Is there an economic benefit to planting trees by saving downstream assets?

Background paper prepared for the State Sustainability Strategy

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Summary

The assumption that planting trees in catchments will protect downstream assets, including fresh water supplies, rural infrastructure and biodiversity is examined using three case studies in Western Australia. These are the Collie Catchment (Wellington Dam), the Rural Towns Program and Toolibin Lake.

The information provided by hydrological models, which are themselves based on field measurements, indicates that, with few exceptions, to restore the salinity balance in time to prevent significant degradation of the asset, will require almost all the catchment above the asset to be planted.

To achieve freshwater targets in the Wellington Dam will require between 88 and 91 percent of the Collie Catchment either to be planted, or to be retained as forest cover. Almost without exception planting trees in the catchments above rural towns will not help urban salinity problems and, so far, Toolibin Lake has been saved by engineering works, with very little indication that tree planting will make a significant difference to salinity risk within economic time periods.

It is concluded that the planting of trees in catchments is unlikely to produce measurable economic benefits. With time and further catchment studies this conclusion may need to be re-examined.

1. Background

1.1. Salinity in the wheatbelt and the role of perennial vegetation

So much has been written about these issues in recent years that only a summary is provided here. Soils in the South-West of Western Australia contain very large quantities of salt, deposited in rainfall over thousands of years[1]. The native vegetation, which has co-evolved with the soils and climate, concentrates salt in the soil by transpiring water. Runoff is insufficient to flush the salt. The position that has evolved can be viewed as a tension between the effort required by the vegetation to remove water from the salty soil solution (a tension which climaxes every year prior to the autumn rains) against the removal of the salt in the little water that runs off from these landscapes (a process that reaches its peak in early spring, especially after wet winters). Removal of the native vegetation by European settlers has destabilised this tension, leading to more water entering the soil and rising groundwater levels. Currently these cleared landscapes are shedding salt at a faster rate than deposition. Peck and Hurle[2] have estimated that the length of time to restore the balance will take from tens of years in high rainfall areas to thousands of years where the rainfall is low. If the rising soil solution is sufficiently salty, as it is in most of the agricultural areas on and to the East of the Darling Range, this watertable rise will kill the surrounding vegetation. By 1996, 90% of the agricultural landscape had been cleared and dryland salinity, that is the development of saline scalds in low lying areas of the landscape, had affected 18,000 km^2 of previously productive agricultural land[3]. Salinity threatens at least 2 to 3 times this area, unless appropriate management systems are developed and implemented by farmers and government[4].

Rising saline groundwaters are a severe threat to biodiversity, as the southwest of WA is recognised as one of the 25 mega-diverse biological regions on the planet, containing over 12,000 native species of flora[5] and a large number of both flora and fauna species are at risk of extinction from

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[1] Hingston and Gailitis, 1976

[2] Peck & Hurle (1973)

[3] Ferdowsian *et al.*, (1996)

[4] George et al. (1997)

[5] Hopper et al (1990), Myers et al (2000)

salinity. In the wheatbelt, where native flora and fauna are only represented in small reserves, as many as 450 extinctions of vascular plant species may result from increased groundwater levels and salinity.

In addition increasing structural damage is being seen in the towns, roads and railway lines of the wheatbelt that were located low in the landscape where fresh water used to be available.

To counteract the effects of increasing groundwater recharge and water runoff considerable effort has and is being devoted to the development of a range of deep-rooted commercial plants in an attempt to better utilise the groundwater. These include a range of perennial halophytic (e.g. saltbush) and non-halophytic (e.g. lucerne) grazing plants as well as other perennial species with commercial potential other than grazing[6]. Maritime pine is suitable for rainfall areas above 600mm per year and oil mallees can be grown at lower rainfalls.

Because there is a need for local processing of these low value[7] products, employment opportunities will be generated. For example the Wheatbelt Development Corporation announces the following project on its web site[8]: "November 2000 funding of A$5 million was finalised for this pilot plant, lead by a multi-million dollar commitment from Western Power and with additional funds from the Australian Greenhouse Office and Ausindustry. The plant will be built at Narrogin, south of Perth in Western Australia. It will be one/fifth the size of a scale plant. It is being designed to process 20,000 tonne per year of fresh, whole tree feed and will produce approximately: · 700 tonne per year of activated carbon · 200 tonne per year of eucalyptus oil · 1 MW of renewable electricity. Start up for this plant is scheduled for the second half of 2001. Enecon will operate the plant."

1.2. The purpose of this study

This is the second of two papers reporting on a study of the economic benefits of the oil mallee industry. The first dealt with employment generation in the wheatbelt as a consequence of growing oil mallees together with local processing into eucalyptus oil, activated carbon and energy. This second paper reports investigations into the downstream benefits of perennial vegetation, including oil mallees, on the preservation of fresh water supplies, infrastructure and biodiversity.

2. Catchment hydrology and the downstream effects of tree planting

2.1. Current knowledge of catchment hydrology

As stated in the introduction, the removal of the native vegetation to make way for farming based on annual plants has caused increased quantities of water to enter the soil profile, causing movements of previously stable salt stores. The pathways of the movement of these increased flows depend on the penetration of water into the soil profile and the permeability of the water through the soil. In sands the water is likely to flow past the roots of the annual agricultural plants deep into the soil and be transmitted to the watertable lower in the catchment. With shallow duplex soils on the other hand, much of the excess water may not enter the soil and will reach the valley floor by a combination of overland flow, slower movement in the surface soil horizons and very slow movement in the lower soil horizons. There are many other combinations between these two extremes.

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[6] This work has been accelerated with the introduction of the Cooperative Research Centre for Plant-based management of Dryland Salinity (see http://www1.crcsalinity.com/)

[7] The low value of woody products at the harvest site means that the material has to be processed locally to extract the higher value products that justify transport costs.

[8] http://www.wheatbelt.wa.gov.au./content/default.asp

Using plants to halt these additional water / salt flows normally requires both perennial plants and short distances (about 200 metres) and a lengthy period (about ten years) before the flow is diminished by drying out the soil profile. There are many places in Australia where the draw-down of groundwater as a consequence of tree planting has been demonstrated. If these plantations are low in a cleared landscape, they are at risk of being killed from the salt that will accumulate under them from the land above. So the least-cost, long-term vegetation management regime requires that perennials are planted across the whole of the landscape to stabilise salt flows everywhere. It is hoped that the plantings will not have to cover the whole of the area, but be in rows, or other formations that will allow conventional annual-plant agriculture to occupy some of the landscape. However the question that has been asked is "How can we estimate the economic benefits from trees in halting-the-salt threatening downstream assets?"

A recent review[9] states:

- "Modelling suggests that catchments in the Eastern and Central region similar to North Baandee and Toolibin do not significantly respond to recharge reductions modelled in this project[10] in the longer term (300 years).
- "However, if there is a fractured rock aquifer of sufficient thickness and permeability beneath the weathered zone, as is postulated, the modelling suggests that the significant gains achieved after 100 years are retained.
- "In any event, modelling suggests that medium levels of intervention buy a significant amount of time in catchments with deep watertables. Episodic recharge will reduce the amount of time 'bought' by new farming systems.
- "Only engineering systems significantly alter this outcome.
- "Very preliminary economic analysis suggests that the interventions are not currently close to 'break even' for farmers. However, many of the assumptions involved in the analysis require testing and consideration, and there are a number of off site issues such as loss of biodiversity, increased flood risk, and danger to rural towns, that need to be taken into consideration."

The risk of salinity has been mapped by the Department of Agriculture in its "Land Monitor" project[11]. There are responsive systems, mainly in the West, wetter and steeper parts of the salt affected region, but also some in the Eastern parts. Some assets are not at risk, such as rural towns on well drained sites.

Specific studies are available in the literature for water supplies, rural towns and biodiversity. These are reported below.

2.2. Water supplies saved from salinity – The Collie Catchment

A report of higher rainfall Collie Catchment has recently been published[12]. In this catchment 677 km^2 out of a total catchment area of 2823 km^2 were cleared, resulting in a salinity level of 885 mg/L. One hundred and eighty four km^2 have been reforested and 37 km^2 are planned for reforestation shortly. By 1990 salinity flows had stabilised after clearing and some streams in the catchment had shown minor (< 10%) reductions in salinity five years after revegetation. The resulting salinity after current revegetation plans have been completed is estimated to be 758 mg/L with a yield of 134 GL/yr. Various combinations of planting and engineering options indicate that it will be difficult to reach the target set by the State Government of 500 mg/L in the Wellington

[9] George et al (1999)

[10] The interventions modelled in the case of Toolibin Lake are given below.

[11] See http://www.landmonitor.wa.gov.au/

[12] Mauger et al (2001)

Dam and that the way to get closest to this target (522 mg/L) is by pumping to remove saline groundwaters from the catchment. Other engineering schemes are also being evaluated. However revegetation with perennials is a cheaper option and to achieve the target of 500 mg/L between 88 and 91 percent of the catchment needs to be in trees[13].

2.3. Land area saved or recovered from salinity

The effect of trees on the control of water and salt movements is the subject of a recent publication by Stirzaker, et al[14]. For a catchment near Katanning in Western Australia. Eighty percent cover restores groundwater levels to valley stream levels within 50 years, while 10% tree cover in belts has only a marginal effect[15]. A rule of thumb in this case might be that 80% revegetation will recover the 30% of the catchment susceptible to salinity degradation. That is that controlling salinity using trees results in a nett loss of the farming area of fifty percent.

Recent calculations by the author have indicated that the time bought by planting oil mallees is a significant factor in determining whether oil mallees should be established. When oil mallees are planted this will slow the rate of spread of salt scalds and thus allow agriculture to continue for a longer period. When this is brought into the equation then farming with oil mallees is more profitable than farming without. But the hydrology models also indicate that, eventually the spread of salinity will be as much as if oil mallees had not been planted.

2.4. Infrastructure saved from salinity

Following extensive studies the Department of Agriculture[16] has published a report on the means by which rural towns under threat of rising groundwaters and salinity can delay or ameliorate this threat.

“In all cases, there are three general options to control groundwater rise:

- “Reducing the amount of imported water available to enter the groundwater table (more efficient use of water within the town);
- “Intercepting the water before it is able to recharge the groundwater (use of improved stormwater drainage and trees); and
- “Removal of water from the groundwater below the areas of (any) town most endangered over the next four to twelve years (pumping).”[17]

The report then provides information about the damage costs and control costs for six towns.

Mark Pridham[18], one of the report’s authors divides rural towns into three categories:

1. Towns set on broad valley floors in the wheatbelt, with low transmissivity soils, which would not benefit from trees planted higher up in the catchment. An example is Merredin. Tree planting in the town, pumping and improved drainage are suitable treatments.
2. Towns high in the landscape where, as a consequence of the introduction of the Goldfields Water Supply, additional water has been added to the urban landscape, causing waterlogging. Examples are Morawa and Wongan Hills.

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[13] Mauger (Personal Communication)

[14] Stirzaker, Vertessy and Sarre (2001)

[15] Stirzaker, Vertessy and Sarre (2001) p 34-5

[16] Department of Agriculture WA (2001)

[17] Department of Agriculture WA (2001)

[18] Officer in charge of the Rural Towns Program, Department of Agriculture.

3. Towns located on or close to paleochannels, or on floodplains, where the infrastructure damage is due to shallow and rising water tables. Examples are Wagin, Kellerberrin, Cranbrook and Tambellup.

Essentially the movement of sub-surface water is so slow that any effects of planting trees on watertable draw-down will only occur within a few tens of metres of the trees (George et al 1999). A further 22 towns have been studied in less detail, but in no case was planting in the catchment above these towns seen as a solution to the towns' problems[19].

In discussions with Don Burnside, one of the authors of the above report the following table was constructed:

Table 1 Rural Towns Program – Solutions to case study towns

Town	Solution	Will oil mallees help outside the town boundary but within catchments flowing into the town?
Katanning	Pump, seal the creek from leaking into the groundwater	No
Morawa	Prevent recharge	No
Brookton	Can pump to irrigate oval	Possibly[20]
Corrigin	Can pump for garden use	No
Cranbrook	No problem until 2020, but can plant trees in the town and put it off further	No
Merredin	No problem until 2050, pumping scheme trial already in place	No

In his opinion, any form of tree planting in the catchments of streams flowing into rural towns would have little benefit, as the transmissivity of the soils in wheatbelt valley floors is very low. So there appear to be no opportunities to save urban infrastructure with oil mallee plantings.

2.5. Biodiversity saved from salinity – Toolibin Lake

The loss of biodiversity occurs due to increased flows of water, which in most cases contains salt, into the low-lying areas of the catchment where a diverse range of species exists, often endemic to very small areas. Recent surveys of these areas show that a lot of this diversity exists amongst the invertebrate fauna, especially the shrimps and the spiders[21].

Although it does not seem to contain any species at risk of extinction, Toolibin Lake is the last remaining freshwater lake in the Wheatbelt region of Western Australia and, as such, constitutes not only a threatened community, but also an icon in the preservation of Western Australia's biodiversity. More money has been spent saving the natural values Toolibin Lake than any other area in Western Australia.

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[19] Pridham (personal communication).

[20] The modelling study did not include the entire catchment that runs into the town.

[21] Keighery et al (2001)

2.5.1. Toolibin Lake background

Toolibin Lake lies 40 km East of Narrogin. It is part of Arthur River Catchment, which in turn is part of the Blackwood Drainage Basin[22].

It is an ephemeral wooded lake, with extensive sheoak and melaleuca woodlands across the Lake floor. This makes the Lake an attractive breeding location for a number of bird species, similar to the Macquarie Marshes in New South Wales. For most of the time the lakebed is dry, but in wet years the Lake fills with water flowing from the catchment, and this triggers a breeding event for the waterbirds. Natural revegetation of the lakebed requires eight years without inundation.

The Lake's catchment is approximately 470 km^2, of which 90% cleared of native vegetation, the cleared land being used for cereal farming and grazing. The average gradient of the catchment is 1%. Annual rainfall drops from West to East and averages 420 mm. Salt stores are about 0.5 to one tonne per square meter. The soils normally constitute 30 meters of weathered profile, gritty at the base, saprolite in the middle and with alluvium on the valley floors. In the duplex soils lateral flow is very slow, with a maximum velocity of about one meter per year. So it can be calculated that the groundwater would take 40,000 years to flow from the catchment boundary to the Lake.

Three landforms occupy the catchment, each occupying about one third of the total area:

1. Valley floors, with slopes of less than 1% - Depth to the water table varies from less than one meter (where salt rise from capillary movement can be expected, leaving salt on the surface that can be mobilized through overland flow), to places where the depth to water table is 10 – 15 meters below the surface, though the water table is rising in these areas from increased infiltration associated with the changed land use, both in the valley and on the adjacent slopes and upstream. These waters can be too saline for use even by halophytes and the only option for such water is engineering treatments, with 'safe' disposal.
2. Slopes with high lateral permeability (mostly sandplains, but also including some better quality duplex and gradational soils) where planting up to 16% of the landscape with belts of oil mallees is estimated to soak up all the excess water from the intervening agricultural activities. These occur mainly in the Eastern part of the catchment at some distance from the Lake.
3. Slopes with low permeability (duplex soils) where lateral transmissivity is low and where trees will have to be closer together to soak up the excess water from the intervening agricultural activities. The area occupied by trees may not need to be greater than 16% (White et al 2002), but the effectiveness of trees is not well known. These soil types will require phase crops in addition to perennial belts, because they are not very responsive. Phase crops could include lucerne or woody species yet to be developed.

The Lake itself is underlain with a paleochannel, which is separated from the lake floor by a semi-confining layer on the Eastern side of the Lake, whereas the confining layer is less permeable on the Western side. The hydraulic head of the aquifer within the paleochannel is about 30 cm below the level of the lake, which means that there is a positive head when the lake is full of water and a negative head, or capillary rise, when the Lake is dry. The water in the aquifer is about 50,000 mg/L salinity.

2.5.2. The threat of salinity

The major threat to the Lake community is from groundwater accessions (to the western edge) and a more general accumulation of salt in the Lake and the Lake waters to the point where the soil

[22] Wallace (2001)

becomes too salty for plant and animal survival[23]. There is already evidence of this occurring in parts of the lakebed. An additional hazard is that the flows selected (see below) to enter the Lake are either too frequent for tree revegetation, or too infrequent for waterbird breeding.

2.5.3. Current mechanisms to control the hazard

Wallace[24] outlines the steps that have been taken and are planned to control the salinity threat to the Lake (see also Appendix One). Wallace divides the actions into two; "firstly those that are required in the short to medium term to protect against catchment conditions that will inevitably worsen" and secondly "there is a set of actions that it is predicted will halt, and then reverse, salinisation of the catchment"[25].

To control the amount of salt entering the Lake a diversion drain has been constructed which allows the diversion of low flows[26] around Toolibin Lake and into Lake Tarbilin downstream. In addition twelve bores have been sunk and are being pumped to reduce the upward water pressure of the saline groundwater. Two of these are in the highly permeable paleochannel.

Wallace's long-term solution is that eventually, the catchment will have to be revegetated so as to restore the pre-clearing water balances. Wallace[27] believes that commercial perennial options will eventually be available to landholders to restore the pre-clearing water balance. Currently these are not available for other than sandplain soils and need to be proven both physically and economically even there.

2.5.4. Previous calculations of benefits arising from the introduction of perennials to the Lake Toolibin Catchment

In their report to the State Salinity Council George et al[28] produce the economic results of four treatments imposed on the catchment of Toolibin Lake. These are reproduced in Tables 12 and 13 below.

[23] See Halse (1987, 1988), Halse et al (1993) and Sanders (1991), quoted by Wallace (2001)

[24] Wallace (2001) p180

[25] Wallace (2001) p180

[26] It is normal for low and early flows from a catchment to be much more saline than heavy and later flows.

[27] Wallace – personal communication 18/12/01

[28] George et al (1999)

Table 12. Agreed treatments for Toolibin Lake Catchment (from George et al, 1999)

Landscape changes to the water balance		
Low	**Medium**	**High**
Sandplain soils planted to tagasaste (10 %) plus phase farming system over the remainder (90%), consisting of 5 years lucerne, 5 years of cropping and pasture	1. Sandplain soils planted to Pines (10 %) plus a phase farming system over the remainder (90%), 5 years lucerne, 5 years cropping and pasture, except for two blocks of oil mallees at the break of slope and near the saline area (each 10% of the area). 2. Sandplain soils planted to Pines (10 %) plus a phase farming system over the remainder within the matrix of an oil mallee alley system (50 m spacing)	Medium intervention plus groundwater pumping at two locations at the break of slope and in the valley floor

Table 13. Detailed analysis of the impact of the 4 principal treatments. The lucerne alley systems at Toolibin has not be costed (from George et al, 1999)

Location	Low impact strategy	Medium impact strategy	High impact strategy
Toolibin: Current operating surplus: $84/ha Current salt: 10% Salt at 50 years with nil treatment: 35%	10% tagasaste + 10 year phase farming	10% pines + 18% oil mallee blocks + 10 year phase farming.	10% pines + 18% oil mallee blocks + 10 year phase farming + 30% of land containing wells @ 1 well/30 ha.
	Outcome: 26% salt PV costs: $51/ha PV benefit: $26/ha B/C Ratio = 0.51	Outcome: 14% salt PV costs: $259/ha PV benefit: -$14/ha B/C Ratio = -0.05	Outcome: 3% salt PV costs: $495/ha PV benefit: -$1/ha B/C Ratio = 0.00
		Medium Plus	
		10% pines + 7% oil mallee alleys (50 m spacing) + 10 year phase farming.	
		Outcome: 14% salt PV costs: $169/ha PV benefit: -$27/ha B/C Ratio = nil	

From the table above it can be seen that all treatments have very low benefit to cost ratios and would therefore require significant subsidies to implement.

Further the authors state:

"Modelling conducted over a period of 100 years shows that:

- "for the base case current management systems cause 94% of the flow tube to develop a shallow watertable;
- "establishing tagasaste on the sands and phase farming elsewhere (low case) reduces the wet length to 66% of the base case and watertable levels decline beneath the sandplain;

- "establishing the above system, while adding two blocks of trees (medium case 1) only reduces the wet length to 65% of the base case (the lower block of trees was swamped - killed - by rising groundwater) but replacing the blocks with 50 m oil mallee alleys (medium case 2) reduces the wet length to 35% of the base case; and
- "including a groundwater pump with the 50 m alley system (high case) reduces the seepage area to 6% of the base case, while taking away the two blocks and replacing the lower one with a pump only reduces the wet length to 51% of the base case. It is likely that the impact of the pump is overestimated.

"Modelling conducted over 300 years on medium case 1 (pines and phase farming) shows that, while the systems buy time (over 30 years), there is no long term gain."[29]

2.5.5. Mechanical methods that could be used to enhance control of the hazard

A roaded catchment could be constructed along with a detention basin to hold and supply fresh water to the Lake as required. These could then be used to flood the Lake whenever there was a need to either recharge the Lake for salinity control purposes, or to stimulate regrowth of vegetation, or to initiate a bird-breeding event.

3. Conclusions

The best way to avoid salinity damage to downstream assets would have been to preserve the catchment in its original state. The long history of catchment management in Western Australia indicates that the only bodies able to hold land in this state, or change land use to halt-the-salt were government bodies; the WA Government Railways from 1897 onwards[30] , water engineers like Reynoldson in the Mundaring Catchment from 1909[31] and the Public Works Department and Metropolitan Water Board in other water supply catchments in the Darling Range.

Once catchments have been partly or wholly cleared establishing trees and shrubs to reduce salinity threats on downstream assets is going to need significant areas of the catchment, usually in the region of 80 percent or more. Only where soil transmissivity is high will lower proportions of perennial vegetation be effective in reducing the salinity threat to downstream assets.

Using any combination of trees and farming would be extraordinarily difficult to administer to achieve catchment outcomes that would preserve downstream assets, like those in the examples above. This is especially so since the outcomes have long time delays. Success would require extraordinarily strict control over both the farming and the plantation component of land management. It could only be achieved by very significant changes in the way that private land use is regulated by Australian governments.

On the other hand, for localised areas, engineering solutions have proven to be effective in reducing salinity threats to many towns and Toolibin Lake. Diversions of saline flows to improve downstream water quality have been used for many years in the Murray-Darling Basin. Should assets be at risk from upstream salinity then, in the short term, engineering solutions are likely to be more efficient, more effective and more economical than solutions based on replanting catchments to trees.

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[29] George et al (1999) p 6

[30] Bleazby, 1917

[31] WA Government, 1963

4. References

Bleazby, R (1917) ‘Railway Water-Supplies in Western Australia: difficulties caused by salt in soil’. Proc. Inst. Civil Engineers 203: 394-400, p399

Department of Agriculture Western Australia (2001) ‘Rural Towns Program – Economic impacts of salinity on townsite infrastructure’ Bulletin No. 4525/2001

Ferdowsian, R, George, R, Lewis, F, McFarlane, D, Short, R and Speed, R (1996) The extent of dryland salinity in Western Australia. Proc. 4th National Conf. and Workshop on the Productive Use of Saline Lands, Albany, West. Aust. Promoco Conventions Pty Ltd, West. Aust.: 89-97.

George R, Clarke C, Hatton T, Reggiani P, Herbert A, Ruprecht J, Bowman S, and Keighery G (1999) ‘The effect of recharge management on the extent of dryland salinity, flood risk and biodiversity in Western Australia’ for the State Salinity Council Research and Development Technical Group. Soon to be published in ‘Land degradation in drylands: current science and future prospects’ Advances in Environmental Monitoring and Modelling Vol. 1 No. 2 Special Issue. See http://www.kcl.ac.uk/kis/schools/hums/geog/advemm.html

George, RJ, McFarlane, DJ and Nulsen, RA (1997). Salinity threatens the viability of agriculture and ecosystems in Western Australia. *Hydrogeology Journal*, 5 (1): 6-21

Halse S A (1987) ‘Probable Effect of increased salinity on the Waterbirds of lake Toolibin’ Technical Report No 15 Department of Conservation & Land Management, Perth Quoted by Wallace (2001)

Halse S A (1988) ‘The last lake’ *Landscope* Vol 3 p 17-22 Quoted by Wallace (2001)

Halse S A, Williams M R, Jaenesch R P and Lane J A K (1993) Wetland characteristics and waterbird use of wetlands in South-Western Western Australia *Australian Wildlife Research* Vol 20, p 103-126 Quoted by Wallace (2001)

Hingston, FJ and Gailitis V (1976). The Geographic Variation of Salt Precipitated over Western Australia. Aust J. Soil Res. 14, 319-35

Hopper S, van Leeuwen S, Brown S and Patrick S (1990) ‘Western Australia’s Endangered Flora’ Department of Conservation & Land Management.

Keighery G, Halse S and McKenzie N (2001) ‘Why wheatbelt Valleys are Valuable and Vulnerable: The ecology of Wheatbelt Valleys and threats to their Survival’ p 55-65 in Proceedings of the Conference ‘Dealing with the Wheatbelt Valleys’ State Salinity Council and Avon Working Group

Mauger GW, Bari M, Bonieka L, Dixon RNM, Dogramci SS and Platt J (2001) ‘Salinity Situation Statement – Collie River’ Report WRT 29 Water & Rivers Commission, Government of Western Australia

Myers N., Mittermeier, RA. Mittermeier, CG., Da Fonseca GAB. and Ken J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, 403:853-858

Peck AJ and Hurle DH (1973) Chloride Balance of Some Farmed and Forested Catchments in South-western Australia. Water Resources Res. 9, 648-57.

Sanders A (1991)) ‘Oral Histories Documenting Changes in Wheatbelt Wetlands’ Occasional Paper 2/91 Department of Conservation & Land Management, Perth Quoted by Wallace (2001)

Stirzaker R, Vertessy R and Sarre A (2001) ‘Trees, water and salt: an Australian Guide to using trees for healthy catchments and productive farms’ Rural Industries Research & Development Corporation, Publications Number 01/086.

WA Government (1963) ‘Salinity Problems in Western Australian Catchments with particular reference to Wellington Dam – compiled by W H Power’. File PWWS 251/51, Appendix 9.

Wallace K J (2001) ‘Case study – Toolibin Lake and Catchment’ p 177 88 in Proceedings of the Conference “Dealing with the Wheatbelt Valleys” State Salinity Council and Avon Working Group

Appendix One – Actions required to recover Toolibin Lake

(From Wallace, 2001)

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.* 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.***	