the surface in discharge areas. When recharge is reduced to less than 10 mm the groundwater head falls in most areas to levels reported and considered as a pre-clearing situation.

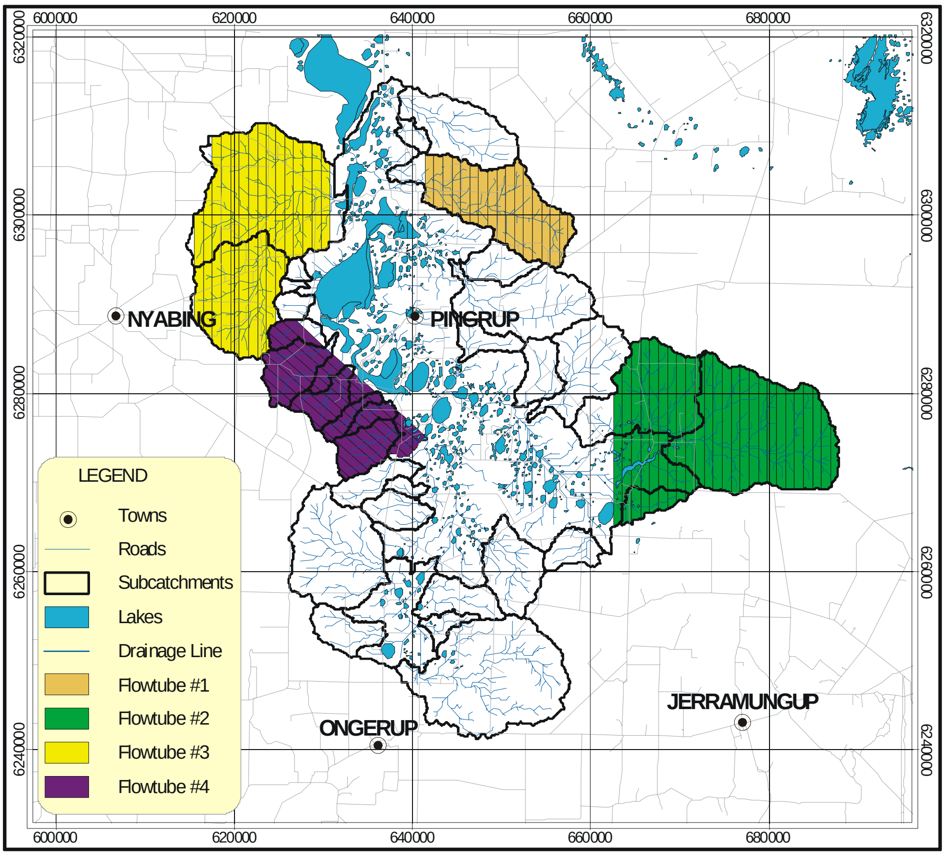

Figure 4: Modelled sub-catchments

FLOWTUBE modelling was used to model the effects of four recharge scenarios: 10, 20, 40 and 60 mm on water levels and groundwater discharge to 2100. Four sub-catchments were modelled. Flowtube#1 represented the flow patterns and rates of rise in a single stream catchment. Flowtube#2 simulated the flow in the presence of the reserve and showed the effect of vegetating more than 50% of the catchment on groundwater levels and groundwater discharge. Flowtube#3 represented multiple flows from a large sub-catchment. Flowtube#4 represented nine minor sub-catchments.

The results of FLOWTUBE modelling for Flowtube#1 (Figure 5) showed that at the present rates of recharge (40 mm), water levels will continue rising at a rate varying between 0.1–0.35 m year. The rate of rise varied depending upon the position in the landscape, with the highest rise being in the upper parts of the catchment that receives the highest recharge. Reducing the recharge to 20 mm, the rate of rise would range between 0.05–0.18 m per year, while reducing the recharge to 10 mm the rate of rise would be only 0.01–0.06 m per year.

Although reducing the recharge rate does not reduce water levels except when the recharge rates are reduced by 90%, the results of the FLOWTUBE modelling showed that the surface water discharge (overflow from the aquifers and subsurface lateral flow) is greatly reduced from 12,000 m^3d^{-1} for 40 mm of recharge to less than 300 m^3d^{-1} for 10 mm of recharge. On the other hand groundwater discharge through the aquifer system would be reduced from 300 m^3d^{-1} for 40 mm recharge to about 150 m^3d^{-1}. This is not greatly reduced as it is controlled by the aquifer thickness and its capacity of transmitting water.

The results of modelling for Flowtube#2 (Figure 6) showed that at the present rates of recharge (40 mm) water levels will continue rising in the cleared part of the catchment at a similar rate to Flowtube#1. The results also showed that the only effect the reserve had is that it shifts the boundary of the groundwater catchment to the edge of the reserve. Due to the rising water levels in the areas adjacent to the reserve, water level gradients will be reversed and groundwater will start flowing back to the reserve at a rate depending on the hydraulic properties of the aquifer. It is expected that if this trend continues, the marginal areas of the reserves would be progressively degenerated. It is also shown that if the reserve is cleared or lost, more than 57% of the area of the catchment will be waterlogged.

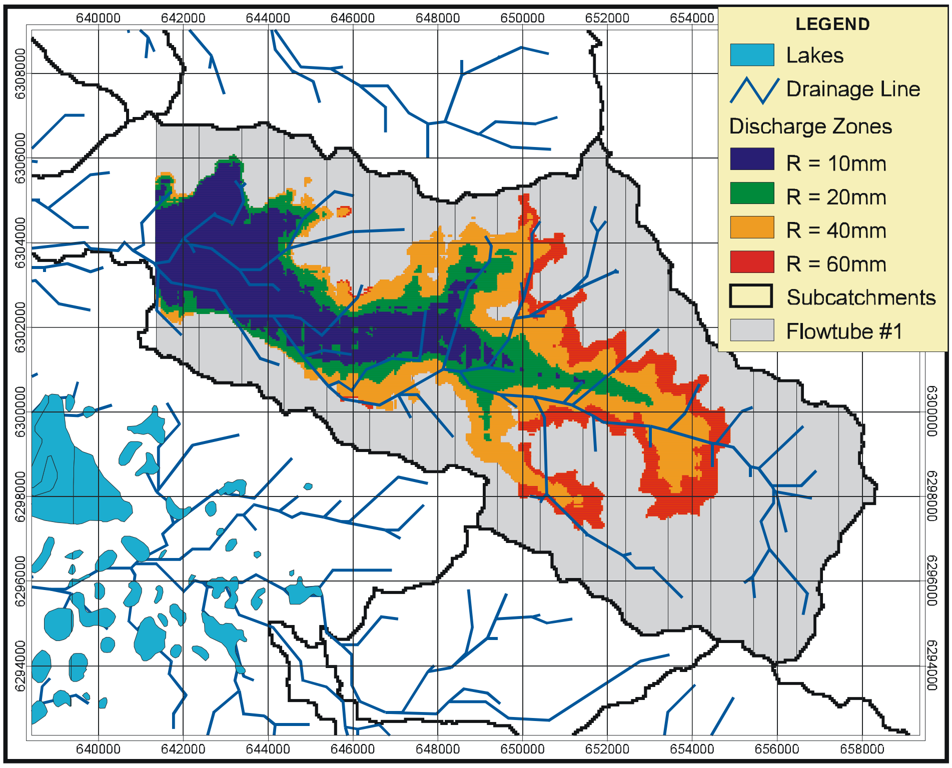

Figure 5: Flowtube#1 Predicted Water tables

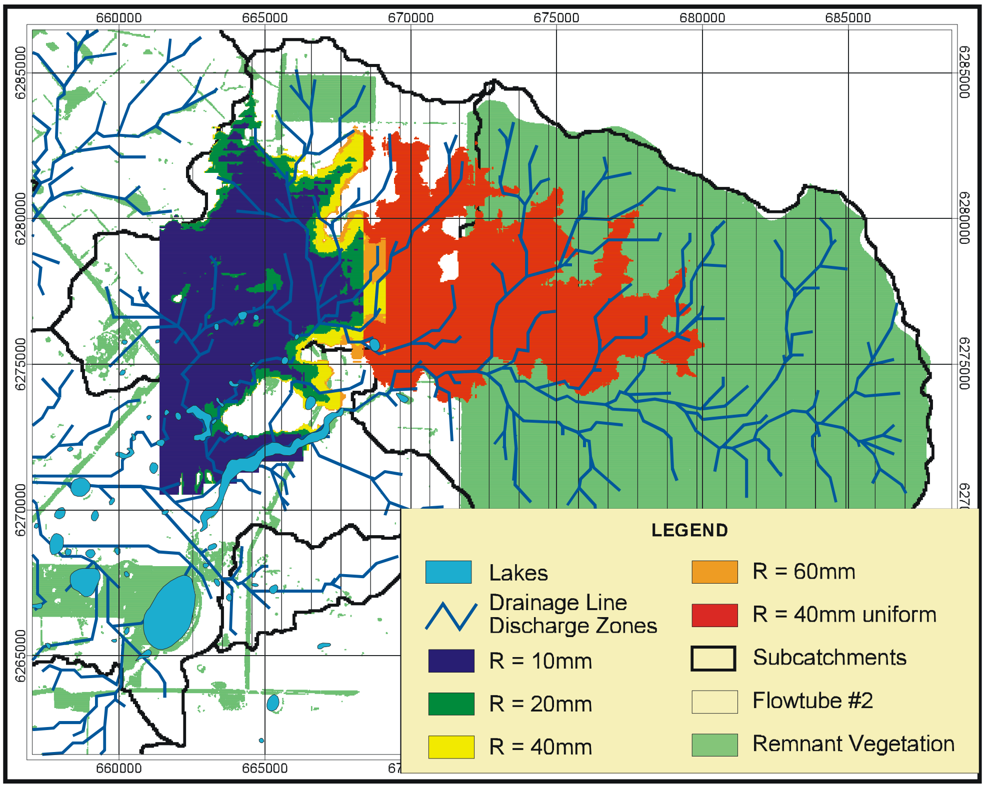

Figure 6: Flowtube#2 Predicted Water tables

Although the waterlogged area under the present regime with the presence of the reserve will be 29% of the total area of the sub-catchment including the reserve, if the area of the reserve is excluded from consideration, the waterlogged area would be more than 60%. While surface and groundwater discharge from this sub-catchment is very low compared to the other sub-catchments due to the presence of the reserve, similar rises of water levels occurred in the cleared areas of the catchment. As these areas are in the lower parts of the landscape and in higher risk areas, the percentage area that will be waterlogged is much higher compared to the other catchments. This clearly illustrates the fact that although planting part of a catchment to trees will reduce surface and groundwater discharge, yet the process of salinisation in the other parts of the catchment will continue largely unabated.

The results of FLOWTUBE modelling for Flowtube#3 and Flowtube#4 showed similar patterns of water level rise to Flowtube#1 and #2.

FLOWTUBE modelling was combined with HARSD techniques to calculate the areas where water level will be within 1–2 m from the surface under the different management options (Table 1). The results show that under present recharge regimes, 45–50% of catchment areas will be waterlogged (groundwater 1-2 m from the surface) after 40 years. Reducing the recharge rates to 20 mm, the affected areas will be 27% in single stream catchments, 37% in multiple catchments and 40% in nine minor catchments that are adjacent to the lake system. On the other hand, reducing the recharge rate to 10 mm, the waterlogged area will be 17% in single stream catchments, 26% in multiple streams and 32% in minor catchments.

Table 1: Percentage of land becoming waterlogged (groundwater 1–2 m from the surface) after 40 years under recharge scenarios of 10, 20, 40 and 60 mm yr^{-1}

Scenario	Flowtube #1	Flowtube #2	Flowtube #3	Flowtube #4
10 mm	17	21 (46)	26	32
20 mm	27	26 (57)	37	40
40 mm	45	29 (64)	50	49
60 mm	55	30 (66)	55	53
Uniform 40 mm	–	57	–	–

(a) no recharge was applied on the reserve area for recharge scenarios 10–60mm;

(b) for a uniform recharge of 40 mm the reserve was cleared. Values between brackets are percentage of waterlogged area in the sub-catchment excluding the area of the reserve

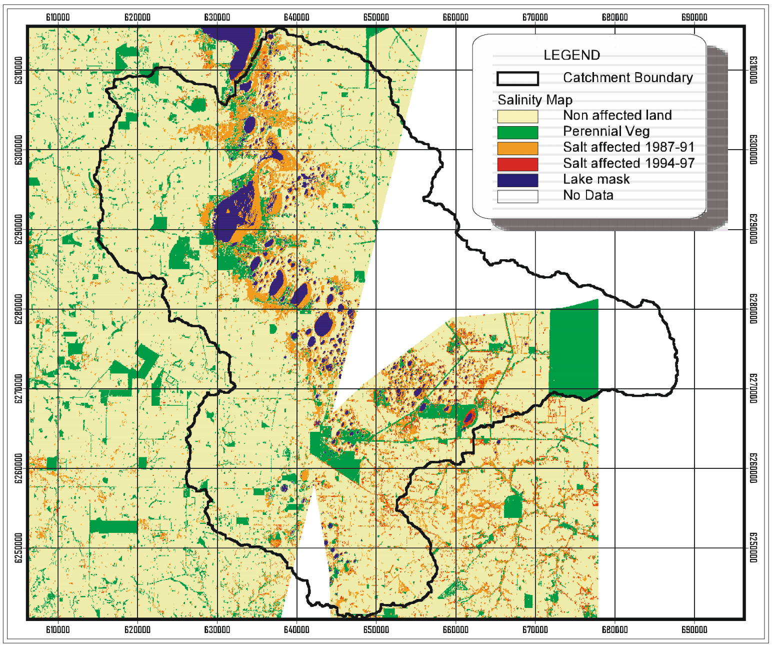

Figure 7: Lake Chinocup Land Monitor Map of Salinity 1997

Table 2: Land Monitor Statistics

Non-Affected Land	72.6%
Perennial Veg	12.1%
Salt Affected 1987–91	9.8%
Salt Affected 1994–97	1.6%
Combined Salt affected area	11.4%
Lakes	3.9%

GROUNDWATER MODELLING DISCUSSION

Based on the results of the FLOWTUBE and HARSD modelling, the following preliminary conclusions were drawn:

- Recharge takes place over most of the catchment (although higher in some places) and most of the groundwater discharge ends up in the lake areas.

- Most of the catchment (50%) will be at risk of shallow water tables in the next 20–40 years. The water levels in the unconfined and perched aquifers can only be controlled by reducing recharge through better agronomic management. If the recharge rate can be reduced to 10 mm yr^{-1}, the area affected by salinity will be reduced to less than 20% of the total catchment area after 40 years.

- The predictive scenario modelling showed that reducing recharge by 90% will be effective in reducing the water levels to several metres below the surface in most parts of the catchment, especially in the high recharge areas. However, due to the gradients that have been created since clearing, groundwater discharge will continue in the lower areas of the catchments for a very long time.

- Although surface and groundwater discharge can be greatly reduced by planting of trees, water level rises in cleared areas of the catchment will not be greatly affected and the process of salinisation in the other parts of the catchment will continue largely unabated for a long period of time.

ASSESSMENT OF SALINITY MANAGEMENT OPTIONS

Salinity management options generally consist of:

- Recharge reduction;
- Groundwater pumping and drainage to lower water tables ;
- Management of the saline land; and/or
- Status quo.

Recharge reduction

The discharge capacity for the deep groundwater systems is estimated to be equivalent to 1–5 mm/yr recharge (i.e. the recharge under native vegetation). The deep drainage under most cropping/pasture agronomic systems generally exceeds that for native vegetation and hence will inevitably lead to rising water tables and increased land salinisation. Hence, as long as agriculture occurs within the catchment, we would expect salinity to also occur.

Recharge control is unlikely to reverse groundwater trends in the foreseeable future. It has been shown that a large reduction in recharge is required to reduce the subsurface lateral flow to the numerous lakes. Even if this is achieved, due to the sluggish gradients and the non-flushing capacity of the system, the salinity already developed in some of parts of the catchment will be difficult to reduce. In nearly all wheatbelt catchments for most years rainfall exceeds the amount of water that can be used by the winter cropping systems and annual pastures. As well as inducing deep drainage and recharge, this can result in waterlogging which affects crop performance.

There are three management strategies that can reduce excess water under winter crops. The first is to ensure the crops have adequate nutrition. The second is to plant the winter crops into drier soil. Annual pastures can create such a buffer on the deep duplex soil but not on the shallow duplex soil. Lucerne can create a dry soil buffer that essentially eliminates drainage through the next crop and fallow from the shallow duplex soil, provided it can extract water to a depth of ~1 m. A third strategy is the encouragement of weedy fallows, which may have a similar effect to pastures in increasing drying of the soil profile prior to the break of season. This could have an effect of 5-10 mm/yr, depending on the weed cover. However, the implications for disease carry over to the subsequent crop and deleterious effects on its nutrition need to be examined before this practice is considered seriously. Summer cropping may have a similar effect, but has a restricted application. The key feature of this discussion is that changes in crop and pasture management are unlikely to achieve the kind of recharge reduction required to significantly reduce the amount of land at risk of salinisation in the longer term. It must be emphasised, however, that recharge reductions can extend the time it will take for salinisation to progress to its full extent. This has value.

Extensive afforestation will reduce recharge to pre-clearing levels in all probability. The feasibility of such an endeavour is questionable. We note that even with the majority of the landscape under dense plantation, water levels in the lower parts of the landscape will continue to rise for a long time as groundwater already in the uplands continues to discharge down slope.

Drainage/Groundwater Pumping

Any response to coping with high saline water tables must consider the value and effectiveness of engineering options. It may be possible to maintain cropping through the judicious use of drainage and surface water control. More intensive engineering interventions (e.g. groundwater pumping) may be justified where built or natural assets at risk have high value. The effectiveness of these more intensive interventions will depend crucially on their design and location with respect to key subsurface hydrogeological features. At present, there is insufficient information about the region to confidently design a drainage or pumping scheme.

The low aquifer transmissivities mean that groundwater pumping is unlikely to be an attractive option except in areas with a more transmissive palaeochannel system underlying the present land surface. These systems have been discovered over most parts of the Wheatbelt and are currently under investigation to assess their capability for increasing the discharge capacity of the system by drains and/or pumps. The difficult problem of disposal of the saline water remains and this must be included as a key consideration in any analysis of the attractiveness of engineering options. It is, however, feasible to save local remnants on a small scale with pumping, at least at a technical level.

Managing saline land

It is clear that the catchment will have more salinised land and water than it does at present, regardless of treatments aimed at recharge control. As the area developing high saline water tables spreads (as it will to some large degree under any reasonable land management scenario), it must be emphasised that not all options for productive use will be closed off. There is ample evidence in the region that saline agriculture (principally, saltland grazing systems) is a feasible and attractive option for many salinity affected soil types (particularly the lighter textured soils). Recognising the likely extent of high saline water tables in the future, plans should be put into place that will facilitate the adoption of new farming systems for saline lands.

Serious consideration and development of industries based on salinised resources is recommended. At present, the National Dryland Salinity Program is awaiting the outcomes of a scoping study aimed at assessing the options and feasibility of such industries. It is recommended that the local community obtain the results when available and assess the local feasibility and attractiveness of saline industry options in the context of the above salinity forecasts.

Status quo

For the status quo option there will be large increases in the areas of shallow saline water tables. Most of the catchment will be at risk of shallow water tables in the next 20–40 years, although only an unknown (but probably large) fraction will actually become saline enough to impact crops.

FUTURE MONITORING

It is essential that a continuous monitoring system be established in selected sub-catchments to monitor the water level trends with respect to recharge and the different management options applied in the catchment. The monitoring system should include all the modelled catchments to monitor the rise in water level and compare it with the modelling results. This will especially include the Magenta Reserve and the sub-catchment downstream of the reserve that showed the highest rise in water levels. In addition, at least one of the wells for the Rural

Town Project in Pingrup should be installed with an automatic water level recorder. In total, it is recommended to install at least twelve loggers and probes in the catchment (approximate cost of $6,000 for the monitoring equipment). It is always better to select wells in the upper and middle slopes of the catchment where most of the recharge is taking place. Monitoring wells in the lower parts of the catchment where most of the discharge is taking place will not be of any use.

WHERE TO FROM HERE

Drought, frosts, terms of trade and other external factors that farmers can have little or no impact on will always be with us. On top of the above, salinity is increasing rapidly, thus further reducing our profitability. The CSIRO/DEP/Murdoch University report suggested that up to 50% of our catchment could be adversely affected by saline water tables within 2 metres of the surface within 50 years if we continue current practices. These predictions are of course a worst case scenario, but the report has given us a feel for the problem facing us.

Questions to be pondered:

- How hard will it be to not let the salinity problem get that big?
- Will it really be as bad as predicted?
- How can we learn to live with it?
- What percentage of salinity are we prepared to live with and can we achieve this level with current knowledge?
- The predictions do not mean that the situation is hopeless, but rather we need some lateral thinking. Are there systems in place to assist this lateral thinking?
- How can we become consistently profitable so that the problems can be addressed every year, not just when there has been a profit?
- Farmers are innovative, but can they come up with the solutions?

FINAL THOUGHTS

We need to decide what level of salinity we can live with and set achievable milestones and targets on our way to achieving this level. Some farmers are prepared to try new ideas without first having proof of the success of it, or if it will be economically sound in the short term. An example is drainage. Farmers' expectations from some actions can differ. Farmers are often merely looking for solutions that will enable them to continue to farm as they currently do, without looking at the short term economic return. New industries that are profitable are required if a rapid uptake of a solution is to be achieved. Farmers have shown that they embrace new ideas very quickly if they see some benefit to themselves.

People are important. If no one remains in rural areas, salinity WILL NOT cease. It will continue to rise. With no one to address these problems, many assets of value will be lost. Therefore a completely new way of tackling the problem needs to occur. Old ideas should be fully explored. No idea should be dismissed, even if it is not addressing the cause, but the symptoms instead. These solutions hopefully will buy us time to discover new ways of addressing and living with salinity. There are too many decision makers who have closed minds, and most of them do not have to live with the results of decisions they make. They merely continue to collect their pay and head back into their own little world. Landholders do not, as some people seem to think, consciously go out to destroy their environment each day, but have to live with both the good and bad decisions they make. Farmers, like all other people, are generally trying to do the right thing by their families, their communities and their environment and should be assisted, and certainly not hindered, in their endeavours.

The risk maps presented to the Lake Chinocup Community have been useful, but for the necessary change to occur top down approaches will never work. Landholders need to be involved at all levels of decision making to successfully tackle this problem.

ACTION FOR POST CONFERENCE

Find the innovative land managers who are working with little assistance and help them develop their ideas into on ground actions. Look again at "integrated catchment planning". The current methods are not working. Some assets of value may need to be given up, e.g. some areas of biodiversity. Prioritise them. Protect our most valuable asset, the rural resident. We are becoming extinct.

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ECONOMICS OF SALINITY IN WHEATBELT VALLEYS OF WESTERN AUSTRALIA

David Pannell[1]

ABSTRACT

Economic, social and environmental dimensions of salinity in wheatbelt valleys are intertwined in a number of ways. For both individuals and the community as a whole, there are limits to the financial resources that can be (or should be) allocated to salinity management, whether for economic, social or environmental outcomes. Sometimes, when considering the options for salinity management, there are tradeoffs which must be made between the economic, social and environmental objectives. Economic incentives influence what farmers and other wheatbelt residents will do to prevent, exacerbate or respond to salinity. This paper commences with a brief description of the links between these issues, so that we can think clearly about the choices in front of us. Then I review the available evidence on the economic costs and benefits of salinity management for impacts of various kinds. I also identify those economic issues about which we have insufficient information. While some aspects of the economics of salinity are rather discouraging, there are also unrealised opportunities to harness economics to pursue win-win outcomes which provide salinity benefits in tandem with other benefits.

INTRODUCTION

In Western Australia, the story of salinity is largely the story of wheatbelt valley floors. The valley floors are special in a number of ways. Today, they contain the worst of Australia's dryland salinity problem, but historically, they were where agriculture was first established in the region, and they often produced the best crop yields. They are home to a host of unique biology, and are the sites of creeks, rivers and lakes. Because of their flatness, valley floors often determined the routes chosen for railway lines, and consequently the locations of many towns now suffering salinity damage. The drawing power of the railway lines is illustrated by the siting for the town of Merredin. The first dwellings established in the locality were on the valley slopes, north of Merredin Rock (near the current golf course), probably to provide easy access to fresh water from the rock. After the railway was installed along the valley floor, the town moved. To my eyes, wheatbelt valleys *look* special, in their vastness and their gentle curves and slopes, reflecting their great age.

The salinity story is complex and multifaceted. Economics is only one facet but clearly it is an important one. Economic development was one of the key objectives in opening up and clearing the Wheatbelt in the first place. These days, many see the harnessing of economic incentives as providing the best prospect for dealing successfully with the salinity which resulted from that clearing (Pannell 2001).

But it is also important to recognise the social and environmental dimensions of salinity. This paper starts by exploring the links and inter-dependencies between economics, social issues and the environmental in the context of salinity. After that, the importance of economic incentives as drivers of behaviour are discussed. Then I review the economic costs and benefits of salinity management in wheatbelt valleys, breaking the review into three sections: agriculture, infrastructure and the intangibles. Finally, the opportunities to harness economics as a force to deal constructively and effectively with salinity are discussed.

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ECONOMICS, SOCIETY AND ENVIRONMENT

As noted above, economic development objectives provided much of the impetus for clearing almost all of the WA Wheatbelt, starting with the valley floors, over the course of the twentieth century. However, social objectives played a key role as well, particularly the objective of providing for returned servicemen following each of the World Wars (Beresford *et al*. 2001). It is hard to distinguish between economic and social objectives in that context. Environmental objectives did not appear to be high on the agenda until late in the Century, but this has changed radically. Indeed, an environmental issue (commercial harvesting of logs from old-growth forests) is credited with contributing substantially to the change of State Government in Western Australia in 2001.

The old-growth forest issue involves difficult and sometimes messy tradeoffs between environmental, social and economic outcomes. Increasingly, salinity will do so as well. Here are three examples which illustrate the shape of things to come.

1. *Disposal of saline water pumped from under towns.*

In towns located on valley floors, such as Merredin and Katanning, prevention of salinity damage will require engineering works, particularly pumping. Disposal of the water poses problems. Use of evaporation basins will be expensive enough in some cases to tip the economic equation away from salinity prevention. Disposal of the water in a creek or river may be the only way it can be made cheap enough to be worthwhile protecting town infrastructure, but this clearly requires a judgement that the damage to the creek or river system is not excessive. Another proposal is to use the pumped water to irrigate salt-tolerant plants, but the feasibility of this would need further investigation.

2. *Social impacts from land use change*

Salinity prevention requires massive land use change. Few people have appreciated how far reaching will be the consequences if we are successful in achieving change on the scale needed. The experience of blue gums on the south coast reveals that social impacts will be prominent among the concerns of local communities. There are grounds to hope that many of the social impacts from new perennials in the Wheatbelt will be positive, but this may require government intervention to curb some of the desired activities of business interests. On the other hand, the involvement of such business interests seems essential to finance perennial establishment over a large scale.

3. *Budget limits and the need for prioritisation*

Protecting assets from salinity is expensive. There are many assets at risk, and there will never be enough public money available to protect them all. Hard decisions will have to be made to prioritise the assets under threat. Is this wetland more or less important to protect than that town?

The sort of trade-offs involved in these examples are the stuff of politics. They will inflame communities, especially those groups who feel they are losers, but they may also act as catalysts for community action and consensus.

ECONOMIC COSTS AND BENEFITS OF SALINITY MANAGEMENT

Until fairly recently, economists considering salinity most commonly attempted to estimate “the cost of salinity”, usually in comparison to a mythical and unachievable scenario of zero salinity. “The cost of salinity” by itself is a concept of almost no practical value (Van Bueren & Pannell 1999; Bathgate & Pannell 2002). Indeed, the large estimated costs have probably done more to mislead thinking about salinity than to improve it. It is better instead to focus on the costs and benefits of specific management strategies, allowing for realistic levels of effectiveness. As much as possible, that will be the perspective taken here.

Agriculture

Salinity management practices for agriculture are considered here in three categories: prevention, living with salinity (adaptation), and repair.

Prevention of salinity

The term “prevention” is used here to mean avoidance (in part or in full) of a further worsening in salinity. It is not intended to imply a reduction in current levels of salinity. The scales of treatments recommended by hydrologists for preventing the various impacts of dryland salinity are daunting, particularly in large wheatbelt valleys. In recent years, we have lost earlier hopes that large-scale preventative impacts on salinity could be achieved by clever selection and placement of relatively small-scale treatments, or by changes to the management of traditional annual crops and pastures (in all but the most localised and small-scaled groundwater flow systems). The new consensus is that large proportions of land in wheatbelt catchments would need to be revegetated with deep-rooted perennial plants (shrubs, perennial pastures or trees) for at least part of the time. The perennials would need to be integrated with engineering works, particularly shallow drainage for surface water management. (Deep drains are discussed below under the heading of "Repairing Salinity")

Even with major revegetation and surface drainage efforts, the degree of salinity prevention in the long run in wheatbelt valleys will probably be less than we would like. Figure 1 shows the results of hydrological modelling for several catchments in Western Australia (George *et al.* 1999). These results indicate that if recharge across a catchment were reduced by 50%, implying perennials on more than 50% of the land, the eventual area of salinity in the catchment would be reduced by 3 to 12% of the catchment.

(Strictly, the indicator of salinity risk shown in Figure 1 is not "area" but "flowtube length". The results are reasonably indicative of those which would be obtained from an analysis based on area. Responsiveness to recharge reductions would be slightly greater on an area basis.)

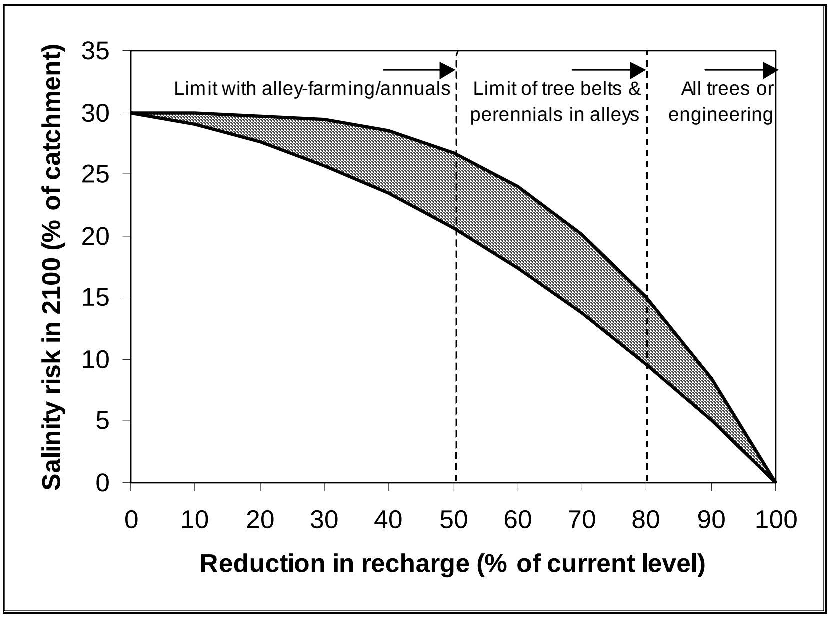

Figure 1: Responsiveness of dryland salinity to reduced recharge (e.g. from perennials or drainage) in a range of catchment types in Western Australia, assuming that "business as usual" would result in salinisation of 30% of the catchment. (Source: based on George *et al.* 1999)

These are modelling results, rather than field measurements, so perhaps the reality will not be so severe. Nevertheless, even if the true responsiveness of salinity to preventative treatments is twice as great as shown in Figure 1, the economics of perennials look adverse, unless the perennials themselves can generate income directly.

How much income would perennials need to generate to be worth growing? Figure 2 shows results of calculations done by Bathgate & Pannell (2001) to answer this question from the perspective of farmers. The answer depends on issues like:

- the area of land protected from salinity per hectare of land sown to perennials;
- the cost of establishing perennials;
- the interest rate;
- the time lag until salinity would have occurred;
- the income from crops or pasture on the land if not replaced with perennials; and
- the potential to earn income from grazing off salinised land.

Bathgate & Pannell (2002) specify the assumptions they made about these and other factors.

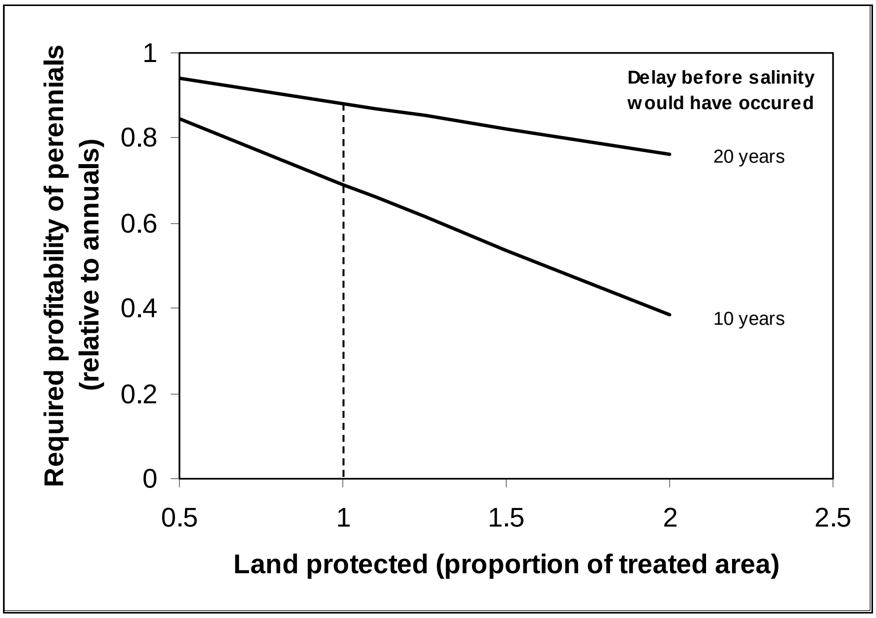

Figure 2: Break-even levels of direct profit from perennial-based farming system required to match long-run financial performance of traditional annuals, allowing for salinity-prevention benefits of perennials

Figure 2 shows how much direct profit would be required from the perennials to justify their inclusion on the farm, from a narrow financial perspective. Consider the result for a lag of 10 years before salinity occurs. The figure shows that if the area treated equals the area protected ("land protected" = 1.0), the perennial would need to generate profits at least 70% as large as the traditional agricultural enterprise grown on the land in question. As the protection of additional untreated land increases, there is a fall in the profitability required to break even, while longer time lags before salinity result in a greater profit requirement.

Even in the most favourable situation, perennials must do better than covering their input costs. For time lags of 20 years or more, the profitability of perennials must nearly equal that of traditional crops or pastures, even if land protected is greater than land treated.

Overall, the results show that the indirect benefits of perennials due to salinity prevention will be small relative to their direct, short-term benefits and costs. In wheatbelt valleys of Western Australia, it appears that it is rarely possible to implement treatments that protect much more than the land on which they are situated (and perhaps not even that much). This information requires us to fundamentally re-think the nature of the salinity abatement problem. It implies that for adoption of perennials to be financially attractive to farmers, the perennials need to be directly profitable, without considering the benefits of salinity prevention. (Alternatively, the indirect or non-financial benefits other than for salinity need to be sufficient.)

In the past, the interdependence of farmers within a large catchment has been emphasised. At least with respect to movements of groundwater, Wheatbelt farmers are now seen to be much less dependent on each other for groundwater management. Importantly, it is now known to be possible for groundwater management to be effective locally, at least temporarily, even without cooperation from neighbours. Typically, soils in the large wheatbelt valleys of Western Australia have low "transmissivity", meaning that little water passes through them. This, combined with the very low slopes, means that lateral water movement is very slow indeed and transmission of pressure is low. Even if equilibrium areas of salinity are reduced (as in parts of Figure 1), the planting of large areas of perennials is likely to delay the process of reaching that equilibrium by between 20 and 80 years (Campbell *et al*. 2000). This delay is worth money directly, and it may also buy time for better management options to become available.

But the treatments still need to generate money directly. The availability of perennial options which can generate an income will be critical for our future salinity management in the Wheatbelt. A big effort to prove (and improve) lucerne is underway. The other option on the horizon is oil mallees. Oil mallees appear likely to become profitable for farms located within the transport limits of processing plants/power generators (Bartle 1999; Cooper 2000; Herbert 2000). A pilot plant is planned for the town of Narrogin. However it is clear that we will need many more options that these two. The new Cooperative Research Centre for Plant-Based Management of Dryland Salinity has as its prime objective the development of new profitable plant based options for salinity management.

Living with salinity

Farmers with large areas of salt-affected land are already trialling and implementing farming systems based on salt-tolerant species (e.g. salt bush, blue bush). In addition, there is growing interest in economic uses for saline water (e.g. aquaculture, electricity generation, irrigation with brackish water, algae [e.g. for agar, β-carotene, pigments, fish food], seaweed) and the potential to extract valuable salts and minerals (e.g. magnesium, bromine, potassium chloride) (see http://www.ndsp.gov.au/opus/menu.htm for the OPUS database, accessed 5 June 2001).

There has been little recent economic analysis of these practices (which seems an important oversight). However, there is reason to expect that they will become of considerable economic importance. Much of the forecast salinisation of land is not technically avoidable without implausibly large changes in land use. The plant-based options for saline land have at least one advantage over perennials planted in recharge areas. Recharge areas are still productive and valuable for traditional production, so farmers will be reluctant to switch to other land uses unless they are about as profitable. Establishing salt-tolerant species on salt-affected areas does not involve the same sort of sacrifice. Therefore, provided that up-front establishment costs are low enough and/or adequate productivity can be demonstrated, the prospects for widespread adoption of new salt-tolerant plants for economic production on salt-affected land appear good. Another advantage is that feed availability from salt-tolerant pastures can be timed to reduce the autumn feed gap, and therefore to increase year-round stocking levels. This remains an advantage so long as the area of salt-tolerant pastures is not so great as to more than fill the feed gap.

Repairing salinity

Many farmers would prefer to repair salinised land and continue with traditional agriculture, if that is possible. This requires engineering. Deep open drains have been installed by many farmers to enhance discharge. Measurements by researchers have found that they reduce groundwater levels within only a few metres of the drain on high-clay soils and rarely more than 40 metres on favourable soils (George 1985; George & Nulsen 1985; Speed & Simons 1992; Ferdowsian *et al*. 1997). However farmers have observed positive effects of deep drains on plant growth over greater distances than this. It is not clear whether these effects at a distance are due to reductions in groundwater levels or reductions in water logging (which could probably be achieved with much cheaper structures). An economic analysis of deep open drains on agricultural land by Ferdowsian *et al.* (1997) reached negative conclusions about their cost effectiveness, but given farmer observations and new evidence that is emerging about their effectiveness in some situations, further research and analysis is needed. A key issue to resolve with deep drainage is the cost-effective and environmentally safe disposal of discharged waters.

Proposals to construct major regional engineering systems, fed by pumping from agricultural land, have been made (Belford 2001; Thomas & Williamson 2001). Particularly in view of the very great resources involved, these proposals would need very careful investigation before funding could responsibly be provided.

Infrastructure

The impacts of salinity on built infrastructure have received increasing attention. According to the National Land and Water Resources Audit (2001), assets across the country at high risk from shallow saline watertables by 2050 include 67,000 km of road, 5,100 km of rail and 220 towns.

Rural towns

Low water "transmissivity" of soils was described earlier in relation to agriculture. It also has important implications for rural towns on valley floors. It is estimated that it would take 3000 years for groundwater to move from the top of the Merredin catchment to Merredin town (Matta 1999). Clearly, the only land that has contributed groundwater directly to Merredin town site in the 100 years since the region was developed is land in or very close to the town site. In particular, areas such as roads are an important source of recharge waters. Hydrologists recommend that the most important and effective treatment for preventing salinity damage within town sites is reducing recharge within the town site, and/or enhancing discharge in and around the town by engineering treatments, such as pumping (Matta 1999; Dames & Moore – NRM 2001). It is believed that, in most cases, benefits from revegetation of surrounding farm land will be insufficient and/or too slow to prevent major damage to town infrastructure.

For towns such as Merredin, which have fresh water piped to them for domestic use, the problem is exacerbated by release of this imported water into the ground from garden irrigation systems or septic tanks. For some towns in Western Australia (e.g. Cranbrook, Tambellup), imported water and runoff from roofs and roads accounts for a substantial part of the groundwater rise within the town.

The Rural Towns Program is concerned with 42 WA towns facing salinity impacts. A number of these towns have been subjected to hydrological studies to identify systems of intervention which would be needed to reduce the impacts of salinity, and for six of them, detailed economic analyses of these interventions have been conducted. These are very important studies and they have major implications for the management of salinity in the towns. Some of the common findings from the six towns are listed below, drawn from the report by Dames & Moore – NRM (2001).

In low-lying towns like Merredin and Katanning, groundwater beneath the towns has low rates of lateral flow through material of low transmissivity. The implication is that actions taken to reduce groundwater recharge higher in the catchment will have very little impact on groundwater behaviour beneath the town within time frames needed to prevent damage. The corollary is that actions to prevent groundwater rise or to lower existing levels need to occur within or immediately adjacent to the townsite.

- Surface water management within the towns is inadequate. In some cases, observed damage is being caused by poor domestic water management or a lack of sealed drainage, rather than rising groundwaters.

- Roads are the biggest cost item from salinity in the towns, amounting to about 60% of the total.

- There is great variability in the situation in different towns. Towns need individual investigation and advice in determining the most appropriate course of action. Without specialist professional input, affected towns are unlikely to grasp the approach to urban water management that is needed.

Some of the actions recommended by the consultants are cheap and could be taken up immediately (e.g. appointment of "Water Wise" coordinators to provide advice to householders, businesses and builders). Nevertheless, managing rising groundwaters effectively in most of the towns will require expensive engineering works. In some of the towns, the cost of the recommended works is so high that it outweighs the potential salinity damage costs which would be avoided, implying that living with the salinity damage may be more economically efficient than attempting to prevent it. This is apparent in Table 1, which shows a summary of the economic analysis for each town. The costs shown are total costs over 30 or 60 years, discounted to present values using a 7% discount rate.

Table 1: Summary of economic analyses of salinity management for six towns in the Rural Towns Program

Town	Timing of onset of major costs	Damage costs from salinity if no works undertaken	Total cost of possible works to control rising groundwater	Potential gain from engineering works
(timescale of estimates)	(years)	($ million)	($ million)	($ million)
Brookton (60 years)	4	0.62	0.28	0.34
Corrigin (60 years)	2	0.21	-0.10	0.31
Cranbrook (60 years)	22	0.61	2.3 to 5.7	-1.6 to -5.1
Katanning (30 years)	1	6.9	7.6	-0.74
Merredin (60 years)	26	0.38	1.8 to 4.6	-1.4 to –4.2
Morawa (30 years)	1	0.25	0.90	-0.65

The final column shows an estimate of the net benefits of strong intervention in the towns, based on an assumption that it would result in prevention of all costs listed in the third column. It is striking that in four of the six towns, the economics of the engineering interventions studied appear adverse. The two positive results, Brookton and Corrigin, have the advantage of being able to make some valuable use of the pumped water. Even in Katanning, which is probably the most salt-threatened town in Australia, the costs estimated for disposal of pumped saline water into lined evaporation ponds is so high that it roughly cancels out all the benefits from salinity prevention. If it is difficult to economically justify lined evaporation basins to protect the extreme example of Katanning, it seems unlikely that this approach could pay off in any less extreme cases.

In the case of Merredin, the consultants concluded that "the actions warranted for immediate implementation include advice with water management to reduce recharge and damage to infrastructure, continual improvement in drainage systems, and tree planting within the town to reduce recharge," (Dames & Moore – NRM 2001, p.13).

Other infrastructure

It was noted above that the biggest costs incurred in salt-affected towns are from damage to roads. Roads outside towns will also be affected. Dames & Moore – NRM (2001) based their road costings on a report of the Murray Darling Basin Commission (1994), which reported, for example:

- The average life of sealed roads in Victorian irrigation areas with water tables of 2.0 m or less was 20 years, compared with 40 years for equivalent roads in dryland areas over deep groundwater tables.
- When replacing major highways, the additional cost in situations with shallow groundwater (less than 2.0 m) was around $100,000 per km, on top of the normal construction cost of around $400,000 per km. Repair costs for a major highway due to shallow groundwater (i.e. the cost of patching and repairing the road to maintain the pavement condition) was $10,000 per km per year.
- For a standard sealed country road, estimated construction costs were $100,000 per km, plus $25,000 to $35,000 in locations with shallow watertables. Additional maintenance costs due to shallow water tables would be $400 to $2,900 per km.
- For gravel roads, the construction cost was $7,000 per km plus $3,000 for shallow water tables, with annual maintenance increased by $200 per km for shallow watertables.

Campbell *et al*. (2000) estimated that for the Great Southern region of southwest Western Australia, 1,200 buildings (15% of all buildings in the region), 3,300 km of roads (26%) and 16,000 farm dams (44%) face the risk of damage or destruction from salinity. No similar study has been conducted for the Central, Eastern or Northern Wheatbelt.

Table 2 shows the infrastructure assets "at risk" in Western Australia by 2020 as estimated by the National Land and Water Resources Audit (2001)

Table 2: Physical infrastructure at risk from dryland salinity in Western Australia by 2020, based on predicted groundwater trends and "best guess" future land use.

Asset	Quantity at risk by 2020
Highways (km)	840
Primary roads (km)	745
Secondary roads (km)	1,425
Minor roads (km)	13,650
Rail (km)	1,490

In the National Land and Water Resources Audit (2001) report, costs of these and other impacts were reported for WA in a way which made interpretation difficult. Nevertheless, the results indicated that costs due to road damage will be the biggest single cost due to salinity in this state.

Flood risk

Increased flood risks have been studied for only a small number of case studies (Bowman & Ruprecht 2000). Extrapolating from these, George *et al*. (1999) concluded that, with the predicted two- to four-fold increase in area of wheatbelt land with shallow watertables, there will be at least a two-fold increase in flood flows.

There has been no economic analysis of this additional flood risk or its management. One question is whether the costs of floods will be sufficient to justify major revegetation of catchments. Based on a consideration of the large areas over which flood waters can be collected in wheatbelt catchments, and the occasional nature of floods, my hypothesis would be that flood risk will provide only small to modest additional incentives for establishment of perennials. It may be more efficient to construct engineering works near to flood prone assets. Further economic studies to examine these issues would be useful.

Intangibles

Environment

According to George *et al*. (1999), in Western Australia, without massive intervention, most or all of the wetland, dampland and woodland communities in the lower halves of catchments will be lost to salinity. There are at least 450 plant species and an unknown number of invertebrates which occur only in these environments and are at high risk of extinction (State Salinity Council 2000; Keighery 2000). National estimates by the National Land and Water Resources Audit (2001) are that by 2050, there will be a high salinity hazard for 2,000,000 ha of remnant and planted perennial vegetation, 41,000 km of streams or lake perimeter, and 130 important wetlands.

Economists have taken an increasing interest in environmental impacts such as these. One body of work attempts to place dollar values on intangible impacts such as these (Van Bueren & Bennett 2001). My view is that this is fraught with the greatest difficulties, and probably makes only modest contributions to the decisions we need to make about these assets. Nevertheless economists can make an important contribution to these decisions by quantifying accurately the direct and indirect costs to the public and private sectors involved in protection of environmental assets.

Social issues

There are at least four distinct sets of social issues related to salinity.

1. Community input to planning and decision-making is needed.

2. There are social impacts of salinity and its management.

3. Social issues affect the uptake of new management practices.

4. The community needs support from government to manage and protect assets at risk.

There are economic dimensions to each of these social issues.

1. Community input to planning and decision-making:

The community should play a strong role in setting the objectives of salinity policy and salinity management. The economic dimension here is that the appropriate balance between economic, environmental and specific social objectives should strongly reflect current attitudes and values of the people with an interest. Members of the farming community, in particular, also provide important site-specific and community-specific information (including economic information) about the salinity problem and its management in different situations.

2. Social impacts of salinity and its management:

Among the various impacts of salinity, social impacts are a prominent category. In addition, there are social impacts of salinity treatments.

Losses of productive land to salinity will contribute to declines in farm numbers and farm incomes, with flow-on social effects on rural towns and the provision of services. Overall, salinity is just one of a number of factors contributing to economic pressures on farmers. For most farmers, salinity is far from being the most important of these factors. The rate of adjustment of some farmers out of agriculture is not likely to be greatly influenced by land salinisation, although it will no doubt be the decisive factor for some individuals. Other economic pressures will continue to be the main influence on farm numbers and farm incomes.

In regions where salinity treatments (particularly woody perennials) are adopted at very high levels, their social impacts are likely to be even greater than those of salinity *per se*. To be adopted at such levels, woody perennials will need to be highly attractive in economic terms. In such cases, they will have positive social impacts (e.g. local employment), particularly where processing and value adding of harvested product occurs within rural areas. A good example is the integrated processing plants which have been proposed for oil mallees, to provide oil, energy and activated carbon. Negative social impacts have been strongly identified by some communities in high-rainfall regions where blue gums have been established over large areas. There are reasons to hope that such negative impacts will not occur in the Wheatbelt (Olsen 2001), but it may be a risk in some situations.

3. Social influences on the uptake of new management practices:

Government policies for salinity rely very much on farmers to voluntarily adopt new farming practices to manage salinity. The speed and level of adoption of new farm management practices depends on many factors. The economic profitability of the practices is probably the most decisive influence, but economics interacts with social factors in this realm as well.

The strength of Landcare groups and catchment groups in Western Australia has been high in the past, but farmer dissatisfaction with the Landcare approach has increased in recent years. In part this reflects the new level of understanding in the farming community about the scale of response needed on farms in order to successfully prevent salinity, and a recognition that voluntary adoption of non-commercial treatments will not be viable at that scale. As a result, the importance of economic drivers for adoption of new practices has been re-emphasised.

Even where commercially viable treatments are available, social factors will play a role in their speed of uptake. Group cohesiveness, strength of information channels, credibility of information sources, and demographic trends all play roles. As an example of demographic influences, Barr *et al*. (2000) has identified that many farmers in parts of the Murray-Darling Basin have other sources of income and may view agriculture as a secondary occupation. A proportion are “on a trajectory out of agriculture”. We cannot expect major investments in long-term land-use changes by people in these circumstances.

The above factors mainly relate to the incentive for change. Farmers also vary widely in their *capacity* to change. That capacity depends on factors such as the farmer's level of economic resources, knowledge, time, family situation and other social pressures.

4. *Government support of the community to manage and protect assets at risk:*

Where particular individuals or groups are responsible for protection of assets of high public value (e.g. an important nature reserve, or a river used for potable water supplies), it may be judged appropriate for the broader community to directly provide resources to encourage and facilitate a high level of management. There has been increasing discussion of the use of "economic policy instruments" to encourage adoption of new farming practices. One set of economic policy instruments involves financial subsidies, designed and delivered in a variety of ways. Realistically, such subsidies probably cannot be provided at sufficient levels to alter land use on a large enough scale across the Wheatbelt.

OPPORTUNITIES

The opportunity I would like to highlight is the potential to harness economics to produce win-win outcomes, where one of the wins is in salinity management, and the other is farm incomes, with resulting social benefits. The broad approach for government policy for salinity has been to rely on farmers to voluntarily make community-minded sacrifices for the common good. Relatively small financial subsidies have been provided to encourage and facilitate the farmers to act. Although some good things have come from this, and many farmers have made important contributions to protection of public assets (particularly environmental assets), the broad approach does not sufficiently recognise and deal with the financial imperatives which farmers face (Frost *et al*. 2001; Pannell 2001).

If it were possible to develop new farming practices which both generated an adequate income and helped to manage salinity, a range of benefits would occur. An increased effort to develop such profitable systems would be one key element in a well-balanced approach to salinity.

The argument applies to on-farm engineering works, to productive plants for saline areas and to perennials for recharge areas. In general, there is a greater need to focus on practical and profitable management options for farmers to use. It is about providing farmers with options which are in everyone's best interests.

This is the philosophy behind the establishment of a new Cooperative Research Centre for Plant-Based Management of Dryland Salinity. It is a national centre, with headquarters at the University of Western Australia. Over the next seven years, the Centre will set about providing a range of profitable new plant-based options for farmers. If it is successful, the CRC will result in some radical changes in land use in the Wheatbelt of WA over the next 50 years. Associated with these changes will be new processing industries based in rural areas to make use of and market the products of the new perennials. These changes will probably be supported by initiatives to address the enhanced greenhouse effect, and increases in consumer willingness to pay for products with "green" credentials.

The CRC focuses on plant-based options. Even more radical methods of making money from salt land and salt water were discussed earlier, and at least some of these are likely to increase dramatically in importance in the medium to long term.

Engineering methods are also receiving increased attention. State Government agencies and the CSIRO are making efforts to resolve the scientific uncertainties and disagreements regarding drainage. They are also taking steps to design regional drainage systems which deal adequately with the off-site impacts. Again, this work will have benefits for both farmers and the broader community. It should give farmers greater confidence (one way or the other) about the economic performance of engineering options, and it will help to protect public assets when those engineering options are used by farmers. Engineering approaches will also probably remain the most important methods for protection of public assets (environmental and infrastructure) for some time, at least until perennial options for recharge areas are sufficiently profitable to be adopted over very large areas and have been in place for some decades.

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FITTING PERENNIALS INTO AN ANNUAL WORLD

Bill Porter[1], John Bartle[2] and Don Cooper[2]

ABSTRACT

Widespread planting of deep-rooted perennial plants offers the most realistic option for the ongoing utilisation of the excess water that is causing salinity in wheatbelt valleys. There are many types of perennial plants, including those with salt-tolerance, which could form the basis of future high water-use agricultural systems. However, to be effective in controlling salinity they must be planted on a large proportion of the landscape (over 30%, perhaps up to 80% in some areas). Over two thirds of the Wheatbelt landscape is being managed by farm families as private enterprises based on annual plants. These individual farmers are the people who will make the decision to grow perennials. Establishing large areas of perennials will not be financially possible unless the perennial plants form part of a profitable, practical, affordable enterprise. Two realistic scenarios are described where farmers plant 40% of their land to unprofitable perennial options. Farmers on average-sized farms would have to either invest $1 million once off, or lose $30,000 per year in perpetuity. An alternative solution for Governments to subsidise the entire farming community for the same scenarios would involve a once-off investment of $2 billion of public funds or ongoing subsidies costing $60 million per year.

Currently there are no perennial based systems that are understood and developed to the extent that large areas (more than 10% of a farm) could be established with confidence by farmers in areas with less than 500 mm annual rainfall. It is not a simple question of extension and education for land managers. The options either do not exist or require further development. Hence it is recommended that well targeted research and industry development is implemented. This should be undertaken in such a way that land managers and other interest groups are participants in the research and build confidence in the new industries. This model has been operated by CALM in partnership with the Oil Mallee Company, and the Department of Agriculture in partnership with the Evergreen Group in the West Midlands. The new Cooperative Research Centre for Plant-based Management of Dryland Salinity offers an opportunity to apply a wealth of expertise to development of new industries.

THE “ANNUAL WORLD”

The focus of this Conference is on salinity – a major negative environmental impact resulting from an agricultural system based on annual plants. Before addressing the question of replacing annuals with perennials, it is worth making sure we have an understanding of the annual system. This analysis will not deal with the impact of the system on salinity – those are adequately covered elsewhere in the Conference. The aim is to consider the production systems currently in place and their economic and social aspects.

The annual world from a State perspective

Annual plants form the basis of the agricultural systems in the Wheatbelt of Western Australia. These annual systems continue to contribute substantially to the community and the economy. The component with the highest value is annual crops (particularly wheat), which represent over 60% of WAs gross value of agricultural production (Table 1). The wealth generated from the Wheatbelt supports directly the population of over 100,000 people located in the region, and provides the basis for economic activity in urban areas worth many times this value. The only perennial plants currently generating revenue in the Wheatbelt are lucerne (mainly on high pH soils in the Southern Wheatbelt) and tagasaste (mainly on deep sands in the Western Wheatbelt). Total revenues attributable to these species is insignificant.

Salinity threatens both agriculture and the natural resources and infrastructure of wheatbelt valleys. On the other hand, the management of salinity has its own risks. The potential treatments for salinity have large development and implementation costs and will diminish the revenues from the annual plant industries.

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Table 1: The gross value of Western Australia's agricultural production 1998/99[1]

Product	Value $m	Value %	Contribution from the Wheatbelt
Crops (excluding pastures and grasses)	**$2,703**	**63**	
Cereals for grain	$1,836	43	***
Crops for hay	$55	1	**
Legumes for grain	$212	5	***
Oilseeds	$231	5	***
Fruit and nuts	$132	3	–
Grapes	$35	1	–
Vegetables	$202	5	–
Pastures and grasses	**$69**	**2**	
Cut for hay	$63	1	**
Harvested for seed	$3	0	**
Livestock slaughterings and other disposals	**$764**	**18**	
Cattle & calves	$351	8	*
Sheep & lambs	$237	6	*
Livestock products	**$636**	**15**	
Wool (b)	$441	10	*
Milk	$157	4	–
Total agriculture	**$4,270**	**100**	

[1] Australian Bureau of Statistics 2001

The annual world at the farm scale

Western Australian farms rely heavily on annual crops. For the three-year period from 1996/97 to 1998/99 more than 40% of farm areas were sown to annual crops in all four major wheatbelt regions (Table 2). The remainder of farms is predominantly annual pasture species grazed by sheep and, to a lesser extent, by cattle. Over the three-year period of the ABARE statistics, there was wide variation in the performance of wheatbelt farm businesses. In all regions the farm business profit was negative for the 'bottom 25%' of farms (in terms of rate of return on capital), and on average was relatively low for all farms (Table 2).

For a farmer to replace a large area of annuals with perennials he or she will require access to finance. The capacity to invest varies greatly between individual wheatbelt farms. The level of equity of a farm business gives an indication of the capacity of that business to borrow further funds for expansion into new enterprises (such as perennials). A rule of thumb often used by the banks is that if equity drops below 70% then the farm business is considered a questionable lending risk (R Kingwell, *pers. comm.*). Over the three years from 1996/7 to 1998/9 the equity averaged 81% and varied from 52% (in the bottom 25% of the South Coast Wheatbelt) to 98% (in the top 25% of the Eastern Wheatbelt) (Table 2). At 30 June 1999 the average equity of WA grain businesses was 74%, close to the bank's cut-off level. However, a reasonable proportion of farm businesses were well-positioned with relatively little debt (Table 3). About 36% of grain farms in WA had total farm debts less than $100,000 and almost 20% of farms had less than $50,000 debt. However, this was prior to the dry season in 2000, and the record dry start to the season in 2001. It is likely that these two seasons will see most farms increase their indebtedness and suffer a reduction in the value of farmland, further eroding their equity.

Table 2: Farm business performance for four WA Wheatbelt regions (average for the three years 1996/7 to 1998/9)[1]

	Unit	Average[2]	Top 25%[2]	Bottom 25%[2]
a. Eastern Wheatbelt				
No. of farms	no.	578	144	144
Farm size	ha	3397	6336	1825
Cropping intensity	%	51	49	72
Equity[3]	%	84	98	63
Age of owner	yrs	43	53	38
Farm cash income[4]	$'000	132	277	42
Disposable family income	$'000	82	141	–3
Farm business profit[5]	$'000	39	181	–61
Rate of return[6]	%	5.3	10.3	–3.8
b. Northern Wheatbelt				
No of farms	no.	875	219	219
Farm size	ha	3108	2939	3675
Cropping intensity	%	50	64	37
Equity[3]	%	82	72	70
Age of owner	yrs	43	53	38
Farm cash income[4]	$'000	161	292	17
Disposable family income	$'000	97	272	0
Farm business profit[5]	$'000	65	245	–107
Rate of return[6]	%	4.7	12.7	–2.9
c. Central Wheatbelt				
No of farms	no.	3920	980	980
Farm size	ha	1871	2863	700
Cropping intensity	%	45	55	30
Equity[3]	%	83	82	94
Age of owner	yrs	50	47	57
Farm cash income[4]	$'000	93	197	23
Disposable family income	$'000	57	106	33
Farm business profit[5]	$'000	22	127	–45
Rate of return[6]	%	2.9	8.3	–3.7
d. South Coast Wheatbelt				
No of farms	no.	461	115	115
Farm size	ha	2508	2553	3185
Cropping intensity	%	43	61	33
Equity[3]	%	58	58	52
Age of owner	yrs	41	35	33
Farm cash income[4]	$'000	68	212	–39
Disposable family income	$'000	50	145	35
Farm business profit[5]	$'000	4	101	–91
Rate of return[6]	%	4.0	8.5	–0.7

1. ABARE 1998, 2000
2. Farms were ranked by their rate of return to capital
3. Equity = ((owned farm capital – liabilities)/owned farm capital) x 100
4. Farm cash income = total cash receipts – total cash costs
5. Farm business profit = farm cash income + changes in trading stocks – depreciation – imputed cost of family labour
6. Rate of return = (profit at full equity / total opening capital) x 100 (where profit at full equity = farm business profit + rent + interest and finance lease payments – depreciation on leased items (i.e. profit at full equity considers the case where the farmer fully owned all the capital used in his/her farm business)

Table 3: Distribution of farm debt among WA grain farms as at 30 June 1999

Debt	% of all farms
No debt	5
Less than $20,000	7
$20,000 to $50,000	7
$50,000 to $100,000	17
$100,000 to $150,000	4
$150,000 to $250,000	16
$250,000 to $500,000	27
$500,000 to $1,000,000	11
More than $1,000,000	7
Total	**100**

Two common perceptions of wheatbelt farms are that they are continually growing in area and that the terms of trade (the ratio of prices received for outputs to prices paid for inputs) are continually declining. Over the 1990s these trends were not as evident as in previous periods. In the South Coast region it does appear to be the case that farm size is increasing (Table 4). However, in other regions there is no clear evidence that average farm size is steadily increasing. Over the past decade the period of high grain prices in the mid–1990s has meant that the often-quoted declining terms of trade for farmers has not been as evident or as strong in the 1990s, as observed in preceding decades (Figure 1).

Table 4: Change in size of WA grain farms during the 1990s

Region	Average size of WA grain farms (ha)		Change in farm size (ha)
	1992/3 to 1996/7	1996/7 to 1998/9	
Eastern	3697	3397	–300
Northern	3119	3108	–11
Central	2029	1871	–158
South-coast	2078	2553	475

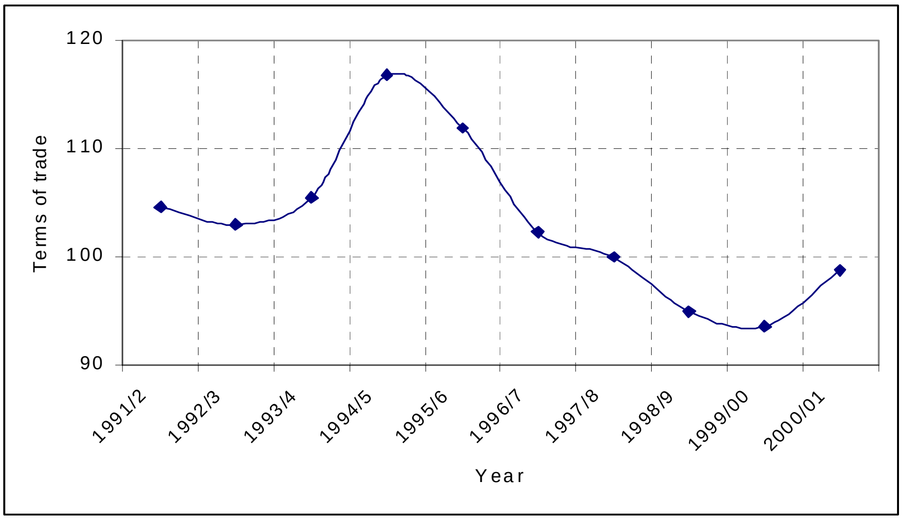

Figure 1: Terms of trade for WA grain farms during the last decade

In summary the picture is one of an agriculture that does not have the capacity to finance large-scale change. However there are also indications that some past downward trends in the Wheatbelt economy may be stabilising, reinforcing the region's ongoing role as a major contributor to the economy and community of Western Australia.

WHY PERENNIALS?

Perennial plants invest a large proportion of their resources to develop deep root systems and so get access to deeply infiltrating water. Access to deep moisture permits a longer active growing season and greater water use than can be achieved by annual plants. Salinity researchers agree that perennials will eliminate recharge over the area on which they stand where annual rainfall is less than 600 mm. There is however debate about whether relatively small areas of perennial plants might intercept significant surface and subsurface flows of water from adjacent annual crops or pastures. Hatton & George (2001) review the circumstances where this will occur. The extent to which water will move to trees is favoured by sloping land, less saline groundwater, thinner regolith (<10 m) and transmissive aquifers. In such a situation White *et al.* (2002) estimated that belts of trees occupying 16% of the landscape would reduce annual recharge generated under upslope annual crops and pastures from 35 to 5 mm. Furthermore, if the pasture phase is lucerne the proportion of trees required to limit recharge to 5 mm was 8%.

It is not clear what proportion of the Wheatbelt might have suitable conditions for perennials in belts or alleys to provide significant reduction in recharge. Such conditions certainly do not prevail on the extensive flat floors of valleys of the medium to low rainfall wheatbelt. It is likely that there will be need both for species suited to belts and for species able to occupy annual cropland as a short, de-watering phase in the rotation. The large and growing area of land affected by high water tables will also require commercial perennial cover. In all cases the extent of perennial use will demand that they are commercially viable before they will be adopted on the scale necessary to control salinity or make productive use of saline land.

However, there are many attractions to commercial perennials other than their impact on the spread of salinity. Perennials will convert surplus water into valuable production. They have great diversity with a wide range of growth habit, soil and climate preference, management regimes and products. They offer diversification into large new industries. There is scope to select perennials that can be efficiently integrated into existing annual plant based agricultural systems. Perennials can be tall and robust and provide shelter and wind erosion control all year round.

Perennials alone will not be adequate to achieve the desirable level of control of salinity. However, they will complement engineering treatments on discharge areas that will be required. The viability of engineering treatments will depend on the volume of saline water to be managed. Extensive use of commercial perennials could reduce that volume by a substantial factor.

Finally, it is too risky to just accept salinity as inevitable – the external/community/non-farm costs are substantial and will always generate conflict and uncertainty for agriculture. If a strategy of passive acceptance of salinity is adopted there is unacceptable risk of national political/environmental regulation and international trade sanction. It is environmentally responsible and commercially prudent for agriculture to be seen to be making every effort to achieve sustainability. Hence we should proceed with development of commercial perennial options. The nation is prepared to invest considerable funds in this endeavour.

WHICH PERENNIALS?

There are currently no perennial species grown commercially on a large scale in the WA Wheatbelt. However, there are a few with a small presence and there are many prospective perennials. Table 5 provides a classification of types of perennials based on plant form, use and site preference. Given the scale of perennial cover required it will be desirable to examine options in all categories.

Trees can produce non-grazing or 'direct harvest' products and there are potential species for both recharge and discharge parts of the landscape, e.g. *Eucalyptus astringins* (mallet) a native wheatbelt species that prefers recharge parts of the landscape and has a small current use for the manufacture of tool handles, while *Eucalyptus occidentalis* is a potentially commercial timber species for recharge areas. There are dozens of tree species that could be developed for commercial use including local natives, Australian natives and exotics like *Pinus*. Sawn wood markets volumes are large.

Table 5: A classification of perennial plants based on form, use and site preference

Plant type and form		Grazing		Direct-harvest	
		Recharge	Discharge	Recharge	Discharge
Woody	Tree				
	Coppice				
	Seeder				
Herbaceous	Non-legume				
	Legume				

Woody plants with the ability to coppice (grow back from the cut stump) can be used as short rotation crops that do not need to be replanted after harvest. The native flora is rich in coppicing species. Mallee is an example now under active development as a large scale biomass feedstock crop. Biomass feedstocks show promise for multiple products including extractives, wood chip and bioenergy. Coppicing species appear generally to be poorly adapted to discharge areas but some mallees and *Melaleuca* species have good tolerance of salinity and waterlogging and have commercial potential. In all some 40 species of mallee eucalypts and *Melaleuca* are currently being investigated for their commercial potential.

Obligate seeding (non-coppicing) woody plants have potential as phase crops where they can produce biomass feedstocks in rotation with conventional annual crops. The genus *Acacia*, a major native legume group, shows most promise for this type of crop. It is large seeded and can potentially be mechanically sown thus reducing establishment cost – an imperative for a short-rotation seeder crop.

There are woody grazing shrubs for both recharge areas (tagasaste) and discharge areas (saltbushes).

The herbaceous perennials will most commonly be grazing plants like the legume lucerne or non-legume grasses. As with grazing shrubs, this category has the significant advantage that they supply already existing industries. They therefore do not face the considerable development costs of direct harvest species where all harvest, transport, processing and marketing operations must be built from scratch.

Lucerne is the herbaceous perennial at the most advanced stage of development as a component of WA farming systems. There are many herbaceous perennials other than lucerne. G. Moore (unpubl. data) listed over 100 genotypes as potential subjects for investigation of their suitability for the WA Wheatbelt. A range of sub tropical perennial legumes could also be used. Ten-year old stands of *Siratro* and *Lotononis* in the West Midlands have survived the driest summers on record (T. Wiley, *pers. comm*.).

The Cooperative Research Centre for Plant-based Management of Dryland Salinity has established a sub-program to identify and evaluate potential species.

While most of the focus of this paper is on perennial plants capable of growing in recharge areas in the landscape, the recharge areas form a significant and growing part of the Wheatbelt. Land affected by high watertables varies in its potential to support plant growth. Barrett-Lennard *et al*. (1999) divided such land into three broad classes – land of ‘high’, ‘moderate’ and ‘low’ productivity on the basis of position in the landscape, soil texture, and the severity of salinity, waterlogging and inundation. Barrett-Lennard (2001) speculates that saltland rated as ‘high’ productivity (shallow brackish groundwater – about 20% of WA’s saltland) may be recognised as the most profitable land on the farm. He suggests it could be used for the growth of high value wood and horticultural crops. Land of ‘moderate’ productivity (duplex moderately saline and waterlogged land – about 40% of WA’s saltland) may be used for the growth of mixtures of halophytic forage shrubs with annual understorey species. These pastures could be used for the grazing of sheep and perhaps cattle. Land of ‘low’ potential (highly saline, waterlogged – about 40% of WA’s saltland) will be mostly only suitable for the growth of samphire species. Together with aquaculture and other more intensive land uses, these industries have been referred to as the PURSL (Productive Use and Rehabilitation of Saline Land) options. The range of these options is still developing. Yensen (2000, cited by E. Barrett-Lennard, *pers. comm*.) estimated that there are

10,000 salt tolerant plant species capable of producing 250 potential halophyte crops.

PRODUCTIVITY OF PERENNIALS

To be useful, a perennial plant needs to be able to produce enough harvestable product or yield to compete economically with current alternative enterprises. The Western Australian Wheatbelt encompasses a wide range of environments (soil types and rainfall). Any one commercial species is unlikely to be adapted equally to them all. The lack of information on the adaptation of perennials to the WA soils and climates makes it difficult to predict their potential for production.

Recent research and farmer experience has demonstrated that lucerne in rotation with crops on hospitable soils during good seasonal conditions will use significantly more water, produce similar or more biomass and support higher subsequent grain yields than an annual pasture (Latta *et al*. 2001; Latta *et al.* 2002; Latta & Blacklow 2001). However, lucerne may not be as productive as the conventional annual alternatives on sandier or heavier soils with low soil water holding capacity and/or high bulk density in the absence of reliable summer rains, especially when soils are also acidic (R. Latta, *pers. comm*.). Approximately two thirds of the Wheatbelt soils are acidic, and there is little summer rain, so lucerne is likely to be limited in the extent to which it can be planted.

Several perennial woody crops have been found to be more productive on some problem soils than the annual plant alternatives. Tagasaste has demonstrated this ability on deep sands (Oldham 1991). Similarly some mallee species perform well on acid wodgil sands in the Central Wheatbelt. Mallee appears to be able to produce at full yield potential on such soils whereas annual crops and pastures can be very poor.

Perennials appear to be better than annuals in tolerating or achieving production under unusual weather conditions such as drought, frost and summer rain. This is perhaps because of their ability to tap into moisture over a greater depth of soil and grow in summer. This broader biological capability may reduce the variability in production of wheatbelt farms reliant on annual crops.

Perennials with a long time to harvest bring different risks to the level of production. Major risks are loss from fire or damage by drought or pests. Regularly grazed herbaceous perennials have a risk profile similar to annual systems because they are harvested regularly over time. The short rotation woody phase crop has greater risk because it leaves the accumulated growth of several years exposed to risk. Coppice crops have a much larger up-front cost but regular harvest and fire resistant coppicing root-stocks limit the risk. Long-rotation sawlog crops are the most exposed but many of the prospective species are not vulnerable to fire. These risks will require extra costs to manage or insure for risk of loss. It will require some experience to develop cost-effective management techniques for these risks.

Considerable attention has been given to optimising the location of tree plantings from the perspective of salinity control or shelter (Hatton & George 2001). Now that it is generally agreed that a large proportion of perennial cover is required to control salinity, different factors must be optimised in planning perennial distribution. Shelter objectives will not need much attention because they are likely to be well met by any extensive planting configuration that exceeds 20%. Maximising the production of woody perennials becomes an important reason to adjust their planting distribution in the landscape.

PERENNIALS AND FARMING SYSTEMS

Perennials can be established either as a long term cover on selected areas or as a phase of limited duration in rotation with annual plants. Long term cover would include trees, coppicing shrubs or herbaceous perennials. These might be block plantings (plantations or pastures) or belts across cropping land. Blocks could be used to target areas with preferred access to subsurface water, sites prone to wind erosion or soils suited to the species (e.g. tagasaste on deep sands). Belts might be preferred for shelter or extensive recharge control on slopes. Phase crops would be used widely across cropland to deplete deep stored water, to provide a break in the annual crop sequence (for weed or disease control) or, if using legumes, to improve soil nutrient status.

It is apparent that the integration of perennials into management systems will be complex. Salinity control will rarely be the sole objective. Optimised systems incorporating perennials are not yet well developed. Good analyses of some aspects of systems are available, for example, for shelter or salinity control (RIRDC). Since salinity control will require quite large proportions of land under perennial cover at any one time their impact on the operations of annual cropping systems will be a strong determinant of perennial distribution and management.

While salinity control objectives might be best served by planting blocks of woody perennials based on hydrological criteria, economics and compatibility with annual crops are likely to require other layouts. The experience with large scale planting of mallee suggests that belt/alley layouts will be preferred. There are some useful observations from the development of mallee layouts (Ian Stanley & Anthony Jack, *pers. comm.*), including:

- belt planting with alley widths down to 100 m do not compromise large scale annual crop operations
- mallee yields appear very good in 2 to 4 row belts
- herbicide drift and grazing do not compromise yield
- design for efficient entry, exit and turning large machinery around at the paddock boundary is essential
- the alley area (the compartment between adjacent belts) can provide a useful planning and operational management unit
- contour belts require more careful design, especially in maintaining alley width as whole multiple of machine passes – this requires a 'keyline' contour with adjacent belts off contour as dictated by the slope of the land and set alley width
- the zone of competition between the mallee belt and the adjacent annual crop or pasture is quite narrow (up to mallee age 5 years without harvest)

The operational evolution of belt designs has made good progress but there is now a need for it to be complemented by careful experimentation.

There are significant gaps in knowledge and farmer-confidence that need to be addressed before lucerne can be adopted at a significant scale. When 35 farmers from five districts were asked what the issues were that inhibited their adoption of lucerne on a broad scale (Olive *et al*. 2001), they raised 200 specific points, many of which related to fitting lucerne into farming systems.

- Can lucerne be established with an annual cover crop (e.g. barley), so reducing the net cost of that first year?
- Is it possible to crop an annual over an established lucerne stand, and increase the flexibility of the lucerne rotation?
- What options are there for weed management within the lucerne phase of the rotation, so reducing the weed burden on subsequent annual crops?
- Are there more flexible ways of grazing lucerne to maintain animal production than a strict rotational grazing system?
- What are the impacts of lucerne on the pests and diseases of other parts of the farming system (e.g. the carryover of virus diseases affecting pulse crops in a subsequent season)?

One of the significant changes for farmers introducing perennial pastures will be in their grazing practices. Perennial pastures will not perform (and many will not persist) under traditional 'set stocking'. Whole farm, planned rotational grazing is required for optimum productivity. This will require investments in farm infrastructure and farmer training (T. Wiley, *pers. comm.*).

ECONOMICS OF PERENNIALS

The on-farm economics of perennials will be the major driver of their adoption by farmers. 'Mainstream' professional agriculturalists predict only small increases in the areas of perennials over the coming decades (McConnell 2000). This reflects a perception that production systems based on perennials are not economically viable. Other stakeholders will support the development of perennials for alternative objectives, in particular to control salinity and protect biodiversity. Both the on-farm economics and the salinity control and biodiversity protection motivation for perennials have been well canvassed elsewhere (State Salinity Council 2000).

The following sections examine the cost of attempting to establish non-profitable perennials as a solution to salinity – the cost to individual farmers and the cost to the broader community – then examines the current understanding of the economics of some of the perennial options under development.

The cost of non-profitable systems to farmers and the state

For the purposes of thinking through the implications of promoting the adoption of non-profitable perennial systems consider the following two scenarios. The scenarios are based on two different perennial systems that might be available to use water and limit the spread of salinity. Then the cost of implementing those options at a farm-scale or at a regional scale are considered.

Scenario 1: A tree system that costs $1,000/ha to establish, then returns enough on an annual basis to break even with the alternative annual system

Scenario 2: A perennial pasture system that costs about the same as the annual system to establish, but then returns $30/ha less each year than the alternative annual system.

Other assumptions common to both scenarios are:

- A target of 40% of the landscape covered with perennials is believed to be required to address salinity;
- An average farm size of 2,500 ha;
- A region the size of the central agricultural region is being targeted (say about 5m ha in extent – so 40% plantings of perennials would cover two million hectares).

The simple calculation reveals the following implications:

Scenario 1: The additional costs involved in adopting the non-profitable tree system over 40% of the landscape would be:

- $1 million in 'start up' capital for each average sized farm;
- $2 billion in 'start up' capital for the region;

with no additional annual net costs over and above the annual system it replaces.

Scenario 2: The additional costs involved in adopting the non-profitable 'perennial pasture' system over 40% of the landscape would require no additional initial investment to establish the system, but would result in the following ongoing impacts:

- $30,000 per year net loss in perpetuity for an average sized farm;
- $60 million per year net cost to the region.

Clearly the amount of money required under these scenarios for farms ($1m initial investment or $30,000 per year) is outside the budget of individual landholders. At a whole region level, the amounts ($2b initial investment or $60m per year) are greater than the level of funding that governments have been willing or able to commit to salinity in one region in the past. The cost of Scenario 1 is more than the $1.5b spent Australia-wide on the Natural Heritage Trust. And the ongoing cost of Scenario 2 is equivalent to half the WA Department of Agriculture's annual allocation from the Government for the entire state.

The following sections reinforce the view that there is a critical need for investment to improve the economics of perennial systems. Whether changes in land management are driven by private investment for profit, public investment, or through regulation, the economics will determine their level of success.

Economics of lucerne

Given the short history of serious efforts to introduce perennials into the Wheatbelt it is not surprising that there have been few economic analyses of lucerne's benefits to the farming system. Bathgate *et al*. (2000) undertook a study of the contribution of lucerne to the profitability of farming systems in three regions in the medium to high rainfall areas of WA. The results of the analysis showed that the value of lucerne to a farm system depends very much on the extent to which its profit is able to compete with that of crops on the same land. Where continuous cropping was an option, a system based on lucerne could not compete. Where animal enterprises were part of the farming system it was profitable to establish lucerne on up to 20% of the land, depending on the favorability of production and price factors towards the lucerne (Figure 2).

The main profit drivers of a farming system including lucerne revolved around the animal components of the system (Table 6). The authors concluded that the amount of lucerne growth in summer is one of the most important factors. The summer growth can be used more efficiently by reducing grain feeding, increasing stocking rate (Figure 2) and altering flock structure from a wool flock to a wool and prime land flock, thereby further increasing the returns to lucerne.

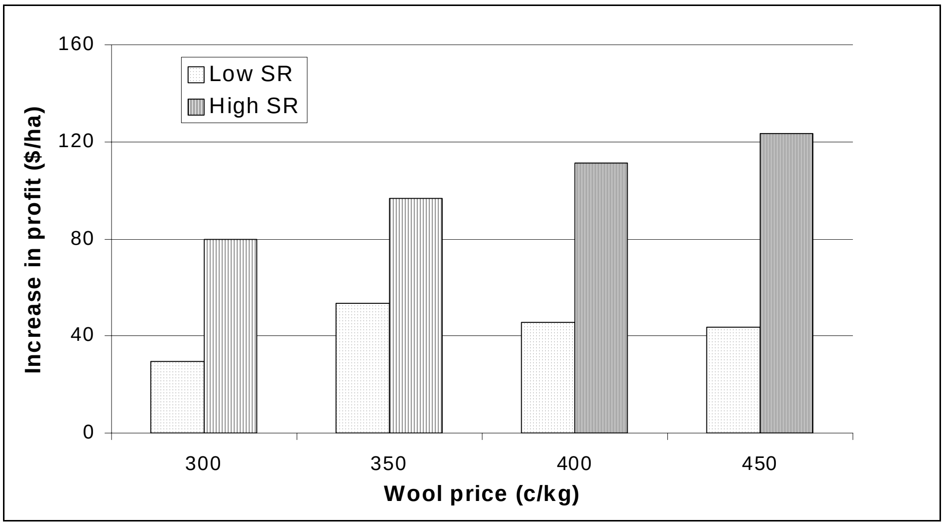

Figure 2: Contribution of lucerne to farm profit at different wool prices stocking rates for the medium rainfall area of the Fitzgerald region (450mm). A low stocking rate (SR) implies grazing pressure was not increased after the introduction of lucerne

Table 6: Relative contribution of factors that influence the benefits of lucerne to profit (from Bathgate *et al.* 2000)

	Increase in $/ha of rotation	Change	Relative Importance	Region
Wool price	4–5	50 c/kg greasy	3	South Coast
Summer growth	4–12	700 kg DM/ha	2	South Coast
Stocking rate	16	2 to 3 dse/ha	2	South Coast
Flock Structure	17–18	wool to prime lambs	1	Great Southern
Soil Structure	N/A		5	NA
Nitrogen fixation	1–2	30 kg/ha	4	Both
Grain protein	3	1.5pp	4	Both
Grain yield	6	10%	3	Both

These analyses were based on little data. Bathgate *et al*. (2000) pointed out that the lucerne production data they used came from a small number of recent experiments that were conducted over seasons that were atypically wet. Young (2000), who analysed the economics of lucerne systems in the Kojonup area highlighted the lack of experimental data for animal performance and lucerne growth on which to base economic analyses.

Economics of mallee

Mallee is not yet in commercial production. Some 900 farmers have planted 8,000 ha since 1994. This high level of commitment by growers was the basis for a feasibility investigation undertaken in 1999 by a consortium of the Oil Mallee Company, Western Power Corporation, Enecon and CALM. It will soon be published (RIRDC 2001). This investigation showed that mallee delivered as chipped green biomass for approx $30/tonne would make integrated processing commercially viable.

Integrated processing is the concurrent production of activated carbon, eucalyptus oil and electricity. The study was based on a plant of 100,000 tonnes/year processing capacity and a haulage radius of 70 km. On the strength of this investigation Western Power Corporation will proceed with construction of a $5 million demonstration scale plant at Narrogin during 2001/2002.

This study used a harvest and transport cost estimate of $15/green tonne and a payment to the grower of $15/green tonne. The payment to the grower was calculated to provide a return competitive with other crop options. Mallee biomass yield varies over the range 12.5–25 green tonnes/ha/year from belt plantings. Harvest is conducted on a 2–3 year cycle. The major costs of mallee production are presented in Table 7 (coppice column). The only published farm scale economic analysis is by Herbert (2000).

There is good potential to improve the economics of mallee production. Some of this will come from genetic improvement of mallee (Bartle *et al.* 1999). Further gain will come from better crop management and better integration into the farm.

For example, the opportunity cost of annual crop or pasture on wodgil soils can be as low as $10/ha (O'Connell, unpublished). Yet these soils give mallee yields at the high end of the range. There are large areas of such soils available and they appear to be an attractive prospect for mallee coppice crop development.

Perennials and cash flow

Costs and revenues for perennials can be very unevenly distributed over time. Herbaceous grazing perennials (e.g. lucerne) is the least affected by this issue, though the loss of revenue from land being established to lucerne is seen as one of the major impediments to its adoption (Olive *et al*. 2001). A sawlog crop requires substantial investment in the year of establishment but generates no return for 25 years or more. Long delayed revenues can impose significant problems in financing the investment. Many perennial crops incur the risk that the initial expenditure must be made up-front while the revenue extends over some years.

The implications of this at a regional level can be seen by calculating the cash flow related to planting one million hectares of wheatbelt farmland to each of the major perennial types (Figure 3). The perennial types represented are:

- *Phase*: typically herbaceous pastures such as lucerne, but also may be woody perennial phase crops;
- *Coppice*: such as oil mallees; and
- *Long-term*: such as timber trees.
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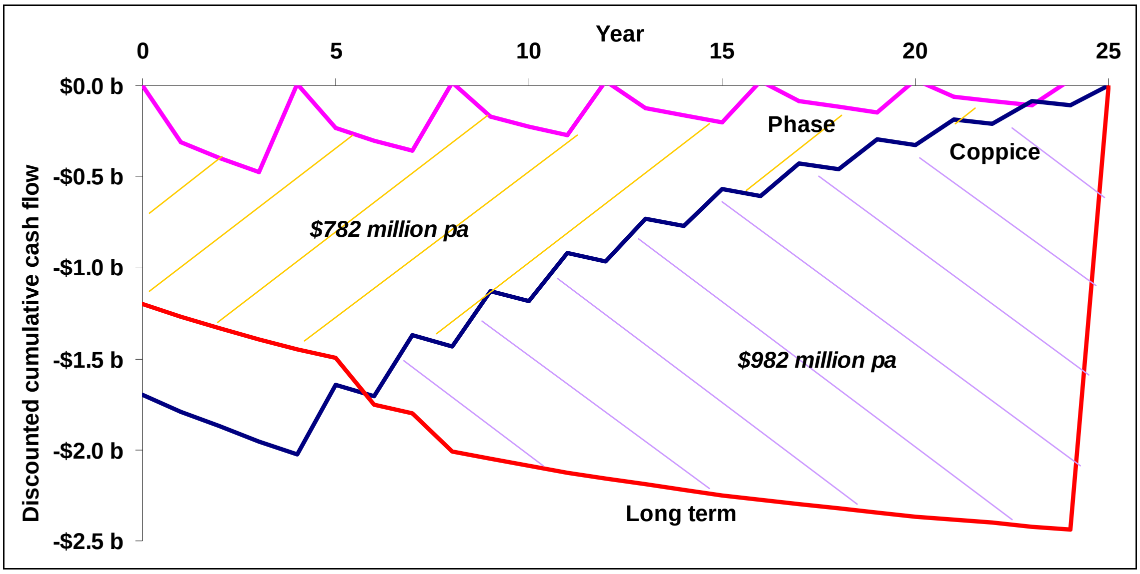

Figure 3: Cash flow for 1 million hectares of three perennial types over 25 years

Table 7: Assumptions used in analysing cash-flow for three perennial options (shown in Figure 3)

	Units	Coppice	Phase	Long-Term
Establishment Cost	$/ha	1700	240	1200
Annual Costs	$/ha	30	30	20
Opportunity cost	$/ha	65	65	52
First harvest	t/ha	42.2	60	90
Coppice harvest	t/ha	42.2	–	–
First harvest	Years	5	4	25
Coppice interval	Years	2	–	–
Density	per ha	1778	1600	500/100
Price	$/t	30	30	70
Adjusted price[1]	$/t	29.64	29.81	131.4

[1]Adjusted price is the change in the current best guess price required to give equivalent NPV in Figure 3

In these analyses it is assumed that each perennial type has the same net present value (NPV). Their costs and revenues are realistic but have been manipulated so that they can be presented here as being equally competitive as an investment (Table 7).

The phase option (lucerne and the woody perennial phase crop) have cash flows that present no particular difficulty to finance (Figure 3). The short rotation coppice crop has high initial establishment cost but its regular harvest revenue steadily depletes the outstanding balance to give an average annual debt over the 25–year period of $782/ha. The long rotation sawlog crop generates no revenue until harvest at Year 25 and has an average debt load of $1764/ha. While lucerne of woody phase crops might be accommodated readily into the farm business without borrowed finance, the coppice and long-rotation tree crops are likely to require financing schemes such as the 'sharefarm' arrangements developed for Blue gums. The Government has announced that it will legislate to smooth the legal process relating to tree crop sharefarming.

Woody phase crops

A woody phase-crop is a tree species that is established to be completely harvested a few years later (say 3–5) and replaced by a different crop (e.g. an annual cropping rotation). Woody phase crops appear to be very attractive because they have a low establishment cost, favourable cash flow and offer diverse biomass production opportunities. Table 7 shows the assumptions behind the phase crop cash flows shown in Figure 3. A cost of $240/ha is included for establishment. This implies that the crop can be established by direct seeding instead of by way of expensive seedling stock. Clearly woody phase crops would have little prospect if they have to carry the establishment costs of coppice crops. Figure 4 shows the sensitivity of phase crop IRR to establishment cost. Techniques by which direct seeding could be done reliably on a large scale are not yet developed. Initial work on such techniques is now underway. The large native plant group *Acacia* appears to offer considerable promise as a source of phase crop species. *Acacia* species are large-seeded and could be readily adapted to direct large scale direct seeding. They are legumes and could provide a nitrogen fixing phase in cereal crop rotations.

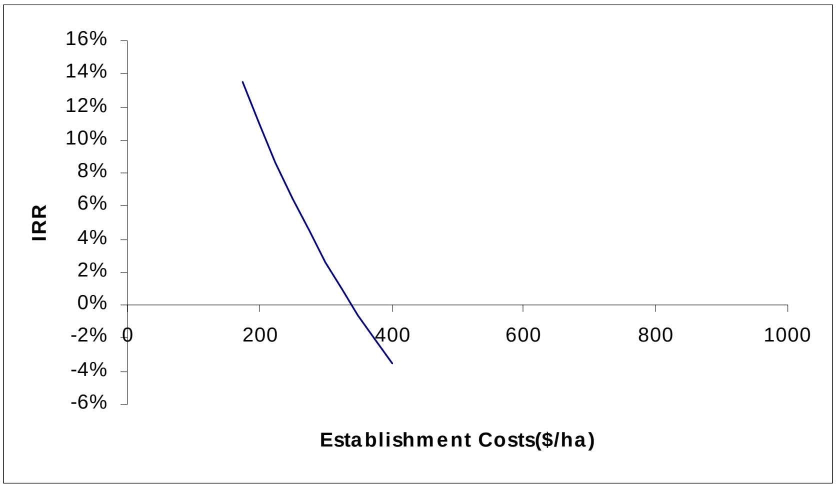

Figure 4: Sensitivity of internal rate of return (IRR) to establishment cost from a woody phase crop

PERENNIALS' PRODUCTS AND MARKETS

Direct harvest perennial crops offer potential for radical diversification of the farm business (Bartle 1999). They could reduce the present reliance on a narrow range of food and fibre products. They might produce a range of non-food products that are not as exposed to the progressive decline in terms of trade that characterises agricultural commodities. They will have different cycles and seasons of operations that will provide opportunity to plan more even flow of activities across seasons.

There are a host of large volume products that can be made from woody biomass feedstocks. They include extractive products (like eucalyptus oil), reconstituted wood products (like fibre and chip board), industrial paper, charcoal and carbon products, bioenergy (including biomass fuel for electricity and biomass for conversion to transport fuels like ethanol and methanol) and chemicals.

The most pessimistic estimate of the proportion of perennial plant cover required to gain control of salinity is up to 80% (George *et al.* 1999). If half of this was to be achieved with woody perennials and typical mallee biomass yields were obtained (15 green tonnes/ha/year) the WA Wheatbelt (15 million ha) would generate an annual yield of some 90 million tonnes. This is several times larger than all current agricultural production. Bartle (2001) shows that if commercial uses are to be found for all this material it would require some 10% of national and Asian region reconstituted wood and industrial fibre markets, most of the State's electricity market and more than half of transport fuels markets. This is indeed a tall order. It suggests that the building of new woody perennial based industries is likely to take a generation or more, that it should focus on the large-scale markets and that success will be critically dependent on bio-energy becoming commercially viable.

It is an appropriate time to be launching infant bio-energy industries. Biomass is a renewable fuel and qualifies for 'renewable energy certificates' under the new Renewable Energy Act. Also the recent international agreement to uphold the Kyoto protocols could see the carbon sink potential of woody perennial crops having a value. Bio-energy consumption appears likely to increase rapidly.

On the other hand, perennial pastures offer the opportunity to expand existing industries, though probably with changes. A recent study was conducted into the potential expansion of beef production in the Wheatbelt, initiated in part because of the potential for expanded perennial pasture options (Peggs 2000). The study concluded that the Wheatbelt region has the potential for greater cattle production, with the ability to expand cattle numbers by some 384,000 head over the next decade. Peggs (2000) warns that expanding the beef and cattle industry into the Wheatbelt needs to proceed with caution because of the current high entry costs. He also said that expanding beef production into the Wheatbelt would require substantial support from the Department of Agriculture by providing information to potential and existing beef producers. Three fundamental issues on which growers need support include the economics of the enterprise, markets and production systems. Similarly Wiley (*Pers. Comm.*) highlights that markets already exist for animal products and a current problem for WA meat industries is a shortage of supply; and that animal husbandry and marketing skills of wheatbelt farmers and consultants will have to be upgraded.

Multi-product crops

Biomass feedstocks from direct harvest perennial crops will commonly produce multiple products. The combination of products makes the crop as a whole commercially viable where any one product might not be viable alone. This is the case for mallee where integrated processing for three products, eucalyptus oil, activated carbon and electricity, appears commercially viable (RIRDC 2001). There is an inherent stability in a crop and an industry that can spread its revenue base across several co-products. There is an obvious parallel with the livestock industries where all parts of the animal are utilised to produce a range of products.

The significance of this for the purchaser of the harvested oil mallees is illustrated with data from RIRDC (2001). The raw mallee feedstock consists of several components that generate different products. Each product can be nominally allocated a share of the biomass feedstock price of $30/tonne. This cost sharing is flexible. Conceptually each product can pay according to its means and its nominal share of the cost burden can be varied to cater for market cycles or new market development. In the case of biomass as fuel or ‘bioenergy’ there is huge potential for large volume consumption of residues if the price is low and the supply is large. The effective fuel cost of mallee residue for electricity generation in integrated processing is only $6/tonne. This is cheaper than coal on a contained energy basis but the centralised supply of coal means vast generating plant can be built adjacent to coalfields thus providing huge economies of scale. However, biomass is a renewable fuel and if the world decides to limit fossil fuel carbon emissions under Kyoto type rules then bioenergy consumption could increase rapidly.

SOCIAL IMPACTS OF PERENNIAL SYSTEMS

A fear associated with the introduction of new large-scale enterprises is that it will impact negatively on rural communities, similar to the effects of Blue gum plantations in the high-rainfall zones of WA. However, none of the perennial options being considered currently appear likely to replace existing production systems with ones that require substantially less labour. In fact the opposite appears likely – the direct harvest products of many woody perennial crops are likely to be biomass feedstocks for a range of extractive, reconstituted wood, charcoal/carbon and bioenergy products. These will commonly be too low in value to be transported out of rural centres, thus locking in local processing and diversification of the regional economy, and providing employment.

In the case of perennial pasture options, on saline or non-saline land, expanded animal industries are likely to result. These will probably have similar labour requirements to current systems, and will continue to require the support of existing agribusinesses and other rural organisations.

Having productive perennial systems covering a significant proportion of the landscape (particularly the saline areas) will have a more intangible social benefit – improved amenity value of the landscape.

AN INDUSTRY DEVELOPMENT MODEL FOR NEW SPECIES, PRODUCTS AND MARKETS

The new perennial crops required to better manage agricultural systems will need to be a fully integrated and functional part of the farm business. It will also be desirable to implement large scale planting of these new perennial crops as rapidly as possible. To achieve these goals it will be crucial for farmers to rapidly build their knowledge and confidence in the new crops and industries.

For the crops which are new, the early industry development stage will not be attractive to entrepreneurs and venture capital. The lead times are too long and the risks too high. A partnership between Governments and organised farmer groups appears to be the best development model for the pre-commercial stage of industry development. This will be best achieved on a whole industry (not regional) basis. During this stage the farmer group should be encouraged to build a strong equity position in the industry. This will sustain farmer confidence in the later stages of commercial development.

This is the development model that is behind the emerging mallee industry (Figure 5; Bartle, 2001).

The first two stages in Figure 5 (Search and Pre-feasibility study) involve objective selection of best prospects for development based on biological attributes and product potential. CALM consolidated the initial work of this type for mallee in the early

1990s. The extension of this type of work to other species and products is now the focus of major national R&D projects supported through the Farm Forestry Program, the Rural Industries R&D Corporation and the Salinity CRC.

The third stage, called industry exploration, consists of three sub-sections (technical, environmental and commercial) and is the stage where direct farmer participation is vital. During this stage public and farmer investment can build the foundation of a new industry. In particular, farmer investment in large scale planting and development of an initial resource base and in pooling this within a commercial structure can provide the springboard for farmer equity in the industry. This stage will take several years before the next stage, commercial feasibility investigation, is warranted. This then leads into commercial investment and large-scale implementation.

Although our Mediterranean climate is well suited to annuals, perhaps the major reason why we have so few commercially viable perennials is that we have not made sufficient investment in R&D to have developed them. Furthermore, where we have invested in perennials R&D, the range of targets have been mostly confined to plants that can be accommodated in current industries like lucerne. The potential for completely new industries based on woody perennial species has been discussed by Bartle (1999, 2001) and is indicated by the emerging mallee industry (RIRDC 2001).

If the development model used for oil mallees and other woody perennials is applied to perennial herbaceous pastures, it appears that lucerne is past the feasibility investigation phase. However, the range of factors affecting the adoption of a relatively well understood option such as lucerne as described in this paper demonstrates the complexity of introducing a new enterprise. Simply growing a new species of plant is a relatively easy task. Developing a production and marketing system that takes into account the intricacies of the biophysical, economic and management issues is a much larger task. Not only are the data sparse, but ideas about how the farming, processing and marketing systems might be optimised are in their infancy.

Historically the length of time to develop a new farming system and introduce it on a large scale can be expected to be at least 20 years. An example of rapid adoption of an agricultural innovation is the development of the lupin industry in Western Australia. The first domestic lupin variety was released in 1967 and by 1987 an area was established equivalent to approximately 5% of the WA agricultural area (Marsh *et al*. 1996). The lupin production system, based on an annual crop plant, is not as radically different to conventional systems as one involving perennials.

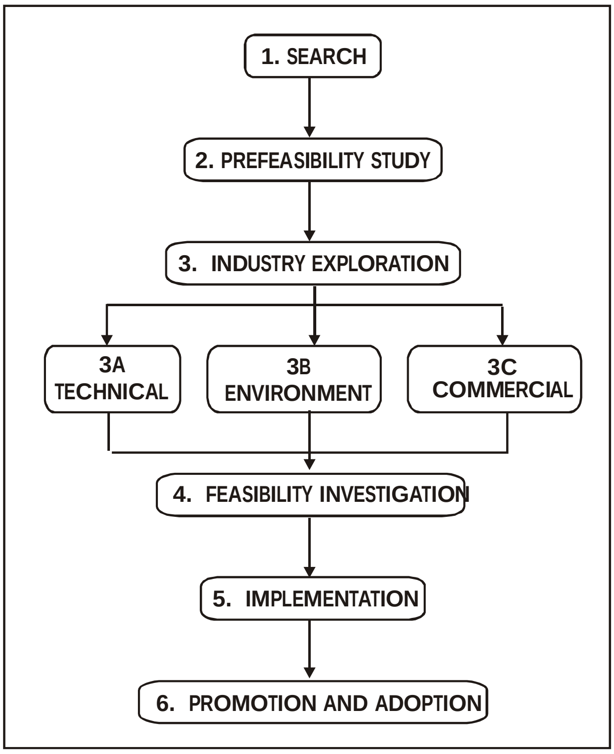

Figure 5: The development model behind the emerging mallee industry (Bartle, 2001)

Managing the development of perennial-based industries

It is one thing to demonstrate the need for research and development, it is another thing to undertake it successfully. There are few involved in Western Australian agriculture who would question the contribution of scientific research to the development of the sector. The partnership between agricultural scientists with specialist knowledge and farmers with a willingness to integrate new knowledge into their farming system is well understood. However, despite this, there is not a shared vision about the place of specialists in the future of salinity management. A simplistic representation of a common view developed over the past decade sees a polarisation of approaches to salinity management into two broad groups – the "researchers" and the "on-ground-workers":

- The "researchers" are sometimes seen by "on-ground-workers" as spending funds on research that is at best directed at the wrong questions or at worst totally unnecessary. One recent quote is: "'Experts' have been a barrier to change as they have said things can't be done";

- The "on-ground-workers" are seen by "researchers" as wasting resources by pushing ahead with strategies that are popularly held to be useful, but which at best are unproven and at worst have been found to be ineffective.

R&D investors and interested parties (e.g. everyone at the Conference) need to have confidence that the research is addressing the right questions and is being conducted in a way that has the best chance of success. Establishing a mechanism for investors to have that confidence is a priority. Over recent years in some quarters there has been a growing trend to farmers participating in setting priorities and undertaking research. Examples of groups that have taken an active role in significant areas of research are the Oil Mallee Association, the Oil Mallee Company, the Evergreen Group (West Midlands), Liebe Group (Northern Wheatbelt), Irwin Mingenew Group (Northern Wheatbelt), the WA Lucerne Growers Association and the primary farmers of the Low recharge cropping systems project.

Wiley (*pers. comm*.) points out that Northern Wheatbelt farmers are adopting lucerne on a broad scale with very little research done in their areas: "Adoption is driven by farmers, not researchers. We need to find out what are the factors which are inhibiting and encouraging farmers to adopt first, and then focus research on these issues. The biggest challenges for farmers when changing to perennial based farming will be the 'systems' changes, rather than simple technical changes. Traditional reductionist R&D is not appropriate for addressing these issues. Farmers will have to do the bulk of the systems development with support from R&D people. This will require a change in thinking for many researchers and farmers."

In addition to a process that allows farmers to be part of the R&D team, it is important that we develop and maintain the capacity of our specialists. We need to ensure that we are supporting people who can undertake quality research and development. The Cooperative Research Centre (CRC) for Plant-based management of dryland salinity is a body that can help support that development.

CONCLUSIONS

- Large areas of perennial plants will not be established in the Wheatbelt unless they are part of profitable enterprises;

- Profitable enterprises based on perennial plants that can be established over large areas do not exist apart from a small number that are under development;

- Developing new agricultural enterprises based on perennial plants involves a complex range of research and development activities covering topics as broad as plant agronomy, farming system development , harvest engineering, product and market development, and management and funding structures.

- There is a need to invest significantly more in relevant R&D than in the past.

- Developing realistic viable perennial options will require a shared appreciation of the needs and direction of R&D through the participation of farmers, scientists and bureaucrats in the entire process.

- There are some successful examples of partnerships between farmers and scientists that provide a basis for developing future R&D teams.

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CASE STUDY - TOOLIBIN LAKE AND CATCHMENT

Ken Wallace[1]

INTRODUCTION

In 1996 a group of scientists and land managers met to discuss "A Vision for a Sustainable Future: A Greenprint for the Wheatbelt". The key headings used below, including those for guiding principles, were developed at that workshop. This case study was intended as one of several to be included in a book arising from the workshop. The book was never published, and this case study has not been updated since 1998. While we have learnt much since then – including that the period over which we thought engineering intervention would be required was much too optimistic – the ideas and comments arising from the case study are still relevant today. Therefore, the paper has been published here with only minor amendments.

THE LAKE AND CATCHMENT

Toolibin Lake nature reserve contains the most important remaining representative of a once widespread natural community. However, without intense management the Lake will become highly saline within 10 years.

The Lake and its catchment lie at the head of the Arthur River which in turn drains into the Blackwood River (Figure 1), a major river of South-western Australia. The catchment is some 49,000 ha in area. Toolibin Lake, with a surface area of about 300 ha, is part of a nature reserve held under management order by the Conservation Commission of Western Australia. Nature reserves are managed by the Department of Conservation and Land Management (CALM) on behalf of the Commission.

Farming based on cereals, mainly wheat, and sheep production for meat and wool, are the primary land uses in the catchment. There are some 40 family-owned landholdings in the catchment. Nature conservation and associated passive recreation and education are also land uses. Toolibin Lake is a focus for these activities.

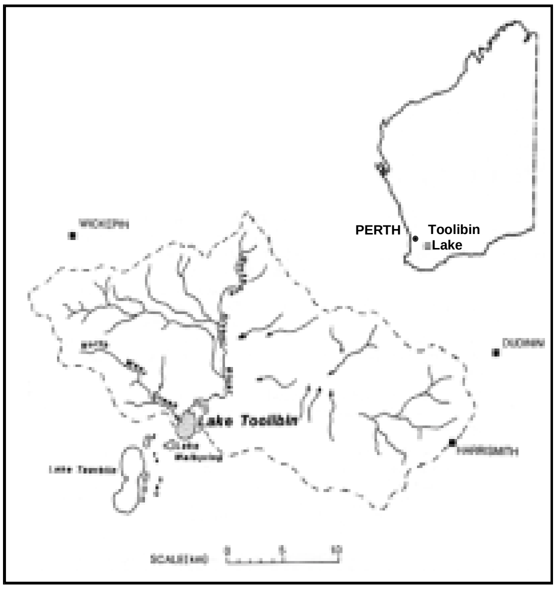

Figure 1: Location of Toolibin Lake (figure adapted from The Status and Future of Lake Toolibin as a Wildlife Reserve, a report prepared by the Northern Arthur River Wetlands Committee, May 1987, and published by the Water Authority of Western Australia

Seasonally flooded, fresh water wetlands with extensive sheoak (*Casuarina obesa*) and melaleuca (*Melaleuca* spp) across their floors were once common in agricultural lands east of the Darling Scarp. These wetlands, with their fresh water and excellent breeding habitat, were very important for waterbirds. All have become saline to some degree, and Toolibin is now the only Lake that still has both reasonable water quality and extensive living stands of sheoak and melaleuca. While water quality in Toolibin has declined, during wetter than average winters the Lake is sufficiently fresh to attract a wide range of waterbirds including those that require fresh water for breeding. Those wishing to explore the relationships between salinity and biota should read papers by Halse (1987, 1988, 1993) and Sanders (1991), and the report on salinity in Western

[1] Department of Conservation and Land Management, Narrogin

Australia by Agriculture Western Australia *et al.* (1996a).

Toolibin Lake is listed on the Register of the National Estate and under the Ramsar Convention as a Wetland of International Importance. It is also recognised as a threatened ecological community under a State classification system (non-statutory), and as a recovery catchment for natural diversity under the *Western Australian Salinity Action Plan* (Agriculture Western Australia *et al.* 1996b). Recognition of the Lake's importance as a recovery catchment provides extra State resources for its management. The values of the Lake are more fully described in the Toolibin Lake Recovery Plan (Toolibin Lake Recovery Team and Toolibin Lake Technical Advisory Group, 1994).

HISTORY OF MANAGEMENT

Clearing of native vegetation began in the catchment during the 1890s, and large areas had been cleared by 1930. Following World War II clearing greatly expanded and by 1996 only 14.6% of the original native vegetation remained (Baxter & Bicknell 1996). Much of this is degraded, and only 3% of the catchment lies within nature reserves.

As a result of deep-rooted, perennial native vegetation being replaced by annual crops and pastures, recharge to groundwater increased. This in turn has caused rising, highly saline groundwaters to detrimentally affect plant growth as waters near the land surface. In worst-affected areas, healthy surface soils and waters become highly saline and only the most salt tolerant species survive, or bare salt pans develop. Salinisation results from both the direct and indirect effects of rising groundwaters.

Direct effects occur when highly saline groundwaters rise into the root zone of vegetation with aerial parts (such as trees, shrubs and grasses) and kill them and soil animals and plants. As salts reach the soil surface they crystallise in surface soils, or pollute surface waters. Indirect effects from salinity occur as surface flows, generally between late autumn and late spring, transport these salts to other areas that in turn become increasingly saline. These processes have dramatically changed many habitats, particularly those on valley floors. Aquatic plants and animals dependent on freshwater habitats and fringes have been most affected. Apart from those species that can use farm dams and ephemeral freshwater pools, such as those on granite outcrops, freshwater life has all but disappeared from the Wheatbelt.

Additionally, the volume of surface water flows have increased as a consequence of clearing native vegetation. Waterlogging and inundation have thus combined with increasing salinity to cause widespread death of native vegetation and their associated fauna, loss of freshwater wetlands, and loss of productive farmland. See chapters in Hobbs & Saunders (1993) for a more detailed explanation of these changes.

During the 1950s and 1960s wetlands downstream of Toolibin became saline, and by the 1970s there was considerable community concern that Toolibin would soon follow. In response to this concern a committee of State Government agencies was formed in the late 1970s to study the Lake's problems and their solutions. The results of the ensuing research are described in a report by the Northern Arthur River Wetlands Committee (1987). In the early 1980s, local farmers, concerned by increasing loss of agricultural lands to salinity, formed a Shire Land Conservation District Committee. Later a specific Toolibin Lake Catchment Committee was formed. Later again, a Recovery Plan[+] for the Lake was produced for CALM by consultants Bowman Bishaw Gorham *et al.* (1992), and this was further developed by the Toolibin Lake Recovery Team and Technical Advisory Group (1994). Blyth *et al.* (1996) have described the history of these groups in more detail.

In general terms, farmers and the Lake Toolibin Catchment Group are primarily concerned with management of freehold land, and CALM is responsible for management of Toolibin Lake with advice and guidance from the Recovery Team and its associated Technical Advisory Group.

PHILOSOPHY

There is no single, consistent philosophy driving work to recover Toolibin Lake and its catchment. Rather, people and groups with differing philosophies and goals are working together to implement actions that will further their individual interests. These individual interests are united and directed by a set of points upon which all participants tacitly agree. These are that:

[+] *Recovery is defined here as "the process by which the decline of an endangered species, group of species, ecological community or ecosystem is arrested or reversed, and threats to its survival are neutralised so that its long term survival in nature can be assured" (Endangered Species Unit 1991).*

- The distribution, storage and movement of surface and ground water in the catchment has changed following land clearing, and this threatens all land uses.
- Catchment water use, storage, loss and distribution must be altered to protect farm and nature conservation values.
- Apart from prohibitively expensive engineering solutions, recovery of the Lake is dependent, in the long term, on recovery of the whole catchment. Actions likely to achieve sustainable agriculture in the catchment are mostly consistent with recovery of the Lake. Thus the two goals are generally congruent. However, it should be noted that some catchment landholders would consider catchment solutions that may endanger the Lake.

Despite general agreement on these points, differences in values and beliefs between catchment stakeholders sometimes result in tensions and disagreements. Also, even within the agreed framework of the three points above, there is not always unanimity on the actions required for recovery, or their priority. While this sometimes creates tension amongst land managers, including those from government agencies, the unifying suppositions are sufficiently strong for effective integration and positive action to occur.

Goals have been written for the Lake (Toolibin Lake Recovery Team and Technical Advisory Group, 1994) and catchment (Lake Toolibin Catchment Group, 1990). The former group is predominantly driven by Government agencies, the Catchment Committee by farmers. However, the groups have interlocking memberships, and this system has worked well.

Goals listed (page (v)) in the recovery plan for the Lake are:

- To conserve Toolibin Lake and its associated wildlife as a freshwater habitat.
- To improve land use decision making and practice within the Toolibin Catchment so that land management: is sustainable, productive and profitable in the long term (over 100 years); reduces the current area of degraded land; and favours conservation of local wildlife.
- To demonstrate that, within a large catchment, it is possible to stabilise hydrological trends which if unchecked threaten land, water and biodiversity resources.
- To demonstrate to other land managers in Australia methods of protecting their biodiversity, land, and water resources.
- To develop mechanisms which lead to community ownership of Western Australia's natural resources including management problems and their solution.

While the recovery of the Lake is of major importance, the value of work at Toolibin as a case study upon which to develop and test catchment solutions for controlling salinity elsewhere is also a major goal of works on the Lake and catchment.

Among the goals developed by the Catchment Group are:

- Establishment of effective drainage of farmland that will not adversely affect the reserve or Lake.
- To increase awareness by developing the Lake and catchment as a model.
- To control groundwater rise.
- To rehabilitate the reserve's vegetation and improve the water quality of Toolibin Lake.
- Willing participation from landholders, Government and corporate sector.
- Preservation of existing vegetation and revegetation of degraded areas.
- To control surface water.
- To establish sustainable land management techniques.

MANAGEMENT ACTIONS

Because I Chair the Recovery Team, I will mainly describe management actions from the perspective of that group. This section is divided into two parts. Firstly, a description of the management actions currently being implemented, and secondly, the relationship of these to a set of guiding principles for integrated management developed at a workshop in February 1996 (outputs from this workshop were not published).

Current and Proposed Management Actions

Recovery actions to protect the Lake are divided into two types. Firstly, those that are required in the short to medium term to protect it against catchment conditions that will inevitably worsen. These emergency actions partly disconnect, in a hydrological sense, the Lake from its catchment, but they are less practicable in the longer term. The emergency actions are a temporary (20-30 years) engineering solution, and they would be expensive to maintain and expand in a catchment that will, if left untreated, become increasingly saline. Emergency actions are necessary to buy time for more sustainable actions to take effect.

Table 1: Actions required to recover Toolibin Lake. The same actions, if successfully implemented, will prevent further deterioration of farmland values, and recover some of the losses. Actions that have been started are marked with a single asterisk (*), started and partially completed are marked (**), and completed actions are marked (***).

	Lake and immediate environs	Catchment
Short term, emergency actions	1. Divert low volume, highly saline surface flows around the Lake*** 2. Lower saline groundwaters beneath the Lake by use of groundwater pumps* 3. Revegetate cleared areas adjoining the Lake to help lower watertable beneath the Lake**	1. Enhance drainage of flats immediately to the north of the Lake to prevent recharge of the flats with consequent salinisation of flats, loss of agricultural land and detrimental effects on the Lake** 2. Revegetate areas of major recharge in the catchment, for example, deep sands** 3. Revegetate and stabilise discharge areas, for example, along drainage lines** 4. Protect remnant vegetation to maintain its evapotranspiration and other water management capabilities**
Long term actions for sustainable Lake and catchment	1. Revegetate degraded sections of floor of the Lake and areas disturbed by engineering works. 2. Revegetate cleared and disturbed areas within conservation lands adjoining the Lake** 3. Regenerate, for example, by using fire, those plant communities identified for management.	1. Agronomic practices adopted that significantly increase water use, land conservation and farm profitability* 2. Revegetation across the landscape, perhaps in alley farming configurations. This vegetation, together with other practices, ensures that recharge to groundwaters are negligible, or at a level counterbalanced by discharge that does not affect the Lake or agricultural areas. Such a system will require new agrisystems to be developed based on woody vegetation. These systems must be economically viable*
Actions for communication and integration	1. Formation of an effective Toolibin Catchment Group and, as necessary, sub-groups. All land managers and other stakeholders involved*** 2. Formation of an effective Recovery Team and associated Technical Advisory Group to guide management of the Lake*** 3. Agencies and non-government funding bodies, such as Alcoa of Australia, to maintain effective lines of communication with each other and land managers outside the operations of (1) and (2), although the latter are primary means of liaison and information flow***	

Secondly, there is a set of practical management actions that it is predicted will halt, and then reverse, salinisation of the catchment. These actions will take some years to implement and decades to have a strong, positive effect on the catchment's hydrology. If successful, these actions will allow the emergency actions instituted for the Lake and its environs to be discontinued. When this point is reached, the Lake will, provided certain biophysical criteria are met, have been sustainably recovered. In the same process, the deterioration of the agricultural values of the catchment will have been stopped, and, in some cases, recovered. Under this scenario the long-term savings achieved by better protecting the agricultural production values of the catchment will far outweigh any costs.

Emergency and long term actions are described in Table 1. Communication and integration actions, which cut across both short and long term actions, are shown as a separate category within the table.

It must be stressed that significant revegetation of the catchment with perennial, woody vegetation is essential to achieve a sustainable recovery of the Lake and its catchment. Without this, it will be impracticable to restore benign hydrological conditions within the catchment.

Part of this revegetation has occurred and is achieving a range of benefits including stock shelter, erosion control, aesthetics, local control of groundwaters, nature conservation goals and forage for stock. However, the current speed and extent of revegetation will not be sufficient to recover the Lake and catchment without significant external resources, or a commercial woody crop, or both.

Thus an important challenge being addressed at Toolibin is that of developing agroforestry systems that achieve the goals of all catchment land managers. While work in this area has been slow starting, it is currently gaining momentum. The Wickepin Shire (within which Toolibin occurs) is one of the first six centres where the development of a eucalyptus oil industry based on mallees (a multi-stemmed, lignotuberous form of *Eucalyptus* spp) is being explored. To date (September 1998) 164,500 oil mallees have been planted in the catchment. Limited harvesting has occurred, however, this will greatly increase. Whether this will develop into a viable industry will depend on:

- sufficient local farmer support;
- opening up of potentially huge markets for use of cineole, for example, as a solvent;
- cheaper means of harvesting and extraction;
- genetic improvement of current stock.

All these constraints can be overcome. However, there is an urgent need to develop further potential industries based on woody vegetation. Toolibin is a vital flagship for developing and promoting profitable and sustainable agricultural systems that utilise woody vegetation.

Action and the Guiding Principles for Integrated Management

The following comments are my perspective on how all catchment land managers - Government and private - are performing in comparison with the aims of the guiding principles for integrated management developed at a workshop in 1996 (outputs were not published).

Learn to live with this country and its environment

Catchment land managers recognise that the hydrological cycle has been pushed into a form harmful to both conservation and production, and most are acting on this knowledge. To this degree we are learning to live with this country and its environment. However, amongst land managers there is uneven knowledge of landscape processes and what we must do to live within the natural system. Even our general understanding of hydrological cycles is imperfect. As will be covered below, general understanding of energy and nutrient processes is poor. Our current system of coping with soil infertility depends on large inputs of fertilisers, and general knowledge of the longer natural cycles (for example, plant regeneration) and the significance of erratic, episodic events, such as fires and cyclones, is poor. We are learning, but we have a long way to go. Some of the necessary changes in knowledge will require more than one generation to establish.

Maintain diversity and keep our options open

By protecting remnant native vegetation better, and acting to recover the Lake, land managers are aiming to protect diversity within the natural system. Actions that have been taken include:

- fencing remnant vegetation;

- buffering remnant vegetation with fringe plantings;
- revegetation of drainage lines and other features, thus connecting and expanding habitat;
- numerous other actions to start restoring a benign hydrology (see Table 1).

However, actions to maintain diversity could be improved. For example, revegetation within the Toolibin Lake Nature Reserve concentrated on establishing trees of local provenance that have high water use. It was intended that understorey species would also be introduced, but this has not yet been undertaken. It is interesting to speculate whether introduction of understorey would decrease current problems with parrot and insect damage to revegetation. This shows that while the broad aims of actions are sound, they can be better targeted to achieve diversity, biological control, and resilience. Also, many plantings in the catchment are not based on local or regional species. Thus revegetation works have not always been undertaken in a way that maximises biodiversity conservation values.

Similar comments apply to diversity of farming enterprises in that, while a much greater range of farming systems is being tested, general application is limited. The goals are correct, but research, development and adoption are far from adequate. Also, the commercial potential of revegetation has not always been maximised.

Manage water, energy and nutrient cycles

While implementation has only begun and there is a long way to go, we can claim that we are moving towards a much more benign hydrological system. The challenge is to ensure that this happens with sufficient speed to be effective in recovering nature conservation and production values. In contrast, we poorly understand energy and nutrient cycles. A sign that these cycles need management attention was the first outbreak of waterbird poisoning at Toolibin as a result of eutrophication in March 1993.

Recognise that our environment is one of extremes, and manage accordingly

To date we have only achieved this in a very limited way. The best example is that our most recent engineering structures have been designed to fail, during large or extreme events, in a way that minimises damage to structures and associated land uses. This is an important step, but there is much further to go. As suggested above, we could increase the resilience of the system by diversifying our revegetation systems, for example, by introducing more understorey species. It can be expected that ecological resilience will also favour the economic resilience of agriculture.

Manage according to natural boundaries

There are no concrete data on changes in farming practice within the Toolibin Catchment. However, Jenny Crisp (*pers. comm*.) estimates (1996) that:

- 50% of farmers in the catchment are working to contour, and that many grade and interceptor banks have been constructed;
- 50% of landholders are working towards full farming to soil types, however, this will take many years to implement; and
- 90% of landholdings are covered by a farm plan. These range from being rudimentary to those that are sophisticated. Implementation and use of plans is also highly variable.

Social, cultural and economic systems congruent with achieving long term goals

This topic can be separated into those socio-cultural and economic factors external to the catchment, and those within the catchment (including stakeholders, such as agencies, that live outside the catchment but work within it).

External socio-cultural factors are beyond the scope of this paper, and are not considered further here. External economic factors have a profound impact, mostly by determining, for example through farm profitability, the level of resources that may be applied on the ground. It is useful to note that changes in relative profitability of farm products may have very important influences on the ground. For example, with the current (1998) drop in wool prices and increased profits from cereal crops, revegetation is indirectly favoured by decreased farm flocks and increased cropping. This is because farmers are more likely to plant seedlings and withhold paddocks from grazing to protect the seedlings. However, the same factors will also increase soil disturbance and nutrient imbalances are likely to increase!

External factors will be similar across most of the case studies covered in this publication. Of more direct interest here are relevant socio-cultural factors within the catchment. These are briefly considered within three categories: relationships between farmer landholders within the catchment; relationships between farmers and the main government landholder in the catchment (CALM); and relationships between government agencies and other groups. Issues relating to philosophy of management apply across these three categories. These matters have been covered above under the section on 'Philosophy'. However, it is re-emphasised here that the varying congruence of goals and philosophies that exist between groups and individuals is both a source of tension (for example, as disagreement) and of creativity (for example, stimulates new ways of looking at issues). Burbidge & Wallace (1994) provide a more detailed discussion of general philosophical issues. Here it is sufficient to note that continuous liaison and positive interaction between groups and individuals is essential to develop and maintain sufficiently congruent goals and philosophies for cohesive, effective management action.

Relationships between farmers within the catchment

Key points are:

1. The Toolibin Catchment covers several farming communities. These are broadly based around the towns of Wickepin, Tincurrin and Narrogin. Thus the catchment boundaries are not congruent with social boundaries, and this has affected interactions amongst catchment landholders. The divided social groupings have not helped communication and unified action.

2. The Lake Toolibin Catchment Group has found that the catchment scale is too broad to maximise effective action on the ground. Rather, it has been found that sub-catchment groups are essential to implement some on-ground actions; larger groups are just too unwieldy and the sense of mutual co-operation too diffuse.

3. Throughout the south-west it has often proved difficult to involve landholders who own properties high in the landscape in catchment activities. Those low in the landscape bear, at least initially, the brunt of landcare problems involving hydrological issues. This separation into upper and lower landscape landholders is a problem that has not been fully resolved.

4. Toolibin Catchment lies within a part of the agricultural region that is comparatively 'safe' in terms of rainfall and consequent production, but, due to the dependence on pastoral as well as agricultural income, there is little cash surplus. The combined effect of these factors seems to be that landholders are mostly conservative in terms of taking up new ideas. This has influenced the intensity with which landholders have attacked landcare issues compared with other parts of the agricultural region.

Relationships between CALM and farmers

Key points are:

1. Co-operative arrangements between CALM and the local farmers are currently working well. There have been difficult periods, and this has occurred for a number of reasons. An important source of friction has been that, particularly with respect to drainage activities, CALM and farmers have sometimes disagreed about the likely outcomes of actions. These problems have been resolved by improved research and engineering design, and by linking approval of drainage activities with agreements to undertake other works, particularly catchment revegetation. While not formal contracts, these agreements are important. If it had been practicable, a formal agreement would have strengthened the clear commitment of the parties involved. While the land management goals of farmers and CALM are often mutually supportive, they are not always so. This can be a source of tension, and the following three points are important in this light.

2. It is difficult for CALM to maintain, in light of changing personnel, a constant contact person within the agency for farmers. This makes it more difficult to develop long-term relationships of mutual trust and understanding.

3. In CALMs Wheatbelt Region there are 35 personnel to undertake all departmental operations including the management of some 1 million hectares of nature reserves. Inevitably management is largely reactive, and while significant time is allocated to Toolibin, other issues make significant demands on personnel. Thus it is difficult to maintain a sufficiently high level of liaison with local farmers to ensure that there is adequate exchange of information, successes and concerns.

4. An important mechanism for counteracting the difficulties raised is to have, as we do at Toolibin, interlocking memberships of the farmland

oriented group (Toolibin Catchment Group) and the Lake oriented group (Recovery Team). This has been very important for information flow, planning and liaison. Additionally, it is important that positive working relationships develop and are maintained between representatives of agency and farm managers. Personalities will obviously influence this process, as it does all relationships within the catchment. However, this should not be allowed to jeopardise good working relationships.

5. The 18 points listed by Blyth *et al.* (1996) and given in Figure 2 have all been found, to some extent, relevant to effective co-operation at Toolibin.

Interactions between government agencies:

Interaction between agencies and other groups, such as CALM, AgWA and Alcoa of Australia, is subject to similar considerations to those discussed above between farmers and CALM. In the case of Toolibin, agency and industry interactions have been very good. Indeed, this has been one of the vital ingredients for successful actions. However, external (to Toolibin) resource demands on agencies have sometimes been a barrier to communication and joint planning. This is inevitable, and will not become an issue provided all parties continue to understand the potential problems and work to prevent them detrimentally affecting the current high level of integrated operations.

Figure 2. Features likely to be present in successful cooperative arrangements between government agencies and the community (taken from Blyth *et al.* 1996)

1. The problem being addressed is clearly defined, short term and has a good expectation of solution.
2. The problem is relevant to, and its solution will benefit, a small-scale and self-sufficient community, and that community plays a leading role in seeking a solution.
3. A clear understanding that benefits to individuals or community may take many forms, of which economic gain is one, and that multiple benefits are usually present in nature conservation programs.
4. The achievement of nature conservation goals is integrated into programs whose major purposes are to achieve other benefits, such as economic returns or better land care.
5. All, or the great majority of, parties to the program feel that the benefits to them outweigh the disbenefits.
6. Coordination between agency and community starts early in the development of the project and is very close, with frequent and continuing personal contact between community members and agency representatives, who are accepted as part of the local community.
7. Any committees or other institutions formed for the program are accepted as a part of the community, and their aims are shared by the community.
8. The arrangement places considerable emphasis on the development of trust, both between the various members of the institution itself and between the institution and the community at large.
9. The rules or mechanisms proposed to solve the problem are designed and accepted by most individuals in the community.
10. The arrangement is seen as a genuinely reciprocal one by all parties, with the assignment of rights and duties seen as fair, certain and appropriately enforced: any impositions on, or sacrifices by, individual members of the community for the common good are distributed fairly and are not too onerous on any individual.
11. As much of the operational activity as possible is conducted by the local community, especially landowners.
12. The program is empowered by clear, widely accepted legislation (but see also point 18).
13. Adherence to rules or conditions is monitored and enforced by an agency (preferably closely allied with the local community) seen as fair and approachable, which has the capacity to levy sanctions against those who break the rules.
14. Any sanctions necessary are applied in a graduated fashion, with understanding of any particular circumstances which may have led to transgression of the rules.
15. Agreed mechanisms for the rapid, low cost resolution of conflicts are available to everyone, and are largely controlled by the local community.
16. The arrangement includes the capacity to change the rules, and accepted processes for making such change.
17. Changes affecting people are not too rapid or too fundamental, and are largely made at the practical operational level, with the agreement of the community.
18. If larger institutions are necessary, the local community or affected interest group will be integrally involved in their design: each level of organisation will be clearly nested within the one above, with overlapping membership, ready communication between levels, and clear legislation setting the overall framework.

CONCLUSIONS

Actions to protect and manage Toolibin Lake and its catchment are being implemented. These actions have taken Toolibin from a Lake doomed to severe salinisation to one that now has a chance of survival, a chance improved with every new management action. The successful recovery of Toolibin Lake now depends largely on the speed and extent with which groundwater recharge can be reduced across the catchment. This in turn depends on a range of actions; most importantly, on woody revegetation that not only significantly reduces groundwater recharge, but also contributes to sustainable agriculture and short term farm profitability.

Toolibin provides a vital case study to test management options and develop sustainable and profitable farming systems that protect all land values for current and future generations.

The social and cultural context of management in the Toolibin Catchment is a significant ingredient in success. The co-operative efforts and contribution of a wide diversity of groups is a management feature of Toolibin and its catchment. While there have been difficulties, integration of efforts has generally been very good, and this has improved over time. The Toolibin experience has emphatically demonstrated that a wide diversity of groups must positively interact to combat expensive and complex management problems. Whether action can be maintained over a sufficiently long time period to bring about substantial, positive change at a landscape scale is a vital question not only for Toolibin, but for every community where sustainable land use and conservation of natural diversity are goals.

ACKNOWLEDGMENTS

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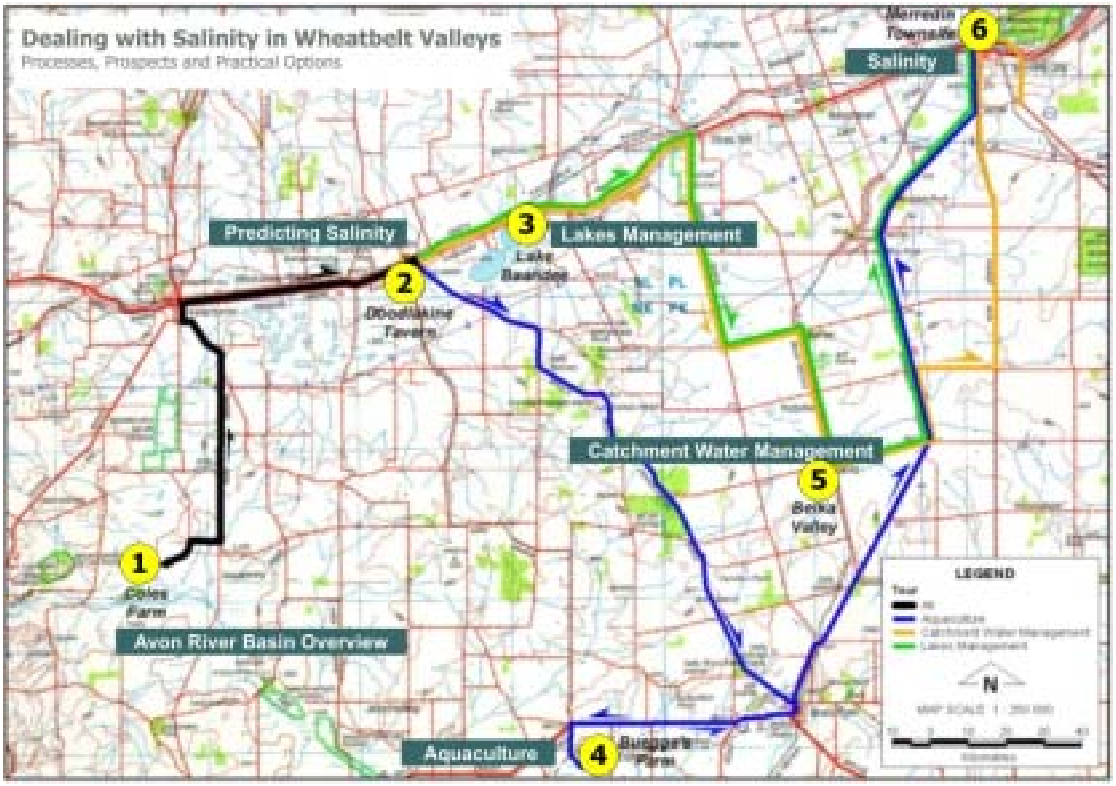
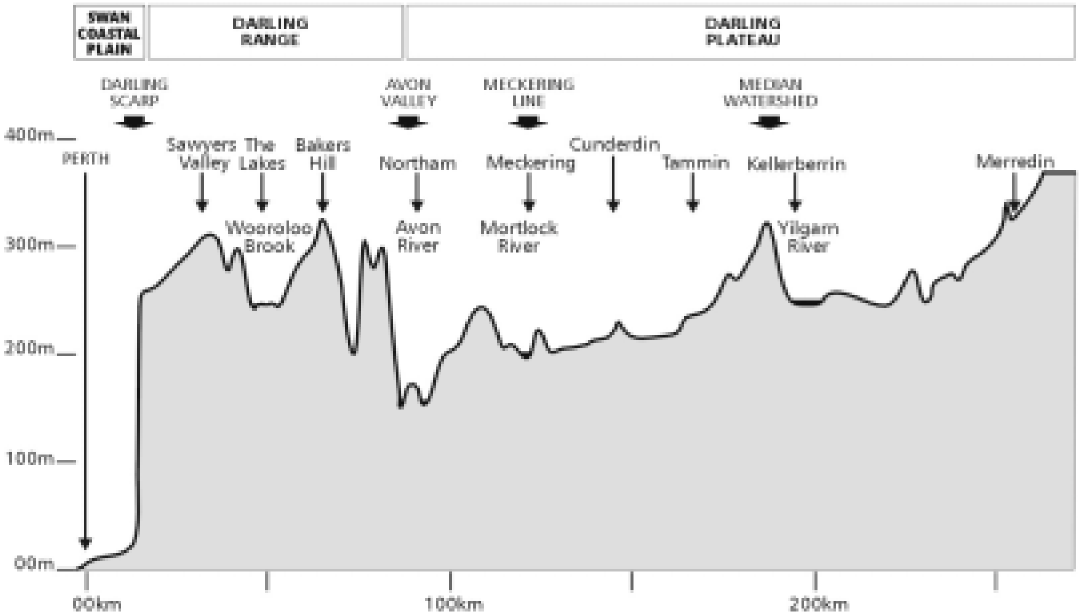
FIELD TOUR NOTES (DAY 1)

FIELD TOUR LOCATIONS

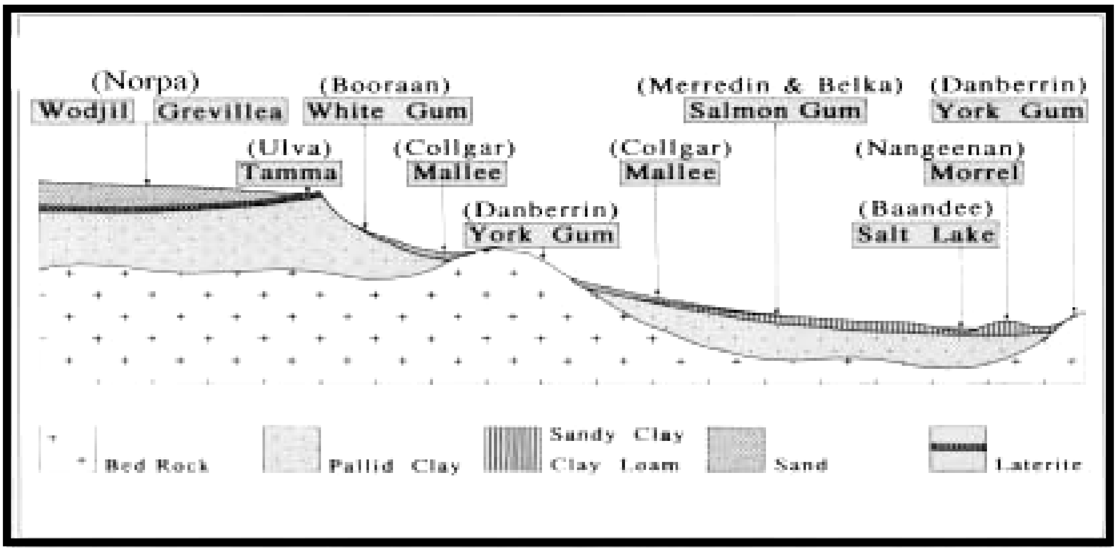


PHYSIOGRAPHIC PROFILE PERTH TO MERREDIN

See also Hydrology and Salinity Overview APPENDIX 1



SOIL LANDSCAPE - VEGETATION RELATIONSHIPS FOR THE EASTERN WHEATBELT



The Yilgarn and Lockhart Rivers are the major flow systems of the Zone of Ancient Drainage. This landscape is characterized by broad flat valley floors with salt lake chains, gently sloping valley sides, some rock outcrop and extensive areas of undulating sandplain. Surface water flow is driven by large rainfall events over all or part of the 2 water catchments.

Bettenay and Hingston (1964) described landscape surfaces for the Eastern Wheatbelt. These have specific topographic characteristics, soil types and associated vegetation types.

Norpa: Deep depositional sandplain of the uplands often covered with Wodgil (*Acacia neurophylla*) on acidic white sands or Grevillea/Banksia communities on yellow sands.

Ulva: Shallow, gravelly soil surface bordering sandplain where wind has eroded the sand. *Allocasaurina* species growing in dense thickets is the predominant vegetation type.

Booraan: This surface marks the eroded edge of the upland and often occurs below lateritic breakaways. *Eucalyptus capillosa* (Eastern white gum) is the predominant vegetation type in the Eastern Wheatbelt.

Collgar: The distinctive sand over clay soil surface of the mid slopes covered with a variety of mallee forms. This vegetation type merges with York gum, Salmon gum and sandplain vegetation communities.
Danberrin: The surface marked by the old soil mantle stripped to bedrock. The soil is usually shallow brown sand over a sandy clay on the top of granite. The York gum (*E. loxophloba*) is the typical vegetation type around rock outcrops.

Merredin and Belka: These are the 2 soil surfaces of the lower slopes to valley floor. Salmon gum (*E. salmonophoia*) and Gimlet (*E. salubris*) are the predominant vegetation types. Merredin soils are colluvial red-brown sandy clay loams occupying broad flat valley tributaries to major drainage lines. Belka soils are grey alluvial sediments occupying magor river systems of the past.
Nangeenan: The surface dominated by Morrel (*E. longicornis*) vegetation is composed of fine powdery aeolian loams and clays, originating from the floors of dry salt lakes. These areas are the depositional phase of the Baandee and typically seen in a lunette or dune form.

Baandee: This surface represents the old drainage lines now infilled and reduced to a series of salt lakes. An erosional phase has often exposed Tertiary remnants and occasionally country rock. Typically the vegetation of these areas is saltbush (*Atriplex* spp) and blue bush (*Maireana* spp) with samphire (*Halosarcia* spp) occupying the most saline areas.

COLES FARM "Avon River Basin Overview"

"Welcome to the Landscape"
(Kath Yarran and Alan Cole)

Large-scale catchment hydrology
(John Ruprecht and Rosemary Nott)

Regional Biodiversity
(Natham McQuoid, Richard McLelland and Greg Keighery)

Remote Sensing Information
(Peter Caccetta)

DOODLAKINE TAVERN "Predicting Salinity"

Large-scale salinity predictions
(Tom Hatton)

Local-scale salinity predictions
(Richard George)

Community response to salinity predictions
(Mike McFarlane)

LAKE BAANDEE "Lakes Management"

Salt lake ecosystems
(Mark Coleman)

Multiple Use of Lake Baandee
(Alan Cole)

Reconstructing altered ecosystems
(Denis Saunders)

Key Outcomes:
- Recognising the ecological values of lakes
- Understanding conflicting interests in lake use and values

BUEGGE'S FARM "Aquaculture"

Rainbow trout in purpose built dams
(Mike and Jeanette Buegge)

Pumping groundwater as a saline resource
(Mike and Jeanette Buegge)

Options for aquaculture
(Jasper Trendall and Peter Lacey)

Surface water management structures/oil mallees/biodiversity
(Rosemary Nott)

BELKA VALLEY "Catchment Water Management"

Belka Valley landforms and hydrology

Drainage and groundwater pumping works
(Richard George and Kevin Jones)

Notes prepared by Richard George and Rosemary Nott **(APPENDIX 2)**

KEY OUTCOMES:

- Emphasis on drains and flood management in the Belka Valley
- Effectiveness was shown by photos and points of discussion

(Dept of Agriculture monitoring was less able to show the full effects, but the photos showed where seepage from a sandplain had been intercepted by downslope drains. Kevin Jones noted areas at risk were still developing
up-valley.)

- The Belka example highlights the issues of design. Drains with major

floodways installed would have their life expectation greatly increased.

MERREDIN "Townsite Salinity"

Notes prepared by Richard George and Jay Matta **(APPENDIX 3)**

Dealing with Salinity in Wheatbelt Valleys

Processes, Prospects and Practical Options

Baandee Lake Circa 1930

Dealing with Salinity in Wheatbelt Valleys Conference

Processes

Dealing with Salinity in Wheatbelt Valleys:

Processes, Prospects and Practical Options
Merredin, 30 July – 1 August 2001

CONFERENCE OVERVIEW

BACKGOUND AND PURPOSE

The valley floors were originally the most productive areas of the Western Australian Wheatbelt. Farming communities were established, towns grew, and roads, and railways were first constructed there. The valley floors are now seriously affected and futher threatened by salinity. The impacts affect all who live and work there.

The three-day conference was designed to consider the causes and extent of salinity in the Wheatbelt Valleys, the extet to which a range of values will be affected, and to develop a *Shared Vision* for managing the problem and deciding what we need to do to achive a realistic yet livable outcome.

PROGRAM

The event was in three parts:

Field Tour to provide a visual landscape overview and to discuss management options on-site with locally informed people. Theme tours related to Aquaculture (Buegge's Farm), Catchment Water Management (Belka Valley) and Lakes Management (Lake Baarndee) .

Conference Papers were presented to establish the current situation with salinity in Wheatbelt Valley's by leading scientists and managers in natural resource management. Case Sudies were also presented. The Program and presented papers are available on the conference website (www.avonicm.org.au/avonicm/wbeltvalleys).

Workshop to develop a Shared Vision and identify Next Steps towards achieving the Vision. The workshop was focussed on 5 Key Conference Questions through a range of management Themes.

ATTENDANCE

The conference was opened by the Hon. Judy Edwards, Minister for Environment and Heritage, and Water Resources.

Total attendance was 223 people from 26 different rural, government or community interest groups. Farmers who attended were over 30% of the total number. Representatives from 6 state government agencies and 3 national organisations also attended. Other representation was from Aboriginal interests, local government, consultants and contractors, universities, industry and research organisations.

The workshop was attended by 155 of the conference delegates.

WORKSHOP SUMMARY

Alex Campbell

INTRODUCTION

- I will cover 4 points, so that there is a shared understanding of the 3 days activities.
  - reflection on where we have come from
  - some key messages from the conference
  - shared understanding of outcomes
  - a "word picture" of that understanding.

- But firstly let me give you confidence that the results **will** be taken notice of and acted upon.

  - The Salinity Council and Avon Working Group sponsored the conference because we wanted direction.
  - The 4 members of the Minister's Salinity Taskforce for attended the full conference
  - Minister Edwards announced to the conference that she was setting up a group to advise on the $4m drainage evaluation initiative. It is understood that 2 potential members have attended the full conference.
  - Regional NRM Groups will be part of the NAP for Salinity and Water Quality and they will be influenced by this conference in setting targets and priorities.

  Get behind these groups and make them work. Contact members that you can relate to and use them. Full contact lists will be in the proceedings.

REFLECTION

- Prior to 1996 we tended to have silos of good work.

  - agencies
  - farmers
  - researchers etc.

- 1996 Salinity Action Plan – a good start at breaking down the silos.
- 1997 Salinity Council – a good start at getting everyone in the same tent (agencies, farmers, enviromentalists, LG etc.etc)
-
- These early days were typified by
  - polarised view of the world
  - little tolerance of other views
  - suspicion

- 2000 Salinity Strategy – another step down the NRM road, after wide consultation.
- I remind you that the Salinity Council commissioned flow tube modelling that spelt out large-scale perennial vegetation and engineering would be needed to effectively manage salinity.
- **Only 5 years ago you couldn't have imagined a conference like this that would have had truly shared views and respect for each other**

KEY MESSAGES FROM THE FIELD TRIP

- Mike McFarlane "Understand our land" "I want seven diversified income streams"
- Jon Flokhart, Kevin Jones and Kevin Lyons presented a measured and clear understanding of deep drainage – the Belka example.

KEY MESSAGES FROM THE CONFERENCE

(No recognition to speakers)

- unique landscapes – our rivers/valleys are different
- Salinity is not the only NRM issue
- Value our water – both fresh and saline. "We live in the driest continent, yet the irony is that too much water is the issue"
- The scale of issues and actions needed mean that we must have profitable options.
- "People, people, people, people!" The social issues are really important.
- Don't count on governments to help you – particularly to subsidise non profitable options.
- Our environment and biodiversity are unique and precious – value it and look after it.
- Don't generalise (our valleys are different).
- Research is needed – Development at the farm scale is critical – Extension and knowledge transfer also critical.
- Annuals have driven agricultural development, but are now under financial pressure and they leak!
- Neither side of the drainage debate has proved their point.
- How can we pigs involve the chooks?
- Enlightened self interest
- We are only limited by our imagination.

POWERFUL NEW DIRECTION

Those that made presentations on:

- deep drainage (and other engineering options)
- salt land pastures
- lucerne
- mallees

Were all understood and respected for describing an option that works and must be considered in an overall approach to NRM management.

SHARED UNDERDSTANDING FOR THE FUTURE

1. People – Communities. They will be better informed, will be making more of their own decisions. New industries will halt the rural population decline. Different views and values will be respected.

2. Profitable Agriculture (at both recharge and discharge). Existing annual production systems will be augmented by various forms of perennials in both phases of farming and permanent woody trees and shrubs. It will include on farm or regional value adding. Income options will be more diverse and many will be less prone to seasonal risk such as drought and frost.

3. Water is our shared most valuable asset (both fresh and salinised). By surface water management, more use will be made of annual rainfall, saline discharge water will be used beneficially in either industrial or environmental outcomes.
4. Salinised land is a valuable resource for both productive, environmental and social outcomes.
5. The environment and biodiversity will be respected, understood, valued and appropriately managed.
6. All 'tools' (options) are viable and will need to be used in the right place and in the right mix. No one 'tool' is likely to work in isolation. Some 'tools' will need regional or state planning and support and this should be with minimal bureaucracy.
7. Shared responsibility at all scales, from farm, to catchment, to Region to State. Leadership and action will have to be locally driven with minimal reliance on State and Federal funds.
8. Continued need for R&D. Research must continue, particular attention to interactive paddock scale development and extension will be needed with extension through all private and agency levels.
9 New Industries, both agriculture and non agricultural based (including eco-tourism) will be developed, as regionally dispersed as scale/economics will permit.

10 Appropriate water management at all scales – recharge banks, large on farm dams, discharge control drains, on farm use of as much water as possible.

WORD PICTURE OF A FUTURE VALLEY LANDSCAPE
(The helicopter view)

Water will be managed effectively:

- Recharge by contour banking for on farm storage and fresh water use.
- Discharge drainage water will be used for commercial and environmental benefit.

- Perennials will be throughout – largest areas in phases of crop rotations, less areas in permanent woody and shrub layouts for various uses.
- Annual systems will continue to improve with enhanced management skills.
- Natural bush areas and replanted areas will be part of the landscape, all properly managed and respected.
- There will be more people, profitably employed in new industries, both on farm and in regional towns.
- Salt affected land will have a range of perennial plants for economic and environmental benefit.
- It will be a pleasing and visually attractive place to be!

RESPONSE TO KEY CONFERENCE QUESTIONS

1. **Predictions have been made of the long-term future extent and impacts of salinity in WA. Do we accept that these changes will occur if we continue as we are?**

   Yes - things will get worse if we do nothing.

2. **Do we have the options that will make a difference?**

   Yes - steps can be taken now to reduce the effects of salinity in valley floors that is occurring now.

3. **Do we have a shared vision for what the Wheatbelt valleys will look like?**

   Yes – we now have a 20 year 'shared vision'

4. **Are we willing and able to make the changes to achieve the shared vision?**

   Yes – it is worth the effort!!

5. **What practical steps are needed to achieve a shared vision?**

   LISTED IN SUMMARY OF '**NEXT STEPS**' DOCUMENT

KEY WORKSHOP OUTCOME STATEMENTS

A. MANAGING CATCHMENT AND VALLEY WATER

Workshop Outcome Statements:

- Change is inevitable
- 'Time is ticking away – some of us are close to midnight!!"
- Need a shared vision at the catchment scale to engage all landholders and engender social cohesion
- Urgent actions required now to alleviate wider future problems
- Managing water up-slope is relatively easy – the difficulty is in the valleys
- Water is valuable – need to find other uses for excess water (maximise water resource use) and attract people back to rural areas in doing so
- Need to manage living systems that are bio-diverse
- It is a people issue more than it is a water management issue
- Moving water away from salinity problem areas is required but safe disposal is important
- Need to develop and apply economic de-salination
- Trading water between farms should be an option. A framework is required to achieve equity in doing this.

Some water use options:

"Without extraction from the landscape"

- Salt-tolerant crops (cereals, horticultural products, salt tolerant native species, breeding or genetically modified options)
- Salt-tolerant forage crops
- Agro-forestry (salt-tolerant species, pharmaceutical products)
- Nature/biodiversity (corridors, eco-tourism, brand-marketing)

"With extraction from the landscape" (by pumping or drainage)

- Recreation industries (tourism, water-based adventure parks, fishing, cable skiing)
- Aquaculture (fin fish, crustaceans, seaweed, algae, B-carotine)
- De-salinised water
- Salt products from extraction ponds
- Energy potential from stored saline water.

Vision Statement

(i) A revitalised rural community, working together, that has achieved fundamental, positive change to create a healthy, well-drained landscape that is maximising biodiversity and landscape resilience with sustainable economic return from existing and new industries.
(ii) A healthy well-drained landscape is one which is free from waterlogging and shallow water tables where water moves in defined pathways

B. RETAINING AND MANAGING BIODIVERSITY

Workshop Outcome Statements:

- Biodiversity of wheatbelt landscapes is high and is internationally recognised
- Salinity significantly threatens wheatbelt biodiversity values

- Priority needs to be given to biodiversity values threatened in wheatbelt valleys, but eventually all valuable remnants to be protected. Choices need to be made about highly degraded natural areas.
- Tthe bush needs to be valued by all of the community, including local government and urban community
- Conservation of biodiversity is a legitimate land use
- Natural areas can't sustain any more compromised management
- The relationship between people and the bush needs to be better recognised
- Need to increase understanding of biodiversity and importance to the landscape
- The potential for profitable enterprises from the bush needs to be recognised
- A wide range of options to manage biodiversity be considered, including corporate, private and public ownership or and an environmental levy on commodities derived from the land. Credit to be awarded for retaining and managing biodiversity, including farm produce marketing advantage
- Conservation planning is a core element modern whole farm/catchment planning.

Vision Statement

(i) The rural and urban community supports and contributes towards innovative and sustainable rural enterprises that encompass and protect biodiversity.

(ii) A hydrologically resilient landscape where an affluent society operates sustainable enterprises within a network of contiguous, healthy and biologically diverse ecological communities.

C. ECONOMIC OPPORTUNITIES AND INDUSTRIES

Workshop Outcome Statements:

- Maximise use of physical resources
- Farming systems that encompass a diversity of income streams
- High water use farming systems

Vision Statement

An evolving system generated from sustainable land and water use composed of a diversity of profitable options in a vibrant and dynamic community.

D. PROTECTING PUBLIC ASSETS

Vision Statement

An increasing rural population serviced by adequate infrastructure and cultural and environmental assets. These assets will, along with new industries, draw people inland again. To service the community structures key assets and their management will be rationalised for maximum public benefit.

E. OUR CAPACITY TO CHANGE

Workshop Outcome Statements:

- Effective leadership at all levels is important – need for a Captain!!
- Find people willing to lead and develop their capacity
- Need to have the desired outcome in mind (a Shared Vision)

- Resources needed to support early innovators/adopters
- Valuing creativeness and openness to ideas
- Appeal to self-interest ("Enlightened Self-interest")
- Working in partnerships is effective – including for new enterprises
- Winners will be those who embrace change
- Community cooperation/teamwork is essential
- Need to understand roles at differing scales
- Need to be visible and emotionally engaging
- Need coordinating body/process to manage change and implement the Vision (like with the Murray Darling Basin Commission)
- Need to think of large change – encourage the outrageous, allow passion to be expressed!!
- Need for an accessible venue that encourages discussion of new ideas
- Technology is not necessarily limiting the required change
- Communicate current ideas and information widely
- Need to engage in two-way discussions (including government)
- Recognise that some do not have the capacity (financial or other) to change
- Willingness to recognise, accept and learn from mistakes
- Need role models for change (eg the Liebe Group)
- Recognise that regulation may have to be a part of change to achieve the Shared Vision
- Change processes are evolutionary.

Vision Statement

Vibrant, well informed communities making cost-effective socially acceptable decisions leading to innovative land management changes based on creative critical thinking, with a committed will to voluntarily embrace changes that are consistent with delivering the financial and social landscape outcomes that enhance the collective interests of all stakeholders.

NEXT STEPS TOWARDS ACHIEVING THE 'SHARED VISION'
Summary Comments From The Workshop

ADVANCING THE VISION

- Communicate the 'Shared Vision' as an outcome of the conference to the State Salinity Council, the Salinity Taskforce, Regional NRM groups, all levels of government and community. It should be promoted as belonging to the entire community.
- Arrange a 'Drafting Group' to refine the Vision and prepare a strategy for it's implementation
- Seek broad political support for the 'Shared Vision' to ensure that it endures beyond the period of the current government
- Engage broad community support for the 'Shared Vision', especially with those in rural communities who were not at the conference.
- Seek commitment to implement the 'Shared Vision' through funding and strategic action
- A response to the 5 Key Conference Questions is required.
- Some considered that a single authority with legislative support for salinity management be established (the 'Salinity Action Commission' was suggested, modelled on the Murray Darling Basin Commission) to implement actions to advance the 'Shared Vision'. However, most were in favour of the existing State Salinity Council, regional NRM groups (such as the Avon Working Group), perhaps the Salinity taskforce and the new Drainage Working Group to be leaders in advancing the vision.
- Suggested key tasks for 'lead body to advance the 'Shared Vision' includes communicating the Vision, setting policy directions, identifying critical R&D pathways, streamlining project implementation, initiating education and training programs and managing media.
- Provide capacity for local communities to prepare 'Local Community Visions' that align with this 'Shared Vision'
- Need to develop a 'Salinity Operation Plan' to achieve the Vision, with a focus on Biodiversity, Hydrology and Valley Floors
- Need 'Demonstration Catchments' based on strategies from the 'Shared Vision'. Integrated practices to be developed and demonstrated (especially PURSL and OPUS initiatives).
- Need to get the National Action Plan for Salinity and Water Quality aligned with the 'Shared Vision'. Partnership Arrangements according to this alignment to be developed.
- All groups need to be 'less exclusive'
- Protocol for agency/community coordination and communication required
- Identify those who attended the conference as the "Wheatbelt 2021 Group" and foster communications within the group (participant contacts to be circulated; website discussion could be encouraged)

INFORMATION, KNOWLEDGE AND EXPERIENCE

- Make existing information for salinity management more available. Information packages should relate to land capability (ie what goes where). Scientific papers should be distilled in a simpler form.
- Need to simplify scientific information and increase extension of relevant information
- Better incorporation of NRM information within Farming Systems development
- Gap analysis for Research and Development required. Salinity R&D 'drivers' need to be identified. Specialised R&D teams with local community input proposed.
- Develop a comprehensive 'knowledge-information framework'
- Too many people are 'defending a belief' rather than absorbing new information
- We often assume that some-one else knows more that we do. Sometimes we need to act on the knowledge that we have – and step into the unknown!!

SUPPORT FOR COMMUNITY ACTION

- Strengthen catchment groups and enable them to formulate plans
- Identify ways to engage all members of the catchment/community
- How do we make Integrated Catchment Management really work?
- Regional NRM groups to be more pro-active in supporting community effort (not just being a funds management body)
- Need to re-structure arrangements for Community Landcare Groups and Agency Support
- Need to identify and value state and local "Assets" (landscape and infrastructural) then assess "Asset Viability" considering the risk of salinity. Communities should be assisted with decisions about the protection of these assets
- Encourage and develop local skills to protect wheatbelt assets
- Provide resources to employ people who can empower local communities, develop local community capacity and develop local community Visions based on future directions

NEW THINKING – NEW ENTERPRISE

- Initiate an integrated group from the worlds of finance, business, service organisations (not necessarily those currently involved in salinity and NRM) to brainstorm new ideas to revitalize country towns. New people with new ideas should be encouraged (such as from people who attended the conference, eg from the Perth 'City Vision')
- Engage expertise in 'Marketing' to assist with development of new enterprises. Link 'marketing' with 'new industry passion'.
- Australia is a leading nation in the third major global trading block!
- How does 'Triple Bottom Line' accounting affect rural communities? Industries need to account for environmental impacts/benefits.

- Need to identify and publicise sets of community "Values and Beliefs"
- Develop dialogue with new innovative groups (eg the Liebe group, WANTFA, Saltland Pasture Group and others)
- Problems and the solutions required are at catchment/regional scale but the main focus is still at the farm-scale
- "Franchise Model" – all farms are franchised businesses to the large 'agricultural corporation' – there are 10,000 members, gross annual income of $5billion – salinity is said to cost about $80m each year!! What action should the corporation take? Options, targets??
- What is a 'viable community'? Which towns should be retained? How important is distance and isolation? What is the minimum social structure required?
- Topic - the Wheatbelt should be seen as an asset – how best to value and utilise the asset?
- Topic – who to get the 'next generation' to adopt the current 'Shared Vision'?
- Topic – the extent to which landholders/agriculture should be responsible for their actions (ie salinity as a result of agricultural land use)
- Avoid "Shared Nostalgia" when setting visions.

INTEGRATED WATER MANAGEMENT (DRAINAGE ISSUES)

- 'Shared Vision' should be more specific about regional drainage systems (the views of proponents for regional drainage strategies were not adequately 'shared'). There should be landscapes that move water!
- New Drainage Advisory Committee should develop "Regional Drainage Systems" with appropriate assessment procedures (including through EPA)
- Manage water, not salinity.
- Protocols and criteria required for information and communication within communities about drainage. Targets should be set.
- Protocols for inter-agency approach to drainage required.
- All paleo-drainage systems should be assessed for salinity risk and their capacity to be effectively drained.
- Demonstrate implementation of major drainage works as urgent action to reduce wider effects of salinity. This should be followed by integrated catchment works to reduce the cause of salinity.
- It is important to manage water within catchment. New initiatives/enterprises required to utilise excess water *in situ* (including discharge water from drains and pumps)
- Need to spend more time making engineering solutions work rather than proving that they don't.
- The C. Y. O'Connor pipeline to take freshwater inland provides a 'model' for what can be achieved by engineering options to "take salt out – it is all down-hill!)

LANDSCAPE ECOSYSTEMS

- Describe and publicise the biophysical status of the environment (rural landscapes that include wheatbelt valleys) as they are predicted to be in 2021
- Biologically significant areas (remnant bush, lakes, wetlands) should be assessed according to values and risks. Priority funding should go to high values at risk
- Sustainability of all systems imposed on our landscape be proven to be not harmful to any other part

CHANGING COMMUNITIES AND LANDSCAPE USE

- Identify the behavioural and cultural determinants of change – what is require to gain successful adoption of best practice?
- Don't knock 'Tall Poppies' – they are probably innovators for our future.
- Need to better identify the personal and community characteristics of those who live in the Wheatbelt (*Homosapien inlander*)
- Decision-makers need to live amongst the decisions that are made
- The community is waiting for science but science is just catching up with the community
- Rural communities want to have 'environmental vandal' tag removed – they did not set out to vandalise!
- Communities need to establish a "durable set of standards" – what are the important values to each local community? Can 'commodity' and 'community' values be merged?

FUNDING

- Provide an audit of how money has been spent
- Use the 'Investment Framework'
- Arrange systems of 'financial rewards' or 'market accreditation' for adoption of best NRM practice or for delivery of measure outcomes towards NRM targets
- A wider range of funding options be assessed (eg Corporate funding for development of 'Carbon Sinks'
- Identify new sources of capital – sharing risk and ownership of farms through investment.

QUOTABLE COMMENT

"……the more I hear about salinity, the less I understand about the issue. It shows how complex the issue is. I think that our community has about 5 years to get it's act together. We need local-based action. We will need to develop our own local Vision based on our best judgements. We can't wait until we understand everything."

from comments made by Russell Crook, Farmer, Westonia Shire Councillor.

See conference website for full list of conference comments (www.avonicm.org.au/avonicm/wbeltvalleys).

'NEXT STEP' COMMENTS

A full list of all comments made at the end of Day 3 of the conference.

The Salinity Taskforce has already been appointed to take our views to the government, they should be the ones to take outcomes of this conference to government.

Publicise options for income diversification that have been successful, to encourage new industries/options.
Let people know what is available and has worked – maybe through CLCs.

Regional groups and sub groups to assist agency/community discussion on what to do at **local** level.
Salinity Council and Regional groups to work with agencies to support sub-regional and local groups.
Salinity Council, agencies and government to provide leadership and resources to move forward.

Prepare report with final recommendations.
Request – Salinity Council and Task Force to digest and act on the recommendations.
Local communities/farmers will continue with their own projects.
These should be followed up to record success/failures.

Step 1. Shared vision not our own visions.
Step 2. Support given to ideas that look at integrated demonstration projects.
Look at projects potential to achieve the vision and give support.

Small sub-committee or existing State Salinity Committee, Salinity Task Force to formulate a number of principal tasks that take into account the shared vision of this conference – that is:
Define and enumerate key tasks, such as

- R & D pathways – critical
- Policy directions/recommendations to state government
- Representations to industry/commerce
- Streamlining Project Implementation.

State salinity program should be minimised as a single agency that deals with different aspect of salinity instead of having many agencies doing parallel work e.g. Agriculture, Water & Rivers Commission, DEP, CALM etc
There should be a single scientific body to assess the individual situation and propose suggestions to solutions.
I would like to see this as a body that farmers can come and say that if my farm is located in such and such place, what would be my best options of management. This body should assess the parameters involved with the farms situation and provide recommendation taking into account all aspects of hydrology, environment, ecology, economic and sustainability aspects.

The shared vision is basically that valley floors be improved. This does not necessarily mean drainage.
It must be conveyed to the task force and to government that the sustainability of all systems imposed on our landscape be proven not to be harmful to any other part of our landscape. It is our landscape. We have given farmers the privilege of managing it.

Communicate findings of conference to all members of the wheatbelt community.
Cost out (both financial and environmental) benefits of the different systems.

Salinity task force is appropriate body to progress outcomes of conference. I doubt if any proposed step has not been included in submissions already sent to them. But in case that is wrong "ask the taskforce to accept further submissions".

Clarify the salinity objective ie can we accept that at the gross scale 30% is inevitable.
Promote the management options we have to deal with salinity.
Move forward and start investing in the RID, creative thinking, community innovation that will utilise the huge resource waiting to be used.

Practical steps to a shared outcome:
Identify corporate sector businesses who are willing to invest in defining the 'best practice' steps for saving the valley floors, then investing in the process of saving them.

Develop a system of incentives for the retention of remnant vegetation (including salt lake system vegetation).
e.g. Accreditation system for sale of products from environmentally sustainable systems i.e. market rewards for being clean and green.
Whole community i.e. taxpayer) funded financial reward systems for retention of remnant ecosystems.

Distillation of knowledge into a structured framework showing gaps and uncertainties, in a public location. This repository will be huge and include multiple 'truths' about processes. It will be in a variety of formats and communicated/pitched to a variety of levels. Its creation will take a number of years, but the knowledge management process is ongoing, as is the review/creation.

Convey to the wider public the visions of the forum.
Gauge the response by questionnaire of public support for the vision.

Share vision with rest of wheatbelt community and gauge their response (Ag memo survey?) to see if they want to be a part of what the conference has done.

Let the wider community know what the vision is.
Do an audit on what has been done to date so we don't reinvent the wheel.
General public survey on possible solutions/techniques to alleviate the problem and also opinions about the vision.

Get an integrated group of young, middle aged and older people from areas of finance, business, service industries, environment etc who can discuss and brainstorm ways to revitalise country towns and diversity opportunities within them.

As a farmer I
- support the Salinity Taskforce in their endeavours
- support the taskforce formation looking at drainage
  - member selection vital in being representative of all views
- salinity finding to be half regional groups and half agencies
- agencies need to regain direction Ag WA – what is now their structure and purpose? Appear to be 'gutted' of personnel and research purpose – more technical resources.

Request the new drainage council to do a comprehensive search on drainage works throughout the wheatbelt – where they are, who did them, are they working – so that future decision can indeed be based on "creative, critical thinking – (identify drainage hot spots). This will allow us to identify GIS and map drainage hot spots in order to select an area to evaluate the effects and benefits of a linked drainage system. 4M$ could be used to link these systems where appropriate.
Request the State Salinity Council to take the vision, refine it to a workable position and TAKE ACTION.

A contact list of conference participants be distributed to all participants (and posted on the web?). It would include contact details and areas of interest. Maybe an on-line discussion group created (this is secondary to first idea).

Fund community groups to employ facilitator/futurist type to help them establish.

Let us move on from repetitive goal setting and circular discussions.
I look forward to moving into implementation of the many ideas previously developed.
Let us ensure that this is an inclusive approach without emphasis towards any partisan group.

Research/analysis of assets to assess viability of maintaining or changing to other options (e.g. new transport technologies). This analysis will trigger decisions in community e.g. (1) cost of services at current rate compared to change eduction system (2) review 'community service obligation' (CSO) services e.g drainage, rubbish etc.
All assets/services to be self-sustaining in long term but may need short term underwriting of capital investment to restore/change.
Use Salinity Council investment framework process to assess values/costs/threats to assets.

PUBLIC ASSETS

Use the investment framework to value and prioritise public assets, so resources allocated to NRM can be spent appropriately.

Look at what constitutes a viable local government size – people
- budget
- size

Government needs to be approached in regard to devoting public funds for
a) blue sky research into economic options
b) employing people to empower communities.

Agencies need to stop making own research/extension visions and listen to what the farming and general community needs to know,…then act.
An inter-agency approach needs to be taken re the arterial drainage to the ocean project. The best research people from whatever agency and appropriate community people need to be involved in a feasibility study.

Establish a dialogue with former groups (Liebe, WANTFA, SPA) to identify and celebrate former successes in sustainable land management for valley floors.

FORGET SALINISATION!
The issues are complex, this has been forgotten recently.
Complex issues requires integrated management systems –

- surface water management
- perennial planting/systems
- veg protection and biodiversity enrichment
- PORSL options
- agriculture
- etc new industries

Not a single tunnel vision response (deep drainage)

Identify and financially support a wheatbelt valley community (not 'group') to plan, implement and evaluate salinity management at a substantive scale.

Survey our ancient river systems (valley floors) to determine how they intercept, receive and carry water; retain and detain water and how might the hydraulic behaviour be improved to facilitate better drainage.

Gain the confidence of the other growers who aren't here!…

- document the existing experiences and quality/quantify (authenticate/provide rigour) those experiences.
- encourage others to uptake and become involved by raising their awareness and understanding of the issues and options
- this needs to be done by local, relevant demonstrations/trials and with local relevant training/workshops etc.
- support those who are willing to try
- support those "groups" who will be extending this information to the on-ground growers

Other steps

- develop new profitable and sustainable options
- encourage innovation

The next generation must be involved and have ownership! (of the vision, strategies etc).

Need to address soil structure so that water can be absorbed and held in the soil so it can be accessed in dry periods for greater plant growth and production.

Reinvigorate progress towards getting the NAP aligned to WA visions with appropriate partnerships with WA community.

Allocate the $6M in Catchment Demonstrations to priority OPUS/PURSL initiatives (not old farm planning).

Website: www.wheatbelt2021.com.au

Attendees of the conference are the inaugural members of the wheatbelt2021 group. (240 members).
A website to combine the information collected, the successes and testimonials and updates. Links to other information relevant to people.
The vision is recorded and our obligation is to reach it. Membership will change over time but the vision is set. Progress can be mapped.
Centralise knowledge and achieve the vision.

I would encourage the skills and people in place now. We are world leaders. We have an asset now, in salt land, water. Direct extra R & D in longer term development of options.

Better communication between the various agencies to speed up the processing of works and project applications. These people need to meet on a very regular basis and make decisions.
The Minister needs to put in place the protocol for this to happen.
This process could be pursued by the State Salinity Council.

Communicate vision to wider community to find if they share it before taking too many more steps.

Evaluate ideas flowing from this workshop session on 1st steps at Regional and District levels. This could involve all relevant local agencies and stakeholders and identify appropriate courses of action for the local setting.

Restructure of Landcare groups/CLC structure agency support

How

- Retain State Salinity Council
- Disband LCDCs (statutory so limited in what they can do)
- Recreate "community landcare groups"

Incorp: consisting of catchment group reps, and fully funded CLCs to support the community group with a community development and Shire Council component.

- Supported by the AWG
- Funding for CLC from Shire and Regional funds
- Agencies to create teams accessible and to support the community landcare group

Create and circulate a database of all participants and experts to aid communication between interested parties.
Develop a protocol for agency – community coordination.
Communities need a process (one-stop shop) to help deal with enormity of the issues and to develop a realistic plan.
Overcome communication problems between LCDC. Sponsor and support formal links of communication.

- Concern that shared vision was not just about drainage…yet focus toward end of facilitated session appeared to be only on that option.
- Unless we can work together from "values and beliefs" then we won't be able to effectively move on. We need to be prepared to listen and understand from others shoes.

Strategies

- Awareness and education focus
  - land mgs
- urban
- rural
- Sharing and linking info of knowledge
- Opportunity to develop the capability of stakeholders in both community and technical connections
- Focus on enterprises that can use H20 in situ

Define and publicise the likely outcome in terms of the biophysical state and the environment in 2020, under current best practice.

Find a way of getting all landowners in a catchment/valley/drainage unit to be part of planning, with an understanding of the hydrology, the use of water.

Incorporating changing farming systems, types of crops, pasture and environmental planting and drainage where necessary.
(Until this happens we will not make the next great leap forward).

1. Any drainage systems should NOT have downstream environmental impacts
2. Attempt to retain excess water in catchment – dealt with in situ – NOT PASSED on to other systems where impacts not understood.

GOAL

Ideally water discharged from a catchment should be no more than was discharged before European settlement.

Broaden focus of Salinity Council to include work on understanding human systems of change i.e. what are the kinds of behaviour and cultural determinants of people or communities that adopt change successfully.

The people that attended the conference should not need a report as much as those people who could not or did not want to attend.
We were part of the vision process and should include those who weren't. It seems as though the same people attend with the same ideas and it would be more beneficial to include new people with new ideas.

Next step is to immediately implement several full drainage schemes and monitor their affect then positively involve the entire catchment in the known perennial, water harvesting, aquaculture, high value tree-cropping etc so that within 5 years we have concrete evidence. Preferably in the organised motivated catchments like Belka, Narrembean and Beacon.

Regional Groups e.g. Avon Working Groups need to be more proactive in embracing community efforts – other than being just a funding body.

Mass communication of workshop outcomes, including shared vision and major research findings

Concerted effort to connect wider community

Extension of information/understanding to be community/affected landholders.

Valley floor problems can that have developed since clearing can be reversed.

Soil is alive it must be kept in balance 1 water/air ratio, humus to produce nutrients etc for soil animals (micro and macro).

Water movement (shallow) from top of catchment to valley floor is creating the majority of the problem and needs to be held where it falls.

How do you get (convince) the reluctant farmer to take that extra bit/acre of arable land for conservation?

The problems/solutions to salinity, and the systems that drive it (both landscape and human economic/social etc) are at least catchment of "regional" in scale and process.

But we are still looking for solutions at farm scale where the "solution space" is too small physically and too narrow in terms of options, and squeezed by external factors (cost/price, loss of land to salinity etc etc).

To delete the disaster, must we erase the cadastre; find catchment/regional scale enterprises to conduct catchment scale land use changes??

Where's the process to start exploring how we might do this?

A shared vision can come only from a shred understanding.

The technical papers covered excellent ground, but maybe they need to be distilled into simpler form so we can all understand and accept them as the basis for developing a vision.

This simpler form would include drawing out the fundamental principles of the landscape, the history, the economics etc on which the vision is built.

There is still too much "defending a belief" being expressed at the conference, indicating that people have not absorbed the new knowledge, but rather are justifying past actions.

P.S. Is there any funding/staff/process to continue to build the vision and action after the conference?

- Communication the shared vision to:
  a) Government – Premier and Ministers chance and Edwards.
  b) Peak existing community based groups (Salinity Council, NRM Regional Groups).

  as a clear expression of the conference participation.

- For a clear statement in response from Government, but particularly the community groups, is support of the shared vision and a commitment to implement it by strategic actions.

Formation or strengthening of catchment groups that involve all landowners and formulate a plan for their catchment.

There is **SO MUCH** information out there already but people don't know what's there.

As a next step we need to make sure this information is available to those who can use it, and that they know how to access it. For example:

- Environment/landcare "shopfronts" across WA – like catchment centres but better resourced. They don't need to be in their own building, they could be a corner of an agency office or shire office.
- A central web resource with links (see salinity.org.au).
- Resources for CLCS as distributors and collectors of information.
- Better sharing of information between agencies and NRM regional groups et al.
- Some kind of central database of contacts and information resources.

We can start this today!!

The shared vision, in my understanding, was about on-farm and/or land holding management of water, it did not accept that a regional drainage system was part of the shared vision.

A first step should not be towards a regional drainage system but systems for within farm, town, etc usage of water, which may include internal drainage – settling ponds etc.

Please refer back to Group B's notes, 'shared vision'.

Any regional drainage proposal would need to be referred to the EPA and properly assessed, it cannot be 'fast tracked'.

A few highly vocal people have repeatedly put a position that has not been shared.

The State Salinity Council have the Minister to survey and check the levels of the ancient river system so that they may be used for drainage of the valleys.

The first step in the formation of a simple Department to manage and plan and reduce salinity.

All work must be authorised by this Minister within an area to be gazetted covering the wheat belt and from the Machinery line and the eastern and northern boundaries of the physical catchments of the From, Moore, Avon and Blackwood rivers.

The M must be vested with the power to do or not do whatever is necessary to progress the Belford Plan.

Once we know what we want to do, we need sources of finance. The community cannot afford to pay. The Government appears unwilling so we need to tap sources of Corporate Funding. We can help corporations achieve their goals and they will pay us to do this eg we can create carbon sinks to assist them in meeting their greenhouse obligations.

The fact that nearly 300 people turned up to this conference is by far the first tangible option of convincing politicians and the community n general that there is a problem that threatens to lower our standard of living.

Start to develop **criteria** between drainers, community, shires, agencies.

Build some shared and agreed **targets** that can indicate if drain, planting, is doing the job.

It's not possible to save all the remnant vegetation patches and $'s are limiting.

Therefore, as a first step we need an audit of what is left and pick out the "Jewels in the Crown" of remnant woodlands that requires urgent action. (ie pumping etc) and act on it.

"Lets get strategic, and act".

All stakeholders need to accept that a **shared** vision belongs to the entire community and is therefore much greater than any single issue – eg:
- drainage
- biodiversity
- production
- etc

It is all of these **together**.
It encompasses all opinions.

- Mass leaflet drop to landholders informing them of the shared vision and how it was developed.
- Appoint a "drafting group" to refine the rough vision developed at workshop into one that can be circulated generally.

- Please don't form another committee or Government Department to tackle this issue. Use existing ones.
- Collect all existing information and research on drainage, saltland revegetation and extend it to stakeholders – (farmers and LCDC's). Extension of existing research is very poorly done. Research is being duplicated.

Pass on all the statements arrived at, to the State Salinity Council and other bodies that can project themselves to the top bucks (Premier, PM etc) on an official level.

Communicate outcomes of valley floors to committees particularly conceptual changes.

Determine how manage on a committee from this floor.

Elect committee of say three farmers and 2 professional onto committee to liaise with Government to determine how best to meet the vision.

- Publish the shared vision in press.
- **State Salinity Council** to take shared vision to State Government.
- Action to be taken on new industries.

1. We need public knowledge of what is biologically valuable to do that:

Coordination between agencies, community groups (eg catchment groups) and "environmental" groups working together to:

- identify ecosystems in area,
- promote findings,
- prioritise highest need to protect,
- plan for protection.

2. To help farmers make decisions about what to do on their land:
- Provide information (in nice neat package) about what options are available to manage water resources.
- Get scientists to simplify current findings – what works, where does it work, why does it work there.
- Agencies to provide role in supporting farmers "try out" different scenarios to determine what works for them.

1. **Convenors** publicise outcomes of this conference ie – Shared Vision.

Clearly address the questions posed on the poster of key conference questions.

2. **Convenors** brief Drainage Committee. Task Force, Avon WG and agency CEO's (ie use existing structures, committees to achieve actions that contribute to the vision on the outcomes of the conference.

- Political Bipartisanship.

This process is much bigger than any government bipartisanship will help convince most that it is worthwhile let Judy talk to Hendy.

- "One-Stop Shop"

Let's have a "Salinity Action Commission" – A' la Murray-Darling Basin Commission.
Perhaps state Salinity Council. Perhaps "Salinity Taskforce". But someone has to take responsibility for coordination and commitment of funds.

The "One-Stop-Shop" could call for or coopt members from workshop.

- Legislative/Statute to implement a Salinity Cap/Biodiversity Cap/Water Table Cap.

Be prepared to get the "City" to fund the innovations. In the business to kick-start alternatives.

To request the Drainage Committee and Salinity Task Force to:

- Consider the vision statement developed by the Valley Floors Workshop.
- Develop and operational plan (objectives, strategies, responsibilities, monitoring of performance criteria) for – biodiversity, management of Valley Floors, hydrology.

State Salinity Council, in partnership with relevant agencies, sponsor and fund a programme of research and extension activities to provide landholders and other stakeholders with technical and financial information and options to high water use options and alternative land use systems.

Fix the drainage problem and set an appropriate regulatory environment for engineering solutions.

- Make landholders **responsible** for their actions.
- Prohibit further land clearing and adverse off-site effects of land management.
- Ban cats.

A practical step to achieve the shared vision is to ensure that existing NRM State committees eg State Salinity Council progress the options expressed at the Merredin conference.

The membership of the committee needs to be expanded to cover **all** state level groups involved in NRM.

Present to the Government with the vision.

Pressure Government to work on a bipartisan approach for super long-term commitment to implementing the vision.

It is obvious that everyone is concerned about drainage.

I feel if a "standard protocol" for our deep drains/groundwater pumping etc was decided upon and that all government agencies agreed and accepted these, all people in the community could get along with more forward thinking.

Once these issues of excess water are decided upon, new and profitable industries will (or can) be created, biodiversity can be controlled and looked after, and farmers and the wider communities will be sustainable, and maybe we "might" even bring back more people to our regional centres.

We must promote new industries in our **"Wheatbelt"** and look after the ones we already have.

Take it back to small groups in our communities and interpret it from what it means to them.

Use the process we used in our own communities to develop our own visions from our own groups – this is the level where a shared vision is most important.

Note: This "shared vision" is lots of words in a motherhood statement – it says a lot but doesn't mean much at all.

It is when not shared with all the community. If it was it would be so vague as to be useless (it already is to some extent as it could have so many interpretations).

Ensure individual components of vision are incorporated into implementation of proposed "Demonstration Catchments" promised by State Government (multi-agency).

Accept findings of Demo Catchments.

Under consultation CLG implement appropriate actions within highest priority catchments.

Establish a network of farming systems development officers who:

- work with local farmers and farmer groups to identify R, D & E gaps,
- work with specialist R & D teams to implement R & D identified by farmers and groups,
- communicate technical knowledge to local farmers.

These farming system development officers will require strong support from experienced professionals and farmers.

Establish specialist R & D teams in the following areas:

- Herbaceous perennials
- Woody perennials
- PURSL
- Engineering and water management

The first step is to implement Valley Floor drainage programs based on successful models already constructed throughout the Wheatbelt.

Seek support for projects already into the feasibility stage like the Jibberding and Beacon projects.

Develop current perennial options with regional adaptive effort (farmer driven R & D).

Identify gaps not filled (physical environments and farming systems) by current technologies.

Seek new options and adequately resource their R & D leading to commercially availability as products.

Information package to suit client needs.

Capability maps to aid in decision making for salinity management tools ie where you can plant trees for salinity control, where you can drop drains.

Commence large scale drainage of the valley floor – forthwith.

Encompass all landholders in the total area of affected catchments not only landholders with the valley floor.

Reason upper area of catchments contribute to the water table and salinity.

Allocation of public money to demonstrate the drainage of saline land can be part of a sustainable landcare package.

This funding should have the purpose of accelerating the adoption of Wheatbelt valley recovery and recommending changes where necessary.

Farm based water management.

- Increased groundwater evaporation on farms.
- Intercept freshwater pollution of saline water.
- On-farm use of water.

Create more open water environments **not** in natural wetlands.

Our shared vision needs to be shared!

Drainage may be a part of that vision as an option. Until we know if drainage is an option then we need to continue to support other options.

Could existing groups be less exclusive – more inclusive please.

The assets of the Wheatbelt valleys must be seen as an asset.

GENERAL COMMENTS (FROM 'POSTBOX')

I think that all speakers were of good quality and had valuable contributions to make. However, I feel there should have been a greater emphasis on new thinking to solve the problems confronting the wheat belt. Much of the content was in well-known subject areas of hydrology and salinity. From 9 am onwards (with the exception of F Frost and D Pannell) there were four speakers on various aspects of hydrology and salinity. I am sure everyone learnt a thing or two new from each, but I do not think they challenged our thinking with new information to solve the problems from a new perspective.

For example, if new enterprises are to be successful, it will require a great deal of passion and commitment from all involved especially the farmers. I would like to have listened to one (or tow short) presentation from someone who has started a new enterprise eg wine industry and could demonstrate passion and commitment. Preferably a woman because they are normally better at showing the passion to others, but could be a female and male tag team.

Next, I would like to have heard a top rate marketing person talking about what is necessary to successfully market primary products. Annimac (the Futurist) touched on this, but more time should have been spent on this because it is a topic that most farmers know little about and are uncomfortable with. This is some of the new thinking. Further, it would have been good to link the experiences of the marketer and the passion and commitment speakers.

The marketer could have presented a successful model for the introduction of a new enterprise. John Bartle got close with the oil mallee model, but I think it was too distant from most farmers for them to relate to.

Finally, what about some more information on the Triple Bottom Line? Look on www for examples.

Financial
Environment
Social and Cultural

Let's hear from some organisations and consultants who are grappling with what it means and have some discussion about how their experience can benefit country people.

Well worth my coming over from South Australia. Useful information, challenging discussion, great contacts, excellent organising and good food. Well done 10 out of 10.

Look forward to ongoing links with Western Australian farmers and agency people. I'll be back.

Thank you for telling us what we already knew.

A much better outcome would be to brief us on were all the salinity and NHT money has been wasted.

What we need is an output measure on all money that is being spent, with an audit of **all** monies spent.

Thanks for the talk by the futurist. Boy did that make the trip worthwhile **NOT!**

Excellent conference – could a list of delegates be made available, wither on the web or some other way? Thanks.

SURVEY RESULTS

INTRODUCTION

A survey of attendees at a salinity conference in Western Australia was conducted at both the outset and conclusion of the 3-day proceedings. The survey consisted of sixteen questions that related to salinity in Western Australian Wheatbelt valleys, particularly the way people perceived its extent and impacts, and options for its treatment.

METHOD

Responses from the surveys were entered into an Excel database and interrogated using the statistics program, Statistica. All valid responses were used to generate an overview of attitudes before and after the conference. The initial survey had a sample size of 117 respondents, whilst the repeat survey had a sample size of 76 respondents. We could not ascertain how many people filled out both surveys as most people did not disclose their name on the survey.

Agency staff and rural landholders were isolated from the complete dataset to perform further analysis, which accounted for approximately 75% of the original sample. It was assumed that local government representatives from rural shires were also landholders in the associated district.

RESULTS

Part 1. General Outcomes

Risk

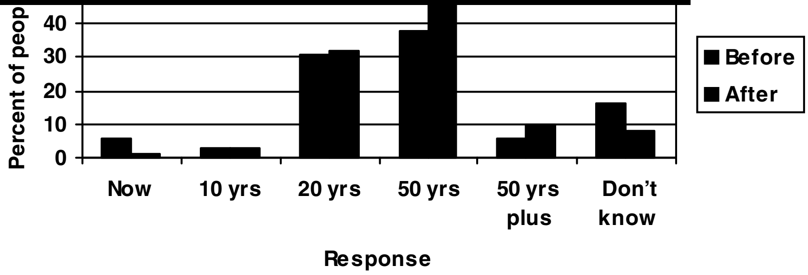
Most people attending the conference held the prior view that the risk of further salinity in wheatbelt valleys was serious (31% stated that there was a high risk; 61% stated there was a very high risk). This general perception was not altered by the conference.

Where the two surveys differed was in the number of people that did not know the risk of further salinity: at the beginning of the conference five percent of respondents stated that they did not know the risk, whereas there were no respondents in this category in the second survey. There was a comparable increase in the number of people rating salinity as a very high risk in the second survey, indicating that the conference heightened people's perception of the risk.

Timeframe

In both surveys, the majority of respondents believed that most salinity will have appeared in the next 20 years (31% in survey 1; 32% in survey 2) to 50 years (38% in survey 1; 46% in survey 2). At the end of the conference, attitudes had shifted away from an urgent to a longer time scale – the figure below shows a decrease in the percentage of people in the now category and an increase in the number of people in the 50 years and 50 years plus categories.

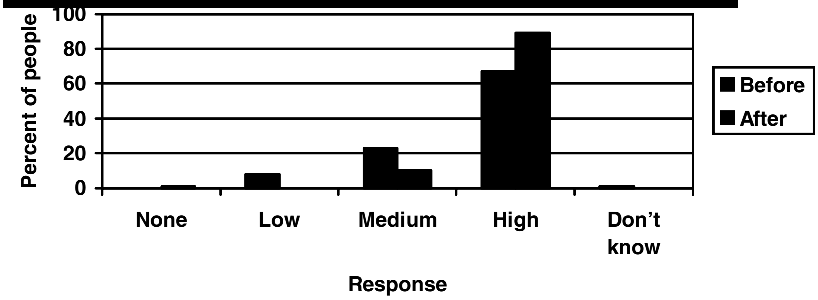
[redacted]



Offsite Impacts on Biodiversity

A notable outcome of the conference is the large shift in attitudes towards viewing the impact of salinity on native plants and animals with high importance. The figure below shows that 67% of respondents were in the high category in the first survey, compared to 89% in second survey.

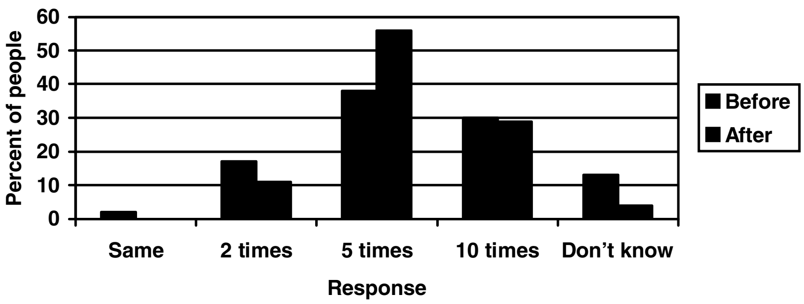
[redacted]



External Costs to Rural Infrastructure

Opinions on the costs relating to the impact of salinity on rural infrastructure were normally distributed across the choice categories. Attitudes in the second survey were less variable with no respondents believing the costs would be the same and an additional 20 per cent of respondents believing that the cost would be at least 5 times greater than now (see figure below).

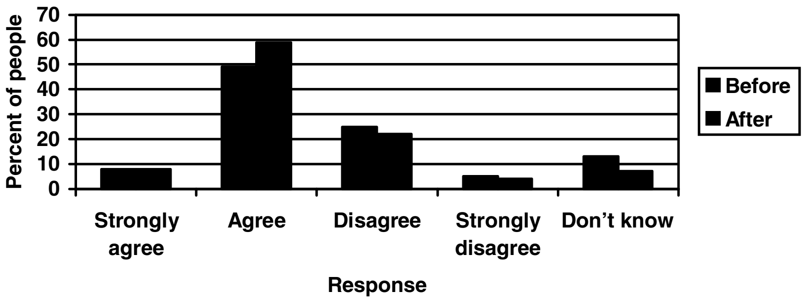
[redacted]



Options

The majority of people attending the conference agreed that the options for dealing with salinity are currently available, and the proportion of people holding this sentiment increased by 10 per cent by the end of the conference (see figure below).

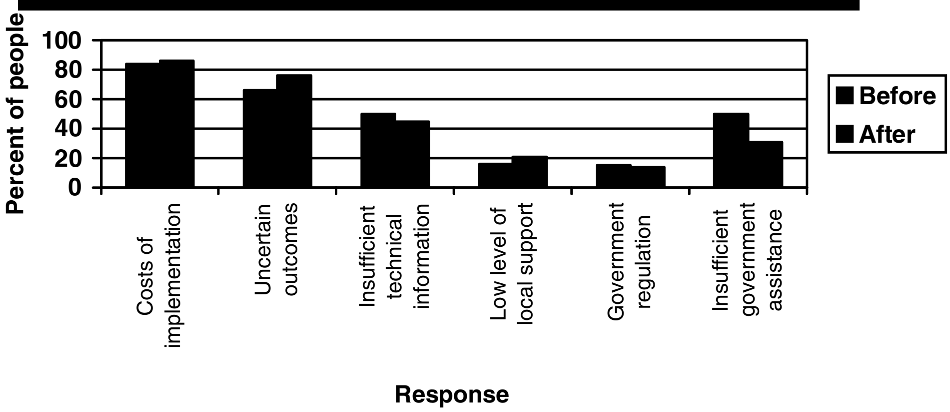
[redacted]



Limitations

The results graphed below show that the costs of implementation are the greatest deterrent to the uptake of suitable options for salinity. This is closely followed by uncertain outcomes. Factors that were the least limiting were local support and government regulation. Less people believed that insufficient government assistance was a limiting factor at the end of the conference (50% in the first survey; 31% in second survey).[1]

[redacted]



[1] Respondents had the option of choosing more than one limiting factor. Therefore, percentages for the six options do not collectively add up to 100 per cent.

Vision Setting

The initial response to the survey showed that the vast majority of people attending the conference were in support with the statement that it is important to have a shared vision for salinity in wheatbelt valleys (43% agreed; 47% strongly agreed). This perception was strengthened at the conclusion of the conference, with the percentage of respondents who strongly agreed with the statement increasing to 57 per cent.

Respondents were also asked to prioritise what groups should be included in the vision .[2] To analyse this question we considered cumulative values. For instance, to obtain the percentage of people that ranked neighbours as their third choice, we would add together the percentages of people that ranked it as their first, second and third choice.

In the initial survey the highest ranked choice for sharing the vision between was neighbours. This was followed in order by; catchment groups, regional groups, local government, state government and federal government. The rankings were the same in the second survey, but there was far less variation in people's choices (see table below).

[redacted]

Values appearing in this table are cummulative percentages.

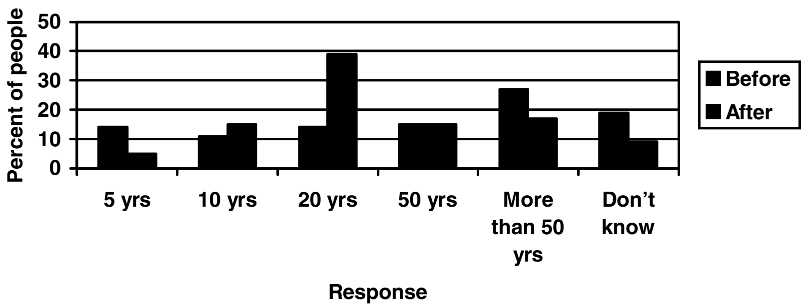
Ranking (1 is highest priority)	Neighbours		Catchment Groups		Regional Groups		Local Government		State Government		Federal Government	
	Befo re	After	Befo re	After	Befo re	After	Befo re	After	Befo re	After	Befo re	After
1	[redacted]	[redacted]	21	14	10	9	3	3	7	3	8	3
2	64	77	[redacted]	[redacted]	31	23	11	11	20	8	10	3
3	74	86	79	92	[redacted]	[redacted]	44	35	29	15	21	5
4	75	92	89	94	87	97	[redacted]	[redacted]	53	26	30	9
5	87	95	97	98	93	98	83	92	[redacted]	[redacted]	44	17
6	100	100	100	100	100	100	100	100	100	100	[redacted]	[redacted]

Respondents also considered the timeframe for the vision. By the end of the conference there was a significant increase in the percentage of respondents wanting the vision to cover a 20 year timeframe.

This could possibly relate to the strong message delivered by the workshop facilitator that this is the appropriate timeframe for vision setting.

[2] A number of responses could not be incorporated in the analysis because equal ratings were placed on some of the options. Thirty-one responses were excluded from the first survey and 10 were excluded from the second survey.

[redacted]



FUTURE LANDUSES

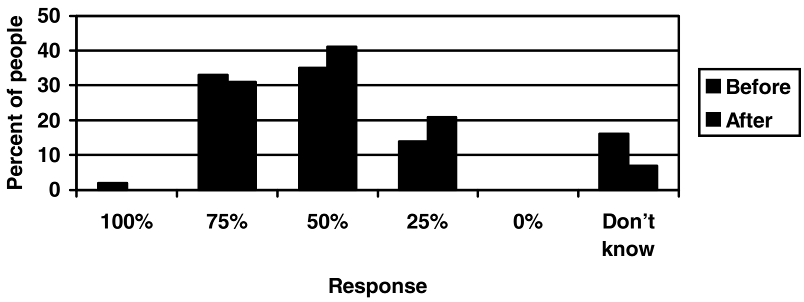
In broad terms, respondents were asked their desired response to salinity, assuming that salinity will increase under current practices. In both surveys, 56 per cent of people wanted to stop it getting worse and only 8 per cent wanted to return it to the way it was before clearing the land. The number of people that said that we should live with it increased marginally from 20% in the first survey to 23% in the second survey.

The main reason for change away from traditional rural industries was seen as salinity (39% in both surveys) and the continuing trend of increasing input costs and declining returns on agricultural commodities (37% in the first survey; 45% in the second survey).

Taking this a step further, people were asked to what extent they thought traditional rural industries would be the main source of farm income in wheatbelt valleys 30 years from now. Respondents saw a place for agriculture in the future, with approximately two thirds of people believing it will comprise between 50 and 75 per cent of the farm income.

There was a difference between the results of each survey. The second survey saw a shift away from relying on traditional agriculture (see figure below).

[redacted]



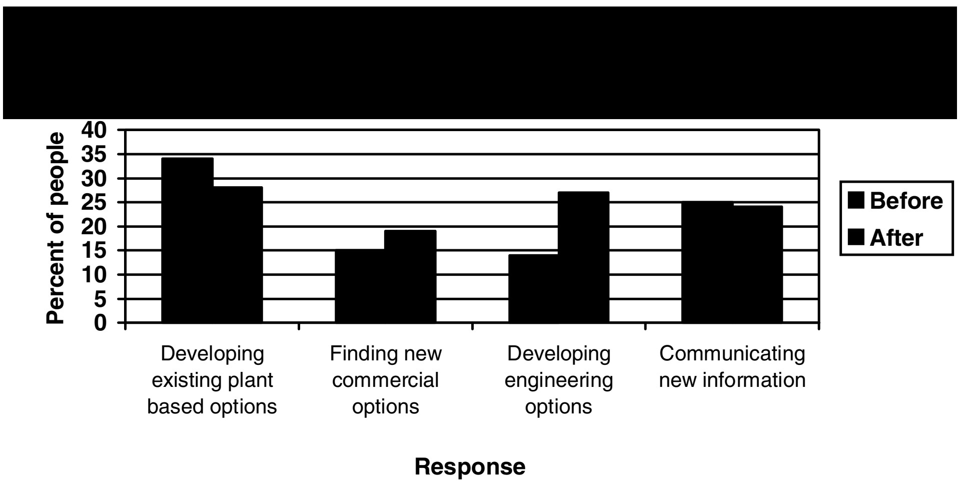
Respondents were given the opportunity to provide qualitative information on what should be done with land severely impacted by salinity. Responses varied from do nothing to full reclamation. Emphasis was placed on finding economic uses for the land in the areas of salt and mineral mining, aquaculture, saltland pastures and energy production. Other options concentrated on creating a new saline ecosystem, through fencing and revegetation with native salt tolerant vegetation. Some people considered drainage, pumping and evaporation pumps as other alternatives.

EXPENDITURE

In light of the theme of the conference, we would expect the scenario where respondents were asked to allocate 10 million dollars of additional government funds to be strongly biased towards the environment. However, respondents obviously still had the bigger picture in mind with funds being spent in both surveys on health, education, law and order and other areas.

Total investment by attendees in the first survey was as follows; health 12%, education 20%, law and order 6%, environment 59% and other areas 3%. The distribution of investments in the second survey was very similar and included; health 11%, education 22%, law and order 6%, environment 53% and other areas 8%.

Government investment in viable options for salinity was generally viewed as being insufficient in the areas of developing existing plant based options, finding new commercial options, developing engineering options and communicating new information. Respondents were more optimistic about government investment in new commercial and engineering options at the end of the conference (see figure below). The level of public support was also viewed by most as being insufficient.



2. VIEWS OF AGENCY PERSONNEL AND RURAL LANDHOLDERS

Stack bar graphs, such as the figure featured below, were used to compare and contrast the views of agency personnel and rural landholders. As these graphs involve multiple attributes, interpretation can be time consuming. Hence, it was decided to provide a brief textual summary of the results.

SUMMARY OF RESULTS

(these should be viewed in context with the general outcomes described above);

* At the outset of the conference, rural landholders rated the risk of salinity higher than agency personnel. At the end of the conference, responses within the two samples were more closely aligned.
* For both surveys, rural landholders stated that the onset of salinity would be sooner compared to the responses given by agency personnel.

* For both surveys, agency personnel rated the importance of offsite impacts on biodiversity higher than rural landholders.

* A greater number of agency personnel disagreed with the statement that the options are currently available to tackle salinity in wheatbelt valleys.

* For both surveys, a greater number of rural landholders believed that the costs of implementation were limiting the uptake of suitable options. In comparison, a greater number of agency personnel attributed it to uncertain outcomes.

* A greater number of rural landholders strongly agreed that a shared vision is needed for salinity in wheatbelt valleys.

* In both surveys, agency personnel had a longer timeframe in mind for the vision.

* A greater number of agency personnel stated that their desired response to salinity was to live with it.

* For both surveys, agency personal and rural landholders hold similar views on the appropriateness of government investment in developing existing plant based options and developing engineering options. In contrast, a greater number of agency personnel believe that government investment is insufficient for finding new commercial options. A greater number of rural personnel believe that government investment is insufficient in communicating information.

* At the outset of the conference, rural landholders believed there was lower public support for salinity compared to agency personnel. At the end of the conference, responses within the two samples were more closely aligned.

CONCLUSION

Conducting an attitude survey at the beginning and conclusion of the Salinity in Wheatbelt Valleys Conference has been a worthwhile exercise, generating a valuable dataset that has;

* Captured the way people view the extent and impacts of salinity and options for its treatment in a rigorous, scientific manner.

* Provided an understanding of the "people dimension" to salinity management that will help identify barriers to change,

* Revealed social and ideological bases for future policy development.

* Demonstrated how information delivery and scientific extension relates to changes in attitudes towards natural resource management issues.

Acknowledgements to Kathleen Broderick, Liz Yunken and Chris Manning for their assistance with data entry and to Michael Burton for his assistance with data analysis.

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Dealing with Salinity in Wheatbelt Valleys

Processes, Prospects and Practical Options

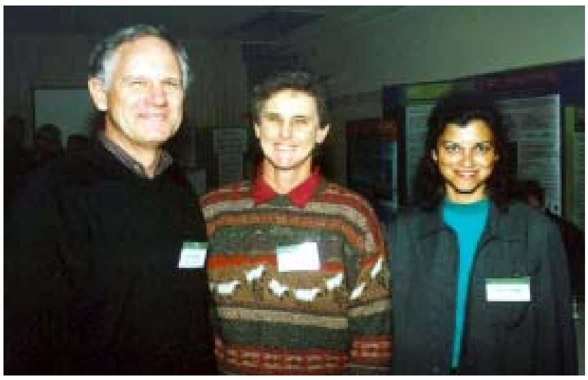
Jim Sorgiovanni (WISALTS consultant and Wheatbelt Area Consultative Committee) and Buntine farmers **Bill Dinnie** and wife **Barbara.**

Robert Apps (Unidata Australia), **Don McFarlane** (Water and Rivers Commission),**Amanda Godfrey** and **Faye Christison**, top (Cunderdin-Tammin Landcare members) and **Dave Davenport** (PIRSA Rural Solutions).

Derek Carew-Hopkins and **Merrilyn Temby** (Bodallin Catchment Group)

Alex Waterhouse and **Phil Commander** (Water and Rivers Commission) with **Cec McConnell** (Dept of Agriculture, Northam)

Vanessa Malcolm (Dowerin-Goomalling CLC) and **Richard McLellan** (Woodlands Conservation Officer)



Don Crawford (State Salinity Council) with **Barbara Morrell** and **Linda Leonard** (Avon Working Group)

Dealing with Salinity in Wheatbelt Valleys

Processes, Prospects and Practical Options

Photo Gallery 2

Ted Rowley (Amron Consulting) and **Hendy Cowan** (State member for Merredin)

Bruce Bone (CALM), Bob Huston (Wooroloo Brooke), Westonia farmers **Ross Wahlsten, John Jefferys** and **David Brown** with **Peter King** (Dept of Agriculture)and **Wayne Clarke** (Avon Working Group)

Seated: **Jessica Johns** (Dept of Agriculture), Bruce Rock farmer **Michael Buegge, Sue Walker** (PGA) Standing: **Sally Phelan** and **David Bowran** (Dept of Agriculture)

Peter Wittwer (Carnamah farmer), **Ian Landsmeer** and Director **David Singe** (Wheatbelt Development Commission)

The Conference Venue

The Workshop Venue

BACK
QUIT
NEXT

Dealing with Salinity in Wheatbelt Valleys

Processes, Prospects and Practical Options

Photos courtesy of **Colin Terry**

to view the full slide show **click here**

APPENDIX 1

HYDROLOGY AND SALINITY NOTES FOR WHEATBELT TOUR

by John Ruprecht and Peter Muirden (Water and Rivers Commission)

BACKGROUND

The Swan and Avon Rivers have a large catchment area of 125,000 km^2 which stretches from Dalwalinu in the north, Southern Cross in the north east and Lake King in the south east down to the mouth at Fremantle.

Most of the catchment area to the mouth of the Swan (73 %) is upstream of Yenyening Lakes (east of Beverley) which is made up of an ancient and very flat landform called the Yilgarn System. The Yilgarn System is likely to have originally flowed out into the Southern Ocean in a series of rivers including the Gairdner, Fitzgerald and Phillips.

Following a rise in landform on the South Coast, the whole system now flows out to the west and into the Avon River through the Caroline Gap south of Kellerberrin. This gap is located just downstream of the confluence of the Lockhart and Yilgarn Rivers, where they join to become the Salt River flowing southwest through the Yenyening Lakes and out into the Avon River.

The north of the Yilgarn System is drained by the Yilgarn River which originates north-east of Southern Cross with Lake Seabrook and Lake Deborah, but with tributaries to the north and south-east. It flows in a south-westerly direction past Merredin to its confluence with the Lockhart River south of Kellerberrin. Its catchment area is 55,900 km^2.

In the south of the Yilgarn system, the land is drained by three major rivers which join south of Kondinin into the Lockhart River an which have a total catchment area of 32,400 km^2:

- the mainstream Lockhart River originates at Lake Magenta and winds its way northwest to Newdegate, Kondinin, Corrigin and Bruce Rock, before joining the Yilgarn River south of Kellerberrin.
- the Camm River to the east draining from Lake King through Hyden to Kondinin where it meets the Lockhart River.
- The Pingrup River which arises near Lake Cairlocup and flows North to Lake Grace and the Lockhart River.

Flows have been measured in the Yilgarn and Lockhart Rivers since 1976 and contrary to popular belief flow occurs every year (although some years the flow is very small). For instance, on the Lockhart River, the annual flow was in excess of 10 GL in seven out of the 25 years of record, while in 10 years it was less than 1 GL.

The Avon River itself, originates at Yealering and upstream of the confluence with the Salt River at Yenyening Lakes has a catchment area of 3,200 km^2. From there it flows past Beverley, York and Northam before the confluence with the Mortlock River. Excluding the Salt River (Yenyening) catchment (91,500 km^2), the Avon River at Northam is 8,100 km^2, while the Mortlock River adds a further

YENYENING LAKES

The Yenyening Lakes, also known as “The Beverley Lakes” are a system of interconnected salt lakes that lie 25 km south east of Beverley on the Salt River just upstream of its confluence with the Avon River.

The lakes themselves are actually a series of lakes of less than one kilometre in diameter and covering a length of the Salt River of approximately 15 km. The floor of the lakes slope gently down towards the Avon River confluence with a slope of approximately 1 in 20,000.

Construction of a permanent causeway at Qualandary Crossing immediately upstream of the Avon River confluence, initially occurred in 1956 with the road level 0.5m lower than the current causeway was constructed in 1965. The causeways were installed with culverts, but were usually blocked off until 1983. Since then, there has been a controlled outlet of water during flow periods.

The construction of the gated causeway has meant that:

- water can be held back in the Yenyening Lakes during spring and summer for recreational users and water birds,
- the Avon River can be protected from the hypersaline water from the Lakes and Salt River (mainly during spring and early winter); water is released from the lakes only when flows in the Avon are moderate,
- salinities in the lakes have increased through water retention and subsequent evaporation,
- the lakes are inundated for longer periods and possibly have caused increased land salinisation,
-

The salinity of the lakes is generally around sea-water standard (35,000 mg/L) when they are full, but as they evaporate, salinities rise above 100,000 mg/L.

Since level records began in 1983, the causeway has been overtopped on eight occasions from rainfall events in the Yilgarn or Lockhart catchments. This causes “flushing” of the saline lakes and helps moderate the build-up of salt. Only one of these events was significant (January 2000), when the causeway was overtopped by 0.85 m and had a measured flow of 180 m^3/s.

During 1998, the capacity of the causeway culvert was increased and it is now likely that only two or three of the eight events that overtopped the causeway since 1983 would now do so.

WHEATBELT HYDROLOGY

Flow in the Yilgarn and Lockhart Rivers is highly variable which is shown in Figure 1. The Mean Annual Flow (MAF) for the Yilgarn River at Gairdners Crossing is 7,300 ML while for the Lockhart River at Kwolyn Hill it is 11,000 ML. At Yenyening Lakes the MAF of the outflow is approximately 13,000 ML. While the total inflow into the lakes is 18,000 ML, a large proportion is lost in evaporation when the runoff is trapped by the lakes.

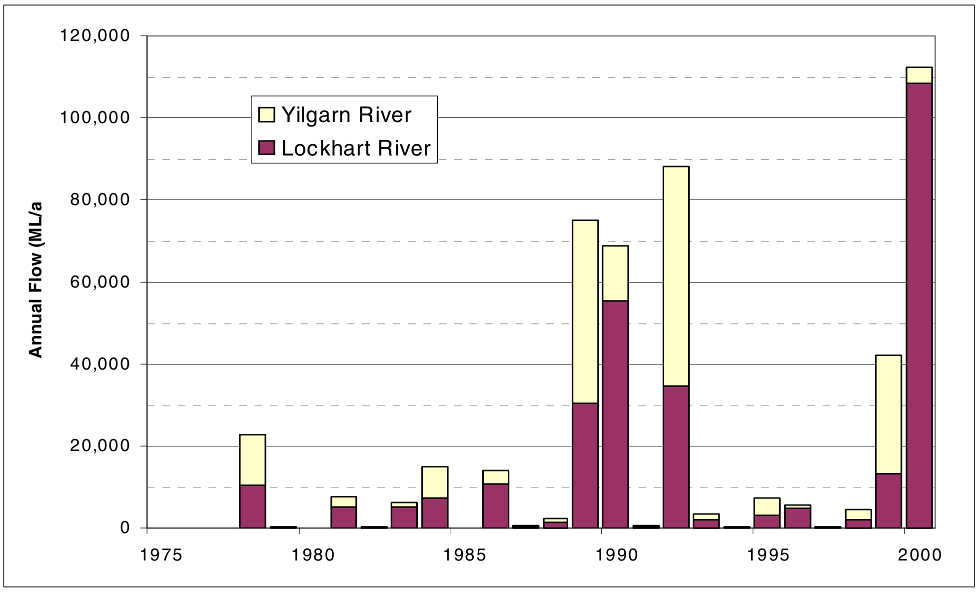
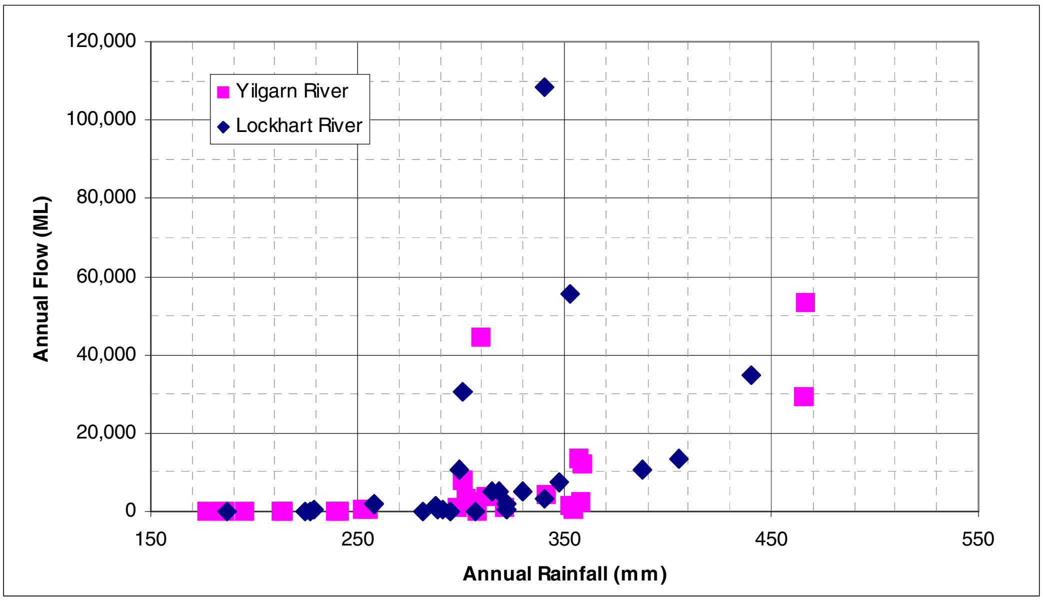


Figure 1 **Recorded flows in the Lockhart and Yilgarn rivers**

The total amount and duration of rainfall play a large part in the hydrology of the catchment. There are many lakes along each of the rivers which need to fill before longitudinal flow will occur. At least 280 mm of annual rainfall is needed for substantial flow in either the Yilgarn or Lockhart rivers (Figure 2). Significant flow events can occur from rainfall derived from either severe summer events or above average winter rainfall.



Unlike the valleys of most rivers, which usually broaden downstream, the valley of the Avon is wide near its source (77 km) and narrows to 5 km or less after Toodyay. These broad shallow valleys of the upper Avon are characteristic of the wheatbelt rivers.

The eastern part of the Avon catchment is characterised by inter-connected lake systems. Some of these lake systems are terminal and do not connect to the main drainage channel even in major flood events.

Following significant rainfall in the Avon River catchment on 21st and 22nd January 2000, there were high river levels experienced from Lake King to Perth. The 2 day rainfall was in excess of 100 mm in a large area from east of Hyden to Beverley, with the highest reading being 172 mm east of Corrigin.

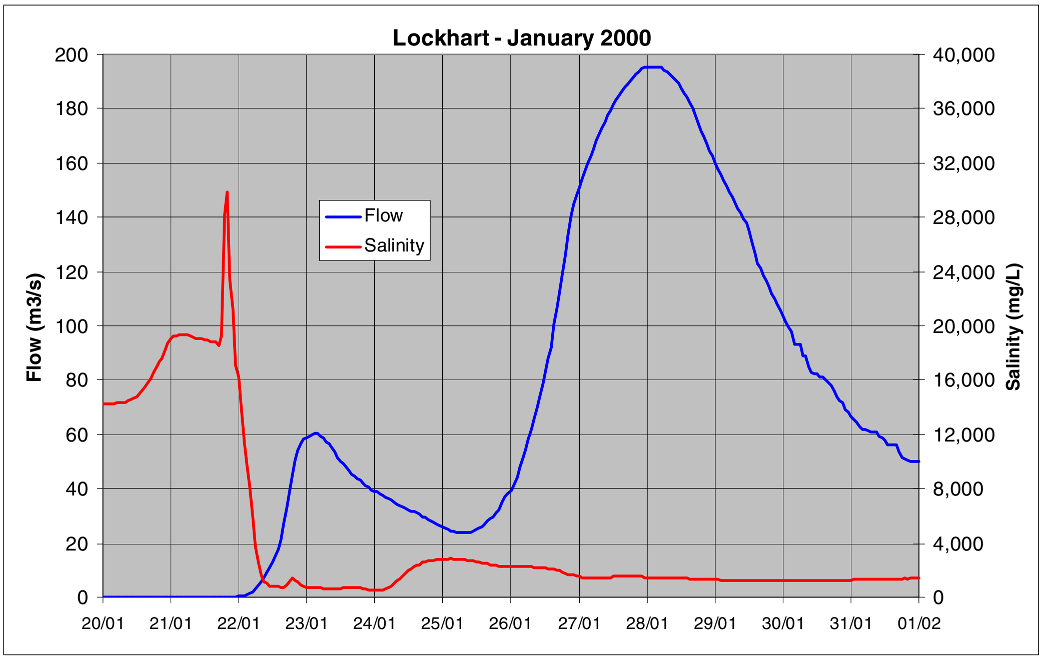
Much of the mainstream Avon River upstream of Northam, the Mortlock River upstream of Northam and the Salt River upstream of Yenyening, had flow rates in excess of 150 m^3/s. Below Northam the flow rates were in excess of 300 m^3/s with the peak flow in the Swan River at Great Northern Highway (GNH) of 312 m^3/s occurring on Tuesday 25th January 2000.

On the upper Swan River the flood had an overall average recurrence interval of 1 in 8 years (using all record since 1970), and an average recurrence interval of 1 in 20 years for summer events.

The volume of water reaching the Swan River during the event was 270 GL which compares to the approximate estuary volume of 50 GL. Downstream tributaries of the Swan River like Ellen Brook and Canning River had proportionally minimal contribution to the flow.

Water Quality from the upper Swan River indicated that the river carried an estimated 1,200 kT of Salt, 800 T of Nitrogen and 35 T of Phosphorous from 23 January 2000 to 1 March 2000. For this event, the flow-weighted salinity on the Swan River at Walyunga averaged 4,500 mg/L TDS, Total Nitrogen 3.0 mg/L TDS and Total Phosphorous 0.12 mg/L. The salinity of the Swan River at the Narrows Bridge reduced from its normal 24,000 mg/L TDS prior to the event to 4,400 mg/L at peak flow.

The Lockhart River experienced the worst flooding of the event with high river levels inundating large areas of land adjacent to the mainstream and high flow velocities causing extensive erosion. While a total of 108 GL of water flowed in the river during the event there was also 307 kt of salt. However just after the first peak on Sunday 23 January, the water was actually fresh with a salinity of 480 mg/L measured for a period of three hours. The estimated peak flow on the Lockhart River at Kwolyn Hill (just upstream of the confluence with the Yilgarn River is 196 m^3/s which had an average recurrence interval of 1 in 25 years (Figure 3).



STREAM SALINITY

Salt River and its two mainstream tributaries, normally have very high levels of stream salinity. Table 1 shows the relative flows and salt loads contributing to the Avon River. It can be seen that the Lockhart and Yilgarn River only contribute 20 % of the average salt load potentially received at the Swan River although a significant proportion is thought to be captured by the Yenyening Lakes.

In a typical winter flow year like 1998 shown in Figure 4, flow in the Lockhart is highest in winter when the salinity is lowest. However, the salt load closely follows flow and it is also highest when flows are high. During 1998, Total flow was 2,000 ML, load was 66 kT TDS and average salinity was 34,000 mg/L TDS.

Table 1 - Estimated Mean Annual data for Avon Basin

River	Area (km²)	Clearing (%)	Flow[(2)] (ML/a)	Salinity[(2] (mg/L TDS)	Salt Load[(2)] (kT TDS)
Lockhart River	32,40(	85	7,90(	29,70(	23(
Yilgarn River	55,90(	85	6,40(	20,50(	13(
Outflow Yenyening Lakes	91,500	70	11,30(	● ● Unknown	●●
Mortlock Rivers	16,80(	85	42,00(	12,00(	50(
Avon River (Northam)	99,60(	85	145,00(	5,90(	85(
Swan River (GNH[1])	120,70(	65	360,00(	5,20(	1,90(

(1) Great Northern Highway
(2) Mean annual flow, mean flow weighted stream salinity, mean annual salt load respectively

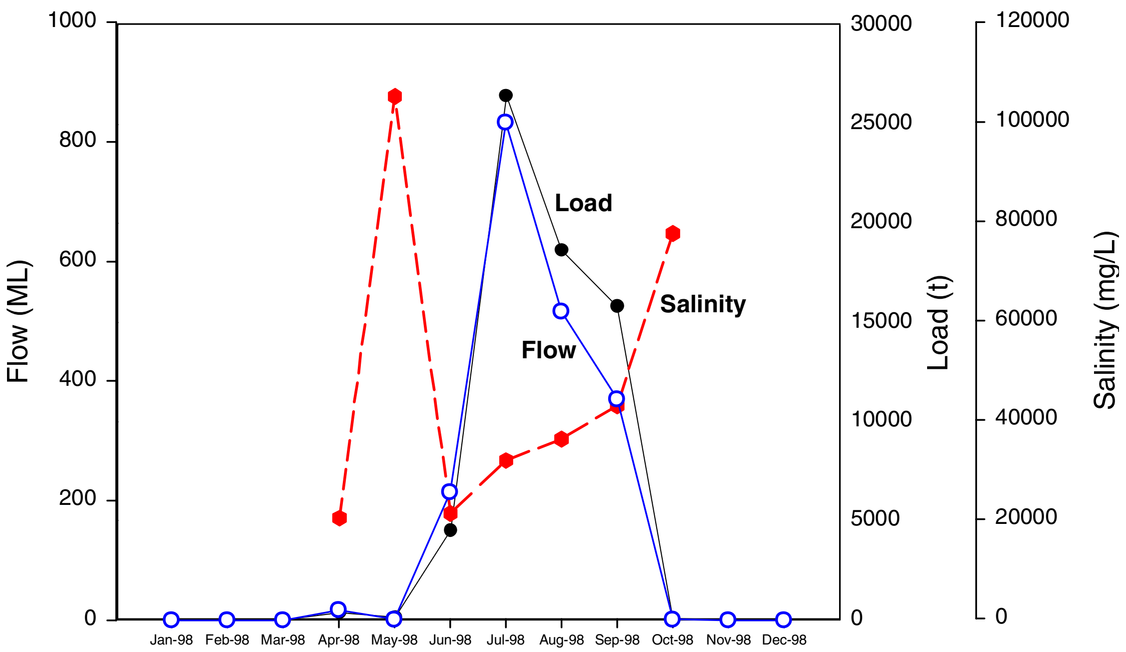


Figure 4 Salinity on the Lockhart River at Kwolyn Hill (1998)

EFFECT OF ARTERIAL DRAINS

The increasing extent of salinisation predicted for the Avon catchment mean that there is increased likelihood of waterlogged valley floors. Therefore without any further intervention there will be significant increases in flooding along these valley floors. Mechanisms to alleviate land salinisation and waterlogging include surface water management and arterial drainage. The impact of the approaches on the downstream infrastructure and environment will depend on aspects such as the location, design and management of these drains.

In some cases the impacts of arterial drainage will be limited to the immediate catchment. There are some lake systems which are terminal, which mean that the impacts of arterial drains will be limited to the receiving lake system. However other lake systems are inter-connected and can impact on significant areas downstream.

Arterial drainage can provide a number of benefits including reducing waterlogging and salinisation, reduction in water table levels, enhanced evacuation of floodwaters, and reduced road maintenance and construction costs. However arterial drainage can result in adverse impacts such increased severity and duration of downstream flooding, increased export of sediments, salt and nutrients into downstream receiving waters and damage to wetlands and fringing vegetation. It is important that any arterial drainage scheme ensures that the adversed impacts are avoided.

Drainage projects can have both on-site and off-site impacts, and may also have a cumulative effect. By this we mean that, while one drainage project draining into a large river basin may not significantly affect water quality or flood risk, the effects could increase as more projects were implemented and larger areas drained into the same river basin.

APPENDIX 2

WATER MANAGEMENT OPTIONS
Bus Tour Notes - Doodlakine to Merredin.

This conference tour will cover aspects of Wheatbelt valley water management, in particular, engineering options for lowering watertables and reducing inundation and waterlogging of valley soils.

The bus trip travels east from Doodlakine then turns south at Hines Hill through extensively saline soils of the 'Baandee' soil association. These areas contained large areas of primary salinity that were once covered by 'boree' (Melaleuca) and other salt tolerant trees and shrubs, prior to clearing. Prior to clearing, there was little or no salinity south of Hines hills at settlement (c1910). The distribution of salinity and valley form should be noted.

Turning east, the bus crosses the lower Belka Valley (catchment area ~170,000 ha) at a site where surface water management, such as pumping impounded waters and other forms of drainage were undertaken in the late 1970s and early 1980s. To the southeast, WISALTS banks were monitored over several years (1980s) and their impacts documented.

The Belka valley was the first studied in the Wheatbelt (Bettenay et al, 1964). Research on the hydrologic processes concluded that valley morphology was a good indicator of risk, with 'Baandee' at highest risk, 'Belka' type valleys at high risk and 'Merredin' type valleys at lower risk. The later had higher mainstream slopes. Bettenay also drilled shallow wells and indicated that salinity was mainly associated with '…a more spatially extensive wet zone…' than watertable rise. There was no documented evidence of the later. They also associated recharge with granite runoff and valley recharge in extreme events.

Recent monitoring has shown that watertables remain close (< 2-3m) throughout much of the Belka, and salinity is expanding in most areas, especially in tributary valleys and to the east. Watertable monitoring in these valleys (cleared 1910 to 1950) and on slopes, mainly cleared in the 1950's and 1960's show 0.2-0.3 m/yr. rates of rise. Sandplain seeps are common.

Current drainage works in the valleys are restricted by infrastructure such as roads and railways. The bus will stop and discuss the impacts of restricted drainage on upstream managers.

Groundwater pumping is an alternative for salinity management in valleys, although little experience exists to determine its practicability in valleys such as the Belka. Several aquifers systems exist although most are relatively low yielding and the radial impact of wells uncertain. The location of palaeochannel and related sediments has not been determined although airborne geophysics (AEM) maybe a means of locating such features. Aspects of pumping will be discussed and compared to other forms of drainage.

Management of discharged water within and from drains represents a significant issue for land managers. Groundwater seepage may either be lost to larger lakes, evaporate or infiltrate as transmission losses through sediments can be high, especially where drains and watertables are shallow.

The bus will pass an extensively altered remnant (Belka Rail reserve), typically saline 'Salmon Gum' dominant valley soils, giving visitors a view of damage due to shallow watertables and salinity. Remnants in valley locations are at significant risk of salinity, with many reserves in valley locations. Surface and groundwater drainage examples, upstream and downstream, can be seen.

Turning north towards Merredin on the Bruce Rock Rd, the bus will stop to discuss large surface water management systems. Large floodways were constructed to the Belka to reduce the impacts of severe flooding experienced in the 1960s and again in the 1970's. Recently, deep drains have been constructed near these banks.

Jones' drains are an example of salinity management at the foot of a sandplain slope. Drainage systems into well-structured clays will be shown and the landowner and contractor will discuss their effectiveness, problems and constraints.
Leaving this site, the bus will travel to Merredin, passing upland remnants as we head onto the Merredin

response to town flooding. Over 100 kilometers of level banks were constructed and to date, similar rainfall events have not resulted in severe flooding in town.

In 1986 drilling was commenced to look at salinity risk in the town and catchment.   Like the Belka, watertables are rising at rates of 0.1-0.3 m/yr. However unlike the conclusions of Bettenay twenty years before, research in the mid-1980s and 90's indicates there is a high salinity risk in the Merredin type valley, with groundwaters now within 3-5 m of the towns CBD.

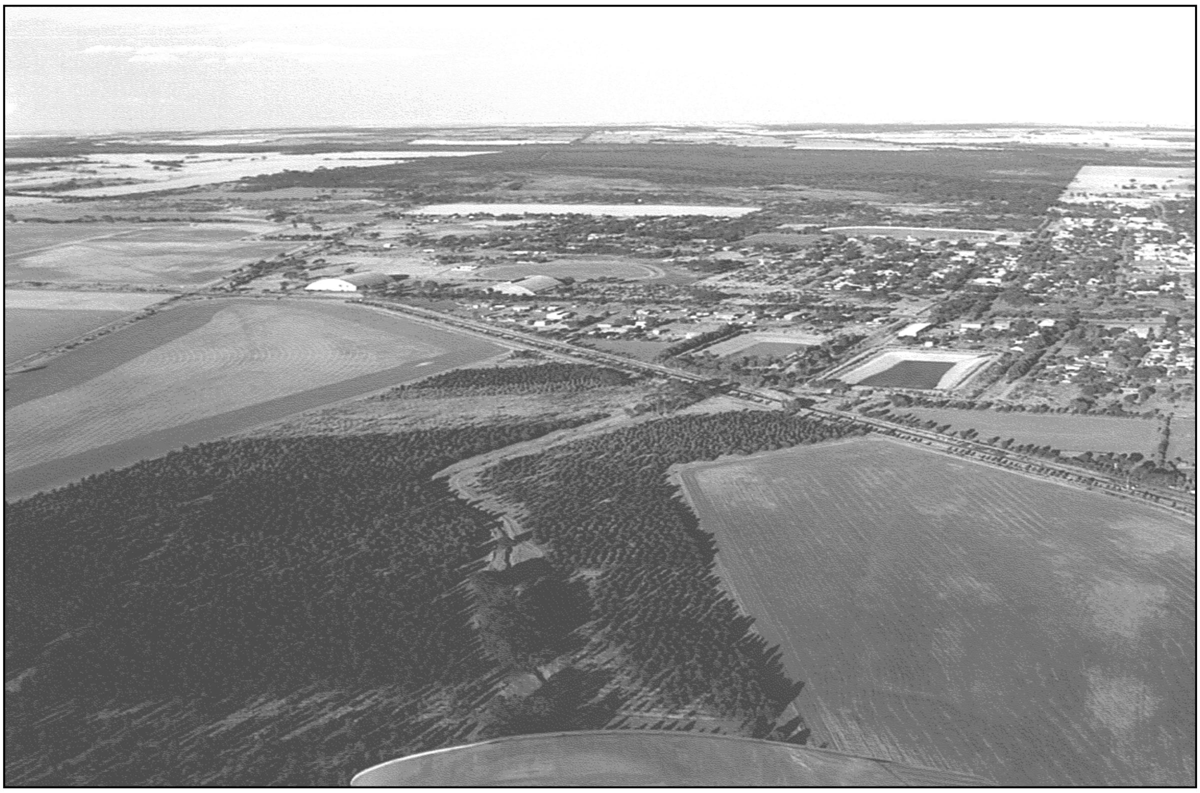
Salinity management has included a range of measures; tree planting and trial pumping and associated desalinisation and evaporation of water is planned. The bus tour will travel through areas in town likely to develop watertables within the root zone, including the conference venue. The route will allow discussions of the impact of the Department of agriculture Rural Towns Program, Shire and local community efforts.

Travelling west, the bus will pass the Merredin town dams, revegetation areas where over 33,000 trees (for wood and water use) were planted in 1991, major CBH handling centre, Dryland Research Institute and proposed evaporation basins before returning to Merredin for the Civic Reception.

A detailed set of notes on the Merredin section is available and several Conference papers will refer to engineering, salinity risk and resource opportunities for the use of saline groundwater (e.g. see Ali and Coles, George and Coleman, Jones and others). In addition maps of the Belka and Merredin catchment will be available at the Conference, showing present salinity and predictions of areas with a likely shallow watertable.

APPENDIX 3

MANAGING WATER AND SALINITY IN THE MERREDIN CATCHMENT



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Merredin Land Conservation District Committee

Shire of Merredin

Department of Agriculture Western Australia, staff of the Dryland Research Institute and hydrologists Dr Richard George and Mr. Jay Matta.

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SUMMARY- TIMELINE OF RECENT SIGNIFICANT EVENTS

Pre – 1975 Regular flooding to the town of Merredin due to extensive clearing for agriculture in the Merredin catchment. Significant flooding events during 1942/43 and 1961/62. Town drains to Cohn's Creek constructed and levee bank on north side of town.

1975-84 Prosecution of person for taking firewood from a local reserve prompted Mr Joe Crook to think of wood lot farming in Merredin.

1978-79 Merredin flooded in extreme rainfall event.

1978-84 Planning and design for surface water control in Merredin Catchment. Surface water control structures implemented in 1984. No floods in Merredin despite above average rainfall years.

1980 Formation of Merredin Land Conservation District. Mr Joe Crook (founding president), and Mr Roy Little (secretary).

1983 Dryland Research Institute established to support the Merredin community in land conservation, extension, and research with the appointment of a Project Officer, Soil Scientists, Soil Surveyors, Water Resource Scientists, and Agronomists.

1984 Merredin LCDC influential in the introduction of clearing controls in Western Australia.

Large drains constructed in town for surface water control.

1985 Department of Agriculture appoints first hydrologist to Merredin to research eastern Wheatbelt salinity problems.

1986 Department of Agriculture investigation of salinity in the Merredin catchment using piezometers, salinity survey, electromagnetics, and seismic surveys. Piezometers have been monitored monthly since 1989 by Mr. Ted Gebert.

1987-98 Appointment of Project Officers to assist in Land Care projects throughout district.

1991 Planting of 37,000 trees in the recharge/discharge area at the western end of the town. This was achieved with community co-operation involving individuals through land swapping, Shire of Merredin with land swapping and support, Merredin LCDC with planning and implementation, Schools with implementation and Department of Agriculture with advice, planning, and implementation

1991 Agriculture Western Australia and Geological Survey of WA installed a combination of 15 piezometers and observation wells in the Merredin townsite to monitor water table trends.

1994 Water Authority donated 5.58ha Acacia reserve to Merredin LCDC.

1995 2900 Acacias planted as a source of seed for revegetation.

1996 Rural Towns protection program instituted**.**

1997-98 LCDC promotional piezometer installed in main street
Merredin community awards make new category for "Service to agriculture and landcare"

1998 Merredin - Nungarin Landcare Implementation Project funded by NHT and Community Landcare Coordinator appointed

1999 Formation of the Merredin Water Action Group formed as part of Merredin LCDC to concentrate on water issues within the township

1999-2000 Drilling investigations conducted throughout town as part of the Rural Towns project. Pump test of town aquifer undertaken.

1999-2000 Computer modelling undertaken to groundwater movement beneath the Merredin Township.

Water samples collected for a groundwater chemistry analysis.

2000 Formation of the Merredin Bushland Conservation Group to raise Awareness of remnant vegetation issues in the Merredin township and wider community

2000 Groundwater pumping and desalination pilot project funded by Salinity Council.

2001 SSC project commences with the building of an evaporation basin. Desalination of pumped groundwater for drinking quality water to test the long-term feasibility of such a project for both Merredin and other rural towns.

2001 Merredin townsite salinity management strategy to be developed

RECENT HISTORY OF WATER AND SALINITY IN THE MERREDIN CATCHMENT

Since settlement in the Merredin Shire, the Merredin townsite has been prone to intermittent flooding. For example the summer of 1942/43 resulted in flooding of the north Merredin area, while in 1961/62 the central business area was flooded. Minor drainage works within the town towards Cohn's Creek did little to reduce the effects of episodic events.

The severe flooding events of 1978 and 1979 prompted the local community to take action. After six years of planning in co-operation with the Department of Agriculture Western Australia, approximately 110 kilometres of level absorption banks were surveyed and constructed. In 1984 the creekline throughout town had been deepened and lined with concrete and rock batters.

A groundwater investigation of agricultural and urban land in the Merredin catchment was carried out by the Department of Agriculture in cooperation with the LCDC and Shire of Merredin in 1985 (George and Frantom 1990). The investigation included borehole drilling at 15 sites, pump tests to determine aquifer characteristics and some limited geophysical surveys. The main objectives of the investigation were:

(i) to describe the nature and distribution of aquifer systems in the area,
(ii) to establish piezometric monitoring network and
(iii) to help develop catchment management plans with the LCDC and Shire of Merredin.

The monitoring network was completed in 1986. The bores are located along a profile extending from Southeast (sandplain ridge near the Merredin airport) on the Narembeen road, through the townsite and Dryland Research Institute, to near Hines Hill in the West.

Based on initial hydrogeological investigation and a subsequent drilling program within the town and West Merredin catchment (joint project between the Department of Agriculture and the Geological Survey, 1990-1991) two major recommendations were made to manage salinity in the town:

(i) planting trees in recharge and discharge areas at strategic locations. The Shire and LCDC decided to proceed with the revegetation plan,
(ii) pumping groundwaters within alluvial and deeper saprolite aquifers to lower groundwater levels. This option was canvassed by not acted on.

One of the priority planting sites recommended for revegetation was located immediately downslope of the town, in an area at risk of salinity. The Shire and LCDC organised a land swap to gain access to the required land. The trees were to provide recharge control and allowed to maintain sufficient cover to enable maximum water use. However it was planned that the trees would also able to be selectively felled for firewood, to take pressure off remnant vegetation surrounding town.(George and Frantom 1990).

In 1991, 70ha of heavy-textured, alluvial soils in a broad floodplain were planted with a range of eucalyptus species over shallow (<2m), saline groundwater (George and Frantom 1990). Prior to planting, a shallow geophysical survey was conducted across the planting area to determine the root zone salinity into which the trees were to be planted. The area was then subdivided into 4 sections on the basis of a set of tree options developed by the Department of Agriculture:

Zone I - extremely high saline zone (EC> 175 mS/m)
Zone II - very high saline zone (140-175 mS/m)
Zone III- high saline zone (100-140 mS/m)
Zone IV- moderate saline zone (< 100 mS/m).

The tree species were selected for their salt tolerance and potential wood production. In total about 31200 trees of 36 species were planted. Two years after the trees had been planted the water levels began to decline throughout the planted. By 1996 the water levels were about 2.0 m lower than the predicted from the pre-planting trend (George *et al.* 1999).

The level banks and tree planting, while effective in controlling the flooding of the Merredin townsite, and promoting an active interest in landcare, were not proven to be adequate in controlling watertable rise.

The groundwater pumping option proposed and initiated by George in 1990 (George and Frantom 1990) concluded that pumping might be useful for controlling groundwater and salinity in the West Merredin area.

In 1999 the Department of Agriculture's Rural Towns Program chose Merredin as a site to test the application of a groundwater model to assist the section of management options. A more comprehensive pump test was conducted along with a further drill program to obtain aquifer properties for calibrating the model.

Three scenarios were then modeled: tree planting, groundwater abstraction through pumping wells and a "do nothing differently" scenario. The model found that pumping would be effective at lowering the watertable within a radius of 200 m, tree planting would be effective at reducing recharge in the immediate vicinity of the plantation and doing nothing would result in extended areas of land within the town with a watertable within 2 m of the surface in 10 years time.

In 2000 the Merredin Council secured a State Salinity Council Grant for the "Merredin Townsite pumping and evaporation basin project". This project aims to look at the longer term potential of lowering groundwater levels in the town, the technical feasibility of desalination and the environmental implications of a 2 ha evaporation basin.

PHYSICAL ENVIRONMENT OF THE MERREDIN CATCHMENT

Topography and Climate

The Merredin catchment is located 265 km east of Perth on the Great Eastern Highway. The total area is approximately 400 km^2. The catchment is characterised by a flat topography low relief (109 m).

The climate of the area is semi-arid with hot dry summers and cool, wet winters. Average annual rainfall (1901-1998) measured at Merredin Shire is 328 mm, with 70% falling between May and October. Ten km west of Merredin at Nangeenan the average annual rainfall is 305 mm. The estimated potential pan evaporation is about 2,630 mm/yr.

Vegetation

Approximately 10% of the Merredin catchment retains a cover of remnant vegetation. Bettenay and Hingston (1964) described the soil-landform characteristics of the Merredin district. The areal extent of each unit and its predominant vegetation was as follows: Danberrin (York gum) 9%, Ulva (tamma) 20%, Norpa (grevillea, wodjil) 15%, Booran (white gum) 20%, Collgar (mallee) 5%, Merredin (salmon) 20% and Nangeenan (morrell) 11%.

Surface Water Hydrology

The catchment is located in the Swan-Avon drainage basin. Surface drainage is from east to west via a series of intermittent creeks. The catchment discharges into the salt lake chains at Hines Hill, which form part of the Yilgarn River palaeodrainage system.

In 1984, 110 km of absorption banks were constructed throughout the Merredin catchment to protect the townsite from extreme flood events and reduce catchment erosion. The town had previously constructed a network of storm water drains to deal with street runoff within its perimeter.

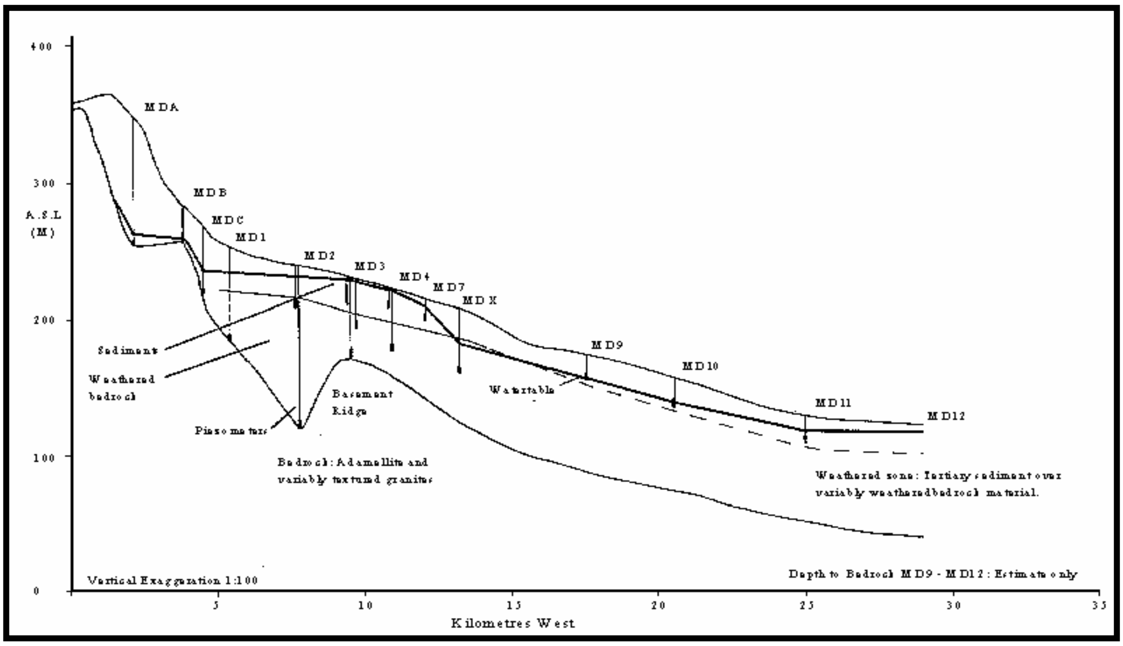
Geology

The Merredin catchment is underlain by highly weathered Archaen age granite and gneissic bedrock. Major lineaments (faults, fractures in bedrock) trend in NNE and ESE directions. Dolerite scree from Proteozoic intrusions and quartz veins are present in the upper, more dissected area of the catchment (George and Frantom 1990).

Above the bedrock there is up to 50 m of clay-rich unconsolidated material derived either from in situ weathering of the underlying bedrock or from transported material. The insitu-weathered profile consists of a poorly weathered saprock zone underlying a more intensely weathered pallid zone.

Above these units can be found sequences of colluvial, alluvial and aeolian sediments derived from erosion of the upper slopes. A graphical representation of the relationship between the sedimentary and weathered zones in the upper valley area is presented in Figure 1.

Figure 1. Hydrological cross-section of the Merredin catchment



Hydrogeology

According to George (1992), groundwater occurs in the following aquifer types in the Wheatbelt:

(i) coarse grained soils overlying pallid sandy clay (Collgar-duplex soils and Norpa-yellow sandplain soils),
(ii) just above the bedrock in the intensely weathered granites,
(iii) in alluvial deposits within major valleys (Belka unit),
(iv) possibly in aquifers deep within the bedrock.

There are two aquifer systems in the Merredin Catchment

(i) Deep system with a recharge area extending from the highest part of the catchment through to the valley floor and a discharge area at the lowest point which is the salt lake chains at Hines Hill (Figure 4). Groundwater velocities in the deep aquifer system are very low (5cm/day in the mid to lower catchment).
(ii) Shallow system controlled mainly by variation in local topography.

Recharge

There are three main mechanisms of recharge in Merredin district:

(i) direct recharge through general infiltration over wide area (dominant in the eastern part of the catchment);
(ii) indirect recharge from concentrations of creek flow along water ways (e.g. Cohns Creek that drains to the West of Merredin);
(iii) recharge from garden irrigation, septic tanks, leaking pipes, reticulation systems and other anthropogenic (man-made) influences.

Depth to Groundwater and Salinity

Depth to groundwater in the town area ranges from 2 to 7 m. In other parts of the catchment, depth of groundwater varies from 0 to 35m. Groundwater salinity in the Merredin catchment ranges from 630 to 43930 mg/L (Electrical conductivity ranges from 30 to 4700 mS/m).

Groundwater Monitoring

A network of piezometers was setup in the Merredin catchment to study trends in groundwater level and salinity. Water level fluctuations in the catchment have been monitored at monthly intervals for 19 piezometers since 1986. Locations of these bores in relation to the townsite may be seen in figure 2.

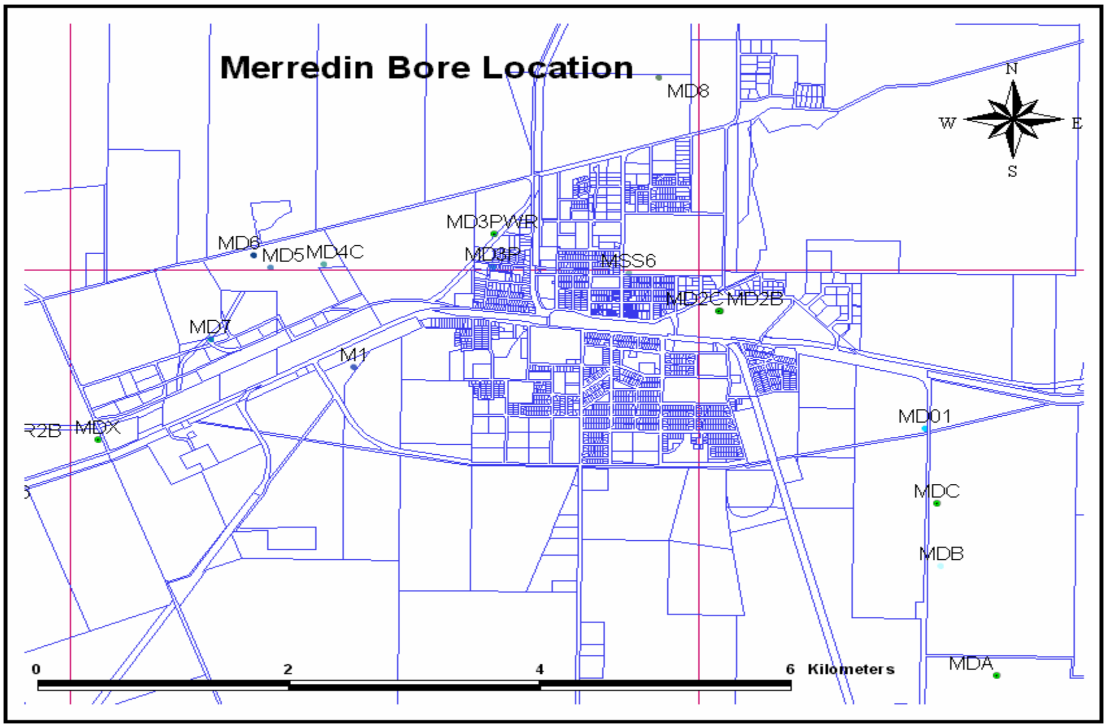


Figure 2. Merredin town bore locations

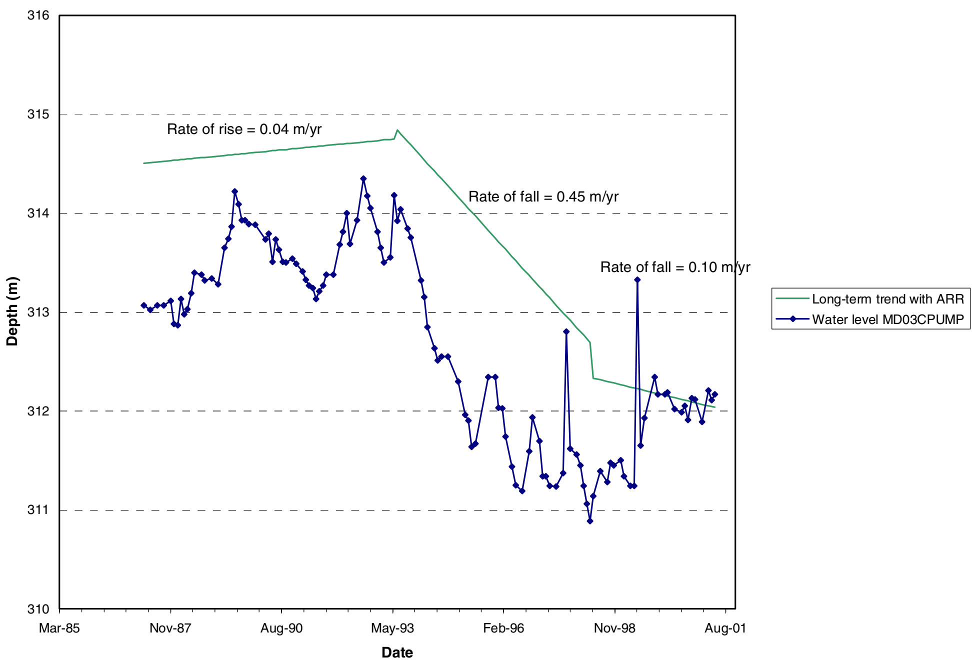
(i) Seasonal fluctuations

Aquifers in areas with direct hydraulic contact with creeks show seasonal fluctuations. Water levels rise during wet periods (usually winter) and fall during dry periods. For example, higher rainfall during the 1991 summer and autumn was reflected by larger water level rise during winter. Conversely, lower rainfall between 1988 and 1990 resulted in smaller water level rises.

Water level fluctuations in piezometers MD3A, MD3C, MD3-pump, MD4, MD4B and MD7 show both recharge and discharge cycles in the annual pattern. Long term water levels from piezometer MD3-pump in a replanted area showed that water levels were rising from 1986 to mid 1993 at a rate of 0.04 m/yr, but between mid 1993 and April 1998 the water levels fell by about 2 m (at a rate of at approximately 0.45 m/yr.)

Since 1998 the water levels have been rising, but if long term average long-term rainfall is taken into account, the trend is still downward at a rate of 0.10 m/yr. The hydrograph for MD03p with the long-term trend with annual residual rainfall may be seen in Figure 3. Piezometers, MD4, MD5, and MD6 show a similar trend. These are all located in the planted area.

Figure 3. Water levels with accumulative annual residual rainfall for MD03CPUMP



Monotonically rising

In the upper slopes (recharge areas) where the rate of groundwater recharge is high, water levels are rising 0.15-0.54 m/yr. For example, in cleared sandplain areas the water levels are continuously rising. The situation may be exacerbated by local recharge from the level banks.

However, piezometer MDB that is located between MDA and MDC does not exhibit a similar pattern (this is because this area is heavy-textured and does not have such a high recharge rate).

Contrary to established trends, the water levels have declined in MDB since June 1994 and then risen in the wet year of 1999. Piezometers MD2 and MD8 located in the valley area show a steady rise with minimal seasonal response.

This is probably due to the contribution from a lateral flow from the hillslopes and leakage from surface flows. MDX was rising at 0.30 m/yr. until mid 1994 when the rate of rise has been zero. This is possibly a delayed effect of the tree plantation.

Figure 4. Shows the hydrographs for MDA, MDC and MDX. Figure 5 shows the hydrograph for Md02b and c.

Figure 4. Water levels with accumulative monthly residual rainfall for MDA, MDC and MDX

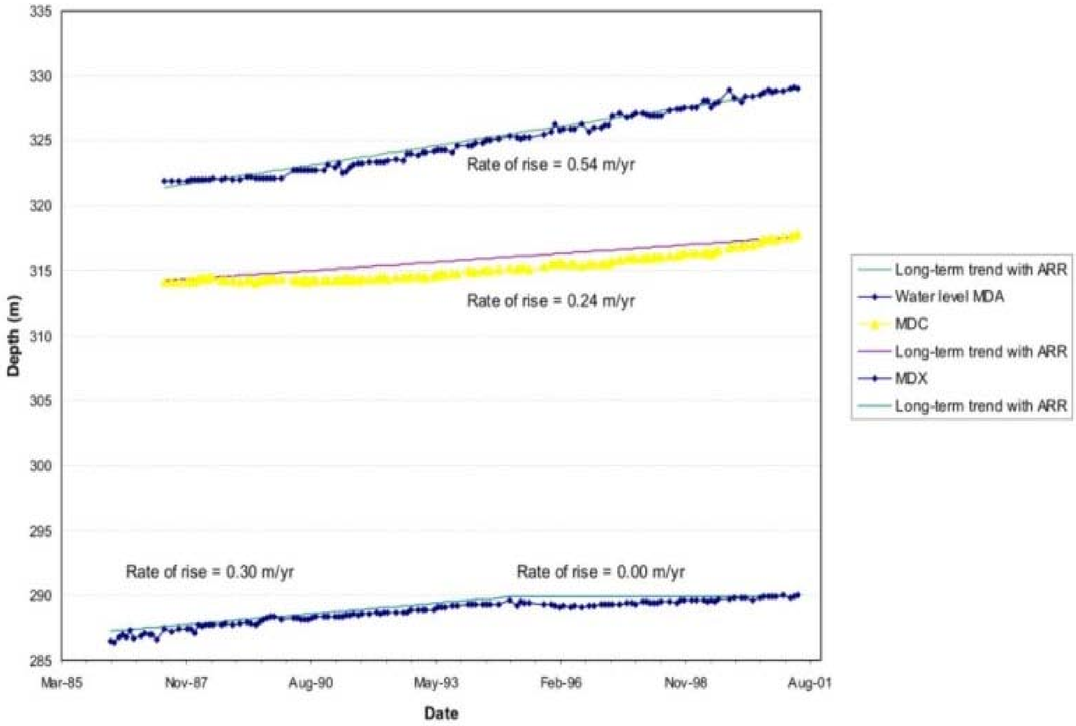
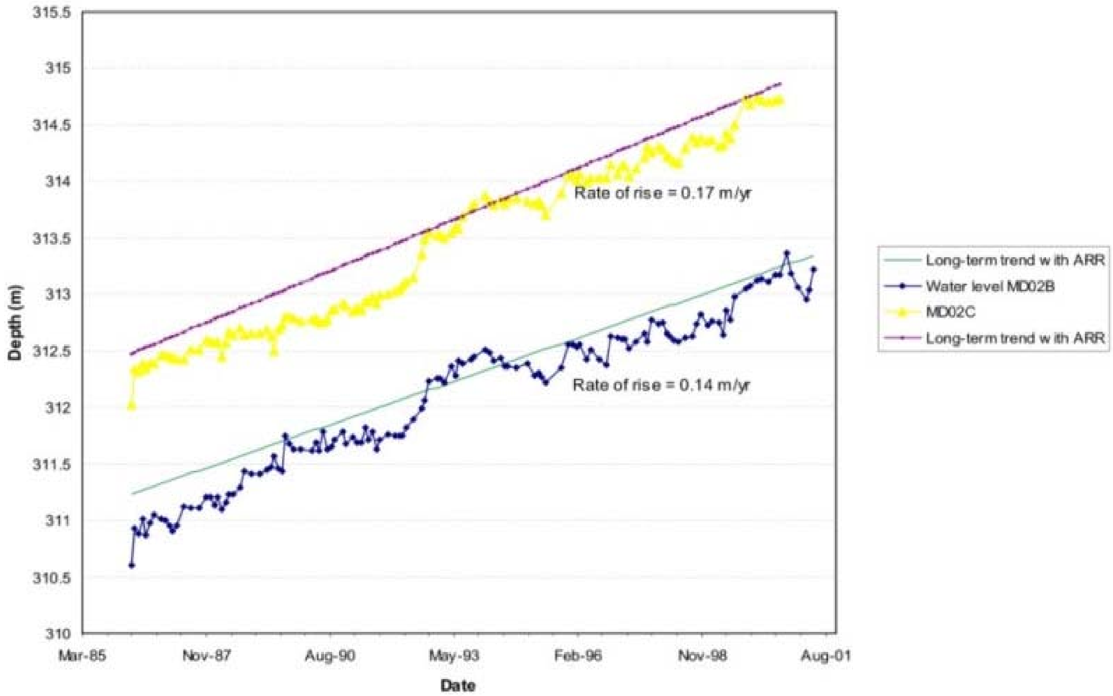


Figure 5.Water levels with accumulative monthly residual rainfall for MD02b and MD02c



MANAGEMENT OPTIONS FOR MERREDIN

Management systems need to be developed which suit the community in both the short and longer term. Options which have a high cost need to be developed in tandem with ones which have a lower cost (eg trees, agronomic options) or higher financial return.

Factors such as chance of success, infrastructure damage, flooding risk and community impact need to be considered along with the impacts on agriculture.

Perennial plants in recharge and discharge areas

Tree planting in the area west of the township has resulted in the decline of water tables by about 2 m. The amount of recharge into the shallow and deep aquifer system can be reduced by planting more trees close to and within the town boundary.

However, maximum reduction in groundwater levels can be achieved by integrating both biological and engineering management options.

Groundwater Pumping

The alluvial aquifers and lower saprolite (weathered and fractured basement materials) have a moderate permeability. Therefore, if the present trend in rise of water tables continues, groundwater pumping will be a technically feasible option.

Disposal of the resulting saline water to evaporation ponds and by desalination for drinking purposes is being trialled.

Improving the management of natural drainage systems

During the wet season, some of the town areas are waterlogged due to poor drainage. For example, Cohn's creek and land adjacent to the Dryland Research Institute is waterlogged and is contributing to groundwater recharge. In addition, some tributary creeks are not efficient in conveying surface runoff to the main drainage system.

To overcome this situation it is recommended to facilitate the natural flow of water along creek lines, and to revegetate the drainage lines to create a soil-water buffer.

Construction of a new town dam

A third town dam has been built to augment current storage capacity. Overflow of stormwater drainage from the current dams will be collected by the proposed dam. The dam also collects water from the roof of the Co-operative Bulk Handling storage.

This may decrease risk of flooding, groundwater recharge and water logging problems.

Formation of the Water Action Group and the Bushland Conservation Group

The formation of these two groups will maintain community interest in the vegetation and water use issues related to the Merredin community.

FURTHER INVESTIGATIONS AND MANAGEMENT OPTIONS

1. Continue monitoring piezometer network to detect changes in the watertables
2. **Development of management information options and tools such as groundwater models to help community test options.**
3. **Prepare town development plan with a view towards water and salinity issues**
4. Pilot study for desalination plant and evaporation basin will be completed in 12 months from inception. The feasibility of extending and enlarging the program will be carried out.
5. Prepare salinity hazard maps showing the likely affected areas and time frame when salinity may develop. Use groundwater models to undertake 'what if" management options.
6. Review water use and drainage systems in the town site for evidence of excessive recharge.
7. **Develop low recharge farming systems for arable land**
8. Airborne survey (magnetic and radiometric) for specific areas of the catchment to refine underground geology, delineate structures and determine depth to bedrock (thickness of regolith) and delineate soil systems for recharge mapping.
9. This information will enable the areas of high salinity risk to be better delineated and determine where the best yielding pumping bores maybe located.
10. **Maintain and increase community support for water and salinity issues**
11. Manage and monitor evaporation basins and desalination plant input/output and performance
12. Plan to develop a solar energy pond to generate power. Trial solar energy pond.

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Title	First Name	Last Name	Company	Position	Address	Town/Pc
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