MULTI-CRITERION APPROACH TO RECOVER A SALINE WATER RESOURCE, WELLINGTON RESERVOIR, AUSTRALIA

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Abstract

The management of the water resource of the Wellington Reservoir located in the Collie River catchment presents an ideal case study of the conflict between land use and water resources management. The salinity of the inflow to the Reservoir has increased four-fold for a median flow year from < 280 mg/l in 1945 to ~ 1000 mg/l in 1992. The human-induced land use change of replacing deep-rooted native vegetation with annual agricultural plants has altered the natural water balance in the catchment, increasing the recharge rate. The change to the water balance has caused a substantial rise in groundwater levels resulting in land salinisation and seepage of saline groundwater into the Collie River.

A multi-criterion analysis of the potential options to lower salinity to ~ 550 mg/l by 2015 considering the hydrogeological setting, as well as economic, social and environmental impacts, was carried out. The study presented 13 potential options addressing reduction of recharge by re-planting trees and deep-rooted perennials, enhancing discharge by groundwater pumping, and engineering work such as diversion of saline water. The study showed that diverting the highly saline early winter and late summer flows into abandoned mine voids in the catchment is the most viable option as a short-term solution (1-5 years). A combination of groundwater pumping to lower the watertable and the partial diversion of saline early winter flow is considered to be a mid-term solution (5-10 years). In the longer term, however, new farming systems that will be both sustainable and acceptable to the stakeholders will need to be developed.

INTRODUCTION

The salinisation of land and water resources is a major ecological and economic problem facing Australia. Approximately 12 million hectares of arable land and many of the water resources and wetlands in southern Australia are predicted to be affected by increased salinity in the next 100 years (Short and McConnell, 2001). About seventy percent of this land and the majority of wetland and water resources occur in the south-west of Australia.

The initial reports of stream salinisation in Western Australia were published around 1900. By the 1920s it was recognised that ring-barking trees for water supply (Bleazby, 1917, Power 1963) and clearing native vegetation for agriculture (Wood, 1924) resulted in rapidly increasing stream salinity in all areas of the south-west except those with high rainfall (> 1100 mm/yr). Since that time the salinities of major rivers, including the Collie River, in the south-west of Western Australia have increased dramatically (Schofield et al, 1988). In response to the increasing salinity of the Collie River two significant decisions were made; (i) legislation to control clearing of native vegetation in the Collie River catchment, with compensation paid to affected landholders, and (ii) reforestation in the Collie River catchment through land purchase.

Experiments into the impacts of clearing on stream salinity were commenced in 1974 and into reforestation in 1978. These studies have demonstrated the effectiveness of the reforestation (Ruprecht and Schofield, 1991a,b) in lowering the groundwater level and, in turn, reducing the flux of saline groundwater discharge into the rivers. At present ~72% of the Collie River catchment is covered by native bush, 5% has been reforested and the remaining 23% is still farmed with shallow-rooted cereal crops and pasture. The effect of reforestation, however, was only to stabilise the salinity of the Collie River at ~ 1000 mg/l.

A comprehensive review assessed the hydrological, social, environmental and economic aspects of potential management options to lower the salinity to a potable level. Thirteen options were recommended encompassing recharge management by planting perennial vegetation and/or adopting engineering options such as saline water diversion and groundwater pumping on a sub-catchment scale (Mauger et al., 2001).

The three objectives of this paper are to present:

i) the history of the Collie River catchment and the gradual increase in the salinity of the Wellington Reservoir due to clearing;
ii) the multi-disciplinary approach that included surface and groundwater hydrology, numerical modelling, environmental and social assessment as part of evaluation of the salinity management options; and
iii) the results of the multi-criterion analysis used to select the management options for salinity recovery to a potable level by 2015.

LOCATION AND CLIMATE

The Collie River catchment extends over 2448 km^2 and is located ~ 200 km south-west of Perth in Western Australia (Fig 1). The catchment has a typical Mediterranean climate with cool, wet winters and warm, dry summers. The temperature ranges for the town of Collie in the Collie Coal Basin (Fig. 1) is from 5 to 16 °C during winter and from 13 to 30 °C during summer. The average long-term annual rainfall decreases systematically from ~ 1200 mm in the west to 600 mm in the eastern boundary ~ 100 km inland (Fig. 2). Mean annual pan evaporation increases from the south-west to north-east. The average annual pan evaporation ranges from 1400 mm to 1830 mm.

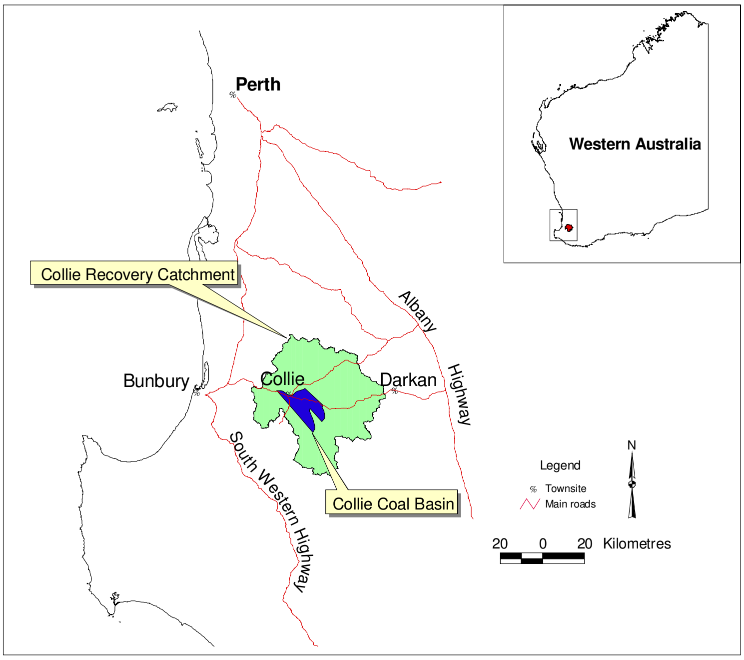

Figure 1. Location of the Collie River catchment

HYDROGEOLOGICAL SETTING

Archaean basement rocks (2.6 G year) of the Yilgarn Craton underlie most of the catchment. The basement rocks are divided into two main regions based primarily on lithological variation: the igneous granitic rocks, and the metamorphosed rocks mainly granitoid gneiss (Wilde and Walker, 1982). The Collie Coal Basin in the west of the catchment is a graben-like structural depression within the Archaean basement and is filled with Permian sediments (Fig 1). The Basin contains the largest coal deposit in Western Australia. The basement rocks (except in the Collie Coal Basin) are extensively lateritised, and weathered to an average depth of 30 m. Groundwater across the catchment occurs in this weathered profile. The weathered profile in the Collie River catchment can be described according to three main horizons (Dogramaci, 2000). A horizon developed above the basement at the weathering front is characterised by the formation of relatively permeable aquifer. Yields from this aquifer are highly variable ranging from 15 m^3/day to 150 m^3/day (Dogramaci, 2000). The estimated hydraulic conductivity ranges from 0.1 to 10 m/day. Above the lower horizon, primary minerals are weathered to clay promoting the development of a sandy-clay horizon. Hydraulic conductivity of this horizon is lower than for the deeper aquifer and ranges from 0.01 to 0.1 m/day. This contrasts with consistently higher hydraulic conductivity of the surficial sediments which range from 1 to 10 m/day (Dogramaci, 2000). The surficial sediments of medium to coarse-grained quartz sands and clays overlie the *in situ* weathered profile.

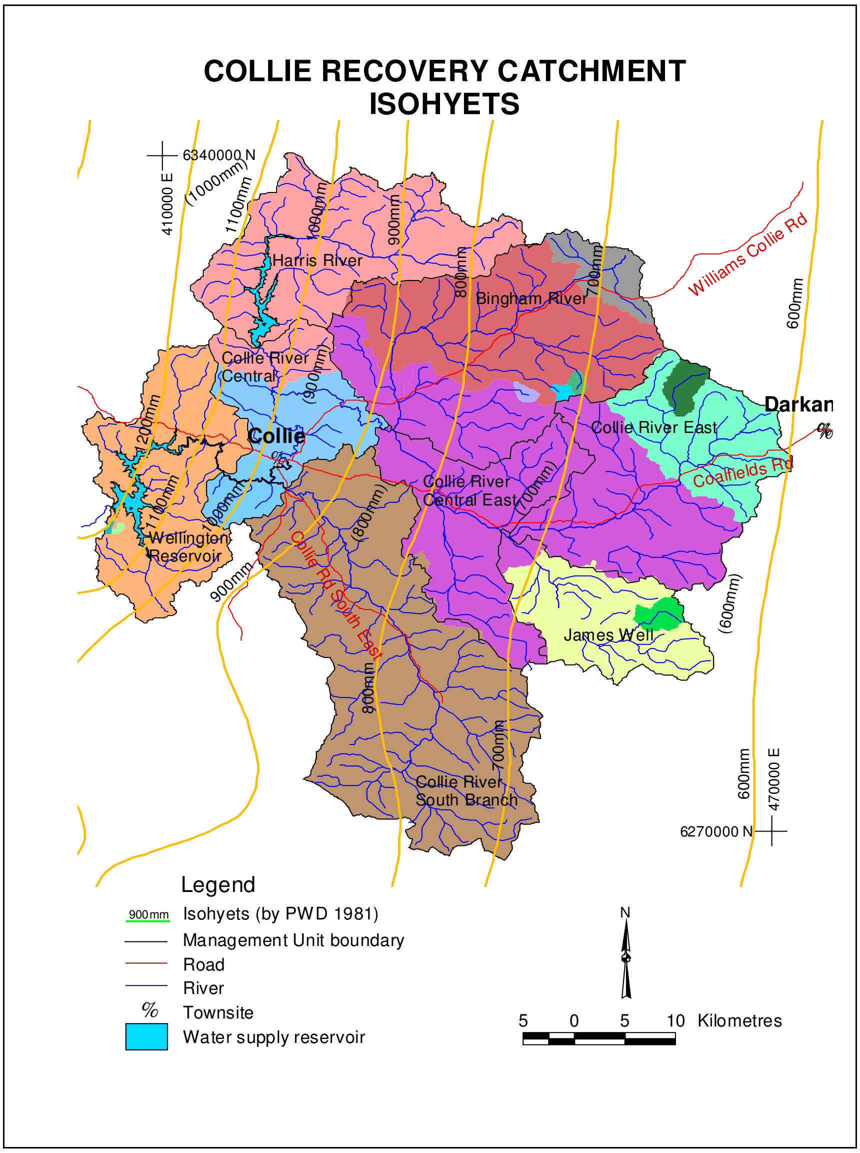

Figure 2. Collie River catchment isohyets

VEGETATION AND CLEARING

The variation in the types of vegetation across the catchment corresponds to changes in soils, climate and physiography. In the western part where rainfall is relatively high > 1100 mm/yr (Fig. 2) the open jarrah (*Eucalyptus marginata*) and marri (*Eucalyptus calophylla*) forest is dominant consisting of upperstorey to a height of 20 to 35 m. In the drier part to the east, jarrah and wandoo (*Eucalyptus redunca*) are prevalent with swamp yate (*Eucalyptus occidentalis*) and an understorey of *Melaeuca spp* in and around small lakes and swamps. Open heath (*Myrtaceae*) and high closed forests frequently vegetate drainage lines (Smith, 1974).

A small-scale clearing of the native vegetation for agriculture on the eastern boundary of the catchment around Darkan started in1870s. The growth of agriculture was slow to the 1900s, with only 1% of the catchment used for the wheat production at that time. The soils in the swampy flats in the eastern boundary are generally more fertile than soils on the catchment rim. The release of this part of the catchment proceeded by government after the First World War and a rapid expansion occurred between 1900 and 1930. By 1943 the cleared areas were only 186 km^2 covering ~ 6.5 % of the catchment. Due to infertile nature of the soils particularly in the catchment rim, clearing generally took place in the valley flats leaving the higher parts of the landscape covered by native vegetation. Clearing continued until 1976 when the Western Australian government introduced clearing control legislation. By then, 660 km^2 amounting to 28 % of the catchment had been cleared.

WATER ALLOCATION OF WELLINGTON RESERVOIR

The Collie River is one of the major water resources of the south-west region of Western Australia. It was dammed in 1933 with a storage capacity of 35×10^6 m^3 to supply the Collie River irrigation district on the coastal plain. In response to increased irrigation demand the dam was raised in 1946. An increase in storage capacity was again required by the mid-1950s to satisfy plans for much enlarged irrigation areas and the Great Southern Towns Water Supply Scheme. Major development work on the reservoir began in 1955 and the dam was raised to its current capacity of 186×10^6 m^3 by 1960. The mean annual flow for the Collie River at the Wellington Reservoir is 140×10^6 m^3. The Harris Dam was built in 1989 after the salinity in the Wellington Reservoir exceeded 1000 mg /l TDS during the dry years of the late 1970s. Currently, 68×10^6 m^3 from the Wellington Reservoir is allocated to downstream irrigation and an additional 26×10^6 m^3 is scoured from the base of the Reservoir to reduce salinity of the irrigation supply water.

The Collie Coal Basin in the mid-western part of the catchment (Fig.1) contains relatively large volumes (~ 7×10^9 m^3) of fresh groundwater (< 500 mg/l). Coal was discovered in the Basin and mining activity established in the early 1900s. Underground mining for coal required dewatering of the mines and the fresh groundwater was discharged into the Collie River. Underground mining was replaced by open-mining in the late 1960s and large voids (up to 180×10^6 m^3) excavated in the Basin. With the expansion of mining activities, the mining companies required allocation of groundwater for dewatering. The current groundwater allocation for the mining activity in the Basin is ~ 25×10^6 m^3.

SALINITY DEVELOPMENT

The relationship between clearing native vegetation and salinity development was highlighted in the early 1900s. The Chief Engineer of the Goldfields Water Supply, N. C. Reynoldson, attributed the rapid increase in the salinity of the Mundaring Reservoir (20 km north-east of Perth) to ring-barking and agriculture within the catchment (Power, 1963). He recommended that the authorities should purchase the existing agricultural land to prevent further agricultural activities.

Wood (1924) presented the hypotheses that the salt originated from the ocean, was deposited on the landscape in rainfall and stored in the soil. The removal of native vegetation allowed more water to percolate to the groundwater mobilising the stored salt. The rising groundwater brought the salt to the surface resulting in stream salinisation. It was only in the early 1970s that research was carried out to demonstrate and validate Wood's (1924) hypothesis. Despite these early observations, there is little evidence to suggest that the scientific community or water resource managers were concerned about stream salinity at the time. This was because there was a low demand and an abundance of fresh water supply particularly in the south-west region. After the Second World War a major expansion of land release for agriculture by the government led to a rapid increase in demand for water for irrigation, mining and domestic supply. The early signs of salinity increase in the Collie River appeared after this widespread clearing in the catchment.

Recognising the conflict between land use and additional water supply, a committee to advise the government was established in 1950. The first submission to halt land release and stop clearing in the catchment was received by the committee in 1951 from the Public Works Department. By the mid-1950s there was ample evidence that the salinity of tributaries of the Collie River draining the eastern part of the catchment had increased by 2 fold to ~ 350 mg/l (Fig 3). By then still only 10% of the catchment was cleared.

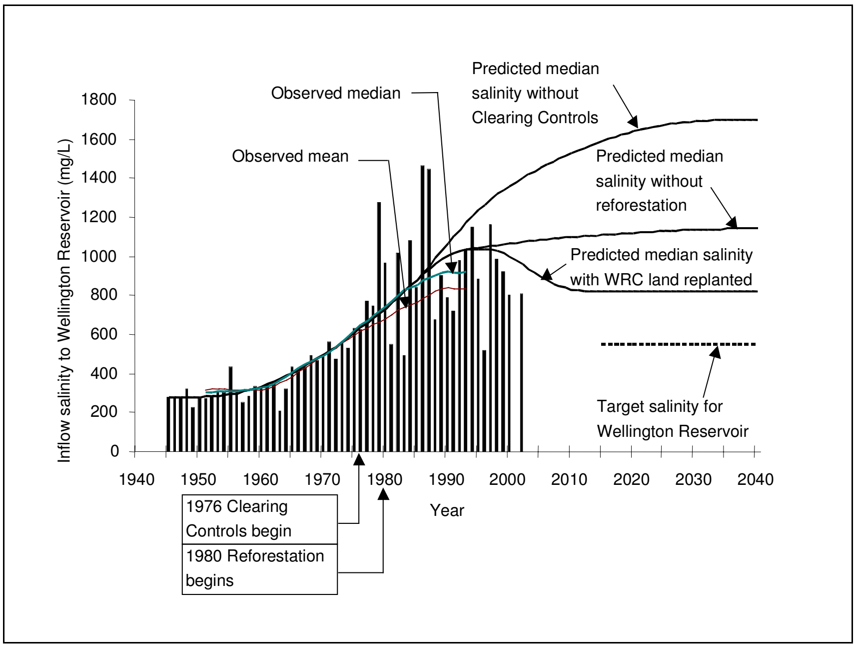

Figure 3. Observed and modelled salinity trend of the inflow to the Wellington Reservoir

Based on the committee's recommendation, in 1960 the government of Western Australia decided to stop further land releases in the Collie River catchment. By this time the salinity of the inflow to the Wellington Reservoir after a very dry winter in 1959 had increased to ~ 400 mg/l (Fig. 3). However without active intervention, the salinity of the inflow continued to rise. In late 1960 long-term research to document the relationship between clearing and the stream salinity increase had begun. By this time the salinity of the median inflow year had risen to ~ 500 mg/l.

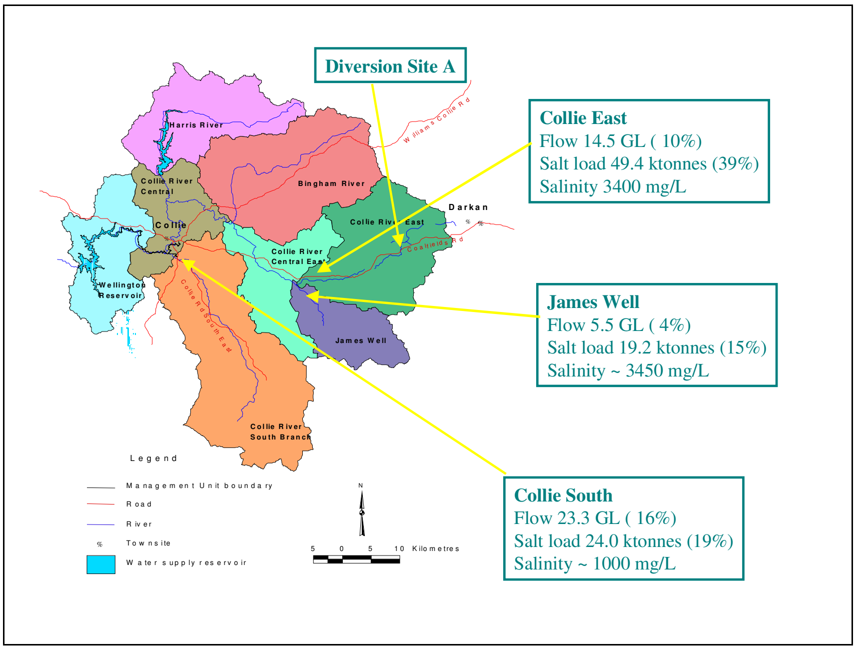

Figure 4. The relative contribution of flow and salt from the Collie River tributaries to the Wellington Reservoir.

In 1974, pairs of small catchments across different rainfall zones were selected and instrumented to measure the input and output of salt and to monitor the response of groundwater and its interaction with stream water before and after clearing. The result of this work was published in 1987 when the salinity of the median inflow year reached ~ 900 mg/l (Peck and Williamson, 1987).

Based on modelled salinity trend it was also anticipated that the salinity of the inflow would increase to ~ 1100 mg/l if 25% of the catchment remained cleared (Fig. 3). The trend analysis over the last 60 years shows that the salinity for a median flow year has increased from 280 mg/l in 1945 to ~ 1000 mg/l in 1992 (Fig. 3). This corresponds to average of 5 mg/l annual increase up to 1955 and to ~15 mg/l between 1955 and 1965 and to ~ 30 mg/l by the mid-1980s. Since 1992, however, the salinity of the inflow has stabilised and no upward trend has been detected. The East Collie branch, where most clearing occurred, has the highest salinity in the catchment and contributes only 10% of the flow but 39% of the salt load to the Reservoir (Fig. 4).

THE WATER RESOURCE RECOVERY CATCHMENT APPROACH

Consideration of the regional land use objectives and the expectations of the land users within the catchments did not feature in the management planning in the early stages of catchment management. Catchment reforestation, which aims to replace the hydrological function of the native vegetation, was considered the surest way to restore salt flow equilibrium. Cost-effective analyses of the available options at the time showed that the engineering solutions such as removal of saline stream flow and diversion of saline flow were expensive, wasteful of the resources and offered only an interim solution compared with reforestation. By mid-1990, it was recognised, however, that although catchment reforestation is an important part of the management, a combination of options including engineering work should be considered to lower the salinity inflow at least as a short term solution. Recognising this, the Western Australian Government designated the Collie River catchment as one of the five Water Resource Recovery Catchments (Salinity Action Plan, 1996). The aim of this action was specific in terms of time frame "to lower the salinity of the inflow to the Reservoir to 550 mg/l by 2015".

Furthermore, while stopping further land releases, imposing clearing controls and buying back land and reforestation was hydrologically sound, these measures caused community resentment and eroded trust in government actions. By 1996, a new approach to protecting public water resources was being adopted. The government now worked in partnership with communities and industry to achieve public water resource benefits as well as private benefits through community involvement and some cost sharing. A Collie Recovery Team with farmer, state and local government agency and industry representatives was formed and developed a strategic action plan. This strategic action plan set out the range of salinity management options.

Unlike the previous catchment management strategy of the late 1970s, which tended to focus exclusively on the hydrological aspects of the salinity problem, the current strategy aims to fully involve the stakeholders in implementing management options. One of the major concerns of the stakeholders (farmers) in the catchment was the failure of the early strategy in 1976 to consider the social aspects of the reforestation program such as depopulation of the area and its impact on the local community.

PRELIMINARY ASSESSMENT OF SALINITY MANAGEMENT OPTIONS

The long-term impacts of the salinity management options (set out below) were simulated using a numerical groundwater model MAGIC (Mauger et al, 2001). The model produced a catchment water balance and estimated the location and quantity of deep groundwater discharge (seepage to the stream) and volume of stream flow (Mauger et al., 2001). The initial study evaluated the following management options:

1. Upland commercial trees: This involved alley plantings in a range of row densities on all suitable upland areas with soil good for growing trees for sawlogs or woodchips.
2. Lowland trees: This option involved land unsuitable for large chipwood or sawlog trees of option 1, but perhaps suitable for planting with other commercial or non-commercial tree varieties. This land is usually situated in the low in the landscape and subject to waterlogging and salinity.
3. Lucerne: Planting deep-rooted perennial pasture such as lucerne on all suitable land can significantly reduce groundwater recharge. Lucerne is being trialled for recharge reduction at a number of sites in the Collie River catchment. The trials are exploring the practicalities of managing lucerne and its hydrologic benefit. There is also potential for rotating lucerne with shallow-rooted crops.
4. Shallow drainage: Shallow drains in discharge areas reduce soil erosion, inundation and waterlogging. The drains do not affect the rate of discharge of salt from the ground, but may remove some salt downstream at a faster rate than would otherwise occur.
5. Groundwater pumping: A series of deep groundwater extraction bores can be constructed where deep groundwater discharge would otherwise occur. The objective is to lower groundwater levels. A pipeline and associated pumping stations would be required to move the saline water from the catchment or, if possible, to a site for treatment.
6. Diversion: Streamflow from the most saline tributaries could be intercepted by a dam and transported out of the catchment by a pipeline. Alternatively, diversion of only the low flows in these tributaries could significantly improve downstream salinities, because the low streamflows over summer are much more saline than the high flows during winter storms.

The results of this study highlighted that only replanting the whole cleared area of the catchment with trees could achieve the target of lowering the salinity to 250 mg/l (Table 1). However, due to the long delay between planting and its full effect on stream salinity and the social consequences on the farming community, this option has not been considered. Engineering options such as diversion of the saline water and groundwater pumping are the two options which could reduce the inflow salinity to ~ 550 by the designated time (2015). As part of further evaluation of groundwater pumping a trial site has been established. More site-specific modelling has indicated that groundwater pumping would reduce surface water salinity by 20% after two years of continuous pumping (Dogramaci, 2002a,b).

Table 1. Summary of modelled management options

Management scenario	Inflow to Wellington Reservoir			Seepage area
	Salinity mg/l	Flow Gl/yr	Salt load Tonnes/yr	area km^2
Current	880	150	128 078	52
Low-flow diversion	800	140	107 483	52
Shallow drainage	750	135	99 688	38
Lucerne with plantations	650	120	77 213	33
Upland trees	600	100	61 285	16
Lowland trees	600	120	59 905	13
Full diversion	550	130	66 822	47
Groundwater pumping	550	130	67 724	?
Upland & lowland trees	250	80	16 008	11

In addition to the management options simulated by Mauger et al (2001) the coal mining company, Griffin Energy, mining in the Collie Coal Basin has developed an integrated energy project including a coal-fired power station (HGM, 2002). This potential project aims to significantly reduce the salinity of the Collie River by diverting the highly saline (> 10 000 mg/l) early winter and late summer flows into one of the abandoned mine voids. This is similar to the full diversion option shown in Table 1. The diversion of the Collie River can be implemented as the mining voids become available for filling with saline water. Initially it is proposed that the Collie River water be diverted to the relatively small voids (Chicken Creek 15 $x10^6$ m^3). Once the project is established, a much larger void (Muja 150 x 10^6 m^3) will be utilised for the project. Such schemes have the potential to reduce the salinity of inflow into Wellington Reservoir to ~ 550 mg/l (Table 1). Due to the limited number of voids, however, this could only be regarded as a short-term solution as there is only a storage of 200 $x10^6$ m^3. The estimated saline water diversion volume is 10 x 10^6 m^3/year which is only 15 to 20 years life span for the project depending on the size of the project and the method of implementation. Therefore, Griffin Energy proposes the reuse of the saline water through desalinisation using the energy from the proposed power plant as an essential and integrated part of the proposed project.

DETAILED EVALUATION OF SALINITY MANAGEMENT OPTIONS

Thirteen management options were identified with objectives of inflow salinity to the Reservoir of either 550 or 600 mg/l (Table 2). These options were evaluated for their implementation needs and time-scale of benefits, and their social, economic and environmental impacts upon the catchment and surrounding region (URS, 2002 a). The selection of management options in terms of performance and social acceptability is measured according to the criteria set in Table 3.

In November 2002 the Collie Recovery Team conducted a workshop to enable representatives of all stakeholders (46 participants) in the catchment to contribute a formal evaluation of the 13 options. The aim was to review the salinity management options and select five preferred options for continued, more detailed development. Each participant had the right to vote for his or her preferred option on priority orders. The voting and selection process is documented by URS (2003).

Most participants favoured options with a quick outcome (less than 5 years) in terms of improved water quality. The most preferred option, by a large margin, was for a 50% diversion of the Collie River into available mining voids as suggested by Griffin Energy (Table. 2). The second most preferred option was for full diversion at Site A (Fig 4). However, a slower option (groundwater pumping and partial commercial reforestation) received reasonable support and was considered as the third most acceptable option. The fourth option was building a diversion dam on Collie East River and installing 227 pumping bores with a disposal pipeline to the ocean. The fifth preferred option was the planting of 6000 ha of ‘upland trees’ and 700 ha of ‘lowland trees’ (Table 2). A suggested approach from the workshop was to use the time gained with the short-term diversion options to develop new land use options that will be more acceptable to the stakeholders.

Table 2 Specific Salinity management options

	Option		Option description	Overall scores
550 mg/l	1.	Groundwater pumping	670 groundwater bores, with disposal pipeline to ocean	1
	2.	Upland Trees	16 000 ha of upland trees and 700 ha of lowland trees	7
	3.	Lowland Trees	8000 ha lowland non-commercial trees	1
	4.	Combined trees and pumps	225 groundwater bores with disposal pipeline to ocean, and 3 000 ha lowland trees	17
	5.	Desalination	Desalination of saline water (19 GL) from eastern Collie branch	5
600 mg/l	6.	Groundwater pumping	404 groundwater bores with disposal pipeline to ocean	4
	7.	Upland trees	14 400 ha upland commercial trees in eastern Collie River catchment	3
	8.	Lowland trees	6200 ha lowland non-commercial trees in eastern Collie River catchment	0
	9.	Dam	Diversion dam on Collie East River with disposal pipeline to ocean	21
	10.	Dam and pumps	Diversion dam on Collie East River with disposal pipeline to ocean and 227 groundwater pumping bores in central and southern Collie River catchment	16
	11.	Pumps and Trees	180 groundwater bores with disposal pipeline to ocean, and 2000 ha lowland trees	4
	12.	Mine Void Diversion	Diversion of Collie East river into mine void	32
	13.	Desalination	Desalination of saline water from eastern branch	3

Table 3 Social, economic, environmental and implementation criteria for assessment

Theme	Criterion
Implementation issues	Technical certainty Ease of staged implementation Level of long-term management complexity
Social	Population trends and movement Farming business numbers Employment in Collie River catchment Employment outside the Collie River catchment Business activity in Darkan Business activity in Collie Business activity in Bunbury Collie and Darkan and schools Community activities and personal security
Economic	Costs of works and land use changes Loss in land values due to area salinised Loss of shire rating income Greenhouse implications
Environment	Vegetation, flora, introduced weed species, feral animals, Water quality, water quantity, aquatic fauna, Wetlands, Flood-prone land, Erosion, Greenhouse gases, Fire and Culture and Heritage

The final assessment of the viability of diversion into the mine voids is currently under consideration. Technical uncertainties regarding potential contamination from the disposal of saline water into mine voids is being investigated. The estimated seepage from mine voids to the surrounding fresh groundwater is expected to be up to 30% of the volume of the disposed water. This is because the water level in the voids would be ~ 20 m higher than that of the surrounding groundwater levels. To overcome this problem, the void must empty at least six months of the year to allow the seeped saline water to re-enter the void. The operational plan for the management of the water level in the void is a pre-requisite to the approval of this option. Other potential problem is the increase in acidity of the saline water due to exposure to coal seams in the void. Investigations are currently under way to address these problems. Similar studies regarding the technical uncertainness of the options 2 3 4 and 5 are also currently under way. The outcomes from this phase would be a recommendation to Government on the preferred options for salinity recovery on the Collie River.

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