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Value of Returns to Land and Water and Costs of Degradation

Project 6.1 Final Report to the *National Land & Water Resources Audit*

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Volume 2 (Appendices)

Submitted by Policy and Economic Research Unit CSIRO Land and Water on behalf of consortium members

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APPENDIX A Value of Production Methods and Data

A1 Methodological information

One of the key building blocks for Project 6.1 is the construction of a means to assess the economic implications of fine scale changes in attributes that describe changes in the state of the land and water resources used and connected with agriculture. Essentially, there are two ways this could be done:

- Biophysical estimates could be aggregated up to the scale that most economic information is available; or
- A fine-scale economic data set could be built so that economic assessments can be made by modelling at a fine scale.

Whatever method is used to generate estimates, the resultant data should still be interpreted at a scale at which the coarsest data is collected. Modelling at the fine scale in a GIS framework, however, enables aggregation of data in many different ways – by soil type, by land-use practice, by catchment, by region, by electorate, etc. For this reason, the latter approach was taken. Essentially, the approach facilitates aggregation by any spatial attribute.

The methodology integrates a spatial description of land use and the associated productivity yields for all major agricultural activities (as described by ABS production statistics), with data describing variable and fixed costs of production (including labour and capital), government support, and potential benefits from addressing degradation issues. Each data layer is linked using a profit function enabling the calculation of gross local value of agricultural production; profit at full equity; net economic return to land and water resources; and net social return to land and water resources. These values are modelled for each cell but are interpreted at the national, regional and industry scales.

A1.1 Land-use Map Enhancements

The Bureau of Rural Sciences produced a land use map for the NLWRA as a 1km^2 grid covering Australia for the year of 1996/97. The map supplied to the Audit by BRS is at a higher level of aggregation than we used necessary for our work. To facilitate construction of the profit function data we accessed affinity codes and built a new map that is based on 65 land-use codes. In addition, we removed a strip of agricultural land across the Nullabor Plain that is not used for Agriculture. All land uses are partitioned into dryland and irrigation categories. For different analyses we have aggregated this map on the basis of major industry groupings (see Figure A.1). These major industry groupings also form the basis of tabulated data. More information on the changes we made to the land-use map are summarised in Appendix

The aim was to give spatial definition to variables of the profit function that were used to calculate economic returns to the natural resource base. Each of the profit function variables were mapped at a scale of 1km2 and aligned to the agricultural activities described by the land use map.

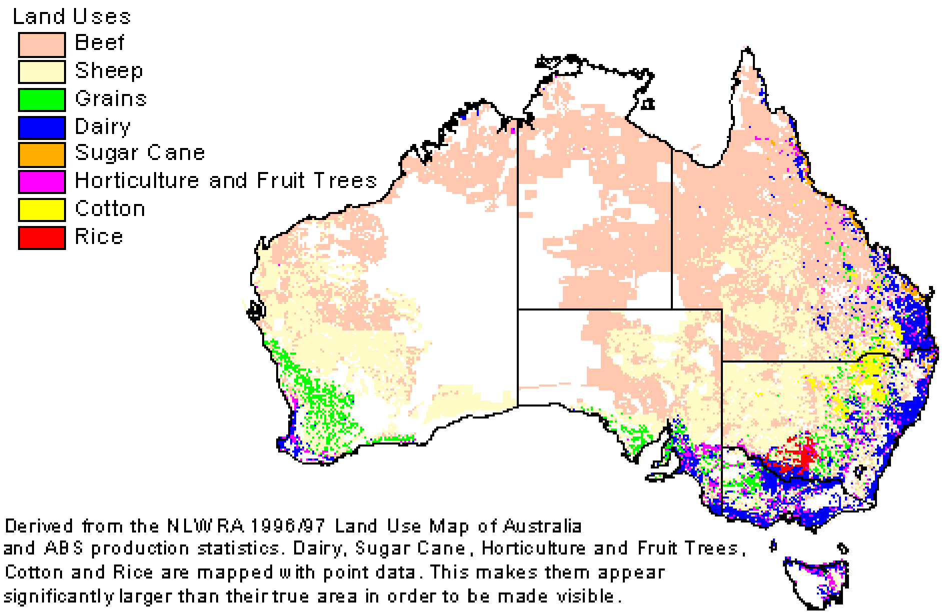


Figure A.1 Land Use Map of Australia

The variables were sourced from data at three regional levels: statistical local area (SLA), broad profit regions used by ABARE, and States. Assignment to an individual pixel was based on the specific land use assigned to that pixel and the region in which it occurred.

The yield surface for each agricultural activity was determined from ABS production and area statistics at the SLA level. Within an SLA yield for individual land uses was weighted according to NDVI, such that greener pixels were given a proportionally higher yields. Apart from minor changes to the classification of cropping and pasture land uses, the main addition to the land use map was the classification of pasture into beef, sheep or dairy land uses. This was necessary as sown, residual and native pastures needed to have an associated commodity if they were to be included in the profit function.

The area defined as pasture was converted to numbers of livestock (beef cattle, dairy cattle or sheep) using ABS production statistics for 1996/97. Beef, sheep and dairy cows were the only types of livestock considered. A standard conversion rate was used to covert numbers of these animals into Dry Sheep Equivalents (DSE). They were then allocated to pasture on a proportional basis (eg in a given SLA, if 50% of DSE rating were sheep, then 50% of pasture area was allocated to sheep). The normalised difference vegetation index (NDVI), an index of vegetation health/greenness derived from satellite data, was used to assign pasture, in priority order of greenest to driest, to dairy cows, beef cows and sheep.

A1.3 Nature of Profit Functions

A profit function was developed to provide a consistent approach that was capable of calculating; gross local value of agricultural production; profit at full equity; net economic return to land and water resources; and net social return to land and water resources. This approach enables easy integration with other components of the Audit. In addition, the structure is designed so that it can be incorporated into the full suite of natural resource issues associated with Australian agriculture. Consistent with ABARE practice, the main measure of performance is "Profit at Full

Equity." This provides an estimate of the financial return to land, water and capital plus managerial skill. All production costs and an imputed estimate of the value of farm labour is deducted. As modelled, the function is able to:

- link with ABS data on production – (sheep and dairy land uses have primary and bi-products);
- differentiate variable costs that are a function of yield and those that are a function of the number of production units – to enable economic impacts of alternative degradation scenarios to be estimated with changing yield functions;
- differentiate between fixed operating, capital, and labour costs;
- differentiate between water dependant and land dependant costs - capacity to assess specific issues associated with land and water management practices separately; and
- utilise both gross and local value of production data – to estimate the effect of price changes.

For some, this structure may seem unnecessarily complex. The reason for specifying the equation in this form is that it enables us to use a consistent definition for each variable and to manipulate data quickly without having to write code that takes account of different forms of the same equation. The profit function can be written as

$$PFE = ((P1 \times Q1TRN) + (P2 \times Q2 \times Q1)) - ((QC \times Q1 + AC) + (WR \times WP) + (FOC + FDC + FLC))$$

Where:

PFE = Profit at Full Equity

P1 – Farm Gate Price ($/ha or $/DSE)

- Derived from ABS data at the statistical local area level.
- Determined by dividing local value (does not include transport and marketing costs) by production.
- For dairy and sheep production, this represents the price from selling the animal (the primary product).

Q1 – Yield or Stocking Rate ($/ha or $/DSE)

- Derived from ABS data at the statistical local area level and NDVI satellite data.
- Represents the quantity of the primary product produced within the pixel.
- Determined by dividing production by area of production. NDVI is used to stretch production data such that greener pixels are assigned higher values.

TRN – Turn-off Rate (Ratio)

- This is the portion of livestock sold in the financial year. For all other forms of production, TRN is set at 1.00

P2 – Price of Secondary Product ($/kg or $/l)

- Only sheep and dairy land uses have a secondary product, namely wool and milk.
- This is the farm gate price (prior to transport and marketing costs).
- Production and prices were obtained from ABARE regional data sets (ADIS and ASPIRE)

Q2 – Yield of Secondary Product (kg/DSE or l/DSE)

- Only sheep and dairy land uses have a secondary product, namely wool and milk.
- This is the quantity of wool or milk yielded per sheep or dairy cow.
- It is obtained from ABARE data by ABARE region in the ASPIRE package.

QC – Quantity Dependant Variable Costs ($/t or $/DSE)

- Costs that vary with the quantity of output produced, eg harvest costs, marginal fertiliser costs.
- Developed for each land-use category in each of 29 ABARE regions, as they were shown to be undertaken - data is specific for each land use in each ABARE region.
- Derived from the ABARE ASPIRE package, Gross Margin Handbooks, and Farm Management consultant data

AC – Area Dependant Variable Costs ($/ha)

- Production costs that are applied on an area basis but vary between enterprise types
- Developed for each land-use category in each of 29 ABARE regions, as they were shown to be undertaken - data is specific for each land use in each ABARE region.
- Derived from the ABARE ASPIRE package, Gross Margin Handbooks, and Farm Management consultant data

WR – Water Requirement of Land Use (ML/ha)

- Water use rates for each major crop type were determined for each major irrigation area within the each ABARE region.
- Sourced primarily from the ANCID report Australian Irrigation Water Provider Benchmarking Report.

WP – Water Price ($/ML)

- Water prices were determined for each major irrigation area within the each ABARE region.

- Sourced primarily from ANCID report Australian Irrigation Water Provider Benchmarking Report.

FOC – Fixed Operating Costs ($/ha)

- Production costs that are fixed per unit area for typical farm types (eg. dairy, broad-acre cropping, horticulture). This include land rates, accountant fees, etc.)
- Developed for each farm category in each of 29 ABARE regions, as they were shown to be undertaken – several land uses may be undertaken within a farm category
- Derived from the ABARE ASPIRE package, Farm Management consultant data

FDC – Fixed Depreciation Costs ($/ha)

- Machinery and infrastructure depreciation costs that are fixed per unit area for typical farm types (eg. dairy, broad-acre cropping, horticulture)
- Developed for each farm category in each of 29 ABARE regions, as they were shown to be undertaken—several land uses may be undertaken within a farm category
- Derived from the ABARE ASPIRE package, Farm Management consultant data

FLC – Fixed Labour Costs ($/ha)

- Labour costs that are fixed per unit area for typical farm types (eg. dairy, broad-acre cropping, horticulture)
- Developed for each farm category in each of 29 ABARE regions, as they were shown to be undertaken—several land uses may be undertaken within a farm category
- Derived from the ABARE ASPIRE package, Farm Management consultant data.

In addition net economic return to land and water resources; and net social return to land and water resources can be calculated with the inclusion of resource use externalities and net government payments received. These terms have been defined for Audit purposes as:

Net Economic Return (NER) = PFE – Government Support

Net Social Return (NSR) = NER – Resource Use Externalities

Government Support

In addition to the variables used to determine PFE, government support data to land uses was determined from Productivity Commission reports (State, Territory, & Local Assistance to Industry, and Trade and Assistance Review). These data were presented as industry and or state aggregates, they were converted for the Audit either as a value per hectare or a percentage of gross product value. Rates were subdivided down to each commodity type as far a data permitted. State and Federal support were aggregated.

Profit Functions linked to ABS data
The land-use map and production descriptions are consistent with ABS Level 3 classifications – as separate crops or livestock activities, eg wheat, cotton, rice, dairy or beef (see Table A.1). As a result the profit function was developed to calculate value of production, etc. for each activity rather than for whole farm enterprises.

At fine scale, the data must be interpreted with extreme care. The land-use map is a model of land-use with in each statistical local area and is a representation of the land-use that actually occurred in 1996/97. The profit at full equity data is a representation of what money would be received and spent if the land-uses where undertaken by a typical farm in that area. The available fixed and variable cost of production data sets are derived from information obtained from ABARE, from ABS, from State departments of agriculture and from surveys.

Table A.1 Land Use Map Categories

Dryland Categories		Irrigated Categories	
Almonds (D)	Lupins (D)	Almonds (I)	Oil Poppies (I)
Apples (D)	Maize (D)	Apples (I)	Oranges (I)
Avocado (D)	Mung Beans (D)	Apricots (I)	Other Veges (I)
Bananas (D)	Non-Cereal Hay (D)	Avocado (I)	Peaches (I)
Barley (D)	Oats (D)	Bananas (I)	Peanuts (I)
Beef (D)	Other Veges (D)	Beef (I)	Pears (I)
Canola (D)	Peanuts (D)	Canola (I)	Plums (I)
Cereal Ex Rice (D)	Pears (D)	Cereals Hay (I)	Potatoes (I)
Cereal Hay (D)	Pineapple (D)	Cherries (I)	Rice (I)
Chick Peas (D)	Potatoes (D)	Cotton (I)	Sheep (I)
Citrus (D)	Safflower (D)	Dairy (I)	Sugar Cane (I)
Coriander (D)	Sheep (D)	Faba Beans (I)	Tobacco (I)
Cotton (D)	Soybeans (D)	Grapes (I)	Triticale (I)
Dairy (D)	Sugar Cane (D)	Macadamia (I)	Wheat (I)
Faba Beans (D)	Sunflower (D)	Maize (I)	
Grain Sorghum (D)	Triticale (D)	Mangoes (I)	
Grapes (D)	Vetches (D)	Nectarin (I)	
Lentils (D)	Wheat (D)	Non-Cereal Hay (I)	

ABARE data is organised by farm enterprise and covers the majority of agricultural industries but not all of them. They have the most comprehensive data on actual performance but it is not available in an unidentified and can not be linked to data on soil attributes etc. Moreover, these data can not be organised by land-use type. ABS data contains the most comprehensive information on the quantity of each activity but very little economic information that is suitable for our purposes. State department data is usually in the form of gross margin budgets. These provide the most comprehensive information on product performance but, in some cases, may portray what is possible rather than what is actually happening. Moreover, they do not account for land-use synergies. These alternative data source were combined and cross checked to provide variable and fixed cost of production data in a compatible form to the land-use map.

96/97 Base Year and 5 Year Data

The base year for the Audit is 96/97, both 1996/97 prices and mean prices for the five years up to and including 96/97 are used. The prime data set that we have supplied to the Audit in real 1996/97 prices.

Profit Function Corroboration

National totals for revenue, costs (variable and fixed) and profit from the profit function were compared against similar data from the Australian Bureau of Agriculture and Resource Economics (ABARE) and the Australian Bureau of Statistics (ABS). Values for income, costs and the net value of production generated in this project lie between commensurable values from ABS and ABARE. The data sets can be compared for industries covered in this project as follows:

Table A.2 Comparison of economic data used in this project with that available from other sources

	ABS[a]	CSIRO (NLWRA)	ABARE[b]
Revenue ($Millions $)	$24.694	$27.867	$28.040
Costs ($ Millions $)	$18.317	$21.622	$23.808
Net Value of Production ($ Millions $)	$6.377[c]	$6.245	$4.232
Area of Ag. Land (ha millions)	453.7	472.7	466.1

(a) Derived from: ABS (1998) "7507.0 *Agricultural Industries, Financial Statistics, Australia, Final Issue (1996/97)*", Australian Bureau of Statistics, Canberra. ISSN: 0810-459X.

(b) Derived from ABARE (2000) "1999 Australian Commodity Statistics", Australian Bureau of Agriculture and Resource Economics, Canberra. ISSN 1325-8109.

(c) Determined by subtracting ABS costs from ABS revenue.

Comparisons are based on data items in ABS and ABARE that are most similar to the profit function variables. Exact comparisons are not possible because ABS and ABARE data measures slightly different variables.

APPENDIX B Estimating the Spatial Extent and Impact of Dryland Salinity

In Theme 2 of the Audit, States and Territories have provided data on the spatial extent of dryland salinity using inconsistent definitions and techniques. In most cases, hazard or risk, rather than extent of impact, was estimated. For economic assessments, however, data on the spatial extent and severity of impact is needed. For the purposes of making a nation-wide estimate of the cost of economic impacts and the value of opportunities associated with dryland salinity, all spatial estimates of hazard were first converted into estimates of spatial extent and severity of impact. This requires a series of assumptions that stretched the limits of the data sets. It is stressed that the resulting estimates should be interpreted at a very broad scale. Estimates were made in terms of impact on

- agricultural productivity; and
- infrastructure.

The assumptions used to estimate extent and impact are described in this appendix.

Classification of extent
To simplify the task ***and*** provide a standard framework for assessment of extent was developed.

Table 1 Dryland salinity impact categories

Dryland Salinity Impact Class	Assumed Impact on Agricultural Productivity			Impact on Infrastructure
	Description	Yield reduction	Assumed relative productivity	
I	No Impact	None	100%	None
II	Slight Ag. Impact	1-20%	90%	None
III	Moderate Ag. Impact	21-50%	65%	Slight Infra. Impact
IV	Severe Ag. Impact	51-70%	40%	Moderate Infra. Impact
V	Extreme Ag. Impact	71-100%	15%	Severe Infra. Impact

Where appropriate high, low and best estimates are provided. "Low" was defined as the estimate that has less impact on total cost.

Conversion assumptions by State and Territory

Metadata for the data sets supplied to the National Land and Water Resources Audit for the salinity hazard maps supplied by States and Territories indicates that the methods used in each region were significantly different. Moreover, the metadata indicate that the data supplied needs to be adjusted to derive consistent estimates of hazard across all states. Specifically, these metadata provide area multipliers so that information derived from the maps provided by states and territories can be adjusted to obtain the numbers provided in the Audit's Australian Dryland Salinity Assessment 2000 Report. Conceptually, these areas provide estimates using a more consistent estimate of hazard. The area multipliers are summarised in Table 2.

Table 2 Area multipliers to obtain a consistent understanding of the definition of hazard supplied by each State and Territory

State	2000	2020	2050
QLD	na	Na	1.00
SA	1.00	1.00	1.00
VIC	1.00	1.00	1.00
WA	1.00	1.00	1.00
TAS	0.83	1.09	1.47
NSW (and ACT)	0.14	0.32	0.49

Source: Theme 2 metadata for dryland salinity estimates. For reasons set out below we consider that the Area multipliers for South Australia are incorrect as this State mapped "extent" not "hazard"

South Australia

The South Australia area multiplier for proposed by the Audit is 1.00 for 2000, 2020 and 2050. For the reasons set out below, however, and after discussions with the people who prepared the maps for South Australia, we consider this to be an incorrect assumption.

Unlike other States, South Australia has mapped spatial extent in 2000 and their extent expectations for 2020 and 2050 assuming no change in land-use practice or salinity management strategy. In each case, the data supplied is a map showing the area where salinity can be observed from aerial photographs. Advice from the people who did this mapping suggests that these areas contain land that is 25% in Dryland Salinity Impact Class III, 50% in Class IV and 25% in Class V. They advise that a surrounding area "approximately equal to the area mapped" would be in Class II and Class III. This was simulated by using the buffer function in ArcInfo, estimating the necessary buffer increase if the polygon was a circle and then adjusting this by a factor based on the ratio of the radius of the circle and the actual perimeter of the polygon.

Where the area affected by salinity in 2020 is larger than that in 2000 after growing the polygon by its area, we assume the 2020 High Hazard extent to provide the best boundary for the extent of the area where there is an impact but it is not mapped.

Where the area affected does not increase from 2000 to 2020, we assume that an equal area of unmapped impact is an area equivalent to the mapped area. This was estimated by extending each high hazard polygon by an appropriate distance.

For areas where the high hazard area is not expected to increase in either 2020 or 2050, we assume that the Impact on relative productivity and on infrastructure extends for a small distance past the boundary of the high hazard area mapped.

Table 3 South Australia Year 2000 spatial extent and impact estimation rules used for all high hazard areas where the hazard area is not increasing

Dryland Salinity Impact Class	Area mapped as High Hazard			Areas near those mapped as High Hazard		
	Low estimate	Best estimate	High estimate	Low estimate	Best estimate	High estimate
I	0%	0%	0%	60%	50%	30
II	25%	0%	0%	30%	30%	30%
III	30%	25%	20%	10%	20%	30%
IV	25%	50%	30%	0%	0%	10%
V	20%	25%	50%	0%	0%	0%
Mean relative productivity	55%	40%	33%	94%	90%	81%

Thus for areas mapped as high hazard in either 2000 or 2020, we assume that the mean relative agricultural productivity of any 100ha mapped as high hazard to be as follows

For the best estimate

(0ha @ 100%) + (0ha @ 90%) + (25ha @ 65%) + (50ha @ 40%) + (25ha @ 15%) = 40%

For the low estimate

(0ha @ 100%)+ (25ha @ 90%) + (30ha @ 65%) + (25ha @ 40%) + (20ha @ 15%) = 55%

For the high estimate

(0ha @ 100%)+ (0ha @ 90%) + (20ha @ 65%) + (30ha @ 40%) + (50ha @ 15%) = 33%

Similarly for areas near those mapped as high hazard in either 2000 or 2020, we assume that the mean relative agricultural productivity of any 100ha mapped as high hazard to be as follows

For the best estimate

(50ha @ 100%) + (30ha @ 90%) + (20ha @ 65%) + (0ha @ 40%) + (0ha @ 15%) = 90%

For the low estimate

(60ha @ 100%)+ (30ha @ 90%) + (10ha @ 65%) + (0ha @ 40%) + (0ha @ 15%) = 94%

For the high estimate

(30ha @ 100%)+ (30ha @ 90%) + (30ha @ 65%) + (10ha @ 40%) + (0ha @ 15%) = 81%

For our 2020 estimates, we assume that the same estimates apply.

Western Australia
The Western Australian area multiplier proposed by the Audit is 1.00 for 2000, 2020 and 2050.

In Western Australia, salinity hazard was mapped on a much coarser scale. Essentially, the area mapped in each case is that outer boundary of all areas where there is some affect on productivity.

Table 4 Western Australia impact estimation rules used for all high hazard areas

Dryland Salinity Impact Class	Assumed proportion of each mapped polygon in each class		
	Low estimate	Best estimate	High estimate
I	80%	50%	35%
II	10%	20%	25%
III	5%	15%	20%
IV	4%	10%	10%
V	1%	5%	10%
Mean relative agricultural productivity for high hazard areas	94%	83%	76%

On this basis we would expect the mean relative agricultural productivity of any 100ha mapped as high hazard to be as follows

For the best estimate

(50ha @ 100%) + (20ha @ 90%) + (15ha @ 65%) + (10ha @ 40%) + (5ha @ 15%) = 83%

For the low estimate

(80ha @ 100%)+ (10ha @ 90%) + (5ha @ 65%) + (4ha @ 40%) + (1ha @ 15%) = 94%

For the high estimate

(35ha @ 100%)+ (25ha @ 90%) + (20ha @ 65%) + (10ha @ 40%) + (10ha @ 15%) = 76%

For infrastructure in Western Australia we assume that for 15% of each area the impact is slight, for 10% of each area the impact is moderate, and for 5% it is severe.

We assume that these same estimates apply to all areas in Western Australia mapped as high hazard in 2000, 2020 and 2050.

New South Wales and Australian Capital Territory

Dryland salinity mapping for New South Wales used a different technique and appears to be coarser than that used in the states described above. As for Western Australia, it appears that the areas mapped represent an outer boundary of the area where an impact can be detected. The area multipliers for New South Wales proposed by the Audit are

- 0.14 for 2000;
- 0.32 for 2020; and
- 0.49 for 2050.

Using the 0.14 area multiplier for New South Wales and Western Australia as a benchmark, for 2000 we adjust the data for this state by reducing the Western Australian assumptions of the area affected by the area multiplier. Thus, the best estimate of the area in Dryland Salinity Impact Class 1 increases by (1-0.14). The resulting assumptions for New South Wales in 2000 are summarised in Table 5.

Table 5 New South Wales impact estimation rules used for all high hazard areas in 2000

Dryland Salinity Impact Class	Assumed proportion of each mapped polygon in each class		
	Low estimate	Best estimate	High estimate
I	97.2%	93.0%	90.9%
II	1.4%	2.8%	3.5%
III	0.7%	2.1%	2.8%
IV	0.6%	1.4%	1.4%
V	0.1%	0.7%	1.4%
Mean relative productivity for high hazard areas	99%	98%	97%

On this basis we would expect relative agricultural productivity to be as follows

For the best estimate

(93ha @ 100%) + (2,8ha @ 90%) + (2.1ha @ 65%) + (1.4ha @ 40%) + (0.7ha @ 15%) = 98

For the low estimate

(85.8ha @ 100%)+ (7.1ha @ 90%) + (3.3ha @ 65%) + (2.4ha @ 40%) + (1.4ha @ 15%) = 96%

For the high estimate

(90.9ha @ 100%)+ (3.5ha @ 90%) + (2.8ha @ 65%) + (1.4ha @ 40%) + (1.4ha @ 15%) = 97%

For 2000 infrastructure in New South Wales, the resultant best estimate assumptions are that the impact for 2.1% of each polygon is slight, for 1.4% of each polygon the impact is moderate, and for 0.7% it is severe.

For 2020 the area multiplier is 0.32. This results in the assumptions summarised in Table 6.

Table 6 New South Wales impact estimation rules used for all high hazard areas in 2020

Dryland Salinity Impact Class	Assumed proportion of each mapped polygon in each class		
	Low estimate	Best estimate	High estimate
I	93.6%	84.0%	79.2%
II	3.2%	6.4%	8.0%
III	1.6%	4.8%	6.4%
IV	1.3%	3.2%	3.2%
V	0.3%	1.6%	3.2%
Mean relative productivity for high hazard areas	98%	94%	92%

For 2050 the area multiplier is 0.49. This results in the assumptions summarised in Table 7.

Table 7 New South Wales impact estimation rules used for all high hazard areas in 2050

Dryland Salinity Impact Class	Assumed proportion of each mapped polygon in each class		
	Low estimate	Best estimate	High estimate
I	90.2%	75.5%	68.2%
II	4.9%	9.8%	12.3%
III	2.5%	7.4%	9.8%
IV	2.0%	4.9%	4.9%
V	0.5%	2.5%	4.9%
Mean relative productivity for high hazard areas	97%	91%	88%

No salinity hazard was identified in the ACT and we assume this to be the case.

Queensland
The data supplied for Queensland is very different to that provided by other States and Territories. In particular, this State chose to supply hazard estimates only for 2050. Thus, to proceed with the development of nation-wide estimates of cost we needed first to develop hazard maps for 2020 and 2000. Great care must be used in interpreting Queensland data at less than a very broad regional level. Salinity experts in Queensland recognise that what we have done is that best that is possible but are fearful that the resultant maps could be used by local decision makers to make site specific decisions. This should never be done.

In addition to the 2050 map of dryland salinity hazard, we were able to obtain data from a dryland salinity survey of Queensland in the early 1990s. These data identified the location of known dryland salinity sites at that time. The resultant dataset identifies 450 points where salinity was expressing itself on the surface in the early 1990s (Ian Gordon 2000, pers. com.). Using these data the Audit Theme 2 report suggests that the current extent of salinity in Queensland is 48,000ha.[1]

Overlaying the early 1990s points with the 2050 hazard map, however, revealed that this data set was not used during the development of the 2050 map. In fact, the fit[2]

[1] The area derived by summing the early 1990 estimate area attributes is in the vicinity of 3,500 ha. For the 100 points that have no area attribute attached to them, we assume an area of 1 hectare. The Audit Theme 2 report says that the 48,000 ha estimate was derived from "field observations in the 1990s and workshop-based observations. p28"

[2] Only 84 of the 450 points (19%)lay within the 2050 map polygons. A further 34% (236-84) lay within 1 km and 410 are within 10 kilometres. Three points where over 50 kilometres away from a 2050 polygon.)

is very poor with only 19% of the "1990" points falling within the 2050 polygons.[3] Consequently, we decided to combine the two data sources and then develop a set of decision rules that would convert the result into hazard maps for 2000 and 2020. Our aim in doing this was to develop a map that would be as consistent as possible with the definitions of salinity used in Western Australia. For this to occur, the final set of polygons should have 50% of the area of each polygon in Dryland salinity classes II to V. That is one estimate of the area of high salinity hazard in 2000 for Queensland is 48,000/0.5= 96,000 hectares. Mismatch between the 2050 map and this map, however, plus the likely increase in area since the early 1990s suggests that this map be a conservative estimate.

An alternative technique is to assume that the rate of growth in salinity hazard in Queensland will be the same as that in NSW. After applying the area multipliers to the NSW data this produces data that suggests that the area in 2000 should be around (180,600*0.14)/(13,00,807*0.49)*100= 3.97% of the 2050 hazard area. As a result of combining the 2050 and early 1990s maps the total 2050 area is (3,117,189+17,439)=3,134,628 hectares. As illustrated in Figure 1, 3.97% of this number is -124,445 hectares.

Pragmatically and realising that we are working with very poor data sets, we choose the less conservative estimate and assume that the 2000 dryland salinity hazard area of Queensland is -124,445 hectares.

The next challenge is to use these data to prepare hazard maps for 2000 and 2020 so that we can model the extent to which salinity and infrastructure data sets interact. The rules that we used were as follows

1) All early 1990 point estimates were retained but grown by a factor of two to convert them into an estimate of "hazard" rather than "extent." Of the 450 points, 126 had no value for salt extent. These were assigned a default value of 1 ha of extent. The resultant area outside the 2050 hazard map was 17,439 hectares. So we assumed that the total area of salinity hazard in 2050 would be 3,117,189plus 17,439 = 3,134,628 hectares.

2) All 2050 polygons were then shrunk by 1,251.5 m[4] and all areas smaller than 5 hectares dropped out on the assumption that they would not be observable in 2000. The result is a 2000 map that has an area of 124,421 ha which is within 0.0002% of the target area.

The same NSW rate extrapolation technique was used to develop a 2020 hazard estimate. In 2020, the area of dryland salinity hazard was 9.31% of the 2050 area.[5] This produces a target dryland salinity hazard area of 290,210 hectares. Once again, all "early 1990" estimates were retained at their original size and all 2050 polygons reduced by 778m. Polygons, which reduced to less than 5 hectares in size, were

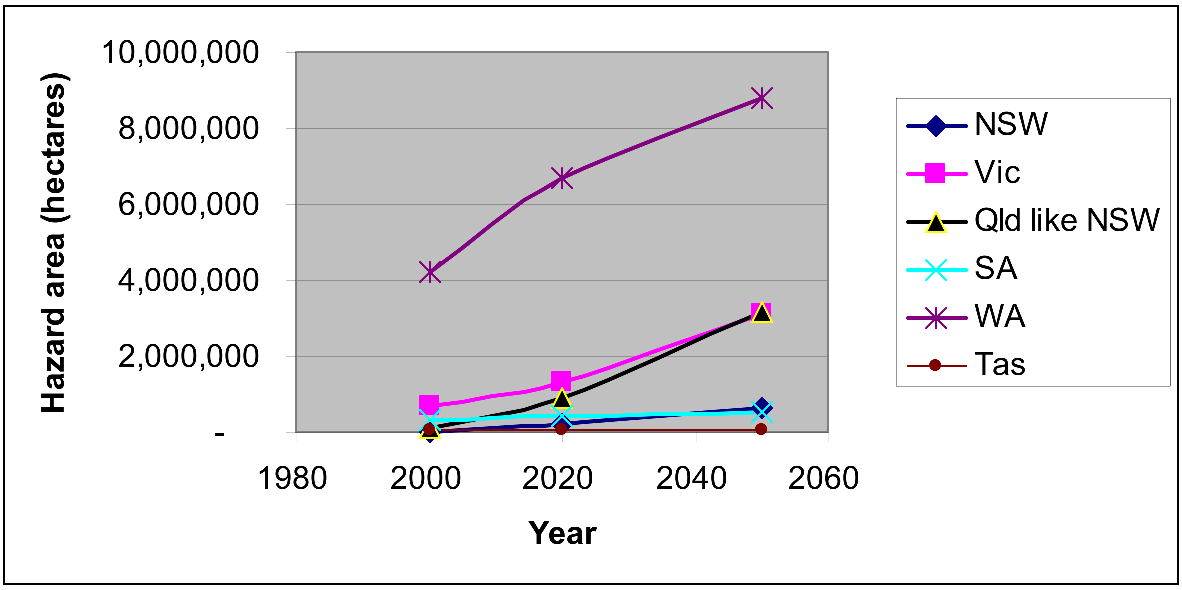
[3] Only 84 of the 450 points (19%)lay within the 2050 map polygons. A further 34% (236-84) lay within 1 km and 410 are within 10 kilometres. Three points where over 50 kilometres away from a 2050 polygon.)

[4] This was done iteratively until we obtained an area that was close to 124,445 hectares for 2000 .

[5] (185,352*0.32)/(13,00,807*0.49)*100 = 9.31%.

assumed not to exist in 2020.[6] The result is a 2020 map that has an area of 290,482 ha, which is within 0.0011% of the target area.

Figure 1 Hazard area estimates for each State with alternative estimates for Queensland derived by assuming that the rate of increase from 2000 to 2050 is that same as that for New South Wales



Having made these changes, the estimates of extent were then made using the Western Australian assumptions summarised in Table 4.

We caution that this process provides a very coarse estimate that is much less reliable than that available in other states. The approach, however, does allow people to overlay the resultant maps over maps of infrastructure, agricultural land use, etc and begin to derive indicative estimates of the likely extent of economic impacts of salinity over the next 20 years.

Victoria

Having inspected that data and read the reports describing these estimates we understand the definitions used to be consistent with definitions used in Western Australia in Table 4.

Tasmania

After preparation of the Theme 2 report on Dryland Salinity, Tasmania provided the Audit with a revised data set for this State. The revised data, however, has the same area multipliers. Applying them is the same way as described above for NSW produces salinity extent assumption tables for 2000, 2020 and 2050 that are consistent with the Western Australian definitions of hazard.

For 2000 the area multiplier is 0.83. This results in the assumptions summarised in Table 8.

6 This was done iteratively until we obtained an area that was close to 124,445 hectares for 2020.

Table 8 Tasmanian impact estimation rules used for all high hazard areas in 2000

Dryland Salinity Impact Class	Assumed proportion of each mapped polygon in each class		
	Low estimate	Best estimate	High estimate
I	83.4%	58.5%	46.1%
II	8.3%	16.6%	20.8%
III	4.2%	12.5%	16.6%
IV	3.3%	8.3%	8.3%
V	0.8%	4.2%	8.3%
Mean relative productivity for high hazard areas	95%	85%	80%

For 2020 the area multiplier is 1.09. This results in the assumptions summarised in Table 9.

Table 9 Tasmanian impact estimation rules used for all high hazard areas in 2020

Dryland Salinity Impact Class	Assumed proportion of each mapped polygon in each class		
	Low estimate	Best estimate	High estimate
I	78.2%	45.5%	29.2%
II	10.9%	21.8%	27.3%
III	5.5%	16.4%	21.8%
IV	4.4%	10.9%	10.9%
V	1.1%	5.5%	10.9%
Mean relative productivity for high hazard areas	93%	81%	74%

For 2050 the area multiplier is 1.47. This results in the assumptions summarised in Table 10.

Table 10 Tasmanian impact estimation rules used for all high hazard areas in 2050

Dryland Salinity Impact Class	Assumed proportion of each mapped polygon in each class		
	Low estimate	Best estimate	High estimate
I	70.6%	26.5%	4.5%
II	14.7%	29.4%	36.8%
III	7.4%	22.1%	29.4%
IV	5.9%	14.7%	14.7%
V	1.5%	7.4%	14.7%
Mean relative productivity for high hazard areas	91%	74%	65%

Northern Territory
No areas are mapped as high hazard in the Northern Territory and, hence, we assume that the economic impacts of dryland salinity on the economy of the Northern Territory now and in 2020 are negligible.

Summary
All definitions of extent are comparable across States and Territories although the spatial confidence attributable to the data varies considerable. The numbers we supply should only be used at the regional levels and not for local decision making without carefully reading the metadata that underpins these data sets and the assumptions made above.

A2 Metadata
Full metadata will be supplied with the final report at the same time that the data is delivered so that the two sources are 100% consistent.

APPENDIX C Sodicity Relative Yield Functions

The sodicity relative yield functions relate exchangeable sodium percentage (ESP), a measure of sodicity (see appendix D for how a sodicity map for Australia was produced) to relative yield in crops and pastures. Functions were developed by Pichu Rengasamy from the University of Adelaide for 28 representative crop/pasture types. These were linked to the 1996/97 land use map of Australia (see Appendix A). The sodicity relative yield functions are disjoint linear functions, with relative yield given at ESP values of 0, 5, 15, 30 and 50 for each crop/pasture type.

Land use types for which response curves were developed:

#	Land use	Indicative Crop
1	RESIDUAL	Native timber
2	AGROFORESTRY	Agro-forestry
3	PASTURE	Dryland & unimproved grazed by cattle or sheep
4	SOWN PASTURE	Irrigated lucerne grazed
5	SOWN PASTURE	Dryland clover
6	CEREALS	Wheat dryland
7	CEREALS	Wheat irrigated
8	RICE	Rice
9	LEGUMES	Soybeans
10	OILSEEDS	Canola
11	SUGAR CANE	Sugar cane
12	NON-CEREAL FORAGE CROPS	Hay
13	COTTON	Cotton
14	OTHER NON-CEREAL CROPS -	Hops (in Tas)
15	OTHER NON-CEREAL CROPS -	Turf (Close to cities)
16	OTHER NON-CEREAL CROPS -	Tobacco (in Vic))
17	OTHER VEGETABLES	Mixture of a typical farm
18	POTATOES	Potatoes
19	CITRUS	Oranges
20	APPLES	Apples
21	PEARS	Pears
22	STONE FRUIT	Apricots in southern irrigated areas
23	STONE FRUIT	Mangoes in tropics
24	NUTS	Macadamia
25	BERRY FRUIT	Strawberries
26	PLANTATION FRUIT	Bananas
27	GRAPES	Grapes (dryland)
28	GRAPES	Grapes (irrigated)

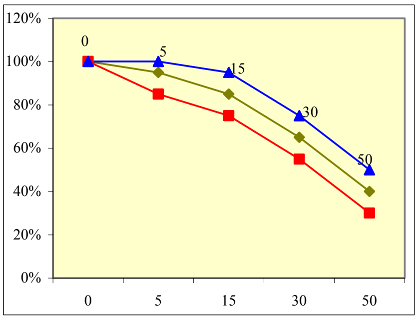
Residual-Native timber

Land Use	RESIDUAL
Indicative Crop	Native timber

Confidence Range	10%

ESP	Yr	b
0	100%	-0.0100
5	95%	-0.0100
15	85%	-0.0133
30	65%	-0.0125
50	40%	0.0080

Lower Yr	Upper Yr
100%	100%
85%	100%
75%	95%
55%	75%
30%	50%



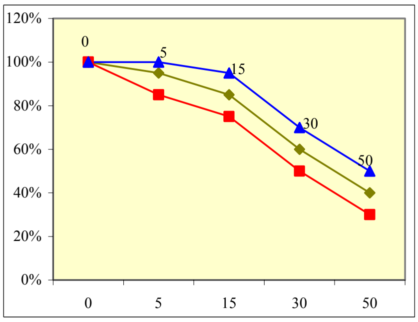
Agroforestry

Land Use	AGROFORESTRY
Indicative Crop	Agro-forestry

Confidence Range	10%

ESP	Yr	b
0	100%	-0.0100
5	95%	-0.0100
15	85%	-0.0167
30	60%	-0.0100
50	40%	0.0080

Lower Yr	Upper Yr
100%	100%
85%	100%
75%	95%
50%	70%
30%	50%



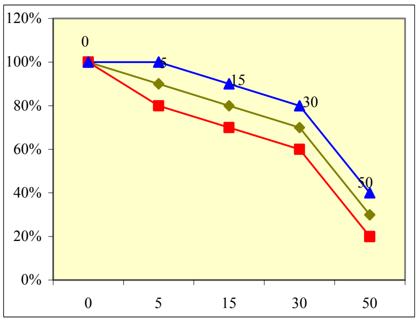
Pasture

Land Use	PASTURE
Indicative Crop	Dryland & unimproved grazed by cattle or sheep

Confidence Range	10%

ESP	Yr	b
0	100%	-0.0200
5	90%	-0.0100
15	80%	-0.0067
30	70%	-0.0200
50	30%	0.0060

Lower Yr	Upper Yr
100%	100%
80%	100%
70%	90%
60%	80%
20%	40%



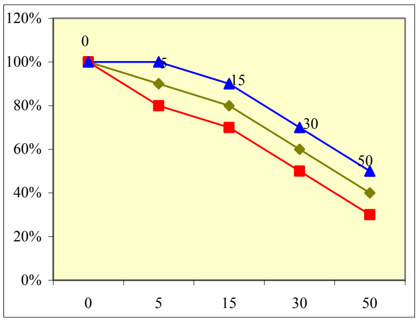
Sown Pasture-Lucerne

Land Use	SOWN PASTURE
Indicative Crop	Irrigated lucerne grazed by

Confidence Range	10%

ESP	Yr	b
0	100%	-0.0200
5	90%	-0.0100
15	80%	-0.0133
30	60%	-0.0100
50	40%	0.0080

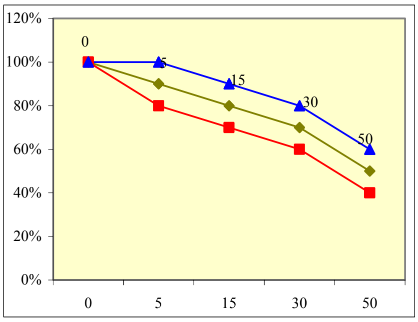
Lower Yr	Upper Yr
100%	100%
80%	100%
70%	90%
50%	70%
30%	50%



Sown Pasture-Dryland Clover

Land Use	SOWN PASTURE
Indicative Crop	Dryland clover
Confidence Range	10%

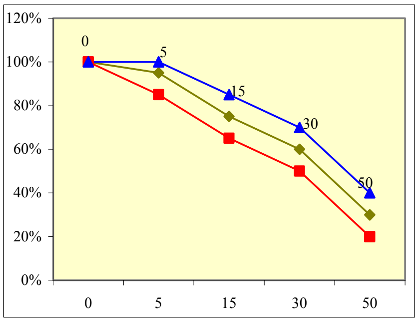
ESP	Yr	b	Lower Yr	Upper Yr
0	100%	-0.0200	100%	100%
5	90%	-0.0100	80%	100%
15	80%	-0.0067	70%	90%
30	70%	-0.0100	60%	80%
50	50%	0.0100	40%	60%



Cereals-Wheat Dryland

Land Use	CEREALS
Indicative Crop	Wheat dryland
Confidence Range	10%

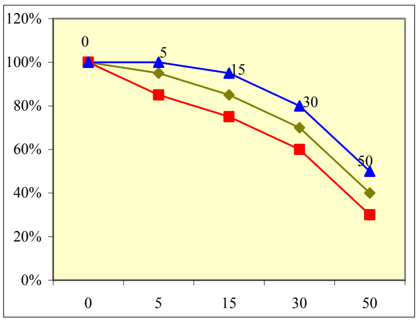
ESP	Yr	b	Lower Yr	Upper Yr
0	100%	-0.0100	100%	100%
5	95%	-0.0200	85%	100%
15	75%	-0.0100	65%	85%
30	60%	-0.0150	50%	70%
50	30%	0.0060	20%	40%



Cereals-Wheat irrigated

Land Use	CEREALS
Indicative Crop	Wheat irrigated
Confidence Range	10%

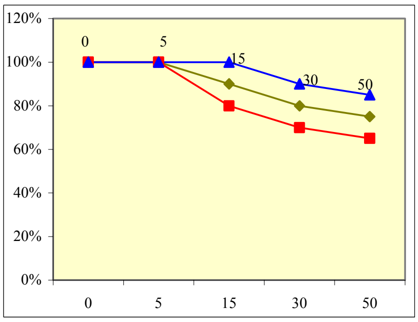
ESP	Yr	b	Lower Yr	Upper Yr
0	100%	-0.0100	100%	100%
5	95%	-0.0100	85%	100%
15	85%	-0.0100	75%	95%
30	70%	-0.0150	60%	80%
50	40%	0.0080	30%	50%



Rice

Land Use	RICE
Indicative Crop	Rice
Confidence Range	10%

ESP	Yr	b	Lower Yr	Upper Yr
0	100%	0.0000	100%	100%
5	100%	-0.0100	100%	100%
15	90%	-0.0067	80%	100%
30	80%	-0.0025	70%	90%
50	75%	0.0150	65%	85%



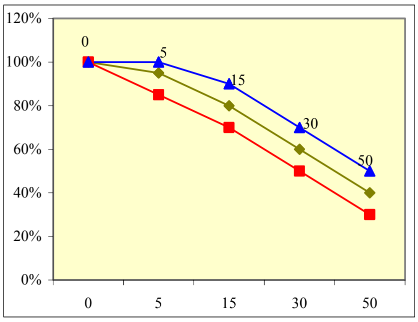
Legumes

Land Use	LEGUMES
Indicative Crop	Soybeans

Confidence Range	10%

ESP	Yr	b
0	100%	-0.0100
5	95%	-0.0150
15	80%	-0.0133
30	60%	-0.0100
50	40%	0.0080

Lower Yr	Upper Yr
100%	100%
85%	100%
70%	90%
50%	70%
30%	50%



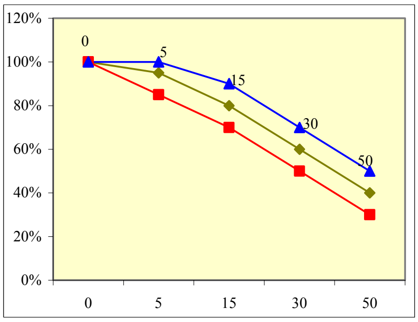
Oilseeds

Land Use	OILSEEDS
Indicative Crop	Canola

Confidence Range	10%

ESP	Yr	b
0	100%	-0.0100
5	95%	-0.0150
15	80%	-0.0133
30	60%	-0.0100
50	40%	0.0080

Lower Yr	Upper Yr
100%	100%
85%	100%
70%	90%
50%	70%
30%	50%



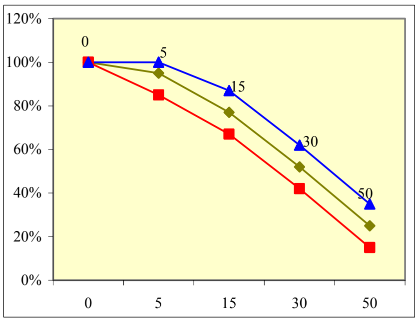
Sugar Cane

Land Use	SUGAR CANE
Indicative Crop	Sugar cane

Confidence Range	10%

ESP	Yr	b
0	100%	-0.0100
5	95%	-0.0180
15	77%	-0.0167
30	52%	-0.0135
50	25%	0.0050

Lower Yr	Upper Yr
100%	100%
85%	100%
67%	87%
42%	62%
15%	35%



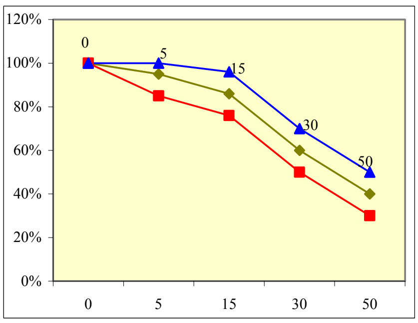
Non Cereal Forage Crops

Land Use	NON-CEREAL FORAGE CROPS
Indicative Crop	Hay

Confidence Range	10%

ESP	Yr	b
0	100%	-0.0100
5	95%	-0.0090
15	86%	-0.0173
30	60%	-0.0100
50	40%	0.0080

Lower Yr	Upper Yr
100%	100%
85%	100%
76%	96%
50%	70%
30%	50%

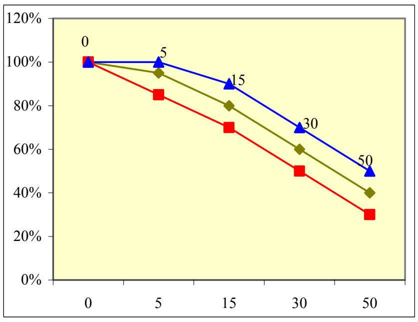


Cotton

Land Use	COTTON
Indicative Crop	Cotton

Confidence Range	10%

ESP	Yr	b	Lower Yr	Upper Yr
0	100%	-0.0100	100%	100%
5	95%	-0.0150	85%	100%
15	80%	-0.0133	70%	90%
30	60%	-0.0100	50%	70%
50	40%	0.0080	30%	50%

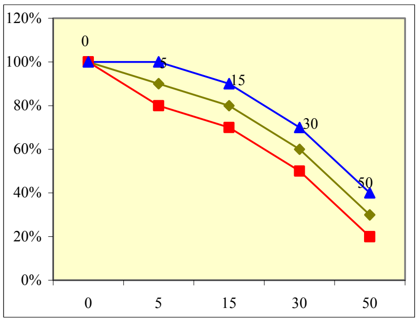


Other Non Cereal Crops-Hops

Land Use	OTHER NON-CEREAL CROPS -
Indicative Crop	Hops (in Tas)

Confidence Range	10%

ESP	Yr	b	Lower Yr	Upper Yr
0	100%	-0.0200	100%	100%
5	90%	-0.0100	80%	100%
15	80%	-0.0133	70%	90%
30	60%	-0.0150	50%	70%
50	30%	0.0060	20%	40%

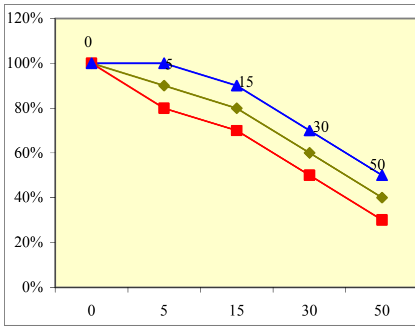


Other Non Cereal Crops-Turf

Land Use	OTHER NON-CEREAL CROPS -
Indicative Crop	Turf (Close to cities)

Confidence Range	10%

ESP	Yr	b	Lower Yr	Upper Yr
0	100%	-0.0200	100%	100%
5	90%	-0.0100	80%	100%
15	80%	-0.0133	70%	90%
30	60%	-0.0100	50%	70%
50	40%	0.0080	30%	50%

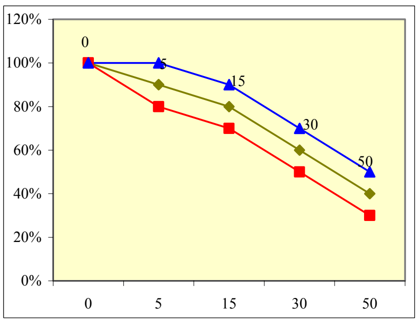


Other Non Cereal Crops-Tobacco

Land Use	OTHER NON-CEREAL CROPS -
Indicative Crop	Tobacco (in Vic))

Confidence Range	10%

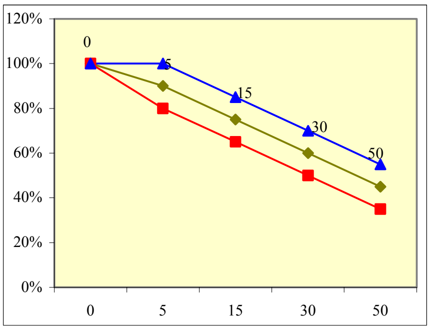
ESP	Yr	b	Lower Yr	Upper Yr
0	100%	-0.0200	100%	100%
5	90%	-0.0100	80%	100%
15	80%	-0.0133	70%	90%
30	60%	-0.0100	50%	70%
50	40%	0.0080	30%	50%



Other Vegetables

Land Use	OTHER VEGETABLES
Indicative Crop	Mixture of a typical farm
Confidence Range	10%

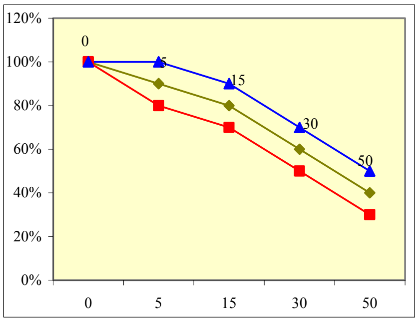
ESP	Yr	b	Lower Yr	Upper Yr
0	100%	-0.0200	100%	100%
5	90%	-0.0150	80%	100%
15	75%	-0.0100	65%	85%
30	60%	-0.0075	50%	70%
50	45%	0.0090	35%	55%



Potatoes

Land Use	POTATOES
Indicative Crop	Potatoes
Confidence Range	10%

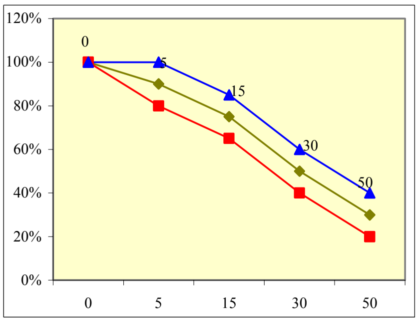
ESP	Yr	b	Lower Yr	Upper Yr
0	100%	-0.0200	100%	100%
5	90%	-0.0100	80%	100%
15	80%	-0.0133	70%	90%
30	60%	-0.0100	50%	70%
50	40%	0.0080	30%	50%



Oranges

Land Use	CITRUS
Indicative Crop	Oranges
Confidence Range	10%

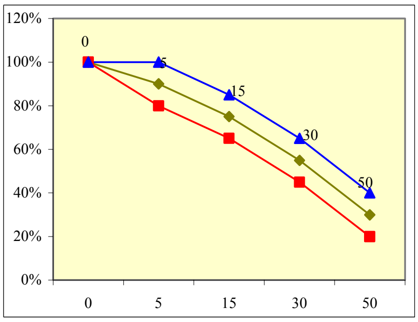
ESP	Yr	b	Lower Yr	Upper Yr
0	100%	-0.0200	100%	100%
5	90%	-0.0150	80%	100%
15	75%	-0.0167	65%	85%
30	50%	-0.0100	40%	60%
50	30%	0.0060	20%	40%



Apples

Land Use	APPLES
Indicative Crop	Apples
Confidence Range	10%

ESP	Yr	b	Lower Yr	Upper Yr
0	100%	-0.0200	100%	100%
5	90%	-0.0150	80%	100%
15	75%	-0.0133	65%	85%
30	55%	-0.0125	45%	65%
50	30%	0.0060	20%	40%



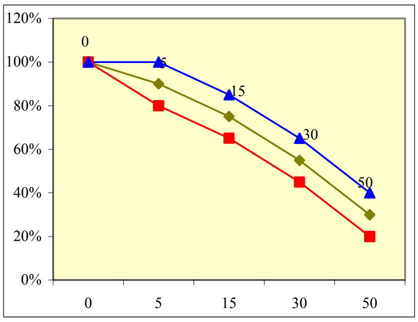
Pears

Land Use	PEARS
Indicative Crop	Pears

Confidence Range	10%

ESP	Yr	b
0	100%	-0.0200
5	90%	-0.0150
15	75%	-0.0133
30	55%	-0.0125
50	30%	0.0060

Lower Yr	Upper Yr
100%	100%
80%	100%
65%	85%
45%	65%
20%	40%



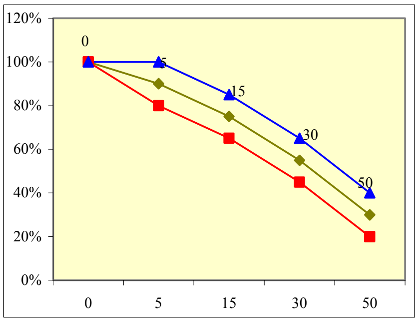
Stonefruit-Apricots

Land Use	STONE FRUIT
Indicative Crop	Apricots in southern irrigated areas

Confidence Range	10%

ESP	Yr	b
0	100%	-0.0200
5	90%	-0.0150
15	75%	-0.0133
30	55%	-0.0125
50	30%	0.0060

Lower Yr	Upper Yr
100%	100%
80%	100%
65%	85%
45%	65%
20%	40%



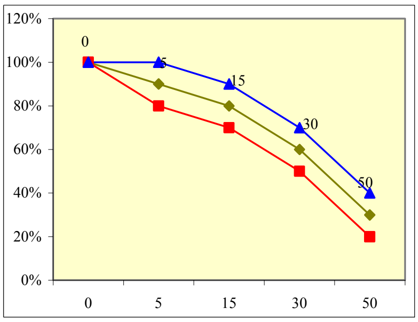
Stonefruit-Mangoes

Land Use	STONE FRUIT
Indicative Crop	Mangoes in tropics

Confidence Range	10%

ESP	Yr	b
0	100%	-0.0200
5	90%	-0.0100
15	80%	-0.0133
30	60%	-0.0150
50	30%	0.0060

Lower Yr	Upper Yr
100%	100%
80%	100%
70%	90%
50%	70%
20%	40%



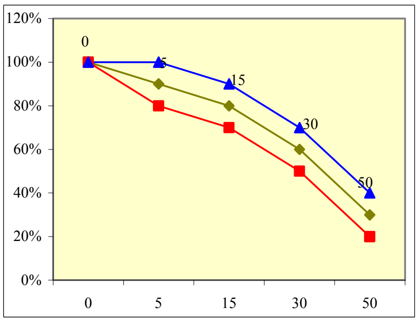
Nuts

Land Use	NUTS
Indicative Crop	Macadamia

Confidence Range	10%

ESP	Yr	b
0	100%	-0.0200
5	90%	-0.0100
15	80%	-0.0133
30	60%	-0.0150
50	30%	0.0060

Lower Yr	Upper Yr
100%	100%
80%	100%
70%	90%
50%	70%
20%	40%



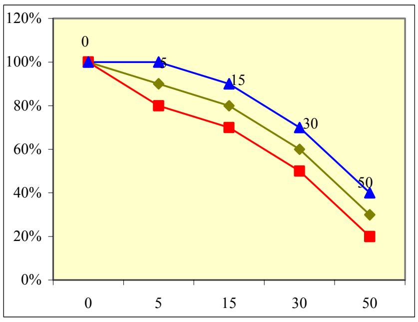
Berry Fruit

Land Use	BERRY FRUIT
Indicative Crop	Strawberries

Confidence Range	10%

ESP	Yr	b
0	100%	-0.0200
5	90%	-0.0100
15	80%	-0.0133
30	60%	-0.0150
50	30%	0.0060

Lower Yr	Upper Yr
100%	100%
80%	100%
70%	90%
50%	70%
20%	40%



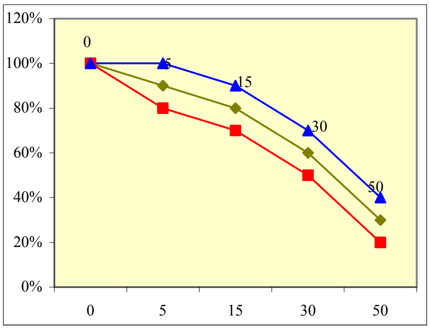
Bananas

Land Use	PLANTATION FRUIT
Indicative Crop	Bananas

Confidence Range	10%

ESP	Yr	b
0	100%	-0.0200
5	90%	-0.0100
15	80%	-0.0133
30	60%	-0.0150
50	30%	0.0060

Lower Yr	Upper Yr
100%	100%
80%	100%
70%	90%
50%	70%
20%	40%



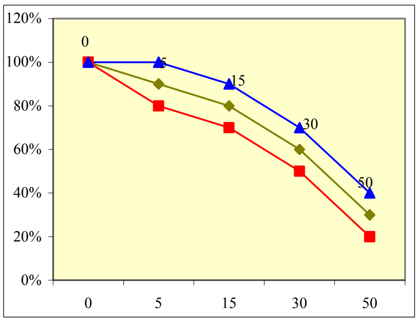
Grapes-Dryland

Land Use	GRAPES
Indicative Crop	Grapes (dryland)

Confidence Range	10%

ESP	Yr	b
0	100%	-0.0200
5	90%	-0.0100
15	80%	-0.0133
30	60%	-0.0150
50	30%	0.0060

Lower Yr	Upper Yr
100%	100%
80%	100%
70%	90%
50%	70%
20%	40%



Grapes-Irrigated

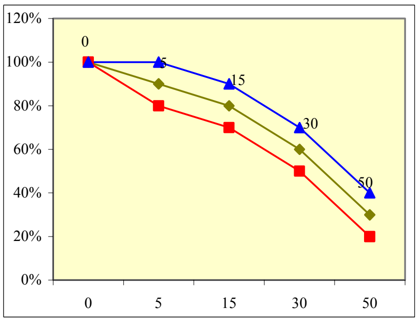
Land Use	GRAPES
Indicative Crop	Grapes (irrigated)

Confidence Range	10%

0.96

ESP	Yr	b
0	100%	-0.0200
5	90%	-0.0100
15	80%	-0.0133
30	60%	-0.0150
50	30%	0.0060

Lower Yr	Upper Yr
100%	100%
80%	100%
70%	90%
50%	70%
20%	40%



APPENDIX D Methodology for Developing a National Sodicity Surface

This appendix describes how a national surface of exchangeable sodium percentage, a measure of soil sodicity, was developed from existing data sets. It has been written and prepared by Graeme Watmuff of the Spatial Technologies Unit of CSIRO Land and Water.

GIS Methodology

Since actual soil ESP determinations were virtually only available for eastern and central Australia, not Western Australia, a separate approach was taken in each of these regions to produce a national sodicity (ESP) map.

Eastern Australia

ESP determinations for the top 15cm of soils were geo-referenced mainly to the town address of the farmer. In South Australia, however, about half the soil samples were more precisely located at cadastral Hundred or Section centroids. Some grid referenced samples (approx. 1:100,000 scale) came from Tasmania and the MIA in southern NSW.

The total number of samples was 109,226 and these were geo-referenced to 3,816 map points. Breakdown of map points by state is as follows:

ACT/NSW	1030
Victoria	1449
South Australia	681
Queensland	421
Tasmania	221
Northern Territory	9

The mean ESP was calculated for each map point and these were then used as the basis for an interpolated floating point grid surface for ESP. However some map points were too sparsely scattered to make a continuous grid interpolation meaningful for all points. Therefore theissen polygons were generated around each map point. The theissen polygons less than or equal to an area approximately equivalent to that of a 25 km radius circle were then selected and used to create a maximum extent (clipping polygon) for continuous grid interpolation of ESP. Where a map point fell outside the extent defined by the smaller theissen polygons, grid interpolation was limited to a buffer zone of radius 25km about that point.

A further geographic restriction was applied by clipping the above defined grid extent to areas of soil that had been defined as sodic in the Atlas of Australian Soils (Northcote, K.H. and Skene, J.K.M., 1972).

The ESP grid interpolation was then a two-step process: a TIN (Triangulated Irregular Network) surface of the map point ESP mean values was first generated, clipped to the above-defined extent. The TIN was then converted to a floating point grid (espsodgrd1) which became the ESP grid surface for eastern and central Australia.

Western Australia

The sodicity classification for the Atlas of Australian Soils (Northcote, K.H. and Skene, J.K.M., 1972) was used as the basis for constructing an ESP grid across the intensive land use zone of Western Australia. The sodicity classification is represented in the Atlas by a coded value between 2 and 7 inclusive. Values 2, 3 and 4 represent alkaline sodic soils. Values 5 and 6 represent non-alkaline sodic soils.

Mean ESP values for each these 5 sodicity classes were estimated by overlaying the ESP grid for eastern and central Australia on the sodic soil polygons selected from the Atlas of Australian Soils, using the 'summarize zones' functionality provided by ESRI's ArcView Spatial Analyst extension. The resultant estimates for each class are given in the table below:

Sodicity Class	**Mean ESP**
2	4.3278
3	2.6361
4	4.2780
5	3.1959
6	3.0292

These mean ESP values were then attached as attributes to the sodic soil polygons of the Atlas of Australian soils that fall within the Western Australian intensive land use zone by means of a table join. The intensive land use zone boundary for WA is the same as that used for the soil surfaces generated in NLWR Audit theme5.4D. The polygons were then converted to a floating point grid theme (espsodgrd_wa) for ESP.

National ESP Grid

The eastern and central Australian grid (espsodgrd1) was merged with the Western Australian grid (espsodgrd_wa) to generate the final national ESP grid, nat_ESP. Where albeit slight overlap between the two grids occurred, the WA grid values were given preference.

Data sources:

1. Geo-referenced ESP determinations for the top 15cm of eastern and central Australian soils tabulated from fertilizer company and government databases for the 2000 National Land and Water Resources Audit by Spatial Technologies Unit, CSIRO Land and Water, Adelaide.

2. Sodicity classification of soil type from the Atlas of Australian Soils (Northcote, K.H. and Skene, J.K.M., 1972).

Reference

Northcote, K.H. and Skene, J.K.M. (1972), Australian Soils with saline and sodic properties, CSIRO Soil Publication No. 27.

APPENDIX E Report on Downstream Impact Costs Caused by Salinity

National Land and Water Resources Audit

Ex-situ Costs of Australian Land and Water Resources Degradation to non-Agricultural Industries, Infrastructure and Households

REPORT A: EX-SITU COSTS OF SALINITY

By

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The Resource Economics Unit

&

D.C Cruickshanks-Boyd

PPK Environment & Infrastructure Pty Ltd

March 2001

This report is provided to CSIRO Land and Water by the Resource Economics Unit under contract Folio Number 00/105 STR/91, and provides the Indicative Economic Assessment for sub-project 6.1.3 of the National Land and Water Resources Audit, Theme 6, Project 1.

GLOSSARY OF TERMS AND CONVERSIONS

Amortisation	Conversion of a lump sum to an annual value at a given discount rate.
Control cost	Costs incurred by government, individuals, industries, or infrastructure providers to control or improve the condition of the natural resource.
Damage cost	Costs incurred by industries, infrastructure providers or households, as a result of the degradation of the natural resource: these costs are divided into (a) recurrent damage costs in the form of loss of income from impaired economic activity, additional repair or maintenance expenditure, reduced service life of capital items, and (b) non-recurrent investment costs on such items as replacement source development or desalination plants.
Discount rate	The rate of time preference for real income: for risky projects the discount rate is taken as the average real rate of return on capital in the private sector, of about 7%; for riskless projects a lower rate, of 4%/year has been assumed.
EC Units	Electrical conductivity units, μSm^{-1}, a measure of water salinity: equals approximately 1.6 times TDS.
Salinity of water	Four quality classifications are used: • Fresh (TDS < 500 mgL^{-1}) • Marginal (TDS 500 to 1,500 mgL^{-1}) • Brackish (TDS 1,500 to 5,000 mgL^{-1}) • Saline (TDS >5,000 mgL^{-1}).
TDS	Total dissolved solids in a water sample, in mgL^{-1}: equals approximately 0.625 EC Units.
TFS	Total Filterable Solids
TSS	Total soluble salts in a water sample, in mgL^{-1}: a "true" measure of salinity, but in practice this measure is very similar in value to TDS; TSS is not used in this report.

ACKNOWLEDGEMENTS

We would like to acknowledge the work of GHD (1999), which provided a wealth of information that has been used within this report, sometimes in conjunction with extra data and some modification. The advice and assistance of Mr Rod Burton and Mr Laslo Kosca on the impacts of salinity on the WA Water Corporation is gratefully acknowledged. Mr Alan Stevenson of the WA Ministry for Housing provided advice and assistance with data on plumbing replacement rates for Homeswest (WA). We thank all the local authorities, listed in Appendix III, who completed a questionnaire. Vic Roads and Transport SA also provided valuable information. Notwithstanding the above, the authors take complete responsibility for the estimates and judgements within this report.

EXECUTIVE SUMMARY

Ex1. Overview

Theme 6 of the National Land and Water Resources Audit is titled "Capacity for Change". Project 6.1 addresses economic dimensions of resource degradation. Projects 6.1.1 and 6.1.2 are concerned with agricultural impacts and Project 6.1.3 is concerned with the impacts on non-agricultural industries, infrastructure and households. Finally, Project 6.1.4 provides estimates for recreational and ecosystem values.

Within Project 6.1.3 the work was divided into two streams: (a) Dames and Moore (now Urscorp Australia) dealt with *in situ* effects, while (b) Resource Economics Unit (REU) and PPK Environment & Infrastructure (PPK) dealt with *ex-situ* aspects. Dames & Moore also took responsibility for impacts on tourist industries, whether *in-situ* or *ex-situ* in nature.

This report presents standardised cost functions summarising the "*ex situ*" impacts of land and water salinity on non-agricultural industries and households. For the purposes of the report *ex situ* impacts have been defined as phenomena that occur away from the original site of degradation, by processes of water transfer. Note that the impacts of rising groundwater tables (saline and fresh) on infrastructure are excluded, and are treated in the report on *in situ* impacts by Urscorp Australia.

Ex.2 Summary

Marginal recurrent damage cost functions with respect to changes in TDS have been developed for (i) households, (ii) manufacturing and processing industry, and (iii) commercial and service activities. These are presented in Table 11 and discussed in the following summaries. The recommended marginal recurrent cost function for situations where hardness is not related to salinity is summarised in Table 11.

Table 11 Recurrent marginal damage costs for urban and industrial water users with no allowance for any hardness that may be associated with salinity in a water supply.

Demand Sector	Sectoral Marginal Damage Costs ($/kL/year) T = mgL^{-1} TDS	Typical proportional weighting	Weighted Marginal Damage Cost ($/kL/year) T = mgL^{-1} TDS
Households	0.001147T	.60	0.000688T
Industry	0.005478T	.30	0.001643T
Commerce	0.002370T	.10	0.000237T
Total recurrent costs		1.00	0.002569T

Where possible, unweighted damage costs shown in Column 2 should be calculated for the individual demand sectors, but the total recurrent (weighted) cost in Column 4 may be used as a default value. The proportional weights, given in Table 11 are based on water use estimates for South Australia (Australian Bureau of Statistics, 2000). This State is the biggest receptor of salinity from a single source, namely the Murray-Darling system.

In some cases damage costs may be avoided by making non-recurrent investments. For example, a water supply authority may source water through a different, less-saline system, as has occurred in Western Australia. In such cases the recurrent cost should be adjusted.

Where an increase in TDS will also lead to an increase in the hardness of a water supply, the separate cost of hardness should also be included. The lower Murray-Darling system is such a case. Table 12 gives adjustment factors based on Murray-Darling data, using the approximation that hardness = 0.3TDS.

Table 12 Adjustment of marginal damage functions for hardness-related costs in the lower Murray-Darling system

Sector	Sectoral Marginal Damage Costs ($/kL/year) T = mgL^{-1} TDS	Hardness Adjustment Factor on the T Coefficient	Marginal Damage Cost for Salinity and Hardness ($/kL/year) T = mgL^{-1} TDS	Weights	Weighted Marginal Damage Cost for Salinity and Hardness ($/kL/year) T = mgL^{-1} TDS
Households	0.001147T	1.316	0.001509T	0.6	0.000905T
Industry	0.005478T	Nil	0.005478T	0.3	0.001643T
Commerce	0.002370T	nil	0.002370T	0.1	0.000237T
Total				1.0	0.002786T

While an exact comparison cannot be made, due to our lack of access to the river system model used in GHD (1999), the estimates presented here are considerably higher than those given in GHD (1999). This is illustrated in Table 13, using provisional estimates of the use of water supplied from Morgan (Reach 20 in GHD, 1999). This study concludes that the marginal cost of salinity and related hardness costs to urban and industrial users from water drawn from the River Murray at

Table 13 Calculation of marginal damage per EC Unit in water supplied for urban and industrial purposes from Morgan on the Murray River, (includes hardness factor).

Demand Sector	Estimated Water Use from Reach 20 (kL/yr)	Marginal Cost of Salinity and Associated Hardness ($/kL/year) T = mgL^{-1} TDS = 0.625 EC	REU Marginal Cost of Salinity and Associated Hardness ($/yr/EC Unit)	Using GHD (1999) Functions without truncation(1)
Households	$118*10^6$	0.000943EC	111,270	27,513
Industrial	$16*10^6$	0.003424EC	54,780	21,800
Commercial	$5*10^6$	0.001481EC	7,400	0
Total			173,450	49,313

Note (1) GHD (1999) assume no costs above a salinity level of around 250 mgL-1 for some uses, but this "truncation" has been ignored in the calculations presented in the table.

Morgan are of the order of $173,000/yr/EC Unit, compared to approximately $50,000/EC Unit in GHD (1999). The largest part of this difference occurs in the domestic households sector and results from differences in the cost function derived by REU for plumbing items, and the use of economic amortisation formulae rather than straight-line depreciation. The PPK estimates for industry and commerce were also significantly higher than the GHD (1999) estimates (see below).

Ex.3 Domestic Sector

Salinity cost functions for the domestic sector are summarised in Table 14. The marginal damage function for domestic items of $0.281/household/year/ mgL^{-1} increase in TDS, is approximately double that developed by GHD (1999). This is despite the fact that the REU estimates are essentially a re-working of the GHD data set based on economic amortisation and some new Western Australian data for plumbing items. Two items dominate the domestic costs of salinity according to both the GHD and REU estimates, namely domestic plumbing items (43%) and water heaters (31%). The main difference between the two sets of estimates is in respect of rainwater tanks, found to be significant by GHD, where amortisation produces a much higher annualised cost than straight-line depreciation.

Table 14 Recommended cost functions for domestic impacts of salinity, excluding any associated hardness costs

Item	GHD (1999) Marginal Damage Cost (a: $/household/ year) T> 250 mgL^{-1} TDS	REU (2001) Marginal Damage Cost (a: $/household/ year) T= mgL^{-1} TDS)	REU (2001) Marginal Damage Cost (b: $/kL/year) T = mgL^{-1} TDS)	REU Percent of Marginal Damages (%)
Soaps & detergents	Nil	Nil	Nil	0
Domestic plumbing	0.064T	0.121T	0.000494T	43.1
Hot water systems:	0.061T	0.086T	0.000351T	30.6
Bottled water	Nil	Nil	Nil	0
Domestic filters	0.009T	0.009T	0.000037T	3.2
Rain water tanks	0.005T	0.065T	0.000265	23.1
Water softeners	Nil	Nil	Nil	0
Total	0.138T	0.281T	0.001147T	100.0

A comparison of the REU results with calculations based on Tihansky (1974) and AMDEL (1982) is shown in Table 15. A number of household items, which were found to be significant in the literature, were judged by GHD and accepted by REU to be insignificant or not investigated. Expenditure on soaps and detergents and purchases of bottled water were judged to be insignificant, while fabrics, washing machines, cooking utensils, and garbage grinders, which contribute significantly to Tihansky's damage functions, were not investigated. In addition, a number of water-contacting domestic items, which have become common since Tihansky (1974), were not considered by GHD: for example, dishwashers and coffee machines. Car radiators and engines were not investigated in the literature or by GHD: while special coolant mixtures are standard for new motor vehicles, these are not universally used. On the other hand, expenditure on water softeners, which according to GHD is significantly affected by salinity, was thought by Tihansky (1974) to be entirely related to water hardness.

Table 15 Percentage of total marginal damages due to each item: REU compared with GHD (1999), Tihansky (1974) and AMDEL (1982)

Item	REU (%)	GHD (%)	Tihansky (%)	AMDEL (%)
Soaps & detergents	0	0	5	51
Domestic plumbing	43	55	38	33
Hot water systems:	31	35	17	13
Bottled water	0	0	11	0
Domestic filters	3	6	0	0
Rain water tanks	23	4	0	0
Water softeners	0	0	0	3
Washing machines	0	0	11	0
Fabrics	0	0	13	0
Other	0	0	5	0
Total domestic costs	100	100	100	100

The AMDEL (1982) estimates were heavily influenced by their estimate of the effect of salinity on purchases of soaps and detergents. Both GHD and Tihansky considered a larger range of other items than AMDEL, but there was a complete miss-match comparing the "other items" in Tihansky (bottled water, washing machines, fabrics, and other) with those in GHD (domestic filters, rain water tanks, and water softeners)

Ex.4 Industrial and Commercial Sectors

Previous studies of the costs of salinity to water users (Cruickshanks-Boyd, 1983 and GHD, 1999) have been updated by PPK Environment & Infrastructure Pty Ltd, and are reported in full in a separate document (PPK Environment & Infrastructure, 2001). New cost functions have been developed, expressed as costs per kL of water used per year. These cost functions are given in Table 16

Table 16 Summary of industrial and commercial damage cost functions

Purpose of Water Use	Proportion of industrial water use based on Adelaide)	GHD (1999) Individual Use marginal damage cost ($/kL/year) T = TDS (mg/L)	PPK (2001) Individual Use marginal damage cost ($/kL/year) T = TDS (mg/L)	GHD (1999) Weighted	PPK (2001) Weighted
General (e.g. washing, cleaning, site maintenance)	0.50	0.0003T	0.0003T	0.00015T	0.00015T
Cooling towers	0.13	0.0009T	0.0096T	0.00012T	0.00115T
Boiler feed water	0.23	0.0049T	0.0162T	0.00113T	0.00373T
Process water	0.14	0.0056T	0.0030T	0.00078T	0.00045T
Total	1.00			0.00218T	0.00548T

The marginal damage costs presented above for industrial water users are much higher than those estimated in GHD (1999): by a factor of 10 for cooling towers, and a factor of 4 for boiler feed water. These results are obtained primarily because:

PPK assumed a higher cost rate for supplied water: 92c/kL compared with 40c/kL in GHD(1999),

PPK considered likely differences in salinity abatement strategies for boiler water as between small, medium and large industries. The GHD study assumed that all industries would use capital-intensive reverse osmosis water treatment technology above a salinity level of 265 mg/L TDS (for which the operational costs are largely independent of salinity). In practice, many small and medium size industries have not, and are unlikely to, install reverse osmosis water treatment technology due to the capital cost.

PPK assumed a blowdown salinity of 2000 mg/L for cooling tower operation, which we believe is more representative of industry practice than the figure of 2500 mg/L used by GHD.

Ex.5 Service Sector

A review has been made of water use patterns within service sector activities, to determine which water uses within the sector could face industrial-type damage costs, from uses in boilers, cooling towers etc.

In the case of commercial water users (eg. offices, shopping centres, hotels, hospitals, public buildings) the cost function derived in the current study (refer Table 11) is similar to that derived by GHD (1999). Discussions with energy providers have suggested that salinity is not a cost issue for hydroelectric schemes. A sample survey of local councils indicated that, while salinity is having a significant impact, this is confined to *in-situ* infrastructure impacts. *Ex-situ* impacts on local government are not significant.

Ex.6 Water Utilities

A detailed case study was conducted on the cost impacts of salinity on the Western Australian Water Corporation. It has found that, while the utility is in many respects protected from increasing salinity, due to its forested catchments and groundwater reserves, nevertheless:

- increased costs have been incurred for additional source development following salinisation of one large surface reservoir: estimated at $0.53/household served /year/mg/l change in TDS (alternatively, $0.00177/year/kL supplied/ mg/l change in TDS)
- increased catchment management costs are being incurred
- higher costs of water treatment will be experienced in future because new diversions of brackish or saline surface water will require desalination: estimated at $0.025/household/year/mg/l change in TDS for the particular catchment (alternatively, $0.000083/year/kL supplied/ mg/l change in TDS).

Water utilities in other salt-affected regions, such as the Loddon-Campaspe catchment in Victoria, reported only minor cost implications from salinity, because of their capacity to withdraw fresh water for urban supply from major irrigation channels. GHD (1999) concluded that salinity had no measurable cost impacts on water utilities that withdraw water from the Murray Valley (Murray-Darling Basin).

In regions constructing replacement infrastructure or desalinating their water supply as a result of salinity an additional $0.1/household/year/mg/L TDS should be allowed as an indicative estimate (alternatively, $0.000333/year/kL supplied/ mg/l change in TDS). However, it is recommended that, where possible, information on specific catchments should be used rather than a standardised function.

Table 17 Comparison of marginal cost functions (no adjustment for hardness)

Cost Area	REU-PPK Marginal Cost Function T=TDS mgL^{-1}	GHD (1999) Marginal Cost Function T=TDS mgL^{-1}
Households (y = $/household/yr):		
Plumbing corrosion	0.12100T	0.01400T (T<262)
		0.06400T (T>262)
Hot water systems:		
Cylinders		0.03100T
Electric elements		0.02600T
Relief valves		0.00410T
Total hot water system	*0.08600T*	*0.06110T*
Domestic filters	0.00875T	0.00875T
Rainwater tanks	0.06500T	0.00450T
Domestic water softeners	Nil	Nil
Bottled water consumption	Nil	Nil
Industry (y = $/kL):		
General Use	0.0003T	0.0003T
Cooling tower operation	0.0096T	0.0009T
Boiler operation	0.0162T	0.0049T (T<250)
		Nil (T> 250)
Process water treatment	0.0030T	0.0056T (T<250)
		Nil (250<T<1000)
Commercial and Services (y = $/kL)		
All activities	0.00237T	Nil

Table 18 Comparison of cost functions (with adjustment for hardness-related cost)

Cost Area	REU-PPK Marginal Cost Function T=TDS mgL^{-1}	GHD (1999) Marginal Cost Function T=TDS mgL^{-1}
Households (y = $/household/yr):		
Plumbing corrosion	0.1592T	0.02T (T<262)
		0.081T (T>262)
Hot water systems:		
Cylinders		0.05100T
Electric elements		0.04280T
Relief valves		0.00680T
Total hot water system	*0.11318T*	*0.10060T*
Domestic filters	0.01152T	0.00875T
Rainwater tanks	0.08554T	0.00450T
Domestic water softeners	0.04800T	0.04800T
Bottled water consumption		Nil
Industry (y = $/kL):	**0.0003T**	**0.0003T**
General Use	0.0096T	0.0009T
Cooling tower operation	0.0162T	0.0049T (T<250)
		Nil (T> 250)
Boiler operation	0.0030T	0.0056T (T<250)
		Nil (250<T<1000)
Process water treatment		
Commercial and Services (y = $/kL)	**0.0024T**	**Nil**
All activities	0.0003T	Nil

INTRODUCTION

1.1 Requirements of the Brief

The CSIRO, as the main contractor to the National Land and Water Resources Audit for Theme 6 Project 1, requires estimates of standardised cost functions expressing the cost of salinity to non-agricultural industries, infrastructure and households. CSIRO has planned to use the standardised cost functions in conjunction with estimates of current and future resource condition to generate estimates of current and future total and marginal cost.

The general form of a standardised salinity cost function is:

$$C/U = f(T)$$

Where:

C	=	total cost in year 2000 Australian dollars ($) incurred in respect of any item that is affected by salinity
U	=	**the denominator for unit costs (e.g. number households, employees, total water used)**
T	=	the TDS of water supplied

Marginal costs are calculated as the difference in total costs for different levels of salinity. Four main groups bear damages from raised salinity of water supplies:

- Irrigated agriculture: Crop yield reductions, increased water use and irrigated soil salinisation
- Households: Increased repair and maintenance costs for plumbing and water-contacting items, substitution of equipment of water sources
- Industry: Increased operational, repair and replacement costs for boilers, cooling towers, process water and general water uses
- Commercial and Public Services: Combination of households and industrial cost types

Salinity costs to irrigated agriculture are not addressed in this report.

1.2 Methodological Issues

1.2.1 Estimation procedures

Morrison, Groenhout and Moore (1995) identified seven methods of estimating environmental values:

- Dose-response: measures the direct response of individuals, households or firms to change resource condition
- Preventative expenditures: outlays that directly address control or avoidance of environmental degradation. These may include both capital and operational-type expenditures and are usually estimated by means of survey data, or through modelling of representative processes
- Replacement/repair expenditures: in the absence of preventative expenditures these are inevitable costs from the point of view of the receptor of environmental damages. These are usually estimated by means of survey data, or through modelling of representative processes
- Contingent valuation: a measure of hypothetical willingness to pay, usually applied to individuals or households
- Travel cost
- Hedonic price: infers environmental values by observed changes in market values, e.g. of property
- Household production: measures additional productive activity within households in response to changed environmental conditions (more often used in economies that have less-well developed markets)

Dose-response relationships, preventative expenditures, and replacement/repair expenditures dominate the literature on the ex-situ costs of land and water salinity to non-agricultural industries, infrastructure and households, and are generally the appropriate tools for this project.

The Contingent Valuation method has sometimes been used to estimate households' willingness to pay for improvements in urban water supply quality, particularly where it has been difficult to develop a dose-response relationship such as in relation to certain chemical constituents of water, including nutrients. Carlos (1991) estimated willingness to pay for improved water quality through control of salinity and turbidity in the Yass District of New South Wales. However, it is difficult to develop estimates of willingness to pay for different levels of water salinity. Therefore, for this study dose-response methods, preventative expenditures and maintenance/replacement costs were used.

Dose-response relationships for the items of interest to this report are estimated through engineering-type calculations/models, using market values of costs. REU's project proposal for estimating salinity costs advocated the use of dose-response models based on process modelling for a number of industries, and individual household appliances. Simple curves were used to express the dose-response relationship between salinity of water supply and replacement rates of plumbing items (see Appendix A). PPK's study of industrial and commercial costs due to salinity used simple industry process models (see separate PPK report).

Preventative expenditures and replacement/repair expenditures are usually estimated through surveys of organisations and households. A survey was made of local government, road and rail organizations to assess, inter-alia, salinity impacts on these organizations.

1.2.2 Spatial dimensions

By definition, *ex situ* effects of resource degradation are spatially removed from the site of origin. This poses a methodological issue, because damage cost functions generally are expressed in terms of dose-response at the receiver end of the system. In many situations the quality of service at the receiver end may be influenced by inputs of varying quality obtained from different sources.

It is recommended that the salinity cost functions presented be applied to water demand regions, by weighting the contribution of different sources, where appropriate. For example, the salinity costs incurred in Adelaide should be obtained as a flow-weighted sum of costs from (i) the Murray River and (b) the Mount Lofty Ranges catchments.

1.3 Work Program

The Murray Darling Basin Commission undertook a major study of salinity costs in 1999. Given the recency of their study, and the fact that the Murray Valley receives a significant proportion of national salinity impacts, the work undertaken requires special attention by the National Land and Water Resource Audit. Therefore, the estimated salinity cost functions given in this report are adaptations of those given in the study commissioned by the Murray Darling Basin Commission (Gutteridge Haskins and Davey, 1999).

The south west of Western Australia also experiences serious problems from secondary salinity. Therefore, data were sought from, and provided by, the Western Australian Water Corporation and the Western Australian Ministry of Housing, and were used to supplement the GHD study.

The report has also used the following sources of information:

- literature review
- questionnaire surveys and interviews with water utilities and local governments
- interview with the materials engineer of Southcorp Ltd, the main supplier of water heaters in Australia.

It did not prove possible within the scope of this consultancy to estimate the potential economic costs of increased flooding risks associated with land degradation. Where land is waterlogged or salinised, increased overland flow occurs, especially during extreme events. However, we have not been able to find any study, which both quantifies this effect for the range of catchments in Australia and relates the incremental flooding effects to likely economic damages to non-agricultural industries, infrastructure and households. There are good reasons for this. Firstly, the extreme variability of rainfall-runoff in Australian catchments makes any empirical multi-variate analysis extremely uncertain. Secondly, any effect arising from land degradation has to be separated from changes in other explanatory variables, not least of which are underlying climate change and land use change. Thirdly, the level of any economic damage will depend on past investments in flood protection, and the settlement geography of individual catchments, and this makes it extremely difficult to derive a degradation-specific cost function.

LITERATURE REVIEW

The most recent evaluation of ex-situ salinity impacts in Australia is the study performed for the Murray Darling Basin Commission by Gutteridge Haskins & Davey Pty Ltd (1998). Following this report, the Commission developed a Draft Technical Paper which summarises the cost functions developed by Gutteridge Haskins & Davey (Murray-Darling Basin Commission, 1999), and compares them with earlier cost functions developed by Australian Mineral Development Laboratories (AMDEL, 1980,1982 &1983) and Dwyer Leslie Pty Ltd., (1984). The cost functions deal with impacts on households, industrial users and irrigation water users supplied from the Murray River. As part of the study, GHD undertook a national and international literature review on methods for evaluating salinity costs. This tended to concentrate on Australian studies while mentioning the most notable USA studies.

A summary of the GHD findings about the impacts of salinity on the costs associated with urban and industrial water uses is given in Table 19. The following observations are made:

- GHD point out that data sources vary widely and thus confidence in the results is limited

- areas identified for further research included (a) improved price and maintenance cost data for hot water systems; (b) a panel of "model" houses to track impacts on plumbing components; and, (c) improved survey information on household ownership of key affected items including water softeners, rainwater tanks, bottled water usage, hot water system life, and water filters

- the GHD study omitted expenditures such as the re-lining of water distribution pipes in Adelaide, on the grounds that these decisions were independent of TDS; there could however be examples of other defensive expenditures by water utilities that are not covered by the GHD study: for example replacement water sources such as in WA

- impacts on parks and gardens were considered to be insignificant

- the GHD study does not go into very great detail on industrial costs, but flags these as significant

- GHD were concerned only with the range of salinities and user impacts found within the Murray River Catchment. GHD's salinity cost functions are estimated for changes in salinity within the range 150 to 500 mgL^{-1} TDS, and may not apply to areas with significantly higher TDS. Therefore, data from Western Australia including town supplies with salinity of up to 1,000 mgL^{-1} were considered in the current study.

- overall, the GHD study concluded that, relative to earlier estimates, urban and industrial costs per unit increase in TDS had declined since the early 1980's largely as a result of changed materials within affected appliance/plant inventories.

Table 19 Summary of urban and industrial impacts of salinity (Source: Gutteridge, Haskins and Davey Pty Ltd., 1998)

Topic	Basis for estimates	Notes
Soaps & detergents	▪ Inter-city comparisons ▪ Interviews with manufacturers, retailers	▪ Not significant
Household & commercial plumbing corrosion	▪ Inter-city comparisons ▪ 91 questionnaires to plumbers and suppliers ▪ AMDEL and SA Housing Trust data	▪ increased use of non-corrosive materials ▪ 2c TDS cost
Hot water systems	▪ Interview with Southcorp leading (80%) supplier ▪ Inter-city comparisons	▪ improved cylinder linings ▪ cylinder costs apportioned between salinity and hardness, which are often related ▪ 3.1c cylinder cost (7c per unit hardness) ▪ 0.7c relief valve cost ▪ 4.3c element cost ▪ gas use not significant
Taste and odour (includes substitution of tanks and filters, plus bottled water purchases)	▪ inter-city comparisons adjusted according to the proportion of taste & odour differences attributable to TDS ▪ Heyworth et al (1988) ▪ 37 questionnaires to suppliers and manufacturers of filters and tanks ▪ interviews with major distributors of soft drinks	▪ 0.9c for filters ▪ 0.5c for rainwater tanks ▪ bottled water purchases not significant
Household water softening	▪ 39 interviews with manufacturers and suppliers	▪ 4.8c for water softening ▪ large standard error due to insufficient ownership data
Water supply infrastructure capital and maintenance costs	▪ Interviews with water utilities	▪ not a significant cost ▪ increased use of DICL and PVC pipes ▪ most pipe corrosion comes from the exterior ▪ complex relationships involved in pipe lifetime/maintenance costs ▪ concrete structures and plastic equipment unaffected ▪ stainless steel in facilities is upgraded if TDS> 1,000

Topic	Basis for estimates	Notes
		mg/L at a cost of +10%, but it is only 2-5% of total plant cost
Municipal water treatment costs	Interviews with water utilities	▪ overall, not significant ▪ energy & maintenance costs not considered ▪ operator time not considered significant ▪ chemical costs respond to turbidity and colour, independently of TDS ▪ higher treatment levels are needed (e.g. reverse osmosis) if TDS>1000 mg/L, but were ignored in GHD
Commercial & industrial boilers	▪ AMDEL (1983) ▪ contacts with major suppliers of feedwater chemicals, and ion-exchange and reverse-osmosis equipment	▪ properly-maintained boilers are not affected by TDS ▪ blowdown costs estimated ▪ 0.49 TDS [+.003 if TDS < 265 or +.016 if TDS > 265] c/kL feedwater
Industrial process water treatment	▪ assumption that industry would install pre-treatment if TDS affects their process ▪ ion exchange used if TDS < 286 mg/L ▪ reverse osmosis used if TDS > 286 mg/L	▪ impacts of poor quality water are significant in many industrial processes, especially, food, beverages, paper, electroplating and automotive painting ▪ 0.000056c/kL/yr for de-ionising[TDS < 286] ▪ 0.016c/kL/yr for de-ionising [TDS > 286]

The purpose of the REU review of the GHD work was to determine:

- the extent to which results from the GHD work can be utilised within Project 1.3, and conversely
- where the GHD work should be supplemented by fresh investigations within Project 1.3.

The review found that some additional development of the cost functions developed by GHD should be undertaken for the national assessment required in Project 1.3. In particular,

- REU recommends use of amortisation in converting expected asset lifetimes into annual costs, which is the standard procedure in economic analysis.
- GHD concentrated on the effects of changes in salinity in the range from 150-500mgL^{-1}, whereas significantly higher salinities are, or may be, encountered in some areas within Australia. An analysis of Western Australian plumbing

data over a greater range of water supply salinities has been conducted. Slightly (but not radically) different results were obtained.

- Some household items were not investigated by GHD: REU has not been able to pursue these items.

- The relative contribution of hardness and salinity to capital and operating costs were subject to assumptions by GHD in many cases: this is also true of the WA plumbing data analysis reported in Appendix I.

- It was felt that considerably more attention should be given to industrial and commercial impacts.

Table 20 summarises REU's detailed recommendations and subsequent actions relating to each item for which cost functions were derived by GHD or appear in the literature.

Table 20 Detailed recommendations following from REU Review of GHD (1999)

	Sector	Recommendations from REU review of GHD	Actions undertaken in project 1.3
	Household Sector:		
1	Soaps and detergents	Accept GHD finding that soaps and detergents expenditures are unrelated to salinity: no further work on this item	No action required
2	Household plumbing	As the GHD study went to considerable lengths to obtain a large sample from plumbers, but found great variation and difficulties in reaching a reliable result, it seems pointless to attempt to repeat this exercise. The GHD estimate based on SA Housing Trust data should be adopted, subject to revision in the light of similar data, which REU should seek from other parts of Australia.	No action required Western Australian Ministry of Housing data analysed and results incorporated in standardised cost function
3	Hot water systems	Southcorp be approached for improved information In the event of accurate statistical data not being available from Southcorp, an alternative questionnaire-based approach be used	Done: better understanding of Southcorp analysis, and incorporated Southcorp estimates into standardised cost function
4	Bottled water	Additional data needs to be obtained before bottled water purchases should be dismissed. Roy Morgan Opinion Polls has national and regional data on bottled water purchases by households.	Agreed with Dames and Moore to exclude this
5	Household filters	The GHD salinity cost function for household water filters should be adopted, without any further study	Done
6	Rainwater tanks	The proportion of rainwater tanks that are installed for the reason that no reticulated drinking water supply is available, needs to be determined. Data on rainwater tank installation as a function of TDS and other water quality parameters need to be determined for a selection of areas across Australia	Not done. GHD cost function amended using amortisation rather than straight-line cost averaging.
7	Household water softening	Further work is needed on the relationship of hardness and salinity in public water supply systems Further work is needed on ownership levels of household water softeners	Not done
	Industrial and Service Sectors:		
8	Cooling Towers	PPK should undertake detailed modelling of a number of industrial processes	See PPK report
9	Commercial and Industrial Boilers	**PPK should undertake more detailed modelling of key industrial processes**	See PPK Report

	Sector	Recommendations from REU review of GHD	Actions undertaken in project 1.3
		as a basis for more accurate estimates	
10	Industrial Process Water	There is a need to become more specific about the costs of salinity at the individual industry level, and this should be the focus of PPK efforts	See PPK Report
11	Water Supply Infrastructure	PPK-REU should review the GHD findings, in particular by ascertaining the nature of the information obtained by GHD and the conclusion drawn.	Done; additional control and treatment costs estimated for relevant WA catchments
12	Municipal Water Supply Treatment	PPK-REU should review the influence of the quality of raw water on the level of treatment conjunctively with its assessment of the way the quality of the natural resource influences overall infrastructure planning.	Done: see Appendix II
13.	Service Sector	That REU-PPK consult a number of large-scale service establishments, including hotels, restaurants, hospitals, airports, and large office blocks to determine whether, GHD's assumption of equivalence with the household sector is a reasonable one, and if not to substitute an alternative function.	See PPK Report

HOUSEHOLD DAMAGE COSTS

3.1 Method

The procedure followed in estimating household damage costs follows that of Tihansky (1974). This combines recurrent costs incurred by households with changes in the total capital costs of household items due to reduced service lives of items. An amortisation formula is used to convert reduced service life to an annualised cost basis. In this study the conventional economic (compound interest) method of amortisation has been used, rather than straight-line (arithmetic) annualisation.

In calculating annual costs for reduced service life GHD divided the purchase cost by the estimated service life. The GHD costs for an item with a 12-year service life are approximately 78% of the cost that would be obtained with an amortisation procedure and a 4% real discount rate. The difference is even larger for items with longer service lives or higher discount rates. For example, GHD's calculation of the annual cost of an item such as a rainwater tank with an estimated service life of 40 years would be 50% of the amortised cost calculated using a 4% discount rate.

3.2 Soaps and detergents

Both AMDEL (1982) and Tihansky (1974) estimated that salinity has some effect on purchases of soap and detergents. It is notable that the effect of hardness on soaps and detergents expenditure is much greater than that of salinity, and this is recognised in Tihansky (1974), who nevertheless attributed a positive, though small, effect to salinity. In Tihansky (1974) increased purchases of soaps and detergents accounted for only 5% of total marginal damage costs of salinity at 500 mgL^{-1} TDS.

GHD recorded the opinion of manufacturers and industry associations who had found that there was little response in sales to inter-regional differences in hardness and/or salinity, either in the UK or in Australia. GHD also utilised data for 1997 and 1998 on purchases of soaps and detergents from AC Nielsen McNair for Sydney (approx 100mgL-1 TDS), Melbourne (approximately 50 mgL-1 TDS) and Adelaide approximately 360mgK-1 TDS), and found virtually constant expenditure per household in the three cities.

While the range of salinities considered in this comparison is quite small, it is recommended that the NL&WRA accept the GHD findings that expenditures on soaps and detergents are unrelated to salinity.

3.3 Household plumbing

The GHD study involved interviews and surveys with 88 plumbers and suppliers in Sydney, Melbourne, Adelaide and locations along the River Murray, plus information on costs obtained from the South Australia Housing Trust and the Defence Housing Trust in South Australia.

The plumber data produced estimated costs and lifetimes, but there was wide spread in the data obtained, and GHD stated that there is significant uncertainty associated with the results. There was also difficulty in assigning weights to TDS and hardness in explaining variations in lifetime and repair costs, and variations in costs due purely to locational factors. The data from the SA Housing Trust, which include all plumbing costs, show a good correlation at higher levels of TDS. GHD used an adjusted estimate from the plumbers' data for the low salinity range (<262 TDS) and the SA Housing Trust data for higher TDS levels. However, since Adelaide's mean salinity is 360 TDS, the SA Housing Trust data provided the policy-relevant estimate.

As the GHD study went to considerable lengths to obtain a large sample from plumbers, but found great variation and difficulties in reaching a reliable result, it was considered pointless to attempt to repeat this exercise.

For this study REU was provided with data from the WA Ministry of Housing on the frequency of replacement of plumbing items in Homeswest properties, and the WA Water Corporation provided data on typical water supply salinities for a comparable set of town water supply areas selected for a range of salinity levels between 100 mgL^{-1} TDS and 1,000 mgL^{-1} TDS. This data analysis is reported in Appendix A.

It was found that the replacement rates for taps shower roses and tap/shower arms in WA Homeswest properties were associated with variations in water supply salinity. The inferred annual costs per household for these items were slightly higher, though comparable in order of magnitude, to those estimated by GHD:

- GHD-estimated coefficient — \$0.081 mgL^{-1} TDS
- REU-estimated coefficient based on WA Homeswest data — \$0.121 mgL^{-1} TDS

No obvious relationship was found between replacement rates for other plumbing items in Homeswest properties and water supply salinity. These included toilet cisterns, basins, baths, and piping. The lack of any obvious relationship for these items does not mean that no relationship exists. It appears that inclusion of other factors such as differences in the average age of Homeswest properties between different areas, and possibly differences in the socio-economic composition of the tenants might improve the results.

3.4 Hot water systems

Water heaters assume a very significant proportion of total household salinity costs according to the GHD calculations. The GHD results are based on information from (i) 17 responding plumbers and/or heater suppliers, (ii) State departments of housing and (iii) an interview with Southcorp Pty Ltd., the leading supplier of water heaters. The data from Southcorp are in broad agreement with the estimates of AMDEL, though the slope of the salinity damage based on comparisons of Adelaide with Melbourne and Sydney is higher in the AMDEL estimates than in the Southcorp estimates. The data obtained from plumbers and other suppliers is not convincing, because it produces higher costs in Melbourne than in Adelaide (GHD 1999, Table 6.7 p 94). The data from State departments of housing (GHD 1999, Figure 6.11 p 95) appear to relate mainly to maintenance expenditure as the annual costs are much lower than the Southcorp and AMDEL figures: approximately 30%, and were not used in GHD’s final cost functions.

Thus, the GHD result is due largely to the estimates supplied by Southcorp. However, the basis for the estimates supplied by Southcorp was unclear from the GHD report. Southcorp were therefore requested by REU to provide access to raw data on the length of service life of water heating systems, but they declined. However, Mr Gary Chater, Southcorp Senior Materials Engineer provided information on the analytical procedures that had been followed in producing the numbers quoted the GHD report. It appears from his description that Southcorp routinely and carefully analyses a large data set on replacements of water heaters. It appears that the estimates are reliable.

It was therefore decided to adopt the Southcorp figures quoted in the GHD report. However, the GHD analysis has been re-worked to take account of an alternative annualisation procedure previously used by other authorities on salinity damage cost estimation. This results in a higher estimate of damage costs, as follows:

- GHD estimate 73 + 0.051 TDS
- REU re-calculation 119 + 0.086 TDS

3.5 Taste and odour

3.5.1 Bottled water

GHD found that the per capita consumption of bottled water was significantly higher in Adelaide than that in rural areas that were receiving water supplies of similar salinity to Adelaide's. However, the exact nature and source of the GHD data is not clear. GHD concluded that consumption of bottled water was independent of salinity level. It was suggested that differences in consumption levels were probably related to cultural and economic factors. GHD also stated that inter-annual fluctuations in beverage sales, including sales of bottled water, and the existence of multiple sources of supply for bottled water, would make it difficult to conduct a meaningful sample of suppliers.

The resources available to this study did not make it possible to conduct further household surveys. Consequently, REU has accepted the GHD conclusion that no relationship exists between the level of purchases of bottled water and water supply quality.

3.5.2 Household filters

GHD found a high correlation between the costs of installing and operating water filters and salinity level in Adelaide, Melbourne and Sydney. The GHD salinity cost function for household water filters was adopted for the purposes of this study

3.5.3 Rainwater tanks

Heyworth et al (1988), found that ownership of rainwater tanks was very much higher in Adelaide (54% of households) and other parts of South Australia (68% Port Lincoln, 96% in the Riverland) than in Melbourne (5%). Since the security of reticulated supply in South Australia is good, it can be inferred that these differences are due to perceived differences of quality as between rainwater tanks and public supplies. This is a significant cost of water quality degradation.

As with other items, GHD used straight-line depreciation rather than amortisation in calculating annual costs of rainwater tanks. An expected life of 40 years was used, with an average cost of $650/tank. This difference in methods for calculating annual costs yields substantially different results. Straight-line depreciation as used by GHD gives an annual value of 650/40 = $16.25/tank. The annual value of $650 amortised at a real discount rate of 4% over 40 years is $32.8/tank, and using a 7% real rate of discount produces a figure of $48.75/tank.

GHD recognised that the propensity to install water tanks was related to perceived water quality differences, and emphasised the importance of taste and odour. GHD assumed that salinity might account for only a quarter of rainwater tank installations, but no firm data was presented to support this.

The following calculation produces an alternative estimate, using amortisation and the same values as GHD for average cost per tank and proportions installing in Adelaide and Melbourne.

	4% rate of discount	7% rate of discount
Average cost of tank	\$650	\$650
Cost of tank annualised over 40 years	\$32.8	\$48.75
Proportion installing in: • Melbourne (50mgL^{-1}TDS) • Adelaide (360mgL^{-1}TDS)	 .05 .54	 .05 .54
Simultaneous equation for proportion installing as a function of TDS: • Melbourne (50mgL^{-1}TDS) • Adelaide (360mgL^{-1}TDS)	.05 = m.50 + C .54 = m.360 + C	.05 = m.50 + C .54 = m.360 + C
Solution of the simultaneous equations above, shows the proportion installing as a function of TDS	p = .00158.T - .029	p = .00158.T - .029
Amortised costs of installed tanks per total households in the population: • Melbourne (50mgL^{-1}TDS) • Adelaide (366mgL^{-1}TDS)	\$32.8 * 0.05 = \$1.64 \$32.8 * 0.549 = \$18.02	\$48.75 * 0.05 = \$2.44 \$48.75 * 0.549 = \$26.76
Therefore, equations for costs/hh/year as a function of salinity are: • Melbourne • Adelaide	1.64 = 50.T + C 18.0 = 366.T + C	2.44 = 50.T + C 26.76 = 366T + C
Solution of the simultaneous equations above, shows cost/household/year as a function of TDS	\$ = .052T – 1.03	.077T - 1.42

Thus the cost coefficient assuming that TDS accounts for 25% of rainwater tank installations (as assumed by GHD) is 0.052/4 = .013 at the 4% discount rate and .077/4 = .019 at the 7% discount rate. Respectively, these estimates are approximately 3 and 4 times the value of the coefficient for rainwater tanks estimated by GHD (.018/4 = .0045: see GHD page 103).

On the basis of real interest rates of between 4% and 7% at present it was decided to use the average of these two, thus producing a damage function of:

- Rainwater tanks cost/hh/year .065 T - 1.22

3.6 Household water softening

GHD referred to the high rate of use of household water softeners in Adelaide, explained this by the relatively hard water supplied in Adelaide, and calculated a cost in terms of $/household /year. GHD then converted the cost in terms of salinity (TDS). The resulting cost function seems to depend on the assumption that hardness would increase with increases in salinity, which is questionable. Also, as GHD point out, the estimate has a large error, due to considerable uncertainty in the estimated proportion of households owning a water softener.

It is therefore recommended that no salinity damage cost be included for water softeners.

3.7 Comparisons with other studies

A comparison of the REU results with calculations based on GHD (1999), Tihansky (1974) and AMDEL (1982) is shown in Table 21. A number of household items, which were found to be significant in the literature, were judged by GHD and accepted by REU to be insignificant or not investigated. Expenditure on soaps and detergents and purchases of bottled water were judged to be insignificant, while fabrics, washing machines, cooking utensils, and garbage grinders, which contribute significantly to Tihansky's damage functions, were not investigated.

Table 21 Percentage of total marginal damages due to each item: REU compared with GHD (1999), Tihansky (1974) and AMDEL (1982)

Item	REU (%)	GHD (%)	Tihansky (%)	AMDEL (%)
Soaps & detergents	0	0	5	51
Household plumbing	43	55	38	33
Hot water systems:	31	35	17	13
Bottled water	0	0	11	0
Household filters	3	6	0	0
Rain water tanks	23	4	0	0
Water softeners	0	0	0	3
Washing machines	0	0	11	0
Fabrics	0	0	13	0
Other	0	0	5	0
Total household costs	100	100	100	100

In addition, a number of water-contacting household items, which have become common since Tihansky (1974), were not considered by GHD: for example, dishwashers and coffee machines. Car radiators and engines were not investigated in the literature or by GHD: while special coolant mixtures are standard for new motor vehicles, these are not universally used. On the other hand, expenditure on water softeners, which according to GHD is significantly affected by salinity, was thought by Tihansky (1974) to be entirely related to water hardness.

The AMDEL (1982) estimates were heavily influenced by their estimate of the effect of salinity on purchases of soaps and detergents. Both GHD and Tihansky considered a larger range of other items than AMDEL, but there was a complete mis-match comparing the "other items" in Tihansky (bottled water, washing machines, fabrics, and other) with those in GHD (household filters, rain water tanks, and water softeners).

3.8 Hardness Effects

GHD (1999) gave considerable attention to the issue of hardness-related effects on household items.

REU discussed the GHD assumptions with Dr Andrew Hertzeg of CSIRO Land and Water. The critical issue was whether hardness and salinity were independent or inter-related. CSIRO data were examined for both the Darling River and the Murray River. It was concluded that while the hardness:salinity ratio is higher for the Darling River it is also significant in the Murray River. Further, it was concluded that resource management initiatives, such as salt interception works or recharge reduction, that are aimed at reducing salinity in either of these rivers are likely to reduce hardness as well as salinity in the water diverted at Morgan. Therefore, it is correct to adjust the salinity damage cost functions upwards, to take account of the related hardness effects. The GHD correction factors for hardness in lower Murray-Darling water supplies were accepted, and are used in the Executive Summary to this report.

INDUSTRIAL WATER USERS

Readers are referred to the Executive Summary (this report) and the separate report by PPK Environment & Infrastructure Pty Ltd.

SERVICE SECTOR

For data on the costs to service sector activities refer to the separate Report by PPK Environment & Infrastructure Pty Ltd

Government forms a part of the service sector. A local government questionnaire survey has been undertaken by REU, and the results to are reported in Appendix C.

Extra operating and capital costs to local governments in areas suffering from serious local salinity and waterlogging problems are estimated from the preliminary survey results to be from $25/capita/year in the Murray-Darling Basin to $50/capita/year in Western Australia.

While it is clear from this survey that local governments in regions suffering from secondary salinisation are experiencing significant impacts from salinity, it is also clear that by far the major impact is *in situ* in nature. The main impacts of salinity on local government occur through such phenomena as increased infrastructure repair and maintenance costs including roads, groundwater pumping and surface water management. The other significant area of cost to local government is in land management and environmental management and in protection activities related to salinity and waterlogging.

From independent estimates made as a part of the study by Dames & Moore and Resource Economics Unit on the costs of salinity and rising groundwater tables to towns in the WA wheat belt, it would appear that costs to local government (mainly in respect of local district roads) are approximately 20% of total costs, with the remaining costs being borne by the WA Main Roads Department, and the private sector, mainly by industry, commerce and private households. These are all *in-situ* costs.

DAMAGE AND CONTROL COSTS IN WATER SUPPLY SYSTEMS

Previous studies

Tihansky (1974) found a positive correlation between municipal, water systems costs and the level of water supply salinity.

GHD concentrated on water treatment systems that target colour and turbidity, which are common in the Murray-Darling Basin. GHD concluded that "municipal water treatment costs can be seen to be largely independent of TDS levels, and no relationship is proposed." GHD also refers to the use of membrane treatment where TDS exceeds approximately 1,000mgL^{-1}. However, as the salinity of Murray River waters rarely, if ever, reaches this level, this type of treatment cost was ignored.

GHD (1999) concluded:

> "*interviews with major water boards, including SA Water, suggest that no process model can be developed for a relationship between TDS and the capital/maintenance costs for water infrastructure. Given the changing mix of materials installed, and the move towards corrosion-resistant materials, it seems likely that the cost increase related to any TDS increases will be minimal*".

This conclusion appears reasonable against the terms of reference for the GHD study, and the particular study area. As with some of the other items investigated, there was a tendency amongst GHD's respondents to refer to improved pipe and appliance materials or good management practice as negating the potential cost effects of changes in TDS. It is not at clear, however, that these adaptations are costless and/or independent of TDS.

However, a broader view is needed of the way the quality of raw water influences the choice of supply/treatment system and thus costs in other parts of Australia. It is to be expected that quite radically different supply alternatives (including treatment alternatives) must be entertained where the choices lie between sources of much higher salinity than is experienced in the Murray Valley.

6.2 Case Study of the WA Water Corporation

Western Australian landscapes and water resources are extensively affected by salinity. Therefore, in order to further examine the impacts of salinity on water utility costs a case study was conducted on the Western Australia Water Corporation, which has a near-monopoly of water supply in that State. The case study is reported in full in Appendix II.

The case study indicates that the WA Water Corporation incurs (or may in future incur) three kinds of cost impacts from salinity:

- additional costs due to the substitution of new sources of water for resources that have become brackish or saline. The cost is estimated to be

$0.194/household/year/mg/L TDS improvement in the salinity of the original source (in the case study it was the Wellington Reservoir) based on the cost of constructing the Harris Dam in 1990, as a substitute source of water for the Great Southern Towns Water Supply Scheme

- costs of catchment management aimed at rehabilitating or protecting water supplies from increased salinity were estimated to be from $0.065/household/year/mg/L TDS to $0.185/household/year/mg/L TDS in the Collie Catchment

- higher treatment costs, where desalination is used (perhaps in combination with the "shandying" of fresh and brackish sources). The additional costs incurred have been calculated to be of the order of $0.248/household/year/mg/L TDS for desalination of water likely to be impounded in future from the Wooroloo Brook.

These indicative estimates can be compared with user damage cost estimates of between $0.14/household/year/mg/L TDS (GHD, 1999) and $0.28/household/year/mg/L TDS (REU, this report).

The estimation of a cost to the utility depends on the relevance of the particular catchment to the current and evolving water supply system and on the physical condition of the particular catchment. Therefore it appears inescapable that any standardised cost function that is proposed to assess the impact of land and water resource degradation for the purposes of the Audit must be weighted to reflect the contribution of any particular catchment or stream reach to the current and planned water supply system. River basins in the South West of Western Australia have been classified in Appendix B in terms of the relevance or otherwise of utility control cost functions or user damage functions

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Appendix I: Analysis of Homeswest (Western Australia) Plumbing Replacement Data

OBJECTIVE

The objective of this analysis was to determine whether there is any relationship between the frequency of replacement of plumbing items in the dwellings owned by Homeswest (a part of the Western Australian Ministry of Housing) and the salinity of water supplied by the Western Australian Water Corporation in calendar year 1999.

METHOD

A cross-sectional analysis was conducted which compared the rates of replacement of plumbing items per 1000 Homeswest dwellings across a set of towns which received different public water supply salinities. The analysis was limited to just the two variables of concern, namely the replacement rate and the salinity level. Other factors, which might help to explain differences in replacement rates, such as the age of the Homeswest dwelling stock or the socio-economic composition of Homeswest tenants, were not investigated. Therefore, the analysis reported here should be regarded as a preliminary reconnaissance of the data. The concluding section offers suggestions for further research.

DATA

Plumbing data

Homeswest owned 39,806 dwellings at the end of 1999. A Homeswest database records the frequency of replacement of gas and plumbing items in 54 zones across Western Australia, of which 8 are metropolitan. A total of 28 plumbing codes and 8 gas codes were used to extract data on the frequency of replacements of the items shown in Table 22.

Table 22 Homeswest gas and plumbing codes used to identify frequency of replacement of

Item	Homeswest Plumbing/Gas Codes
▪ Copper mains renewal	G103,G104,PD60A, PD60B
▪ Water heaters	G66, G66B, G66C,G66F, G66G, G66I, PD122, PD217, PD163, PD165
▪ Wash troughs	PD21A, PD21B, PD22, PD23, PD48, PD53
▪ Baths	PD40, PD42,
▪ Shower roses/arms	PD70P, PD71, PD71B, PD71C, PD72A, PD73A, PD74P, PD75
▪ Taps	PD49, PD50, PD79, PD85, PD92
▪ Cisterns	PD8

Mr Alan Stephenson, Homeswest Plumbing Advisor gave guidance on the database codes, which would give the best indication of repair and replacement items (for example replacement water heaters and copper mains were classified both within the "gas" and the "plumbing" sections of the Homewest data base).

Water Supply Salinity Data

The selected towns are shown in Table 23.They contain a wide range of water supply salinities. The Western Australian Water Corporation provided data on water quality from the main service reservoirs for each town. The number of water quality measurements differed between towns and between service reservoirs, and a simple average of all measured salinities was calculated for each town. Average water supply salinity in terms of conductivity and total filterable solids is shown in Table 23.

Mr Laslo Koska, water quality consultant with the WA Water Corporation provided general advice on the water quality and water quality data of the selected towns, which is noted at the foot of Table 23. It can be seen that some of the towns selected for analysis had relatively small numbers of Homeswest properties. As replacement items are undertaken for around 5% of properties in any one year this led to small values that could be un-representative in a few cases.

Table 23 Selected towns, with indicators of their water supply salinity and number of Homewest properties

Homeswest Zone	Conductivity (mS/m)	Total Filterable Solids (mg/l)	Homeswest Properties
Albany(1)	82.4	526.7	733
Bridgetown(2)	33.9	179.4	363
Broome	55.4	366.2	684
Dongara	139.5	805.6	83
Esperance(3)	115.8	803.3	435
Geraldton	129.3	731.5	1208
Kalgoorie/Boulder(4)	66.0	336.7	1387
Karratha/Dampier	82.8	594.0	731
Meekatharra(5)	137.7	932.7	227
Metro Fremantle	27.5	142.5	2664
Metro North	53.1	325.8	6775
Newman(6)	98.8	767.5	129
Norseman	80.9	431.0	53
Port Hedland	92.1	639.7	1081

Notes:

(1) Albany water quality has a relatively high hardness factor.

(2) The water quality data are for Bridgetown (41 Homeswest properties), but the Homeswest plumbing data in Col 4 relate to a zone which includes Manjimup, Pemberton, Nannup, Northcliffe and some other small centres.

(3) Esperance water quality has a relatively high hardness factor.

(4) Water quality data are for Kalgoorlie only.

(5) The water quality data are for Meekatharra (138 Homeswest properties) but the Homeswest plumbing data in Col 4 relate to a zone which includes Mount Magnet, Cue and Wiluna

(6) Water quality records for Newman are relatively sparse as the WAWC only recently acquired the Newman water supply system.

I.4 RESULTS

General

In general there was only weak evidence of a relationship between the number of repairs and replacements of plumbing items and water supply salinity as measured by TFS. Data on water troughs and baths was insufficient for any analysis and these items or not discussed any further.

Shower Roses/Arms

There is some evidence of a relationship between the rate of replacement of shower roses/arms and TFS of water supply salinity. The data are plotted in Figure 2.

The relationship is not statistically significant. However, from "eyeballing" the data a straight line passing through coordinates (350,1000) and (100,200) was drawn. By solution of the simultaneous equation for these two coordinates the indicated relationship appears to be:

R = 37.5 + 0.31 TFS

where

R is the number of replacement per 1000 properties, and TFS is total filterable solids in mg/l.

Linear regression provided a least-squares best fit of:

R = 144 + 0.13 TFS.

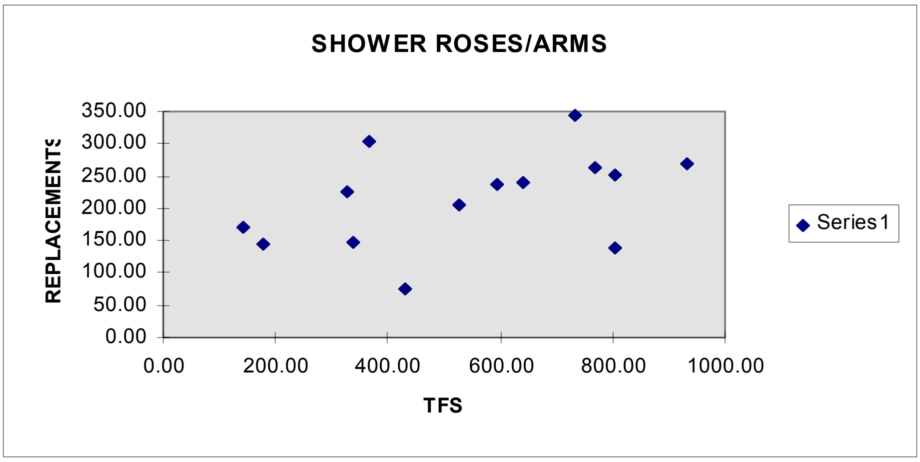
The data for Northern Metropolitan and Metropolitan Fremantle zones were also compared, because there are much larger numbers of properties in these two zones. The two data pairs were (225,326) and (170,143). Solving the simultaneous equation for these two coordinates gives an estimated relationship of:

R = 127 + 0.3 TFS,

which is remarkably similar to the "eyeball" estimate for all towns, given above.

The difference in the rate of replacement between these two zones is statistically significant, because there are such a large number of properties involved. However, it cannot be claimed in a statistical sense that the difference is due to differences in salinity.

Figure 2 Number of replacements of shower roses/arms per 1000 properties vs salinity of water supply (TFS)

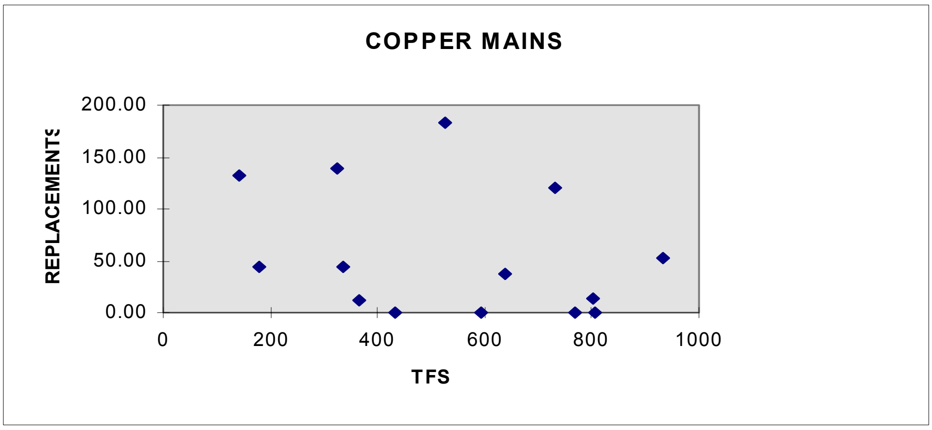


Copper Mains

The data on copper mains, which were obtained from both plumbing and gas maintenance records, are displayed in Figure 3. It is seen that there was wide variability in the rate of replacement and no relationship with TFS is evident.

The data for two large metropolitan zones were examined, but despite a significant difference in their water supply salinity there was hardly any difference between the replacement rates: 138/1000 properties in the North Metropolitan zone (326TFS) and 132/1000 properties in the Metropolitan Fremantle zone (143 TFS).

Figure 3 Number of copper mains replacements per 1000 properties vs salinity of water supply (TFS)



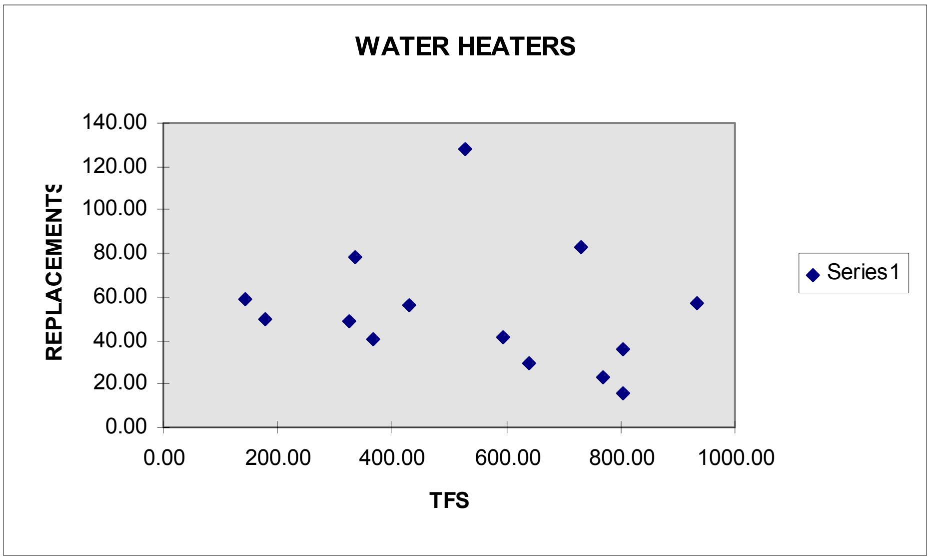
Water Heaters

Homeswest properties are mainly provided with instantaneous gas heaters, with some gas storage heaters and much smaller numbers of electric and solar types. The data are displayed in Figure 4. It is seen that there was wide variability in the rate of replacement and no relationship with TFS is evident. If anything, there appears to be a *negative* correlation.

The data for two large metropolitan zones were also examined, but the difference replacement rates, of 48/1000 properties in the North Metropolitan zone (326TFS) and 59/1000 properties in the Metropolitan Fremantle zone (143 TFS), was opposite in sign to the difference in salinity.

These results are plainly at odds with the opinions of water heating engineers and plumbers, and the data supplied by Southcorp Ltd. It cannot be claimed that there is no relationship without further investigation, because other factors such as the age of the Homeswest dwelling stock in different areas, and differences in the demographic and socio-economic composition of Homeswest tenants in different zones might also play a part in explaining inter-zonal differences in replacement rates.

Figure 4 Number of water heater replacements per 1000 properties vs salinity of water supply (TFS)



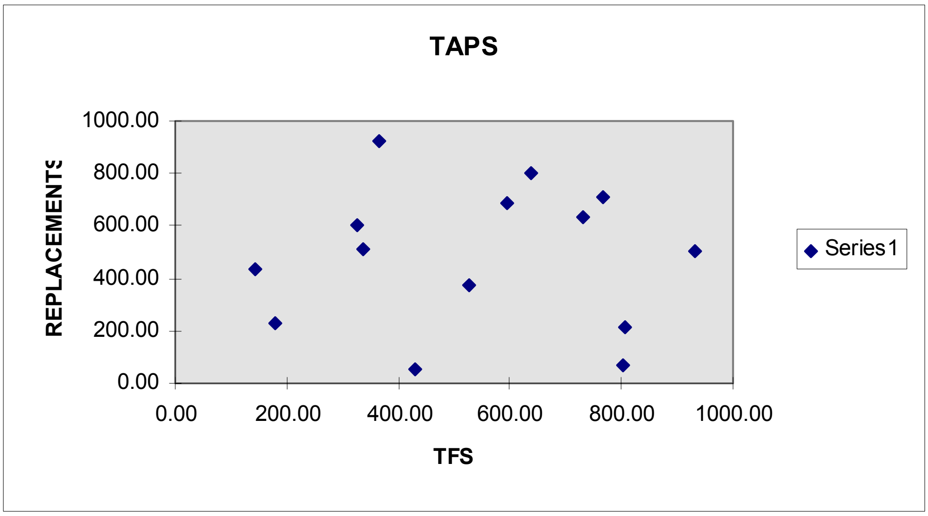
Taps

The data on taps are displayed in Figure 5. It is seen that there was wide variability in the rate of replacement and no relationship with TFS is evident.

The data for Northern Metropolitan and Metropolitan Fremantle zones were also compared, because there are much larger numbers of properties in these two zones. The two data pairs were (600,326) and (436,143). Solving the simultaneous equation for these two coordinates gives an estimated relationship of:

R = 307 + 0.9 TFS.

Figure 5 Number of tap replacements per 1000 properties vs salinity of water supply (TFS)



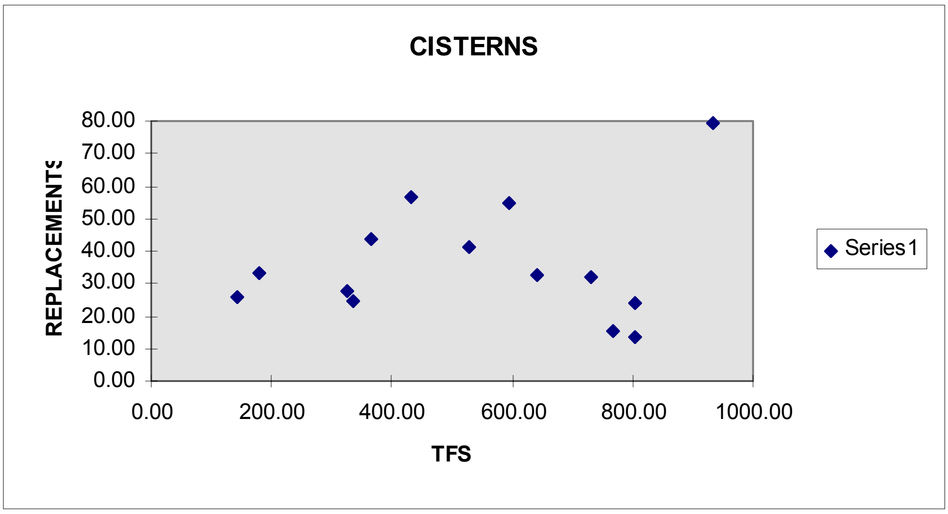
Cisterns

The data on cisterns are displayed in Figure 6. It is seen that there was wide variability in the rate of replacement and no relationship with TFS is evident. However, it is noticeable that there were three zones with relatively high salinity of approximately 800 TFS and very low replacement rates of less than 20/1000 properties (see Figure 6). These zones were Esperance, Newman and Dongara, all of which are relatively small areas. Their exclusion would leave a data set with some suggestion of a relationship between replacement rate and TFS, but the inference of a causal relationship would be very weak.

The data for Northern Metropolitan and Metropolitan Fremantle zones were also compared. However, there was hardly any difference between the two replacement rates 27.5/1000 properties and 25.9/1000 properties respectively.

It is concluded that the data provide no evidence of any relationship between replacement rate and water supply salinity for cisterns.

Figure 6 Number of cistern replacements per 1000 properties vs salinity of water supply (TFS)



ECONOMIC DAMAGE FUNCTIONS

The analysis of frequency of replacements per 1000 properties as a function of water supply salinity indicated some relationship for shower roses/arms and for taps. The replacement functions for these two items may be converted into economic costs by multiplying the number of replacements by their average cost of materials and installation. This yields:

Shower roses/arms

\$Rs = 40(127 + 0.3TFS); equation based on Perth Metropolitan replacement data

Taps

\$Rt = 100(307 + 0.9 TFS); equation also based on Perth Metropolitan replacement data

where \$R = replacement cost per 1000 households per year.

Shower roses/arms plus taps

The combined economic damage function for the two previous items is therefore:

d\$Rs/dTFS = .3 * 40 = \$12/1000 properties/mgl^{-1} TFS

plus

d\$Rt/dTFS = .9 * 100 = \$90/1000 properties/mgl^{-1} TFS

Combining the two functions gives a total replacement cost for these two plumbing items of:

$d\$Rp/dTFS = \$102/1000 \text{ properties}/mgl^{-1} \text{ TFS}$

This estimate can be compared with one by GHD for household plumbing items affected by salinity in the Murray River of between $14/1000 properties/$mgl^{-1}$ TDS and $64.4/1000 properties/$mgl^{-1}$ TDS. It should be noted that the GHD data, obtained from the SA Housing Trust and a plumbers' questionnaire, covered taps and cisterns, and excluded shower roses. It is also stressed that the cost data used in this analysis of the Western Australian data are provisional and subject to review.

CONCLUSIONS

A preliminary analysis was undertaken of data on water supply salinity obtained from the WA Water Corporation and on the rate of replacement of plumbing and household items obtained from the WA Ministry of Housing.

A relationship is indicated between water supply salinity and replacement rates for shower roses/arms and taps. However, no relationship has been found for water heaters, baths, wash troughs, cisterns or copper mains replacements.

The economic damage cost functions provisionally estimated from the Western Australian data for shower roses/arms and for taps are broadly consistent with the damage function derived from data in the GHD report on impacts of salinity in the Murray river system, though there are differences in the composition of the two estimates, notably the exclusion of cisterns in the WA-derived estimates due to non-significance.

The estimates and analyses presented in this report are provisional. It appears that a more exhaustive analysis is required which takes account of inter-zonal differences in age of properties and socio-economic composition of tenants in Homeswest properties, and more accurate estimates of average water supply salinity for the Ministry of Housing zones. A further review of the plumbing codes used in this analysis is also needed.

Appendix II: Case Study of the Costs of Salinity to the Western Australian Water Corporation

INTRODUCTION

This case study discusses the implications of rising stream salinity for the costs of the WA Water Corporation, which, with the exception of the Bunbury Water Board, is the sole supplier of mains water in the State. The south west of Western Australia has experienced widespread salination of surface water resources following clearing of native vegetation for agriculture.

Section II.2 outlines the development of salinity problems. Section II.3 describes the current water supply system, and Section II.4 considers the implications of salinity for its design and operation. Section II.5 then presents an economic assessment of the impact of salinity on the Corporation.

BRIEF HISTORY OF SALINITY IN THE SOUTH WEST OF WESTERN AUSTRALIA

Wood (1924) was the first to suggest that removal of native vegetation was responsible for increasing salinity of rivers and streams in the South West, following difficulties with railway water supplies. An attempt to increase runoff to the Mundaring reservoir by tree removal resulted in saline flows, leading Weller (1926) to put forward a cyclic salt theory by estimating that for a forested catchment the total salt load in the stream balanced the inflow of salt in rainfall. Table 24 summarises the salinity status of river basins in the south west of western Australia as reported for 1983-84.

In 1988 a WA Parliamentary Select Committee on Salinity reported that: *"stream salinity is expected to continue to increase in the immediate future as the result of past and present agricultural development. Rising groundwater tables and associated increases in dryland salinity will mean that further small watercourses will become saline. The Water Authority in its submission estimated that only 48% of all streams and rivers remain fresh and 35% have become so saline that they are no longer potable. The remaining 17% are of marginal quality and require active management to minimise their further deterioration."*

The Select Committee produced statistics, reproduced in Table 25, showing salinity trends in 17 South West rivers. The table excludes the Swan-Avon which has long been considered too salty to be considered as a water resource, and a number of rivers in the Darling Range close to Perth that remain fresh as a result of the retention of forest cover through gazettal, all of which are now dammed (see Section II.3 for details). It is seen that many of the rivers in the table have salinities well in excess of the acceptable maximum for human consumption, of 1500 mg/l TDS. The WA Water Corporation tries to keep the salinity of supplies within 500 mg/L, but this is not always possible given the available local water resources particularly in the interior of the State.

Table 24 Salinity status of river basins in the south west of Western Australia, 1983-84

Basin No	River Basin	Fresh	Marginal	Brackish	Saline	Total
601	Esperance Coast	9	0	91	0	100
602	Albany Coast	5	13	48	34	100
603	Denmark R.	23	50	28	0	100
604	Kent R.	19	0	81	0	100
605	Frankland R.	1	0	99	0	100
606	Shannon R.	100	0	0	0	100
607	Warren R.	17	83	0	0	100
608	Donnelly R.	100	0	0	0	100
609	Blackwood R.	21	4	75	0	100
610	Busselton Coast	100	0	0	0	100
611	Preston R.	100	0	0	0	100
612	Collie R.	26	61	13	0	100
613	Harvey R.	100	0	0	0	100
614	Murray R.	59	0	41	0	100
615	Avon R.	7	0	70	23	100
616	Swan Coast	43	3	23	30	100
617	Moore-Hill R.	15	10	15	60	100
618	Yarra Yarra Lk	0	0	0	0	0
619	Ningham	0	0	0	0	0
	Total Division VI	48	16	30	6	100

Table 25: Trends in river salinities, South West Australia

River	From	To	Cleared Area (%)	Average salinity in last 5 years of record (mg/l TDS)	Average annual increase in salinity over period of record (mg/l/yr TDS)
Denmark	1960	1986	17	890	26
Kent	1956	1986	40	1870	58
Frankland	1940	1986	35	2192	74
Warren	1940	1986	36	870	15
Perup	1961	1986	19	3410	117
Wilgarup	1961	1986	33	863	14
Blackwood	1956	1986	85	2192	58
Capel	1959	1976	50	423	14
Preston	1955	1975	50	354	11
Thompson	1957	1985	45	534	17
Collie	1940	1986	24	730	24
Murray	1939	1986	75	2792	93
Williams	1966	1986	90	2425	95
Hotham	1966	1986	85	3711	89
Wooroloo	1965	1986	50	2092	39
Brockman	1963	1986	65	2040	72
Helena	1966	1985	10	1257	48

WA WATER CORPORATION SUPPLY SYSTEM

In the South West of Western Australia the WA Water Corporation supplies Perth, other towns, the southwest irrigation scheme, farms in the wheat belt (reticulated supply for domestic and stock purposes), and the Goldfields. The Corporation also supplies the Great Southern, the mid-West and North West Regions. The central wheat-belt and the Goldfields are supplied via long-distance pipelines from Mundaring Weir near Perth. Where necessary Mundaring Weir is augmented with water from the Perth Metropolitan Supply system, which is supplied conjunctively from both local ground water and Darling Range catchments. The Great Southern Towns Water Supply Scheme pipes water from the Harris Dam in the Darling Range to towns and farms in the southern wheat-belt.

Development of water supplies from the catchments of the larger fresh rivers of the Darling Range began in 1891 with the building of the Victoria Reservoir. Development continued at a rapid pace in the 20th Century, with dam or pipehead constructions at Mundaring (Helena R, 1903), Bickley Brook (1921), Churchman's Brook 1923-28), Wellington Dam (Collie River), Harvey River, Canning River (1933-40) Serpentine River (1955-61), North and South Dandalup Rivers (1969-74), and the Wungong River (1975-79). More recently, the Harris River Dam (1990) was constructed to serve the Great Southern Towns Scheme following deterioration of water quality in the Wellington Dam (Collie River).

Ground water from the Swan Coastal Plain sand aquifers was used for the public supply system from the early 1970's, when it became apparent that the scope for further development of surface water catchments was very limited and generally more costly than groundwater. While the salinity of the developed aquifers varies, it has not been affected by changes in vegetation in the modern era, because there is little salt storage in the sandy soils of the coastal plain.

The report *Water for the 21st Century* (1988) examined a range of water supply options for a State population of 3.1 million by the year 2051, taking account of possible climate change scenarios. It concluded that viable future water supply options were available. Desalination of seawater was considered an option after the year 2020-21.

The Water Corporation has since published a planning document *Perth's Water Future Strategy* (1995). This proposes development of a further eight surface/groundwater systems to meet anticipated demands up to the year 2020-21. Five of these are coastal plain groundwater systems, and three are proposals to divert some limited remaining fresh flows from the Darling Range (Harvey and Waroona dams) and to install pump-backs (Lower Serpentine, Jane Brook and Wellesley Creek). This strategy is being reviewed by the Water and Rivers Commission, as part of the National Land and Water Resources Audit Water Availability Theme.

To summarise, the system has been, and will continue to be, made up of many small to moderate-sized surface catchments and groundwater areas. There are stringent controls aimed at maintaining the currently good quality of water obtained from this system. However, further surface water development is constrained by both salinity and competing environmental demands. While rising salinity does lead to ecosystem change, it has had the beneficial result of leaving the major rivers un-dammed and free for recreational uses.

EFFECTS OF SALINITY ON THE CORPORATION'S SUPPLY SYSTEM

The three largest river systems of the South West, namely the Swan-Avon, the Murray and the Blackwood drain very large areas of the wheat-sheep belt and are saline. These rivers are not regarded by the Water Corporation as a potential water source for the future. If they had remained fresh, and could have been made available to the Water Corporation, then the costs of augmenting the water supply system to meet future demands in the 21st Century would undoubtedly be lower. It is now regarded as uneconomic to attempt to reverse rising salinity trends in these rivers. However, whether they would ever have been made available for water supply purposes is questionable because of competing recreational and environmental demands for the water. Moreover, incomes generated in agricultural production would have been foregone if land clearing had been stopped or reversed.

Despite the widespread incidence of salinity in the South West of Western Australia the water supply system has been largely isolated from the problem. The retention of closed forests in the Darling Range close to Perth in the late 19th Century was perhaps more a matter of luck than judgement, and resulted from two facts. Firstly, the forests were located on very rough country that was not amenable to clearing for agriculture: the terrain is highly dissected with steep slopes, granite outcrops are common and the surface is lateritic. Second, an outbreak of typhoid around the turn of the Century convinced the water supply authorities that exclusion of human activities from water catchment areas was a good idea. The result is that the metropolitan catchments from the Helena River south to those of the North and

South Dandalup Rivers remain largely forested and yield fresh runoff. The principle land use change within the forested area has been the introduction of bauxite mining and coal mining. The total area involved is relatively small, and elaborate precautions are taken to protect the water resource from deleterious effects from these activities.

The major exception occurred in the Collie River catchment, which is harnessed by the Wellington Dam to supply water to the irrigated dairy industry located on the coastal plain. Agricultural clearing has resulted in a marked increase in stream salinity (see Tables II.10 and II.11). In the 1980's a rehabilitation program was put in place. This aims to re-forest a large part of the cleared area, through farm buy-backs and incentives for private investment in tree planting.

ECONOMIC ASSESSMENT

Overview

The WA Water Corporation completed a questionnaire and provided comments on the impacts of natural resource degradation on its costs. In determining costs due to salinity the Corporation assumed that the necessary improvements to natural resources by way of reversal of degradation would have to be achievable in practice. The Corporation is of the view that the vast majority of existing degradation to surface waters in the south west of western Australia cannot for all practical purposes be recovered. Therefore, the resulting possible cost reductions are relatively low.

Nevertheless, the Corporation may experience cost effects from salinity in three ways:

- additional water source development costs,
- additional water treatment costs, and
- additional water resource management costs

Each of these is discussed in turn in the following section.

Utility cost functions

II.5.2.1 Additional source development costs: the Harris Dam project.

One instance of increased source development costs for the Corporation within the planning time frame for the Audit was identified, namely the Harris Dam.

The Wellington Dam on the Collie River was constructed to supply the irrigated dairy industry on the coastal plain and the Great Southern Towns Water Supply Scheme. This scheme delivers 9.46 million m^3 to some 30,000 properties in the southern wheat-belt. By the 1980s, when the Collie River had reached a salinity of over 2,000 mg/l TDS, the WA Water Corporation continued to use the reservoir by varying off-takes from the density-stratified impoundment. The Corporation continues to deliver a water supply to pasture irrigators of around 800 mg/l TDS, in adequate quantity, by this means.

The Harris Dam was constructed in 1990, as a substitute source of water for the Great Southern Towns Water Supply Scheme. The cost of the new dam was $42 million, or expressed on an annualised basis over 30 years at 7% discount, approximately $3.5 million per year. The new dam achieved a reduction in water supply salinity of the Scheme from around 800 mg/l TDS to around 200 mg/l TDS. Converting the cost of this reduction to a cost per household:

- 9.46 $m^3 \times 10^6$/year serves approximately $3x10^4$ households in the GSTWSS
- expressed as an annual cost per household served this gives $3.5x10^6/(3x10^4) equals $1.17x10^2 / household/year for a salinity reduction of around 600 mg/l TDS
- the implied cost is therefore $(1.17x10^2)/(6 x10^2) equals $0.194/hh/year/mg/l TDS

The above cost of $0.194/hh/year/mg/l TDS may be compared with the marginal household damage cost functions of $0.281/hh/year/mg/l TDS estimated by REU (see Main Report Executive Summary). However, it is debatable whether the Corporation would have been able to continue to supply water at 800 mg/l TDS to the Great Southern Towns Scheme if it had to rely on Wellington Dam water alone, and so the salinity reduction of 600 mg/l TDS used in these calculations might be an underestimate. If this is the case then the implied cost of providing the fresher water supply could be lower than the figure of $0.194/hh/year/mg/l TDS.

II.5.2.2 Additional Water Treatment Costs

Currently, the WA Water Corporation does not incur any additional water treatment costs due to increasing salinity. Groundwater supplies, which are of higher salinity than surface water supplies, are treated by aeration for iron removal, but the higher salinity level of coastal plain ground water is not due to any modern degradation processes. However, in the longer-term future some brackish surface waters of the Darling Range such as Wooroloo Brook, which has been affected by secondary salinity, could be desalinated and mixed with fresher water.

Wooroloo Brook to the east of Perth is a possible future source that is currently saline. The WA Water Corporation has no intention of attempting to rehabilitate this catchment, but it may be developed in future for desalination and mixing with the Perth supply system. The cost of desalination as compared with the cost to the Water Corporation, if that resource had remained fresh, is an economic cost resulting from salinity.

The resource could be expected to yield 26 million m^3/year at an inflow salinity of 2100 mg/l TDS. The cost of a desalinated supply from this source, at this salinity level, is expected to be around $1.45/$m^3$. This compares with an estimated cost of $0.32/ m^3 if the resource had remained fresh. Converting to a cost per household:

- 26 million m^3/year would serve approximately $(26 \times 10^6)/(3.3 \times 10^2)$ households, equals 7.9×10^4 equals 79,000 households, where average household consumption equals 330 m^3/year
- additional cost equals $1.45/$m^3$ minus $0.32/ m^3 equals $1.13/$m^3$, which multiplied by yield equals $1.13/$m^3 \times 26 \times 10^6$ m^3/year equals $29.4 million/year

- expressed as an annual cost per household served equals ($\$29.4 \times 10^6$)/($7.9 \times 10^4$) equals $372/household/year for a salinity reduction of around 1500 mg/l TDS

- the implied cost is therefore $37/1500 equals $0.248/hh/year/mg/l TDS

The above cost of $0.248/hh/year/mg/l TDS may be compared with the marginal household damage cost functions of $0.281/hh/year/mg/l TDS estimated by REU (see Report Executive Summary). It thus appears that desalination as planned by the WA Water Corporation would be efficient.

II.5.2.3 Additional water resource management costs

Past and present catchment management actions such as tree planting have arrested the increasing trend in salinity in the Wellington Reservoir. However, further measures would be required if the reservoir were to be returned to potable quality. No plan has been prepared that can show which catchment treatments could return the reservoir to a potable condition, but current studies suggest that substantial expenditure is probably required. Such expenditure may not be justified by the economic value of Wellington water to the Water Corporation. The Water and Rivers Commission is developing a strategy, as part of the State's Salinity Action Plan, to return Wellington to potable condition by the year 2015. This strategy does not currently link treatments to their effectiveness in returning Wellington to potable condition, or to the cost of alternative treatments, though both of these investigations are planned.

The WA Water Corporation is currently investigating expenditure of $3.5 to $10.0 million to reduce Wellington salinity by 30 mg/l. Expressed as an annuity over 30 years at 7% this equals $\$0.282 \times 10^6$/year to $\$ 0.806 \times 10^6$/year. Dividing by the improvement of 30 mgL^{-1} in salinity gives $\$.0094 \times 10^6$/year/ mg/l to $\$.0269 \times 10^6$/year/ mg/l.

Reservoir yield is approximately 48 million m^3, and this is used for pasture irrigation. If, however, this catchment were being used for household water supplies it would be serving approximately $48 \times 10^6/3.3 \times 10^2 = 14.545 \times 10^4$ households. Dividing the cost per mgL^{-1} by this number of households gives from $\$.065/mgL^{-1}$/household /year to $\$.185/mgL^{-1}$/year/household as the cost. This is lower than the marginal damage cost of $0.281/hh/year/mg/l TDS estimated by REU (see Report Executive Summary). It thus appears that catchment rehabilitation would be efficient at the assumed cost effectiveness of the tree-replanting scheme.

CONCLUSIONS OF THE CASE STUDY

Utility Costs are catchment-specific

From the above discussion it is apparent that the costs of salinity to the WA Water Corporation vary between different catchments in the south west of Western Australia, depending on whether the resource is already developed, will be used in future, the type of response and the physical circumstance of the particular catchment.

The developed sources are protected by current management arrangements.

Even for those resources that are developed but threatened, such as the Collie River, it is apparent that the cost function to the Corporation is discontinuous because the engineering/technological choices are discrete. These include full or partial desalination, reservoir stratification and mixing strategies, and full or partial reafforestation.

Utility costs estimated in the case study ranged from \$0.025/household/year/mgL^{-1} TDS for desalination of Wooroloo Brook to \$0.194/household/year/mgL^{-1} TDS for building the Harris Dam. The costs of rehabilitation of the Collie River for use by households would appear to lie between these two limits, though the feasibility of this has yet to be proven.

Additivity of user damage and utility costs

From the point of view of the WA Water Corporation the costs discussed in Section II.5 should be compared with the damage costs averted in an ex-ante benefit-cost analysis undertaken from the point of view of the Corporation.

From a *national*, or *social*, perspective the Corporation's costs are also a damage cost of salinity. Prior to the implementation of abatement works, the user damage costs from high salinity in water supplies would be relevant to the national assessment. After implementation of the works some damage costs would continue to be incurred, albeit at a new, lower level of salinity, and the cost of water to users (or taxpayers if the control is funded from government revenue) would be higher due to the additional utility costs. The social optimum would be a solution that minimised the sum of these damage and control costs. But from the national, or social, point of view, both should be counted, at the appropriate level.

WA Catchments with prospective salinity control costs

The case study demonstrates that costs to the utility or water users are only incurred if a source is developed, or if salinity causes additional water supply system costs through the enforced choice of more costly alternative sources. Furthermore, many of the fresh sources that are now developed in the south west of Western Australia have stringent catchment land use management in place, so stream salinity is not likely to increase from its current low levels. Other rivers that are currently fresh, such as the Shannon and Donnelly, are excluded from development for environmental reasons, and are protected by land use management plans. Table 26 groups the river basins of the South West into 5 categories, based on their salinity and developmental status in 1983-84, and indicates where the calculation of damage and control costs will be relevant to the Audit.

The case study demonstrates that in assessing the control costs and user damage costs of salinity in particular river catchments it is essential to ascertain the contribution of the river catchment or river reach to current or future water supply quantity and quality.

Table 26 Classification of South West river basins, in terms of relevant control cost and damage cost functions

Category	River Basins	Relevant Control Cost and Damage Cost Function
1. Brackish and saline rivers of no further interest for water supply	▪ Esperance Coast ▪ Albany Coast ▪ Kent R. ▪ Frankland R. ▪ Blackwood R. ▪ Murray R. ▪ Avon R. ▪ Moore-Hill R.	Control cost function not relevant for WA Water Corporation, damage cost function not relevant for water supply consumers
2. Fresh and protected rivers which are already used for water supply	▪ Harvey R. ▪ Swan Coast (pt)	Control cost function not relevant given current management arrangements; user damage cost function applicable but rivers are fresh.
3. Fresh rivers that are not currently used	▪ Preston R.	Control cost function and water supply user damage cost function relevant only if in WA Water Corporation Plan
4. Marginal or stressed rivers that are being used or could be used in future	▪ Denmark R. ▪ Warren R ▪ Collie R. ▪ Swan Coast (pt)	Form of control cost function is related to broader diversion and management strategies; water supply user damage cost function applicable
5. Fresh Rivers which are protected from diversion	▪ Shannon ▪ Donnelly R.	Control cost function not relevant given current water allocation arrangements

Appendix III: Local Government Questionnaire and Analysis

OBJECTIVE

A questionnaire survey of local government authorities across Australia was undertaken in order to assess the ex-situ costs of natural resource degradation on local governments. The objective was to derive estimates of additional costs per head of population and per unit area in 1999 that were experienced by local governments.

Forms of degradation considered in the questionnaire included:

- increased flooding risks
- salinity and waterlogging
- erosion and sedimentation
- nutrients and eutrophication
- acid soils

QUESTIONNAIRE DESIGN

It was judged likely to be clearer to respondents if the questionnaire covered all cost increases, rather than ask them to try to separate out ex-situ and in-situ effects.

Also, it was considered to be too ambitious to try to get a quantified answer from respondents in terms of a measure of degradation. It is anticipated that the National Land and Water Resources Audit will itself be in a position to supply the best available quantification of the severity of resource degradation across Australia. Therefore, the questionnaire concentrated on (i) identifying the ***types*** of degradation that are affecting local government and (ii) obtaining estimates by local governments of the ***percentage reduction in capital and operating costs*** that they think they could achieve across a range of cost items if natural resource degradation in their area could be reduced.

A copy of the questionnaire and accompanying instructions is given at the end of this Appendix.

It will be seen that no attempt was made to tie cost changes to specific levels of degradation within the questionnaire. This was done in the interest of keeping the questionnaire as simple as possible, despite dealing with a difficult topic. It was anticipated that sufficient numbers of responses would be obtained from regions that were dominated by one or perhaps two major forms of degradation, to allow analysis of the influence of particular types of degradation using extraneous data. For example erosion and sedimentation is a problem in the north of coastal Queensland, but salinity is not present there.

SAMPLE AND RESPONSE

Sample design

A random sample of 220 local governments was obtained using the Australian Local Government Association's Directory *Australian Local Government Council Listing December 15th 1999*. This was done in two equal stages. The second mail out was undertaken when it was realised that overall response was low.

Before taking the sample councils in offshore islands and major metropolitan local government authorities were excluded, except for some that lie on the periphery of a metropolitan area. A total of 706 local government Councils is listed in the directory, of which 87 were excluded as being metropolitan and 5 in offshore islands. Thus, the survey of 220 councils was intended to capture a representative sample of approximately one third of mainland local governments (including Tasmania) outside of the metropolitan areas.

Response

Overall, the response rate has been disappointing with a total of 30 responses, of which 17 were a "nil return", indicating that the responding local government felt that natural resource degradation was not affecting its costs, and a further three were not analysable due to insufficient data. The responding local governments are listed in Table 27.

Nevertheless, the data should not be dismissed as valueless. The responding councils that reported cost effects had a combined population of over 700,000, and the respondents were spread across regions that are known to be suffering from resource degradation in one form or another.

Table 27 Responding Councils

Councils which reported costs arising from natural resource degradation	Councils which reported that natural resource degradation did not affect their costs
Queensland:	Queensland:
▪ Boulia	▪ Laidley
▪ Gold Coast	▪ Millmerran
▪ Johnston	
▪ Kingborough	
▪ Thuringowa	
▪ Mareeba	
▪ South Burdekin	
New South Wales:	New South Wales:
▪ Mildura	▪ Bogan
▪ Gloucester	▪ Wingecarribee
	▪ Hay
Victoria:	Victoria:
▪ Loddon	▪ City of Ballarat
▪ City of Greater Shepparton	▪ George Town Council
Tasmania:	Tasmania:
▪ West Tamar	
South Australia:	South Australia:
▪ Mount Remarkable	
Northern Territory:	Northern Territory:
▪ Katherine	
▪ Darwin	
Western Australia:	Western Australia:
▪ Cunderdin	
▪ Corrigin	
▪ Kellerberrin	
▪ Northam Town	
▪ Pingelly	
▪ Shark Bay	

RESULTS

Overview

Table 28 summarises the counts obtained, according to each form of degradation and each affected area of local government operations mentioned in the questionnaire. It is seen that many respondents reported that multiple forms of resource degradation had affected their costs, suggesting that regions that suffer from one form of degradation often suffer from other forms as well.

The three most commonly mentioned causes of cost increases were (i) increased flooding risks, (ii) salinity and waterlogging, and (iii) erosion and sedimentation. Fewer respondents mentioned "nutrients and eutrophication" or "acid soils". The areas of local government operations most commonly cited as being affected by cost increases were, in order of frequency: (i) roads, bridges, paths and verges, (ii) land management activities, (iii) groundwater pumping and (iv) surface water drainage. The first and third of these are clearly dealing with damage problems that are in-situ in nature, while the second and fourth are more likely to be concerned with addressing ex-situ problems across all types of resource degradation and are more in the nature of control costs.

Table 28: Number of respondents affected by each type of resource degradation

Area of Local Government Operations	Increased Flooding	Salinity & Waterlogging
Land Management	9	5
Buildings repair & maintenance	2	5
Waste mgt & landfills	2	1
Groundwater pumping	5	5
Underground tanks	0	0
Swimming pools	0	1
Graveyards	2	2
Roads, bridges, paths & verges	9	9
Other transport	1	0
Health services	0	0
Surface water drainage	7	5
Parks, gardens, sporting venues	2	6
Environmental mgt & protection	2	0
Other items	0	1
Total	41	40

Note: as many respondents suffered increased costs from multiple forms of resource degradation the numbers sometimes exceed the total number of respondents (n = 20)

II.4.2 Additional costs due to natural resource degradation

Table 29 summarises the reported operating costs that local councils incurred as a result of all forms of natural resource degradation in their areas. Responding councils had a combined operating cost in affected areas of operation of $ 34.6 million. Just under a half of this was on roads. Respondents estimated that around

16% of these costs could be avoided if resource conditions in their areas could be improved. The main areas for percentage cost reduction were land management activities and environmental management and protection, activities that are obviously addressing resource degradation. After these, the main areas where costs could be reduced if natural resource conditions improved were roads etc and parks & gardens. Other areas of current operations where cost reductions could be achieved providing natural resource conditions could be improved included waste management /landfills, groundwater pumping, and surface drainage.

Overall average per capita cost savings contingent on improved resource conditions amounted to $7.47/capita of the respondents' populations, the main areas of potential savings being land management, environmental management and roads.

Table 29 Operating costs of respondents, and the estimated cost reductions if natural resource condition could be improved.

Area of operation	Total costs of respondents ($000s)	Achievable cost reduction (%)	Extra Cost ($000's)	Per capita extra cost ($)
Land Management	3,208	47.8	1,533	2.06
Buildings repair & maintenance	670	10.4	70	0.09
Waste mgt & landfills	765	12.0	92	0.12
Groundwater pumping	136	65.1	88	0.12
Underground tanks	0	0.0	0	0.00
Swimming pools	315	0.2	1	0.00
Graveyards	323	19.1	62	0.08
Roads, bridges, paths & verges	15,978	8.1	1,293	1.74
Other transport	35	2.0	1	0.00
Health services	0	0.0	0	0.00
Surface drainage	597	13.6	81	0.11
Parks, gardens, sporting venues	9,476	8.6	811	1.09
Environmental mgt & protection	3,085	49.1	1,516	2.04
Other items	36	25.0	9	0.01
ALL ITEMS	34,622	16.0	5,555	7.47

The capital costs reported to have resulted from resource degradation are shown in Table 30. Responding councils had a combined average annual capital cost in affected areas of operation of $ 41.2 million. Slightly over a half of this was on roads.

Table 30 Capital costs of respondents, and the estimated cost reductions if natural resource condition could be improved.

Area of operation	Total costs of respondents ($000s)	Achievable cost reduction (%)	Extra Cost ($000's)	Per capita extra cost ($)
Land Management	9,265	0.91	84	0.1
Buildings repair & maintenance	980	0.76	7	0.0
Waste mgt & landfills	4,090	0.08	3	0.0
Groundwater pumping	1,216	2.15	26	0.0
Underground tanks	0	0.00	0	0.0
Swimming pools	160	0.75	1	0.0
Graveyards	345	1.04	4	0.0
Roads, bridges, paths & verges	21,032	1.71	360	0.5
Other transport	75	0.40	0	0.0
Health services	0	0.00	0	0.0
Surface water drainage	1,228	2.21	27	0.0
Parks, gardens, sporting venues	1,692	1.12	19	0.0
Environmental mgt & protection	1,105	6.82	75	0.1
Other items	29	6.00	2	0.0
ALL ITEMS	41,217	1.48	610	0.8

Respondents estimated that only 1.5% of these costs could be avoided if resource conditions in their areas could be improved. The percentage cost reduction varied between 7% for environmental capital works to less than 1% for several items, and most were less than 2%. By far the main area for cost reduction in dollars and per capita dollars was on roads etc. Other areas of capital investment where cost reductions could be achieved providing natural resource conditions could be improved included investment in land management and environmental management: clearly these activities are of the nature of control costs.

Overall average per capita capital cost savings contingent on improved resource conditions amounted to $0.80/capita of the respondents' populations, the main areas of potential savings being land management, environmental management and roads. Thus the potential reductions in capital cost outlays by local government appear to be much smaller than those for operational cost, if natural resource conditions improve.

III.4.3 Regional analysis: Western Australia

In order to examine the likely influence of salinity, a regional analysis was undertaken of a group of councils that suffer solely from salinity problems at present, namely the responding councils from Western Australia.

The reported costs for these councils, shown in Table 31 are considerably higher on a per capita basis than the figures noted above for the sample as a whole. This group of councils reported additional operating costs of $44.8/capita/year and additional capital costs of $0.1/capita /year.

Table 31: Extra operating costs per capita contingent on natural resource degradation (viz salinity) in responding Western Australian councils

Area of operations	Operating	Capital	Total
Land Management	1.0	0.0	1.0
Buildings repair & maintenance	0.6	0.5	1.1
Waste mgt & landfills	0.0	0.1	0.1
Groundwater pumping	0.9	0.0	0.9
Underground tanks	0.0	2.0	2.0
Swimming pools	0.0	0.0	0.0
Graveyards	0.0	0.0	0.0
Roads, bridges, paths & verges	34.1	0.0	34.1
Other transport	0.0	22.4	22.4
Health services	0.0	0.0	0.0
Surface water drainage	3.9	0.0	3.9
Parks, gardens, sporting venues	3.4	1.8	5.2
Environmental mgt & protection	0.0	0.4	0.4
Other items	0.8	0.0	0.8
TOTAL	44.8	0.1	44.9

Regional analysis: Murray-Darling Basin

Like the responding councils in Western Australia, those responding from within the Murray-Darling Basin are predominantly affected by salinity. The group of responding councils from the Murray-Darling Basin reported additional operating costs of $23.0/capita/year and additional capital costs of $0.9/capita /year: see Table 32. While there seem to be differences in relative cost as between the Western Australian and Murray-Darling councils, they both are very significantly different from reported extra costs due to natural resource degradation noted above for responding councils in Queensland, which represent the erosion and sedimentation component of additional costs.

Table 32 Extra operating and capital costs per capita contingent on natural resource degradation (mainly salinity) in responding councils within the Murray-Darling Basin

Area of operation	Operating	Capital	Total
Land Management	0.0	0.0	0.0
Buildings repair & maintenance	0.7	0.0	0.7
Waste mgt & landfills	0.0	0.0	0.0
Groundwater pumping	1.6	0.0	1.6
Underground tanks	0.0	0.0	0.0
Swimming pools	0.0	0.0	0.0
Graveyards	0.0	0.0	0.0
Roads, bridges, paths & verges	13.2	0.9	14.1
Other transport	0.0	0.0	0.0
Health services	0.0	0.0	0.0
Surface water drainage	0.0	0.0	0.0
Parks, gardens, sporting venues	8.3	0.0	8.3
Environmental mgt & protection	0.0	0.0	0.0
Other items	0.0	0.0	0.0
TOTAL	23.7	0.9	24.6

DISCUSSION

While still deficient in terms of total numbers of respondents, the analysis presented above suggests a number of tentative conclusions:

- The questionnaire design appears to have been appropriate for local councils to complete, as no difficulties in completing the questionnaire were reported by respondents.
- Local councils' costs are being affected significantly by natural resource degradation.
- Indicative figures for areas suffering from salinity are $25.0/capita/year for councils in the Murray-Darling Basin and $50.0/capita/year in Western Australia.
- The reported additional costs appear to divide approximately equally as between (i) damage costs in the form of additional capital and operating expenditures on roads, and (ii) control costs such as expenditures on land management and environmental management and protection.
- By far the largest element of reported additional costs due to salinity or rising ground water tables is on items that are of an "in-situ" nature.

It is emphasized that the costs reported in this paper are the *additional* costs incurred by *local councils*. From current studies being undertaken by REU for the Western Australian Rural Towns Program it is evident that local councils bear only a part of the total costs of salinity and waterlogging. For example, it is likely that State Government costs are at least of a comparable order of magnitude, and that costs to private sector organisations and households may reasonably be expected to be roughly equal to the total public sector costs. Thus, a very rough yet conservative estimate would be that per capita social costs arising from the types of natural resource degradation dealt with in the questionnaire are at least four times the amounts reported in this Appendix.

FORM LETTER ADDRESSED TO COUNCILS

«Title» «First_Name» «Last_Name»

«Position»

«Company»

«Address»

«City»

«State» «Post_Code»

18/4/00

Dear «Title» «Last_Name»,

Costs of Land and Water Degradation in Australia

A Project of the National Land & Water Resources Audit

The Resource Economics Unit is working with CSIRO Land and Water, and Dames and Moore Pty Ltd., on this national study to quantify the economic costs of natural resource degradation across Australia.

Salinity, rising groundwater tables, erosion, sedimentation, nutrient enrichment of waterways, acid sulphate soils and eutrophication are each important and vary regionally.

I am seeking your assistance in quantifying the costs to local governments of these forms of degradation, by completing the enclosed questionnaire.

I emphasise that this study is of strategic importance for future government policies on protecting and rehabilitating degraded land and water resources.

I have also enclosed some information about the Resource Economics Unit.

Thank you in anticipation of your cooperation.

Yours sincerely,

Jonathan F. Thomas.

QUESTIONNAIRE

NATIONAL LAND & WATER RESOUCRES AUDIT

COSTS OF NATURAL RESOURCE DEGRADATION

LOCAL GOVERNMENT QUESTIONNAIRE

When you have completed the questionnaire, please return it to:

Jonathan Thomas

Resource Economics Unit

Amberley House

35 Union Street

Subiaco

Western Australia 6008

For queries call:

TEL/fax: 08 9388 2461 or Email: recunit@enternet.com.au

1. Your name………………………………………………

2. Position…………………………………………………….

3. Contact Number(s)…………………………………………

4. Local Government Organisation…………………………………………………..

5. Population Served……………………………Percentage Urban……………………

6. Area administered…………………………………….Sq Km

7. If you do not suffer ANY costs as a result of natural resource degradation, please put a cross in this box and return this page only.

☐

1. Please add any comments on issues related to this questionnaire here.

…… …………………………………………

INSTRUCTIONS FOR FILLING IN THE QUESTIONNAIRE

Table 1 lists different areas of Local Government operations, and different kinds of natural resource degradation, which can lead to increased costs. Please tick the items where your costs are affected, and the kind of natural resource degradation that causes the increased cost.

Table 2 repeats the list of Local Government operations, and has five columns to be filled in, if your organization experiences cost increases.

- Column 1: please tick if your organisation's costs for this item are affected.
- Column 2: please enter the typical total annual operating costs incurred by your organisation in each ticked area by giving EITHER the actual cost with a $ sign, OR by using the following scale with a # sign (clearly, we would prefer the more accurate figure if you can give it).

Cost Range (per year):	Enter one of the numbers below in Column 2
Less than $5,000	#1
$5,000 to $9,999	#2
$10,000 to 19,999	#3
$20,000 to $49,999	#4
$50,000 to $99,999	#5
$100,000 to $499,999	#6
$500,000 to $999,999	#7
Over $1,000,000	#8

Column 3: please enter the total capital costs incurred by your organisation during the last 5 years using EITHER the actual amount with a $ sign, OR the above scale with a # sign.

- Column 4: please enter the percentage reduction in operating costs that you think could be achieved against each item ticked in Column 1, if the adverse natural resource conditions, which have affected your costs, could be rectified.
- Column 5: please enter the percentage reduction in capital costs which you think could have been achieved against each item ticked in Column 1, if the adverse natural resource conditions, which affected your costs, could have been be rectified.

For example, a single row in your completed Table 2 might look like this:

Roads	√	4	$85,000	20%	nil

This would indicate that (i) your road costs are affected by natural resource degradation in your area, (ii) your typical annual operating costs for roads are in the range $20,000 to $49,999, (iii) your organisation had capital expenditure related to roads of $85,000 during the last five years, (iv) you believe your annual operating costs could be reduced by 20% if the condition of natural resources in your area were improved and (v) the capital expenditure item would not have been changed by improved natural resource condition.

TABLE 1: WHICH FORMS OF NATURAL RESOURCE DEGRADATION AFFECT YOUR COSTS?

Please tick which items are affected by cost increases, then indicate with a tick the kind of natural resource degradation that causes the problem.

Area of operation	Increased Flooding	Salinity & Water-logging	Erosion & Sediment	Nutrients & Eutrophication	Acid Soils
• land management					
• buildings repair & maintenance					
• waste management incl. landfills					
• groundwater pumping					
• underground tanks					
• swimming pools					
• graveyards					
• roads, bridges, pathways & verges					
• other transport services					
• health services					
• drainage services					
• parks, gardens and sporting venues					
• environmental management & protection					
• other items (specify)					
•					
•					
•					

TABLE 2: YOUR ESTIMATE OF THE COSTS INVOLVED

Area of operation	Item is relevant (tick)	Total Operat-ing Cost	Total Capital Cost	Possible Reduction Operating (%)	Possible Reduction Capital (%)
• land management					
• buildings repair & maintenance					
• waste management incl. landfills					
• groundwater pumping					
• underground tanks					
• swimming pools					
• graveyards					
• roads, bridges, pathways & verges					
• other transport services					
• health services					
• drainage services					
• parks, gardens and sporting venues					
• environmental management & protection					
• other items (specify)					
•					

Thank you for completing the questionnaire.

APPENDIX F Report on Industrial and Commercial Impact Costs Caused by Salinity

The Ex-Situ Impacts to Industrial and Commercial Water Users Due to Degradation in the Quality of Water Resources

PPK Environment & Infrastructure Pty Ltd

A Parsons Brinckerhoff Company

PPK House
101 Pirie Street
Adelaide SA 5000
PO Box 398
Adelaide SA 5001
Australia

Telephone: (61 8) 8405 4300

Facsimile: (61 8) 8405 4301

NCSI Certified Quality System to ISO 9001

23 January 2001 ABN 80 078 004 798

Our Reference /DCB/cc

23 January 2001

Dr Mike Young

CSIRO Land and Water

PMB 2

GLEN OSMOND SA 5064

Dear **Mike**

The Ex-Situ Impacts to Industrial and Commercial Water Users Due to Degradation in the Quality of Water Resources

Please find enclosed our report on the above component of the NLWRA project 7.18.6.1 (CLW 14). We have completed a comprehensive literature review and an industry survey, and developed cost functions applicable to Australian industry. The scope of this work was determined between CSIRO and the Resource Economics Unit (REU), as detailed in the REU Workplan dated 24 November 1999.

Two previous major studies (Cruickshanks-Boyd, 1983 and GHD, 1999) had estimated costs of River Murray salinity to South Australian water users. They found that the costs to industrial water users were approximately 10% of the total costs to both domestic and industrial water users.

The current study has updated this previous work and developed new cost functions for industrial and commercial water users expressed as abatement (treatment) costs per kL of water used per annum. These cost functions are as follows:

Industrial Water Use Category	% of Total Industrial Water Use	Recommended Cost Function $per kL per annum (T=TDS in mg/L, H=Hardness in mg/L)
General water use (eg washing, cleaning, site maintenance)	50%	Cost = $0.0008H (e.g. Cost = $0.0003T in SA)
Boiler feed water – commercial/industrial	23%	Cost = $0.0162T
Cooling tower – operation and maintenance	13%	Cost = $0.0096T
Process water	15%	Cost = $0.003T

A generalised cost function, based on the above distribution of industrial water use is recommended, namely:

Cost = $0.0056T per kL per annum

where T = TDS in mg/L

A generalised cost function has also been developed for commercial water use (offices, public buildings, hotels, education facilities, shopping centres, hospitals) namely:

Cost = $0.00237T per kL per annum

where T = TDS in mg/L

Yours faithfully

Dr David Cruickshanks-Boyd

National Manager - Environmental Services

PPK Environment & Infrastructure Pty Ltd

Context and Scope of this Study

Introduction and Context

This report represents one component of the broader economic study being managed by CSIRO Land and Water, on behalf of the National Land and Water Audit. The CSIRO-led project is, in turn, part of Theme 6 of the National Land and Water Audit – Theme 6, Capacity for Change. The objective of the CSIRO-led study is to estimate the economic impacts of natural resource degradation.

This particular report addresses the economic impacts to industrial and commercial water users arising from resource degradation – referred to as *"ex-situ impacts"*.

A comparison study, being undertaken by the Resource Economics Unit, addresses the economic impacts to domestic water users and to municipal water authorities – also ex-situ impacts.

The detailed scope of these two "ex-situ" impact studies was presented to the study manager (CSIRO) by the Resource Economics Unit in the Workplan dated 24 November 1999.

Scope of This Study

The following summarises the key elements of the scope of the REU-PPK study:

- The estimates of the national economic costs of resource degradation should include abatement costs as well as damage costs, with appropriate care being taken to avoid "double counting". Damage costs may be defined as those economic impacts which may directly result from the resource degradation, whereas abatement costs may be defined as those economic impacts related to improving the resource condition (or arresting the decline in the resource condition). Since the objective of government policy must be to maximise net benefits to society, both damage and abatement costs must be considered.
- The economic impacts of ex-situ resource degradation should address salinity, turbidity/sedimentation and nutrients/eutrophication only.
- Damage/abatement cost functions should be identified for each type of impact, for use in benefit-cost analysis at the project or catchment level.
- As far as possible, due to the limited budget available for this component of the overall study, existing literature and information should form the basis of the analysis, supported where possible by case study information.
- Damage cost functions will be provided as annualised (total) capital and operating costs incurred by receptors per unit of resource degradation in 1996/7, with adjustment to year 2000 price levels.
- Cost functions will be expressed as damages incurred per capita, per household, per establishment, or per unit of water used, as appropriate.
- Indicative estimates of potential abatement expenditures will be developed by the Resource Economics Unit. Estimated abatement expenditures over a 24 year timeframe (from 1996/7 to 2020/21) will be provided as regional

totals in the first instance. Where possible, these expenditures will be attributed to cost-bearing sectors eg industry, households and governments.

- The following were outside the REU-PPK brief (ie not included in the scope of this study):

    < all *'in situ'* effects of resource degradation;

    < pesticide contamination;

    < acid-sulphate soils;

    < degradation impacts of flooding;

    < degradation impacts of draughts SHOULD THIS BE DROUGHTS; and

    < general landscape deterioration.

- CSIRO/Dames & Moore/NLWRA are responsible for production of GIS type data on population, households and water use – to be incorporated into the overall model that generates dollar values and locations for costs.

Methodology

Literature Review

Approach
A comprehensive literature review was undertaken as a key component of this study, the methodology for which is described in this section, together with a brief summary of the major contributions from the previous research undertaken and reviewed. Sections 3 and 4 of this report discuss the research findings in more detail.

The aim of the literature review was to establish what published research has been done in respect of the economic impacts of water resource degradation on industrial and commercial water users; to critically analyse this past research; and to identify data gaps which should form the focus for additional work in the present study.

The following data sources were searched during the literature review:

- Current contents;
- Streamline;
- Compendex;
- Industrial Civil Engineering Abstracts;
- Waterhen;
- Aqualine;
- Water Resources Abstracts;
- ASCE;

- Science Citation Index;
- Dialog;
- Biological Abstracts;
- Macspirs;
- Ecological Abstracts;
- Aquatic Science and Fisheries Abstracts; and
- Econlit.

In addition, contact was made with the following organisations to identify additional information:

- SA Water Corporation;
- CRC for Water Quality and Treatment;
- Adelaide University;
- Flinders University;
- AWWA;
- Murray Darling Basin Commission;
- State Library of SA.

Summary of Outcomes of the Literature Review
There have been very few reports produced which have examined the impacts on industrial and commercial users of water resource degradation.

AMDEL Studies

The first major studies in Australia were commissioned by the Engineering and Water Supply Department of South Australia (E&WS) between 1977 and 1983 and undertaken by the contract research and development organisation AMDEL. The aim of the AMDEL studies was to assess the potential economic benefits to South Australia to be gained from reductions in the salinity of the River Murray.

The first AMDEL study was undertaken by Blesing and Tuffley (1977), which found that the only significant studies accessible in the literature at that time had been associated with the Colorado River Water Quality Improvement Program in the USA. Using the methodology derived by the US investigators, Blesing and Tuffley concluded that economic impacts on municipal and industrial users of River Murray water in Adelaide would be $0.00017/a/kL/unit increase in total dissolved solids in 1977. However, Blesing and Tuffley emphasised that these estimated impacts were 'order of magnitude' costs only. Furthermore, they noted the significant differences in the chemical composition between the Colorado and Murray river waters with the latter having much higher chloride levels and lower hardness levels.

Following the first AMDEL study, three further studies were reported in 1980, 1982 and 1983 (Dillon, 1980; Cox and Dillon, 1982; and Cruickshanks-Boyd, 1983). Stage 1 of these additional studies involved basic data collection and methodology development (Dillon, 1980). Stage 2 of the additional studies resulted in two reports; one on the economic impacts of River Murray salinity on domestic water users (Cox and Dillon, 1982) and the other on the economic impacts of River Murray salinity on industrial water users (Cruickshanks-Boyd, 1983).

Cox and Dillon (1982) concluded that the domestic impact of a 1 mg/L rise in the salinity of the River Murray at Morgan amounted to an economic impact of 22c/household/per year (at 1980 prices). Cruickshanks-Boyd (1983) concluded that a 1 mg/L rise in River Murray salination at Morgan would amount to an economic impact to industrial water users in South Australia of between $5,360 and $6,010 per year.

The following broad categories of impact on **industrial water users** were identified and costed: steam generation; cooling water and process water. Of these three broad categories, the economic impacts on steam generation (related to blowdown costs and softening/demineralisation costs) were approximately 70% of the total costs, with cooling water and process water impacts contributing 25% and 5% respectively.

Other Studies

We have been unable to find any other reports which have attempted to estimate the economic impacts to industrial users of water resource degradation, to the same level of detail of the AMDEL studies, other than the major study undertaken by GHD on behalf of the Murray Darling Basin Commission (GHD, 1999). Several reports published after the AMDEL reports have included the AMDEL estimates in their findings, but without updating or attempting to improve the estimates (Bain, 1991;Dwyer Leslie, 1984a and 1984b; Creswell, 1986; Murray Darling Basin Commission, 1989; Whish-Wilson and Lubulwa, 1997; Whish-Wilson and Shafron, 1987; Wilson, 1995a; Wilson, 1995b; Gomboso et al, 1995; and Oliver et al, 1996).

GHD Study

GHD were commissioned by the Murray Darling Basin Commission in 1998 to undertake a major review of the economic impacts of the River Murray System salinity (GHD, 1999). In respect of industrial water users, the GHD study examined the impacts on cooling towers, boilers (commercial and industrial) and process water treatment.

The following cost functions were established for industrial and commercial water users for these three categories of water use:

Cooling Towers

Cooling tower cost = $0.0009T per kL per year.

(T = TDS in mg/L)

Boilers

Boiler feedwater cost per kL per year} = $0.0049T + 0.3 (where T <265 mg/L) or

= \$1.6 (where T >265 mg/L)

Industrial Process Water Treatment

Where the process requires high quality water supply, the following cost function was calculated/estimated to apply:

Treatment cost per kL per year	= \$0.0056T (where T <286 mg/L) or
	= \$1.6 (where T >286 mg/L)

The GHD (1999) report then applied these cost functions to estimate the economic impact of River Murray Salinity to South Australia. They concluded that in the range 400-800 mg/L TDS, the relative contributions of non-agricultural economic impacts are:

	% Contribution
Domestic Impacts	89%
Industrial Impacts:	
▪ Boilers	2%
▪ Cooling Towers	5%
▪ Process Water	4%

Additional Data Collection – Industry Survey
As part of the current study, a survey was undertaken to further refine the Amdel and GHD work.

The survey targeted two key groups: service providers, in terms of those who service water using plant and equipment, including water softeners and boilers; and selected industrial water users of associated equipment.

Survey candidates were selected based on sectors listed by the ABS. Specific organisations were identified with the assistance of the South Australian Employers Chamber. The number of contacts was kept to a minimum by targeting those companies most likely to be impacted by a decline in water quality supplied to their operations. Two water treatment service providers were included in the survey.

The Industry sector surveyed for the study are as follows:

- Plastic and Rubber
- Metal Treatment/Finishing
- Service Organisations (boilers, water cooling tower etc)
- Steel Manufacturing
- Meat Processors

- Commercial Buildings
- Food and Beverage
- Brickmakers
- Wine, Beer and Distillation
- Printing
- Dairy Processors
- Timber Manufacturers
- Fabric Cleaners.

The survey was aimed at determining annual costs of maintaining water-using plant and equipment, as a function of decline in water quality. This included cost areas such as:

- Equipment used, pre-filters cooling towers, boilers, water softeners.
- Maintenance regime, labour, parts.
- External service frequencies ie service fee increase.
- Water cost and quality.
- Capital expenditure of plant and equipment.

Other information obtained included number of employees at the site, units of product processed, and associated downtime costs. Details of equipment used, type of equipment and numbers were sought to assist in establishing a model of water use at the site. Process descriptions were requested, related to water-using plant and equipment.

Repairs and maintenance (R&M) questions related to the type of maintenance schedule conducted, for example what percentage of time is attributed to preventative maintenance compared to reactive maintenance.

The surveys revealed that accurate records are usually kept on repairs and maintenance, and that those records were able to be used to determine the percentage of costs related to servicing water-using equipment.

Information was obtained from service contractors in terms of the actual servicing and cost increases due to water quality degradation.

Information was also obtained to establish the relationship between supplied water quality and potential impacts on the product produced (ie process impacts).

Conduct of the Survey

Thirty two industrial producers were selected for the mail out survey. Two service providers were selected. Six detailed responses were received, along with a number of more-limited responses. This response confirmed that generally companies do not monitor costs related to water quality, other than the cost of third party servicing and general repairs and maintenance.

Detailed Findings of Literature Review

Early Studies
The USEPA (1971) study on salinity impacts of users of the Colorado River included industrial penalty costs associated with use of cooling water and boiler feed water. Other industrial penalty costs were recognised with the other industrial uses (process water, general-purpose water) but were not included because of the difficulty of attempting an impact assessment of the large number and varied manufacturing industries in Southern California. It was considered that even though the derived penalty costs were understated they nevertheless represented the impacts associated with up to 70% of the total industrial water used.

Cooling and boiler systems which were sensitive to minor changes in salinity of the make-up water were evaluated. These included fresh water cooling systems which had controlled bleed-off at a salinity of 2,000 mg/L TDS and low-pressure boilers with a blow-down set at 3,500 mg/L TDS. It was found that cooling water use accounted for at least seven times the boiler feed usage and therefore a volume-weighted tolerance was calculated to be 2,200 mg/L TDS.

In calculating industrial penalty costs, four steps were determined:

- present and future make-up water demands for the cooling and boiler feed water uses;
- the quality of the available supplies including the effect of blending different supplies;
- the required increase in make-up water to offset quality degradation in the towers and boilers calculated by mass balance; and
- the penalty costs.

Based on target year salinity levels at Hoover Dam of 876 mg/L TDS in 1980 and 990 mg/L TDS in 2010 compared to 697 mg/L TDS in 1960 the total penalty costs were expressed as $US950/mg/L TDS in 1980 and $US1820/mg/L TDS in 2010.

In the later US Bureau of Reclamation study of impacts due to changes in Colorado River salinity, data was taken from the EPA (1971) work and industrial detriments were estimated to be $US1500/mg/L for the entire lower region (Kleinman, Barney and Titmus, 1974).

In the generalised costs presented by Lawrence (1975) industrial impacts were determined using essentially data determined by Leeds, Hill and Jewett (1968) and Eliassen and Rowland (1962). A linear relationship was assumed between the industrial cost and TDS in the range 200 mg/L TDS to 800 mg/L TDS. The costs were calculated on the basis of industry consuming 20% of the total municipal and industrial usage which was assumed to be 247 kl/cap/a.

At 200 mg/L TDS the cost of industrial water treatment was estimated to be US0.9c per kL; at 500 mg/L – 2.2c/kL; and at 800 mg/L – 3.6c/kL.

Blesing and Tuffley (1977) utilised the USEPA methodology and applied it to the South Australian situation. In estimating the additional make-up and treatment costs for cooling towers water costs were assumed to be 17c/kl and the cooling tower bleed controlled to a salinity of 2,500 mg/L TDS. Calculations were based on a hypothetical case of having a cooling tower with an evaporation rate of 1 kl/a. The annual additional cost was calculated for different salinity levels up to 800 mg/L TDS.

A similar cost estimation was made for boilers assumed to have a blowdown operating at a TDS of 3,000 mg/L.

The relative annual cost for additional make-up to cooling towers and boilers was estimated using the industrial water consumption calculated for the River Murray.

The total industrial impact for River Murray water was estimated to be about $1,100a/mg/L TDS in 1977 and projected to be about $2,500/a/mg/L TDS in year 2010 for an average salinity of 500 mg/L.

Australian Studies

Effect of Water Quality on Steam Generation

During boiler operation it is necessary to control the level of dissolved solids in the boiler at a maximum desirable value. Typically, this maximum desirable level is of the order of 2,000 mg/L TDS.

A consequence of this requirement is that a certain proportion of the boiler water must be removed as "blowdown". Th proportion removed increases as the salinity of the boiler feedwater increases, and vice versa. There are three principal economic costs associated with the blowdown operation, namely loss of heat energy, loss of water and loss of treatment chemicals. In their report, Blesing and Tuffley (1977) had considered only the latter two costs, and salinity impact studies carried out as part of the Colorado River Water Improvement Quality Programme similarly had not included loss of heat energy in their estimates of economic impact. However, discussions with specialists in steam generation emphasised the overwhelming importance of the loss of heat energy.

The influence of salinity on the blowdown costs associated with boiler operation depends on whether the supply water is softened or demineralised prior to use as feedwater for the boiler. (Almost without exception one of these two methods of water treatment are applied to supply water used as boiler feedwater.) If the supply water is softened then the feedwater salinity will increase directly as the supply water salinity increases. If the supply water is demineralised, however, then the feedwater salinity is independent of the supply water salinity.

Cruickshanks-Boyd (1983) extended the cost estimations of the effect of salinity on steam generation costs, to include the costs of heat energy lost. He concluded that the economic impact of salinity (for salinities in the range 200 to 600 mg/L) on steam generation costs in South Australia ranged from $1.38 million at 200 mg/L TDS, to $3.27 million at 600 mg/L TDS. Using the Cruickshanks-Boyd (1982) methodology, the relationship between cost and salinity can be expressed as a linear function:

$$y = 0.009\,x + 0.0824$$

where y = cost of make-up water in $ per kL
and x = total dissolved solids (mg/L)

GHD (1999) further updated the cost estimates by including pre-treatment capital costs as well as operating costs (the Amdel study by Cruickshanks-Boyd in 1982 had only included operating costs). Major suppliers of boiler feedwater chemicals were contacted to establish operating regimes and costs. Major suppliers of ion-exchange and reverse-osmosis equipment were similarly contacted, as well as major boiler manufacturers, such as Maxitherm Boilers, who consider that a 'properly maintained' boiler will have a consistent life, regardless of the TDS of the feedwater. The approach taken in the GHD study was therefore to concentrate solely on blowdown, and the chemical, water and energy losses involved.

Water losses in boiler operation are replaced by make-up water which adds some TDS. This concentration cycle is controlled to limit the maximum concentration of substances in the boiler and generally a TDS limit is set. For a medium pressure boiler, this TDS limit would typically be approximately 2,000 mg/L.

As these TDS levels, scaling, corrosion and other undesirable processes are controlled by adding chemicals to the boiler feed water. As a proportion of these are lost in the blowdown, a cost is incurred.

In addition, it is generally considered inappropriate to operate a boiler at greater than 10% blowdown. For feedwater with relatively high TDS levels, this means some form of pre-treatment must be fitted to reduce the incoming TDS in the make-up water. For waters less than about 265 mg/L TDS, ion exchange can be used. Above this limit, membrane processes such as reverse osmosis are typically used. Ion exchange tends to have a relatively low capital cost but can only reduce the TDS by a limited amount. Reverse osmosis systems are more costly, but can achieve low TDS levels from an elevated level in the feed stream, thus reducing blowdown requirements.

There is an additional cost associated with blowdown. The water lost through blow down is at an elevated temperature and has an associated energy cost which is directly proportional to the amount of blowdown.

Cost analyses were undertaken on the basis of the following assumptions:

- Costs are incurred from the following factors:
  - < loss of water and boiler chemicals in the blowdown;
  - < capital and operating costs of the required pre-treatment equipment;
  - < energy loss in the blowdown water.
- Boiler life does not alter with TDS. This applies if appropriate operating and maintenance regimes are followed.
- Boilers are gas fired, with an incremental energy cost of 0.554c/MJ.
- Ion exchange is workable until the feed TDS is approximately 300 mg/L.
- Reverse osmosis can be used with minimal pre-treatment, which may not be true for unfiltered supplies.

The GHD analysis produced the following outcomes, compared to the AMDEL methodology:

- At lower TDS levels, increasing the feed TDS requires additional blowdown a 'step' change to more expensive pre-treatment (ion exchange or RO) occurs at approximately 300 mg/L TDS.

- At higher TDS levels, the costs of installing RO has already been incurred, with only the incremental cost of RO treatment for increasing TDS. This cost increase is much lower than the cost increase for installation.
- The AMDEL figures are much lower because they ignored pre-treatment capital costs and considered only operating costs. AMDEL did not investigate boilers at lower feed TDS levels.

GHD-derived the cost function can be expressed as:

Boiler Feedwater Cost ($/kL feedwater/yr) = 0.0049T + 0.3

= 1.6 (where T > 265 mg/L)

where T = TDS in mg/L

Effects of Water Quality on Cooling Towers

In the 1982 Amdel study, Cruickshanks-Boyd (1983) applied the following methodology. Data required to enable an assessment of the effect of salinity on cooling water were obtained from a leading company involved in water treatment of cooling equipment. From these data it was estimated that 2,520 Ml of River Murray water is consumed annually in cooling water make-up.

The salient features of the calculations were as follows:

Make up water cost – 27c/kl
Corrosion inhibitor (polymer phosphanate) cost – 0.26c/g

Calculations were made on the basis of 1 kl/year evaporation, and cooling tower bleed of 2,500 mg/l TDS containing 150 mg/l of corrosion inhibitor.

Costs were determined for a baseline salinity of 400 mg/l and for assumed River Murray salinities of 200, 300, 500 and 600 mg/l.

For example, at 400 mg/l salinity, the following calculation serves to illustrate the method:

Concentration factor = 6.25
Make-up water 6.25x = 1 + x,
where x = bleed rate in kl/year
x = 0.191
6.25x = 1.191; equivalent to a water cost of $0.322/year.
Inhibitor concentration in make-up water is 150)6.25 = 24 mg/l
Inhibitor cost is $0.074/year
Total cost is 0.322 + 0.074 = $0.396/year, based on an evaporation rate of 1 kL.

Using the same procedure, the total cost was calculated for assumed River Murray salinities of 200, 300, 500 and 600 mg/l.

An annual consumption figure of 2,520 Ml, at a baseline salinity of 400 mg/l, was used to obtain the total costs associated with cooling water use in South Australia.

The Amdel analysis estimated the cost of salinity in the River Murray on South Australian users to be in the range $748,000 at a TDS of 200 mg/L, to $942,000 at a TDS of 600 mg/L. Updated to 1998 economic costs, the Amdel (1982) analysis can be expressed by the following linear function:

$$y = 0.002\,x + 0.6776$$

where y = cost per kL of make-up water;

and x = total dissolved solids in TDS

GHD (1999) further examined the impact of salinity on cooling towers. The basis of their methodology is as follows:

Cooling towers can be divided into three broad types: single pass, where the water is not recycled; closed circuit, where the cooling water passes through some form of enclosed heat exchanger; and multipass evaporative cooling towers in which the cooling water is recycled.

The majority of operating cooling towers are multipass evaporative towers which are generally constructed of timber or fibreglass, with a small proportion being steel. Neither timber or fibreglass are affected by TDS and manufacturers believe that changes in TDS will not affect the initial cost or lifetimes of units. The GHD study therefore considered only the operating costs.

In the first two types of cooling towers the salinity of the water has no impact. In the third type, evaporative cooling towers, the water circulates through the system and then back through the tower. Water lost by evaporation is replaced by make-up water. To prevent a build up of TDS a proportion of the water is 'blown down' to waste. Operators control this blowdown to restrict the TDS in the system to some maximum figure, typically 1,500 to 2,000 mg/L.

Several problems affect cooling towers, including corrosion, scaling and microbial action. To mitigate these problems, complex additives of various types are added depending on the composition of the make-up water. These chemicals are lost in the blowdown, together with water, and these represent a cost which is directly related to the TDS of the water supply.

Based on the recommendations of major tower and pre-treatment chemical suppliers, the maximum TDS for tower operation is 2,500 mg/L. Using this maximum figure for a typical operating blowdown rate, it is possible to derive a cost/kL of make-up water. This cost includes the cost of both the water and the chemicals.

Calculation of the operating costs for cooling towers was largely based on the following information provided by NALCO (major suppliers of chemicals to the cooling water industry):

- Maximum TDS of 2,500 mg/L.
- Chemical cost of $9.10/kg.
- A typical evaporation rate of 1% of the total inlet flow.
- Typical chemical concentrations in the tower of 150 mg/L.
- Water costs of $0.40/kL.

- 25% of industrial water use is for cooling towers.

GHD determined the following relationship between cost and TDS:

Cooling tower cost ($/kL/yr) = 0.0009 T (where T = TDS in mg/L)

A comparison of the Amdel (1982) and the GHD (1998) cost estimates reveals that, at lower salinities the Amdel analysis provides a significantly higher cost impact, but that the cost impacts become similar at high salinities of the order of 1,000 mg/L.

For example at 200 mg/L:

Amdel cost = $0.7 per kL of make up water

GHD cost = $0.2 per kL of make up water

Whereas at 800 mg/L salinity:

Amdel cost -= $0.9 per kL of make up water

GHD cost = $0.8 per kL of make up water

Effect of Water Quality on Process Water

A number of industries have a set of process water quality requirements which are unique to the particular industry. In the second Amdel report, Dillon (1980) considered the following industries and associated water quality requirements.

a) Food, beverages.

b) Textiles.

c) Chemicals, oil, coal products.

d) Glass, clay, other non-metallic mineral products.

e) Basic metal products.

f) Fabricated metal products.

g) Transport equipment.

h) Industrial machinery, household appliances.

i) Leather rubber, plastic, miscellaneous goods.

Table 33 summarises various water treatment processes for specific pollutant removal.

a) Food and Beverages

Baking

The preferred water is of medium hardness (500-100 mg/L). Other salts are either not significant or may alter the quality slightly eg a stiffer dough with increasing calcium and magnesium.

Brewing

Process water is extensively used, eg pasteurisation, cooling, clean-up and bottle washing. It is important that water be soft for bottle washing, particularly with the final rinse.

The main criterion for water used directly in the brewing process and constituting a major ingredient in the final product is that it conforms to the standard of a drinking water. The taste of the product is highly dependent on the nature of the water used, but this should be viewed as the water imparting a certain character to the beer, rather than a water being 'good' or 'bad'. The chloride ion is said to alter bitterness, to give a more mellow palate and increase fullness.

A criteria that should be mentioned is the need for consistency. A brewer aims at producing a consistent product. Any drinking quality water can be used to make a quality beer but it taxes the brewer's skill to the utmost when the water which constitutes 90%of the final product is inconsistent in quality.

Confectionary

Requirements are not severe except for the need for a low dissolved salts concentration for hard candy manufacture. Maximum chloride is said to be 250 mg/L.

Dairy Industry

The requirements for process and cooling waters are generally similar to those of the brewing industry. The presence of iron, manganese or copper in the water is undesirable and the concentration limits for these ions is said to be less than those of drinking water; however, the validity of these limits is doubtful when the stated limit for chloride (<320 mg/L) is observed, as this criterion would never be achieved in most parts of Australia.

Table 33 Selection of Water Treatment Processes for Specific Pollutant Removal

Treatment	T/Dissolved Solids	Hardness	Colour/Colloids	Turbidity	Silt	Bacteria	Iron and Manganese
Screening				✓	✓		
Lime Softening and filtration		✓	✓	✓		✓	✓
Slow Sand Filtration		✓		✓			
Microfiltration				✓	✓		
Flocculation, settling			✓	✓			
Rapid Sand Filtration							
Activated Carbon						✓	

Treatment	T/Dissolved Solids	Hardness	Colour/Colloids	Turbidity	Silt	Bacteria	Iron and Manganese
Carbon Adsorption							
Dissolved Air Flotation				✓	✓		
Ultraviolet Light Disinfection						✓	
R Osmosis	✓	✓					
Filter Press				✓	✓	✓	

Crocket & Muntisov, pg 16, Modern Techniques in Water and Wastewater Treatment

Food Processing, Canning and Freezing

There are no special requirements for process water in these industries, except that canning requires a low TDS water for the final rinse.

The water incorporated into the food should not be excessively soft or hard or contain metal ions such as Fe, Mn or Cu which can alter taste. Copper can interfere with Vitamin C levels.

Soft Drink Manufacture

Production and process waters must be of at least drinking water standard. Low alkalinity is desirable because of the acid nature of the product, and final rinse water should be low in total hardness.

b) Textiles

Water is extensively used in the manufacture of textiles and quality must be high. Hardness removed to a level of 25 mg/L ($CaCO_3$) is necessary to prevent precipitation of calcium carbonate into the cloth. Copper needs to be low (0.01 mg/L) as it interferes with dyes.

c) Chemicals, Oils, Coal Products

The uses for water in this grouping are so diverse that it is not possible to specify common criteria or even to make general statements. Examples of the use or effect of water are:

- The manufacture of high purity pharmaceutical chemicals where water standards are necessarily high.
- The catalytic effect of water impurities on some chemical products.
- The combined effect of chloride concentration, temperature, pressure and stress in causing the stress corrosion failure of a stainless steel item in an oil refinery.

d) Glass, Clay, Other Non-metallic Mineral Products

Non-metallic mineral products are relatively inert and although the industries in the grouping are diverse, it can be said that in general, provided a water is drinkable, then it can be used in the manufacturing process. This certainly applies to concrete, the most widely used material of all. The adverse effects of sulphates on ceramic materials and chlorides on the reinforcing bars in concrete are not significant at the levels commonly occurring in drinking water.

e) Basic Metal Products

The main use of water for base metal production is in cooling, otherwise the requirements are not severe and drinking water criteria would be well within those applicable to these industries.

f) Fabricated Metal Products

Water is used for:

(i) Cooling/lubrication;

(ii) Stripping, pickling, cleaning;

(iii) Metal finishing et electroplating anodising.

For (i) and (ii) the requirements are not high, the main one being that hardness is low if soaps or alkaline cleaners are used. Higher standards apply for (iii) above.

g) Transport Equipment

The uses to which water is put in this category would be very similar to that of Fabricated Metal Products.

h) Industrial Machinery, Household Appliances

The comments made for 'Basic Metal Products' would equally apply to this grouping. Many of the processes would be common eg electroplating.

i) Leather, Rubber, Plastic, Miscellaneous Industries

Water is used directly in the manufacture of leather products and the requirements are surprisingly high, especially with the finishing steps. A chloride limit of 250 mg has been indicated, however, mention is made of distilled or demineralised water.

In the case of rubber and plastics the main use of water is in heating and cooling.

Cruickshanks-Boyd (1983) surveyed 100 companies to establish information on processes which are directly or indirectly influenced by the salinity of the supply water. The general response was that, with the exception of boiler feedwater and cooling tower make-up water, most industrial processes being carried out are insensitive to changes in the salinity of the supply water. However, two principal areas of salinity-related process water use were identified, namely washing and scouring processes in the textile industry, and metal finishing. In the former, large-scale softening of the mains water is performed, although two companies contacted indicated that they used bore water in preference to mains water because of its more consistent quality.

In the metal finishing industry, plating and painting operations require a consistent water quality with a low dissolved solids content. It is commonplace, therefore, to utilise demineralised water in these applications.

The River Murray study concluded that the economic impact of salinity on process water use in Adelaide ranged from $86,000 per year at a TDS of 200 mg/L, to $259,000 per year at a TDS of 600 mg/L (in 1980/81 $). These costs represented only 3.9% of the economic cost to industry (at 200 mg/L) and only 5.8% of the cost (at 600 mg/L).

GHD (1998) further examined the economic impact of process water quality on industry and concluded that industries where process water quality is significant include:

- Food
- Beverages
- Paper
- Electroplating
- Painting (automotive).

The impact of poor water quality on each of these industries is significant, and in many cases there is significant investment in pre-treatment. This investment may not be related to TDS alone, as turbidity, colour and other components (including taste and odour) may be more detrimental to the industry.

A cost relationship was developed based on the following assumptions:

- Industry would choose to install pre-treatment if TDS rose sufficiently to harm their process.
- Ion exchange is appropriate up to about 250 mg/L TDS.
- Reverse osmosis is appropriate above that level.

The cost of 'deionising' water was developed as a function of TDS up to a TDS level of 286 mg/L. While all industries do not adopt this, and choose to accept some losses and costs when TDS changes, it is not possible to estimate these costs.

GHD concluded that the process water treatment costs (to completely remove TDS) are:

Cost ($kL/yr) = 0.0056 T (where T < 286)

= 1.6 (where T > 286)

where T – TDS in mg/L

Note that only a fraction of industries will require this level of treatment.

Survey Findings

Summary of Survey Responses

The capital expenditures, repairs and maintenance and third party servicing programs related to water treatment are considered a normal day to day component of operational activities for business. Water supply quality in terms of hardness and TDS have a wide range of impacts for each business. This was reflected in the range of water treatment technologies used prior to manufacturing processes.

For example, the food and beverage sector survey results indicated a relationship between TDS and hardness in terms of the Quality Control issues specific to those business. High quality steam is linked to the level of pre-treatment used in filling operations and salination controls. The risk of bacteria contamination and wild yeast contamination are some of the Quality Control issues monitored on a daily basis, as well as those directly linked with water hardness and TDS.

Application of Survey Findings – Generic Models

The following generic models have been based on the following industry example. A factory which has a steam boiler and cooling tower used in manufacturing production.

1. Steam Boiler Plant capacity - 5000 kw (1500 m^2).
2. Refrigeration Condenser Cooling Tower capacity – 500 tonne.

The steam boiler requires mains water pre-treatment. Basic pre-treatment required for a low pressure steam boiler make up water would include a sand filter and water softener. A high pressure boiler would require better pre-treatment, such as demineralisation.

Error! Reference source not found. illustrates typical water treatment technologies employed by various industry sectors.

Filtration

Sand Filtration

Filter performance is affected by water quality issues such as sediment loads and turbidity. Generally, not all the turbidity can be filtered using sand filter, so flocculation is necessary prior to other forms of filtration. Sediment particles are filtered through a multi media sand filter. High sediment loads would result in the filter requiring additional backwashing, contributing to wear and tear on the control valves and higher water consumption due to more frequent backwashing and rinsing of the filter.

Table 34 Generic Water Treatment System Comparison by Industry Sector

Generic Model Sequence	Dairy Processor	Wine Making	Wool Processor	Beverage	Wood Products
Sand Filter	Multimedia Filter	Multimedia Filter, iron removal	Multimedia filter	Multimedia filter	Multimedia Filter
Coagulation	Carbon Filter	Water softener	Water Softener	Utrafiltration, Nanofiltration membrane.	Water softener
Filtration	10 um Filter, Utrafiltration, Nanofiltration membrane.	Boilers	Reverse Osmosis	Water Softener	Cooling Towers
Carbon Filter	Water Softener		Boiler	Boiler	Demineralisatio n
Water Softener	Anti Scalent		Water Cooling Tower		Reverse Osmosis
Utrafiltration, Nanofiltration membrane	RO membrane		Humidifiers		
Reverse Osmosis	Boiler				
Cooling tower	Refrigeration Compressor				
Boiler	Air conditioner Cooling				
Evaporation Cooling	Cooling tower water				
	CIP (Cleaning In Place)				

For example, a filter to handle a 5,000 kw boiler operation of 24 hours per day seven days per week. A typical make up water flow rate of 150 litres per minute will consume approximately 3 m^3 of water to backwash and rinse the filter each backwash cycle. It was not possible to obtain information which would enable a quantitative relationship to be estimated in terms of water quality relative to the frequency of backwashing required for the filter. Normally a filter is sized on a nominal flow rate required for its duty. The surface area would be enough to backwash at 2-3 times per week. If the level of suspended solids increases this would cause an increase in the differential pressure across the filter media. Therefore the unit may need to be backwashed more frequently, say on a daily basis, otherwise the filter media would foul and restrict the flow rate.

Although there was no information or data available to determine a quantitative relationship, an estimation is provided below which considers costs related to an increase in backwash frequencies.

Table 35 Cost Comparison for Daily Backwashing and Twice Weekly Backwashing

Daily Backwash	Water cost @ 3 kl per day x 350 days operation @ 92c kl = $966.00 water costs per annum
Twice Weekly Backwash	Water costs @ 3 kl per day x 100 days operation @ 92c kl = $276.00

Daily backwashing compared to twice weekly backwashing would therefore cost an extra $690 per annum ($966-276).

Frequent backwashing would result in additional control valve servicing etc. The standard schedule if the filter is backwashed twice weekly would be once per year. If backwashing is conducted daily the service frequency would be every three months depending on the type of control valve used. The service costs and parts could be in the order of $2000 per annum extra.

Therefore total extra costs would be in the order of $2,690 per annum.

(Further work would need to be undertaken to quantify the relationship between concentration of suspended solids, turbidity and colour and the frequency of backwashing.)

Membrane Filtration

Membrane filtration is used as a prelude to many water treatment systems throughout the world. The primary function is the removal of unwanted pollutants prior to other water treatment processes, such as UV disinfection as applied in the food and beverage manufacturing sectors or prior to equipment such as cooling towers.

Membrane filtration is very effective at removing human pathogens and it also reduces fine colloids responsible for the colour in turbid water supplies.

The traditional technologies of chemical coagulation utilising ferric or alum have always provided difficulties in terms of chemical management issues, including storage and handling of the chemicals and the ultimate disposal of the chemical sludge.

Membrane filtration is used as the preferred process at the 'front end' of most water treatment systems and is increasingly being used prior to boiler feed water and cooling tower systems.

There are three types of membrane filtration available, each of which are specific to the size and type of pollutant to be removed from the supplied water source these . Table 36 illustrates the relative size and type of filter compared to the pollutant being removed.

Table 36 Comparison of Filtration Operating Costs

Filter Type	Pollutant Type	Particle Size (Φm)	Pre-treatment Required	Cost (Cents/kL)
Sand Filter and UV disinfection	Algae, Protozoa,	90 – 8	None	12 – 17
Membrane Filtration	Bacteria, Sediment, Algae, Protozoa, Virus	150 – 0.08	None	18 – 22
Ultra Filtration	Bacteria, Virus, Colour, Organics	0.08 – 0.01	Yes	30 - 34
Non Filtration	Colour, Organics	0.05 – 0.001	Yes	42 – 46
Reverse Osmosis	Colour, Organics, Metal ions	0.001 – 0.05	Yes	60 - 65

The capital and operating costs of membrane filtration are variable and relative to the extent of operational control (instrumentation etc). On going operational expenditure consists of the frequency of membrane replacement, the effectiveness of the preventative maintenance programs and the diligence of the operator regarding routine upkeep.

Membrane filtration is used for the reduction of calcium related hardness benefits of removing colloidal solids responsible for colour in water supplies.

Surveyed information from industry and specialist water treatment contractors revealed no information available to determine a relationship between water quality and costs for membrane filtration. Although monitoring of water quality is regularly conducted the survey respondents had not examined in detail the relationship between degradation in key water quality parameters and the associated short or long term operation and maintenance costs.

Cooling Tower Operation and Maintenance

Introduction

Cooling Towers (CT) require specific water quality criteria. Cooling towers use on average one quarter to in excess of one half of water used by most industry sectors. This is due to the make-up water used by the plant itself.

The basic concept of the CT is that of a heat exchanger. Residual processing heat is dissipated by vaporisation to atmosphere. This process tends to accumulate the TDS levels in the water, as the salts are not evaporated. To offset a rise in TDS, low salt water is fed into the CT while the increased TDS water is bled from the system, also known as blowdown.

Water Quality Issues

Water quality issues associated with cooling towers include the following:

Metal Corrosion – generated by TDS the degree of corrosion is related to the increased electrical conductivity, in terms of the normal anode and cathode reactions. Metals such as iron, manganese, and aluminium facilitate the corrosion process due to their ability to oxidise. Corrosion inhibitors are added to control the extent of oxidation of metals in contact with the water.

Scaling - the principal deposits of scaling are those of calcium carbonate, sulphate and phosphate, and are associated with the presence of magnesium. Scaling is found on the hot surfaces in the cooling tower from the hot process water from the manufacturing operations. For those organisations that can afford it, ion exchange is an effective means to remove the magnesium and calcium. Phosphate and calcium are also precipitated using lime additions and filtration. However disposal of the associated wastewater may be an issue in terms of low pH etc.

Microbial Growth – is associated with the level of nutrients present in the make-up water, such as N & P. The resultant algal-like growths impede the ability of the water to flow through the cooling tower reducing the heat transfer efficiency of the system. Mixes of chemical controls are normally added to the water and include biocides, acid, and scale inhibitors. Management of health risk is the primary focus of cooling tower issues in terms of potential legionella risk.

Generic Model Example

Assume a cooling tower capacity of 500 tonne.

Operation @ 100% load 24 hours per day 350 per days per annum.

TDS controlled between 1800 – 2000 mg/1 in the tower basin water system.

Capital cost typically $7,000, with a service life of 20 years.

Water Costs

Based on 400 mg/1 TDS for the make up water, the bleed rate required will be approximately 10,000 litres per day.

Based on 600 mg/1 TDS for the make up water, the bleed rate required will be 40,000 litres per day.

An extra 30 kl of water will be lost via the bleed to drain per day. Water cost = 30 kl x 350 day operation = 10,500 kl per annum @.92c kl = **$ 9,660.00 of extra water costs per annum.**

Chemical Costs

Water treatment chemical consumption would also increase running costs due to being lost via the drain. Scale and corrosion inhibitor costs would increase by approximately $30.00 extra per day x 350 days = **approximately $10,500 worth of extra chemical costs per annum (if the TDS increased from 400 to 600 mg/litre).**

Water Softener Example

Generic Model Example

The following example reflects the cost impact of hardness on water softener operation.

Based on a 5000 kw boiler with 75% average load and 30% condensate return.
Raw water make-up = 4030 litres per hour x 24 hours = 96,720 litres per day.

Based on Mains Water 100 mg/L Total Hardness

Capacity of softener required = 9.7 kg to soften 97 m^3 water

If the water softener holds 250 litres of resin, the minimum salt usage = 11.0kg. 25 kg of salt would be required to regenerate the softener – regeneration would be once per day. Salt cost 25 kg = $4.00 x 350 day operation. Therefore, running cost per annum = $1,400.00.

Equipment capital cost approximately = $6500.

Standard service fee @ one call/per annum $500.00, and includes valve servicing, backwashing and air scouring to remove solids accumulation.

Based on Main Water of 150 mg/L Total Hardness

Salt consumption to regenerate the softener would increase to 50 kg per regeneration = $2,800.00 per annum.

Extra running cost would be $1,400.00 per annum.

Demineraliser

Generic Model Example

A water demineralisation plant to supply 100 m^3 per day of demineralised water. Based on 400 mg/1 Total Dissolved Solids (TDS).

Regeneration costs for acid and caustic.

Table.37 Regeneration Costs Per Day

Acid	180 litres	$140.00
Caustic	200 litres	$180.00
Total Regeneration Cost		**$320.00**

If the TDS of the raw water increased to 600 mg/L, to produce 100 m^3 per day of demineralised water:

Table.38 Regeneration Costs Per Day

Acid	288 litres	$224.00
Caustic	300 litres	$270.00
Total Regeneration Cost		**$494.00**

Extra cost for regeneration = $174.00
Operation of plant = 300 days per year
Total increased costs of regeneration = $52,200.00

If the demineralisation plant had to be regenerated daily due to the TDS increase of the raw water, extra wear and tear would occur in the control valves which would result in an increase in servicing. These types of plant have many valves for control of regeneration and costs associated with service could run into thousands of dollars depending on the type of valves fitted. Service contractors estimated on extra $5,000 for services due to the higher raw water TDS.

Therefore, total cost increase due to TDS rising from 400 to 600 mg/L would be $57,500 per annum.

Boiler

Introduction

As the GHD and AMDEL reports discussed all boilers use some form of pre-filter prior to the boiler units. However solids are known to accumulate in the boiler as a function of changing from the liquid phase to the steam phase. Solids are generated, as a matter of course, due to the boiler receiving make-up water. However, if the return water consists of 100% condensate very little sludge would be produced.

Solids and sludge accumulate in the boiler, controlled blowdown evacuates the sludge build up from the boiler water removing the concentration of solids. Boiler blowdown is variable and is related to the quality of the make-up water, operating pressures, water treatment and the type of boiler.

Impacts of Water Impurities on Boilers

The main issues related to water impurities in boiler water are as follows:

Scaling – is associated with the precipitate like crystals on the boiler walls. Overheating is a function of hot spots from the calcium carbonate and sulphates. Elevated amounts of silica relative to alkaline water are known to contribute to scaling.

Priming – is known as the carry over of water droplets in the steam resulting in reduced energy efficiency of the steam and contributes to the formation of salt precipitates on the superheaters. The presence of organic matter, total salinity and alkaline water determine the potential for foaming which is related to the relative viscosity of the water. Condensates resulting from priming are known to cause corrosion of the steam supply infrastructure. This requires pre treatment or conditioning.

Carryover – the transfer of a silica type material at boiling point is identified as the most damaging of substances in the boiler chamber. The risk of carryover increases with pressure and hence temperature, and impacts on components such as turbine blades.

Corrosion – water treatments such as pH adjustment, removal of dissolved oxygen and the application of magnetite or phosphate on the walls of the sheet metal assist in corrosion prevention. This includes treatment of make-up water and condensates.

Preventative Maintenance

All surveyed respondents indicated that they use service organisations for the regular repair and maintenance of water-using plant equipment. The responses indicated that most organisations lacked the internal skills within their businesses to service their own plant, and there was no justification for specific service training of internal staff.

The key to efficient boiler operation is ongoing, regular maintenance. Unfortunately, internal maintenance is often confined to crisis situations. Preventative maintenance helps avert equipment problems and reduces the possibility of production downtime.

One of the routine maintenance checks related to supplied water quality includes ensuring that water control valves are functioning, since faulty operation due to sludge or scale build up will cause the boiler to shut under low or high water conditions. Prevention includes the regular checking of water level controls. Other routine checks on the water side of boiler include:

- Check surfaces for oxygen-related damage such as erosion of metal surfaces, blistering of tubes, scale in heating surfaces, corrosion caused by oxygen in raw water, and signs of carryover water that might cause foaming or priming. Boiler service organisations provide advice on the level of the proper chemical treatment and the optimum blowdown schedule for the boilers, which includes the analysis of the feedwater and the amount of raw make up water used.

Boiler technology has advanced considerably during the past twenty years. Boiler downtime related to poor quality feed water is becoming less of an issue due to innovations in boiler/burner computer program and control.

In the course of one year, mineral scales and other deposits can form within the boiler. These particles are insulators that inhibit heat exchange and cause the boiler to lose heat transfer, thus efficiency. For example, scale that is only 1/16-in. thick will cause the boiler to use 15% more fuel, l/8 in. of scale requires 20% more fuel, and 1/4 in. of scale increases fuel consumption by 39%

Steam Quality and Reticulated Water Quality

Boiler steam quality and water quality are related to the end use or application of the product. There are four steam quality grades, associated with the following uses:

- Filtered (food grade) - normal industrial steam conditioned and filtered to 5 microns or less
- Industrial - steam delivered from a normal industrial boiler.
- Pure steam raised in a clean steam generator and always from de-ionised or distilled water with a purity such that it will contain virtually no pyrogens or endotoxins.
- Clean steam raised in a clean steam generator and from de-ionised water.

Food grade steam comes in direct contact with the products as in the food and drink industry; eg the dairy-processing sector. Processing equipment such as filling machines and cookers and product transfer lines are examples of processes which require steam cleaning for obvious sanitation and health regulatory reasons. Poor quality feed water containing silts and Psuedomonis bacteria can cause serious health impacts to consumers of contaminated food stuffs.

Hard water is known to leave powdery deposits on the surfaces of cleaned stainless steel equipment, this provides ideal locations for Psuedomonis. Other micro-organisms such as wild yeast strains can have a major impact on product quality. Industry sectors including wine and beer and soft drinks and dairy food processing are especially subject to this type of contamination risk.

Generic Model Example

Estimate of extra fuel and water costs associated with the operation of a steam boiler and cooling tower if the raw water TDS increased from 400 to 600 mg/L TDS.

Boiler 5000 kw. Evaporation = 7840 kg/hour @ 100% load. At average 75% load = 5880 kg/hour. Assume natural gas fired.

Blowdown required to control dissolved solids concentration to a maximum TDS of 2,000 mg/L in the boiler water.

Based on 400 TDS in feed water:

Water Loss = $\frac{5880 \times 400}{2000 - 400}$ = 1,470kg/hr water loss (and associated heat via blowdown)

Based on 600 TDS in feed water:

Water Loss = $\frac{5880 \times 600}{2000 - 600}$ = 2,520 kg/hr water loss (and associated heat via blowdown)

The increased feedwater TDS results in 1,050 kg/hr extra water (and associated heat loss).

1,050 kg/hr = approximately 656 kw = approximately 3200 MJ/hr extra fuel cost.

3200 MJ at say 4c per MJ = $12.80 hour x 24 hours = $307.20 day x 350 days operation.

Therefore, extra gas fuel costs = $107, 520.00 per annum.

Water cost would equate to 1050 litres per hour
x 24 = 25200 litres per day
x 350 = 8820 kl per annum @ 92c kl
= $8, 114.00 per annum extra water cost.

Therefore, total estimated cost increase as water quality deteriorates from 400 to 600 mg/L TDS would be $115,634 per annum.

Winery Case Study, Riverland Region
One surveyed winery indicated that prior to establishing their new site, water analysis was conducted to establish the level of water treatment required for the winery operations. The winery was to take its water directly from the river, and hence the potential impact on boilers and other equipment needed to be determined prior to the selection process.

Water analysis indicated high total dissolved solids/minerals and calcium levels. The result was that a reverse osmosis plant was advised to be fitted prior to any boilers. Other pre-treatment included a media filter deaerator and water softener. The justification was related to avoiding excess blowdown and large dosages of chemical. Since the make-up water is high in dissolved solids, alkalinity, and silica, the company considered that the membrane separation process in the RO system would be very effective due to the high-pressure continuous system.

The water treatment process water begins with an automatic, twin-cycling water softener, at which point calcium and magnesium are removed, preventing the semipermeable membranes in the reverse osmosis treatment process from becoming clogged or scaled. The boilers are then protected from scaling, maximising the heat efficiency.

Chemical flocculant is added to the water post-softening, which is fed into the make-up water. The coated suspended solids, particles of greater than 10 micron are captured as they enter the media filter. Remaining suspended solids larger than 5 microns are removed with a cartridge filter prior to reverse osmosis treatment.

305 litres per minute of water at 50 55 psi is delivered to the reverse osmosis plant. 88% to 97% of the dissolved solids are removed at 385psi using the semipermeable membranes, while only 60 to 78 litres of reject water per minute are generated from the system.

Boiler corrosion and pitting is reduced from the make-up water by the use of a deaerator resulting in the removal of dissolved gases including oxygen. A benefit of the deaerator is the preheating of feedwater resulting in a maximised efficiency of the boiler.

The winery water treatment system provided a 2.5-year payback on capital costs (figures not provided). This included savings on blowdown costs and chemicals.

Proposed Cost Functions

Distribution of Industrial Water Use
The USEPA (1971) study on salinity impacts of users of Colorado river water estimated that cooling water use accounted for at least seven times boiler feed use. For the South Australian situation, Cruickshanks-Boyd (1983), however, determined the following relative industrial use distribution:

- Boiler feed water 46%
- Cooling tower water 25%
- Process water 29%

In their later study of River Murray salinity impacts GHD (1999) estimated the following industrial water use distribution:

- General use (washing, cleaning, site maintenance 53%
- Boiler feed water 17%
- Cooling tower water 15%
- Process water 15%

(Note: the GHD and Cruickshanks-Boyd distribution estimates are similar, when general water use is excluded.)

For the current study, it is recommended that the following industrial water use distribution is assumed:

- *General use (washing, cleaning, site maintenance) 50%*
- *Boiler feed water 23%*
- *Cooling tower water 13%*
- *Process water 14%*

Cost Functions
Key baseline costs:

- Water @ 92c per kL
- Gas @ 0.4c per MJ

General Use Water
It is a reasonable assumption that for many industrial facilities, in which supplied water is used for general washing and cleaning purposes, that the water will be filtered and softened. As discussed in Sections 4.2.1 and 4.23., deterioration in water quality (e.g. increased hardness related to increased TDS, or increased turbidity/sediment loads) will be accompanied by increased operational and maintenance costs.

The example in Section 4.2.1 provided an estimate of cost increase on filtration costs due to increased sediment/turbidity as a step increase of $0.029 per kL per annum. (It has not been possible to relate this to the concentration of suspended solids or turbidity.)

Using the example in Section 4.2.3, the costs of softening water for general use can be related directly to the hardness of the water, which in turn can be related to salinity using typical conversion factors (although these would vary from water source to water source). The relationship between softening costs and hardness can be expressed by the simple linear function:

Cost = $0.0008 H per kL per annum

where H = Total Hardness in mg/L

As an example, the relationship between salinity and hardness for Adelaide water may be expressed by the following relationship:

TDS = 2.6 Total Hardness

Thus, the cost of softening water in Adelaide can be related to salinity through the following simple linear function:

Cost = $0.0003 T per kL per annum
where T = TDS in mg/L

Boiler Feed Water

There are considerable differences in the cost functions derived by Amdel, GHD and the present study, in respect of the economic impacts of salinity on boiler feed water.

Cruickshanks-boyd (1983) in the Amdel study found that approximately 70% of the economic impact on industrial water users was related to boiler feed water costs, and that the relationship could be expressed as:

Cost = $0.0009T + 0.0824 per kL/annum

where T = TDS in mg/L

GDH (1999) developed the following relationship:

Cost = $0.0049T + 0.3 (where T < 265 mg/L)

= $1.6 (where T > 265 mg/L) per kL/annum

(The GHD cost functions was based on a supplied water cost of 40¢/kL, compared to 92¢/kL assumed in the current study. Also, a major assumption in their study was that industry would use reverse osmosis treatment technologies for water with salinity above 286 mg/L.)

The cost functions derived by the current study (refer Sections 4.23 to 4.25) should be discussed under three separate categories:

Small industries

These represent approximately 50% of industries throughout Australia. Boiler feed water is likely to be filtered and softened only. Costs due to increased salinity relate to softening costs, and water/heat energy lost due to blowdown. From the current study, the following cost function has been derived:-

Cost = $(0.0003 + 0.0165)T

Softening blowdown

Cost = $0.0168T per kL per annum
where T = TDS in mg/L

Medium - large industries

These represent approximately 30% of industries throughout Australia. Boiler feed water is likely to be filtered and demineralised. Costs due to increased salinity relate to demineralisation treatment costs, and water/heat energy lost due to blowdown. From the current study, the following cost function has been derived:

Cost = $(0.0095 + 0.0165)T

Demineralisation blowdown

> ***Cost = $0.026T per kL per annum***
>
> ***where T = TDS in mg/L***

Large industries

Based on the experience of boiler water treatment companies surveyed in the current study, only about 20% of industries (usually large water users) have installed reverse osmosis or similar membrane technology treatment systems. In such cases, as discussed by GHD in their study (GHD 1999) the costs for boiler operation are largely independent of salinity, with the cost being expressed in their study as $1.6 per kL per annum.

Australian Industry Average

For Australian industry as a whole, a reasonable approach to a generic cost function for the impact of salinity on boiler operation would be:

Cost = $0.5 (0.0168T) + 0.3 (0.026T) + 0.2 (0T)

Softening Demineralisation Reverse Osmosis

> ***Cost = $0.0162T per kL per annum***
>
> ***where T = TDS in mg/L***

Cooling Tower Operation and Maintenance

Cruickshanks-Boyd (1983) developed the following cost function for the impact of salinity on cooling tower operating costs:

Cost = $0.0002T + 0.6776 per kL per annum

where T = TDS in mg/L

GHD (1999) further derived on the following relationship

Cost = $0.0009T per kL per annum

where T = TDS in mg/L

The costs of cooling tower operation and maintenance are very sensitive to the level at which the maximum TDS is set for the cooling tower. This controls the number of cycles of concentration in the cooling tower, and therefore the bleed rate (volume of water and associated treatment chemicals lost per day). For example, at a feed water TDS of 400 mg/L, the bleed rate for a 100 tonne cooling tower would be 2044 litres per day (for a 2000 TDS limit; 5 cycles of operation). For a 1600 mg/L limit the bleed rate would be 4088 litres per day (5 cycles of operation); and for a 2400 mg/L the bleed rate would be 1022 litres per day (6 cycles of operation).

In their study, GHD used a maximum cooling tower TDS of 2500 mg/L. However, as discussed in their report and confirmed in this present study, in practice most operators control the maximum TDS to within the range 1500-2000 mg/L. In the present study, therefore, the following cost function has been derived using a maximum TDS of 2000 mg/L.

Cost = $0.0096T per kL per annum

where T = TDS in mg/L

(This cost function is considerably higher than the GHD-derived function due to three factors: the maximum TDS operating level, a water cost of 92c/kL compared to 40c/kL, and higher chemical costs.)

Process Water

The Cruickshanks-Boyd (1983) study of the economic impacts of River Murray salinity to South Australian users of River Murray water found that the impact on process water was only about 5% of the total impact of industrial water use. GHD (1999) derived a cost function of:

y(cost) = $0.0056T (where T < 286 mg/L) per kL per annum

= $1.6 (where T > 286 mg/L)

but noted that only a fraction of industries will require treatment.

Section 3.2.3 of the current study discusses the process water requirements of various industrial activities. Typically, process water will be filtered and softened (or demineralised). (The level of treatment will be dependent on the sensitivity of the process). Small industries (representing approximately 50% of Australian industry) will generally utilise filtration and softening only; medium industries (30%) filtration and demineralisation; and large industries (20%) filtration and reverse osmosis treatment.

The following cost function has been derived from the present study, to represent Australian industry as a whole:

Cost = $0.5 (0.0003T) + 0.3 (0.0095T) + 0.2 (0T)

Softening Demineralisation Reverse Osmosis

Cost = $0.003T per kL per annum

where T = TDS in mg/L

Commercial Water Users
The cost functions derived in Section 5.2 have also been used to derive a generalised cost function for commercial water users (namely offices, hotels, public buildings, hospitals, education facilities).

Most modern commercial premises utilise refrigerative airconditioning systems, rather than evaporative systems, due to lower maintenance costs and due to the health concerns surrounding evaporative systems (legionella). There has been a significant move in this direction in the ten years. It is estimated based on discussions with commercial air-conditioning maintenance companies that approximately 80% of systems are refrigerative, and 20% evaporative. Only evaporative systems use water as a coolant, and are therefore sensitive to the salinity of the water supply.

Heating in most commercial buildings is provided either by closed system hot water boilers (with minimal make up water and therefore salinity-related blowdown costs) or by electrically-heated heater banks, or a combination of the two. In some cases, reverse-cycle heating/cooling systems may be used. In all cases, the operation of the heating systems is largely independent of supply water quality. Some older facilities, particularly hospitals, still operate steam boilers for heating and other uses. For the purposes of this study, it has been assumed that a nominal 5% of water supplied to commercial premises (15% for hospitals) is used for make-up water in heating systems.

Based on the ABS figures for Perth (Australian Bureau of Statistics (2000) Water Account for Australia, 1993-94 to 1996-97. Australian Bureau of Statistics, Canberra, Catalogue No. 4610.) commercial water use distribution is approximately as follows:

Offices/public buildings/shopping centres - 60%

Hotels and education facilities - 28%

Hospitals - 12%

Within each category the following approximate water use figures have been used to develop a generalised cost function for the commercial water use category:

Type of commercial premises	General water use (washing, cleaning, etc)	Cooling	Hot water heating	Steam generation
Offices, public buildings, shopping centres	80%	15%	5%	Nil
Hotels/education facilities	90%	5%	5%	Nil
Hospitals	75%	10%	5%	10%

A generalised cost function has then been derived using the cost functions for general water use, cooling, and boiler operation previously derived (refer Section 5.2). The generalised cost function is :

$$[0.6\ (0.8 \times \$0.0003 + 0.15 \times \$0.0096T + 0.05 \times \$0.0162T]\ +$$

[0.28 (0.9 x $0.0003 + 0.05 x $0.0096T + 0.05 x $0.0162T] +

[0.12 (0.75 x $0.0003 + 0.10 x $0.0096T + 0.15 x $0.0162T]

Hence the generalised cost function is:

Cost=$0.00237T per kL per annum

(where T = salinity in mg/kL).

APPENDIX G Report on Downstream Impact Costs Caused by Erosion and Sedimentation

National Land and Water Resources Audit

Ex-situ Costs of Australian Land and Water Resources Degradation to non-Agricultural Industries, Infrastructure and Households

REPORT B: EX-SITU COSTS OF EROSION AND SEDIMENTATION

By

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The Resource Economics Unit

February 2001

This report is provided to CSIRO Land and Water by the Resource Economics Unit under contract Folio Number 00/105 STR/91, and provides the Indicative Economic Assessment for sub-project 6.1.3 of the National Land and Water Resources Audit, Theme 6, Project 1.

Glossary of Terms and Conversions

Amortisation	Conversion of a lump sum to an annual value at a given discount rate.
Control cost	Costs incurred by government, individuals, industries, or infrastructure providers to control or improve the condition of the natural resource.
Damage cost	Costs incurred by industries, infrastructure providers or households, as a result of the degradation of the natural resource: these costs may be in the form of loss of income from impaired economic activity, additional repair or maintenance expenditure, reduced service life of capital items, and defensive investments on such items as additional water treatment plants or provision of replacement reservoir capacity.
Discount rate	The rate of time preference for real income: for risky projects the discount rate is taken as the average real rate of return on capital in the private sector, of about 7%; for risk-less projects a lower rate, of 4%/year has been assumed.
NTU	National Turbidity Units: potable water supplies are usually of no more than 1 to 2 NTUs. A raw water quality of NTU >5 requires advanced water treatment.
Sediment concentration	Concentration of inorganic and organic solids in water, measured in mgL^{-1}.
Turbidity	The clarity or opaqueness of a water sample measured by photometric means as NTUs; turbidity is related to, but not directly proportional to sediment concentration as different sediment characteristics produce different turbidity levels. Turbidity is a routine water quality parameter for water supply utilities.

Executive Summary

E.1 Background

Theme 6 of the National Land and Water Resources Audit is titled "Capacity for Change". Project 6.1 addresses economic dimensions of resource degradation. Projects 6.1.1 and 6.1.2 are concerned with agricultural impacts and Project 6.1.3 is concerned with the impacts on non-agricultural industries, infrastructure and households. Finally, Project 6.1.4 provides estimates for recreational and ecosystem values.

Within Project 6.1.3 the work was divided into two streams: (a) Dames and Moore (now Urscorp Australia) dealt with *in situ* effects, while (b) Resource Economics Unit (REU) and PPK Environment & Infrastructure (PPK) dealt with *ex-situ* aspects. Dames & Moore also took responsibility for impacts on tourist industries, whether *in-situ* or *ex-situ* in nature.

This report presents the results of the assessment by REU of the ex-situ costs of erosion and sedimentation. A companion report deals with the ex-situ costs of salinity.

E.2 Causes and spread of sedimentation

Many Australian waters receive large quantities of sediment, and are in general highly turbid. The main problem areas are in coastal Queensland, the Murray Darling basin, the South Australian Gulf and the South East Coast Drainage Divisions. Parts of the south west of Western Australia and northern Australia are also affected.

Inappropriate farming practices including widespread tree clearing, mould-board ploughing, and large flocks of sheep or cattle have increased the natural rates of sediment movement and inland water turbidity. Inadequate earth moving practices and failure to provide sediment traps along stream banks and silt traps in river channels exacerbate the problem. However, in river systems that have experienced a history of erosion and sedimentation over decades or more, the relative contribution of freshly eroded material and remobilised channel materials is difficult to ascertain.

E.3 Measurement Units

Sediment concentration is normally measured as mgL^{-1}, with long-run average concentrations in the range 0 –1,000 mgL^{-1}. Turbidity is measured by photometric means, the result being expressed in "National Turbidity Units" (NTU), with 5 NTU being the maximum recommended for potable water supply.

The relationship between NTU's and total solids content varies for different kinds of water. Nevertheless, the two are broadly correlated. Using the data given in Brown (op cit) the following relationship was obtained, and used in all necessary conversions.

$$\text{Log}_{10}(\text{NTU}) = 0.1517 + 0.533\text{Log}_{10}(\text{SC}) \qquad \textbf{(Eq.1)}$$

Or, conversely:

$$\text{Log}_{10}(\text{SC}) = -0.2846 + 1.8762\text{Log}_{10}(\text{NTU}) \qquad \textbf{(Eq.2)}$$

Where:

NTU	=	National Turbidity Units
SC	=	Sediment Concentration (mg/L)

E.4 Previous studies

There have been only a limited number of Australian studies on the ex-situ economic costs of erosion from soils or river channels. The extent of off-site damages has been difficult to estimate, and hard to value.

E.5 Types of ex-situ impact

This paper identifies four categories of *ex-situ* impacts of erosion, sedimentation and turbidity leading to cost increases to households, industry and infrastructure:

- Sedimentation of reservoirs
- Impacts of sediments and turbidity on water treatment costs
- Costs of sediment clean-up by local government and road and rail operators
- Costs to navigation authorities

E.6 Monetary units used in cost functions

All cost estimates given in this Executive Summary are expressed in Australian $, at year 2000 values.

E.7 Costs of replacing reservoir storage capacity

It is assumed that all dams are designed to cope with the sediment loads expected at the time of construction, and that capacity loss will be associated with any *increases* in sediment loads beyond the sedimentation design capacity. The recommended indicative damage cost function is:

$$\mathbf{C_R = 0.35 * \Delta SL} \qquad \textbf{(Eq.3)}$$

Where:

$\mathbf{C_R}$	=	Cost of lost reservoir capacity ($)
0.35	=	Average replacement cost per unit of reservoir capacity ($/cu.m): it is assumed that 1 cu.m. of sediment displaces 1 kL of storage capacity
$\mathbf{\Delta SL}$	=	Change in sediment load (cu.m/year), equal to streamflow (kL/yr) times the increase in sediment concentration (kg/cu.m.)

The coefficient 0.35 ($/unit of capacity lost) has been obtained from an analysis of data on the costs of dam/weir raising from Queensland.

The estimate given here should be reduced by a "bleed factor' where data is available, to allow for operator discharges of increased sediment loads below the dam or weir. Clearly, the estimate of costs of lost reservoir capacity applies only to existing dams or weirs. Data on dams and their capacities are available within the Audit database from Theme 1 studies.

E.8 Costs of additional water treatment

The costs of water treatment due to increased sedimentation/turbidity must be divided into three cost components:

- The "Base" capital costs of installing new water treatment plants where they were not previously needed. These costs depend on the size of plant, measured in terms of its capacity (annual throughput), and are calculated at the minimum sediment concentration. For Audit purposes, it can be assumed that a treatment plant needs to be installed if raw water quality exceeds a sediment concentration of 10mg/L, because at that level the National Water Quality Management Guideline value of 5 NTU's (National Turbidity Units) is likely to be exceeded.
- An additional "marginal" capital component, which depends on the actual sediment concentration of the raw water.
- The operating costs for new or already-installed treatment plants

E.9 Base capital cost function for water treatment plants

Un-amortised capital cost function for a new plant (gives cost as a function of the treatment plant capacity):

$$\mathbf{Log_{10}(CC_{TP})\_ = -1.4 + 0.611\ Log_{10}(W)} \qquad \textbf{(Eq.4)}$$

Where:

CC_{TP} = Capital cost of a treatment plant ($ Million)

W = Water throughput (kL/d)

This cost function has been obtained by fitting a curve to the results of an engineering-type model of water treatment plant costs, with throughput being varied, but assuming a low level of sediment throughput.

E.10 Marginal capital cost function for raised sediment concentration

The marginal capital cost function adds an additional capital cost, which is due to the sediment concentration of influent. The indicative marginal capital cost function for a water treatment plant is:

$$\mathbf{M_{CC} = (W*365) \times (0.000222 + [0.000895 \times f(SC)])} \qquad \textbf{(Eq.5)}$$

$$\mathbf{F(SC) = 8.5/(1 + 2 \times e^{(-0.45SC)})}$$

Where:

M_{CC}	=	Marginal capital cost ($)
W	=	Capacity of the plant (daily throughput in kL)
SC	=	Sediment concentration of influent (mg/L)

This cost function has been obtained by fitting a logistic curve to the results of an engineering-type model of water treatment plant costs, using parameters for a medium-sized treatment plant, and varying the values for the sediment concentration of influent.

E.11 Water treatment plant operating cost function

For a new treatment plant that has to be constructed because of turbidity problems the total annual operating cost should be counted. An indicative order of magnitude for operating cost would be 0.5% of the capital cost.

For an existing treatment plant, the *marginal* operating cost attributable to increased dissolved organic carbon, based on the additional cost of alum, is:

$$M_{OC} = W*365 * 3.6164 * 10^{-6} DOC \quad \text{(Eq.6)}$$

Where:

M_{OC}	=	Annual marginal treatment plant operating cost ($)
W	=	Capacity of the plant (daily throughput in kL)
DOC	=	Concentration of Dissolved Organic Carbon (mgL^{-1})

It is suggested that, as a default value, DOC can be taken as 20% of the influent sediment concentration. Thus the marginal operating cost function may be changed to:

$$M_{OC} = W* 365 * 0.72328* 10^{-6} (SC) \quad \text{(Eq.7)}$$

Where:

SC	=	Sediment concentration (mg/L)

If the capacity of treatment plants is not known, the total diverted stream flow may be substituted.

E.12 Cost function for costs to local governments

Queensland data were taken to reflect costs in regions where long term average river sediment concentrations are of the order of 250mg/L. Assuming a linear correlation between (i) costs to local government and (ii) river sediment concentration in the particular region, the implied cost per mg/L of sediments to local government is:

$0.02888/capita/yr/mgL^{-1} sediment concentration in local rivers **(Eq.8)**

It may be possible from other Audit studies to develop a regionally-based soil erosivity index, which could be used instead of sediment concentration in local rivers.

E.13 Cost function for road and rail operators

Data on total costs were obtained for Victoria and South Australia. However, it was not possible to relate these to relative levels of soil erosivity. As a guideline value, it is suggested that costs of sedimentation to road and rail operators be taken a 50% of the costs to local authorities.

E.14 Costs to Navigation Authorities

Using the data reported in Zvirbulis (1994), and adjusting for year 2000 values, it is recommended that an indicative cost for navigation is:

$20/cu.m of sediment load to restricted navigational channels **(Eq.9)**

Hypothetical Example

Background Data

The Murky Creek catchment has an area of 250,000 hectares, where 4,000 people live. Of these 1,500 live in the town of Littleville and the remainder on farms in the surrounding rural area. The mean annual flow of Murky Creek is 15 GL.

There is a dam on the Murky Creek just above its confluence with the Evenmurkier River. The major town of Settlement, on the Evenmurkier River, with a population of 10,000, receives its town water supply from the Murky Dam, which has a capacity of 12 GL and supplies around 5 GL/year for town supply and 7 GL/year for irrigation use. The town water is currently treated by sedimentation and chlorination.

Ever since clearing of the landscape for mixed livestock farming in the 19th Century the catchment has experienced some erosion problems, but there has been an increasing trend in the sediment concentration of Murky Creek above the reservoir site. The flow-weighted average sediment concentration of Murky Creek is now 50 mg/L. When the reservoir was built it was assumed that there would be no problem with sediment build-up.

The Evenmurkier River flows into the Poor Inlet, which lies on the Southern Ocean. Poor Inlet has a narrow mouth, through which the local fishing fleet passes to unload its catch at the local port.

Reservoir Capacity Losses

Sediment load (SL)	=	15×10^9L x 50mg/L/yr (Eq3)
	=	750×10^9mg/yr
	=	7.5×10^{11}mg/yr
	=	7.5×10^2 t/yr
	=	7.5×10^2 cu.m./yr
Capacity Cost = $0.35*ΔSL (cu.m.)	=	$0.35 x 7.5×10^2/yr
	=	$262.5/yr

Water Treatment Plant

The town of Settlement has a water supply that no longer complies with the National Water Quality Management Guidelines for potable supply. A sediment concentration of 50 mg/L makes the water too turbid for potable use. According to the recommended standard conversion:

Log_{10}NTU	=	0.1517 + 0.533Log_{10} (SC)
	=	0.1517 + 0.533 x Log_{10}(50)
	=	0.1517 + 0.533 x 1.6990
	=	1.0573
NTUs	=	11.45

A new water treatment plant is required. The costs will be as follows.

Base capital cost

The throughput (W) of the Settlement town treatment plant is 5 GL/yr, equals 5×10^9 L/yr, equals 5×10^6kL/yr, equals 13,698.6 kL/d. Un-amortised capital cost function for a new plant is:

$Log_{10}CC_{TP}$	=	-1.4 + 0.611 Log_{10} (W)	(Eq.4)

Therefore Base Capital Cost equals:

Log_{10} (CC_{TP}) ($M)	=	-1.4 + 0.611Log_{10} (13,698.6)
	=	-1.4 + 0.611 x 4.1367
	=	1.1275
Capital Cost	=	$13.44 million

Marginal Capital Cost

The additional capital cost due to the sediment load is:

M_{CC}	=	(w*365) x (0.000222 + [0.000895 x f(SC)]) (Eq 5)
f(Sc)	=	8.5/(1 + 2 x $e^{(-0.45SC)}$)
	=	8.5/(1 + 2 x $e^{(-0.45SC)}$)
	=	8.5/(1 + 2 x $e^{(-0.45 \times 50mg/L)}$)
	=	8.5
M_{CC}	=	5 x 10^6 (cu.m/yr) * (0.000222 + 0.000895 x 8.5)
	=	$.038 million

Therefore the total capital cost for the water treatment plant is $13.44M + $.038M = $13.478M

Operating Cost

As the increase in sediment concentration led to the installation of a new water treatment plant, the total annual operating cost of the plant should be counted.

The average annual operating cost for a water treatment plant is estimated to be 5% of its capital cost, which in this case is 5% of $13.478M = $0.674M/yr

The marginal operating cost attributable to increased dissolved organic carbon would be:

M_{OC}	=	W*365*0.72328*10^{-6}SC	(Eq.7)
	=	5*10^6*0.72328*50mg/L	
	=	$181/yr	

Costs to Local Government

The Littleville Shire has a population of 4,000. As no direct data on local government costs is available, the cost to local government is estimated to be:

C_{LG}	=	P* $0.02888/capita/yr/mgL^{-1} sediment concentration in local rivers	Eq.8
	=	4,000 * .02888 * 50	
	=	$5,766/yr	

This cost is relatively low. The highest costs in Australia are experienced by local authorities in Queensland, which experience local sediment concentrations of around 250mg/L, compared with 50 mg/L in the Murky Creek.

Other public service providers

Taking an overall factor of 0.5 times local authority costs as an estimate of the costs to all other public service providers in the Murky Creek catchment, we derive an indicative estimate of $2,883/yr.

Navigation

The increased sediment loads from Murky Creek will eventually add to the deposition of sediment at the mouth of the Poor Estuary. Using the standard cost of $20/cu.m of sediment load, gives an annual cost of:

C_N	=	$20/cu.m/yr* SC(mg/L)*SF(L)*10^{-9}
	=	$20/yr (15 * 10^9 L)*(50(mg/L))*10^{-9}
	=	$15,000/yr

Summary of Hypothetical Cost Estimates

The various costs of erosion and sedimentation in the Murky Creek catchment are summarised in the following table.

Item	Capital Cost ($M)	Annual Cost ($/yr)	Present Value(1) ($M)
Reservoir capacity		262.5	0.003
Water treatment:			
Capital	13.478		13.478
Operating		674,000.0	8.364
Shire		5,766.0	0.072
Other public service		2,883.0	0.036
Navigation		15,000.0	0.186
Total Cost	**13.478**		**22.139**

(1) Annual costs have been converted to present values using a discount rate of 7% over 30 years.

Total present value of costs is estimated to be $21.953 million. This is mainly for a new water treatment plant for the downstream town of Settlement, (capital plus operating costs of $21.842 million). The remaining $0.186 million is due to costs of reservoir capacity loss, shire costs and other public services, including navigation. If Settlement already had a suitable water treatment plant the marginal operating costs from increased sediment loads would be a mere $181/year. The present value of total costs would then amount to $0.367 million.

Introduction

Sediments and Turbidity in Australian Waters

Australian inland waters receive large quantities of sediment, and are in general highly turbid. The main problem areas are in coastal Queensland, the Murray Darling basin, the South Australian Gulf and the South East Coast Drainage Divisions. Parts of the south west of Western Australia and northern Australia are also affected.

It is probable that inappropriate farming practices including widespread tree clearing, mould-board ploughing, and large flocks of sheep or cattle has increased the natural rates of sediment movement and inland water turbidity. Inadequate earth moving practices and failure to provide sediment traps along stream banks and silt traps in river channels exacerbate the problem. However, in river systems that have experienced a history of erosion and sedimentation over decades or more, the relative contribution of freshly eroded material and remobilised channel materials is difficult to ascertain. Researchers have developed techniques of sediment sourcing using radionuclides that may allow more accurate modelling of sediment transport and turbidity in erosive catchments, but the application of these techniques is quite new.

Scope of this investigation

A complete listing of possible ex-situ costs arising from erosion/sedimentation is shown in Table 39. This paper addresses four categories of off-site impacts of erosion, sedimentation and turbidity leading to cost increases to households, industry and infrastructure. The four categories are:

- Impacts of sediments and turbidity on water treatment costs
- Sedimentation of reservoirs
- Costs of sediment clean-up by local government and road and rail operators
- Costs to navigation authorities

For a number of reasons, cost functions have not been developed for nutrient discharges and eutrophication. Firstly, there is a close relationship between water treatment costs arising from sedimentation and those due to nutrients in raw water. It was not possible to separate these two effects. It is considered that the water treatment cost functions presented for sediments will cover water supply treatment costs associated with both sediments and nutrients. Secondly, while nutrient discharges may degrade water resources, they are not always associated with land degradation (for example the wash-off of nutrients may not be associated with land degradation). Thus, higher water treatment costs or reservoir management costs associated with nutrient enrichment in the absence of a sedimentation problem, are excluded. Thirdly, tourist and recreational industries, (including for example cost impacts of sediments and nutrients on the Great Barrier Reef tourist industries) were outside the REU-PPK brief, and have been considered by Dames & Moore. Finally, the main impacts of nutrients and eutrophication are in the areas of recreation and ecosystems, which are dealt with in Project 6.1.4.

Table 39: Ex-situ effects of erosion/sedimentation processes, with notes on REU-PPK Work Program

Ex-situ, non-agricultural effects	REU-PPK Work program
▫ Deposition of sediments on roads	▫ local government survey
▫ Siltation of dams, reservoirs and water supply delivery channels	▫ desk research/assumptions
▫ navigable channels (including harbours)	▫ literature review
▫ estuaries and related activities, including fishing and tourism	▫ not addressed
▫ coral lagoons and related activities, including fishing and tourism	▫ not addressed
▫ increased turbidity affecting in-stream uses	▫ not addressed
▫ increased turbidity affecting water treatment costs	▫ detailed cost model developed
▫ health effects from airborne dust	▫ not addressed
▫ air transport effects of airborne dust	▫ not addressed

Measurement of Sediments and Turbidity in Water

Sediment content of water relates to total solids. Australian rivers and streams have widely varying sediment concentrations in both space and time. For example, Brown (1983, p.57) showed a graph of sediment concentration in the Tumut River, New South Wales, for two consecutive winter months in 1960, with sample values ranging from around 10mg/L to 500 mg/L. Calculations on data obtained for Queensland catchments (see Section 2) suggest long-term average values of 100mg/L to 300mg/L in different catchments in that region.

Dissolved organic carbon is a constituent of sediment load that is of particular concern for water treatment engineers (see below). Dissolved organic carbon concentration is normally expressed in mg/L. The level of dissolved organic carbon is correlated with turbidity. As with turbidity, its relationship with sediment concentration varies for different waters. However, as a general guide, around 10% of the sediment load may be found as dissolved organic carbon

Turbidity is a measure of the opaqueness or clarity of water. The turbidity of a water sample is measured by the reflectance or transmission properties of the particles that it contains, and the result is expressed as NTU 's (National Turbidity Units), on a scale of 0 to around 100 in practical terms. Water turbidity depends on the amount of organic and inorganic particles present in suspended or dissolved form, but also their character. For example, a water sample containing only large particles may have a high suspended sediment content but may remain with low turbidity, due to its reflectance properties.

The relationship between NTU's and total solids content varies for different kinds of water. Nevertheless, the two are broadly correlated. Using the data given in Brown (op cit) the following relationship was obtained.

$$\text{Log}_{10}(\text{NTU}) = 0.1517 + 0.533\text{Log}_{10}(\text{SC})$$

Or, conversely:

$$\text{Log}_{10}(\text{SC}) = -0.2846 + 1.8762\text{Log}_{10}(\text{NTU})$$

Where:

NTU = National Turbidity Units

SC = Sediment Concentration (mg/L)

Literature Review

There has been only a limited number of Australian studies on the ex-situ economic costs of erosion from soils or river channels. The extent of off-site damages has been difficult to estimate, and hard to value. The few Australian estimates, taken from the Envalue Data Base, are summarised in Table 40.

Table 40: Studies of the ex-situ costs of soil erosion

Topic	Basis for estimates	Notes
Loss of water storage capacity	▫ additional income to dairy farmers from reduced erosion from Eppalock catchment, Victoria	▫ \$71/acre foot of soil conserved (1974-5). Dept of Environment, Housing and Urban Development (1978)
Urban water supply ▫ additional water treatment costs	▫ engineering estimates	▫ 1% increase in turbidity produces a 3% increase in chemical treatment and disposal costs Moore & McCarl (1986) ▫ 1% increase in turbidity produces a .01 to .13% increase in operating & maintenance costs in water treatment plants Holmes (1988)
Electricity plants ▫ water treatment for steam generation and cooling	▫ engineering estimates	▫ similar to water supply cost above
Soiling and damage to materials from aeolian particles	▫ No Australian studies	▫ Not considered in this report
Navigation hazards: ▫ Teranore Inlet, Tweed Heads ▫ Black Ned's Bay, Swansea ▫ Palmer Channel, Lk Woolaweyah ▫ Throsty Basin, Newcastle	▫ public records	▫ 6\$/m^3 of sediment ▫ \$9/m^3 of sediment ▫ \$15/m^3 of sediment ▫ \$16/m^3 of sediment (all from Zvirbulis, 1994)

Methodology

Conceptual issues

Definition of damage and control costs

A frequently used term for the costs to non-agricultural industries, infrastructure and households arising from resource degradation is *damage costs* (Pearce, 1976; Thomas, 1998). These are the costs incurred by any section of society as a result of the existence of a given level of resource degradation. They may include, for example, losses of income from interrupted economic activity, costs of repair and maintenance, or costs incurred to rectify the effects of reduced resource quality at the receptor end of the chain: e.g. if water supply quality is so reduced as to require treatment or substitute sources. The *benefits* to be gained by reducing, arresting or reversing resource degradation are *avoided damage costs*.

Some commitment of resources (expenditure) or sacrifice of income will be required to bring about an improvement (or to arrest a continuing decline) in natural resource condition. Such expenditures are termed *control costs*. The important conceptual point about control costs for this study is that they must eliminate or reduce the problem at its source. That is, from the point of view of society as a whole and for the purposes of framing national policies for management of erosion and sedimentation, only those expenditures that improve the condition of the natural resource qualify as control costs.

An examples of expenditure that appears to "control" a water resource degradation problem from the point of view of users, but which, *from the point of view of society as a whole*, represents a cost of natural resource degradation, is the money spent on water treatment plants that were installed in Sydney during the 1990's in response to declining chemical and biological quality of runoff from the city's major catchments.

Role of environmental standards

The widespread use at State and Commonwealth levels of environmental standards or guidelines is a principal trigger for expenditure by agencies. The *National Water Quality Guidelines: Drinking Water Quality* (Department of Primary Industries and Energy, 1995), while not a statutory instrument, is treated very much as a supply standard for potable use by Australian water utilities and regulators. If the condition of the natural resource deteriorates, then expenditure is triggered in order to comply with the standard. For example, the new water treatment plants recently installed in Ballarat through Central Highlands Water and at Bendigo through Coliban Water, were largely in response to a perceived need to comply with the National Water Quality Guidelines. Similarly, the *National Water Quality Guidelines: in-Stream Water Quality* (Department of Primary Industries and Energy, 1995) guides regulators in controlling pollutant discharges, and this in turn triggers expenditure on preventative measures such as source controls e.g. higher levels of sewage treatment prior to discharge, or interception controls such as restoration of riparian vegetation to intercept nutrient-rich runoff from farms. However, since the latter kind of cost is incurred in order to protect the environment, as opposed to being a reaction to some up-stream degradation issue, this type of cost is not considered in this report.

Technical committees take account of a wide range of factors in offering their advice about appropriate standards or environmental guidelines to government. Very often there is no economic analysis. For example, recommended drinking water quality standards, including turbidity, are based on human health requirements and observed consumer preferences. It is possible that the implementation of a standard would not pass an environmental benefit-cost analysis in some cases. Nevertheless, there is no doubt that the expenditures described result directly from the "unsatisfactory" resource condition, and that the promulgated standard serves to define what is unsatisfactory. For the purposes of this report national costs of sedimentation are estimated assuming that the national turbidity standards will continue to apply. This substantially affects the estimated costs of sedimentation through its link to turbidity and the national standards for turbidity in potable water supplies.

Amortisation and discounting

It is conceptually straightforward to estimate recurrent, or operational-type costs of resource degradation, as an annual value per unit such as per household, per firm, or per hectare.

However, some costs are "lumpy" in nature, such as investments to cope with reduced resource quality or reduced service lives of capital items. Reduced service life, for example of a water heater affected by salinity of water supply, can be calculated either on "straight-line" or "amortised" basis. The general, but by no means universal practice has been to use amortisation. This produces a higher annual cost than straight-line average cost.

Two ways of accounting for costs that are "lumpy" in nature are: (a) the defensive capital expenditures can be counted at their full market value at the future date they are expected to be incurred, and then discounted to the present, or (b) the defensive capital costs can be amortised.

Amortisation requires a choice of discount rate. The choice of discount rate is discussed in Thomas (1998), who argues that a social rate of return is appropriate rather than an opportunity cost of capital approach. Norgaard and Howarth (1992) have shown that while discounting is appropriate to choices about the current generation's resources it is not appropriate when the current generation is primarily concerned with re-distributing resource rights to future generations.

For the purposes of this study discount rates of 4% and 7% have been considered in amortisation. The former represents a "risk-free" discount rate, while the latter approximates to the rates recently used by Commonwealth and State Governments in benefit-cost analysis across a wide range of programs.

Standardised Cost Functions

The brief for Project 6.1.3 requires the development of standardised cost functions. To do this it was necessary to distinguish two related cost functions, namely (a) total cost function and (b) marginal cost function. The total cost function takes the form:

$$C = f(Q)$$

Where

C = total costs of owning an item or undertaking a process

Q = an index of water resource quality (e.g. total dissolved solids, sediment concentration or national turbidity units)

The marginal cost function, which gives the cost due to a unit change in the index of resource quality is:

dCdQ

The total cost associated with a given level of resource quality index is therefore

$$\int_{Qb}^{Qa} C\,dQ$$

Where

Qa = the value of the resource quality index following degradation

Qb = a base value of the resource quality index, which corresponds with either (i) pristine resource condition or (ii) the existing level of resource degradation

The cost functions are sometimes obtained as a generalised result from a process model.

Estimation methods

Morrison, Groenhout and Moore (1995) identified seven methods of estimating environmental values:

- Dose-response: measures the direct response of individuals, households or firms to change resource condition
- Preventative expenditures: outlays that directly address control or avoidance of environmental degradation. These may include both capital and operational-type expenditures and are usually estimated by means of survey data, or through modelling of representative processes
- Replacement/repair expenditures: in the absence of preventative expenditures these are inevitable costs from the point of view of the receptor of environmental damages. These are usually estimated by means of survey data, or through modelling of representative processes
- Contingent valuation: a measure of hypothetical willingness to pay, usually applied to individuals or households
- Travel cost
- Hedonic price: infers environmental values by observed changes in market values, e.g. of property
- Household production: measures additional productive activity within households in response to changed environmental conditions (more often used in economies that have less-well developed markets).

Dose-response relationships, preventative expenditures, and replacement/repair expenditures dominate the literature on the ex-situ costs of erosion/sedimentation

to non-agricultural industries, infrastructure and households, and are generally the appropriate tools for Project 6.1.3.
The Contingent Valuation method has sometimes been used to estimate households' willingness to pay for improvements in urban water supply quality, particularly where it has been difficult to develop a dose-response relationship such as in relation to certain chemical constituents of water. Carlos (1991) estimated willingness to pay for improved water quality through control of salinity and turbidity in the Yass District of New South Wales. Dwyer Leslie Pty Ltd (1991) estimated household willingness to pay to avoid any further deterioration in the quality of Sydney's water. This study played a part in decisions to install water treatment plants in Sydney during the 1990's. However, since the survey was concerned only with maintaining the *current* quality of water there was no need to develop a schedule of willingness to pay for different levels of water quality, and no underlying dose-response relationship for sediments, turbidity, nutrients or biological quality was reported.

Dose-response relationships for the items of interest to this report are estimated through engineering-type calculations/models, using market values of costs. Due to the paucity of primary data sets on the level of ex-situ economic damages from erosion this study has used a large amount of secondary data and inference in order to arrive at indicative cost functions. Natural resource data, engineering-type calculations, reports from utilities/government departments and questionnaire surveys were combined. The principal methods used were as follows.

- The cost of sedimentation impacts on reservoirs is based on data from Queensland on sediment loads, and engineering-type calculations on reservoir capacities and costs.
- The cost of sedimentation and turbidity to water treatment plants is based on an engineering-type model of capital and operating cost impacts with a selection of Australian data obtained from recent papers in the literature.
- Costs to local government, and road/rail operators is based on questionnaire survey information
- The costs to navigation use the only available source in the literature review.

Costs of Sedimentation in Reservoirs

Overview

As a result of the inherent variability of rainfall and runoff throughout Australia, storm events dominate the inflows of most Australian reservoirs. This, together with the tendency for Australian soils to be characterised by highly erodible clays means that storm runoff contains high concentrations of particulate material. Land use changes have in many places increased soil erodibility and sediment transport rates. These changes include the clearing of natural vegetation, tillage and fallow practices in cropping areas and the introduction of hoofed grazing animals, particularly cattle.

The effects of catchment land use on erosion and sedimentation in Queensland coastal catchments are illustrated by calculations of average sediment flows based on data from Moss et al (1992). The results are shown in Table 41. The estimated sediment export rates in tonnes per hectare are generally highest for cropping activities. However, as grazing is the dominant land use in these catchments it makes the highest overall contribution to sediment loads at the river mouths. It is assumed that the Audit will be able to provide similar, but more up-to-date, estimates for the whole of Australia.

Erosion Processes, Sediment Transport and Re-distribution

Various types of land erosion process are identified in the literature, such as sheet, rill and gully erosion. These lead to deposition of sediment in or near watercourses, and may contribute to sediment concentrations downstream. Sediment transport is greatest during peak rainfall events.

In addition, complex processes of erosion and sediment transport occur within the channels. A significant proportion of the increased sediment loads in river systems that have been observed since European settlement of Australia has been due to bank erosion due to increased flooding characteristics following removal of native vegetation in catchments, and to the activity of introduced aquatic species such as European Carp.

Sediments are transported in suspension. However, there is a continual process of suspension, deposition and re-suspension within river systems. Therefore, the dose-response relationship, while well documented in general terms, is extremely complex. Very few studies have been undertaken that quantify and model these processes. In attempting to derive indicative estimates of costs it has been necessary to completely bypass the detail of sediment generation, transport and re-distribution. Instead the discussion concentrates on estimating the likely costs of replacing reservoir capacity following increased sediment loads.

Nature of Sedimentation in Reservoirs

Sediments are carried in watercourses and collect at the base of dam walls. Few reservoirs are unaffected by this phenomenon. Therefore, most dams contain low-level off-takes that allow the operator to discharge silt, thus maintaining storage capacity. However, an increase in the stream sediment load may exceed the design parameters for a reservoir, leading to sediment build-up within the reservoir and loss of storage capacity. In large reservoirs that have a relatively shallow depth sediments may remain distributed across the floor of the reservoir for considerable period of time, rather than collect at the base of the dam wall. In these circumstances it becomes very difficult to prevent loss of storage capacity.

Table 41: Estimated sediment export rates from Queensland coastal catchments, by land use type (t/ha)

Catchment	Pristine	Grazing	Cropping	Urban	Total
Gold Coast	0.181	0.737	1.824	0.406	0.702
Brisbane	0.063	0.259	0.654	0.400	0.256
Sunshine Coast	0.228	0.911	2.256	0.400	0.658
Mary	0.156	0.623	1.559	0.500	0.507
Burnett-Kolan	0.048	0.191	0.481	0.500	0.177
Curtis Coast	0.108	0.423	1.136	0.333	0.385
Fitzroy	0.032	0.129	0.324	0.400	0.130
Shoalwater Bay-Sarina	0.211	0.854	2.134	0.000	0.766
Pioneer-O'Connell	0.432	1.754	4.381	0.333	1.834
Proserpine	0.364	1.467	3.648	0.000	1.360
Don	0.120	0.457	1.220	0.000	0.457
Burdekin-Haughton	0.051	0.211	0.527	0.400	0.212
Rose-Black	0.245	0.991	2.000	0.400	0.837
Herbert	0.145	0.571	1.432	0.667	0.543
Tully-Murray	0.607	2.441	6.093	0.000	1.419
Johnstone	0.655	2.618	6.546	0.500	2.433
Mulgrave-Russell	0.672	2.704	6.773	0.667	2.332
Barron	0.173	0.688	1.724	0.400	0.524
Mosman-Daintree	0.526	2.114	5.306	0.667	1.025
North-East -Cape York	0.144	0.574	1.364	0.000	0.484

Source: Moss et al (1992)

The discharge of silt tends to result in a build-up of sediments downstream of the dam wall, and these may accumulate locally if there is limited residual flow available to transport the sediments further downstream. However, dams in catchments which experience large rainfall events, and which incorporate large spillways, may have sufficient flushing capacity to prevent local sediment deposition downstream of the dam.

Reservoirs are generally designed so that their storage capacity is just sufficient to prevent the reservoir from being drawn down to the lowest off-take during a period of extreme drought. Silt can be discharged in effect continuously. However, some Australian reservoirs, such as the Harding Dam in the Pilbara Region of Western Australia are designed to be empty for possibly extended periods, and are used to capture runoff from infrequent rainfall events, which is then used to recharge an aquifer.

Control Strategies

A number of alternative strategies are available for dealing with the problem of reservoir sedimentation, including (i) catchment re-vegetation, (ii) tree planting along streamlines (iii) fencing to prevent livestock, particularly cattle, from encroaching on stream banks (iv) eradication or population control of channel-eroding fish species, e.g. European Carp, (v) provision of sediment traps on tributaries, (vi) increasing the height of the reservoir wall, thus maintaining storage capacity and (vii) acceptance of the loss of storage capacity, and therefore average annual yield, and construction of additional capacity elsewhere. The alternative to control is of course to (viii) accept the loss of storage capacity and reservoir yield, in which case the costs are damage costs in the form of lost opportunities for the use of the water.

Clearly, the costs listed above will differ greatly for different reservoirs and for different catchment conditions. It is reasonable to assume that operators will seek to minimise the sum of damage and control costs in each particular case. In some catchments it will be optimal to undertake catchment control actions, namely options (i) to (v) above, and avoid any new construction to replace capacity. In other cases new construction will be preferred, and rarely, the storage capacity losses and resulting damage costs will be accepted and nothing done.

Indicative Damage and Control Costs: Queensland Case Study

Since, by assumption, control plus damage costs will always be minimised an estimate of either control costs or damage costs will be an approximation to this minimum. Therefore, an estimate of either (vi) or (vii) above will provide an indication of costs, assuming that capacity will be restored by additional construction. Data were found for a number of projects in Queensland involving the raising of dams or weirs. Since these projects correspond most closely to the kind of capacity restoration involved following reservoir sedimentation, estimates were developed for item (vi), namely the costs of increasing the heights of dams or weirs.

For the purposes of the Audit it is recommended that a cost function based on the average cost of dam raising per unit volume of storage capacity regained will provide a reasonable indication of overall costs. The Queensland Water Infrastructure Task Force (1997) provides data on the costs of raising a number of dams and weirs. These have been combined with an estimate of likely storage capacity losses to provide an indication of the possible magnitude of costs.

2.5.1 Sediment loads

Typical sediment concentrations in the Queensland coastal catchments are given in Table 42. It is seen that the catchments may be grouped into a southern and a northern set, in terms of typical sediment concentration. The southern catchments, from the Gold Coast to the Rose-Black catchment, have sediment concentrations of around 250 mg/L, while the typical concentration is about a half of this in the Herbert catchment and further north. The rate of storage capacity loss in some Queensland reservoirs and weirs has been estimated using these typical sediment concentrations.

Table 42: Estimated sediment loads and concentrations for Queensland coastal catchments

Catchment	Mean Annual Flow (GL)	Runoff Coefficient (ML/sq.km.)	Sediment Load at Mouth (kt)	Sediment Concentration (mg/L)
Gold Coast	1,700	0.28	402	236
Brisbane	1,350	0.10	313	232
Sunshine Coast	2,300	0.35	571	248
Mary	2,300	0.24	573	249
Burnett-Kolan	2,900	0.07	724	250
Curtis Coast	1,500	0.16	374	249
Fitzroy	7,100	0.05	1,774	250
Shoalwater Bay-Sarina	3,700	0.33	924	250
Pioneer-O'Connell	2,650	0.68	657	248
Proserpine	1,400	0.56	349	249
Don	700	0.18	175	250
Burdekin-Haughton	10,850	0.08	2,711	250
Rose-Black	1,100	0.38	265	241
Herbert	5,000	0.41	624	125
Tully-Murray	5,300	1.88	660	125
Johnstone	4,700	2.02	582	124
Mulgrave-Russell	4,200	2.08	521	124
Barron	1,150	0.53	137	119
Mosman-Daintree	4,250	1.63	528	124
North-East -Cape York	19,100	0.44	2,387	125

2.5.2 Costs of raising dams and weirs

The Queensland Water Infrastructure Task Force (1997) gives estimates of construction costs for a number of new dams and weirs, including several involving the raising of existing structures. (It is not suggested that the dam and weir raising projects were necessarily undertaken to restore lost capacity). Capacities and total costs are given in Table 5. Also shown are estimated sediment flows and resultant capacity loss, assuming a zero bleed factor and using the typical sediment concentration of 250mg/L for Queensland's southern coastal catchments derived above in Table 43. Then, the annual average cost of lost capacity is calculated for each dam or weir, based on its construction cost data.

It can be seen that there is a wide variation in the construction cost per unit of capacity for the different projects. The four projects which involved dam or weir raising had costs ranging from $0.17 to $0.78 per KL of capacity, with an overall flow-weighted average of $0.32/KL. These were Bingegang Weir, Borumbah Dam, Mary River barrage and Jones Weir. The four large dams have the lowest unit costs, ranging from $0.10 to $0.28 per KL of capacity, and with a flow-weighted combined average cost of $0.114/KL. These are the St George off-Stream Storage on the Balonne River, the Comet River Dam, the Dawson River Dam and the Barambah Creek

Dam. The new weir projects, including Condamine, Comgoa, Nagram, and Paranui, had generally higher unit costs, with a flow-weighted average of $0.77/KL.

Table 43: Estimated Costs of Lost Storage Capacity: selected new projects in Queensland (1997)

Proposed Water Supply Scheme	Capacity (GL)	Total Cost ($M)	Cost per unit of capacity ($/KL)	Ratio of Stream Flow to Capacity	Sediment Flow @ 250 mg/L (tonnes =kL)	Capacity Loss with zero bleed (%/yr)	Capacity Replace-ment Cost ($/yr)
St George Off-stream Storage (Balonne R.)	125.0	13.3	0.11	1.00	31,250	0.025	3333
Condamine Weir	12.6	9.1	0.72	1.00	3,150	0.025	2275
Nagram Weir (Condamine R.)	0.6	0.6	0.94	1.00	150	0.025	141
Comgoa Weir	27.7	25.0	0.90	1.00	6,925	0.025	6250
Raising Bingegang Weir by 3.5m	12.0	4.4	0.36	1.25	3,750	0.031	1359
Borumba Dam Raising by 2m	12.0	2.0	0.17	1.00	3,000	0.025	500
Raising of Mary River Barrage	3.1	1.2	0.39	1.00	775	0.025	300
Paranui Weir	11.5	5.9	0.51	1.00	2,875	0.025	1475
Raising Jones Weir 1.4m at Munduberra	1.9	1.5	0.79	1.00	475	0.025	375
Comet R. Dam	1480.0	150.0	0.10	0.25	92,500	0.006	9375
Dawson R. Dam	1100.0	120.0	0.11	0.20	53,900	0.005	5880
Cressbrook Ck Weirs	0.1	0.3	3.00	1.00	25	0.025	75
Lower Barambah Ck Dam (a)	76.0	36.0	0.47	0.25	4,750	0.006	2250
Lower Barambah Ck Dam (b)	142.0	40.0	0.28	0.15	5,325	0.004	1500

Source: Calculations based on data in Queensland Water Infrastructure Task Force (1997)

The estimated average annual capacity losses for each project shown in Table 43 are multiplied by the cost per KL of new capacity, to arrive at an annual average replacement cost for capacity lost due to sedimentation assuming zero bleed factor. This annual average cost would be considered as an annuity and the present value of costs for the life of the structure would then be calculated.

Recommended Cost Function

For the purposes of the Audit, it is considered that the average cost of dam or weir raising, of $0.32/KL of regained capacity, should be used in estimating the likely costs of lost capacity from sedimentation. Adjusting this figure to year 2000 values would give approximately $0.35/KL of capacity regained. This is a capital cost, which would be incurred periodically unless the reservoir could be re-designed to achieve greater sediment discharges. Clearly, there comes a point where a dam can be raised no more, and alternative responses are required (see Section 2.4). However, for the purposes of the Audit the assumption that all capacity will be regained at this cost level is a reasonable indication of the costs involved.

A critical question is the extent to which sediment flows exceed a reservoir's design "bleed factor", as this determines the amount of capacity that will be lost and when capacity loss will begin. A proportion of any increased sediment load will be transported over dam spillways during peak rainfall events. Therefore, it cannot be assumed that all of the increased sediment flow will accumulate in the reservoir. However, it has not been possible to develop a way of incorporating this into a standardised cost function, and consideration should be given to the typical reservoir designs in each drainage division in order to estimate a factor by which increased sediment loads should be multiplied to take account of this.

As a compromise, it is suggested that the assumption be made that all dams are designed to cope with sediment loads expected at the time of construction, and that capacity loss will be associated with any increases in sediment loads. The recommended indicative damage cost function is therefore:

$$CR = 0.35K * \Delta SL/K$$

$$= 0.35 * \Delta SL$$

Where:

CR = Cost of lost reservoir capacity ($/yr)

K = Reservoir capacity (kL)

ΔSL = Change in sediment flow (kl/year)

Putting this into a present value framework, by treating the $0.35/KL as an annuity and assuming a dam life of 50 years, a present value of $4.83/KL is obtained using a 7% discount rate, where lost capacity is expressed as the annual average rate of loss (KL). The estimate given here should be reduced by a "bleed factor' where data is available, to allow for operator discharges of increased sediment loads below the dam or weir. Clearly, the estimate of costs of lost reservoir capacity applies only to existing dams or weirs. Data on dams and their capacities are available within the Audit database from Theme 1 studies.

Water Treatment Costs

Impacts of Sedimentation on Water Suppliers and Users

While large particulates are readily treated by sedimentation in simple treatment plants, turbid waters cause many problems for water utilities. Turbidity, along with acidity and bacteriological quality, is one of the three parameters that are regularly used in water quality compliance reporting by the utilities. The *Water 2000 Study* (Department of Resources and Energy, 1983) suggested that turbidity resulting from soil erosion was the main non-point pollution problem for urban water supplies.

Dissolved organic carbon may shield bacteria and other micro-organisms from disinfection chemicals and is linked to the microbiological status, taste, odour and disinfection by-products in water. In water disinfection processes the soil particles in turbid water shield bacteria and viruses, and the larger amounts of chemicals then required for disinfecting give the treated water an unpleasant taste and odour. The level of turbidity is often associated with the presence of sediments and nutrients and therefore is also implicated in algal bloom development. The development of toxic algae in water supply reservoirs is of particular concern for water utilities.

To the consumer, turbidity is highly visible and usually unacceptable. Food processing industries require water of low turbidity, and this has also been a factor in decisions to install water treatment plants.

The National Water Quality Management Guidelines: Drinking Water gives 5 NTU's (corresponding to approximately 10mg/L sediment concentration) as the maximum turbidity of potable water supplies, and 1 NTU as the desirable level of turbidity in drinking water. The NWQMG upper limit of 5NTU has been taken in this report as the threshold value at which a water supply will require installation of a treatment plant. Thus it has been assumed that a water resource that degrades to a sediment concentration above this level will require treatment if it is used for a potable urban water supply.

Economic Effects

Natural resource degradation leading to increased turbidity increases the costs of water treatment, particularly where filtration is required. For example, the surface water supplies of Melbourne and Perth come from forested catchments where clearing for agriculture is banned, and human activities are tightly controlled (though logging proposals are an issue in the Melbourne catchments and bauxite mining takes place in some of the Darling Range catchments). These supplies are treated simply by chlorination, for disinfection, at minimal cost. In contrast, Adelaide and Brisbane obtain their water supplies from catchments that have been extensively cleared for agriculture and other activities and their water supply requires a high level of treatment. In the 1990s Sydney found it necessary to invest in four new water treatment plants following concerns about deteriorating organic and biological quality of its reservoir inflows. Both New South Wales and Victoria have put in place new water treatment plants serving the urban communities of the Murray-Darling basin, such as those recently constructed under 'Build-Own-Operate-Transfer" (BOOT) schemes by the Central Highlands and Coliban water authorities. Many of the current investments have been conceived as a part of State Government programs to rectify long-standing deficiencies in water supply quality, particularly in rural areas.

Treatment Methods
Water utilities employ a variety of treatments for turbid water. Treatment typically involves coagulation, flocculation and filtration with pre-treatment such as sedimentation or flotation where necessary to avoid overloading the filtration system with suspended material. If the treatment system is well designed the treated water will have very low turbidity.

The most commonly used coagulant since the late 1800s has been aluminium sulphate, or "alum", which is usually supplied in bulk liquid form to water treatment plants. When added to water the main reaction of alum is with either the natural alkalinity (e.g. calcium bicarbonate) or added alkalinity (e.g. added lime or soda ash), resulting in the formation of a colloidal aluminium hydroxide which then flocculates into large particles like snow flakes in which suspended matter and colour in the water are mechanically trapped or absorbed. This reaction results in lowering the pH of the water, and therefore it is often necessary to neutralise the treated water by adding lime, soda ash etc. Soft, coloured and acid waters present many problems in coagulation and are difficult to clarify satisfactorily as the doses of both coagulant and alkali are critical: very careful control is necessary to maintain a high quality filtrate and minimum residual aluminium in solution. The dose-response rate, and consequently process optimisation, for alum in Australian water treatment plants has not been well understood.

More recently a range of alternatives has been increasingly used. These include ferric chloride, polymeric cationic coagulants, granular activated carbon, and resins. Some of these are claimed to be more cost-effective than alum, but usually improved treatment performance, such as improved removal of dissolved organic carbon and associated pathogens, is also cited. There is a range of additives, which are employed to improve coagulation and flocculation performance.

The operating costs of treatment plants are influenced by the turbidity of influent. Increased amounts of chemicals are used in treatment and larger volumes of sludge have to be dewatered and removed from the treatment plant.

Capital Cost Estimates
The first type of cost that may result from natural resource degradation is the capital cost of installing new water treatment plants where they were not previously required. Sydney Water faced these costs in the 1990s, though it was prompted more by concerns about bacteriological quality than the level of turbidity. Once a decision to construct a plant is made, some aspects of its design depend on the turbidity of the influent, and this changes the capital cost for any given plant capacity.

There is no readily accessible, authoritative source for cost estimation. Therefore, for the purposes of the Indicative Estimates, a cost model was developed for prototype water treatment plants at capacities varying from 10,000 cu.m/day up to 500,000 cu.m/day. The estimates are for conventional treatment plants employing sedimentation, coagulation, gravity filtration and filter press sludge dewatering. Table 44 shows the treatment plant design variables used in the model. Two of these were varied for the purposes of this investigation, namely the plant throughput and influent turbidity. The turbidity variable is the concentration of solids in the influent, measured as kg/cu.m of influent.

Table 45 shows calculations of costs for a plant capacity of 50,000 cu.m/day. A total capital cost of $30 million was estimated (at Year 2000 prices). This appears consistent with observed costs for small treatment plants. It can be seen that, although turbidity and associated properties of influent water are the main reason for construction of any such treatment plant, the costs of many of the individual plant components are a function of throughput and independent of the turbidity of influent. The main impact of turbidity on capital cost occurs in the sludge storage and dewatering process. This reinforces the point, made above, that the degradation of a resource that previously required no treatment to a condition where a treatment plant needs to be constructed involves a very large cost.

Table 44: Design variables and their start values in the water treatment plant model

DESIGN VARIABLE	START VALUES
Throughput	10,000cu.m/d
Sedimentation rate	1.5M/hr
Filtration rate	5M/hr
Storage period for filtered water	2 hrs
Storage period for raw water	0.5 hrs
Pump standby capacity	50%
Chemical complexity score	7/10
Equipment standard score	5/10
Multiplier for un-costed civil components	1.4
Multiplier for un-costed mechanical components	1.1
Sludge solids concentration	0.02kg/cu.m of throughput
Sludge thickening time	24hrs @ mean of 0.02cu.m/kg
Sludge volume as % of throughput	0.05%
Clarification time	1 hr
Spare capacity for sludge holding	150 cu.m
Cake quality	3.68kg dry solids/sq.m filter area
Filter press operational time	5days/week
Filter press downtime	15%
Sludge storage time	3 days

Table 45 shows the calculation of costs for a plant having a capacity of 50,000 cu.m./d., giving a total plant cost of $30 million, of which some $17 million is mechanical and $13 million civil engineering costs.

The model was used to simulate the sensitivity of capital costs to changes in the turbidity of the influent. Table 46 shows the estimated total capital costs at each design capacity versus the sedimentation concentration in the feed water. These range from $11.5 million to $125.5 million for the least turbid influent and from $14.6 million to $262.8 million for the most turbid influent, with design capacities varying from 10,000 to 500,000 cu.m/d.

Table 45: Calculations performed by the water treatment plant model for a 50,000 cu.m/d plant with influent solids concentration of 0.2 Kg/cu.m (= 200mg/L) of throughput

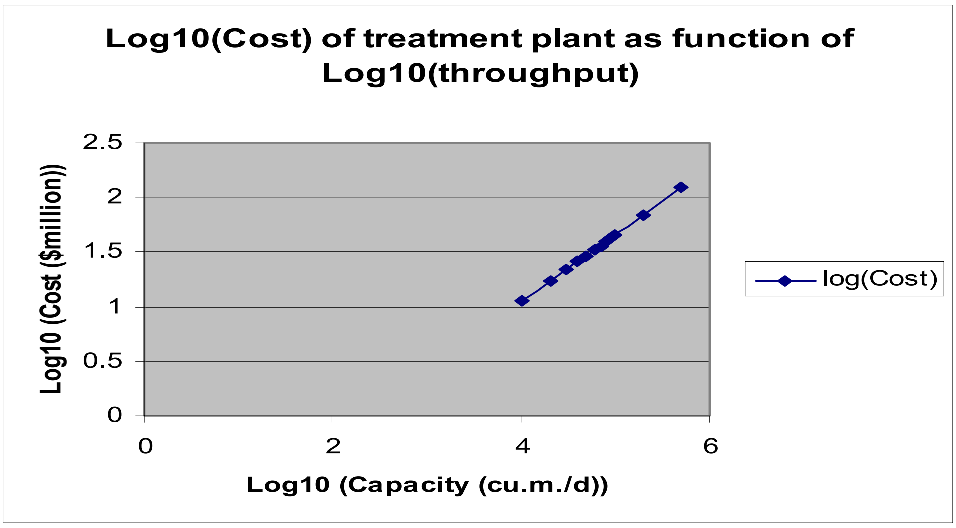
PLANT COMPONENT	CALCULATIONS	CIVIL COST ($M)	MECH COST ($M)
1. Settling ponds	Sedimentation area = 100,000/1.5*24=2,780sqm		
	Cost = 2.832(2.78)^0.76	3.635	
2. Filtration	Filtration area = 100,000/(5*24) =834 sqm		
	Civil Cost = 2.825(0.834)^0.81	1.390	
	Mech cost = 3.181(0.834)^0.68		1.754
3. Tanks (contact & filtered water)	Storage vol(filtered) = 100,000*2/24 = 8,340 cum		
	Civil Cost = 0.503(8.34)^0.48	0.998	
	Storage vol(raw) = 100,000*0.5/24 = 2,080 cum		
	Civil Cost = 0.503(2.08)^0.48	0.513	
4. Pumps	Pump capacity = 1.5*100,000/24 = 6,250cum/hr		
	Mech Cost = 1.165(6,250)^0.77		0.572
5. Buildings	Building area = 31.6*(100,000^0.85)		
	Civil Cost = 1805*(1.584^0.94)	1.598	
6. Chemical equipment	Mech Cost = 2.23(100,000)^0.46(Chem score)		11.763
	^1.17(standard)^1.3		
TOTAL ABOVE		8.134	14.089
7. Multipliers for CIV & MECH		11.551	16.765
8. Sludge Filter Press	Press area = solids content * throughput/cake quality		
	*7/5*1/0.85		
	Mech Cost = 2052* (press area^0.87)		0.899
	Civ Cost = 1158*(press area)^0.74	0.507	
9. Sludge Concentration	Tank volume =spare capacity + 2*((solids content/d14)		
	+ (sludge vol/24))* throughput		
	Civil cost = 403.3 * ((tank vol/1000)^0.56)	0.185	
10. Sludge storage	Tank volume = daily throughput * sludge vol/cu.m *		
	No. of days stored / 40		
	Civil cost	0.095	
TOTALCOST		12.338	17.665
	TOTAL COST = $30.002 million		

Table 46: Total capital costs ($ million) as a function of plant capacity (cu.m/d) and solids content of influent (mg/L)

Plant Throughput (cu.m/d)	10 mg/L	20 mg/L	50 mg/L	100 mg/L	200 mg/L
10000	11.5	11.6	12.1	12.9	14.6
20000	17.0	17.4	18.3	19.8	23.0
30000	21.6	22.0	23.4	25.7	30.4
40000	25.6	26.2	28.0	31.1	37.2
50000	29.3	30.0	32.3	36.0	43.6
60000	32.7	33.6	36.2	40.7	49.8
70000	35.9	36.9	40.0	45.3	55.8
80000	38.9	40.1	43.7	49.6	61.6
90000	41.8	43.2	47.2	53.9	67.3
100000	44.7	46.1	50.6	58.0	72.9
200000	69.1	72.0	80.7	95.4	124.7
500000	125.5	132.7	154.3	190.4	262.8

Figure 7 shows a log-log plot of total cost as a function of throughput for a plant that has a minimal (10mg/L) sediment concentration. From this it is seen that average capital costs for plants of different capacities can be estimated using a simple linear fit to this plot.

Figure 7: Capital cost function for new water treatment plant, derived from cost model



Marginal capital costs were calculated as a function of the solids content of influent from the data in Table 45, and these are shown in Table 46. The conclusions of this analysis are that (i) marginal capital costs increase at a constant rate as the sediment concentration of influent increases, and that (ii) marginal capital cost levels are remarkably constant across the range of plant capacities considered. The Table shows un-amortised capital costs. If these are amortised at a 7% discount rate over a thirty operating life for the treatment plant they give the cost per cu.m of water delivered. All values are approximately $4 in capital cost per Kg/cu.m of solids in influent, and the amortised value of this is $0.32/cu.m of water delivered to consumers per Kg/cu.m of solids in the influent. (1 Kg/cu.m equates to 1,000mg/L, which is a large value for sediment increase).

Table 47: Marginal capital costs (un-amortised)

	Marginal capital cost ($/cu.m of annual throughput) per Kg/cu.m solids in influent: to be added to "base" capital cost			
Sediment Concentration Capacity (cu.m/day):	**10-20 mg/L ($)**	**20-50 mg/L ($)**	**50-100 mg/L ($)**	**100-200 mg/L ($)**
10000	4.33	5.81	7.92	8.44
20000	4.21	5.64	7.67	8.15
30000	4.15	5.56	7.55	8.01
40000	4.12	5.51	7.48	7.93
50000	4.09	5.47	7.42	7.88
60000	4.07	5.45	7.39	7.83
70000	4.06	5.42	7.36	7.80
80000	4.05	5.41	7.33	7.77
90000	4.04	5.40	7.31	7.75
100000	4.03	5.38	7.30	7.73
200000	3.98	5.32	7.20	7.62
500000	3.94	5.26	7.11	7.52

In order to generate a marginal capital cost function, the sediment concentration values shown in Table 46 were transformed using a logistic equation to linearise the plot of capital costs versus sediment concentration, shown in Figure 8. Coefficients of the logistic equation were found by trial and error by varying their values in a spreadsheet. The resulting marginal capital cost function for increased sediment concentration of influent is:

$$M_{CC} = (W*365) \times (0.000222 + [0.000895 \times f(SC)])$$

$$F(SC) = 8.5/(1 + 2 \times e^{(-0.45SC)})$$

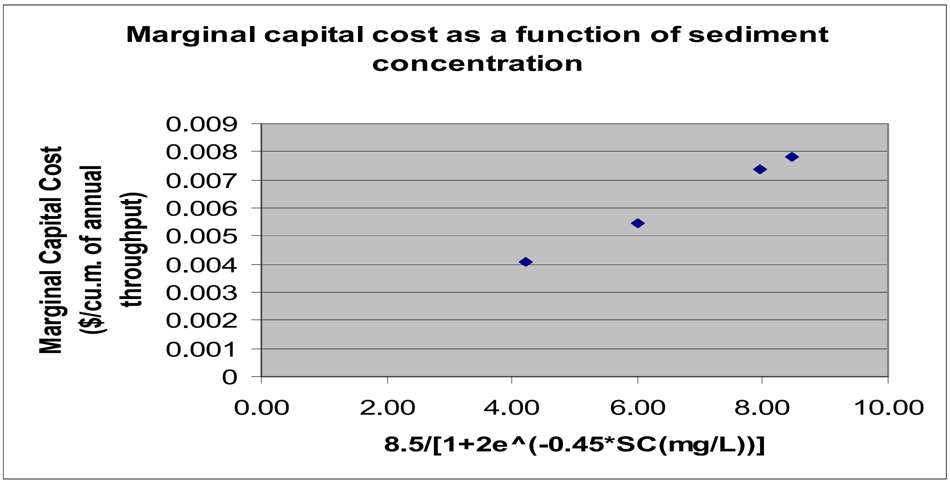
Where:

MCC = Marginal capital cost ($)

W = Daily throughput of plant (kL)

SC = Change in sediment concentration (mg/L)

Figure 8: Marginal capital cost function with respect to influent sediment concentration, derived from cost model



Operating Costs

As the turbidity of influent rises, more chemicals are used for coagulation and for maintaining the acidity level at or near neutrality. Transport or pumping costs for removal of sludge also increase. Operating costs of water treatment plants vary markedly depending on the process used. Nguyen (1997) gives indicative operating costs of four processes shown in Table 48.

Table 48: Typical operating costs for water treatment processes

Process	Typical Operating Cost ($/cu.m)
Conventional coagulation	0.024
MIEX^{TM} (Resin + Coagulation) Process	0.070
Granular Activated Carbon (incl. regeneration)	0.180
Nanofiltraton	0.210

The more expensive options address dissolved organic carbon, which is linked to microbiological status, taste, odour and disinfection by-products, whereas conventional coagulation addresses fine particle removal only. As already indicated, there is a general movement towards the improvement of water treatment methods by adaptation of existing treatment plants, development of new coagulants and enhancement of alum coagulation plants with supplements that improve e.g. pH control or flocculation characteristics.

Thus, in the case of a water supply catchment that degrades from not requiring treatment to requiring a sedimentation-coagulation-filtration process, the choice of technology will have a big influence on the subsequent levels of operating cost, and of course quality of the final product. For the purposes of assessing the operating costs of increased sediment flows in a catchment, the costs of a conventional alum coagulant have been used. This gives a minimum estimate of the marginal operating costs of increased sedimentation.

Discussions were held with CIBA Speciality Chemicals Ltd and Coogee Chemicals Ltd, both being suppliers of coagulants to the water industry. Coagulants are supplied to treatment plants generally in liquid form. The dose rate varies with the particular coagulant and with the turbidity of the raw water.

For alum, the dose rate for plants can vary from around 20mgL^{-1} to 120 mgL^{-1} (see for example the rates examined in Kaeding et al, 1997). Nguyen (1997) suggests an alum dosage rate of 50 ppm for treatment of water with 7.5mg/L dissolved organic carbon in a 50,000 cu.m/day plant. On the advice of Mr Sciliano of CIBA Speciality Chemicals the alum dose rate could be greater for difficult waters, such as are found in parts of Queensland. Thus, for a 50,000cu.m/day plant the minimum annual alum dose requirement would be 365 (days) x 50 (million litres) x 20mg^{L-1}, equals 365 tonnes. The cost of alum delivered in this quantity is approximately $200/tonne. Thus the annual cost of alum would be $73,000/year. At the largest dose rate alum would cost six times this amount i.e. $438,000/year. These estimates equate with a unit cost for alum of $4 to $24 per ML of treated water.

The CIBA cationic coagulant is applied in doses of 1 ppm, and although the cost per tonne is 5 times that of alum, the total cost is about a half of the alum cost. However, as most plants are still based on conventional alum treatment, the alum volumes are probably the most indicative for assessing the costs of natural resource degradation.

Based on data given in Nguyen (1997) a cost function for alum application is:

$$C = (24 * K) + P * K * (6.6 * (D - 7.5))$$

$$= (24 * K) + ((P * K * (6.6D - 49.5))$$

where:

C = total alum cost

P = the price of alum ($/Kg)

K = the daily throughput of the plant (ML)

D = dissolved organic carbon in influent (mg/L)

For example, in a 50 ML/day plant, alum cost of $0.2/Kg, and dissolved organic carbon concentration of 22.5 mg/L the total operating cost is:

Total alum cost = (24 * 50) + (0.2 *50 *6.6 *(22.5 - 7.5) = $8,910/yr

Annual cost/unit capacity= $8,910/50ML/d = $178.2/ML/d, or $0.178/cu.m.

The marginal operating cost attributable to increased dissolved organic carbon (which is some fraction of total sediment load) for a treatment plant of 50ML/day is therefore:

$$dC/dD = 6.6*P*K \ (\$/ML/mgL^{-1}), = 66(\$/mgL^{-1})$$

Expressing this in terms of cost per cubic metre of water treated gives

$\$66.0/(365 * 50*10^3) = 3.6164 * 10^{-6}(\$/cu.m/mgL^{-1})$

Costs of Sedimentation to Local Government, and Road and Rail Operators

Local Government Questionnaire Survey

Resource Economics Unit distributed over 200 questionnaires to shires and country towns. Useful data were obtained from 24 respondents, who reported experiencing additional "ex-situ" costs due to erosion products. The principle areas of increased cost were roads and land management.

Table 49: Number of Local Authorities reporting costs due to erosion and sedimentation

	Area of Operations	N
1	Land management	8
2	Buildings repair & maintenance	3
3	Waste mgt & landfills	2
4	Drainage/pumping	5
5	Underground tanks	0
6	Swimming pools	1
7	Graveyards	1
8	Roads, bridges, paths & verges	15
9	Other transport	0
10	Health services	0
11	Drainage/pumping	7
12	Parks, gardens, sporting venues	6
13	Environmental mgt & protection	4
14	Other items	0
	Total Responding Authorities	**24**

Due the small size of the responding sample only a broad classification is possible. In order to provide an indication of the *ex-situ costs* of erosion and sedimentation to local government, the costs reported by (i) respondents from areas in Queensland that are well known to experience sediment deposition, are compared with (ii) respondents from other parts of the country who reported negligible costs from the deposition of erosive materials.

From Tables 12 and 13 it is seen that operating costs of $6.80/capita/year and additional capital costs of $0.42/capita/year were reported by Queensland local governments, giving a total cost of $7.22/capita/year.

Recommended Cost Function for Local Government

It is not possible to indicate how these costs vary in relation to the severity of sediment generation and transport rates experienced by respondents to the questionnaire. However, as a very broad way of assessing costs in relation to resource condition, the Queensland data can be taken to reflect costs in regions where long term average river sediment concentrations are of the order of 250mg/L. Assuming a linear correlation between (i) costs to local government and (ii) river sediment concentration in the particular region, the implied cost per mg/L of sediments is $7.22/250 = $0.02888/capita/yr/mgL^{-1} sediment concentration in local rivers. Alternatively it may be possible from other Audit studies to develop a regionally-based soil erosivity index, which could be used instead of sediment concentration in local rivers.

Table 50: Extra operating costs per capita due to natural resource degradation (primarily erosion and sedimentation) in Queensland.

	Area of Operation	Extra Operating Costs ($/capita/yr)
1	Land management	3.08
2	Buildings repair & maintenance	0.06
3	Waste mgt & landfills	0.06
4	Drainage/pumping	0.00
5	Underground tanks	0.00
6	Swimming pools	0.00
7	Graveyards	0.12
8	Roads, bridges, paths & verges	0.28
9	Other transport	0.00
10	Health services	0.00
11	Drainage/pumping	0.02
12	Parks, gardens, sporting venues	0.09
13	Environmental mgt & protection	3.08
14	Other items	0.00
15	**Total**	**6.80**

Table 51: Extra capital costs per capita per year due to natural resource degradation (primarily erosion and sedimentation) in Queensland.

	Area of operation	Extra Capital Costs ($/capita/yr)
1	Land management	0.15
2	Buildings repair & maintenance	0.01
3	Waste mgt & landfills	0.01
4	Groundwater Pumping/drainage	0.00
5	Underground tanks	0.00
6	Swimming pools	0.00
7	Graveyards	0.01
8	Roads, bridges, paths & verges	0.08
9	Other transport	0.00
10	Health services	0.00
11	Surface water drainage	0.00
12	Parks, gardens, sporting venues	0.01
13	Environmental management	0.15
14	Other items	0.00
15	Total	0.42

Costs of Erosion and Sedimentation to Road and Rail Operators

Questionnaire survey results

Resource Economics Unit addressed a questionnaire on the cost impacts of erosion and sedimentation to 12 road and rail operators. Four responses were obtained, from NSW, Victoria, South Australia and Western Australia. Responses from WA and NSW acknowledged that costs were being incurred as a result of degradation, but the agencies were not able to make any estimate for the magnitude, as the relevant expenditures were hidden within general repair, operational and maintenance accounts and were inaccessible except at substantial costs to the respondents.

The main costs reported by South Australia and Victoria were in the areas of cleaning and debris removal from verges, culverts, embankments, bridges and tunnels. Erosion and sedimentation issues were closely related to increased flooding characteristics. The problem of erosion *from* roads and railways was also mentioned, but this is not an *ex-situ* effect except in the sense of erosion from roads and railways being accentuated in some areas by increased flooding characteristics following natural resource degradation. In South Australia erosion products associated with extreme flooding events sometimes lead to road closures. Table 52 summarises the results obtained for South Australia and Victoria.

Table 52: Additional operating and capital costs due to erosion and sedimentation in Victoria and South Australia ($m)

	VicRoads		Transport South Australia	
	Operating	**Capital**	**Operating**	**Capital**
Cleaning/debris removal	0.750	0.750		
Diversions/closures	0.075	0.300	0.050	
Verges, hard shoulders	0.750	0.750	0	
Culverts	1.500	1.500	0.025	
Embankments	1.500	1.500	0.010	
Bridges & tunnels	0.300	1.500	0.025	
Pavements	2.500	2.500	0.050	
Weed infestation	0.750	1.500		
Rabbit & weed damage	0.300			
Total	**8.425**	**10.3**	**0.151**	

Recommended cost function

The cost data from Vic Roads and Transport South Australia are expressed in Table 53 as rates per km of roads, or number of culverts etc. However, it has not been possible to express these costs in terms of a standardised cost function, which relates the level of costs to the severity of resource degradation. As with the cost data for local government, it may be possible from other Audit studies to develop a regionally-based soil erosivity index, which could be used.

Table 53: Costs per number of units at risk of erosion and sedimentation impacts ($)

	Vic Roads		Transport South Australia	
	Operating	**Capital**	**Operating**	**Capital**
Cleaning/debris removal (km)	441	441	1,000	Nil
Diversions/closures (km)	50	2,000	500	Nil
Verges, hard shoulders (km)	682	682		Nil
Culverts (n)	1,250	1,250	5,000	Nil
Embankments (km)	1,875	1,875	500	Nil
Bridges & tunnels (n)	437	2,678	1,250	Nil
Pavements (km)	2,500	2,500	500	Nil
Weed infestation	750	1,500	0	Nil
Rabbit & weed damage	750	nil	0	Nil

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APPENDIX H Report on Total Ex-situ Damage Cost Estimates for Salinity, Water Turbidity and Erosion

National Land and Water Resources Audit

Ex-situ Costs of Australian Land and Water Resources Degradation to non-Agricultural Industries, Infrastructure and Households

REPORT C: TOTAL EX-SITU DAMAGE COST ESTIMATES FOR SALINITY, WATER TURBIDITY, AND EROSION

By

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The Resource Economics Unit

July 2001

This report is provided to CSIRO Land and Water by the Resource Economics Unit under contract Folio Number 00/105 STR/91, and provides the Indicative Economic Assessment for sub-project 6.1.3 of the National Land and Water Resources Audit, Theme 6, Project 1.

Glossary of Terms and Conversions

Amortisation	Conversion of a lump sum to an annual value at a given discount rate.
Basin	Australian Water Resources Council River Basin (data for 133 of these are analysed in the report)
Catchment	The area within a watershed. This term is used sometimes to refer to Basins, and also to refer to sub-basins
Control costs	Costs incurred by government, individuals, industries, or infrastructure providers to control or improve the condition of the natural resource.
Discount rate	The rate of time preference for real income. For risky projects the discount rate is taken as the average real rate of return on capital in the private sector, of about 6%; for riskless projects a lower rate, of 3% has been assumed.
Drainage Division	Australian Water Resources Council Drainage Division. There are 12 in total, but only 5 covering the principal mainland areas of agricultural development are analysed in this report.
EC Units	Electrical conductivity units, μSm^{-1}, a measure of water salinity: equals approximately 1.6 times TDS.
Ex-situ Damage Costs	Costs incurred by industries, infrastructure providers or households, as a result of the degradation of water resources. These costs comprise (a) recurrent damage costs including loss of income from impaired economic activity, additional repair or maintenance expenditure, or reduced service life of capital items; and (b) non-recurrent investment costs on such items as replacement source development, desalination plants or upgraded water treatment plants.
Marginal Damage Cost	The damage costs to urban, industrial and commercial water users arising from a given % deterioration in water quality in $ millions.
Measurement Station	Steam water quality measuring stations providing water quality data to the Audit database. Data for a total of 935 measurement stations were analysed in producing this report.
NTU	National Turbidity Units: potable water supplies are usually of no more than 1 to 2 NTUs. A raw water quality of NTU >5 indicates that advanced water treatment is required.

Salinity of water	Four salinity classifications are used: - Fresh (TDS < 500 mgL^{-1}) - Marginal (TDS 500 to 1,500 mgL^{-1}) - Brackish (TDS 1,500 to 5,000 mgL^{-1}) - Saline (TDS >5,000 mgL^{-1}).
Sediment concentration	Concentration of inorganic and organic solids in water, measured in mgL^{-1}.
TDS	Total dissolved solids in a water sample, in mgL^{-1}: equals approximately 0.625 EC Units.
TFS	Total Filterable Solids
TSS	Total soluble salts in a water sample, in mgL^{-1}: a "true" measure of salinity, but in practice this measure is very similar in value to TDS; TSS is not used in this report.
Turbidity	The clarity or opaqueness of a water sample measured by photometric means as NTUs; turbidity is related to, but not directly proportional to sediment concentration as different sediment characteristics produce different turbidity levels. Turbidity is a routine water quality parameter for water supply utilities.

Executive Summary

Ex1. Overview
Theme 6 of the National Land and Water Resources Audit is titled "Capacity for Change". Project 6.1 addresses economic dimensions of resource degradation. Projects 6.1.1 and 6.1.2 are concerned with the value of agriculture and impacts of land degradation within it. Project 6.1.3 addresses the impacts on non-agricultural industries, infrastructure and households. Finally, Project 6.1.4 provides estimates for recreational and ecosystem values.

Within Project 6.1.3 the work was divided into two streams. (a) Dames and Moore (now URS Australia) dealt with *in situ* effects, including the impacts of rising groundwater tables (saline and fresh) on infrastructure, and the impacts of resource degradation on tourist industries, while (b) Resource Economics Unit (REU) and PPK Environment & Infrastructure (PPK) dealt with *ex-situ* aspects.

For the purposes of this report *ex situ* impacts are defined as phenomena that occur away from the original site of degradation, by processes of water transfer.

The REU-PPK component resulted in three earlier reports:

- Unit damage cost functions for the ex-situ impacts of salinity (REU, February 2001)
- Unit damage cost functions for the ex-situ impacts of erosion and sedimentation (REU February 2001)
- Industrial and commercial impacts of impaired water quality (PPK, March 2001)

This report presents estimates of national marginal costs due to water degradation from salinity, turbidity and erosion/sedimentation in Australia. The estimates employ the standardised unit cost functions presented in the previous REU and PPK reports. The unit cost functions have been combined with data on resource condition supplied by the National Land and Water Resources Audit, and supplementary data on affected activities and infrastructure to provide the total national cost estimates.

Ex.2 Adequacy of the results for informing public policy
This report is the first attempt to apply the large amount of data on resource condition assembled by the National Land and Water Resources Audit in order to derive estimate the ex-situ costs of land and water degradation in Australia.

In order to meet the overall Audit deadlines, the report has been prepared under severe time constraints. Within those constraints efforts have been made to identify and correct remaining anomalies, to "patch" missing data, and to identify the intervening chain of human activities that complicate the link between raw resource condition and the level of user damages. The last of these points needs some further explanation.

It is paradoxical that in many regions that suffer from severe resource degradation the impacts in terms of user costs can be quite modest. For example, even in highly saline environments, there is often a source of fresh water that suffices for local needs, especially if the community is not large. If the geographical scale of information were fine enough, it would be possible to identify exactly which communities can or cannot avoid high damage costs. However, if reliable estimates of costs and decisions about worthwhile investments are to be made, the richness of the database of usage patterns, infrastructure and inter-basin water transfers has to match the data for resource condition. Even after the Audit, that database still does not exist. For example, in order to calculate marginal damage costs from turbidity it was necessary for REU to undertake a survey of current water treatment practices to establish a "base" from which the incremental marginal damages could be calculated. Responses to this survey were still being returned at the time of writing. More broadly, we still know relatively little, in a statistical sense, about the usage patterns and water using technology of industrial and commercial users.

Therefore, it is important to note that the estimates of ex-situ costs in this report are based on the following assumptions.

- That population, economic activity and patterns of water use in each receiving area will remain constant over time. Given the likelihood of demographic and economic growth this is likely to lead to an underestimate of future costs.
- That postulated future changes in water quality variables would have an immediate effect (rather than being a graduated change over time). This assumption tends towards overestimation of costs in the near term.
- That the maximum percentage change in water pollution and erosion is an immediate 10% increase. It is possible that this could underestimate costs in some basins and overestimate them in other basins.
- That in basins that have multiple measurement stations, only those sub-catchments with "good" (fresh) or "fair" (marginal) salinity exceedence values will be used for water supply purposes: this assumption has been introduced in order to approximate the behaviour of water utilities in diverting the best available local resource for water supply to urban and industrial users.
- Subject to the above, the area-weighted median salinity, derived from a number of measurement stations in a river basin, is assumed to be representative of the quality of water delivered from that basin to water users. This will be true only if water is supplied from sub-catchments in proportion to their areas, and the measurement station readings are representative.
- That the standardised unit damage cost estimates for salinity, turbidity and erosion/sedimentation, which were developed by REU and PPK, apply in all river basins (i.e. variations in cost due to local factors are not considered)
- That there is a "threshold" level of salinity, of 300 EC Units, below which no user damage costs are incurred. This level of water supply salinity generally would be considered "excellent" by water supply agencies and regulatory bodies.

The level of economic damage incurred by water users from degradation of the resource is often limited because of "sunk costs" i.e. past investments that have enabled communities to live with the problem of degradation. Examples of this are the already high levels of water treatment addressing turbidity offered by urban water suppliers drawing water from the Northern Victoria, Western New South Wales and the Adelaide Hills; and the salinity-proofing of urban and industrial water supplies in the South Australian Gulf and the south west of Western Australia by investments in long-distance pipelines, careful management of reservoirs, decisions about land use in water supply catchments, and increasingly into the future, improvements in desalination technology. These past investments weaken the correlation between general resource condition and the level of user damage cost: which, of course, is exactly what they are intended to achieve. As far as possible, the standardised marginal damage cost functions, being based on the quality of water actually delivered, allow for this, but local variations in defensive investments are not taken into account.

An additional, and related point, is that on inspecting the Audit results it has to be concluded that the costs that have been sunk in ongoing management of rivers and catchments have largely succeeded in *stabilising* the condition of surface water resources over the past decade. The result is that the frequency of reports of increasing trends in water pollution is very low. As a part of this project it was necessary to inspect the Audit data from 935 measurement stations in 133 river basins. A field was provided in the Audit database to record "increasing", "decreasing" or "no trend", for each water quality parameter (salinity, acidity, total phosphorus, total nitrogen, turbidity, faecal coliforms, and frequency of blue-green algae occurrences). Reports of increasing trend were rare. Thus, when the analysis was limited to those basins showing a worsening trend, the total estimated damages nation-wide across all water quality parameters was substantially reduced.

This is not to say that there is no need for concern about the condition of water resources. Put simply, when considering future public policies and future investments in water quality improvement, it is necessary to consider the likely cost impacts of *potential future* changes in resource condition as much as the historical record, which is in any case very patchy. For this reason, the report presents estimates of cost impacts resulting from a given percentage worsening in each water quality parameter. For the purposes of the report a 10% worsening in each water quality parameter was considered.

However, it makes little sense to base policies on notional percentage changes in future water quality, if these are unlikely to occur in practice. Therefore, river basins were next classified into two groups, namely (a) those facing a *significant risk* of increased salinity in future, and (b) those *not facing a significant risk*. For example, considerable damages would be incurred if the Sydney water supply were to suffer increases in salinity, even if salinity remained relatively low. However, there is no prospect of such an increase, and the Hawkesbury river basin was classified as not facing a significant risk.

Provided the above qualifications are borne in mind, the data set and damage functions developed in the course of the study provide cost benchmarks for researchers and policy advisors wishing to investigate the damage cost implications of different scenarios for future water quality.

To ensure that the overall investment in the Audit bears fruit, in terms of (i) better economic assessments of national and regional environmental policies, and (ii) better-targeted scientific research and monitoring programs, an ongoing program leading to refinement of the estimates provided here should be put in place. The last Section of this Executive Summary outlines the work required.

Ex. 3 Results

Total marginal cost estimates were developed for salinity, turbidity and sedimentation at the level of 133 AWRC River Basins, Drainage Divisions and States.

These covered all the agricultural regions from the Daintree catchment in northern Queensland to the Murchison in Western Australia. Five Drainage Divisions were included: I, North East Coast; II, South East Coast, IV Murray-Darling Basin, V South Australian Gulf and VI South West Coast.

An Excel Workbook, "***REU Catchment Master.xls***", which has been supplied to CSIRO Land & Water and the National Land and Water Resources Audit, contains the full set of calculations and results. The Workbook is presented in an interactive mode, through which the user may vary key assumptions including: the time period for analysis, discount rates, potential changes in water quality parameters, variations in mean and maximum values for water quality parameters, and the values or forms of the unit cost functions.

Ex.3.1 Salinity

Ex.3.1.1 National Costs

Table 54 gives the results obtained for salinity, assuming a universal deterioration of 10% in river and stream water quality, and including hardness costs in calculations for the Murray-Darling basin, using a discount rate of 6 per cent, while Table 55 shows the results for a 3 per cent rate of discount.

Salinity emerges as the largest potential cause of damage costs to urban and industrial water users, and affects all States considered. Using a real discount rate of 6%, the Present Value of national economic damage costs, for a 10% across-the-board increase in river and stream salinity in fresh or marginal water sources with salinity currently above 300 EC units, would be over $1,716 million. This is a significantly higher estimate than has been obtained from earlier studies. It results from differences in the way the unit damage cost functions have been estimated, using (i) new data and (ii) economic amortisation procedures (see REU Report A). It was not possible to develop national marginal damage costs separately for industrial, commercial and household users, as the Audit water use data were lumped at the total urban and industrial level.

Table 54: Summary of estimated marginal damage costs for a 10% worsening in water quality, across selected water quality variables, by State, assuming zero cost for basins currently supplying water below 300 EC units (Net Present Value over 30 years at 6% real discount rate, $million at constant year 2000 prices).

Basin Group	ACT	QLD	NSW	VIC	SA	WA	TOTAL
All basins	0	191	99	429	711	286	1,716
Basins at Significant Risk	0	26	93	121	709	285	1,233
Increasing Trend	0	0	0	0	0	16	16

When the analysis is limited to those basins assessed as being at risk of some increase in salinity, a 10% increase would cause damage costs of $1,347 million, when discounted at 6 per cent. But if salinity is assumed to increase only in those basins where there has been a recent upward trend the national damage costs, at $16 million, would be very small. This result is obtained because there are only a few instances of upward trend, and these are found in basins from which only small amounts of water are diverted for urban and industrial use.

Lowering the discount rate to 3% per year increases the present value estimate of national damages for all groups considered, but the relativities between them are unchanged.

Table 55: Summary of estimated marginal damage costs for a 10% worsening in water quality, across selected water quality variables, by State, assuming zero cost in basins currently supplying water below 300 EC units (Net Present Value over 30 years at 3% real discount rate, $million at constant year 2000 prices).

Basin Group	ACT	QLD	NSW	VIC	SA	WA	TOTAL
All freshwater basins	0	273	141	610	1,013	407	2,444
At risk basins	0	38	132	172	1009	406	1,757
Basins with increasing trend	0	0	0	0	0	23	23

Moreover, the broad order of magnitude of the ex-situ salinity damage cost estimates is not changed very much by this lower discount rate.

Ex.3.1.2 Regional Impacts

The largest individual State damage cost from salinity would be incurred in South Australia: NPV of $ 711 million at the 6% discount rate and $1,000 million with the 3% discount rate. For South Australia, there is little difference between the "10% across all basins" scenario and the "at risk" basins scenario, because all but one of the South Australian Gulf basins and all of the lower Murray-Darling basins was judged to be at some risk of a salinity increase in future.

Victoria and Western Australia also have high levels of potential damage costs, because they have a significant number of river basins with relatively high EC values and high levels of water use from these basins.

Potential salinity damages in Victoria a spread throughout the State, including the coastal catchments in the south west of the State, as well as those in the Murray-Darling basin. However, the estimates of damage costs in Victoria are more sensitive to the assessment of which catchments are at risk than is the case in South Australia.

The southwest of Western Australia emerges with a significant level of ex-situ damages to urban and industrial water users. It should be noted that all of the surface water supply systems in the South West Coast Drainage Division were classified as facing a significant risk of raised salinity in future. A number of water supply catchments in the Darling Ranges, which have not been cleared for agriculture, remain fresh, and, provided current catchment land uses are maintained, should remain so. On this basis, the basins in question, notably the Swan Coast basin (which actually comprises several small catchments), might be excluded from the "at risk" category, with a consequent reduction in Western Australian costs.

Queensland emerges with relatively high damages from salinity when all of its freshwater catchments are included, but this result is substantially reduced when the analysis is limited to river basins that are assessed as facing a significant risk of an increase in water supply salinity. In other words, neither the initial salinity levels nor the magnitude of urban and industrial water use were particularly high in the catchments identified by the Audit's dryland salinity assessment as being at risk.

The situation is somewhat different in New South Wales and the ACT, where there is little difference between the upper estimate and that for basins at risk. In other words, in New South Wales and the ACT nearly all the basins where salinity costs were positive were deemed to be at risk of an increase. Note, in this regard, however, that all the results discussed here assume a salinity cost threshold of 300 EC, and this excludes several major New South Wales catchments, including the Hawkesbury Basin, which supplies most of Sydney's water requirements.

Ex.3.2 Turbidity

Turbidity is a significant cause of potential damage costs to water users. The calculations depend on an assumed current level of water treatment in each freshwater river basin, and a comparison of this with the level that appears to be required for (i) the current median turbidity level, and (ii) an assumed increased turbidity level.

The current treatment level assumed for all river basins where actual treatment practices were not reported is: (i) chlorination, (ii) Ph remediation where necessary, (iii) sedimentation, (iv) sand filtration and (v) coagulation-precipitation. This is a common treatment train in river basins currently experiencing medium to high turbidity levels. Capital costs for additional treatment would generally be associated with higher-grade filtration or coagulation-precipitation processes, and higher capital expenditure on sludge processing. Increased operating costs would be associated with higher expenditures on treatment chemicals.

Table 56: Estimated marginal damage function for increased turbidity (Present Value using 6 per cent real rate of discount over 30 years in year 2000 prices)

Cost Category	ACT	QLD	NSW	VIC	SA	WA	TOTAL
Treatment Plant Upgrades	7	264	102	157	111	25	666
Capital cost for increased turbidity	4	52	50	62	17	19	205
Operating Cost Increases	1	113	116	35	91	4	361
Total Turbidity Cost	12	428	268	255	219	48	1231
Total Turbidity Cost in basins with increasing turbidity trend	0	0	71	8	89	0	168

The largest component of estimated turbidity costs is associated with an apparent gap between the level of treatment currently offered in each river basin and the level suggested by the model. This item has been termed "water treatment plant upgrades without turbidity increases". The estimated cost of $666 million in Present Value terms using the 6% discount rate appears consistent with the level of ongoing water treatment upgrades occurring in Australia, and could even be an under-estimate.

Table 57: Estimated marginal damage function for increased turbidity (Present Value using 3 per cent real rate of discount over 30 years in year 2000 prices)

Basin Group	ACT	QLD	NSW	VIC	SA	WA	TOTAL
Upgrades to existing WTPs	7	264	102	157	111	25	*666*
Upgrades for specified increase in turbidity	4	52	50	62	17	19	*205*
Operating Cost impacts	1	160	165	50	130	6	*514*
Total Turbidity	13	447	325	262	385	80	*1,511*
Total Turbidity Cost in basins with increasing turbidity trend	0	0	79	9	95	0	*184*

A 10% increase in turbidity in all freshwater basins would lead to an estimated marginal damage cost of $205 million.

The calculations for turbidity should be regarded as having large error bounds, mainly because local circumstances, not captured by the model, could change the results significantly. While the capital and operating costs of treatment plants were scaled in accordance with the volume of water used in each basin, the cost of more advanced chemical treatment facilities was difficult to estimate. The marginal damage cost function has been based on a theoretical model, which while giving broadly plausible results has not been tested against the actual experiences of water treatment plant operators faced with changed turbidity.

Ex.3.3 Erosion and Sedimentation

Using the 6% discount rate, the costs associated with erosion by-products, are shown in Table 58.

The costs to local governments, State main roads departments and rail operators due to expenditure on cleaning-up deposited materials following heavy rainfall events are based on a questionnaire survey of local government requesting information on per capita expenditure incurred in relation to various forms of environmental degradation. Expenditure by local governments in highly erosive regions was compared with that in regions of low erosivity, and a factor was introduced to adjust this expenditure to take account of regional road and rail operators. The survey of local government suggested that expenditure per resident due to erosion problems is around $7/head/year, even in the regions that have high rates of hill slope erosion. Based on limited information from State road and rail operators, it is estimated that their costs due to erosion are approximately 1.5 times those incurred by local authorities. This analysis of expenditure was then related to the rates of hill slope erosion by basin, collected for the Audit. The Present Value of total estimated ex-situ cost to local government, road and rail operators due to clean-up of erosion by-products is $167 million at the 6% rate of discount and $238 million at the 3% discount rate..

Estimated cost of reservoir capacity losses are relatively low, because the rate of capacity loss appears to be generally very slow, even in the Queensland catchments that relatively high rates of hill slope erosion. New data on sediment loadings collected by the National Land and Water Resources Audit suggests that most Australian reservoirs have low rates of fine particle deposition, and long expected lifetimes in terms of the rate of accumulation of sediments. Thus a relatively low

Present Value of damage costs, amounting to $40 million at the 6% discount rate, and $57 million at the 3% rate was obtained.

The data for costs to agencies managing navigable waters are based on the most recent environmental economic survey data. However, it was difficult to estimate the implications of sediment export rates from catchments on channel management, as most of the sediment load in the major Australian harbours is transported out to sea, rather than being deposited in harbours. The Present Value of costs to authorities managing navigable waters and harbours is estimated at $108 million using the 6% discount rate and $153 million at 3%.

Table 58: Erosion and Sedimentation Results: 6% Discount Rate

Basin Group	ACT	QLD	NSW	VIC	SA	WA	TOTAL
Local Government Road and Rail	1	113	43	6	3	1	167
Reservoirs	0	25	13	1	0	0	40
Channels	0	78	26	3	0	0	108
Total Erosion and Sedimentation	1	216	82	10	3	1	315

Table 59: Erosion and Sedimentation Results: 3% Discount Rate

Basin Group	ACT	QLD	NSW	VIC	SA	WA	TOTAL
Local Government Road and Rail	2	161	61	9	4	1	238
Reservoirs	0	36	19	2	0	0	57
Channels	0	111	38	4	0	0	153
Total Erosion and Sedimentation	2	308	117	15	5	2	448

Thus the study concludes that the ex-situ costs of erosion and sedimentation to non-agricultural industries, infrastructure and households, while significant, are small relative to the costs of salinity and turbidity.

Ex.4 Other Water Quality Parameters

Damage cost estimates have not been developed for nutrient enrichment, blue-green algae or the effects of increased flooding characteristics that can result from broad scale landscape degradation and reduction of vegetative cover.

With respect to nutrients the main impacts of degradation are in respect of environmental quality, and the principal costs are environmental protection costs. Atech Group Pty Ltd have recently estimated the cost of planned environmental protection measures to be $120 million per year, for management of sewage and stormwater, wastewater management from agriculture and industry and expenditure on rehabilitation of degraded aquatic environments. Aztech also estimated a cost to urban water supply authorities, of $20 million per year (equivalent to an NPV of $400 million) including investigations, monitoring, water treatment and distribution, and cost of interruptions to potable water supplies due to algal blooms.

It is thought likely that the cost functions developed in this report for turbidity would cover the cost of potential treatment upgrades. There is likely to be an association between turbidity level and nutrient levels, so to add the two would be likely to involve double-counting. Similarly, the cost of managing reservoirs that are affected by nutrient enrichment have not been estimated directly. However, it may be assumed that water utilities will weigh up the cost of reservoir management (including chemical dosing of reservoirs) versus the enhancement of water treatment facilities or enhanced total scheme capacity, for their particular situations. The two forms of control are to a degree mutually exclusive, so counting both reservoir management costs as well as water treatment plant upgrades is likely to involve double counting.

Much more effort needs to be put into the inter-related impacts of turbidity, nutrient enrichment and -algal blooms on water treatment costs.

Ex.5 Symmetry/A-symmetry in the Damage Cost Functions

The report discusses marginal damage costs using a 10% increase in the values of water quality variables, and the exposition is largely in terms of the potential costs of a worsening of water quality. What would be the benefits if water quality were improved? Could the same functions be used?

The functions dealing with salinity and erosion/sedimentation are dominated by recurrent impacts of water quality (even where some of the impacts are on service lives of capital items). In these cases the damage cost functions may be taken as symmetrical and apply to both improving as well as worsening resource condition. The position is less clear for turbidity, because of the fixed nature of investment in water treatment plants. It seems likely that the capital component of the damage costs, for water treatment plant upgrades, would not be relevant in assessing benefits from an improvement in raw water supply turbidity. However, the operating cost components for water treatment would be relevant in assessing the benefits of improved water turbidity.

Ex.6 Work Program for Refinement of the Estimates

Ideally, the estimates presented in this report should be refined by further work to take account of likely future changes in receptor populations, estimates of probable likely future rates of change in water quality variables at the basin level, and by a review of the REU assumptions about salinity risk. This would provide

- agreed estimates of the likely phasing of potential salinity increases
- estimates of likely future change in populations and economic activities at risk
- mathematical functions for combining these above estimates for estimation of Present Values
- testing of the correlation between river basin water quality and the quality actually received by water users
- better quantification of the proportion of water used for different purposes, from individual river basins.

Ex.7 Summary

The estimated ex-situ economic damages that would be incurred by non-agricultural industries, infrastructure and households as the result of (a) an across-the-board increase of 10% in salinity and turbidity in freshwater catchments, and (b) a 10% increase in erosion everywhere, total an estimated $2.779 billion. This is equivalent to approximately $200 million/year for thirty years at both the 6% and the 3% discount rates.

There is little evidence from the Audit that water quality is actually in decline. Nevertheless, in many cases the condition of the resource is poor. There is no reason for complacency, as the potential economic damages indicated in this report suggest that significant continuing investment in the prevention of any worsening of water quality, or in achieving an improvement, is likely to be economically efficient. The appropriate level of investment needs to be determined by more detailed benefit-cost analysis for individual catchments and water supply systems.

The analysis presented in this report should be developed further, as a matter of urgency. In particular, (i) probabilities should be included for future trends in water quality variables at the river basin level; and (ii) there should be further investigation of the correlation (or lack of correlation) between median water quality variables and the water quality actually delivered to users. This would provide:

- agreed estimates of the likely phasing of potential salinity increases
- estimates of likely future change in populations and economic activities at risk
- mathematical functions for combining these above estimates for estimation of Present Values
- testing of the correlation between river basin water quality and the quality actually received by water users
- better quantification of the proportion of water used for different purposes, from individual river basins.

Requirements of the Brief
The brief for this part of Project 1.3 was to make estimates of national ex-situ marginal damage costs incurred by non-agricultural industries, infrastructure and households arising from water quality degradation at the level of individual river basins.

This was to be done by applying the standardised unit cost functions previously estimated by REU and PPK Environment & Infrastructure (see REU Reports A and B). This required combining estimates of current water usage and river water quality, trends in quality and data on erosion rates at river basin and sub-basin levels, which were obtained from other Audit sources, with supplementary data on affected items.

Conceptual framework

Marginal Cost Equation
Marginal costs are calculated as the difference in total costs for different levels of a water quality parameter, in each river basin. The general form of the damage cost functions used is as follows.

DCivB = UB fi(dVB)*Ltr

Where,

CivB	=	Total marginal cost in year 2000 Australian dollars ($) incurred in respect of item i that is affected by water degradation of form V in basin B
UB	=	Total water supplied from basin B for urban and industrial water use, in GL (used as a scaling variable)
DVB	=	a specified change in median resource condition V (e.g. median salinity, turbidity, or sedimentation rate) in basin B
fiv	=	a function expressing the relationship between resource condition measured in terms of V and amortised damage costs per unit of urban and industrial water use, that are incurred in respect of item i, this being derived from REU/PPK Reports A and B

Ltr = a factor which converts the annual (amortised} damage costs to a Present Value. L is equal to $[(1+r)^t-1]/[r(1+r)^t]$, where t is the time period for calculation of Present Value and r is the annual rate of discount, expressed as a proportion.

As some unit cost functions are expressed as annual values, which combine capital and current costs by means of amortisation of the former (for example in calculating the costs of reduced service lives of household items), their calculation embodies an assumed discount rate for the capital cost components. Therefore, the values of r and t used in calculating total marginal costs should strictly be the same as those used in estimating the unit cost functions. For the purposes of this report a 6% discount rate has been used, to conform with the discount rates generally employed in presentation of Audit results However, the standardised unit cost functions have not at this stage been adjusted, and remain at the 7% level. This approximation is defended on the basis that the unit cost functions themselves are not highly sensitive to changes in discount rate. As will be seen, other assumptions play a much larger part in defining an error range for the marginal damage cost estimates.

It should also be noted that the estimates are for marginal damage costs incurred by *all* users of water from each river basin, including users from basin exports. For example, the estimates of damage costs for the lower Murray River in South Australia include damages incurred in that basin, in Adelaide and in Whyalla. It is not possible to identify the intra-basin, Adelaide or Whyalla components, from this report, because this would require a complete matrix of the origins and destinations of water supplies, and this has not been compiled.

The calculation of total marginal cost estimates follows straightforwardly from Equation (1), and is performed in an Excel spreadsheet, which was provided to CSIRO Land & Water and to the National Land & water Resources Audit. This spreadsheet is described in detail in Appendix A.

Items incurring damage costs

REU/PPK reports A and B had previously identified seven items as the principal receptors of ex-situ damages:

Water Supply Salinity:

▫ Households:	Increased repair and maintenance costs for plumbing and water-contacting items, substitution of equipment of water sources
▫ Industry:	Increased operational, repair and replacement costs for boilers, cooling towers, process water and general water uses
▫ Commercial and Public Services:	Combination of households and industrial cost types

Water Supply Turbidity:

▫ Water Treatment Plants	Increased capital and operating costs of urban and industrial water suppliers

Erosion and Sedimentation:

▫ Reservoirs	Costs of lost reservoir capacity due to siltation
▫ Local Governments and Road & Rail Operators	Costs of cleaning up erosion products, particularly those experienced following storm events
▫ Navigation channels	Dredging costs

Assumptions about the rate of change in resource condition (dV_B)

Initially it had been thought that it would be possible to estimate the future rate of change in each water quality parameter, V, in each river basin, and therefore to estimate marginal damage costs in a way that would reflect this likely rate of change in resource condition. This would be done, for example, by using the change in water quality expected to take place over the next twenty years, this differing between basins. A field was provided in the Audit database recording "increasing", "decreasing" or "no trend", for each water quality parameter (salinity, acidity, total phosphorus, total nitrogen, turbidity, faecal coliforms, and frequency of blue-green algae occurrences). However, on inspecting the Audit results from 935 measurement stations in 133 river basins, it was concluded that the frequency of reports of increasing trends in water pollution was very low. It appears that the condition of surface water resources has generally been stable over the past decade, or that the data are inconclusive regarding trends. As a result, the trend data could not be used to estimate likely percentage change in resource condition at the basin level.

Consequently, it was decided to present results for total marginal damage costs (TMDC) on the basis of a 10% increase in the value of water quality parameters (salinity, turbidity etc) for three different river basin groupings:

- **all river basins**
- **basins judged to be at risk of increasing salinity in future**
- **basins where the particular water quality parameter has shown an increasing trend.**

The first of these groups, all basins, almost certainly gives an over-estimate of probable salinity damages in Australia, because there are significant numbers of basins where no increase in salinity is likely. For example, the Hawkesbury basin provides water of very low salinity to Sydney, but a 10% increase in its salinity, which would still cause significant damage costs (because the volume of water used for urban and industrial purposes is so great), is not likely to occur. Nevertheless, basing the damage cost calculation on all basins provides an upper limit to the estimates.

The third group, namely basins with increasing trend, probably provides an underestimate of potential future costs, for a number of reasons, including (a) past management has influenced past trends, (b) there may be catchments where salinity could increase in future as a result of recent land use change, even though the past trend is stable, and (c) trend data is difficult to establish given the climatic variability experienced in Australia.

Therefore the second group, catchments assessed as having a significant future salinity risk, provides the best available estimate of national marginal damages from increased salinity.

Assumptions about the Use of Water Resources

For river basins with multiple water quality measurement stations, it was assumed that water would be supplied only from those sub-catchments providing "good" (fresh) or "fair" (marginal) water quality exceedence values. This assumption reflects likely water supply practice. For example, the Loddon basin in Victoria has ten sub-catchments, eight of which are too saline to be used for a typical urban or industrial water supply and two of which are fresh. The assumption is made that water is provided from the two fresh sources, and their area-weighted median EC value is representative of the quality of water received by consumers.

The turbidity values for the cost estimates were based on area-weighted median turbidity in those sub-catchments that provide acceptable water ***salinity***. This was done because the EC value is the prime determinant of whether a water resource is used for urban and industrial supply purposes.

While the assumption appears reasonable, the Loddon example illustrates the extent of local checking which would be needed to firm up the cost estimates. It is known that water utilities in the Murray-Darling system often obtain water from irrigation supply channels, which carry fresh water from the eastern highlands; but the budget for this part of the Audit investigations (both in terms of time and money), did not allow for checking whether one or both of the two "fresh" measurement stations in the Loddon basin were representative of the actual source used for urban and industrial water supply, which might be an irrigation supply channel. Nevertheless, the local availability of a fresh resource is confirmed by the Audit data set for that river basin, and this justifies use of the lower EC values obtained from the two "fresh" measurement stations in the salinity cost estimates for the water that is diverted from the basin. It is also clear from the example that the use of water quality data from all available measurement stations in the basin would give a gross over estimate of salinity damage costs.

It should also be noted that approximately one third of all basins had just one measurement station. For these basins the median EC and Turbidity values were generally accepted. However, very high EC values were recorded from single measurement stations in a few basins in the South Australian Gulf Division. It seemed very unlikely that the recorded salinity was representative of the quality of water supplied from the basin for urban and industrial use. In these cases a default value of 1,000 EC was used. The default values are highlighted in red in the damage cost workbook.

Assessment of validity

For several reasons, a good deal of effort had to be put into checking results.

- The data set for resource condition was brand new.
- The damage cost functions described in Equation 1 are essentially untested (i.e. they are indicative estimates that are not backed by full survey data).
- The median value of the water quality parameter in a river basin may not be representative of the quality of water actually delivered to users.
- Extraneous data had to be supplied for reservoir capacities and the current level of water treatment.
- A decision was needed about which parameters should be used. For example, the rate of fine particle deposition in reservoirs was selected as probably a better indicator of sedimentation in a downstream harbour than the rate of sediment export from the catchment. This is because a large percentage of the sediment flux near river mouths is transported through harbours and out to sea.

Because of these uncertainties, each step in the calculation was checked, and modifications were made where necessary. However, it is stressed that the indicative estimates are essentially a "first cut".

3.Ex-Situ Costs of Increasing Salinity

Methodological Issues

Basin Groupings

The Audit results were not conclusive about trends in water salinity at the river basin level. This is mainly because the river basins, which are being used for urban and industrial water supplies, have been either (i) pre-selected as being free of salinity threats, or (ii) subjected to salinity mitigation works that have so far negated any worsening tendency.

As outlined above, marginal salinity costs were therefore estimated for (a) a notional 10% across-the-board increase in salinity, (b) those basins deemed to be at significant risk from a future increase in salinity, and (c) basins showing an increasing trend in the Audit data base

Basins that were assessed as having a significant risk of increasing salinity included:

- a number of Queensland basins in Division I, the North East Coast, that were identified in the Audit *Dryland Salinity Assessment* as likely to be affected by increasing dryland salinity
- a number of basins in Division II, the South East Coast, where salinity is already a significant issue, including the Hunter Basin in New South Wales, the Latrobe Valley in Victoria, the Victorian coastal basins west of the Otways, and the Millicent Basin in South East of South Australia
- all basins in Division IV, the Murray-Darling Basin, that had evidence of increasing trend in the publication by Williamson et al "*Salt Trends: Historical*

trend in salt concentration and saltload of streamflow in the Murray-Darling Basin" (MDBC Dryland Technical Report No 1, 1997)

- all basins in Division V, the South Australian Gulf
- all basins in Division VI, the south west of Western Australia (note, however, that current land use management policies will limit actual increases)

Damage Functions
The salinity damage cost functions are described in REU Report A. Functions were separately estimated for damages incurred by households, industries and the commercial sector. However, water use data were not available for this level of dis-aggregation, so an overall urban and industrial damage function was used in conjunction with Audit data on urban and industrial water use. This was varied in the case of basins within the Murray-Darling system, to allow for hardness as well as salinity effects, where the two are causally related.

Salinity Data
The national results presented below are particularly sensitive to assumptions for South Australia. Three basins in Drainage Division V, the South Australian Gulf, namely Gawler, Broughton and had very high median salinities in the Audit database. It is unlikely that these high salinities are representative of the quality of water actually delivered to water users from these basins. Therefore, the salinity value of these basins was arbitrarily set at 1,000EC Units. Other basins within the Mount Lofty Ranges including Torrens, Myponga, Onkaparinga and Fleurieu, also had high median salinity values, which may overestimate the salinity of water supplied to users. The sensitivity of the results to a downward revision of the salinity data for these catchments was also examined.

Results

National Costs
Table 60 gives the results obtained for salinity, assuming a universal deterioration of 10% in river and stream water quality, and including hardness costs in calculations for the Murray-Darling basin, using a discount rate of 6 per cent, while Table 61 shows the results for a 3 per cent rate of discount.

Salinity emerges as the largest potential cause of damage costs to urban and industrial water users, and affects all States considered. The estimates are based on the complete set of salinity data across Australian river basins. Using a real discount rate of 6%, the Present Value of national economic damage costs for a 10% across-the-board increase in river and stream salinity would be over $1,716 million. This is a significantly higher estimate than has been obtained from earlier studies. It results from differences in the way the unit damage cost functions have been estimated, using (i) new data and (ii) economic amortisation procedures (see REU Report A).

Table 60: Summary of estimated marginal damage costs for a 10% worsening in water quality, across selected water quality variables, by State, assuming zero cost for basins currently supplying water below 300 EC units (Net Present Value over 30 years at 6% real discount rate, $million at constant year 2000 prices).

Basin Group	ACT	QLD	NSW	VIC	SA	WA	TOTAL
All basins	0	191	99	429	711	286	1,716
Basins at Significant Risk	0	26	93	121	709	285	1,233
Increasing Trend	0	0	0	0	0	16	16

Varying the discount rate increases the present value estimate of national damages, from $1.716 billion to $2.444 billion if all water sources suffer a 10% increase in salinity.

When the analysis is limited to those basins assessed as being at risk of some increase in salinity, a 10% increase would cause damage costs of $1, 234 million, when discounted at 6 per cent, and $1,756 million at 3 per cent. Thus, the broad order of magnitude of the ex-situ salinity damage cost estimates is not changed very much by this constraint.

Table 61: Summary of estimated marginal damage costs for a 10% worsening in water quality, across selected water quality variables, by State, assuming zero cost in basins currently supplying water below 300 EC units (Net Present Value over 30 years at 3% real discount rate, $million at constant year 2000 prices).

Basin Group	ACT	QLD	NSW	VIC	SA	WA	TOTAL
All	0	273	141	610	1,013	407	2,444
At Risk	0	37	132	172	1009	406	1,756
Increasing Trend	0	0	0	0	0	23	23

However, if the scenario for future salinity increases is limited to those basins which have shown a rising trend according to the Audit data, very low estimates of national damage costs are obtained, because a rising trend has been reported for only a very few basins.

Regional Impacts

The largest individual State damage cost from salinity would be incurred in South Australia: NPV of $ 0.7 billion at the 6% discount rate and $1.0 billion with the 3% discount rate. There is little difference between the "10% across all basins" scenario and the "at risk" basins, because all but one of the South Australian Gulf basins and all of the lower Murray-Darling basins was judged to be at some risk of a salinity increase in future. Victoria and Western Australia also have high levels of potential damage costs, because they have a significant number of river basins with relatively high EC values and high levels of water use from these basins.

Potential salinity damages in Victoria a spread throughout the State, including coastal catchments in the south west of the State, as well as catchments in the

Murray-Darling basin. However, the Victorian estimates are more sensitive to the assessment of which catchments are at risk than is the case in South Australia.

The southwest of Western Australia emerges with a significant level of ex-situ damages to urban and industrial water users. It should be noted that all of the surface water supply systems in the South West Coast Drainage Division were classified as facing a significant risk of raised salinity in future. A number of water supply catchments in the Darling Ranges, which have not been cleared for agriculture, remain fresh, and, provided current catchment land uses are maintained, should remain so. On this basis, the basins in question, notably the Swan Coast basin (which actually comprises several small catchments), might be excluded from the "at risk" category, with a consequent reduction in Western Australian costs.

Queensland emerges with relatively high damages from salinity when all of its catchments are included, but this result is substantially reduced when the analysis is limited to river basins that are assessed as facing a significant risk of an increase in water supply salinity. In other words, neither the initial salinity levels nor the magnitude of urban and industrial water use were particularly high in the catchments identified by the Audit's dryland salinity assessment as being at risk.

The situation is somewhat different in New South Wales and the ACT, where there is little difference between the upper estimate and that for basins at risk. In other words, in New South Wales and the ACT nearly all the basins where salinity costs were positive were deemed to be at risk of an increase. Note, in this regard, however, that all the results discussed here assume a salinity cost threshold of 300 EC, and this excludes several major New South Wales catchments, including the Hawkesbury Basin, which supplies most of Sydney's water requirements.

Basin results

Table 62 shows the top 20 basins in terms of potential damage costs for a 10% increase in salinity. The list is dominated by basins supplying water to South Australia, which have both high levels of urban and industrial water use and high median salinities of the current water supply. All three Drainage Divisions which supply water for urban and industrial use in the southern part of South Australia, namely the Murray-Darling, the South East Coast and the South Australian Gulf Drainage Divisions are represented in the top 20 basins. The south west of Western Australia is also represented (Swan Coast and Harvey Basins).

Notable inclusions in the top 20 basins are the Burnett basin in Queensland, and Lake Corangamite and the Portland Coast basins in Victoria.

Table 62: Ranking of the "at risk" river basins according to the magnitude of their potential damage costs: top 20 basins.

Rank	Basin Name	AWRC Basin Number	Urban & Industrial Water Use(GL)	Salinity (Weighted Median EC Units)	NPV of Damage Costs ($M)
1	Lower Murray	426	180	581	276
2	Swan Coast	616	102	757	170
3	Onkaparinga	503	53	1380	162
4	Torrens	504	36	1382	111
5	Murray Riverina (Vic)	409	88	313	73
6	Gawler	505	30	1000	66
7	Harvey	613	67	395	59
8	Millicent	239	10	2550	56
9	Murray Riverina (NSW)	409	25	624	35
10	Macquarie - Bogan Rivers	421	31	345	24
11	Burnett	136	47	467	17
12	Broughton	507	8	1000	17
13	Lachlan River	412	17	453	17
14	Myponga	502	11	648	16
15	Lk Corangamite	234	4	1680	15
16	Avon	615	1	8296	13
17	Blackwood	609	1	3825	12
18	Portland Coast	237	5	980	11
19	Collie	612	13	365	10
20	Darling River	425	10	405	9

Potential Ex-Situ Costs of Increasing Turbidity

Methodological Issues

Resource Condition

REU Report B identified water treatment as an area of significant cost impacts from increased turbidity. As with salinity, the Audit results were not conclusive about trends in water turbidity at the river basin level, and marginal costs were estimated for a notional 10% across-the-board increase in turbidity. However, as with salinity, it was assumed that water treatment plants would only be supplied by fresh or marginal water, where available. Therefore an area-weighted mean of the available turbidity data for fresh or marginal sub-catchments in each river basin was calculated, and used in estimating damage costs.

Application of the Cost Model

The cost functions were based on a generalised model of water treatment capital and operating costs, which is described in REU Report B. In this model, cost is a function of the scale of the plant (approximated in this study by the level of diversion); in addition, three aspects of treatment plant construction and operation are dependent on the turbidity of influent:

- degree of chemical complexity in the treatment,
- facilities required for sludge handling, and
- costs of treatment chemicals.

In applying the model to estimate marginal capital and operating costs for a given change in the turbidity of influent it is necessary to know the standard of treatment offered prior to the postulated change in turbidity. As there was no easily accessible source of information on this, REU decided to issue a questionnaire to all water supply agencies in Australia.

The questionnaire, which is given in Appendix B was made as simple as possible, and attracted an excellent response, with 58 questionnaires out of a total of 130 being returned within the short period of time allowed. The questionnaire returns demonstrated a very distinct pattern of water treatment practices within Australia. In regions with low turbidity levels there may be little further treatment than chlorination. Fluoridisation is common but is not regarded as a "treatment" for the purposes of this report. In regions with relatively high river turbidity levels the almost universal method of treatment is chlorination, sedimentation, sand filtration and coagulation-precipitation. In these regions there are relatively few utilities with more advanced filtration systems. The more advanced systems have been installed in those large population centres where biological quality of raw water is a concern, including Adelaide, Brisbane and Sydney.

Groundwater tends to be treated differently from surface water, with few examples of sedimentation, coagulation or precipitation, but more emphasis on iron and manganese removal. As groundwater is not affected by turbidity to any great degree, these types of treatment plant were excluded.

The water treatment plant model developed by REU included a dummy variable for chemical complexity of the treatment train, on a score of 1 to 10.

Table 63: Levels of water treatment, with chemical complexity scores

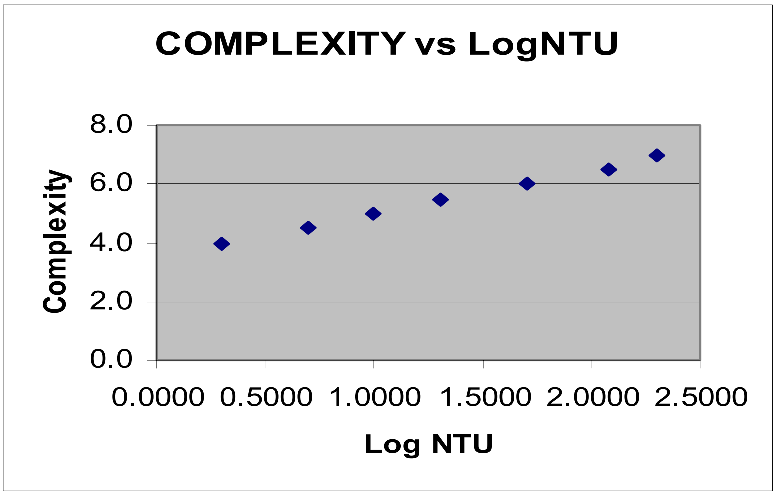
Treatment Type (Cumulative)	Chemical Complexity Score
Chlorination	1
Sedimentation	2
Sand Filtration	3
Coagulation-Precipitation	5
Micro-filtration	7
Reverse Osmosis	7
Membrane	8

It was further assumed that the degree of chemical complexity required in a treatment plant would be correlated with the turbidity level of the raw water, as shown in Figure 9. Thus, the more advanced chemical treatment methods at the top of the scale (and hence higher cost) were assumed for waters with very high turbidity, while the mid-point of the scale, requiring coagulation-precipitation was set approximately equal to the chemical complexity score given to the treatment plants in river basins with median NTU readings of approximately 10 NTU. Rivers with median NTU readings at or below 2 NTU in effect were assumed to require only chlorination/sedimentation, and have correspondingly lower cost.

The calculation of turbidity costs then is made in three steps:

- the modelled cost of a water treatment plant for (a) the measured turbidity level was compared with an estimate of the cost for a plant having (b) the chemical complexity score of surveyed plants in that or a similar river basin
- an additional capital cost was calculated as the extra cost for upgrading the plant in response to a hypothetical increase in turbidity
- an additional operating cost was derived for the same hypothetical increase in turbidity.

Figure 9: Curve fitted to estimate chemical complexity score in the water treatment plant model, from the turbidity of influent



Results

National Cost Estimates

Results are shown in Table 64. Total marginal costs of $1.231 billion were estimated for an across-the-board 10% increase in turbidity in freshwater basins.

Table 64: Total marginal costs of additional water treatment, discounted at 6% assuming that turbidity increases in all freshwater basins by 10% (Present Value $ million at 2000 prices)

	ACT	QLD	NSW	VIC	SA	WA	TOTAL
Upgrades to existing WTPs	7	264	102	157	111	25	666
Upgrades for specified increase in turbidity	4	52	50	62	17	19	205
Operating Cost impacts	1	113	116	35	91	4	361
Total Turbidity	12	428	268	255	219	48	1231

It is seen that the largest component of costs is the item termed "Upgrades to existing waste water treatment plants". This item reflects a difference between the existing treatment level (estimated from survey data by REU) and the level suggested to be appropriate by the cost model. This can be interpreted as a model calibration issue. In many basins data were not available on existing treatment level, and the assumption was made that current treatment practices were similar to those used elsewhere in the same Drainage Basin. This is clearly a major assumption. Ideally, data should be collected on the adequacy of current treatment levels against the National Water Quality Guidelines, as a means of checking the estimated costs of required upgrades. Nevertheless, upgrades to water treatment facilities are being undertaken by water utilities in many river basins, so the estimate obtained here probably does reflect an ongoing need.

The two other cost components are strictly the marginal costs of changed turbidity. They include investments in improved treatment, as well as increased operating costs, assuming that there is no difference between the modelled estimate of the initial treatment level and the current treatment level.

Regional Impacts

Two areas of particularly high marginal damage costs are the North East Coast Drainage Division (Queensland) and the Murray-Darling Basin (all basin States). In both these regions, river turbidity is much higher than elsewhere in Australia: weighted median turbidity values for these basins ranged from 50 to over 300 NTU. Elsewhere, significant costs tend to be flagged by the model in basins which have relatively large volumes of water that are diverted for urban and industrial use, even though the initial turbidity level may be relatively low (e.g. less than 20 NTU). Drainage Divisions II, the South East Coast and VI, the South West Coast, have relatively few basins where significant damage costs would arise from the hypothetical 10% increase in turbidity.

Basin Summary

Table 65 shows the top 20 basins having the highest computed costs for raised turbidity. They tend to be large rivers with high initial turbidity or high levels of diversion for urban and industrial use, and are concentrated in the Murray-Darling Basin and the North-East Coast Drainage Division in Queensland.

Table 65: Ranking of river basins according to the magnitude of their potential turbidity damage costs: top 20 basins

Rank	Basin	AWRC Number	Weighted Median Turbidity (NTUs)	NPV of Damage Costs ($M)
1	Fitzroy	130	338	96
2	Brisbane	143	115	94
3	Lower Murray	426	133	89
4	Yarra	229	17	63
5	Murray Riverina	409	114	59
6	Latrobe	226	16	35
7	Onkaparinga	503	55	34
8	Murrumbidgee River	410	20	33
9	Burdekin	120	91	32
10	Ross	118	55	32
11	Mary	138	18	28
12	Harvey	613	24	26
13	Darling River	425	116	26
14	Condamine	422	200	25
15	Burnett	136	29	24
16	Pine	142	24	23
17	Condamine-Culgoa	422	104	22
18	Murray Riverina	409	40	20
19	Lachlan River	412	26	20
20	Border Rivers	416	113	19

Ex-Situ Costs of Erosion and Sedimentation

Methodological Issues

REU Report B gives estimated damage cost functions for impacts of erosion and sedimentation on reservoir owners, local government, road/rail operators, and harbour/water way managers. A number of modifications were made to these damage cost functions in the light of data on resource condition made available by the Audit.

Reservoir Siltation

Estimates of the rate of reservoir siltation were provided by Audit Project 5. These estimates were incorporated directly into the master spreadsheet, and combined with REU's estimate of typical costs for capacity replacement.

Local government, road and rail operators

Local government ex-situ damage cost functions, given in REU Report B were based on a questionnaire survey. The damage cost function as originally estimated by REU was expressed in terms of sediment concentrations in streams within the regions where the particular local authority is situated. This damage function was replaced with one based on an estimate of the rate of hill slope erosion in each river basin, still utilising the questionnaire survey data on expenditure by local governments in regions of high and low erosion rates.

Navigable Waterways

A literature review reported in REU Report C provided the basis for unit damage costs. River basins containing significant navigable channels, and particularly harbours at their river mouths were identified by entering a "1" in the spreadsheet, which was then used to trigger the damage cost. After consultation with Dr Ian Prosser of CSIRO Land and Water it was decided to use the siltation rate for reservoirs in each river basin as the sedimentation variable.

Results

Estimated total marginal damage costs incurred by reservoir operators, local government, road and rail operators and navigable waterways managers, for a 10% across-the board increase in erosion and sedimentation rates are given in Table 66.

Table 66: Total marginal costs of erosion and sedimentation excluding turbidity effects assuming that erosion and sedimentation rates will increase in all river basins by 10%: by State and Drainage Division (NPV $M at 6% discount rate in year 2000 prices).

	ACT	QLD	NSW	VIC	SA	WA	TOTAL
Reservoirs	1	113	43	6	3	1	167
Local Government, Road and Rail	0	25	13	1	0	0	40
Channels	0	78	26	3	0	0	108
Total Erosion & Sedimentation	1	216	82	10	3	1	315

The results using a 3% discount rate are shown in Table 67.

Table 67: Total marginal costs of erosion and sedimentation excluding turbidity effects assuming that erosion and sedimentation rates will increase in all river basins by 10%: by State and Drainage Division (NPV $M at 3% discount rate in year 2000 prices).

	ACT	QLD	NSW	VIC	SA	WA	TOTAL
Reservoirs	2	161	61	9	4	1	238
Local Government, Road and Rail	0	36	19	2	0	0	57
Channels	0	111	38	4	0	0	153
Total Erosion & Sedimentation	2	308	117	15	5	2	448

APPENDIX A: DETAILS OF THE SPREADSHEET USED FOR CALCULATIONS

A.1 Overview

The Excel Workbook provided to CSIRO Land & Water contains eleven permanent Work Sheets, which are inter-linked by formulae. The contents of the work sheets are summarised in Table A.1. Users may add further worksheets, for example to store results.

Table A.1 Contents of Work Sheets in *REU Catchment Master.xls*

▪ Assumptions:	Under the headings of (a) salinity, (b) turbidity, and (c) erosion/sedimentation, this work sheet allows the user to vary a number of global assumptions. The assumptions feed into the calculations within all other work sheets.
▪ Results:	Provides summary tables by state, drainage division and types of damage cost, corresponding to the particular set of assumptions entered by the user.
▪ Basin Summary	Reads key basin-specific results from all State sheets, for production of rankings, using the Data/Sort facility in Microsoft Word.
▪ Salinity Graph	Produces a histogram of the ranked basin results.
▪ QLDIa	North East Coast Drainage Division in Queensland (northern part, Basins 108 to 130)
▪ QLDIb	North East Coast Drainage Division in Queensland (southern part, Basins 132 to 146); Queensland part of the Murray-Darling Drainage Division, Basins 416 and 422; data for Basin 919 are also included, but are not reported in the Results work sheet.
▪ NSW	All Basins in New South Wales, in two groups: the New South Wales part of the South East Coast Drainage Division (Basins 201 to 222), and The New South Wales part of the Murray-Darling Drainage Division (Basins 409 to 425 plus the NSW part of Basin 401)
▪ ACT	ACT part of the Murrumbidgee Basin (Basin 410)
▪ VIC	All basins in Victoria, in two groups: the Victorian part of the South East Coast Drainage Division (Basins 221 to 238), and Victorian part of the Murray-Darling Drainage Division (Basins 401 to 415)
▪ SA	All basins in South Australia, in four groups: (a) the South Australian part of the South East Coast Drainage Division (Basin 239); (b) the South Australian part of the Murray-Darling Drainage Division (Basins 414 to 426); (c) the South Australian Gulf Drainage Division (Basins501 to 513); and the South Australian part of the Lake Eyre Drainage Division, Basin 1003)
▪ WA	Basins in the southern part of Western Australia, namely in the South West Coast Drainage Division (Basins 601 to 617), and the Indian Ocean Drainage Division (Basins 701 and 702).

In each State Work Sheet, the individual measurement station readings and river basin totals/weighted averages are arranged across the columns. There are also blue-highlighted columns for summation to AWRC Water Regions, but these have not been used. The States Work Sheets share the same set of row headings, and Excel Row Numbers. These give data on water quality variables, scaling data and results. At the bottom of the rows, in Columns A and B, there are summations across all basins in each of the Drainage Divisions within the State.

A.2 Row Headings in State Work Sheets

The Row Headings of State Worksheets within *REU Catchment Master.xls* fall into the clusters shown in Table A.2. Table A.3 gives the individual Row Headings for the States' Work Sheets

Table A.2: Summary of data held in *REU Catchment master .xls*

Row Numbers	Contents of Row Cluster
1 to 8	Basin identifiers
9 to 16	Sub-catchment areas associated with measurement stations, and associated calculations of area weights for water quality data. Median salinity (Row 80) and median turbidity (Row 120) may be weighted by either: (a) all measurement station areas (weights in Row 10) or (b) the measurement stations having acceptable salinity for water supply purposes (weights in Row 12). Erosion and sedimentation data were always weighted by Row 10. For basins with only one measurement station the Row 10 and Row 12 values are the same.
17 to 20	More basin identifiers
20 to 28	Data on storages, capacities and fine particle deposition estimates (from CSIRO Land & Water)
29 to 42	1983-84 data on water use from Review 85
43 to 50	1996-97 data on water use, from Audit Theme 1
51 to 55	Number of towns of given size classes in each river basin:
	Class 1: > 250,000
	Class 2: 100,000 to 250,000
	Class 3: 20,00 to 100,000
	Class: 4 < 20,000
56 to 72	Data on the number and treatment levels of water treatment plants
73 to 83	Salinity data (EC Units, from MEASURESTN.xls)
84 to 91	Acidity data (PH, from MEASURESTN.xls)
92 to 99	Phosphorus concentration data (Total P from MEASURESTN.xls)
100 to 107	Nitrogen concentration data (Total N from MEASURESTN.xls)
108 to 115	Faecal Coliforms data (FC Count from MEASURESTN.xls)
116 to 123	Turbidity data (NTUs from MEASURESTN.xls)
124 to 131	Suspended solids data (Mg/L from MEASURESTN.xls)
132 to 135	Blue-green algae data (from MEASURESTN.xls)
136 to 143	Fine sediments erosion data (from CSIRO Land & Water)
144	Count variable (0 for measurement stations, 1 for river basin totals)
145 to 175	Salinity cost calculations
176 to 206	Turbidity cost calculations
207 to 224	Erosion and sedimentation cost calculations

Table A.3 Individual Row Titles of *REU Catchment Master.xls*

Row	Name	Row	Name	Row	Name
0		40	Total Use 1984	80	EC_MED
1	State ID	41	Surface Sources	81	EC AREA-WEIGHTED MED
2	BASIN NAME	42	GW Sources	82	EC CALC MED
3	BASIN_NO	43	Audit Use Data 96-97 (ML):	83	EC_TREND
4	MEASURE_STN_ID	44	BASIN_ID	84	ACIDITY
5	MEASURE_STN_ID	45	MEAN_ANNUAL_RUNOFF	85	PH_EXCEED_CLASS
6	MEASURE_STN_LONGTDE	46	DIVERSION_SW96	86	PH_MIN
7	MEASURE_STN_LATDE	47	TOTAL_ALLOCATION	87	PH_MAX
8	STATION_DESC	48	TOT_ALLOC_SW_U_I	88	PH_MED
9	MEASURE_AREA	49	CITY_USE	89	PH WEIGHTED MED
10	MEASURE WEIGHTS	50	Choose SWUI or DIVERSION	90	PH CALC MED
11	EFFECTIVE AREA SALINITY	51	Towns:	91	PH_TREND
12	MEASURE WEIGHTS SALINITY	52	Class 1	92	PHOSPHORUS
13	EFEECTIVE AREA TURBIDITY	53	Class 2	93	TP_EXCEED_CLASS
14	AREA WEIGHT TURBIDITY	54	Class 3	94	TP_MIN
15	EFECTIVE AREA SEDIMENTS	55	Class 4	95	TP_MAX
16	AREA WEIGHT SEDIMENTS	56	WTP Level (Qre Data):	96	TP_MED
17	START RECORD_DATE	57	Respondent	97	TP WEIGHTED MED
18	END RECORD_DATE	58	Total WTPs	98	TP CALC MED
19	MEASUREMENT	59	Surface WTPs	99	TP_TREND
20	MEASURE_STN_ID	60	Basin Ave WTP Level	100	NITROGEN
21	Total Number of Storages	61	Class 1 town(s): N of WTPs	101	TN_EXCEED_CLASS
22	Sum of capacities (Mm^3)	62	Class 1 town(s): level	102	TN_MIN
23	ANCOLD number of storages	63	Class 1 town(s): throughput	103	TN_MAX
24	ANCOLD capacities (Mm3)	64	Class 2 town(s): N of WTPs	104	TN_MED
25	Fine particle deposition (kt)	65	Class 2 town(s): level	105	TN WEIGHTED MED
26	Is there use for U&I Supply? (1,0)	66	Class 2 town(s): throughput	106	TN CALC MED
27	Surface withdrawals 83-84	67	Class 3 towns: N of WTPs	107	TN_TREND
28	Proportion of Region developed	68	Class 3 towns: level	108	FAECAL COLIFORMS
29	Reticulated use 83-84 (GL):	69	Class 3 towns: throughput	109	FC_EXCEED_CLASS
30	Urban & Industrial	70	Class 4 towns: N of WTPs	110	FC_MIN

Row	Name	Row	Name	Row	Name
31	Irrigation	71	Class 4 towns: level	111	FC_MAX
32	Rural	72	Class 4 towns: throughput	112	FC_MED
33	Total Use 1984	73	SALINITY	113	FC WEIGHTED MED
34	Surface Sources	74	EC_EXCEED_CLASS	114	FC CALC MED
35	GW Sources	75	Value = 1 if Fresh (or "Good")	115	FC_TREND
36	Self-extracted use 83-84 (GL):	76	Value = 1 if Marginal (or "Fair")	116	TURBIDITY
37	Urban & Industrial	77	Value = 1 if Fresh (Good) or Marginal (Fair)	117	TURB_EXCEED_CLASS
38	Irrigation	78	EC_MIN	118	TURB_MIN
39	Rural	79	EC_MAX	119	TURB_MAX
120	TURB_MED	160	Div II NPV (a) $M	200	Reserved
121	TURB WEIGHTED MED	161	Div II NPV (b) $M	201	Reserved
122	TURB CALC MED	162	Div II NPV (c) $M	202	Reserved
123	TURB_TREND	163	Div IV NPV (a) $M	203	Reserved
124	SUSPENDED SOLIDS	164	Div IV NPV (b) $M	204	Reserved
125	SS_EXCEED_CLASS	165	Div IV NPV (c) $M	205	Reserved
126	SS_MIN	166	State NPV (a) $M	206	Reserved
127	SS_MAX	167	State NPV (b) $M	207	EROSION AND SEDIMENTS
128	SS_MED	168	State NPV (c) $M	208	(a) Local Government+Roads
129	SS WEGHTED MED	169	Reserved	209	Hillslope erosion (t/ha)
130	SS CALC MED	170	Reserved	210	Total Local Gov + Road & Rail
131	SS_TREND	171	Reserved	211	(b) Lost Reservoir Capacity
132	BLUE GREEN ALGAE	172	Reserved	212	Fine particle deposition (kt)
133	BGA_EXCEED_CLASS	173	Reserved	213	NPV lost reservoir capacity
134	BGA_TREND	174	Reserved	214	(c) Dredging of navigable channels
135	Reserved	175	Reserved	215	Navigable Channel (0,1)
136	FINE SEDIMENTS	176	TURBIDITY	216	NPV Channel Costs
137	FineSedErosion(kt/y)	177	Area-weighted turbidity	217	NPV Erosion & Sed Costs
138	FineSed_ErosionRate (t/ha/y)	178	Median Turbidity (NTUs)	218	NPV ($M) River Basins with Inc. Trend
139	AWRC Number	179	Log10(Turbidity)	219	Div II NPV (a) $M
140	Sum of Area Ha	180	New Turbidity Level (NTUs)	220	Div II NPV (b) $M
141	Total Hillslope Erosion	181	Log10(New Turbidity Level)	221	Div IV NPV (a) $M

Row	Name	Row	Name	Row	Name
142	Reserved	182	Current Treatment Level	222	Div IV NPV (b) $M
143	Reserved	183	Required Treatment Level	223	State NPV (a) $M
144	Count (insert 1 for inclusion)	184	Augmentation factor	224	State NPV (b) $M
145		185	WTP Full Cost		
146	NSW COST CALCULATIONS	186	WTP Upgrade Cost		
147	Reserved	187	Treatment Level for new turbidity		
148	Reserved	188	Augmentation factor for new turbidity		
149	SALINITY:	189	Additional Cost for changed turbidity		
150	Lump Sum Factor	190	NPV Marginal Operating Cost ($M)		
151	Urban & Ind Water Use Est (GL)	191	NPV ($M) for specified % increase in NTU		
152	Median EC	192	NPV ($M) River Basins with Inc. Trend		
153	Weighted Median EC	193	Div II NPV (a) $M		
154	Significant Risk of Future Increase?	194	Div II NPV (b) $M		
155	$/kL/yr/EC Unit	195	Div IV NPV (a) $M		
156	$/yr/EC Unit	196	Div IV NPV (b) $M		
157	NPV ($M) for Specified Increase in EC	197	State NPV (a) $M		
158	NPV ($M) River Basins with Inc. Trend	198	State NPV (b) $M		
159	NPV ($M) River Basins with Significant Risk	199	Reserved		

A.3 Equations Implemented in *REU Catchment Master .xls*

The equations implemented in ***REU Catchment Master.xls*** are listed in the following Sections, using the formulae that appear in Column C of each State Work Sheet, Column C being the first containing the calculation for a measurement station or river basin. Left-hand-side references are to the terms defined in Equation 1 in the main report.

A.3.1 Lump Sum for Present Value Calculations (Row 136)

Ltr=(1-(Assumptions!$D$16^-Assumptions!$D$17))/(Assumptions!$D$16-1)

Where:

Assumptions!$D$16	=	Discount factor (e.g. 1.06 for 6% discount rate)
Assumptions!$D$17	=	Time period for discounting (years)

A.3.2 Weights for Measurement Station Water Quality Variables (Rows 9 to 11)

The Audit data set for water quality gave minimum, maximum and "median" values at each measurement station within a river basin, for each water quality variable. The area-weights for the measurement stations within each river basin are calculated in Rows 10 and 11, with the result in Row 12 for salinity area weights. In Row 11 the "effective area for salinity" is set to 0 if the median salinity reported for that measurement station is poor, brackish or saline, and to 1 if it is good, fresh or marginal.

These weights were used to calculate a weighted median value for each river basin, for each water quality variable, V_B.

A.3.3 Urban & Ind Water Use Est (GL), (Row 151)

An Excel logical function was used to select the Audit estimate for 1996-97, entered in Row 48 or, (if that was not available), to use the 1983-84 data from Review '85, entered in Row 30.

U_C = IF (C48>0,C48/1000,C30)

Where

C48	=	Audit estimate of Urban & Industrial Water Use in 1996-97 (in ML) from surface withdrawals
C30	=	Review '85 estimate of Urban and Industrial Water Use from surface withdrawals in 1983-84

A.3.4 Weighted Median Salinity (EC Units), (Row 153)

Weighted median EC for each river basin was estimated as the sum of area-weighted median EC at each measurement station.

V_C= C82 =IF(C80>C81,C80,C81),

Where

C80 = Recorded median EC for the measurement station

C81 = Calculated median EC in basins with multiple measurement stations

As weighted measurement station EC will always be less than the original measurement, the effect of this switch is that in basins with only one measurement station the value in Row 80 is selected. Weighted EC values are summed in Row 82 in the column that gives the total, i.e. the weighted median, for the particular river basin. Note, as basins have different numbers of measurement stations this row-wise summation is specific to each river basin.

A.3.5 Calculation of Marginal Damage Costs from Salinity (Rows 149 to 159)

Row 155 consults the assumed salinity cost per EC unit per kL of water consumed in an urban and industrial supply system, based on REU Report A, and expressed in the Assumptions Work Sheet:

$/EC/kL/yr = Assumptions!$D$21

For basins in the Murray-Darling Drainage Division the calculation of $/EC/kL/yr includes provision for hardness effects to be included, using an Excel logical function:

$/EC/kL/yr

=IF(Assumptions!$D$24="No",Assumptions!$D$21,Assumptions!$D$21*Assumptions!$D$22)

Where:

Assumptions!$D$24 = A "Yes/No" variable which switches on the hardness factor

Assumptions!$D$22 = Hardness adjustment factor

Row 156 calculates the salinity cost per EC unit for the particular river basin. It does this by multiplying the salinity damage cost per kilolitre per year per EC Unit in Row 155 (see above) by Row 151 (total urban and industrial water use in the particular basin in GL times one million).

($/EC/yr)C= C155*C151*10^6

Rows 157 to 159

Finally, Present Value of total marginal damage costs in the particular basin is calculated for three different groupings of the river basins in Rows 157,158 and 159.

The groupings are:

(a) all river basins (subject to any other global constraints that are assumed, such as counting only basins with salinity within an acceptable range for urban and industrial water supply, or only those where the current median salinity exceeds an assumed threshold value): Row 157

(b) river basins for which the Audit data indicates an increasing salinity trend (determined by reference to Row 83): Row 158

(c) river basins that are assessed as facing a significant risk of future increase in salinity (determined by a 0/1 variable in Row 154): Row 159

An Excel logical function is used to check whether salinity in the particular basin exceeds the threshold level (IFAssumptions!$D$28<C153). If it does, then Row 157 multiplies $/EC/yr in the particular basin by 10% of the median EC level for the basin (the assumed proportional increase in EC), and by the Lump Sum factor for Present Value:

NPV of Damage Costs (All Basins), in Row 157

=IF(Assumptions!$D$28<C153,C150*C153*C156*(10^-6)*Assumptions!$D$26,0)

Where:

Assumptions!$D$28	=	The threshold level of EC at which salinity costs > 0
C153	=	Weighted median EC Units in the particular basin
C150	=	Lump Sum factor for converting annual costs to Present Value (see Section A.3.1 above)
C156	=	S/EC/yr in the particular basin (see notes on Row 140 above)
Assumptions!$D$26	=	The proportional increase in EC for which marginal costs are to be calculated (10% increase was adopted)

Row 158 excludes all basins except those with an increasing salinity trend:

NPV of Damage Costs (Basins with increasing salinity trend), in Row 158

=IF(C83 = "Inc. Trend",C157,0)

NPV of Damage Costs (Basins with a significant risk of future increase in salinity), in Row 159

=IF(C154="Y",C157,0)

where:

C154	=	a 0/1 variable, 1 indicating a significant risk

The salinity results at river basin level are summed into Drainage Divisions in Rows C160 to C170, using a count variable given in Row 144. The number of Drainage Divisions varies between the different States.

A.3.6 Calculation of Marginal Damage Costs from Turbidity (Rows 151 to 173)

A.3.6.1 Waste water treatment plant upgrades

The "required" level of treatment for the current median turbidity level is calculated in Row 183

=1.25+(6.94*C179)

Where:

C179	=	LOG_{10}(C178)
C178	=	adjusts weighted median EC given in Row 177, by substituting NTU equals 1 in basins where the NTU reading was zero, to allow the logarithm to be calculated.

The required treatment level is next compared with the existing treatment level given in Row 182. If the required level is greater than the existing level, a proportion of the full cost of a water treatment plant, which would suffice to upgrade the existing treatment plant, is calculated in Row 186, as follows.

WTP Upgrade Cost

=IF(AND(C$77>0),IF(C$144=1,C185*C184,0))

Where

C$77	=	A value greater than zero where a river basin's salinity is "good", "fresh" or "marginal", and otherwise 0
C$144	=	A count variable, equals 1 in river basin total columns

Thus, an upgrade cost will be calculated ONLY if the basin's water is good enough, in terms of salinity, to use as an urban and industrial water supply.

A.3.6.2 Marginal capital cost for increased turbidity

The next calculation, in Rows 187 to 189, gives an estimate of the additional investment in treatment plant that would be required for a given proportionate increase in turbidity over the current level.

Estimation of the marginal capital costs of turbidity starts in Row 180 with a calculation of a "new" turbidity level, which in this report is taken to be 10% higher than the original median turbidity in the river basin. The proportional increase in turbidity is controlled by the Assumptions Work Sheet, Cell D52.

New turbidity level (Row 180) =C178*(1+Assumptions!$D$52)

Additional cost for new turbidity level (Row 189)

=IF(AND(C$77>0),IF(C$144=1,C185*C188,0))

Where:

C$77 = A value greater than zero where a river basin's salinity is "good", "fresh" or "marginal", and otherwise 0

C$144 = A count variable, equals 1 in river basin total columns

C185 = WTP Full Cost

C188 = Cost increase factor for new turbidity level

And:

C188 = IF(C$144=1,0.1*(C187-C183),0)

C144 = Count variable

C187 = The new required treatment level

C183 = The original required treatment level

A.3.6.3 Marginal Operating Costs of Water Treatment

The Present Value of marginal operating cost for increased turbidity is calculated in Row 190:

PV Marginal Operating Cost

=IF(AND(C$77>0),IF(C$144=1,C150*6.6*10^4*0.5*C178*Assumptions!$D$52/10^6,0))

Where C$77 is the salinity constraint and C$144is the count variable, and

C150 = = Lump Sum Factor for Present Value

C178 = Current median turbidity in the basin

Assumptions!$D$52 = Hypothetical proportional increase in turbidity

A.3.7 Marginal Damage Costs of Erosion and Sedimentation

A.3.7.1 Reservoir Capacity Replacement

Costs of replacing lost reservoir capacity are calculated in Row 183, as follows:

Cost of replacing capacity (Row 213) =IF(C$144=1,0.35*C212*C150*10^-3,0)

Where C$144 is the count variable for river basins, and:

C212	=	Fine particle deposition rate in the basin (kt/year)
C150	=	Lump Sum Factor for Present Value

A.3.7.2 Costs to Local Government, Road and Rail Operators

These costs are calculated in Row 208, as

Marginal Damage Costs for Local Government + Roads

=IF(C$144=1,2.5*C209*C151*10^-2*0.2034*C150*Assumptions!$D$63,0)

Where C$144 is the count variable for river basins, and

C209	=	Hillslope erosion rate in the basin (kt/ha/year)
C151	=	Urban and industrial water use in the basin (UB)
C150	=	Lump Sum Factor for Present Value
Assumptions!$D$63	=	Assumed proportional increase in the rate of hillslope erosion

The factor 2.5 reflects an assumption that costs to road and rail operators are 1.5 times the costs to local government. The formula presented here is a re-working of the damage function given in REU Report B, to take advantage of superior data on hillslope erosion.

A.3.7.3 Costs to Managers of Navigable Waterways and Harbours

These costs are calculated in Row 216, as follows:

NPV Channel Costs

=IF(C$144=1,C25*10^-3*20*C150*C215*Assumptions!$D$63,0)

Where C$144 is the count variable for river basins, and:

C25	=	Fine particle deposition rate in the basin (kt/year)

		(kt/year)
C150	=	Lump Sum Factor for Present Value
C215	=	Zero if there is no navigable channel or harbour in the basin, or 1.0 if such a channel or harbour exists.
Assumptions!$D$63	=	Assumed proportional increase in the rate of fine particle deposition

A.4 The Assumptions Work Sheet

NATIONAL LAND & WATER RESOURCES AUDIT

Estimates of Ex-Situ Costs of Water Resource Degradation in Australia

This workbook calculates marginal costs of water resources degradation incurred by non-agricultural industries, infrastructure and households using data sets provided by the National Land & Water Resources Audit. The work sheets are organised by State, for ACT, Queensland (2 work sheets), New South Wales, Victoria, South Australia and Western Australia. Each State work sheet presents data for river basins (133 in total) and sub-basin measurement stations (935 in total).

This sheet allows the user to vary key assumptions by changing values in Column (d). The next sheet "Results" summarises the results at the level of States and Drainage Divisions. Go to the individual State work sheets and the "Basin Summary" Sheet to find results for individual river basins.

	Units	Suggested Value	Your Value	Notes
(a)	(b)	(c)	(d)	(e)
A. GENERAL VARIABLES				
Discount Factor (DF)	N	1.05	1.07	E.g. 1.05 for 5%
Time period (T)	Years	30	30	
NPV Formula (Constant Annual Cost)	Function			NPV = $[1-DF^{-T}]/[DF-1]$, where DF = Discount factor and n = no of years
B. SALINITY				
Marginal Damage Cost Function	$/kL/yr/EC Unit	0.00161	0.00161	
Hardness Factor (Where relevant)	n	1.19	1.19	This factor applies to total urban water uses: households factor = 1.316
Hardness factor to apply?	Yes/No	Yes	Yes	If "Yes", the factor is used for Murray-Darling Basin costs
EC/TDS Ratio	n	1.6	1.6	Assumes 800 EC Units = 500 mgL^{-1} TDS
Indicator % increase in salinity	e.g. 0.1 for 10%	0.1	0.1	For large river systems 10% is a lot; for small river basins salinity can increase by up to a factor of 10 following land use change.
Threshold level for costs	EC Units	300	300	This sets the lowest level at which salinity damage costs should be calculated
Include only basins at "significant risk"?	Y/N	Y	Y	If "Y" is entered, only those catchments with a significant salinity risk will be included
C. TURBIDITY				
Water Treatment Plants Capital Cost	Function			Log_{10} Capital Cost = -1.4 + $0.611Log_{10}[W]$, W = annual throughput/365
	Units	Suggested Value	Your Value	Notes
(a)	(b)	(c)	(d)	(e)

Augmentation factor	Function			WTP Treatment Level is an index of the existing level of water treatment (L= 1 to 8): it is assumed that the capital cost of upgrading WTPs is proportional to the difference between the current level of treatment and the required level of treatment, for given level of turbidity (NTUs): i.e. Capital Cost * [1-0.1[L^R - L^0]]
Required treatment Level (RTL)	Function			RTL =1.25 + 6.94Log_{10}[NTU]
Indicator % increase in turbidity		0.1	0.1	Enter 0.1 for a 10% increase in turbidity
WTPs Marginal Operating Cost				Marginal Operating Cost = 264W* 10^{-6}[SC]; W = annual throughput/365; SC = sediment concentration (mg/L)
D. EROSION IMPACTS				
Channels Marginal Cost Function	Function			Fine particle deposition rate is used as the erosion variable
Local Government/Utility Cost Function	Function			Hillslope erosion is used as the erosion variable
Indicator % increase in hillslope erosion	Proportion	0.1	0.1	Enter 0.1 for a 10% increase in hillslope erosion rates
Reservoirs Marginal Cost Function	$/m3	0.35	0.35	$/m3 of capacity is multiplied by the annual change in sediment deposition in reservoirs, then NPV is calculated by treating this as a constant annual cost

APPENDIX B: WATER TREATMENT PRACTICES QUESTIONNAIRE AND RESULTS

B.1 Questionnaire

NATIONAL LAND & WATER RESOURCES AUDIT

PROJECT 6.1.3 COSTS OF RESOURCE DEGRADATION

SURVEY OF WATER TREATMENT PRACTICES

When you have completed the questionnaire, please return it to:
Jonathan Thomas
Resource Economics Unit
Amberley House
35 Union Street
Subiaco
Western Australia 6008

For queries call:

TEL/FAX: 08 9388 2461 or Email: recunit@enternet.com.au

1. Name of Water Utility……………………………………………………………
2. Your name…………………………………………………
3. Position…………………………………………………….
4. Contact Number(s) TEL:……………………….EMAIL:……………………………
5. Population Served……………………………
6. Total water supplied………………(ML/day) Percentage urban:…………(%)
7. At how many separate locations do you treat your raw water?………………..
8. Please give the name of each treatment location for which you have provided information in Question 9 (over):

Treatment Location	Treatment Plant Name/Location (e.g. River Basin)
1	
2	
3	
4	
5	

9. For each treatment location, please indicate the throughput in ML/day. For other features use ticks to describe the type of treatment.

Treatment Feature	Treatment Location				
	1	2	3	4	5
Throughput (ML/d)					
Type of raw water (tick)					
• Run of river					
• Irrigation canal					
• Reservoir or lake					
• Roaded catchment					
• Aquifer					
Type of Treatment Undertaken:					
• Chlorination					
• Ph remediation					
• Iron removal					
• Manganese removal					
• Ion-exchange softening					
• Aeration					
• Sedimentation					
• Automatic straining					
• Slow sand filter					
• Rapid sand filter					
• Membrane filtration					
• Coagulation/precipitation (alum)					
• Coagulation/precipitation (other)					
• Reverse osmosis					
• Micro filtration					
• None of the above					

Thank you for completing the questionnaire.

B.2 Summary of Survey Results

Characteristics of the survey respondents

Number of Respondents	Number of Treatment Plants	Total Water Supplied		Population served	% Urban	Urban Population
		(ML/d)	(GL/yr)			
58	248	9,843	3,577	9,346,057	77.5	7,246,176

Sources of water for surveyed treatment plants

Type of Raw Water	Frequency	%
Run of river	96	39
Irrigation canal	21	8
Reservoir or lake	70	28
Roaded catchment	15	6
Aquifer	46	19
Total	248	100

Key statistics of respondents by Drainage Division

Division	Population served (000)	Total Water Supplied (ML/day)	% Urban	Urban Population	No. of Plants
1. N.E.Coast	1,900	1,037		1,384,804	83
2. S.E.Coast	2,610	5,731	834	2,349,293	64
3. Tasmania	281	89	63	38,465	11
4. Murray-Darling	2,444	29,422		358,980	187
5. S.A. Gulf	1,460	740		72	19
6. S.W. Coast	30	25	70	21,000	6
8. Timor Sea	130	145	0	100	5
9. Carpentaria	22	48		47.0	2
10. Lk. Eyre	130	145		100.0	5
12. Central Plateau	130	145		100.0	5
Total	9,138	37,527	967	4,152,961	387

Sources of water, by Drainage Division (number of treatment plants)

Division	Run of river	Irrigation canal	Reservoir or lake	Roaded catchment	Aquifer	All Sources
1. N.E.Coast	11	0	12	0.0	20	43
2. S.E.Coast	11	1	17	0.0	3	32
3. Tasmania	4	0	4	2.0	0	10
4. Murray-Darling	66	20	27	13.0	7	133
5. S.A. Gulf	2	0	7	0.0	0	9
6. S.W. Coast	0	0	0	0.0	6	6
8. Timor Sea	2	0	2	0.0	8	12
9. Carpentaria	0	0	2	0	0	2
10. Lk. Eyre	0	0	0	0	1	1
12. Central Plateau	0					0
Total	96	21	71	15.0	45	248

Sources of water, by Drainage Division (Percent of treatment plants)

Division	Run of river	Irrigation canal	Reservoir or lake	Roaded catchment	Aquifer	All Source s
1. N.E.Coast	26	0	28	0	47	100
2. S.E.Coast	34	3	53	0	9	100
3. Tasmania	40	0	40	20	0	100
4. Murray-Darling	50	15	20	10	5	100
5. S.A. Gulf	22	0	78	0	0	100
6. S.W. Coast	0	0	0	0	100	100
8. Timor Sea	17	0	17	0	67	100
9. Carpentaria	0	0	100	0	0	100
10. Lk. Eyre	0	0	0	0	100	100
12. Central Plateau						
Total	39	8	29	6	18	100

Type of treatment undertaken, by Drainage Division (No of Plants)

Type of Treatment	Drainage Division								
	1	2	3	4	5	6	8	9	Total
Chlorination	41	24	11	108	8	6	6	2	206
Ph Remediation	30	12	7	71	9	0	0	0	129
Iron removal	11	3	1	4	0	6	0	0	25
Manganese removal	15	4	1	9	0	6	0	0	35
Ion-exchange softening	1	0	0	2	0	0	0	0	3
Aeration	25	4	0	5	0	4	1	0	39
Sedimentation	20	9	1	62	8	0	0	0	100
Automatic straining	1	0	0	1	0	0	0	0	2
Slow sand filter	3	2	1	19	0	2	0	0	27
Rapid sand filter	19	11	7	70	8	2	0	0	117
Membrane filtration	0	5	0	4	0	0	0	0	9
Coagulation/precipitation (alum)	15	17	5	83	3	0	0	0	123
Coagulation/precipitation (other)	7	5	3	14	5	2	0	0	36
Reverse osmosis	0	0	0	0	1	0	1	0	2
Micro filtration	0	0	0	3	0	0	0	0	3
None of these	0	0	0	5	0	0	2	0	7
No Plants	83	64	11	187	19	6	5	2	5

Percentage of plants using each type of treatment, by Drainage Division

Type of treatment	Drainage Division							
	1	2	3	4	5	6	8	9
Chlorination	49	38	100	58	42	100	120	100
Ph Remediation	36	19	64	38	47	0	0	0
Iron removal	13	5	9	2	0	100	0	0
Manganese removal	18	6	9	5	0	100	0	0
Ion-exchange softening	1	0	0	1	0	0	0	0
Aeration	30	6	0	3	0	67	20	0
Sedimentation	24	14	9	33	42	0	0	0
Automatic straining	1	0	0	1	0	0	0	0
Slow sand filter	4	3	9	10	0	33	0	0
Rapid sand filter	23	17	64	37	42	33	0	0
Membrane filtration	0	8	0	2	0	0	0	0
Coagulation/precipitation (alum)	18	27	45	44	16	0	0	0
Coagulation/precipitation (other)	8	8	27	7	26	33	0	0
Reverse osmosis	0	0	0	0	5	0	20	0
Micro filtration	0	0	0	2	0	0	0	0
None of these	0	0	0	3	0	0	40	0

Note: percentages do not add to 100. For example, 49% of plants in Division 1 chlorinate, and 36% undertake Ph remediation.

APPENDIX I Report on Non-market Values

Estimating community values for land and water degradation impacts

Final Report

Prepared for the National Land and Water

Resources Audit, Project 6.1.4

November 2000

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Chapter 1 Introduction

The purpose of this study is to estimate dollar values for non-market environmental and social impacts that are associated with land and water degradation in Australia. It provides quantitative information about the size of trade-offs between different social and environmental outcomes that stem from different resource use decisions. The study emerges out of a need to understand how the Australian community values goods and services that are not exchanged in markets. A better knowledge of these values will assist resource managers to make more informed policies based on a comprehensive set of costs and benefits associated with resource use changes.

The Project focuses on both "use values " and "non-use values". Examples of use values include outdoor recreation and the passive enjoyment of scenic beauty. Non-use values refer to benefits that society obtains from environmental resources in the absence of any tangible, current interaction with the resource. For instance, individuals may benefit from knowing that a natural area exists in an intact, "healthy" state even if they never intend to visit the area. Similarly, a non-use benefit may stem from the knowledge that country communities are in a viable and prosperous state. Together, these use and non-use values contribute to the total non-market impacts associated with a change in resource use.

A key objective of the study is to produce value estimates for a set of generic attributes that characterise the environmental and social impacts of land and water degradation at national and regional levels. The goal is for these attribute value estimates to be transferable across different regions and populations within Australia (a practice known as benefit transfer). The concept of transferability is appealing because it overcomes the need to undertake expensive surveys each time a new project proposal is evaluated, and is consistent with the rapid assessment approach being promoted by the Audit. However, the practice can lead to significant errors if the source values obtained from a pre-existing study are context-dependent and that context does not match the conditions which prevail at the target area of interest (Brouwer, 2000). Thus, an important component of this study is an investigation of the conditions and limits that apply to benefit transfer, and the development of a systematic procedure for calibrating value estimates so that they can be validly transferred from one policy context to the next.

A survey technique known as Choice Modelling is used in this study to estimate attribute values and welfare impacts for alternative resource use scenarios. It is the preferred valuation method because it is particularly suited to the role of providing value estimates that can be used as a source of data for benefit transfer. Relative to Contingent Valuation, it enables better control over the frame of reference within which non market goods are presented to respondents for valuing. It also enables the total value of a resource use change to be disassembled into its component attributes.

The report is organised as follows. Chapter 2 contains an overview of the Choice Modelling technique and the challenges of estimating non-market values. Chapter 3 summarises the main research issues that underpin this study, namely the selection of appropriate attributes and the factors that complicate benefit transfer, including framing, scope, and population effects. Chapter 4 contains a detailed description of how the questionnaire was designed and administered. In Chapter 5, a descriptive review of the main results is given. This is followed by an in-depth examination of the national value estimates in Chapter 6. The results of a number of benefit transfer tests are summarised in Chapter 7. These tests investigate the validity of transferring attribute value estimates from one policy context to another. The report concludes, in Chapter 8, with a set of guidelines and recommendations for using the value estimates to assess the non-market impacts of regional and national policies.

Chapter 2 Analytical approach

2.1 The valuation task

In this study the concept of value is treated from an economic perspective. Economists define value in terms of the maximum amount an individual is willing to pay for a good or service less the price paid for that good or service. It is assumed in welfare economics that individuals consume goods with the objective of maximising their wellbeing (or utility), subject to a budget constraint. This assumption holds for both marketed and non-market goods. The strength of people's concerns for the environment, and ethics, are encapsulated by this definition of wellbeing. If the theory of utility maximisation is embraced, it is possible to express all values in terms of a standard money-metric, namely an individual's "willingness to pay".

The task of estimating values for environmental and social impacts is challenging because many of these "goods" are not exchanged through markets. Consequently, market price and demand information is not available. Instead, non-market valuation techniques must be used to estimate the preferences and values of individuals. A variety of non-market valuation methods have been developed for estimating the amount an individual is willing to pay for improvements in environmental or social outcomes. These methods produce marginal values because they concentrate on the value of incremental changes in the level of an outcome.

There are two categories of non-market valuation techniques: Revealed preference and stated preference methods. The former uses observations of people's behaviour to infer values for environmental goods. Examples include visits to recreation sites (the travel cost method) or the selection of residential locations in close proximity to scenic views (the hedonic price technique). Revealed preference techniques are useful for estimating use values but are not capable of estimating non-use values. As non-use values are an important component of this study, a stated preference method was adopted.

Stated preference techniques involve asking respondents about their maximum willingness to pay for a specific change in the supply of a non-market good. The Contingent Valuation Method is one such technique. It has been used in a number of prominent Australian studies for valuing environmental resources. Perhaps the best known of these is a study undertaken by the Resource Assessment Commission to assess the environmental costs of mining at Coronation Hill near Kakadu National Park (Imber, Stevenson and Wilks, 1991). Other studies of national significance include an estimation of forest conservation benefits on Fraser Island (Hundloe et. al. 1990) and an assessment of soil erosion costs in New South Wales (Sinden, 1987).

This study employs an alternative stated preference technique known as Choice Modelling. The technique originates from the marketing and transport literature where it has been used extensively to analyse consumers' choices of products and transport modes, respectively. It has only recently begun to be used by economists for valuing environmental impacts.

2.2 Choice modelling

Technique overview

In a Choice Modelling (CM) application, respondents are presented with a series of questions, each containing a set of options known as a choice set. Typically, five to eight choice sets are included in a questionnaire. In each choice set, respondents are asked to choose their preferred option from a range of alternatives. Figure 2.1 contains an example of a choice set that was used in a study of wetland rehabilitation (Morrison, Bennett and Blamey 1999).

The options can be viewed as outcomes from alternative management policies, which are described in terms of a standard set of attributes or characteristics. Just as a car has a number of distinct attributes that contribute to its appeal (eg. air-conditioning, colour, fuel economy, price), each resource use option in an environmental valuation choice set is described by a number of key attributes and their associated levels.

In a CM application, the options making up the choice sets are formed by allowing attribute levels to vary systematically according to an experimental design. Each choice set also includes a status quo option that describes the outcome that is associated with a "no change" policy. It serves as a base against which to measure respondents' willingness to make trade-offs in securing change. The other options are deviations from the status quo.

Figure 2.1: An example of a choice set and its key components (from Morrison, Bennett and Blamey).

Attributes

Attribute levels

	Option A	Option B	Status Quo
Your water rates	$150 increase	$20 increase	No change
Wetlands area	800 km^2	550 km^2	400 km^2
Waterbirds breeding frequency	every 3 years	every 2 years	every 6 years
Number of native fish species	25 species	12 species	5 species
Irrigation-related employment	2000 jobs	1500 jobs	2800 jobs

I would choose:

- ☐ Option A
- ☐ Option B
- ☐ Status Quo

Respondent's choice of option

The data collected from people's responses to the choice questions reveal the extent to which individuals are prepared to trade-off one attribute against another (see Box 2.1 for detail on the theory that underpins Choice Modelling). Provided one of the attributes is measured in dollar terms, it is possible to estimate the amount of money people are prepared to pay for improving a non-monetary attribute by one unit. This value is known as an **implicit price**. The money attribute used in the choice sets can take the form of a tax, licence fee, entry fee, or some other payment mechanism.

In addition to implicit prices, the CM technique enables welfare impacts to be calculated for various resource use scenarios. Valuation is not restricted to the set of scenarios presented in the questionnaire. Rather, the costs or benefits associated with a whole range of change scenarios can be calculated once parameters have been estimated for the choice model. The CM application need only employ a range of attribute levels sufficient to cover the range of scenarios that are of interest.

The technique can also be used to examine the level of non-monetary community support for alternative policies that have specific outcomes. Support is measured in terms of the proportion of respondents who would choose a particular policy. This type of information can be useful for gauging the relative popularity of various

Box 2.1: Underpinning theory of Choice Modelling

The choice behaviour of respondents is assumed to be underpinned by a theory known as Random Utility Theory. The utility obtained by individual *i* from choosing alternative *j* in a choice set is given by:

$$V_{ij} = (q_j, c_{j,} s_{i,} \varepsilon_{ij})$$

where q_j is a vector of quality attributes, c_j is the cost of the alternative (given by the levy attribute), s_j is a vector of the individual's socioeconomic characteristics, and ε_{ij} is an error term. An error term is included to reflect the fact that the researcher does not know all the factors that contribute to an individual's utility.

The probability of individual *i* choosing alternative *j* is given by:

$$\Pr_{ij} = \Pr[\{v_{ij}(q_j, c_j, s_i) + \varepsilon_{ij}\} \geq \{v_{ik}(q_k, c_k, s_i) + \varepsilon_{ik}\}] \quad \forall j \neq k$$

This equation says that the probability of a respondent choosing alternative *j* is equal to the probability that the utility associated with that alternative exceeds the utility associated with any other alternative *k* in the choice set. The random utility model is made operational by adopting a particular cumulative density function for the unobserved component of utility, ε. If the ε's are independently and identically distributed with a extreme value type I (Weibull) distribution, then the individual's probability of choosing site *j* is given by a multinomial logit model (McFadden 1974):

$$\Pr_j = \frac{\exp(v_j)}{\sum_{k=1}^{J} \exp(v_k)}$$

Parameters of the utility function are estimated by Maximum Likelihood, which finds values for the coefficients that maximise the likelihood of the pattern of choices in the sample of observations. In this study, the software package LIMDEP (Greene, 1995) was used to estimate the multinomial logit model.

strategies among different stake-holder groups.

Technique strengths

Choice Modelling was selected as the preferred method for this analysis because it has a number of potential strengths over Contingent Valuation:

- It forces respondents to consider trade-offs between attributes.
- It makes the policy frame explicit to respondents via the inclusion of an array of options.
- It allows the estimation of implicit prices for attributes.
- It has the flexibility of being able to estimate welfare impacts for multiple scenarios.
- It has the capability to estimate the level of community support for alternative scenarios in non-monetary terms.
- It enables the total value estimate of a resource use change to be disassembled into its component parts (attributes), which facilitates benefit transfer.
- It potentially reduces the incentive for strategic behaviour.

Chapter 3 Research issues

This section of the report contains a brief overview of the research issues that are tackled by this study. Section 3.1 discusses the alternative ways that attributes could be defined and the criteria that were used to select the attributes. In Section 3.2, communication aspects of the CM questionnaire are considered. It includes a discussion of the steps taken in this study to reduce the cognitive burden placed on respondents. Section 3.3 deals with issues relating to benefit transfer, namely sources of transfer error, frame manipulation and the aggregation of benefit estimates. The chapter concludes with an outline of the approach used in this study to investigate the effect of framing and population characteristics on value estimates.

3.1 Definition and selection of attributes

The selection of an appropriate set of attributes that best reflect the impacts of land and water degradation is a critical component of this Project. It entails categorising the physical outcomes of any given resource use scenario into separate components. This task is not straightforward because environmental impacts are inherently complex and interrelated. The attributes need to be sufficiently generic so that they are capable of describing a wide variety of resource-use outcomes at different regions of Australia. They also need to be relevant to the public whilst being measurable and objective. The task of defining attributes is complicated by the added requirement that they be independent and not causally related.

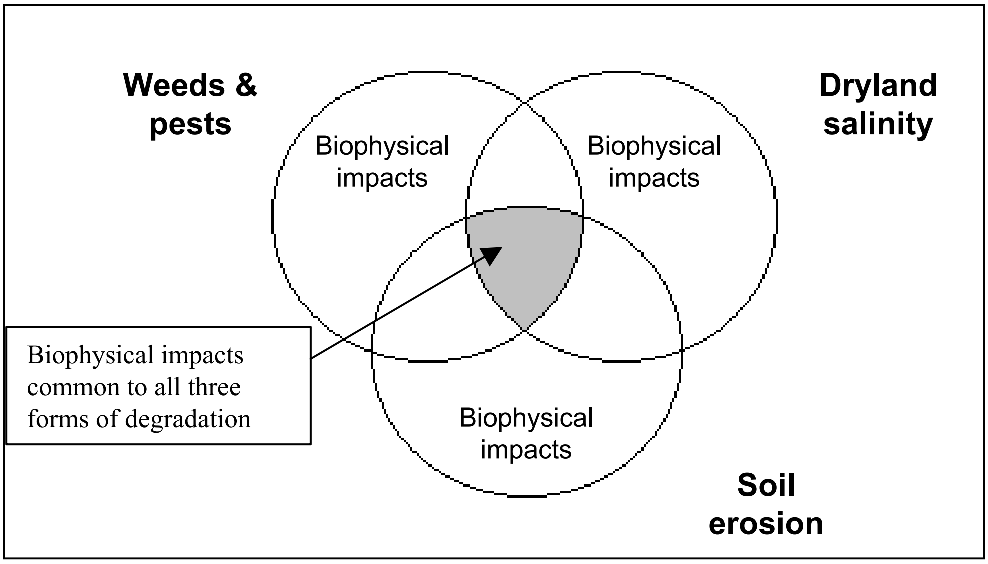
Attribute definition

At least two alternative approaches can be taken to defining the attributes. One possibility is to describe environmental impacts in terms of "degradation issues" (eg. salinity, soil erosion, pests). Using this approach, the area of salinity would be regarded as an environmental attribute. It tends to be consistent with the way resource managers compartmentalise policy outcomes and set priorities for future work.

An alternative method would be to move from an environmental issues focus to one that is based on biophysical impacts. This requires a concentration on specific biophysical factors such as changes in species diversity and fish abundance. Defining attributes in terms of biophysical impacts offers a number of advantages. Firstly, people are usually more concerned about the way in which degradation might affect the things they cherish rather than the processes causing the changes. For the purposes of CM, it is important to define the attributes in terms that are meaningful to respondents.

Secondly, biophysical impacts tend to be more generic than environmental issues and degradation processes. This is because different forms of degradation often share common biophysical impacts (Figure 3.1). Consequently, it is possible to apply one standard set of attributes to describe the impacts of multiple forms of degradation, irrespective of geographic location. For instance, the impact of degradation on endangered species can be expressed generically, regardless of whether losses are caused by dryland salinity or remnant vegetation clearance.

Figure 3.1: A diagram showing the distinction between degradation issues and biophysical impacts.



Selection criteria
A number of criteria were used in this study for selecting attributes. One of the primary requirements of CM is that respondents must perceive attributes to be independent of one another. Meeting this condition is difficult because many environmental impacts are interrelated. For example, an attribute defined as "area of healthy remnant vegetation" could be causally prior to "species diversity", meaning that healthy remnant vegetation may be viewed as a necessary prerequisite for supporting species diversity. Respondents may value both attributes but there is the possibility that less weight will be given to species diversity if it is believed that native vegetation must be restored first.

Causal attributes complicate the modelling of choice behaviour. Previous research has shown that when a causally prior attribute is included in a questionnaire, the value estimated for the "downstream" attribute is depressed relative to the estimate obtained when the causal attribute is omitted (Blamey, Bennett, Morrison, Louviere and Rolfe1998). Therefore, causality should be minimised by omitting either the causal attribute or the downstream attribute. The choice of which one to omit depends largely on how the value estimates are to be used.

Other criteria for selecting attributes include the need to ensure that attributes are meaningful to respondents, quantifiable, and of relevance to decision-makers. It is critical that attributes have common interpretation among all respondents. Poorly defined attributes may prompt some respondents to value a wider array of goods than those intended by the researcher.

3.2 Communication aspects

Compared to Contingent Valuation, a CM questionnaire is longer and more complex. It requires respondents to process a large amount of information including:

- Background information relating to the issues and scenarios.

- A series of five or more choice decisions that involve multiple options.
- Different combinations of attribute outcomes under each option.
- Combinations of attribute outcomes that may appear counter intuitive to respondents.
- A large array of numerical information associated with the options.

Owing to the considerable cognitive burden this process places on respondents, it is important to design the CM questionnaire so that it communicates the choice task to respondents as clearly as possible. Previous CM research has found that respondents use various ways of simplifying the choice task. For instance, "heuristics" may be employed whereby choices are made on the basis of one or two "indicator" attributes with no attention paid to the other attributes. This behaviour is clearly undesirable because the intention of CM is to encourage respondents to weigh up the options based on an appraisal of all the attributes. In an effort to improve respondent cognition, this study adopted visual stimuli as a means of denoting the attributes and their levels. These graphics were intended to reduce the complexity of the choice task and improve the communication of attribute outcomes.

3.3 Benefit transfer issues

An important goal of this study is to estimate values for a set of attributes that can then be transferred to a "target" region and used to evaluate the non-market costs and benefits of public sector investment in different projects and policies. Whilst the concept of transferring "off the shelf" estimates to particular regions of interest is appealing, the validity of this practice is restricted to cases where there is a reasonable degree of similarity between the source study and target area. Framing and population differences could render the estimates from a source study to be inappropriate for informing policy at a target site.

Framing effects

The term frame is used to describe the way in which aspects of a situation influence people's involvement in, and experience of, the situation. Therefore, when an individual is asked about his or her willingness to pay for a particular environmental improvement, the environmental "good" is embedded in a frame. Some important elements of the frame include:

- the scope of changes in resource use under investigation;
- the array of substitute and complementary goods;
- the institutional setting; and
- questionnaire cues.

In order to transfer benefit estimates from one context to another it is necessary to gain and insight into how different frames influence people's values. Embedding is one aspect of framing. Embedding effects are said to occur when respondents are willing to pay more for a good when it is assessed individually compared to when it is valued as part of a more inclusive package. For example, respondents may be willing to pay $150 to protect 50 hectares of remnant vegetation when offered as a single outcome, and only $15 for that same area of bush when offered as part of a bundle of environmental outcomes. This result is common in the non-market valuation literature.

The embedding effect is not an aberration or bias. Its presence is consistent with standard economic theory in that the value of a good is dependent on the range of substitute and complementary goods available to a consumer. Hence, the wider the array of substitutes, the lower the value of an individual good, while commodities that serve as complements generally enhance the value of a good. Thus, the frame in which a good is embedded is important for valuation. The challenge for the researcher is to ensure that the questionnaire frame is appropriate for the policy being investigated.

Population effects

Population differences are another factor that could cause differences between values estimated in different regions. Values are likely to be sensitive to a population's socioeconomic characteristics, attitudes and social norms. The cultural traditions of a region, and its institutions could also be important. The issue of population effects is explored in this study by comparing the results derived from the same estimation procedure being applied across a number of different population samples. Furthermore, values are estimated for a range of different household groups, categorised according to specific characteristics. Information from these analyses is incorporated into the benefit transfer guidelines.

The eventual size of population to which value estimates are to be aggregated (known as the geographic extent of the market) is another important consideration when transferring benefits. The practice of aggregation is, itself, a form of benefit transfer if the source study estimates are derived from a sample that is different to the target population.

Previous work has shown that non-market values, in particular use-values, frequently decline as the distance between a respondent's residence and study site increases (Pate and Loomis, 1997; Sutherland and Walsh, 1985). The same relationship is less likely to hold for non-use values. A choice modelling study by Rolfe and Bennett (2000) found evidence of significant population differences within the state of Queensland. Using a split-sample test, it was shown that respondents who resided in rural areas have lower values for conserving remnant vegetation in the Desert Uplands of Central Queensland than metropolitan Brisbane residents. The implication of this finding is that values are not necessarily inversely proportional to distance. Community attitudes are also influential in determining values.

Minimising transfer error

Differences in population characteristics and attitudes between the source and target regions can partly be accounted for by transferring a "value function" rather than point estimates of value. An example of a point estimate is the average "per person" value of an additional hectare of remnant vegetation. An alternative approach is to specify a value function which specifies an individual's willingness to pay as a function of a number of explanatory variables including population characteristics. This procedure adjusts for some of the differences between source and target sites and has been shown to out-perform point transfers in tests of benefit transfer (Brouwer, 2000).

However, the value function does not necessarily control for all the factors related to frame and population. Thus it was important in this study to quantify the sensitivity of value estimates to different frames and populations. This information provides a guide for calibrating source estimates so that they can be validly transferred to a different site or policy context. The approach taken was to design a framing and sampling strategy that allows the influence of population and frame to be tested.

3.4 Framing and sampling strategy

As the primary purpose of this research project is to develop a set of value estimates for later use in benefit transfer, it is important to gain a better understanding of the way in which frame, scope, and population differences interact to influence value estimates. A research strategy was developed to investigate the following questions:

- To what extent are community preferences and values dependent on the frame?
- Are respondents sensitive to the scope of environmental impacts proposed in a questionnaire?
- Do parochial attitudes play a significant role in influencing values?
- How do community preferences and values change with distance from a study site?
- What adjustments are needed if attribute value estimates are to be validly transferred from a national context to a regional context?

Specifically, the strategy involved the development of three separate questionnaire versions, each representing a **different frame**. One of the questionnaires focused on land and water degradation in a national context, whilst the other two dealt with degradation issues in two case study regions. The regions selected for the case studies were the Great Southern Region (GSR) of Western Australia and the Fitzroy Basin Region (FBR) of Central Queensland. The degradation issues in these regions are markedly different and there is evidence to suggest that Queensland people have different attitudes towards the environment to Western Australians[7]. Thus, the two regions were selected as a means of testing the transferability of the national estimates over a wide range of circumstances.

The other component of the research design was the **sampling strategy**. The national questionnaire was issued to a random sample of the Australian population,

[7] A survey by the Australian Bureau of Statistics (ABS) indicated that WA residents have a greater awareness of environmental problems than any of the other States, and Queenslanders have the lowest levels of awareness (ABS, Catalogue 4602, 1999).

while the case-study questionnaires were administered to households living in the vicinity of each region; one from the region's main population centre and the other from the region's state capital city population. The main population centres for the GSR and FBR are Albany and Rockhampton respectively. The corresponding capital cities are Perth and Brisbane. As depicted in Table 3.1, this framing and sampling strategy allows an investigation of seven different combinations of frame and population, resulting in seven separate choice models.

A common set of attributes was used for all versions of the questionnaire and the same three levy amounts were used across all versions. However, the frame for each version was manipulated by adjusting the levels of the social and environmental attributes so as to match the conditions that exist in each case study area. In addition, the frame of reference was varied across the three different versions by tailoring the background information that accompanied the questionnaires. Respondents were provided with information that reflected the issues and policies that are relevant to each study area (see Appendix C for a copy of the information booklet that was sent out with the national survey).

Table 3.1: Summary of the models estimated for various combinations of population and questionnaire frame.

		POPULATION				
		Regional sample		**Capital city sample**		**National sample**
		Rockhampton	Albany	Brisbane	Perth	National
FRAME	Fitzroy Basin	Model 5		Model 7		
	Great Southern		Model 4		Model 6	
	National	Model 3	Model 2			Model 1

Chapter 4: Questionnaire design and administration

4.1 Survey of scientists and resource managers

An initial list of environmental attributes was compiled by surveying approximately 35 scientists and resource managers. The purpose of this preliminary survey was to obtain a wide-ranging review of attributes that were considered to be important from the perspective of policy makers and their advisers. The questionnaire was framed at the national level. No reference was made to specific case study regions. This initial scoping survey indicated that resource managers find it difficult to differentiate between issues and biophysical outcomes. Nevertheless, the survey provided a starting point for identifying possible attributes.

4.2 Focus groups

The next phase of questionnaire design involved structured focus group discussions with members of the public. In total, approximately 65 people attended seven focus group meetings over a period of two months. The meetings were held in the following locations:

<u>City</u>
- Sydney.
- Canberra.
- Perth.
- Brisbane.

<u>Regional</u>
- Yass, NSW.
- Rockhampton, Qld.
- Albany, WA.

The duration of each meeting was one and a half hours. Market research companies were contracted to recruit ten participants for each group. People from a cross section of the community were selected for the groups, ensuring a mix of genders, age groups (18-65 years), and occupational backgrounds. To prevent the groups from containing a disproportionate number of participants with a pro-environment disposition, care was taken not to divulge the topic of the discussions at the time of recruitment. Recruits were told that they would be helping to develop a questionnaire concerning social issues of national importance.

The initial meetings were primarily used to gain an understanding of public awareness of environmental issues and to generate a list of environmental attributes. Of particular interest was whether people "think" at a local level or at a more general, national level. The meetings held in regional areas provided an insight into the aspirations of country people, and how these contrasted to the preferences of city dwellers. Another goal of the focus group work was to check communication aspects in early versions of the questionnaire. Appendix A contains a copy of the discussion questions that were used in these focus groups.

Environmental awareness

The focus group work revealed that environmental issues are not given a high priority by rural or metropolitan communities relative to other social issues. This finding is consistent with an Australian Bureau of Statistics survey of households in which only nine per cent of households ranked environmental concerns as their top social issue (ABS, Catalogue 4602, 1999).

People from the city focus groups generally had less knowledge of land and water degradation issues than people in the regional centres. They were aware of high-profile issues, such as salinity, through media coverage but they had little understanding of the causes and impacts of degradation. Their greatest concern was the impact that degradation might have on human health via effects on water and food quality. A second-ranked concern was the possibility that degradation may increase the cost of food and water. Mention was also made of the need to maintain "viable country communities". Fewer references were made to the impact of degradation on conservation values.

Attribute selection and definition

The focus group discussions identified a set of concerns that were consistent across most focus groups, albeit with differing degrees of emphasis depending on the particular case study region. The five main categories of environmental and social concerns were:

- Native species and ecosystem functioning.
- Landscape aesthetics.
- Outdoor recreation opportunities.
- Productivity of the land and quality of drinking water.
- Viability of country communities.

Notably, these concerns comprise both use and non-use dimensions. The desire to preserve native species and to maintain viable country communities constitute non-use values. The demand for attractive landscapes, outdoor recreation areas, and the maintenance of production activities reflect use values.

The list of concerns provided by the focus groups was used to define four attributes for the CM application, three of which were environmental and the fourth that captured peoples' social concerns (Table 4.1). Production-related concerns were omitted from the choice model because a separate study within Theme 6 of the Audit estimates the cost of damage to agricultural production. Instead, respondents were asked to concentrate on the conservation-related effects of degradation.

Table 4.1: Environmental attributes selected for the choice modelling questionnaire.

Attribute	Unit of measurement
Species Protection	The number of species protected from extinction.
Landscape Aesthetics	The area of farmland repaired and bush protected.
Waterway Health	The length of waterways restored for fishing or swimming.
Social Impact	The net loss of people from country towns each year.

<u>Species Protection</u>

The *Species Protection* attribute was included to capture respondents' non-use values for ecological protection. It was measured in terms of the number of endangered species protected from extinction under a particular resource use scenario.

Landscape Aesthetics

Landscape aesthetics was measured in terms of "hectares of farmland repaired or bush protected". This unit of measurement accommodates the differing circumstances of the two case study regions. In the Great Southern, the impacts of land degradation are already obvious while in the Fitzroy degradation remains largely a potential of further development. However, there are some possible drawbacks with defining landscape aesthetics in this way. The focus group discussions revealed that some people view the repair of farmland as a production-related activity and bushland protection as conservation-related. Others believed that the better management of the landscape to improve aesthetics would also protect endangered species (a problem of causality). In order to minimise the potential for causality and the risk of respondents broadening their valuations to production-related aspects land management, the aesthetics attribute was repeatedly referred to in the questionnaire as a measure of countryside attractiveness.

Waterway Health

The impact of degradation on recreational opportunities was defined by the *Waterway Health* attribute. This attribute was designed to capture respondents' joint concerns for recreational activities and the preservation of waterway habitats. It was defined in terms of fishing and swimming opportunities so as to deflect attention away from the production values associated with water resources.

Social Impact

The social impacts of resource use policies was measured in terms of the net migration of people from country towns each year. Defining the attribute in this way allows for different levels of depopulation to be specified for alternative resource use policies. However, it does not allow for a net increase in population. The accommodation of population growth would add considerable complexity to the analysis of the choice data.

Responsibilities and funding mechanism.

Another role of the focus group work was to identify possible mechanisms for funding environmental programs that could act as a payment vehicle and to gauge community sentiment about the notions of environmental responsibilities so that payment vehicle bias could be minimised. The discussions revealed that:

- In the main, participants believed that it was society's responsibility to pay for programs that addressed land and water degradation. It was accepted that farmers should not be held accountable for all the mistakes of the past.

- Despite the acceptance of this principle, "free-riding" behaviour was exhibited in many groups. In other words, participants supported the principle of spreading the costs across different sectors of society, providing they did not have to pay anything personally.

- There was support for the concept of an environmental levy. Participants were familiar with this funding mechanism owing to the various examples of these types of special-purpose levies (Gun Buy-Back, East Timor, Medicare). Furthermore, just prior to the focus group meetings, there was a considerable amount of debate in the West Australian and New South Wales media about the possible introduction of a salinity levy.

- Notwithstanding the "in principle" support for a levy, there was a general distrust of government. In particular, participants did not trust governments to manage the funds and spend them wisely. They believed that existing tax revenue is being wasted. Across all groups, there was a strong demand for information about the mechanics of how an environmental fund would be managed. Many participants said they would discard the questionnaire if it did not outline how the payment scheme was to be implemented and managed.

- Participants were very concerned about the equity implications of imposing a tax-based levy. They wanted to know whether the levy would be means tested and whether it would cause financial hardship to the disadvantaged.

- The city-based focus group participants found it implausible that a special on-going levy would be introduced to fund environmental projects in just one region of the State (particularly evident in the Brisbane group).

These sentiments were taken into account when designing the questionnaire. In an evolution to previous Australian applications of stated preference surveys, greater attention was paid to describing the features of the proposed levy scheme. Respondents were told that a trust fund would be established and managed by a committee independent of government (see Appendix C for details).

4.3 Development of choice options

The valuation exercise was introduced to respondents by explaining that public money is currently being spent on a wide range of environmental projects and that this level of action will result in a specific set of future outcomes (the **business as usual scenario**). Respondents were told that extra investment would be required if additional improvements are to be achieved. An environmental levy on households was proposed as a means of funding this extra action. The questionnaire introduced the concept of a household levy to be paid each year for the next 20 years. A specific level of payment was associated with each choice option, being zero for the business as usual scenario and $20 to $200 for the **'levy' options**.

The attribute levels associated with each option, including the business as usual scenario, were expressed relative to a benchmark, namely a **'do nothing' scenario**. Under this scenario, it is assumed that even the current level of remedial work is not undertaken. Figure 4.1 demonstrates the three scenarios and provides an example of future attribute levels based on the *Species Protection* attribute. For each of the levy options, the levels of the environmental attributes were stipulated to always increase over time relative to the business as usual scenario. However, for the *Social Impact* attribute, both positive and negative outcomes were allowed. This takes account of the possibility that some types of environmental programs could displace rural communities (for example, the conversion of farmland into long rotation forestry), and for others to yield a net reduction in the number of people leaving country areas (a positive outcome).

The attribute levels were selected from a feasible range of possibilities and systematically combined according to an experimental design. In order to assist respondents with their deliberations, approximations of the current levels of each attribute were summarised in the introduction to the questionnaire (see Tables 4.2, 4.3, and 4.4 for details).

Figure 4.1: An example of a scenario outcomes for the level of endangered species. Note the chart is not drawn to scale.

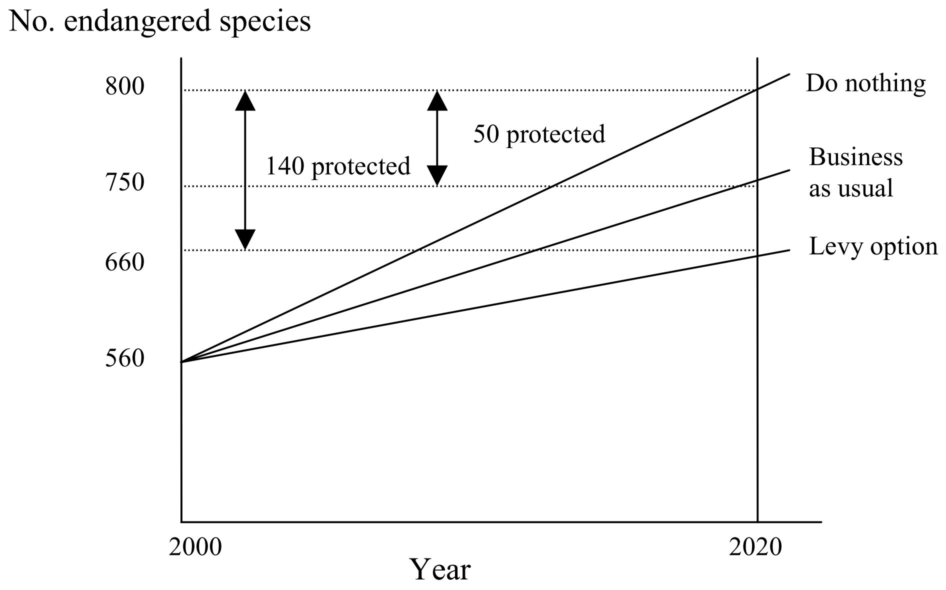


Table 4.2: Attribute levels for the national questionnaire

Attribute	**Current level**	**Information source for current level.**	**Business as usual funding (2020 levels)**	**Range 1**	**Range 2**	**Range 3**
Species	560 endangered	State of the Environment Report, 1996. pp 4-34 Australian National Parks and Wildlife Service (1992), published in the "Australian National Strategy for Conservation of Species and Communities Threatened with Extinction". Estimate does not include vulnerable and threatened species.	50 protected	70	140	200
Waterway health	15,000km degraded	State of the Environment Report, 1996. pp 4-26 30% of waterways are estimated to be in extremely poor condition (Managing Natural Resources in Rural Australia for a Sustainable Future, 1999).	1000km restored	5000	8000	10,000
Look of land	12 mill ha degraded or unprotected	Science, Engineering, and Innovation Council (1999) published in "Moving Forward in Natural Resource Management", p. 13.	4 mill ha rehabilitated	6 mill	8 mill	10 mill
Country communities	8000 people leaving annually	ABS Catalogue 3218.0. Estimate based on the 20 Statistical Local Areas in Australia that suffered the highest decline in population in 1998/99.	15000	5000	10,000	20,000
Levy	$0		0	20	50	200

Table 4.3: Attribute levels for the Fitzroy Basin questionnaire

Attribute	Current level	Information source for current level	Business as usual funding (2020 levels)	Range 1	Range 2	Range 3
Species	20 endangered	Central Queensland Strategy for Sustainablity, (1998). Only includes vascular plants and fauna.	5 protected	10	15	20
Waterway health	1000km degraded	Queensland State of the Environment Report, 1999. p. 7.42	100 restored	500	800	1000
Look of land	1 mill ha degraded or unprotected	Estimate refers to the area of remnant vegetation on private land that remains unprotected, plus areas affected by soil erosion.	250,000 protected	500,000	750,000	1mill
Country communities	450 people leaving annually	ABS Catalogue 3218. Calculated by summing the population loss in 1998/99 across all Statistical Local Areas in the Fitzroy Statistical Division.	1200	450	1000	1500
Levy	$0		0	20	50	200

Table 4.4: Attribute levels for the Great Southern questionnaire

Attribute	Current level	Information source for current level	Business as usual funding (2020 levels)	Range 1	Range 2	Range 3
Species	120 endangered	WA Department of Conservation and Land Management, published in Western Australian Salinity Strategy (2000).	25 protected	35	70	100
Waterway health	800 km degraded	Western Australian Salinity Strategy (2000).	100 km restored	250	500	800
Look of land	1 mill ha degraded or unprotected	Approximately 0.5 mill hectares is salt-affected land (Western Australian Salinity Strategy, 2000). The other 0.5 million constitutes eroded land and unprotected remnant vegetation on private property.	250,000ha rehabilitated	500,000 mill	750,000	1mill
Country communities	520 people leaving annually	ABS Catalogue 3218. Calculated by summing the population loss in 1998/99 across all Statistical Local Areas in the Upper and Lower Great Southern Statistical Divisions.	1500	500	1200	2000
Levy	$0		0	20	50	200

4.4 Choice set design

The choice sets were designed to minimise the cognitive burden on respondents and to fulfil the technical requirements of the analysis. As part of the design process, five of the focus groups were asked to assess alternative formats for the choice sets. The main design features that were investigated included:

- the presentation of attribute levels in marginal or absolute terms;
- the presentation of choice options as either generic or labelled alternatives;
- the presentation of attribute levels in numerical format or the use of icons; and
- the presentation of choice options in columns or horizontal rows.

Marginal versus absolute format

In the absolute format, attribute levels were expressed relative to a 'do nothing' scenario, in which not even the current level of investment is undertaken. For example, respondents were told that the number of endangered species protected under the current level of funding will be $0 + x$, while the levy option will protect $0 + x + y$ species. In the marginal format, respondents were presented only with improvements that are additional to what would be achieved under the existing level of funding. Hence, business as usual outcomes were set to zero and the levy options were set to $0 + y$. An example for the *Species* attribute is shown in Table 4.5.

The focus groups showed a clear preference for the choice set in which attribute levels were presented in absolute terms, using the do nothing option as a base. The marginal format was confusing to some people in the focus group studies, so it was rejected in favour of the absolute format.

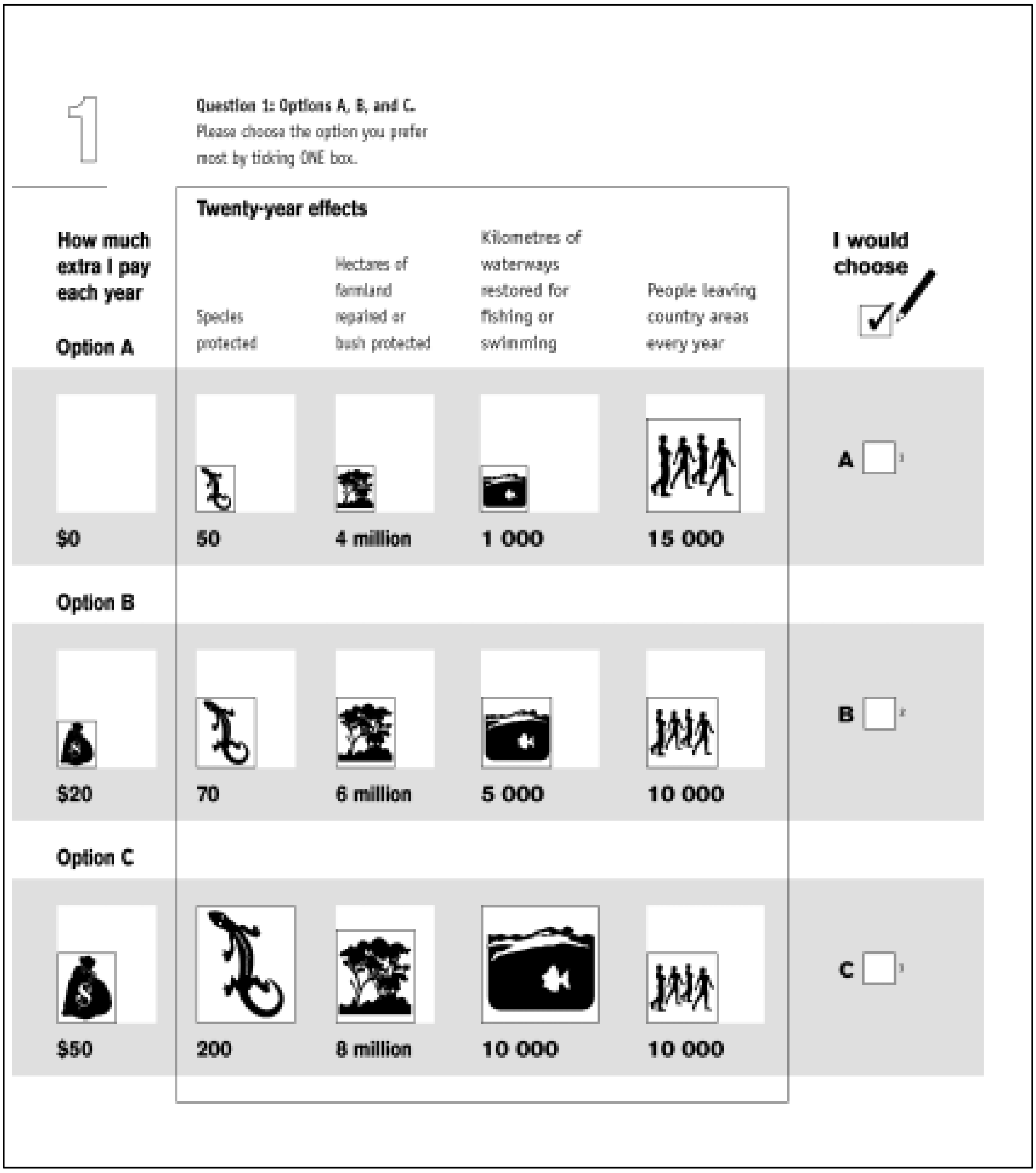
Table 4.5: Presentation of attribute levels using two alternative formats

	Number of species protected	
Scenario	Absolute format	Marginal format
Do nothing	0	-
Business as usual	50	0
Levy	140	90

Option labels versus generic options

A choice set with generic options refers to the situation where each option is only described in terms of an attribute profile, which consists of a specified combination of attribute levels. Options are differentiated with a simple nomenclature such as Option A, Option B etc. In contrast, a labelled choice set refers to the situation where each option is given a policy label. The label describes the type of policy or mechanism that would be used to produce the attribute outcomes. Essentially, the label provides the respondent with an additional piece of information upon which to base his/her choice.

Figure 4.2: Example choice set:



Members of the focus groups were shown both types of choice sets, labelled and generic. Most people preferred the labelled options as they found it easier to choose between the options. Respondents liked the labels because they provided information about the programs or mechanisms that were driving the outcomes. However, in spite of this demand for labels, it was decided to retain the generic options format. This decision was made because previous research has shown that labels can prompt respondents to trivialise the attributes when making their choice, thereby reducing the statistical explanatory power of the attributes in the choice model (Blamey et. al. 1999). Clearly, this would have been undesirable for this Project where the objective was to estimate attribute values for the purposes of benefit transfer.

The request by focus groups for policy labels was addressed by including a statement in the survey introduction. The statement emphasised that many types of projects could be undertaken to improve the environment and viability of country communities, and that different combinations of projects would lead to different outcomes. Respondent were then asked to choose between the options on the basis of attribute outcomes.

Attribute icons

Most CM applications have relied entirely on numerical values to convey information about attributes and their levels. This presentation format may be confusing to some respondents and cause fatigue. In this study, visual stimuli were incorporated into the choice sets in an effort to improve respondent cognition and promote interest. An icon was used to represent each attribute and the size of the icons was scaled to denote the level of the attribute. Figure 4.2 contains an example of a choice set.

4.5 Pre-testing

The survey instrument was pre-tested over two days in suburban Sydney using a door-to-door, drop off and pick up method. The suburbs selected for the pre-test contained households from a broad range of socioeconomic groups. In total, 25 households were interviewed. Only minor modifications were made to the questionnaire following the pre-testing phase as debriefs with the respondent households did not reveal any significant communication problems.

4.6 Sampling

A market research firm (Barbara Davis and Associates) was contracted to draw random samples from "Australia on Disk," a telephone directory database of the Australian population. The size of the total sample was 10,800 households. Table 4.6 contains a breakdown of the population sub-samples.

Table 4.6: Size of sub-samples, by questionnaire version

	Questionnaire Version		
Population samples	National	Great Southern	Fitzroy
National	3200	-	-
Albany	1200	1200	-
Rockhampton	1200	-	1200
Perth	-	1400	-
Brisbane	-	-	1400

4.7 Survey administration

Barbara Davis and Associates was also engaged to administer the survey. The questionnaires were mailed out to households with a covering letter outlining the objectives of the survey. No incentives were provided as a means of increasing response rate.

Respondents were asked to use the reply-paid envelope provided to return their completed questionnaire. Households who failed to return a questionnaire within two weeks were sent a reminder notice. A second reminder was sent out after four weeks had elapsed from the time of the first mail-out. The questionnaire was in the field for a period of approximately six weeks. At the end of the survey period, a follow-up telephone survey of non-respondents was conducted. The purpose of this survey was to identify the reasons why households did not respond and to determine whether non-respondents had significantly different characteristics to respondents.

Chapter 5: Descriptive overview of survey results

This chapter contains an overview of the survey results. The purpose of the overview is to provide an initial description of the data to assist with interpreting the model results. In Section 5.1 the response rate to the survey is reported for each population sub-sample. Particular attention is paid to the proportion of respondents who completed the choice task. Section 5.2 contains a description of the data. Key characteristics of the national sample are summarised and compared against census statistics to determine the representativeness of the sample. Section 5.3 presents the results of a preliminary assessment of respondents' willingness to pay an environmental levy.

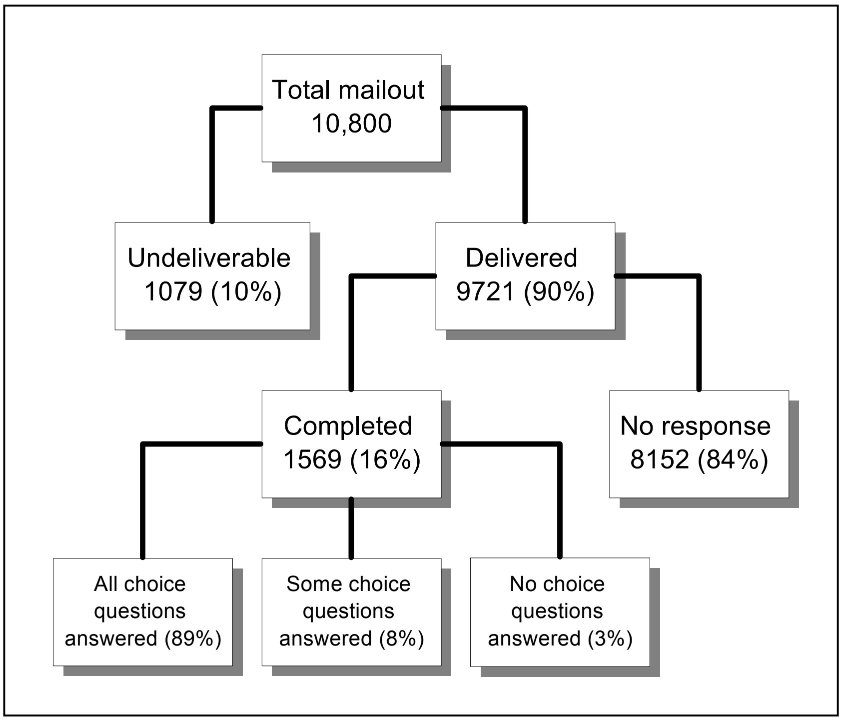
The last section of this chapter (5.4) contains details of the choice model specifications and reports the parameter estimates for the model. An assessment is made of the statistical significance of the models and the extent to which the model coefficients accord with theoretical expectations.

5.1 Response rate

Overall response

The overall response rate to the survey was 16 per cent which equated to 1569 completed questionnaires (Figure 5.1). This response rate is net of the 10 per cent of questionnaires that were undeliverable due to outdated address details. Of those respondents who completed a questionnaire, the majority (89 per cent) answered all five choice questions, while a small proportion (8 per cent) only answered a subset of the five questions. Three per cent of respondents failed to complete any of the choice questions.

Figure 5.1: Response rate



There were significant differences in response rate across the samples[8]. Table 5.1 contains a summary of the response rates by sample and type of questionnaire version administered. The main points to note are:

- The lowest response rate was from Brisbane (13 per cent). In contrast, the Perth response rate was 18 per cent.
- The response by the regional samples (Albany and Rockhampton) to the case study questionnaires is not significantly greater than the response by these same samples to the national questionnaire. Response rates to both versions of the questionnaire range from 14 to 17 per cent. The variation in response between Albany and Rockhampton is not statistically significant at the five per cent level.
- There is no statistical difference in response rates between metropolitan and non-metropolitan residents.

[8] The differences are statistically significant at the 5% level using a chi-squared test.

Table 5.1: Response rates for each sample, by questionnaire version.

	Questionnaire version		
Sample	National	Fitzroy	Grt Southern
National			
Metropolitan	18%	-	-
Non-metropolitan	17%	-	-
Capital city			
Perth	-	-	18%
Brisbane	-	13%	-
Regional			
Albany	17%	-	16%
Rockhampton	14%	16%	-
	16%	15%	17%

State differences in response rate.

Within the national sample there is a large degree of variation in response rate across the States (Table 5.2). Owing to the small sample size for some States, not all the differences are statistically significant. However, ACT's response rate is significantly higher than that of NSW and WA. The education levels of respondents and their environmental disposition are reported in Table 5.3. There is no evidence of a statistically significant correlation between these factors and response rate.

Table 5.2: Response rate for the national sample, by State and Territory

	Total mailout	Delivered	Completed	Response rate
NT	20	16	2	13%
ACT	54	47	13	28%[a]
TAS	73	67	11	16%
SA	266	246	50	20%
WA	307	264	35	13%
Qld.	592	534	95	18%
Vic.	800	719	131	18%
NSW	1088	944	153	16%
	3200	2837	490	17%

[a] Significantly different from NSW and WA at the 5% level, using a chi-squared test.

Table 5.3: Education level and environmental disposition of respondents, by State and Territory. The sub-sample containing NT respondents is excluded owing to its small sample size.

		Proportion of respondents who.....	
	Response rate	hold a tertiary degree	support an environmental organisation
ACT	28%	54%	31%
TAS	16%	36%	36%
SA	20%	38%	30%
WA	13%	49%	29%
Qld.	18%	27%	18%
Vic.	18%	37%	16%
NSW	16%	33%	29%

Table 5.4: Choice set completion rate by age group and education level.

	Under 55 [a]	55 and over	All ages [a]
Primary	80%	81%	81%
Yr 10	88%	83%	85%
Yr 12	93%	84%	90%
Diploma	92%	89%	91%
Tertiary	97%	92%	95%
All levels [b]	93%	86%	

[a] Variation in completion rate across education level is significant at the 5% level, using a chi-squared test.
[b] The difference in completion rate between the two age groups is significant at the 5% level, using a chi-squared test.

5.2 Completion of the choice task.

Of those responding to the questionnaire, 11 per cent failed to complete all or some of the choice questions. The results in Table 5.4 suggest that education and age are significant determinants of respondents choosing to ignore or only partially complete the choice tasks. The values in the table are choice set completion rates, calculated as the proportion of respondents who returned a questionnaire and completed all the choice questions. There is a statistically significant increase in the completion rate with progressively higher education levels, and this is most noticeable for respondents aged 55 years or under (the effect of education is not significant for respondents in the older age group). Completion rate is significantly lower for respondents over the age of 55.

In order to discover what other factors are important in determining completion rates, respondent reactions to the questionnaire were analysed for two groups of participants: Those who completed all the choice questions and those who did not. It was found that a significantly larger proportion of respondents in the latter group found the background information confusing and fewer felt they needed more information (Table 5.5). It would appear that a small percentage of respondents, mostly those with low education levels, had difficulty understanding the issues and trade-offs that were being presented to them.

5.3 Description of data

Sample characteristics

A summary of the key socioeconomic characteristics for each of the five samples is contained in Table 5.6. Albany and Rockhampton stand out because they both contain the highest proportion of respondents in the low-income bracket. The proportion of respondents with pro-environment sentiment differs considerably across the samples, ranging from 13 per cent for Rockhampton up to 27 per cent for Albany. The survey appears to have been self-selecting for male respondents, particularly in the metropolitan city samples. Sample selection bias is discussed at greater length in the following section which examines the representativeness of the national sample.

Some of the socioeconomic characteristics used to describe respondents are weakly correlated with each other. The notable positive correlations are between education and income, and between age and sex (the probability of a respondent being male increases with age). The correlation coefficient for "green" disposition and income is positive but the correlation is not significant. Among the negative relationships, only the correlations between age, income, and education level are significant. A full correlation matrix for all the socioeconomic variables is contained in Table 5.7.

Table 5.5: Reactions to the questionnaire by two groups of respondents: Those that completed all choice questions and those who did not. The proportion of respondents who answered "YES" to the statement are indicated.

	Choice questions completed	Choice questions not completed
I needed more information	32%	24%[a]
I thought the information was biased	21%	22%
I thought the information was confusing	16%	26%[a]
I found options confusing	28%	32%
I thought the options were unrealistic	18%	24%
I think that a levy will one day be introduced	60%	51%[a]

[a] Difference in completion rate between the two groups is significant at the 5% level using a chi-squared test.

Table 5.6: Selected socioeconomic characteristics of the samples.

	National	Perth	Brisbane	Albany	Rock'n
Modal income category	$36,400-51,999	$52,000-77,999	$36,400-51,999	$6239-15,599	$6239-15,599
Modal education category (highest qualification)	Tertiary degree	Tertiary degree	Tertiary degree	Diploma / certificate	Tertiary degree
Modal age group	45-54	45-54	35-44	65 +	35-44
% supporting green group(s)	24%	22%	22%	27%	13%
Male to female ratio	1.6 to 1	1.5 to 1	1.8 to 1	1.3 to 1	1.3 to1
Sample size	490	217	170	356	336

Table 5.7: Correlation matrix for the socioeconomic variables

	Sex	Age	Citizen	Green	Education	Income
Sex	1.0000					
Age	0.1735	1.0000				
Citizen[a]	-0.0029	-0.0297	1.0000			
Green[b]	-0.0945	-0.0756	0.0046	1.0000		
Education	-0.0174	-0.2590	0.0186	0.1608	1.0000	
Income	0.0651	-0.2836	-0.0119	0.0869	0.3095	1.0000

[a] Australian citizenship; [b] Indicator of whether respondent is a member of, or donates to, an environmental organisation.

Representativeness of the national sample

The sample of people who responded to the national survey is not representative of the Australian population with respect to some key socioeconomic characteristics. Notably, the male-to-female ratio of respondents is disproportionately large relative to the national average, which suggests that males were more likely to complete the questionnaire. Further evidence of sampling bias is apparent when the sample statistics are compared alongside the national census data:

- Younger age groups are under-represented (Figure 5.2).
- The sample contains a disproportionately large group of high-income earners (Figure 5.3).
- 35 per cent of respondents have a tertiary degree which is more than double the national level of 14 per cent (Figure 5.4).
- 24 per cent of respondents reported that they donated to, or were members of, an environmental organisation. There is evidence to suggest that this level of commitment to environmental causes exceeds the national average. Whilst directly comparable statistics are not available, the Australian Bureau of Statistics has estimated that only nine per cent of Australians rank environmental problems as their top social issue (ABS, 1999). The Australian Conservation Foundation estimates that five per cent of the national population belong to at least one environmental organisation (M. Fogarty pers. comm. 2000).

Figure 5.2: Age composition of the national sample relative to ABS estimates for the Australian population aged 18 years and over (Catalogue 3201, 1999).

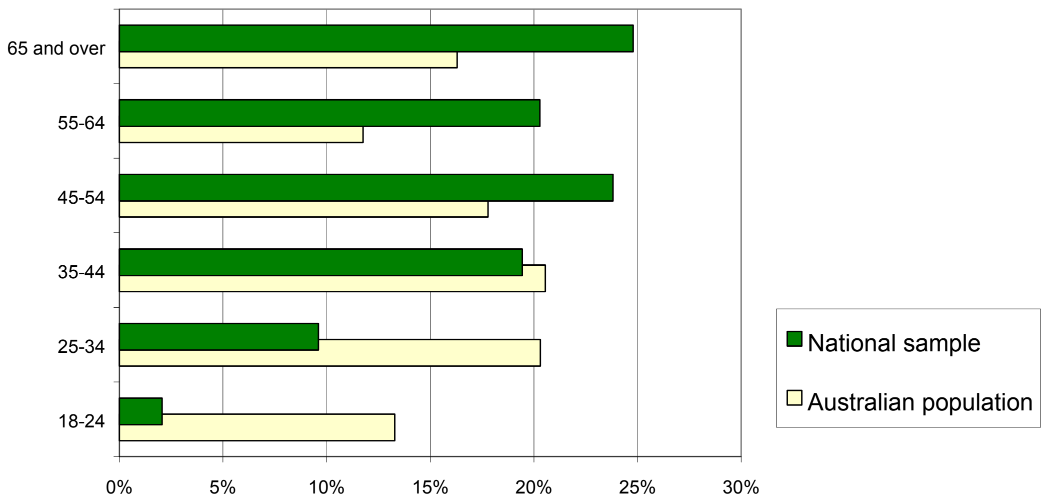


Figure 5.3: Income distribution for the national sample relative to ABS estimates for the Australian population (all income units, Catalogue 6253, 1999).

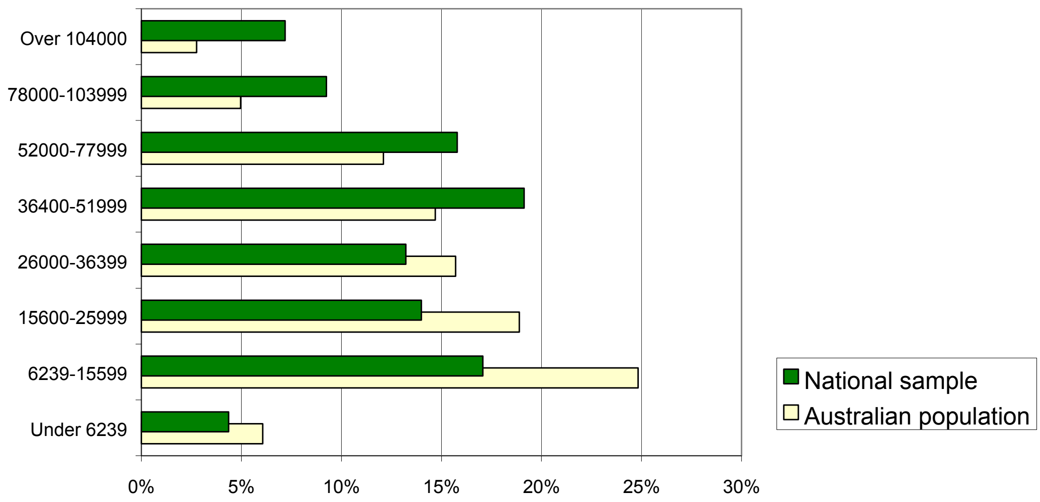


Figure 5.4: Highest level of education attained by respondents relative to the Australian population (ABS, 1998, Catalogue 4224).

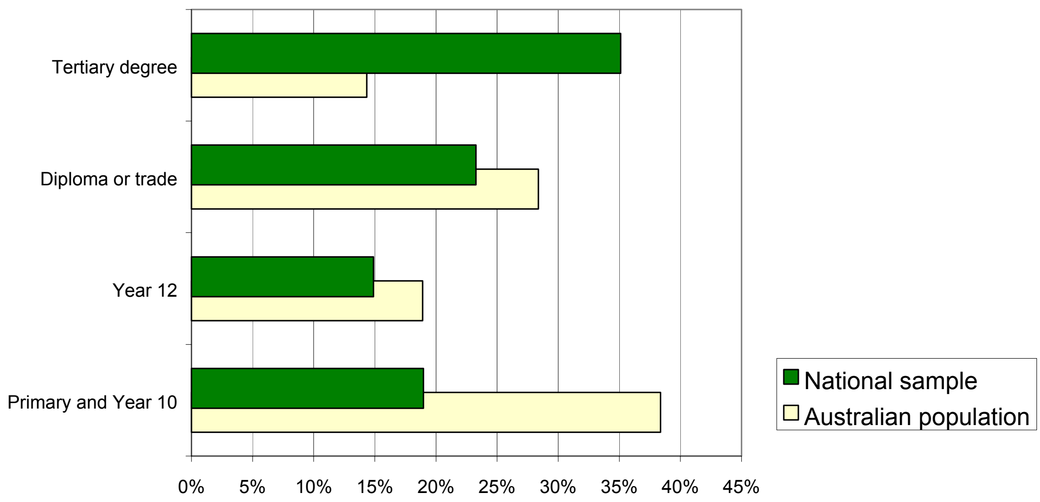
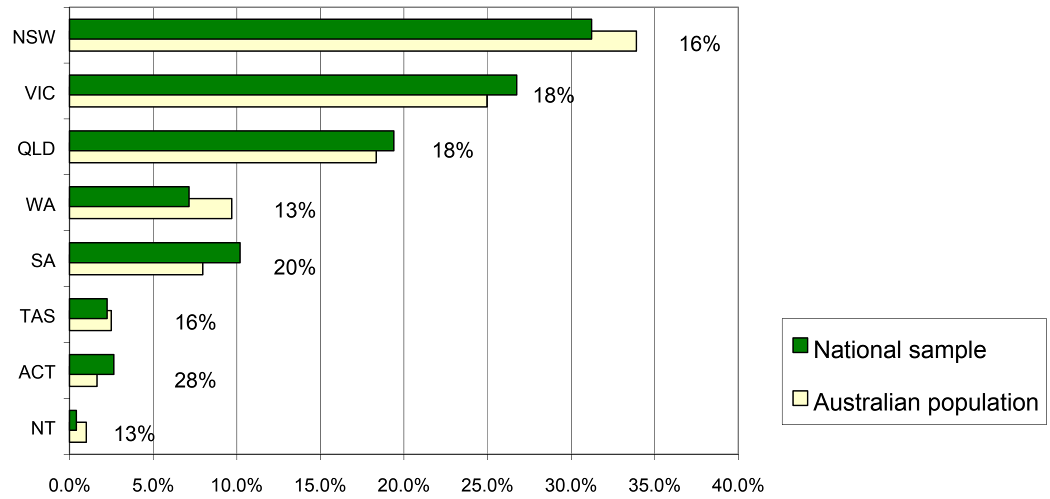


Figure 5.5: Proportional representation of respondents across the States compared to the 1998 distribution of the Australian population aged 18 years and over (ABS Catalogue 3201). Response rates for each State are shown by the labels alongside each bar.



While the national sample is not representative of the Australian population for a number of important socioeconomic characteristics, it does contain a satisfactory representation of respondents from each State. The proportion of respondents from each State is approximately equivalent to the geographic distribution of the Australian population, with the main exceptions being WA, NSW and the NT which are slightly under-represented (Figure 5.6). The poor response from WA and the NT (13 per cent) is partly responsible for the under-representation in these States.

The ratio of respondents from capital cities and non-metropolitan areas is approximately 2:1. This figure is higher than the ratio published by the Australian Bureau of Statistics (Catalogue 3222.0), which is 1.8:1. The proportion of non-Australian citizens in the sample is four per cent which is below the eight per cent of Australian residents who are estimated to be citizens of an overseas country (ABS, Catalogue 3412.0). These statistics suggest a sampling bias towards metropolitan residents and against the inclusion of people without Australian citizenship.

5.4 Preliminary assessment of willingness to pay

Of those respondents who completed all the choice questions, 20 per cent consistently selected the business as usual option in each choice set. The other 80 per cent of respondents chose at least one of the options that involved a levy. This proportion of respondents in favour of a levy exceeds the estimate obtained in a survey of Western Australian households conducted by Patterson Market Research in December 1999. A telephone poll of 400 households revealed that 55 per cent of respondents were willing to pay a levy dedicated to addressing this State's salinity problem. These conflicting results provide further evidence to suggest that the present study self-selected for pro-environment respondents.

Table 5.8 contains a detailed breakdown of those respondents who chose the business as usual option, by sample and questionnaire version. This analysis shows that the metropolitan sample issued with the national questionnaire contains the lowest proportion of respondents selecting the status quo (15 per cent), while the

Rockhampton sample issued with the same questionnaire has the highest proportion (24 per cent). The proportion of status quo responses by the non-metropolitan sub-sample lies in between these two extremes. The differences provide preliminary support for the hypothesis that values are variable across different population groups and questionnaire frames. This initial review of the data suggests that non-metropolitan respondents, particularly the Rockhampton sample, have lower values than their city-based counterparts.

However, there are numerous reasons why respondents may be unwilling to select a levy option. Some may have a genuine low value for the environment and country communities, while others could be trying to influence the results of the survey by protesting against a levy. Another possibility could be that respondents are distrustful of the government and have misgivings about the efficiency with which the funds will be spent. In order to investigate what factors were primarily responsible for people opting not to pay a levy, respondents who consistently selected the business as usual option were asked to tick off the most important reason influencing their choice. A summary of their responses is contained in Table 5.9.

The key findings of this analysis are:

- The dominant reason given for rejecting the environmental levy was that the levy was not affordable. Twenty to 30 per cent of respondents are in this category. A separate cross-tabulation reveals that most of the people in this category have incomes that are below the sample average. Consequently, it can be concluded that the zero bids given by these respondents are likely be "true" zeros rather than protests.

- Another reason given for selecting the status quo was opposition to the levy. This response is highest among Albany, Rockhampton and Brisbane respondents (20 to 30 per cent) but significantly lower opposition was recorded for National and Perth respondents (10-11per cent).

- Distrust of the government was ranked as a primary reason by 6 to 14 per cent of respondents. If these respondents are added to those who stated their opposition to the levy, then the Queensland samples contain the highest proportion of respondents with "protest" bids (approximately 35 per cent).

- Ten to 11 per cent of respondents believed that land and water resources were already well managed and cited this as their main reason for rejecting a levy.

Table 5.8: Proportion of respondents who selected the status quo option for all choice questions.

	Questionnaire version		
Sample	National	Fitzroy	Grt Southern
National			
Metropolitan	15%[a]	-	-
Non-metropolitan	22%	-	-
Capital city			
Perth	-	-	18%
Brisbane	-	22%	-
Regional			
Albany	23%	-	18%[b]
Rockhampton	24%	19%	-
	20%	18%	21%

[a] Significantly lower than the non-metropolitan sample at 5% probability level.
[a] Significantly lower than the Albany-National sample at 5% probability level.

Table 5.9: Nominated primary reason for selecting the business as usual option, by population sample. Values are the percentage of respondents who nominated the stated reason as their primary motivation.

	National	Albany	Perth	Rock'n	Brisbane
Land and water already well managed	9%	11%	3%	6%	0%
Cannot afford the levy	31%	30%	32%	25%	17%
Oppose the levy	10%	19%	11%	21%	29%
Distrust the government	14%	6%	14%	13%	6%
Did not know which option was best, so stuck with the status quo.	4%	8%	3%	0%	3%
Other reason	14%	16%	27%	25%	31%
No response or multiple reasons given.	17%	10%	11%	10%	14%
Total number selecting status quo	77	63	37	63	35

5.5 Model specification and parameter estimates

Specification

A nested structure was used to model respondents' choices of alternative options[9]. This structure assumes that respondents made an initial decision to either support an environmental levy or go with the status quo option (Figure 5.6). If the levy was

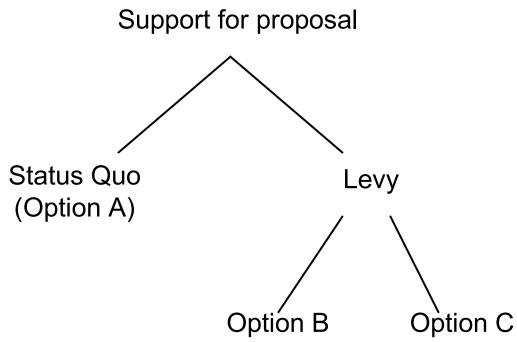
[9] Initially a multinomial logit model was used to describe the data relationships. However, this specification was shown to result in breaches of the Independence of Irrelevant Alternatives (IIA) assumption.

supported, then the respondent was faced with a second-level decision that involved the choice between two different levy options (B and C). This lower-level decision was "nested" below the initial decision. The two levels of the nest are linked by an "inclusive value" which embodies the expected utility associated with the lower-level decisions. The inclusive value is included as a variable in upper-level utility functions.

In this study the upper-level decision was hypothesised to be influenced by the respondent's socioeconomic characteristics (age, sex, income), environmental disposition, and whether or not the respondent was confused by the background information[10]. The probability of the levy being supported was expected to increase with income and pro-environment sentiment, but decrease for respondents who reported confusion. In addition to these individual-specific variables, the choice between retaining the status quo or paying a levy was assumed to be influenced by the expected utility (or inclusive value) associated with each alternative and a constant term for the levy alternative.

The lower level decision between the alternative levy options was hypothesised to be influenced by the attributes of each option. A technical summary of the model specification is contained in Box 5.1 and the variables are described in Table 5.10.

Figure 5.6: Diagram of the nesting structure adopted for the choice model



[10] Missing observations for respondent characteristics were replaced with modal values for the sample.

Box 5.1: Specification of the utility functions.

The upper level utility functions of the nested logit model were specified as follows:

V_{levy} = ASC + β_1Sex + β_2Age + β_3Income + β_4Green + β_5Confuse + α_1IV$_{levy}$

$V_{SQ} = \alpha_2 IV_{SQ}$

where V_{levy} is the utility associated with the levy options and V_{SQ} is the utility obtained from selecting the status quo option. The alternative specific constant (ASC) is specified for the levy option, and the socioeconomic characteristics are incorporated into the model as interactions with this ASC. The IV variables are inclusive values from the lower level of the nest. The coefficient on the inclusive value for the status quo option (α_2) is fixed to one because only one alternative exists in the lower level nest for this option.

The utility functions for each of the lower-level choice options are specified in terms of attributes. The utility for option *j* is given by:

V_j = β_6Species + β_7Look + β_8Water + β_9Social + β_{10}Cost

where *j* is option A (the status quo), B, or C.

Table 5.10: Description of variables used in the choice models.

Variable	Description
Species	Endangered species, measured by the number of species protected from extinction.
Look	Landscape aesthetics, measured by the area of farmland repaired and bush protected (hectares).
Water	Waterway health, measured by the total length of waterways restored for fishing or swimming (kilometres).
Social	Viability of country communities, measured by the net annual loss of population from country towns.
Cost	The environmental levy, measured as an annual levy on household income
ASC	Alternative specific constant for the levy option, assigned a value of 1 for options B and C and zero otherwise.
Sex	Respondent's gender, assigned a value of 0 for females and 1 for males.
Age	Respondent's age category, ranging from 1 to 6 (youngest to oldest).
Income	Respondent's before-tax household income category, ranging from 1 to 8 (lowest to highest).
Green	Dummy variable assigned a value of 1 for respondents who are members of, or donate to, an environmental organisation and 0 otherwise.
Confuse	Dummy variable assigned a value of 1 for respondents who reported that they found the background information confusing, 0 otherwise.
IV	Inclusive value representing the expected utility from alternatives in the lower level of the nest.

Parameter estimates

Seven nested logit models were estimated, each model being specific for a combination of questionnaire version and population sample. A summary of parameter estimates and their statistical significance is contained in Table 5.11. The models exhibit a satisfactory goodness of fit with Likelihood Ratio Indices (LRI) ranging between 0.17 and 0.26.

Parameter estimates for the attributes conform to *a priori* expectations. For the majority of models estimated, the environmental attributes (*Species*, *Look*, and *Water*) are statistically significant and have positive signs, which indicates that increases in the levels of these attributes add to an individual's utility. One exception to this conclusion is *Species* in the Fitzroy models, which is not significant in either of these models. This suggests that the protection of *Species* is not perceived to be a priority issue in the Fitzroy Basin.

The only other exception is *Water* in the Albany-National model. The results suggest that Albany respondents do not perceive this attribute to be important in the national context, although, at the local level, it is highly significant (Model 4). The signs on *Social* and *Cost* are significant and negative across all models, which means that utility is reduced by increases in the levy and higher levels of population loss from country areas.

The individual-specific socio-demographic variables (*Sex, Age, Income, Green*, and *Confuse*) are also significant in explaining respondent choices. The probability of choosing a levy option is shown, in most models, to increase with a respondent's income and pro-environmental disposition. This finding supports the validity of the models, as willingness to pay should be underpinned by an ability to pay. Perth was the only sample for which the choice of levy was independent of income.

Confuse is a significant variable in all but one of the models. Its negative sign agrees with the prior that respondents who were confused by the questionnaire were more inclined to choose the status quo option. *Age* and *Sex* are significant in some of the models but the effect of these variables on choice is not consistent. In several of the models age has a negative sign which implies that older respondents selected the status quo in preference to a levy.

Table 5.11: Parameter estimates for the nested logit choice models. Each model is specific for a population sample and questionnaire frame

Model	1	2	3	4	5	6	7
Frame	National	National	National	Great Southern	Fitzroy Basin	Great Southern	Fitzroy Basin
Population	National	Albany	Rockhampton	Albany	Rockhampton	Perth	Brisbane
Lower level choice variables							
SPECIES	5.49E-03 **	2.39E-03 *	2.89E-03 *	1.28E-02 **	4.07E-03	1.13E-02 **	1.72E-02
LOOK	6.01E-08 **	1.84E-07 **	2.04E-07 **	1.52E-06 **	8.07E-07 **	1.24E-06 **	1.11E-06 **
WATER	6.33E-05 **	4.55E-05	7.54E-05 **	1.29E-03 **	1.04E-03 **	8.05E-04 **	6.71E-04 **
SOCIAL	-6.94E-05 **	-9.46E-05 **	-6.74E-05 **	-4.52E-04 **	-1.15E-03 **	-6.34E-04 **	-8.78E-04 **
COST	-8.13E-03 **	-8.78E-03 **	-1.04E-02 **	-8.28E-03 **	-5.14E-03 **	-8.89E-03 **	-8.54E-03 **
Upper level choice variables							
ASC	-5.85E-01 **	-1.00E+00 **	2.40E+00 **	-2.02E+00 **	9.30E-01 **	2.54E+00 **	2.39E+00 **
SEX	-3.24E-01 **	5.01E-01 **	-5.96E-01 **	5.70E-01 **	-6.94E-01 **	-2.43E-01	-2.89E-01 *
AGE	7.96E-02 **	-1.22E-01 **	-3.50E-01 **	9.03E-02	-7.39E-02	-3.83E-01 **	-4.47E-01 **
INCOME	2.62E-01 **	2.13E-01 **	1.72E-01 **	3.48E-01 **	1.15E-01 **	-5.71E-03	9.65E-02 **
GREEN	2.47E-01 **	4.50E-01 **	6.49E-01 *	1.31E+00 **	2.02E-01	-1.39E-01	-3.22E-01
CONFUSE	-7.07E-01 **	-6.77E-01 **	-1.05E+00 **	-7.74E-01 **	-6.37E-01 **	-3.62E-01 *	
Inclusive values							
IV staus quo	1	1	1	1	1	1	1
IV levy	0.3434 **	0.3914 **	0.1950	0.2461 *	0.2262	0.3595 **	0.0618
No choice sets	2329	860	720	765	818	1046	823
Log Likelihood	-2196.05	-803.75	-645.29	-683.77	-802.10	-976.78	-761.39
LRI	0.2271	0.2155	0.2419	0.2698	0.1770	0.2337	0.2302
LRI adjusted	0.2251	0.2099	0.2355	0.2641	0.1709	0.2293	0.2251

Notes: * denotes significance of parameter at the 10% level, ** denotes significance at the 5% level.

Chapter 6: Value estimates from the national survey

6.1 Overview

The results reported in this chapter of the report relate to the national questionnaire in which respondents were asked to make choices between policy outcomes that have an impact at a national level. Two types of value estimates are provided: Implicit prices and welfare impacts (see Box 6.1 for details on how these estimates are calculated).

Attribute implicit prices are a measure of the willingness of respondents to trade-off household income to secure a single unit increase in a particular environmental or social attribute. Implicit price estimates are most useful when assessing the non-market impact of policies that have single-attribute outcomes. If a management policy is expected to affect the levels of multiple attributes, then an approximation of the benefit generated can be obtained by aggregating the implicit prices of all the attributes affected.

However in such circumstances, particularly when the changes in attributes are relatively large, more accurate estimates of changes in welfare can be achieved using the full choice model. This welfare measure is known as 'compensating surplus' and represents the total value of a change in the levels of multiple attributes away from the business as usual scenario. Use of the full choice model incorporates the impacts of the attributes, as well as the factors influencing choice that have not been defined in the choice sets. In other words, the implicit prices of the attributes alone do not account for the total welfare impact.

6.2 Attribute implicit prices

Implicit price estimates for each of the attributes are summarised in Table 6.1. The estimates are a measure of the amount that households are willing to pay each year for the next 20 years to secure an environmental or social improvement. Across both regional and national samples, respondents hold positive values for environmental attributes, whilst negative implicit prices are estimated for losses of people from country communities. This result implies that respondents perceive depopulation as a cost and are willing to trade-off income to prevent a loss in community viability.

For the national sample, respondent households are willing to pay, on average, 68 cents per annum over the next 20 years for every species that is protected from extinction. The value of *Landscape Aesthetics* is estimated to be 7 cents per 10,000 hectares of bushland protected or farmland restored, while a similar amount (8 cents) is estimated to be the value for every 10 kilometres of waterway restored. A negative implicit price of 9 cents is estimated for every 10 people leaving country communities.

The implicit price estimates assume non-diminishing values for additional improvements in attribute levels. While a non-linear relationship would be expected, at least beyond a certain level of improvement, transforming the data to allow for non-linearity did not improve the model fit. Therefore, it is concluded that implicit prices are constant for changes in the attributes over the range of levels used in the choice sets.

Box 6.1: Implicit prices and welfare calculation

The implicit price (IP) for an environmental or social attribute is equivalent to the marginal rate of substitution between the attribute and the levy. Thus, the implicit price for an attribute *i* is calculated as follows:

$$IP_i = \frac{\beta_i}{-\beta_{COST}}$$

The welfare impacts for a change in environmental and/or social outcomes are measured in in terms of compensating surplus (CS). For the nested logit models specified in this study, the calculation is as follows:

$$CS = \frac{V^1 - V^0}{-\beta_{COST}}$$

where V^0 is the utility associated with the status quo option, which is given by:

$V^0 = \alpha_2(\beta_6\text{Species} + \beta_7\text{Look} + \beta_8\text{Water} + \beta_9\text{Social})$

and V^1 is the utility associated with the change option, given by:

$V^1 = (\text{ASC} + \beta_1\text{Sex} + \beta_2\text{Age} + \beta_3\text{Income} + \beta_4\text{Green} + \beta_5\text{Confuse}) + \alpha_1(\beta_6\text{Species} + \beta_7\text{Look} + \beta_8\text{Water} + \beta_9\text{Social})$.

V^0 is calculated using base levels for the attributes, while V^1 is calculated using levels associated with the change scenario. Sample modes were used for the socio-economic variables (all of which are categorical).

The values held by respondents from regional areas are of a similar order of magnitude to those of people in the national sample, although some differences are evident. Differences that are statistically significant include:

- *Species Protection* is more highly valued by the national sample of households compared to the regional samples; and
- *Landscape Aesthetics* is more highly valued by regional respondents than the national sample.

Given that the majority of households in the national sample are from metropolitan city areas (68 per cent), these differences could indicate that city dwellers place a higher weighting on *Species Protection* (a non-use value) relative to country dwellers and a lower weighting on *Landscape Aesthetics*.

Table 6.1: Implicit prices estimated for attributes in the national context

	Species protection	Landscape Aesthetics	Waterway Health	Social Impact
	$ per species protected	$ per 10,000 ha restored	$ per 10 km restored	$ per 10 persons leaving
National sample				
Lower estimate	0.47	0.02	0.04	-0.11
Best estimate	0.68	0.07	0.08	-0.09
Upper estimate	0.88	0.14	0.16	-0.07
Albany sample				
Lower estimate	-0.03	0.14	0.00	-0.14
Best estimate	0.27	0.21	0.00A	-0.11
Upper estimate	0.51	0.29	0.00	-0.08
Rockhampton sample				
Lower estimate	0.03	0.12	0.01	-0.09
Best estimate	0.28	0.20	0.07	-0.06
Upper estimate	0.58	0.30	0.14	-0.08

A This attribute is 'not statistically significant' from zero

*Best estimate denotes the mean value while the upper and lower estimates represent the 95% confidence interval.

6.3: Welfare impacts from alternative scenarios

The choice model derived from the national sample of respondents was used to estimate the welfare impacts (compensating surpluses) of four alternative resource use scenarios. The impacts are measured relative to a fifth scenario; the 'business as usual' option. The four change scenarios are indicative of the twenty-year outcomes that could eventuate under alternative management regimes (Table 6.2). This analysis demonstrates how the choice model can be used to estimate the benefits of environmental and/or social improvements (benefits gross of the costs of implementing the changes). Results of the analysis are summarised in Table 6.3 and are described below.

Biodiversity protection scenario

This scenario describes the possible outcomes from policies designed to promote biodiversity protection. It is assumed that an additional 100 species would be protected relative to the business as usual outcome, together with an additional one million hectares of improved landscape aesthetics and 200 kilometres of waterway restoration. The annual value of this policy is estimated to range from $88 to $142 with a best estimate of $112 per annum for 20 years. Expressed as a lump sum present value, the best estimate is equivalent to a one off payment of $1,466 (assumes a 5 per cent discount rate).

Table 6.2: Four hypothetical scenarios developed to demonstrate ways that the choice model could be used to estimate the welfare impacts of changes away from the business as usual scenario

Attributes	Business as usual Scenario	Biodiversity Protection Scenario	Waterway Restoration Scenario	Negative social impacts scenario	Positive social impacts scenario
Species Protection (Number of species protected)	50	150	75	100	100
Landscape Aesthetics (Hectares of farmland repaired and bushland protected)	4 mill.	5 mill.	4.5 mill	6 mill	6 mill
Waterway health (Kilometres of waterways restored for swimming and fishing)	1,000	1,200	5,000	2,500	2,500
Social impact (No. of people leaving country areas per year.)	15,000	15,000	15,000	20,000	5,000

Waterway restoration scenario

This scenario involves policies that focus on restoring waterways. It is assumed that an additional 4,000 kilometres of waterways would be rehabilitated by 2020 relative to the business as usual scenario. More modest improvements are assumed for landscape amenity and species protection. Respondent households are estimated to be willing to pay $104 per year for 20 years for the outcomes of this policy, which equates to a lump sum present value of $1,361.

Negative social impacts scenario

This scenario involves improvements to all environmental attributes and does not target a particular environmental outcome. However, the policies used to achieve these environmental improvements are assumed to lead to an additional 5,000 people leaving country communities each year relative to the business as usual scenario. Such a scenario could be encountered if trade-offs exist between conservation objectives and regional development. The welfare impact of this scenario is estimated to be $92 per annum per respondent household, which equates to a lump sum present value of $1,204 per household.

Positive social impacts scenario

This scenario consists of a set of policies that deliver both environmental and social improvements relative to the business as usual scenario. It is assumed that the number of people leaving country areas is reduced by 10,000 per year so that only 5,000 rather than 15,000 people leave per year. Measured against the business as usual scenario, this is a gain of 10,000 people per year. This outcome could eventuate if conservation management policies were adopted that stimulated regional employment. Households would be willing to pay $136 per annum for 20 years for such an outcome, or $1,780 per household when expressed as a lump sum.

Table 6.3: Estimated welfare impacts per household for each of the four hypothetical scenarios *

	Biodiversity Protection Scenario	Waterway Restoration Scenario	Negative social impacts scenario	Positive social impacts scenario
Estimated annual welfare gain per household*				
Low estimate	$88	$77	$63	$114
Best estimate	$112	$104	$92	$136
Upper estimate	$142	$136	$128	$164
Estimated mean lump sum present value per household A				
Low estimate (@3%)	$1,348	$1,180	$965	$1,747
Best estimate (@3%)	$1,716	$1,594	$1,410	$2,084
Upper estimate (@3%)	$2,176	$2,084	$1,961	$2,513
Low estimate (@5%)	$1,152	$1,008	$824	$1,492
Best estimate (@5%)	$1,466	$1,361	$1,204	$1,780
Upper estimate (@5%)	$1,858	$1,780	$1,675	$2,146
Low estimate (@6%)	$1,070	$936	$766	$1,386
Best estimate (@6%)	$1,362	$1,264	$1,119	$1,654
Upper estimate (@6%)	$1,726	$1,654	$1,556	$1,994

* Estimates derived using a full choice model not the simple multiplication of attribute values

A Discount rates shown in parenthesis

6.4 Variability of values across different household groups

Socioeconomic characteristics

Welfare impacts are found to vary substantially over different segments of the Australian community. The 'negative social impacts' scenario is used as an example to demonstrate this variability. The analysis was undertaken by varying independently the level of each respondent characteristic in the choice model and recalculating the welfare impact. Table 6.4 contains a summary of estimated welfare impacts, categorised according to demographic and socioeconomic groupings.

The main findings are:

- Respondents with a pro-environment disposition are willing to pay $30 more per annum than other respondents (pro-environment respondents are defined as those who currently donate to, or are members of, an environmental organisation).

- Females have a significantly higher willingness to pay than males, the difference being in the order of $40 per annum. This finding is consistent with the results of a CM study undertaken in the ACT which estimated environmental values associated with water supply options (Centre for International Economics, 1997).

- Values increase with both age and income. For this particular sample of respondents, age is negatively correlated to income and education level, so a different factor must be influencing older respondents to have higher values. It is possible, for instance, that older respondents have a greater sense of social responsibility. The negative estimate for respondents in the lowest income category should be regarded as a zero value. It means that, on average, a respondent with this level of income has a low to zero value for the scenario.

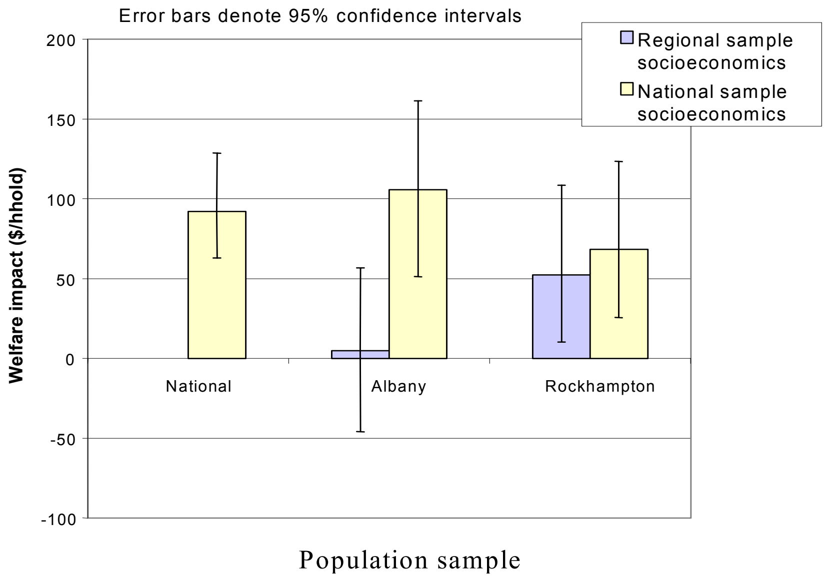
Table 6.4: Variability of welfare impacts across different socioeconomic groups, evaluated for the 'negative impacts' scenario.

Socioeconomic group	Annual welfare impact ($/household)	
	Mean	95% confidence interval
Environmental disposition		
pro-environment	122	83 – 168
not pro-environment	92	63 – 128
Age-group		
25-34	72	37 – 108
35-44	82	51 – 116
45-54	92	63 – 128
55-64	102	68 – 141
65 and over	112	75 – 156
Gender		
Male	92	63 – 128
Female	132	99 – 170
Household income		
6239-15,599	-5	-40 – 36
15,600-25,999	28	-2 – 66
26,000-36,399	60	32 – 95
36,400-51,999	92	63 – 128
52,000-77,999	124	94 – 162
78,000-103,999	156	123 – 196
more than 104,000	189	152 – 232

National versus regional

Statistical tests reveal that the welfare impacts of a resource use change are equivalent across respondents from the national and regional samples once socioeconomic differences are controlled for. This test was performed by estimating separate choice models for each sample (Albany, Rockhampton, and national), then substituting the mean age and income values for the national sample into the Albany and Rockhampton models. This substitution procedure effectively removes any inter-sample variation in welfare impacts that are due to age and income differences. Figure 6.1 shows that once socioeconomic differences are allowed for, there is no statistical difference between the welfare estimates calculated for each sample.

Figure 6.1: Annual welfare estimates from the negative impact scenario, evaluated for different population samples



State differences

Value estimates appear to be consistent for respondents from different States. The two States examined were Queensland and Western Australia (WA). These States were singled out because a survey by the Australian Bureau of Statistics (ABS) indicated that WA residents have a greater awareness of environmental problems than any of the other States, and Queenslanders have the lowest levels of awareness (ABS, Catalogue 4602, 1999). State differences were tested by specifying two dummy variables for 'place of residence'; one for West Australians and the other for Queenslanders. Neither dummy was significant in the choice model, which suggests that people from these states who responded to the survey have the same preference structure.

6.5 Aggregate welfare impacts of resource use change

The 'negative social impacts' scenario described above is used to illustrate the process of calculating the aggregate non-market impacts of land and water degradation in Australia. The aggregate impact of this scenario is estimated to be $3.9 billion in present value terms (5 per cent discount rate). This is an estimate of the community's maximum willingness to pay for the specified set of environmental improvements or, alternatively, the size of benefits foregone if these improvements are not undertaken. The estimate is calculated by extrapolating the per household estimate of $1204 (from Table 6.3) to 45 per cent of the Australian population of

7,185,540 households (ABS, 2000). It is not valid to simply aggregate the value estimates to the entire household population because only 17 per cent of households responded to the questionnaire. A conservative approach to aggregation is to assume that all non-respondents have zero values, thus limiting the extrapolation of benefits to just 17 per cent of the population. However, this would almost certainly be an underestimate of the true aggregate benefits.

The aggregation factor of 45 per cent is an estimate derived from a follow-up survey of 75 non-respondent households. This survey revealed that 37 per cent of people indicated an interest in the questionnaire but had been too busy to answer it. Another 32 per cent were interested in the topic but felt that the questions were inappropriate. Only seven per cent of the respondents replied that they had no interest in land and water degradation issues. On the basis of these results it appears reasonable to assume that at least 37 per cent of non-respondents hold non-zero values. If this proportion of non-respondents is added to the 17 per cent of households who responded, the aggregation factor is calculated to be 48 per cent of the total household population ([0.17+(1.00-0.17)*0.37] = 0.48.). A slightly more conservative figure of 45 per cent is adopted for this analysis as a best-bet measure. Table 6.5 summarises the aggregate welfare impacts for each of the four scenarios.

Table 6.5: Estimated aggregate welfare impacts for each of four hypothetical scenarios *

	Biodiversity Protection Scenario	Waterway Restoration Scenario	Negative social impacts scenario	Positive social impacts scenario
Estimated lump sum present values (billions)				
Low estimate (@3%)	$4.36	$3.81	$3.12	$5.65
Best estimate (@3%)	$5.55	$5.15	$4.56	$6.74
Upper estimate (@3%)	$7.04	$6.74	$6.34	$8.13
Low estimate (@5%)	$3.72	$3.26	$2.67	$4.82
Best estimate (@5%)	$4.74	$4.40	$3.89	$5.75
Upper estimate (@5%)	$6.01	$5.75	$5.42	$6.94
Low estimate (@6%)	$3.46	$3.03	$2.48	$4.48
Best estimate (@6%)	$4.40	$4.09	$3.62	$5.35
Upper estimate (@6%)	$5.58	$5.35	$5.03	$6.45

* Estimates derived using a full choice model not the simple multiplication of attribute values

[A] Discount rates shown in parentheses.

Chapter 7: Transferability of value estimates

7.1 Overview

This Chapter of the report presents results from the questionnaires that asked city and regional households to make choices between alternative options for resource use in each case-study region. The results demonstrate that implicit price estimates for environmental and social attributes are significantly higher when attributes are presented to respondents for valuation in a regional context as opposed to a national context. Furthermore, statistical tests indicate that there are significant differences between the case-study regions in terms of the values estimated for some attributes. These differences indicate that framing and population effects are influential in determining values. The results imply that care must be taken in transferring value estimates from one context to another.

In total, four benefit transfer tests (BT tests) were performed to gain an insight into how values change across different populations and frames of reference. This chapter provides a detailed description of each test, together with a summary of the main results.

7.2 Benefit transfer tests

BT Test 1: Transferability of estimates from a national to regional context

This test examines whether the implicit prices estimated for attributes in the national context are equivalent to values estimated for the same set of attributes in a regional context. The test also establishes the magnitude of differences, and hence the size of scaling adjustment that is required if the national set of implicit prices is to be transferred to a regional setting. The null and alternative hypotheses under investigation are:

$H_0: IP_n\ (NF,NP) = IP_n\ (RF_x,RP_x)$

$H_1: IP_n\ (NF,NP) \neq IP_n\ (RF_x,RP_x)$

where;

- IP_n is the implicit price for attribute n;
- NF,NP denotes the choice model based on the **national frame** and **national population** sample; and
- RF_xRP_x denotes the choice model based on the **regional frame** and **regional population** for case study *x*. The two regional frames and (populations) are Great Southern (Albany) and Fitzroy Basin (Rockhampton).

The implicit prices derived from each of the three models are plotted in Figure 7.1, together with a 95 per cent confidence interval for each estimate (denoted by the error bar). The confidence intervals were calculated using a technique developed by Krinsky and Robb (1986). Implicit price estimates are deemed to be equivalent if the confidence intervals for each estimate overlap. Using this test criteria, the null hypothesis is rejected for all attributes and it is concluded that implicit prices from the regional studies are significantly higher than those estimated for the national study (by a factor of 2 to 26 times, depending on the attribute in question). A number of factors could be responsible for the different value estimates because the case studies differ from the national study in terms of:

- the respondent's frame of reference for valuing attributes;
- the population sampled[11]; and
- the scope of changes being presented to respondents for valuation.

The results support the prior of regular embedding; that is, consumers place a lower value on attributes when framed in a wide, national context versus a narrow, local context. A scope effect could also be responsible for the value differences given that larger changes were presented to respondents in the national study. However, this test does not allow firm conclusions to be drawn about the predominant cause of the differences. BT test 2, the next test to be reported, serves to disentangle framing effects from population differences so that the influence framing can be assessed in isolation.

BT Test 2: The relative importance of framing

This test examines the equality of implicit price estimates derived from the national and regional versions of the questionnaire that were issued to separate samples of the same regional population. The objective of this test is to gauge the extent of the framing effect. This is made possible because the two samples for each case study test are drawn from the same population, so population effects are controlled for. The null and alternative hypotheses are:

$H_0: IP_n\ (NF, RP_x) = IP_n\ (RF_x, RP_x)$

$H_1: IP_n\ (NF, RP_x) \neq IP_n\ (RF_x, RP_x)$

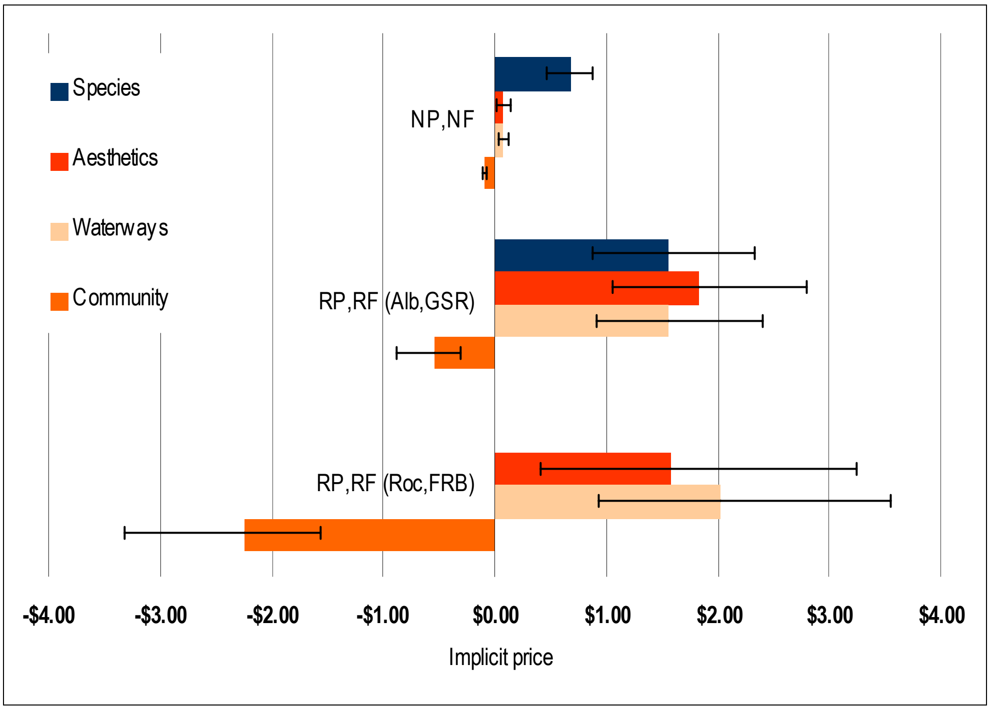
where;

- IP_n is the implicit price for attribute *n*;
- NF,RP_x denotes the choice model based on the **national frame** and **regional population** sample *x*, being respondents from either Albany or Rockhampton.
- RF_xRP_x denotes the choice model based on the **regional frame** and **regional population** for case study *x*.

Upon comparing the IP's from the national and regional frame, the null hypothesis is rejected for all attributes. It is concluded that respondents have significantly higher values when attributes are framed in a regional context (Figure 7.2). The scale of differences is similar to the findings from BT Test 1, which suggests that framing effects (due to scope or context differences) is the primary factor affecting the value estimates rather than population effects.

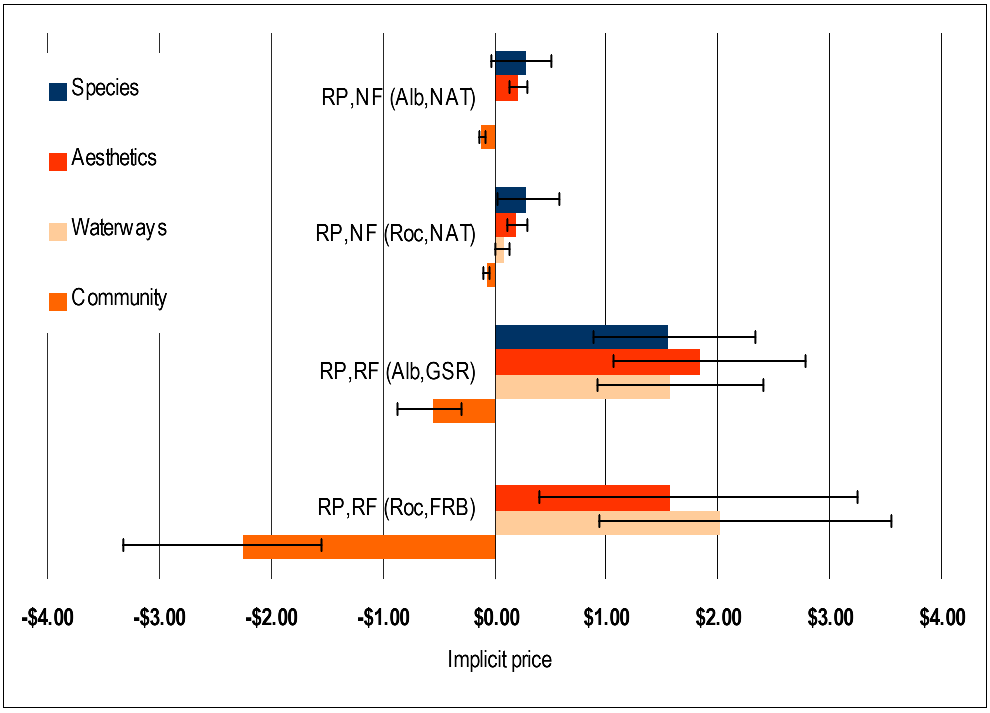
[11] Whilst some socio-economic and attitudinal characteristics of the different populations are 'controlled for' in the modelling process, a wide range of other population characteristics remain unexplained and exogenous to the model.

Figure 7.1: Attribute implicit prices examined under BT Test 1.



Note: Values for non-significant attributes are not plotted. Confidence intervals are shown by the error bars.

Figure 7.2: Attribute implicit prices examined under BT Test 2



Note: Values for non-significant attributes are not plotted. Confidence intervals are shown by the error bars.

BT Test 3: Consistency of values across case study regions

The objective of BT Test 3 is to determine whether attribute value estimates vary across case study regions. Whilst the same set of attributes are being evaluated in each case study, the frame in which these attributes are 'embedded' is substantially different. Furthermore, the characteristics of each case study population are likely to be different. Some of this variation in population characteristics is controlled for by the socioeconomic variables included in the utility functions but attitudinal differences remain unaccounted for. The test was performed for respondents from both city and regional populations. For example, the choice models estimated for the Fitzroy Basin using preference data from Rockhampton and Brisbane respondents were compared to the models estimated for the Great Southern using data from Albany and Perth respondents. The null and alternative hypotheses for each type of comparison are as follows:

<u>Regional respondents</u>

H_0: $IP_n (RF_A, RP_A) = IP_n (RF_B, RP_B)$

H_1: $IP_n (RF_A, RP_A) \neq IP_n (RF_B, RP_B)$

<u>Capital city respondents</u>

H_0: $IP_n (RF_A, CP_A) = IP_n (RF_B, CP_B)$

H_1: $IP_n (RF_A, CP_A) \neq IP_n (RF_B, CP_B)$

where;

- IP_n is the implicit price for attribute *n*;
- RF_A and RF_B denote the **regional frames** for case studies A and B (being the Great Southern and Fitzroy Basin;
- RP_A and RP_B denote the **regional populations** for case studies A and B;
- CP_A and CP_B denotes the **capital city populations** for case studies A and B.

The results indicate that value estimates for some attributes in the Fitzroy Basin and the Great Southern are significantly different. For example, respondent households from Rockhampton hold significantly higher values for social impacts in their local region relative to the values held by Perth and Albany respondents for social impacts in the Great Southern (Figure 7.3). Conversely, species protection is not valued in the Fitzroy region but it is a significant attribute in the Great Southern. These disparities demonstrate that the value estimates obtained in one region do not necessarily reflect community values in a different region, although there is a degree of consistency for some attributes.

BT Test 4: Consistency of values across city and regional respondents

The purpose of this test is to examine whether respondents living within a given case study region have different attribute values to people living outside the region in an adjacent capital city. Therefore, in this test the frame is fixed but the population is allowed to vary. The null and alternative hypotheses are:

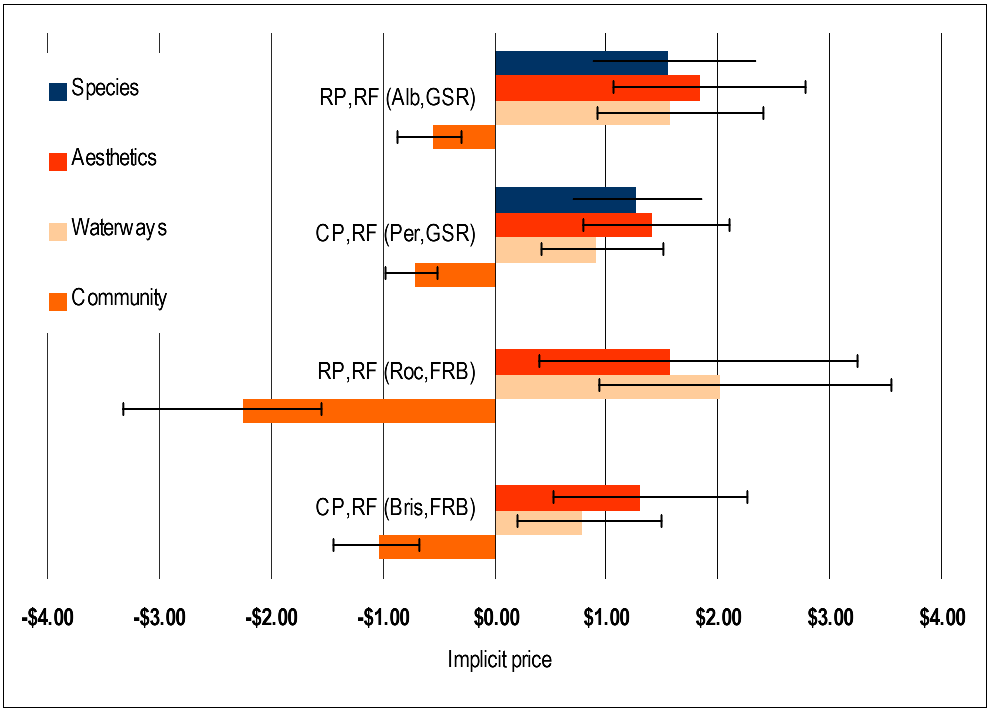
H_0: $IP_n\ (RF_x,RP_x) = IP_n\ (RF_x,CP_x)$

H_1: $IP_n\ (RF_x,RP_x) \neq IP_n\ (RF_x,CP_x)$

- IP_n is the implicit price for attribute *n*;
- RF_x,RP_x denotes the choice model based on the **regional frame** and **regional population** corresponding to case study *x*; and
- RF_xCP_x denotes the choice model based on the **regional frame** and **capital city population** corresponding to case study *x*.

The results indicate that, with the exception of the social attribute, implicit prices for the attributes are statistically equivalent for regional and city households (Figure 7.3). In the case of social impacts, regional households in the Fitzroy Basin study (ie Rockhampton) do have significantly higher values than households residing in Brisbane city. For the other attributes, the results imply that it is safe to aggregate IP estimates from respondents in regional areas to city populations *within the same state*. Importantly, there is no evidence of values declining with distance from either of the case study regions. Parochialism does not appear to have played a significant role in influencing values in the regional communities.

Figure 7.3: Attribute implicit prices examined under BT Tests 3 and 4.



Note: Values for non-significant attributes are not plotted. Confidence intervals are shown by the error bars.

7.3 Conclusions

The most notable result obtained from the benefit transfer testing is the impact that framing has on attribute values. The results show unequivocally that implicit price estimates sourced from the national study are lower than those derived from the regional case studies. One possible reason for the value differences is embedding. That is, respondents could be cognisant of a larger array of environmental issues in the national frame and, hence, associate smaller values to the attributes under investigation. Alternatively, a scope effect could be responsible, meaning that the small changes in attribute levels presented to respondents in the case study questionnaires are valued more highly at the margin than the large changes in the national study. Regardless of which factor is the dominant reason for the value differences, household value estimates from the national study should be scaled up if they are to be validly transferred to a regional policy context. Guidelines for undertaking this transfer are contained in Chapter 8.

Other key results from the case study analysis include:

- for both case studies, the geographic extent of the market for environmental values appears to extend beyond regional areas to include city populations. This finding holds for resource use changes in the local (state) context, but does not hold for changes in the national context where significant differences in values were estimated for city and rural populations;

- the values estimated for social impacts appear to be less amenable for transfer, at least in Queensland where regional respondents (from Rockhampton) have significantly higher values for social impacts than city respondents (from Brisbane);

- attribute values held by people in one region do not necessarily reflect community values in a different region (for the same set of attributes), although there is a degree of consistency for *Landscape Aesthetics* and *Waterway Health*.

Chapter 8: Benefit transfer guidelines

8.1 Overview

The attribute implicit prices estimated in this non-market valuation study are useful for making a 'first pass' assessment of the size of non-market values associated with policies that have particular environmental and social impacts. The estimates are suitable for establishing the impacts of management decisions that affect major regions or the nation as a whole, and that can be described using one or more of the generic attributes. That is, the estimates can be used wherever impacts can be described in terms of changes in;

- the number of species protected;
- the hectares of farmland repaired or bush protected;
- the kilometres of river restored for recreation; and
- the size of rural population.

The estimates are inappropriate for assessing impacts at the individual catchment level, or for valuing resource use changes that have very narrow and specific outcomes. Nor are the estimates suitable for determining the impact of policies that affect environmental assets that are considered to be national or regional 'icons', such as the protection of Koalas.

The guidelines in Section 8.2 demonstrate how the implicit price estimates can be used to evaluate the non-market impacts of different policies. In circumstances where a more detailed and accurate assessment is warranted, the choice models estimated for the national study and regional case-study regions can be used to evaluate the welfare impacts (compensating surplus) of alternative scenarios. This more comprehensive approach was used to evaluate the resource use scenarios in Chapter 7. Guidelines for applying this more comprehensive approach to estimating welfare impacts is given Section 8.3.

8.2 Implicit price transfer

Step 1: Defining the policy context

The first step is to determine whether the management policy is targeted at a particular region or whether it involves projects Australia-wide. If resource-use policies involve changes at a national level, then the set of attribute values estimated using the national sample of households is appropriate. For policies that are targeted at either of the two case study regions, it is recommended that the implicit prices estimated for these regions be used (see Appendix B for a complete tabulation of IP estimates). For regional assessments that do not correspond to one of the case study regions, it will be necessary to use the national estimates and calibrate the IP’s so that the values are appropriate for the region under investigation. A set of scaling factors for performing this calibration is given in Table 8.1. A range of scaling factors is given for each attribute to allow for a margin of variability between different regions and populations.

Table 8.1: Scaling factors for calibrating national value estimates to a regional context

Attribute	National Implicit prices ($)	Scaling Factors
Species Protection	0.68	x 2
Landscape Aesthetics	0.07	x 20-25
Waterway Health	0.08	x 20-25
Social impact	-0.09	x 6-26

Step 2: Defining the attribute changes

This step involves determining which attributes are impacted by the policy under investigation, and identifying the expected change in the attribute levels over a given time period relative to a 'business as usual' policy.

Step 3: Aggregating the attribute values

Each attribute change caused by a particular policy (defined in Step 2) is then multiplied by its scaled implicit price (defined in Step 1). These so-calculated attribute values are then summed to yield an approximation of the average annual per household benefit to be derived from the implementation of the proposed policy.

Step 4: Defining the target population

If the policy under investigation involves resource use changes at a national level, then the appropriate population for aggregating implicit prices is the population of Australian households. The impacts of changes implemented in particular regions should be restricted to the rural and city populations adjacent to the region in question. Extrapolation of values to other populations is speculative and not recommended.

Step 5: Aggregation

It is recommended that the annual household values be aggregated to 45 per cent of the target population. If the analysis calls for an estimate of the full impact of a resource use change over a number of years, the annual values will need to be consolidated to a lump sum present value. A discount rate of 3 to 5 per cent is recommended.

A regional policy assessment example

Consider the case of a proposal to redress land and water degradation in a region located in NSW. Under the proposal, 20,000 hectares of rural land will be rehabilitated, and 160 km of waterways will be restored. Analysis of the policy proposal by scientists indicates that the policy will ensure that three (3) additional species will be protected. Furthermore, it is predicted that 50 additional people per annum will leave the region because of the lower farming intensities the proposal involves.

As a regional project, the implicit prices to be used in the valuation exercise will be scaled from the national estimates. Using the lower bound scaling factors in Table 8.1, the best estimate implicit prices are:

- Species Protection = 0.68 * 2 = $1.36 per species;

- Landscape Aesthetics 0.07 * 20 = $1.40 per ten thousand hectares;
- Waterway Health = 0.08 * 20 = $1.60 per 10 kilometres;
- Social Impact = –0.09 * 6 = – $0.54 per 10 persons leaving each year

Given the changes in attribute levels specified, the best estimate of the community's annual willingness to pay for the scenario is:

(1.36 * 3) + (1.40 * 2) + (1.60 * 16) + (–0.54 * 5) = $29.78 per household

This estimate is the amount, on average, that a *household* is willing to pay *each year* for twenty years to see the project proposed implemented. To estimate an aggregate value it is necessary to multiply the household value by an estimate of the size of the relevant population. This process includes making an adjustment to the survey estimates, via an aggregation factor, to allow for non-respondents in the sample. The following assumptions are used in this example:

- the relevant population includes metropolitan Sydney and proximate areas of rural NSW, which amounts to four million persons;
- the number of people per household is 2.5;
- the aggregation factor is 45 per cent.

Based on these assumptions, the best estimate of annual value would be:

$29.78 * (4,000,000/2.5) * 0.45 = $21,441,600 per annum for 20 years.

Where it becomes clear that the magnitude of the value estimated using this procedure is critical in the assessment of a policy, a more detailed analysis may be required. That analysis in the first instance may involve a refinement of the scaling factors used. By gaining a better understanding of the characteristics of the population to be affected by the policy under consideration, it can be assessed if the situation is closer to the Fitzroy Basin or the Great Southern case studies. Further analysis may also involve the use of a complete choice model rather than the aggregation of attribute values. As a general rule, if the project is justified when lower bound estimates are used, one can be very confident in recommending the project be accepted. Conversely, if a project can be justified only if the best estimate is used, then more analysis is probably needed.

8.3 Choice model transfer

When the changes in attribute levels are relatively large, a more accurate estimate of changes in welfare can be obtained using the full choice model. This welfare measure is known as 'compensating surplus' and represents the total value of a change in the levels of multiple attributes away from the business as usual scenario. Use of the full choice model incorporates the impacts of the attributes, as well as the factors influencing choice that have not been defined in the choice sets.

If a comprehensive assessment of welfare impacts is sought for changes in resource use at a regional level, it is recommended that one of the case study models should be employed for benefit transfer. Tests show that both of the regional models - estimated with data from the corresponding regional population (ie Albany or Rockhampton) - produce the same welfare estimates for a standard change scenario.

However, the Great Southern model yields estimates with a smaller error variability. Furthermore, all attributes in this model are statistically significant, while the insignificance of *Species* in the Fitzroy model is problematic. For these reasons, the Great Southern model is the preferred model for benefit transfer.

The following checklist provides a guide to the procedure that should be followed when transferring the Great Southern model to a different region:

- ❑ Determine whether the set of attributes employed in this study adequately describe the issues in the target region and the policy outcomes that are under investigation.

- ❑ Ensure that the ranges for the attribute levels in the target region are within the ranges used in the Great Southern questionnaire. Extrapolation outside these ranges will introduce transfer error.

- ❑ Specify levels for the attributes that are appropriate for the region and the scenarios of interest. A business as usual scenario should be established as a benchmark against which to compare alternative management strategies.

- ❑ Identify the target population for transfer. Ensure that the target population has attitudes and characteristics that are fundamentally similar to those used in the case study. It is recommended that the target population reside within the same state as the region under investigation. That is, the Great Southern model can be transferred to regions in other states, but the value estimates should only be aggregated to that state's own population. Extrapolation of benefits to other States is speculative. An exception may be the situation where the target region straddles the border of two adjoining states.

- ❑ Determine the mean socioeconomic characteristics of the target population. Two important characteristics include household annual income (before tax) and age. Substitute these mean values into the Great Southern model. The estimated parameters for this model are provided in Table 5.11.

- ❑ Refer to Chapter 6 for technical details on how to calculate estimates of welfare change for a specific scenario relative to the status quo (see Box 6.1). For the Great Southern model, the error variability associated with these estimates is plus 85% and minus 64% of the mean value.

- ❑ Aggregate the resultant household welfare estimates to 45 per cent of the target household population. The target population should be restricted to the rural and city populations adjacent to the region in question. Extrapolation of values to other populations is speculative and not recommended.

- ❑ If the analysis calls for an estimate of the full impact of a resource use change over a number of years, the annual values will need to be consolidated to a lump sum present value. A discount rate of 3 to 5 per cent is recommended.

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Appendix A: Script for the focus group discussions

1. Framing of environmental issues in the wider context.

- What do you think some of the issues are that are being faced by Australian society? What issues are of most concern to you? Please take a moment to write them down on your pad.

- Out of the list on the board, how would you rank the issues in terms of their importance? What ranking would you give to the environment?

2. Awareness of environmental issues

- What are the first things that come to mind when we talk about environmental problems in Australia? I will give you a moment to list your ideas down on your pad. Take your time.

- How would you rank these concerns in order of their relative importance? That is, what are the most pressing environmental problems in Australia?

- In what ways do you think that your concerns about environmental issues are influenced by what you see in your own local area and state, as opposed to other regions of Australia?

- Over the last 10 years do you think the overall quality of the environment in Australia has declined, improved or stayed much the same?

3. Land and water degradation: Attribute definition.

Tonight I want to focus specifically on issues relating to land and water quality in Australia. Obviously the health of land and water is important for food production and the supply of fresh drinking water. But I want you to think about the other ways in which the environment is important to you.

- What specific factors or aspects of the environment do you think are important?

- What factors of the environment would you like to see kept protected/preserved for your children's children?

- Suppose the government was to make additional funds available for addressing environmental problems. What evidence would convince you that the money was being well targeted and successful at improving environmental quality?4.

4. Responsibility and funding mechanisms

- If Australia's environmental problems are to be adequately addressed, more money will need to be raised. How do you think environmental programs should be funded?

- In reality, how do you expect environmental programs will be funded into the future?

- If you were asked to support a proposal to increase the amount of public money spent on the environment, what information would you like to know before you made your decision?

Appendix B: Attribute implicit prices

Implicit prices for attributes, estimated for different combinations of population and (frame)

Frame	National	National	National	Great Sthn	Great Sthn	Fitzroy	Fitzroy
Population	National	Albany	Rockhampton	Albany	Perth	Rockhampton	Brisbane
SPECIES	$ per species protected						
mean	$0.68	$0.27	$0.28	$1.55	$1.27	NS	NS
plus	$0.20	$0.24	$0.30	$0.78	$0.58		
minus	$0.21	$0.30	$0.25	$0.67	$0.57		
LOOK	$ per 10,000 ha of land restored						
mean	$0.07	$0.21	$0.20	$1.84	$1.40	$1.57	$1.30
plus	$0.07	$0.08	$0.10	$0.95	$0.70	$1.68	$0.98
minus	$0.05	$0.07	$0.08	$0.78	$0.60	$1.16	$0.76
WATER	$ per 10km of waterways restored						
mean	$0.08	NS	$0.07	$1.56	$0.91	$2.02	$0.79
plus	$0.05		$0.07	$0.84	$0.61	$1.53	$0.70
minus	$0.04		$0.06	$0.64	$0.49	$1.08	$0.58
SOCIAL	$ per 10 persons migrating from rural areas						
mean	-$0.09	-$0.11	-$0.06	-$0.55	-$0.71	-$2.24	-$1.03
plus	$0.02	$0.03	$0.02	$0.25	$0.20	$0.69	$0.36
minus	$0.02	$0.03	$0.03	$0.33	$0.26	$1.08	$0.42

Notes: NS denotes attribute not statistically significant in the choice model.

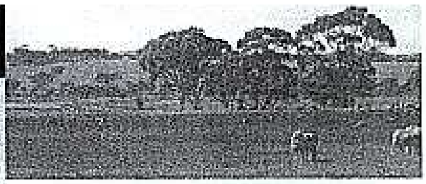
Appendix C: Background information accompanying the national survey

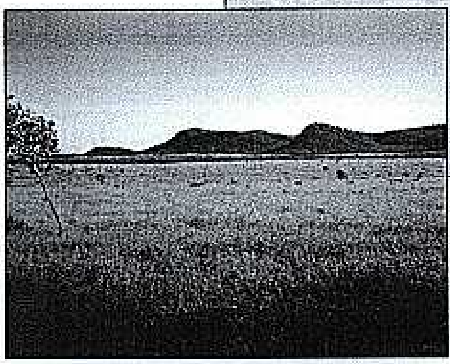
READ THIS BOOKLET FIRST

OPTIONS FOR MANAGING LAND AND WATER DEGRADATION

in Australia

Introduction to the survey





CSIRO

Unisearch

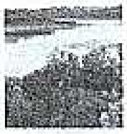
National Land & Water Resources Audit

A program of the Natural Heritage Trust

1

What is this survey about?

This survey seeks your views on land and water degradation in Australia. We would like to know how you feel about the effects of degradation on the environment and on the prosperity of country communities. Your answers will help governments to develop better ways of managing land and water in Australia.



2

What is land and water degradation?

Since European settlement about 70% of Australia's original bushland has been cleared to grow crops and graze animals. This has made it possible to produce food and fibre but, as a side-effect, the environment has become degraded in some places. In parts of the countryside soils have eroded or become salty. Certain types of bushland are endangered. Almost a third of Australia's major waterways have become polluted or no longer flow freely. Natural wetlands are at risk from development pressures and salinity.

How does degradation affect us?

Land and water degradation affects us in many ways. It makes it harder to grow food and fibre, and to obtain fresh drinking water. This could lead to higher prices for these goods.

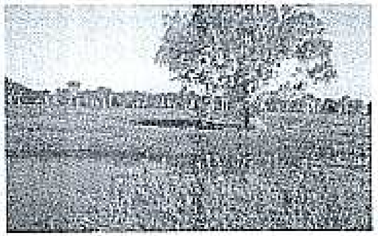
Country communities are also affected because the livelihoods of farmers, and the businesses that service farmers, are dependent on the quality of land and water. Some badly degraded regions now support fewer people.

In addition, a number of species of plants and animals have become extinct. Parts of the countryside do not look as attractive as they once were because of dying trees, erosion, and salt. Some areas are no longer as enjoyable for outdoor recreation such as swimming and fishing.

What is being done?

Governments, farmers, and community groups are working on these problems. For instance, your taxes are being used to plant trees, control feral animals, fence off native bush on farms, and to educate people on how to care for the land.

Programs such as Landcare and Bushcare have made a start towards protecting our land and water. They have raised awareness about the environment and brought together farmers, businesses, and governments to work on the problems. The success of these programs can be seen in the millions of trees that have been planted and the greater use of farming methods that reduce erosion.



5

Is enough being done?

While progress is being made towards improving the way land and water is managed in Australia, challenges remain. More could be done to reduce land and water degradation. In this survey we would like to know whether you think more should be done.

To help you think about this, we have summarised what is likely to happen to a number of key environmental factors over the next 20 years if no extra work is done. This information comes from well respected scientific organisations, including the CSIRO and Environment Australia

You can find out more about the issues in this survey by reading:

- *"Australia State of the Environment, 1996" published by CSIRO. Available from http://www.erin.gov.au/*
- *CSIRO website (http://www.csiro.au/).*
- *"Regional Population Growth" Australian Bureau of Statistics Catalogue No. 3218*

6

What is happening in the bush?

Endangered native species

The natural habitat of native plants and animals has been altered greatly by humans. As a result, about 560 species are now endangered. The amount of money being spent on the environment should safeguard about 50 of these species from becoming extinct over the next 20 years. The remainder will continue to be threatened if no further action is taken.

Look of the land

About **12 million** hectares of farmland is either degraded or contains native bush that is not protected from grazing or clearing. Work is being done to make this land more attractive by repairing eroded land and protecting native bush. With the current amount of money being spent, about **4 million** hectares of this land will be repaired and protected over the next 20 years. Without extra action, the remaining area will continue to degrade.

Waterway health

About **15,000 kilometres** of waterways are no longer clean enough for swimming or fishing. These rivers, lakes and estuaries have either become polluted, salty, or no longer flow freely. If the amount of money currently being spent on waterway management continues, about 1000 **kilometres** of waterways are expected to be restored to a condition good enough for swimming and fishing by 2020. If no further action is taken the remainder will continue to degrade.

7 What further actions could be taken?

A wide range of possible actions could be taken to reduce land and water degradation and improve the environment. Some examples are:

- Compensation could be paid to farmers who agree to set aside conservation reserves on their land.
- Technology could be developed to reduce the impacts of degradation on the environment.
- Farmland that contains important natural areas could be purchased by government and set aside for conservation.
- Water could be purchased from irrigators and put back into rivers in order to increase their flow.

But...

further actions to improve the environment could affect the prosperity of country communities. Also, extra money would be needed to pay for the new projects.

8 Country communities and extra funding

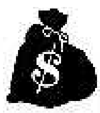
Country Communities

At the moment small country towns across Australia are experiencing a net loss of about **8000** people every year. For a variety of reasons, people are leaving these towns for bigger urban centres. In 20 years time the number of people leaving is expected to increase to about **15,000** each year.

Some types of environmental projects could add to the number of people leaving country areas. This would happen if more farmland is set aside for conservation and taken out of production.

Other types of projects that do not involve taking land out of production could reduce this drift of people to urban areas. For example, healthier land and water would enable more people to be supported in country areas.

Extra funding



More could be done to improve the environment but extra money would be needed. Government could use taxes it already collects to pay for additional environmental projects but this would mean less money for roads, hospitals, schools, and other public services. One possible alternative could be for all households and businesses to pay a **yearly environmental levy** as part of their income tax.

9

Features of the levy

- All revenue would go into a special trust fund only to be used for projects that reduce land and water degradation.
- The fund would be managed by a committee of well-respected scientists and community leaders who are independent of government.
- An internationally recognised body would make sure that the money is being properly spent.
- Laws would be passed to make sure that the trust fund does not replace money that is already spent by government on the environment.

10

What do you think?

We would like to know what you think about paying extra tax for projects that improve the environment. To do this, we ask you to consider eleven different options that we have called **Options A to K.**

Option A is a continuation of the current situation with no levy and no new environmental projects. All the other options involve a levy that would be used to pay for additional environmental projects. **Different options involve different types of projects.**

We would like you to choose the options that you like most by looking at the levy **amount** and the **effects** that the projects are expected to have on the environment and country communities over the next 20 years.

11

What are the effects?

The four effects to think about when making your choice of option are...

- **The number of species protected.**
- **The area of farmland repaired and bush protected.**
- **The length of waterways restored for fishing or swimming.**
- **The number of people leaving country towns every year for bigger urban centres.**

The effects on food production and drinking water are intentionally not listed because a separate study is looking at these issues.

To make things easier we ask you to consider only three options at a time over a series of five separate questions. In each question we would like you to choose the one option that you prefer most.

When answering these questions, please keep in mind all the other ways you could spend your money. You may want to also support other causes, including environmental or social problems overseas, or other issues here in Australia.

12

Now please go to the questionnaire.

Appendix J Summary of economic data by drainage basin and State/Territory

Economic data was compiled on returns to the natural resource base, opportunities associated with soil treatment and offsite infrastructure damage costs. The tables that follow present this data by river basin and State/Territory. Table J.1 lists all the fields that appear in the data summary and their corresponding measurement units. Table J.2 contains all the economic data by river basin and State.

Table J.1. Field descriptions.

Heading	Description / Units
Context:	
State/Territory	State/Territory name
Basin name	Basin name
Basin number	Unique basin identifier
Total area	hectares
Non-agricultural area	hectares
Agricultural area	hectares
Irrigated agricultural area in 1996/97	hectares
Dryland agricultural area in 1996/97	hectares
Revenue, Costs, Profits and Economic Returns:	
1996/97 Gross revenue	$000 per year - 1996/97 dollars
1996/97 Variable costs	$000 per year - 1996/97 dollars
1996/97 Fixed costs	$000 per year - 1996/97 dollars
1996/97 Profit at full equity	$000 per year - 1996/97 dollars
1996/97 Government Support	$000 per year - 1996/97 dollars
1996/97 Economic returns	$000 per year - 1996/97 dollars
5yr (1992/93 – 1996/97) Gross revenue	$000 per year - 1996/97 dollars
5yr (1992/93 – 1996/97) Total costs	$000 per year - 1996/97 dollars
5yr (1992/93 – 1996/97) Profit at full equity	$000 per year - 1996/97 dollars
Irrigated agriculture 5yr profit at full equity	$000 per year - 1996/97 dollars
Dryland agriculture 5yr profit at full equity	$000 per year - 1996/97 dollars
Minimum area of basin needed to produce 80% of profit at full equity within basin[12]	hectares
Ranking of basin in order of contribution to national profit at full equity (#)	Rank
Soil constraints and opportunities:	
Area where lime application, on its own, is the most profitable soil treatment option[13]	hectares
Area where gypsum application, on its own, is the most profitable soil treatment option[13]	hectares
Area where combined lime/gypsum application is the most profitable soil treatment option[13]	hectares
Area where dryland salinity caused yield loss in 2000	hectares

12 This has not been calculated where the entire river basin has negative profit at full equity in 1996/97. In cases where river basins cross multiple States/Territories the areas for basin-fragments can be summed to obtain an estimate for the entire basin.

13 Net present values determined from a benefit cost analysis of soil treatments run in perpetuity using a private landholder discount rate of 10%. This was modelled using a 1km grid. For each 1km by 1km grid cell four soil treatments are possible: do nothing; apply lime; apply gypsum; or apply lime and gypsum together.

Heading	Description / Units
Area where dryland salinity is expected to cause yield loss in 2020	hectares
Maximum gross benefit[14] from ameliorating acidic soils	$000 per year - 1996/97 dollars
Maximum gross benefit[14] from ameliorating sodic soils	$000 per year - 1996/97 dollars
Maximum gross benefit[14] from ameliorating saline soils	$000 per year - 1996/97 dollars
Limiting factor[15] gross benefit	$000 per year - 1996/97 dollars
Impact cost[16] of dryland salinity to agriculture from 2000 to 2020	$000 per year - 1996/97 dollars
Present value[17] of dryland salinity impact cost to agriculture from 2000 to 2020	$000 - 1996/97 dollars
Net present value of lime application in areas where lime application is profitable[18]	$000 - 1996/97 dollars
Net present value of gypsum application in areas where gypsum application is profitable[18]	$000 - 1996/97 dollars
Net present value of lime and gypsum application in areas where combined lime/gypsum application is profitable[18]	$000 - 1996/97 dollars
Local infrastructure cost impacts:	
Local infrastructure cost of salinity and water table rise 2000	$000 per year - 1996/97 dollars
Local infrastructure cost of salinity and water table rise 2020	$000 per year - 1996/97 dollars
Present value[17] of local infrastructure costs from salinity & rising water tables from 2000 to 2020	$000 - 1996/97 dollars
Present value of downstream infrastructure cost impacts:[19]	
• 1% increase in salt loads	$000 - 1996/97 dollars
• 5% increase in salt loads	$000 - 1996/97 dollars
• 10% increase in salt loads	$000 - 1996/97 dollars
• 1% increase in turbidity	$000 - 1996/97 dollars
• 5% increase in turbidity	$000 - 1996/97 dollars
• 10% increase in turbidity	$000 - 1996/97 dollars
• 1% increase in sediment loads	$000 - 1996/97 dollars
• 5% increase in sediment loads	$000 - 1996/97 dollars
• 10% increase in sediment loads	$000 - 1996/97 dollars

14 The gross benefit is the increase in profit at full equity attainable if the soil constraint were removed without cost. It provides an approximate investment ceiling for addressing a soil constraint.

15 For each grid cell, the limiting factor gross benefit is determined from the minimum relative yield of sodicity, acidity and salinity. As such it is not equal to the sum of gross benefits associated with each soil constraint. It is the total gross benefit attainable if all soil constraints were treated without cost. It is an approximation of an investment ceiling on combined treatment of sodic, acidic and saline soils.

16 Impact cost is the expected decline in profit at full equity due to increasing extent and severity of dryland salinity over time.

17 Determined using a discount rate of 5%.

18 Net present values determined from a benefit cost analysis of soil treatments run in perpetuity using a private landholder discount rate of 10%. This was modelled using a 1km grid. For each 1km by 1km grid cell four soil treatments are possible: do nothing; apply lime; apply gypsum; or apply lime and gypsum together. The net present value is summed only for areas where the given soil treatment option performs better than all other soil treatment options.

19 Present values of downstream costs are determined from assumed national increases in river/stream salinity, turbidity and sediment loads. A 5% discount rate is used over a period of 20 years, 2000 to 2020.

Table J.2 Economic data by river basin and State/Territory (field descriptions given above)

Basin name	Basin number	State	Total area	Non-agricultural area	Agricultural area	Irrigated agricultural area in 1996/97	Dryland agricultural area in 1996/97	1996/97 Gross revenue	1996/97 Variable costs	1996/97 Fixed costs	1996/97 Profit at full equity	Minimum area of basin needed to produce 80% of profit at full equity within basin	Ranking of basin in order of contribution to national profit at full equity (#)	1996/97 Government Support
Adelaide River	817	NT	746,769	283,526	463,243	120	463,123	1,859	463	358	1,038	306,708	150	84
Albany Coast	602	WA	1,961,437	624,496	1,336,941	508	1,336,432	206,975	60,706	97,609	48,660	214,599	32	11,408
Archer River	922	QLD	1,383,880	779,860	604,021		604,021	4,126	1,644	2,638	-156		186	775
Arthur River	312	TAS	249,796	239,822	9,974	466	9,507	4,569	1,603	2,829	137	280	169	647
Ashburton River	706	WA	7,567,167	2,583,070	4,984,098		4,984,098	4,065	2,647	3,330	-1,912		229	165
Avoca River	408	VIC	1,420,274	125,682	1,294,592	46,287	1,248,305	367,283	111,947	149,566	105,770	148,440	20	34,008
Avon River	615	WA	11,771,386	3,618,754	8,152,633		8,152,633	1,171,465	421,204	376,328	373,933	2,289,735	2	55,851
Baffle Creek	134	QLD	413,336	211,875	201,460	1,459	200,001	33,752	13,822	12,135	7,794	8,084	103	2,653
Barkly	29	NT	12,400,363	2,966,063	9,434,300		9,434,300	31,574	8,838	7,292	15,444	5,379,087	77	1,421
Barron River	110	QLD	214,679	113,264	101,414	2,708	98,706	40,384	13,724	8,437	18,224	10,944	69	5,494
Barwon River	233	VIC	381,527	64,458	317,069	3,213	313,856	95,854	34,377	55,540	5,937	2,630	111	10,616
Bathurst And Melville Islands	816	NT	748,202	748,202										
Bega River	219	NSW	283,809	183,669	100,139	7,447	92,692	84,036	23,883	26,575	33,577	30,607	48	17,629
Bellinger River	205	NSW	346,954	238,562	108,392	5,748	102,644	71,453	32,099	27,824	11,530	8,305	92	9,341
Benanee	413	NSW	2,136,359	394,224	1,742,135	5,827	1,736,308	93,625	23,673	23,432	46,521	3,886	34	5,070
Black River	117	QLD	114,361	58,832	55,529	1,864	53,665	12,766	6,572	3,349	2,844	1,514	131	693
Blackwood River	609	WA	2,257,563	427,977	1,829,586	2,150	1,827,435	371,515	111,110	128,494	131,912	734,734	16	21,861
Blyth River	824	NT	923,331	923,331										
Border Rivers	416	NSW	2,450,100	539,560	1,910,541	55,793	1,854,747	650,407	288,433	168,593	193,381	129,050	7	23,989
Border Rivers	416	QLD	2,353,680	728,375	1,625,305	27,574	1,597,730	412,854	135,179	99,314	178,361	109,783	11	18,725
Boyne River	133	QLD	250,953	172,779	78,174		78,174	6,460	1,240	2,599	2,621	6,649	132	396
Brisbane River	143	QLD	1,357,934	508,151	849,783	36,890	812,893	454,147	151,118	120,315	182,714	97,553	10	55,521
Broken River	404	VIC	709,505	133,877	575,628	108,314	467,313	507,172	187,667	152,373	167,132	52,723	12	68,279
Broughton River	507	SA	1,639,875	112,525	1,527,350	1,540	1,525,810	423,269	121,493	111,075	190,700	518,851	8	21,941
Brunswick River	202	NSW	51,552	17,041	34,511	4,341	30,170	51,567	23,156	16,800	11,610	4,450	91	2,997
Buckingham River	826	NT	958,503	958,503										
Bulloo River	11	NSW	2,047,591	219,399	1,828,192		1,828,192	6,641	1,084	8,481	-2,924		239	260
Bulloo River	11	QLD	5,507,137	361,168	5,145,970		5,145,970	23,002	3,846	28,182	-9,027		250	974
Bunyip River	228	VIC	407,605	134,721	272,884	10,306	262,578	249,090	106,570	89,180	53,340	4,856	29	28,034

Basin name	Basin number	State	Total area	Non-agricultural area	Agricultural area	Irrigated agricultural area in 1996/97	Dryland agricultural area in 1996/97	1996/97 Gross revenue	1996/97 Variable costs	1996/97 Fixed costs	1996/97 Profit at full equity	Minimum area of basin needed to produce 80% of profit at full equity within basin	Ranking of basin in order of contribution to national profit at full equity (#)	1996/97 Government Support
Burdekin River	120	QLD	13,012,363	992,250	12,020,113	15,632	12,004,481	252,008	121,483	194,002	-63,476		261	14,400
Burnett River	136	QLD	3,331,833	1,113,309	2,218,525	34,710	2,183,815	328,833	138,410	112,503	77,920	62,007	24	33,573
Burrum River	137	QLD	335,595	222,579	113,015	23,578	89,437	96,972	61,758	19,461	15,753	2,348	76	5,310
Burt	27	NT	3,879,707	1,332,179	2,547,528		2,547,528	2,753	1,840	1,969	-1,056		213	124
Busselton Coast	610	WA	308,386	119,456	188,930	2,468	186,462	116,748	32,634	28,666	55,448	38,351	28	18,417
Calliope River	132	QLD	220,600	89,542	131,058		131,058	8,545	2,773	4,942	831	1,016	157	1,001
Calvert River	909	NT	1,004,329	149,673	854,657		854,657	445	572	661	-787		208	20
Campaspe River	406	VIC	405,815	55,020	350,796	32,269	318,526	144,409	58,693	71,435	14,280	12,566	82	22,549
Cape Leveque Coast	801	WA	2,296,610	933,969	1,362,641		1,362,641	1,878	1,128	1,053	-304		190	84
Castlereagh River	420	NSW	1,742,367	164,165	1,578,201	528	1,577,673	243,943	77,914	114,776	51,253	97,558	30	13,587
Clarence River	204	NSW	2,227,981	1,429,927	798,053	4,947	793,106	168,729	60,475	79,646	28,607	34,072	52	14,777
Clyde River-Jervis Bay	216	ACT	6,167	6,167										
Clyde River-Jervis Bay	216	NSW	322,023	293,175	28,848	808	28,040	24,016	6,980	8,150	8,885	9,595	101	5,080
Coal River	303	TAS	68,172	22,239	45,933	1,092	44,841	11,897	2,941	7,403	1,552	364	143	663
Coleman River	920	QLD	1,291,731	458,169	833,562	119	833,443	1,146	820	2,381	-2,055		230	43
Collie River	612	WA	373,212	246,963	126,249	3,205	123,044	57,116	12,001	12,803	32,313	25,523	49	9,583
Condamine-Culgoa Rivers	422	NSW	2,604,164	88,363	2,515,802	2,043	2,513,758	80,798	34,810	69,108	-23,120	47,010	257	3,467
Condamine-Culgoa Rivers	422	QLD	13,654,203	2,107,936	11,546,267	72,637	11,473,630	1,364,339	431,311	420,569	512,458	215,754	1	88,411
Cooper Creek	3	NSW	67,797	67,365	432		432	2	0	2	-1		177	0
Cooper Creek	3	QLD	24,384,108	1,169,250	23,214,858	113	23,214,745	149,928	20,710	165,786	-36,569		260	6,359
Cooper Creek	3	SA	5,302,824	2,327,317	2,975,507		2,975,507	2,018	2,018	8,790	-8,789		249	91
Curtis Island	131	NSW	106		106		106							
Curtis Island	131	QLD	57,532	46,341	11,190		11,190	118	133	350	-365		193	5
Daintree River	108	QLD	191,157	168,558	22,599		22,599	12,042	7,926	2,033	2,082	4,023	137	634
Daly River	814	NT	5,320,643	1,953,347	3,367,296		3,367,296	12,633	3,284	2,603	6,746	2,288,722	108	568
Darling River	425	NSW	11,283,322	676,032	10,607,290	9,063	10,598,227	121,831	40,216	71,037	10,578	614	94	5,110
De Grey River	710	WA	5,673,293	1,361,789	4,311,504		4,311,504	4,412	3,322	3,348	-2,259		233	198
Denmark River	603	WA	262,295	90,747	171,548	609	170,940	33,991	8,734	19,673	5,584	22,767	115	1,827
Derwent River	304	TAS	983,016	660,715	322,302	9,405	312,897	49,887	10,932	43,652	-4,698		244	3,627
Diamantina River	2	QLD	11,912,660	1,087,105	10,825,555		10,825,555	38,945	8,044	56,855	-25,954		258	1,643
Diamantina River	2	SA	3,832,821	572,973	3,259,848		3,259,848	1,795	2,175	9,630	-10,010		251	81

Basin name	Basin number	State	Total area	Non-agricultural area	Agricultural area	Irrigated agricultural area in 1996/97	Dryland agricultural area in 1996/97	1996/97 Gross revenue	1996/97 Variable costs	1996/97 Fixed costs	1996/97 Profit at full equity	Minimum area of basin needed to produce 80% of profit at full equity within basin	Ranking of basin in order of contribution to national profit at full equity (#)	1996/97 Government Support
Don River	121	QLD	357,181	56,640	300,541	3,475	297,066	51,340	15,980	14,563	20,797	1,853	61	2,933
Donnelly River	608	WA	172,862	145,264	27,597	716	26,882	16,839	6,764	4,591	5,484	6,948	117	1,379
Drysdale River	807	WA	2,598,361	1,583,853	1,014,507		1,014,507	1,334	830	784	-281		188	60
Ducie River	926	QLD	680,650	471,545	209,106		209,106	265	167	594	-496		196	12
East Alligator River	821	NT	1,587,130	1,583,164	3,966		3,966	19	4	3	11	2,764	173	1
East Coast	302	TAS	697,848	498,712	199,136	1,752	197,384	37,155	9,873	29,152	-1,870		227	2,742
East Gippsland	221	NSW	114,844	111,693	3,151	99	3,053	1,203	322	451	429	321	164	226
East Gippsland	221	VIC	450,483	443,022	7,461	687	6,774	4,565	1,958	2,129	478	760	163	737
Embley River	924	QLD	469,077	243,293	225,784		225,784	412	290	651	-530		199	18
Endeavour River	107	QLD	207,532	113,740	93,791		93,791	5,548	1,942	1,746	1,860	2,970	140	1,195
Esperance Coast	601	WA	2,015,064	761,167	1,253,896		1,253,896	175,397	52,314	76,566	46,518	295,828	35	8,070
Eyre Peninsula	512	SA	320,531	123,988	196,543		196,543	22,062	6,415	7,906	7,742	29,756	104	1,006
Finke River	5	NT	4,374,942	983,453	3,391,489		3,391,489	3,205	2,406	2,622	-1,823		225	144
Finke River	5	SA	5,634,078	1,319,969	4,314,109		4,314,109	3,335	2,961	12,744	-12,370		252	150
Finniss River	815	NT	950,147	600,838	349,309	601	348,708	10,137	2,124	1,570	6,444	92,288	110	383
Fitzmaurice River	812	NT	1,036,549	629,400	407,148		407,148	1,599	404	315	880	289,401	156	72
Fitzroy River (Qld)	130	QLD	14,266,397	3,025,844	11,240,553	31,690	11,208,863	732,939	268,496	386,624	77,820	13,970	25	41,385
Fitzroy River (Wa)	802	WA	9,384,478	1,301,894	8,082,585		8,082,585	11,614	6,765	6,248	-1,399		221	523
Fleurieu Peninsula	501	SA	98,707	16,093	82,614	1,409	81,204	47,424	12,329	14,638	20,456	19,829	63	8,742
Flinders River	915	QLD	10,970,824	481,586	10,489,238		10,489,238	68,056	14,320	67,790	-14,054		254	3,049
Flinders-Cape Barren Islands	301	TAS	200,379	125,510	74,869		74,869	9,452	1,226	11,003	-2,778		238	388
Fortescue River	708	WA	4,977,698	1,884,580	3,093,119		3,093,119	2,966	2,252	2,348	-1,634		224	132
Forth River	315	TAS	113,707	88,816	24,891	1,859	23,032	16,742	5,125	7,267	4,350	466	122	1,463
Frankland River	605	WA	464,596	84,892	379,704	305	379,399	60,591	13,928	31,365	15,298	87,914	78	2,688
Fraser Island	139	QLD	168,612	168,612										
Gairdner	21	SA	19,788,422	6,662,884	13,125,538	103	13,125,435	266,613	113,761	117,075	35,777	130,946	47	12,366
Gascoyne River	704	WA	7,583,294	396,274	7,187,020	112	7,186,908	8,396	4,821	5,174	-1,600		223	318
Gawler River	505	SA	457,650	33,456	424,194	9,063	415,132	202,365	51,771	61,377	89,217	112,181	22	13,469
Georgina River	1	NT	9,967,809	1,042,949	8,924,860		8,924,860	15,770	7,027	6,899	1,845	23,865	141	710
Georgina River	1	QLD	14,423,009	890,037	13,532,972		13,532,972	54,828	11,345	44,056	-574	36,187	204	2,448
Georgina River	1	SA	395,311	159,528	235,783		235,783	117	156	697	-735	630	207	5

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Gilbert River	917	QLD	4,630,188	398,117	4,232,071		4,232,071	22,619	5,908	29,759	-13,048		253	1,455
Glenelg River	238	SA	16,197	11,517	4,679	391	4,289	3,043	1,139	960	944	1,856	153	335
Glenelg River	238	VIC	1,196,142	342,003	854,139	2,446	851,693	169,215	36,993	104,892	27,329	338,725	53	9,150
Goomadeer River	822	NT	568,195	568,195										
Gordon River	308	TAS	591,648	591,648										
Goulburn River	405	VIC	1,685,502	619,278	1,066,224	118,564	947,659	605,172	243,692	217,730	143,750	25,420	15	74,565
Goyder River	825	NT	1,038,136	1,038,136										
Greenough River	701	WA	2,505,024	188,432	2,316,591		2,316,591	219,139	88,843	85,560	44,735	282,250	40	11,001
Groote Eylandt	929	NT	237,370	237,370										
Gwydir River	418	NSW	2,659,640	427,917	2,231,724	80,142	2,151,581	900,608	402,139	202,579	295,890	71,882	6	31,100
Harvey River	613	WA	203,221	90,628	112,594	6,634	105,959	65,361	14,592	13,937	36,832	18,766	46	11,081
Hastings River	207	NSW	452,239	332,728	119,511	2,424	117,086	63,103	19,119	25,067	18,917	20,324	65	12,468
Haughton River	119	QLD	435,940	135,706	300,234	30,771	269,463	117,326	82,354	18,103	16,869	20,903	73	6,044
Hawkesbury River	212	NSW	2,196,447	1,383,488	812,959	11,893	801,066	204,410	68,902	117,775	17,732	1,030	70	31,449
Hay River	7	NT	6,266,412	3,443,338	2,823,074		2,823,074	3,760	2,106	2,182	-529		198	169
Hay River	7	QLD	283,772	283,772										
Hay River	7	SA	3,429,687	3,259,543	170,144		170,144	91	113	503	-525		197	4
Herbert River	116	QLD	984,798	378,231	606,567	2,924	603,643	191,967	109,922	35,531	46,513	65,407	36	17,780
Hinchinbrook Island	115	QLD	39,658	39,658										
Holroyd River	921	QLD	1,020,877	199,947	820,929		820,929	1,166	712	2,352	-1,898		228	56
Hopkins River	236	VIC	1,009,399	50,584	958,815	3,217	955,598	304,501	100,998	161,045	42,458	275,025	43	36,581
Hunter River	210	NSW	2,143,286	801,991	1,341,295	34,731	1,306,564	331,752	107,470	176,347	47,935	30,148	33	48,122
Huon River	306	TAS	301,024	256,063	44,960	3,350	41,611	113,473	80,718	18,054	14,701	2,173	79	6,641
Isdell River	804	WA	2,001,596	1,279,425	722,171		722,171	1,359	653	558	148	317,421	168	61
Jacky Jacky Creek	101	QLD	294,900	150,659	144,242		144,242	189	116	410	-337		191	8
Jardine River	927	QLD	329,503	326,720	2,783		2,783	0	2	8	-9		178	0
Jeannie River	106	QLD	394,622	236,891	157,731		157,731	7,866	2,766	2,542	2,559	4,046	133	1,692
Johnstone River	112	QLD	232,238	139,299	92,938	4,934	88,004	171,714	101,744	32,716	37,253	32,556	45	15,158
Kangaroo Island	513	SA	443,245	182,872	260,372		260,372	40,353	5,294	30,113	4,947	42,434	120	1,734
Karuah River	209	NSW	437,984	297,823	140,161	942	139,218	32,228	10,344	17,708	4,176	5,431	124	6,015
Keep River	810	NT	594,223	138,766	455,457		455,457	1,832	553	355	924	142,347	155	82

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Keep River	810	WA	590,925	177,215	413,710		413,710	549	339	320	-110		183	25
Kent River	604	WA	249,780	113,623	136,157	101	136,055	23,224	5,534	13,926	3,764	10,380	125	1,507
Kiewa River	402	VIC	190,748	109,051	81,696	1,494	80,203	37,861	15,665	18,778	3,419	16,240	126	6,183
King Edward River	806	WA	1,762,443	945,362	817,081		817,081	29,328	9,332	5,955	14,041	16,440	83	6,245
King Island	313	TAS	109,158	22,901	86,257	95	86,162	25,225	4,308	19,431	1,486	4,179	145	2,483
King-Henty Rivers	309	TAS	178,706	177,511	1,195	92	1,103	170	20	244	-94		182	8
Kingston Coast	305	TAS	76,400	47,481	28,919	272	28,647	2,987	990	5,208	-3,211		241	392
Kolan River	135	QLD	290,992	133,716	157,276	17,245	140,031	63,585	43,839	14,054	5,691	4,369	113	3,525
Koolatong River	901	NT	791,603	791,603										
Lachlan River	412	NSW	9,089,181	777,150	8,312,031	84,474	8,227,557	997,172	369,390	499,471	128,311	259,492	17	50,348
Lake Bancannia	12	NSW	2,328,905	182,007	2,146,898		2,146,898	8,414	1,228	10,213	-3,026		240	326
Lake Corangamite	234	VIC	407,996	65,865	342,132	3,698	338,434	128,323	47,201	66,458	14,664	100,601	80	18,260
Lake Frome	4	NSW	1,943,931	169,406	1,774,525		1,774,525	7,266	987	8,586	-2,307		234	279
Lake Frome	4	QLD	15,239	108	15,131		15,131	60	13	43	4		175	3
Lake Frome	4	SA	18,210,776	2,684,710	15,526,066		15,526,066	37,101	15,589	52,641	-31,129		259	1,638
Lake George	411	NSW	94,055	29,723	64,332		64,332	5,157	1,086	6,323	-2,252		232	210
Lake Torrens	510	SA	2,623,980	664,472	1,959,507		1,959,507	4,346	1,262	3,289	-205		187	173
Latrobe River	226	VIC	467,132	236,445	230,687	11,869	218,818	154,606	63,258	70,218	21,131	44,605	60	25,144
Leichhardt River	913	QLD	3,329,033	184,295	3,144,737		3,144,737	17,452	3,342	8,977	5,132	531,995	119	812
Lennard River	803	WA	1,475,646	276,553	1,199,093		1,199,093	2,141	1,067	927	148	320,481	167	96
Limmen Bight River	905	NT	1,593,358	205,238	1,388,120		1,388,120	733	930	1,073	-1,270		219	33
Liverpool River	823	NT	895,730	895,730										
Lockhart River	103	QLD	286,716	258,446	28,270		28,270	1,965	687	607	671	1,079	159	425
Loddon River	407	VIC	1,564,051	244,384	1,319,667	211,907	1,107,760	555,554	211,521	249,157	94,876	99,041	21	79,803
Logan-Albert Rivers	145	QLD	414,221	129,171	285,050	7,955	277,095	107,186	35,855	26,592	44,739	38,211	39	19,007
Lower Murray River	426	NSW	895,080	89,175	805,905		805,905	4,889	1,677	4,278	-1,065	4,699	214	205
Lower Murray River	426	SA	4,933,879	1,101,378	3,832,501	42,190	3,790,311	755,596	217,775	241,451	296,370	22,346	5	70,950
Lyndon-Minilya Rivers	705	WA	5,272,644	565,443	4,707,201	225	4,706,976	10,744	3,880	3,703	3,161	1,191,463	129	446
Mackay	26	NT	21,556,782	16,064,767	5,492,016		5,492,016	7,833	4,147	4,245	-559		203	352
Mackay	26	SA	443,439	443,439										
Mackay	26	WA	18,304,138	15,542,221	2,761,918		2,761,918	3,128	2,185	2,135	-1,192		217	141

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Macleay River	206	NSW	1,139,094	537,827	601,267	742	600,525	96,437	18,201	58,631	19,605	144,882	64	7,576
Macquarie-Bogan Rivers	421	NSW	7,480,182	485,631	6,994,551	62,800	6,931,751	1,074,145	421,159	462,359	190,628	38,105	9	50,574
Macquarie-Tuggerah Lakes	211	NSW	157,793	120,447	37,346	310	37,035	10,689	3,353	5,463	1,873		139	1,629
Mallee	414	SA	1,996,221	114,894	1,881,326	21,001	1,860,325	482,903	160,703	170,152	152,048	14,103	14	31,933
Mallee	414	VIC	2,151,842	1,364,500	787,342	18,238	769,104	327,028	92,332	110,547	124,150	5,902	18	19,120
Mambray Coast	508	SA	593,875	83,273	510,602		510,602	10,723	2,982	6,566	1,174	6,209	148	484
Manning River	208	NSW	817,645	499,937	317,708	4,616	313,092	108,243	33,327	49,823	25,094	32,326	56	20,481
Maribyrnong River	230	VIC	144,735	36,395	108,340	295	108,045	11,954	3,721	13,817	-5,585		246	769
Maroochy River	141	QLD	160,439	92,963	67,476	5,731	61,745	107,126	47,547	30,929	28,650	7,499	51	6,309
Mary River (Qld)	138	QLD	941,977	518,641	423,336	14,631	408,705	195,322	74,697	50,990	69,635	52,097	26	27,476
Mary River (Wa)	818	NT	807,347	337,893	469,454		469,454	1,834	465	363	1,007	325,993	151	83
Mcarthur River	907	NT	2,002,612	246,028	1,756,584		1,756,584	1,535	1,234	1,357	-1,056		212	69
Mersey River	316	TAS	197,001	127,148	69,853	11,709	58,144	106,386	45,276	36,636	24,474	7,998	58	11,262
Millicent Coast	239	SA	2,696,181	493,799	2,202,382	55,848	2,146,534	504,501	116,058	304,076	84,367	48,914	23	38,029
Millicent Coast	239	VIC	741,698	177,700	563,998	3,059	560,939	104,692	25,219	66,981	12,492	12,526	89	5,643
Mitchell River (Qld)	919	QLD	7,153,857	591,743	6,562,114	9,797	6,552,317	104,726	55,127	54,917	-5,318		245	12,773
Mitchell River (Vic)	224	VIC	487,699	414,266	73,433	2,542	70,892	29,453	9,127	14,473	5,854	2,151	112	2,366
Moonie River	417	NSW	41,956		41,956	647	41,309	4,077	2,177	2,713	-813	3,849	209	160
Moonie River	417	QLD	1,391,410	272,928	1,118,482	2,176	1,116,306	110,910	29,893	37,411	43,606	102,610	42	4,891
Moorabool River	232	VIC	223,272	47,191	176,081	1,760	174,322	40,672	13,020	26,336	1,316	293	147	2,720
Moore-Hill Rivers	617	WA	2,452,084	516,853	1,935,231	1,374	1,933,857	233,907	76,290	118,534	39,082	158,849	44	11,174
Morning Inlet	914	QLD	361,289	75,930	285,359		285,359	807	291	811	-295		189	36
Mornington Island	911	QLD	123,148	18,054	105,094		105,094	27	68	297	-338		192	1
Moruya River	217	NSW	148,250	129,494	18,756		18,756	7,904	2,326	3,159	2,418	2,905	135	1,542
Mossman River	109	QLD	53,740	38,975	14,765		14,765	5,891	3,686	1,068	1,136	2,008	149	388
Moyle River	813	NT	708,989	708,750	239		239	1	0	0	1	239	176	0
Mulgrave-Russell Rivers	111	QLD	200,235	157,031	43,204	1,295	41,910	70,484	45,556	11,006	13,922	20,833	84	4,618
Murchison River	702	WA	9,125,164	862,416	8,262,748		8,262,748	42,561	18,334	32,772	-8,545		248	1,952
Murray River (Qld)	114	QLD	121,406	89,309	32,098	586	31,512	12,160	8,654	2,783	723		158	495
Murray River (Wa)	614	WA	994,736	376,472	618,264	1,253	617,011	121,343	29,697	47,537	44,108	165,039	41	9,371
Murray-Riverina	409	NSW	1,504,147	122,267	1,381,880	214,593	1,167,287	506,700	226,110	162,753	117,837	82,226	19	61,512

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Murrumbidgee River	410	ACT	235,985	203,337	32,648		32,648	4,460	720	3,136	604	1,216	160	280
Murrumbidgee River	410	NSW	7,926,983	1,082,666	6,844,317	313,318	6,530,998	1,605,301	666,390	571,492	367,419	254,947	3	85,967
Myponga River	502	SA	15,122	806	14,316	504	13,812	12,242	3,031	3,589	5,623	4,033	114	2,087
Namoi River	419	NSW	4,199,623	752,710	3,446,913	99,170	3,347,743	1,000,539	410,005	267,089	323,444	151,391	4	43,139
Nicholson River	912	NT	1,575,426	946,343	629,083		629,083	2,429	620	486	1,323		146	109
Nicholson River	912	QLD	3,588,300	645,008	2,943,292		2,943,292	9,285	2,754	8,362	-1,831		226	418
Ninghan	619	WA	2,058,241	910,452	1,147,789		1,147,789	27,636	10,292	15,146	2,197	11,838	136	1,252
Noosa River	140	QLD	195,917	169,011	26,906	1,549	25,357	21,063	8,525	5,919	6,619	5,312	109	2,302
Norman River	916	QLD	5,002,747	171,779	4,830,968		4,830,968	15,151	4,854	31,254	-20,957		256	682
Normanby River	105	QLD	2,430,992	733,783	1,697,209		1,697,209	6,429	3,203	5,800	-2,574		236	782
Nullarbor	22	SA	5,334,235	5,023,487	310,747		310,747							
Nullarbor	22	WA	13,739,410	7,844,743	5,894,668		5,894,668	3,682	2,327	3,508	-2,152		231	141
O'Connell River	124	QLD	238,764	118,086	120,679	7,601	113,078	80,534	52,611	11,704	16,219	26,954	74	4,448
Olive-Pascoe Rivers	102	QLD	419,402	175,985	243,416		243,416	3,252	1,200	1,485	567	963	161	654
Onkaparinga River	503	SA	92,245	23,775	68,470	10,715	57,755	143,728	54,509	42,871	46,348	8,995	37	12,593
Onslow Coast	707	WA	1,782,510	600,183	1,182,328		1,182,328	1,009	772	866	-628		206	43
Ord River	809	NT	1,125,896	4,142	1,121,754		1,121,754	3,798	1,055	867	1,875	683	138	171
Ord River	809	WA	4,423,256	1,645,605	2,777,651	5,575	2,772,076	40,361	12,796	8,984	18,580	1,690	66	2,811
Otway Coast	235	VIC	388,764	179,336	209,428	3,193	206,235	163,753	70,424	75,911	17,418	130,001	71	32,459
Ovens River	403	VIC	797,588	434,102	363,486	8,851	354,636	101,116	31,509	59,509	10,098	5,370	95	10,765
Paroo River	424	NSW	4,052,256	292,621	3,759,635	10,054	3,749,582	51,350	19,253	19,024	13,073	1,443	88	1,601
Paroo River	424	QLD	3,340,946	207,146	3,133,799		3,133,799	21,046	2,344	22,969	-4,267	1,203	243	849
Pentecost River	808	WA	2,914,577	1,212,963	1,701,614		1,701,614	1,806	1,328	1,315	-837		211	81
Pieman River	310	TAS	415,925	410,922	5,003		5,003	507	79	1,009	-581		205	22
Pine River	142	QLD	148,496	83,063	65,432	1,427	64,006	51,606	19,986	17,753	13,867	14,165	85	8,570
Pioneer River	125	QLD	157,129	97,691	59,438	14,375	45,063	83,503	56,695	13,341	13,468	23,116	86	5,873
Piper-Ringarooma Rivers	319	TAS	355,940	217,059	138,882	7,922	130,960	68,631	22,058	36,676	9,897	5,873	98	9,005
Plane Creek	126	QLD	256,001	105,586	150,414	25,731	124,683	156,275	107,264	22,603	26,408	46,054	54	8,766
Port Hedland Coast	709	WA	3,539,323	1,590,057	1,949,266		1,949,266	1,862	1,276	1,418	-832		210	79
Portland Coast	237	VIC	396,773	68,681	328,092	3,894	324,198	129,010	41,623	62,700	24,686	138,771	57	17,429
Preston River	611	WA	113,957	54,806	59,151	2,371	56,780	38,785	13,522	7,908	17,355	6,084	72	4,233

Basin name	Basin number	State	Total area	Non-agricultural area	Agricultural area	Irrigated agricultural area in 1996/97	Dryland agricultural area in 1996/97	1996/97 Gross revenue	1996/97 Variable costs	1996/97 Fixed costs	1996/97 Profit at full equity	Minimum area of basin needed to produce 80% of profit at full equity within basin	Ranking of basin in order of contribution to national profit at full equity (#)	1996/97 Government Support
Prince Regent River	805	WA	1,540,100	1,424,638	115,462		115,462	222	105	89	28	46,045	172	10
Proserpine River	122	QLD	258,497	124,854	133,643	9,246	124,397	51,106	34,855	8,116	8,135	14,444	102	2,741
Richmond River	203	NSW	702,470	310,165	392,304	16,761	375,543	233,183	88,877	86,651	57,656	37,677	27	20,260
Robinson River	908	NT	1,136,765	83,751	1,053,013		1,053,013	439	694	814	-1,069		215	20
Roper River	903	NT	7,962,037	3,012,277	4,949,760		4,949,760	11,156	4,125	3,826	3,205	1,680,562	128	502
Rosie River	906	NT	504,535	95,297	409,238		409,238	151	268	316	-433		195	7
Ross River	118	QLD	139,396	60,931	78,466	349	78,117	5,156	2,598	2,220	339	465	165	693
Rubicon River	317	TAS	67,438	37,592	29,846	4,465	25,381	49,316	14,282	16,607	18,427	2,328	67	3,725
Salt Lake	24	WA	49,483,520	25,620,848	23,862,672		23,862,672	79,380	29,280	46,995	3,106	13,087	130	3,584
Sandy Cape Coast	311	TAS	87,537	86,140	1,397		1,397	591	167	372	52	186	171	101
Sandy Desert	25	WA	40,434,012	37,490,882	2,943,130		2,943,130	2,842	2,149	2,218	-1,526		222	127
Settlement Creek	910	NT	549,355	17,300	532,055		532,055	225	351	411	-537		200	10
Settlement Creek	910	QLD	1,181,569	87,876	1,093,693		1,093,693	4,452	1,373	3,194	-115		184	256
Shannon River	606	WA	330,053	294,455	35,598	611	34,987	19,715	6,798	5,316	7,601	5,386	105	1,812
Shoalhaven River	215	NSW	720,531	414,638	305,893	1,522	304,371	69,713	19,210	40,558	9,946	10,059	97	11,532
Shoalwater Creek	128	QLD	387,548	215,167	172,380	455	171,925	8,282	3,418	6,047	-1,183		216	816
Smithton-Burnie Coast	314	TAS	466,010	243,842	222,168	15,215	206,954	214,867	76,046	88,162	50,659	45,742	31	31,569
Snowy River	222	NSW	893,897	407,938	485,959	199	485,760	41,438	8,217	50,341	-17,120		255	1,729
Snowy River	222	VIC	684,519	601,341	83,178	981	82,197	24,666	9,204	15,546	-84		181	3,639
South Alligator River	820	NT	1,192,143	1,188,903	3,240		3,240	16	4	3	10	2,520	174	1
South Coast	146	QLD	135,140	85,210	49,930	218	49,712	41,518	15,885	9,817	15,817	17,324	75	7,630
South Gippsland	227	VIC	679,783	230,919	448,864	8,627	440,237	276,308	105,808	124,523	45,977	267,164	38	46,027
South-West Coast	307	TAS	549,831	542,447	7,384	720	6,663	14,328	10,285	2,521	1,523	271	144	824
Spencer Gulf	511	SA	1,089,517	151,194	938,323		938,323	72,052	26,311	22,332	23,408	109,605	59	3,315
Staaten River	918	QLD	2,583,804	516,743	2,067,061		2,067,061	6,406	2,117	11,316	-7,026		247	288
Stewart River	104	QLD	269,669	104,782	164,887		164,887	5,814	2,064	2,002	1,748	2,869	142	1,242
Stradbroke Island	144	QLD	49,526	40,881	8,645		8,645	252	103	264	-115		185	11
Styx River	127	QLD	307,479	67,499	239,980	114	239,866	10,025	4,686	7,980	-2,642		237	496
Swan Coast	616	WA	823,321	432,629	390,692	4,204	386,488	72,560	27,317	45,269	-25		179	4,265
Sydney Coast-Georges River	213	NSW	173,502	149,924	23,577	613	22,964	7,755	2,756	4,046	953	511	152	1,445
Tamar River	318	TAS	1,133,001	611,692	521,309	12,289	509,020	131,749	43,470	87,791	488		162	10,124

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Tambo River	223	VIC	420,117	330,811	89,306	782	88,523	21,648	5,932	13,293	2,423	11,584	134	1,907
Thomson River	225	VIC	657,902	470,703	187,200	25,148	162,051	118,465	47,198	50,509	20,758	78,260	62	21,373
Todd River	6	NT	5,963,150	1,749,470	4,213,680		4,213,680	5,133	3,098	3,257	-1,222		218	231
Torrens River	504	SA	113,402	63,780	49,622	2,738	46,884	53,535	25,351	13,738	14,446	1,623	81	4,844
Torres Strait Islands	928	QLD	56,924	35,140	21,784		21,784	3	14	62	-73		180	0
Towamba River	220	NSW	215,505	196,238	19,267	692	18,576	9,394	2,695	3,445	3,253	3,261	127	1,839
Towamba River	220	VIC	3,435	3,435										
Towns River	904	NT	543,712	191,746	351,967		351,967	126	230	272	-376		194	6
Tully River	113	QLD	164,442	125,045	39,397	821	38,576	27,209	17,943	5,071	4,195	3,518	123	1,260
Tuross River	218	NSW	216,077	182,956	33,121	997	32,124	15,323	4,480	5,947	4,897	3,894	121	2,662
Tweed River	201	NSW	107,784	48,883	58,900	1,847	57,054	59,922	35,676	16,751	7,496	8,803	106	4,052
Upper Murray River	401	NSW	521,020	309,908	211,112	601	210,511	41,999	11,471	17,440	13,089	61,233	87	3,043
Upper Murray River	401	VIC	1,014,397	764,235	250,162	1,898	248,264	76,473	23,158	42,320	10,995	72,559	93	9,604
VIC River	811	NT	7,812,695	1,860,921	5,951,774		5,951,774	20,251	5,608	4,601	10,043	4,286,031	96	911
Wakefield River	506	SA	192,269	3,070	189,199	1,025	188,174	68,148	20,301	17,060	30,787	79,198	50	3,848
Walker River	902	NT	972,347	972,347										
Warburton	23	NT	953,759	953,759										
Warburton	23	SA	18,086,360	16,611,614	1,474,746		1,474,746	1,413	1,017	4,244	-3,848		242	63
Warburton	23	WA	18,120,892	18,120,892										
Warrego River	423	NSW	1,127,023	29,070	1,097,954	2,458	1,095,496	29,199	11,399	6,003	11,798	400	90	851
Warrego River	423	QLD	5,167,030	690,885	4,476,145		4,476,145	46,385	6,391	40,542	-548	1,630	202	2,553
Warren River	607	WA	440,923	277,122	163,801	2,145	161,656	64,966	19,937	19,862	25,168	52,564	55	5,147
Water Park Creek	129	QLD	187,851	158,145	29,706	227	29,479	6,372	2,578	2,855	939	227	154	576
Watson River	923	QLD	469,581	242,500	227,082		227,082	277	180	645	-548		201	12
Wenlock River	925	QLD	746,488	160,322	586,166		586,166	740	468	1,665	-1,393		220	33
Werribee River	231	VIC	197,135	72,040	125,094	4,104	120,990	50,486	19,862	25,451	5,173	684	118	3,380
Whitsunday Island	123	QLD	27,508	26,241	1,267	230	1,037	268	106	59	103		170	55
Wildman River	819	NT	480,864	388,610	92,254		92,254	446	99	71	276	70,155	166	20
Willochra Creek	509	SA	662,156	13,324	648,831		648,831	31,562	11,187	14,841	5,533	47,920	116	1,669
Wimmera-Avon Rivers	415	VIC	3,036,540	513,320	2,523,220	4,874	2,518,346	561,131	149,378	253,707	158,046	429,224	13	29,911
Wiso	28	NT	22,931,960	13,286,078	9,645,882	118	9,645,764	25,907	8,750	7,766	9,391	2,508,477	99	1,145

Basin name	Basin number	State	Total area	Non-agricultural area	Agricultural area	Irrigated agricultural area in 1996/97	Dryland agricultural area in 1996/97	1996/97 Gross revenue	1996/97 Variable costs	1996/97 Fixed costs	1996/97 Profit at full equity	Minimum area of basin needed to produce 80% of profit at full equity within basin	Ranking of basin in order of contribution to national profit at full equity (#)	1996/97 Government Support
Wollongong Coast	214	NSW	79,239	49,209	30,029	305	29,724	26,180	8,553	10,258	7,369	9,969	107	5,652
Wooramel River	703	WA	4,189,453	537,032	3,652,421		3,652,421	6,470	2,449	6,358	-2,337		235	259
Yarra River	229	VIC	410,577	263,160	147,416	5,673	141,743	80,033	36,157	34,975	8,900	586	100	6,234
Yarra Yarra Lakes	618	WA	4,218,330	306,641	3,911,689		3,911,689	119,703	48,366	52,924	18,414	113,456	68	5,598
Min	-	-	**106**	**108**	**106**	**92**	**106**	**0**	**0**	**0**	**-63,476**	**186**	-	**0**
Max	-	-	**49,483,520**	**37,490,882**	**23,862,672**	**313,318**	**23,862,672**	**1,605,301**	**666,390**	**571,492**	**512,458**	**5,379,087**	-	**88,411**
Mean	-	-	**2,735,795**	**1,061,278**	**1,797,194**	**15,714**	**1,788,231**	**108,886**	**40,127**	**43,646**	**25,114**	**172,735**	-	**8,579**
Median	-	-	**741,698**	**258,446**	**390,692**	**2,723**	**379,399**	**25,907**	**8,525**	**11,006**	**2,844**	**19,298**	-	**1,729**
Standard Deviation	-	-	**5,524,348**	**3,462,796**	**3,361,360**	**39,679**	**3,358,305**	**222,747**	**84,346**	**83,158**	**65,474**	**610,012**	-	**15,764**
Sum	-	-	**768,758,505**	**296,096,511**	**472,661,994**	**2,357,163**	**470,304,830**	**28,419,353**	**10,473,021**	**11,391,582**	**6,554,750**	-	-	**2,239,234**

Table J.3

Basin name	Basin number	State	1996/97 Economic returns	5yr (1992/93 - 1996/97) Gross revenue	5yr (1992/93 - 1996/97) Total costs	5yr (1992/93 - 1996/97) Profit at full equity	Irrigated agriculture 5yr profit at full equity	Dryland agriculture 5yr profit at full equity	Area where lime application, on its own, is the most profitable soil treatment option	Area where gypsum application, on its own, is the most profitable soil treatment option	Area where combined lime/gypsum application is the most profitable soil treatment option1	Area where dryland salinity caused yield loss in 2000	Area where dryland salinity is expected to cause yield loss in 2020	Maximum gross benefit from ameliorating acidic soils
Adelaide River	817	NT	954	1,918	820	1,099		1,099						283
Albany Coast	602	WA	37,252	213,375	159,689	53,686	1,065	52,621	116,437		4,059	247,345	277,867	16,821
Archer River	922	QLD	-931	5,168	4,274	893		893						0
Arthur River	312	TAS	-511	4,719	4,039	680	77	603	6,720					1,066
Ashburton River	706	WA	-2,077	6,701	5,957	744		744						
Avoca River	408	VIC	71,762	359,699	260,206	99,493	65,391	34,102	3,250	59,741		4,455	9,327	643
Avon River	615	WA	318,081	1,098,839	795,171	303,668		303,668	869,658	106	735	922,763	1,037,539	39,186
Baffle Creek	134	QLD	5,141	37,505	26,151	11,354	2,461	8,894	1,459	2,026	5,053	9	109	988
Barkly	29	NT	14,023	27,610	15,651	11,960		11,960						
Barron River	110	QLD	12,730	41,454	21,914	19,539	7,187	12,353	11,531	236	354	703	2,125	3,543
Barwon River	233	VIC	-4,678	100,109	89,032	11,077	3,047	8,031	13,682	6,706	18,358	8,400	34,889	4,516
Bathurst And Melville Islands	816	NT												
Bega River	219	NSW	15,947	84,915	50,339	34,576	9,959	24,616	40,316			14	32	5,413
Bellinger River	205	NSW	2,189	73,303	59,341	13,962	3,216	10,746	21,708		2,768	28	64	11,029
Benanee	413	NSW	41,451	97,671	47,230	50,441	40,679	9,763		4,396		51	194	
Black River	117	QLD	2,152	14,841	10,161	4,681	3,270	1,411	5,243	233	349			619
Blackwood River	609	WA	110,051	375,970	240,908	135,062	7,812	127,250	238,331	104	205	181,998	228,238	24,980
Blyth River	824	NT												
Border Rivers	416	NSW	169,392	571,833	432,829	139,004	96,771	42,233	34,571	59,799	323	511	5,672	9,547
Border Rivers	416	QLD	159,635	355,317	228,211	127,106	89,207	37,899	866	64,980	4,551	360	1,728	15,097
Boyne River	133	QLD	2,225	7,803	3,828	3,975		3,975		5,183	225		18	76
Brisbane River	143	QLD	127,192	455,287	263,463	191,824	107,379	84,445	48,303	24,728	40,000	1,397	1,676	24,851
Broken River	404	VIC	98,854	536,316	338,861	197,455	177,623	19,832	6,839	173,810	3,581	15,865	52,337	5,062
Broughton River	507	SA	168,759	399,479	231,385	168,094	6,510	161,584	1,213	13,751		52,069	52,074	170
Brunswick River	202	NSW	8,614	54,459	41,223	13,235	7,954	5,281	11,833			14	32	25,249
Buckingham River	826	NT												
Bulloo River	11	NSW	-3,184	8,002	9,555	-1,552		-1,552						0
Bulloo River	11	QLD	-10,001	23,527	31,926	-8,399		-8,399						0
Bunyip River	228	VIC	25,305	267,180	188,647	78,533	60,827	17,707	82,571		35,802			125,440

Basin name	Basin number	State	1996/97 Economic returns	5yr (1992/93 - 1996/97) Gross revenue	5yr (1992/93 - 1996/97) Total costs	5yr (1992/93 - 1996/97) Profit at full equity	Irrigated agriculture 5yr profit at full equity	Dryland agriculture 5yr profit at full equity	Area where lime application, on its own, is the most profitable soil treatment option	Area where gypsum application, on its own, is the most profitable soil treatment option	Area where combined lime/gypsum application is the most profitable soil treatment option1	Area where dryland salinity caused yield loss in 2000	Area where dryland salinity is expected to cause yield loss in 2020	Maximum gross benefit from ameliorating acidic soils
Burdekin River	120	QLD	-77,876	338,027	316,494	21,533	37,177	-15,644	3,478	4,380	932	12,877	32,703	1,615
Burnett River	136	QLD	44,347	368,616	250,218	118,399	34,476	83,923	9,912	41,754	6,659	2,326	6,875	4,276
Burrum River	137	QLD	10,444	104,279	79,986	24,293	18,929	5,364	4,025	558	335	1,810	4,443	2,757
Burt	27	NT	-1,180	3,007	3,822	-815		-815						
Busselton Coast	610	WA	37,030	111,022	61,353	49,669	4,219	45,450	41,900		206	30,451	30,451	11,524
Calliope River	132	QLD	-170	11,848	7,194	4,654		4,654		1,355	1,466	725	1,751	109
Calvert River	909	NT	-807	549	1,240	-692		-692						
Campaspe River	406	VIC	-8,269	153,674	129,945	23,729	24,968	-1,239	1,873	66,173	1,680	16,120	24,201	4,386
Cape Leveque Coast	801	WA	-388	3,846	2,163	1,683		1,683						
Castlereagh River	420	NSW	37,666	266,349	191,539	74,810	707	74,103	210	52,192		1,358	5,610	492
Clarence River	204	NSW	13,830	225,694	146,785	78,909	6,594	72,315	37,541	216	11,544	210	480	10,208
Clyde River-Jervis Bay	216	ACT												
Clyde River-Jervis Bay	216	NSW	3,805	23,334	15,054	8,280	760	7,520	7,657		5,060			2,387
Coal River	303	TAS	890	11,915	10,301	1,614	2,947	-1,333	1,092	273	455			1,244
Coleman River	920	QLD	-2,098	2,351	3,189	-838	-15	-823					128	3
Collie River	612	WA	22,730	53,873	24,874	28,999	5,968	23,031	21,477	517	826	12,290	12,292	3,248
Condamine-Culgoa Rivers	422	NSW	-26,587	78,561	103,480	-24,919	2,279	-27,198	107	860				72
Condamine-Culgoa Rivers	422	QLD	424,047	1,284,197	834,707	449,491	211,656	237,835	24,729	365,735	4,804	10,812	21,900	4,793
Cooper Creek	3	NSW	-1	2	2	-1		-1						
Cooper Creek	3	QLD	-42,928	190,655	186,591	4,064		4,064				11	11	1
Cooper Creek	3	SA	-8,880	3,637	10,822	-7,185		-7,185						
Curtis Island	131	NSW												
Curtis Island	131	QLD	-371	441	488	-47		-47						3
Daintree River	108	QLD	1,449	13,629	10,124	3,505		3,505	8,049				27	1,604
Daly River	814	NT	6,178	12,455	5,823	6,632		6,632						607
Darling River	425	NSW	5,467	144,819	112,653	32,166	29,451	2,715	1,277	3,854	320	10	50	186
De Grey River	710	WA	-2,457	7,834	6,547	1,287		1,287						
Denmark River	603	WA	3,757	34,505	28,714	5,791	732	5,059	28,837		508	8,744	8,744	5,909
Derwent River	304	TAS	-8,324	51,828	54,526	-2,697	5,255	-7,952	7,588	912	1,459	6,021	7,907	2,334
Diamantina River	2	QLD	-27,597	53,023	65,265	-12,242		-12,242				15	15	
Diamantina River	2	SA	-10,091	3,234	11,818	-8,584		-8,584						

Basin name	Basin number	State	1996/97 Economic returns	5yr (1992/93 - 1996/97) Gross revenue	5yr (1992/93 - 1996/97) Total costs	5yr (1992/93 - 1996/97) Profit at full equity	Irrigated agriculture 5yr profit at full equity	Dryland agriculture 5yr profit at full equity	Area where lime application, on its own, is the most profitable soil treatment option	Area where gypsum application, on its own, is the most profitable soil treatment option	Area where combined lime/gypsum application is the most profitable soil treatment option1	Area where dryland salinity caused yield loss in 2000	Area where dryland salinity is expected to cause yield loss in 2020	Maximum gross benefit from ameliorating acidic soils
Don River	121	QLD	17,864	56,095	30,438	25,657	26,927	-1,270	232	2,086	347		37	1,269
Donnelly River	608	WA	4,105	16,414	11,539	4,875	2,623	2,253	7,152			7,035	7,035	1,232
Drysdale River	807	WA	-341	3,546	1,658	1,888		1,888						
Ducie River	926	QLD	-508	637	759	-121		-121						0
East Alligator River	821	NT	10	17	7	10		10						2
East Coast	302	TAS	-4,612	37,607	38,946	-1,339	956	-2,295	10,393	549	2,030	2,005	2,633	1,678
East Gippsland	221	NSW	203	1,383	774	610	135	474	197		296			105
East Gippsland	221	VIC	-259	5,178	4,094	1,084	463	621	2,258		196			987
Embley River	924	QLD	-548	802	939	-136		-136						
Endeavour River	107	QLD	664	5,712	3,687	2,025		2,025	1,543		1,306			3,633
Esperance Coast	601	WA	38,448	164,471	128,788	35,683		35,683	82,974	514		94,935	201,736	3,955
Eyre Peninsula	512	SA	6,736	24,072	14,354	9,719		9,719	7,330	713	305	17,441	17,441	320
Finke River	5	NT	-1,967	3,235	5,018	-1,784		-1,784						
Finke River	5	SA	-12,520	6,009	15,729	-9,720		-9,720						
Finniss River	815	NT	6,061	5,806	3,626	2,180	-174	2,354	601					56,404
Fitzmaurice River	812	NT	809	1,575	710	865		865						104
Fitzroy River (Qld)	130	QLD	36,434	848,853	652,556	196,296	84,967	111,330	8,189	75,323	3,971	23,928	51,065	2,889
Fitzroy River (Wa)	802	WA	-1,921	25,692	13,030	12,663		12,663						0
Fleurieu Peninsula	501	SA	11,714	49,292	26,988	22,304	2,380	19,924		1,208		88	88	0
Flinders River	915	QLD	-17,103	125,044	82,894	42,150		42,150		231		4,975	10,889	1
Flinders-Cape Barren Islands	301	TAS	-3,166	10,646	12,238	-1,592		-1,592						
Fortescue River	708	WA	-1,765	5,241	4,527	715		715						
Forth River	315	TAS	2,886	18,879	12,415	6,464	6,492	-28	4,090					7,441
Frankland River	605	WA	12,610	60,981	45,667	15,315	806	14,509	60,829		102	7,143	7,143	3,431
Fraser Island	139	QLD												
Gairdner	21	SA	23,410	266,762	230,590	36,172	445	35,727	613	41,248		53,840	53,840	178
Gascoyne River	704	WA	-1,917	10,705	9,906	800	788	11						0
Gawler River	505	SA	75,748	189,641	112,460	77,181	32,817	44,364	509	41,276		308	307	682
Georgina River	1	NT	1,135	14,968	13,793	1,175		1,175						
Georgina River	1	QLD	-3,022	71,524	55,653	15,871		15,871						
Georgina River	1	SA	-741	212	854	-642		-642						

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Gilbert River	917	QLD	-14,502	47,364	35,577	11,787		11,787					12	1
Glenelg River	238	SA	609	3,004	2,100	904	492	413						
Glenelg River	238	VIC	18,179	176,695	141,571	35,124	1,525	33,599	45,792	12,422	2,447	42,602	113,849	9,477
Goomadeer River	822	NT												
Gordon River	308	TAS												
Goulburn River	405	VIC	69,186	653,007	459,677	193,330	181,638	11,693	10,166	175,175	4,755	36,168	81,559	15,098
Goyder River	825	NT												
Greenough River	701	WA	33,734	225,569	174,964	50,605		50,605	602,935			75,673	75,673	21,526
Groote Eylandt	929	NT												
Gwydir River	418	NSW	264,790	796,916	571,422	225,494	177,002	48,492	18,077	180,057	107			3,910
Harvey River	613	WA	25,751	61,982	28,533	33,449	16,215	17,234	22,909	207	726	24,821	24,821	7,902
Hastings River	207	NSW	6,449	64,309	43,976	20,333	2,453	17,880	29,372	105	2,845			5,938
Haughton River	119	QLD	10,825	142,041	105,701	36,340	29,250	7,090	1,626	18,575	3,020	1	575	623
Hawkesbury River	212	NSW	-13,716	177,887	155,179	22,708	24,801	-2,093	71,689		24,060	4,264	9,786	35,164
Hay River	7	NT	-698	3,765	4,275	-510		-510						
Hay River	7	QLD												
Hay River	7	SA	-529	163	617	-453		-453						
Herbert River	116	QLD	28,734	193,292	137,396	55,896	1,502	54,394	51,289		3,864	10	208	10,669
Hinchinbrook Island	115	QLD												
Holroyd River	921	QLD	-1,954	2,587	3,054	-467		-467						0
Hopkins River	236	VIC	5,876	324,186	262,081	62,105	1,779	60,326	12,149	65,968	80,763	19,527	77,389	15,011
Hunter River	210	NSW	-187	363,890	280,473	83,416	36,684	46,732	71,488	12,517	21,371	20,473	46,796	43,055
Huon River	306	TAS	8,059	115,553	99,393	16,160	14,560	1,600	2,986		2,715			76,013
Isdell River	804	WA	87	2,823	1,201	1,623		1,623						
Jacky Jacky Creek	101	QLD	-346	454	524	-70		-70						13
Jardine River	927	QLD	-9	1	10	-9		-9						
Jeannie River	106	QLD	867	8,122	5,305	2,817		2,817	2,974					722
Johnstone River	112	QLD	22,096	192,734	140,451	52,283	3,472	48,811	79,073		117	35	631	38,331
Kangaroo Island	513	SA	3,213	40,631	35,748	4,884		4,884	902	201		8,644	8,702	36
Karuah River	209	NSW	-1,839	34,887	27,802	7,086	718	6,367	14,838	104	2,089			1,886
Keep River	810	NT	842	1,806	899	906		906	119					93

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Keep River	810	WA	-135	1,461	677	784		784						24
Kent River	604	WA	2,257	22,555	19,612	2,943	108	2,836	26,134			7,100	7,100	2,852
Kiewa River	402	VIC	-2,765	40,289	34,080	6,209	837	5,372	10,056	498	9,357	4,219	6,408	4,229
King Edward River	806	WA	7,796	30,103	15,326	14,778		14,778						
King Island	313	TAS	-997	31,139	23,759	7,380		7,380						
King-Henty Rivers	309	TAS	-101	247	264	-17		-17	1,011					66
Kingston Coast	305	TAS	-3,603	2,889	5,901	-3,012		-3,012	815					200
Kolan River	135	QLD	2,166	73,451	59,327	14,124	6,479	7,645	2,577	784	1,232	578	1,288	1,104
Koolatong River	901	NT												
Lachlan River	412	NSW	77,963	999,220	862,868	136,351	61,654	74,697	118,064	108,900	7,672	16,154	41,492	30,134
Lake Bancannia	12	NSW	-3,352	9,776	11,431	-1,655		-1,655						0
Lake Corangamite	234	VIC	-3,596	137,155	113,654	23,500	2,088	21,412	12,800	33,402	40,884	11,145	52,878	6,554
Lake Frome	4	NSW	-2,586	8,172	9,567	-1,395		-1,395						
Lake Frome	4	QLD	1	63	55	8		8						
Lake Frome	4	SA	-32,767	49,690	68,384	-18,695		-18,695		311		42	42	1
Lake George	411	NSW	-2,462	6,275	7,393	-1,117		-1,117	808			86	261	190
Lake Torrens	510	SA	-377	9,535	4,761	4,774		4,774						1
Latrobe River	226	VIC	-4,014	157,550	125,384	32,166	11,354	20,812	81,888	9,146	29,862	768	906	23,614
Leichhardt River	913	QLD	4,320	27,243	12,346	14,896		14,896						
Lennard River	803	WA	51	4,447	1,977	2,470		2,470						
Limmen Bight River	905	NT	-1,303	844	2,010	-1,167		-1,167						
Liverpool River	823	NT												
Lockhart River	103	QLD	246	2,009	1,294	716		716	1,438					1,716
Loddon River	407	VIC	15,072	584,394	459,441	124,953	121,647	3,307	2,658	312,771	3,153	22,074	38,481	9,899
Logan-Albert Rivers	145	QLD	25,732	95,241	54,915	40,326	8,001	32,325	19,922	2,503	16,905	67	96	3,354
Lower Murray River	426	NSW	-1,270	6,345	5,949	396		396				2	22	
Lower Murray River	426	SA	225,420	761,942	459,474	302,467	252,917	49,550	1,620	92,189		43,773	66,632	234
Lyndon-Minilya Rivers	705	WA	2,716	13,579	7,527	6,052	968	5,083						
Mackay	26	NT	-912	8,001	8,378	-376		-376						1
Mackay	26	SA												
Mackay	26	WA	-1,333	7,694	4,378	3,316		3,316						0

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Macleay River	206	NSW	12,029	122,559	76,545	46,014	403	45,611	19,007		318			3,284
Macquarie-Bogan Rivers	421	NSW	140,054	1,025,416	866,041	159,375	134,569	24,806	42,253	36,611	7,698	24,534	59,126	42,796
Macquarie-Tuggerah Lakes	211	NSW	244	5,380	4,596	784	1,833	-1,049	2,069		3,417			3,616
Mallee	414	SA	120,115	489,986	331,234	158,752	178,523	-19,771		56,154		6,409	9,362	0
Mallee	414	VIC	105,030	328,246	203,278	124,968	138,065	-13,097		18,133		23,038	25,850	5
Mambray Coast	508	SA	691	11,727	9,588	2,139		2,139	104	104		187	187	1
Manning River	208	NSW	4,613	116,759	82,619	34,141	4,378	29,763	51,439		5,564	91	209	5,700
Maribyrnong River	230	VIC	-6,353	13,257	17,613	-4,356	1,046	-5,402	393	882	393	901	4,838	509
Maroochy River	141	QLD	22,341	111,034	78,429	32,605	22,102	10,503	22,278		2,097			17,596
Mary River (Qld)	138	QLD	42,159	197,796	122,453	75,343	15,986	59,357	61,963	667	9,637	652	773	16,247
Mary River (Wa)	818	NT	924	2,000	836	1,164		1,164						229
Mcarthur River	907	NT	-1,125	1,568	2,588	-1,020		-1,020						
Mersey River	316	TAS	13,212	115,274	81,994	33,280	28,577	4,703	30,263		836			28,080
Millicent Coast	239	SA	46,338	503,284	421,067	82,217	61,021	21,196	98	65,159	3,435	275,804	447,883	702
Millicent Coast	239	VIC	6,849	98,499	92,297	6,202	2,405	3,797		12,692	98	5,819	11,189	45
Mitchell River (Qld)	919	QLD	-18,092	130,370	108,081	22,289	24,371	-2,082	8,975	354	1,534	114	2,544	22,192
Mitchell River (Vic)	224	VIC	3,488	30,621	23,408	7,213	5,637	1,576	2,840	390	1,956	126	159	3,965
Moonie River	417	NSW	-972	3,894	4,839	-945	453	-1,398		108				2
Moonie River	417	QLD	38,715	84,459	65,848	18,611	5,738	12,873		37,352		105	772	34
Moorabool River	232	VIC	-1,404	44,391	39,382	5,009	5,258	-249	2,444	10,049	3,418	1,129	10,871	12,818
Moore-Hill Rivers	617	WA	27,909	231,050	194,951	36,099	9,253	26,846	346,544			186,786	207,290	15,920
Morning Inlet	914	QLD	-331	2,106	1,103	1,003		1,003						
Mornington Island	911	QLD	-340	69	365	-296		-296						
Moruya River	217	NSW	877	7,694	5,407	2,287		2,287	3,706		100	42	96	550
Mossman River	109	QLD	748	6,687	4,827	1,860		1,860	2,363			177	380	181
Moyle River	813	NT	1	1	0	1		1						0
Mulgrave-Russell Rivers	111	QLD	9,304	80,191	59,482	20,710	-35	20,744	33,072				65	6,187
Murchison River	702	WA	-10,498	46,055	51,200	-5,146		-5,146	66,500					1,661
Murray River (Qld)	114	QLD	228	14,911	11,726	3,185	-198	3,383	2,578		117		82	1,734
Murray River (Wa)	614	WA	34,737	126,268	77,377	48,891	10,234	38,657	95,771	209	417	46,577	46,609	10,773
Murray-Riverina	409	NSW	56,326	504,964	385,297	119,667	113,506	6,161	4,406	213,278	1,804	3,760	30,927	1,031

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Murrumbidgee River	410	ACT	324	6,014	3,870	2,143		2,143	302				65	172
Murrumbidgee River	410	NSW	281,452	1,647,881	1,231,632	416,248	298,680	117,568	176,601	201,374	17,925	15,010	78,061	79,024
Myponga River	502	SA	3,535	12,820	6,626	6,194	1,852	4,342		605				
Namoi River	419	NSW	280,305	1,049,351	668,494	380,857	190,587	190,270	15,089	171,736	1,058	1,672	4,328	3,171
Nicholson River	912	NT	1,214	2,084	1,066	1,019		1,019						
Nicholson River	912	QLD	-2,249	18,147	11,136	7,011		7,011						
Ninghan	619	WA	945	26,194	25,409	785		785	25,358			56,634	56,634	857
Noosa River	140	QLD	4,317	22,842	14,348	8,494	3,968	4,526	7,200		665	3	3	2,156
Norman River	916	QLD	-21,639	35,216	36,083	-867		-867					24	
Normanby River	105	QLD	-3,356	9,574	8,997	576		576	1,422			145	437	246
Nullarbor	22	SA												
Nullarbor	22	WA	-2,293	4,714	5,830	-1,116		-1,116						
O'Connell River	124	QLD	11,771	82,956	60,497	22,459	3,061	19,398	23,958	577	2,769	134	690	2,863
Olive-Pascoe Rivers	102	QLD	-87	3,728	2,682	1,046		1,046	2,165					2,696
Onkaparinga River	503	SA	33,755	143,345	96,656	46,688	38,031	8,657	203	8,686	303			177
Onslow Coast	707	WA	-672	1,879	1,628	251		251						
Ord River	809	NT	1,704	3,740	1,903	1,837		1,837						57
Ord River	809	WA	15,769	47,204	21,477	25,727	21,153	4,574	2,017		119			3,449
Otway Coast	235	VIC	-15,041	176,993	145,898	31,095	1,288	29,806	115,070	5,244	13,877	2,202	14,589	13,145
Ovens River	403	VIC	-667	107,169	90,995	16,175	10,104	6,070	21,254	3,499	1,095	10,685	17,820	12,981
Paroo River	424	NSW	11,472	53,372	37,709	15,663	11,419	4,243		5,712				5
Paroo River	424	QLD	-5,115	19,430	25,256	-5,826		-5,826						4
Pentecost River	808	WA	-918	4,784	2,700	2,084		2,084						0
Pieman River	310	TAS	-603	771	1,093	-322		-322	1,574					279
Pine River	142	QLD	5,296	47,682	34,794	12,888	1,712	11,176	15,596		8,452		46	1,884
Pioneer River	125	QLD	7,594	88,302	68,888	19,415	5,883	13,531	26,680	115	1,265			2,418
Piper-Ringarooma Rivers	319	TAS	892	74,496	58,730	15,766	9,504	6,262	18,357		6,716	1,930	2,534	8,962
Plane Creek	126	QLD	17,642	160,820	123,757	37,062	10,919	26,143	44,415	5,049	21,233	8	207	8,022
Port Hedland Coast	709	WA	-911	4,517	2,700	1,817		1,817						
Portland Coast	237	VIC	7,257	136,200	104,366	31,834	2,284	29,551	91,676	10,609	56,259	1,247	19,361	37,499
Preston River	611	WA	13,122	38,694	21,457	17,237	9,279	7,958	2,060		2,989	4,326	4,326	5,871

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Prince Regent River	805	WA	18	488	194	294		294						
Proserpine River	122	QLD	5,394	52,226	39,801	12,425	3,854	8,570	7,164	2,542	11,209		8	1,728
Richmond River	203	NSW	37,395	267,642	185,422	82,219	29,443	52,776	60,368	109	9,093	265	607	22,140
Robinson River	908	NT	-1,089	568	1,518	-950		-950						
Roper River	903	NT	2,703	9,612	7,769	1,843		1,843						1
Rosie River	906	NT	-440	206	588	-383		-383						
Ross River	118	QLD	-354	4,430	3,864	566	247	319		1,978		3	3	31
Rubicon River	317	TAS	14,702	57,203	30,925	26,278	25,577	701	6,601		1,208			13,887
Salt Lake	24	WA	-478	76,988	76,085	903		903					113,323	20
Sandy Cape Coast	311	TAS	-49	695	539	156		156	1,211					204
Sandy Desert	25	WA	-1,652	5,836	4,350	1,486		1,486						
Settlement Creek	910	NT	-547	307	769	-462		-462						
Settlement Creek	910	QLD	-370	10,873	4,558	6,315		6,315		118				
Shannon River	606	WA	5,789	19,353	12,136	7,217	3,689	3,527	17,071		1,526	28,968	28,968	27,464
Shoalhaven River	215	NSW	-1,586	74,542	59,536	15,006	1,582	13,424	24,980		2,940			8,234
Shoalwater Creek	128	QLD	-2,000	10,005	9,462	543	119	424	683		1,365			224
Smithton-Burnie Coast	314	TAS	19,090	218,271	156,703	61,568	35,040	26,528	134,742					55,764
Snowy River	222	NSW	-18,848	50,209	58,578	-8,369	552	-8,921	498			21	48	1,135
Snowy River	222	VIC	-3,723	31,578	25,079	6,500	1,451	5,048	7,643		3,718			1,971
South Alligator River	820	NT	10	15	6	9		9						1
South Coast	146	QLD	8,187	23,202	14,954	8,248	70	8,178	19,169		2,072		123	1,909
South Gippsland	227	VIC	-51	303,868	230,606	73,262	7,569	65,694	140,363	9,410	75,653	3,598	4,845	25,005
South-West Coast	307	TAS	699	14,385	12,805	1,580	2,435	-855	2,160					3,380
Spencer Gulf	511	SA	20,093	65,162	48,266	16,896		16,896		23,647	102	12,151	12,151	39
Staaten River	918	QLD	-7,314	15,480	13,419	2,062		2,062				8	509	8
Stewart River	104	QLD	507	6,075	4,064	2,012		2,012	3,825		358			324
Stradbroke Island	144	QLD	-126	251	366	-114		-114						6
Styx River	127	QLD	-3,138	12,612	12,664	-52		-52	114	1,938	114			102
Swan Coast	616	WA	-4,291	69,783	71,729	-1,945	12,322	-14,267	31,152		526	28,292	28,292	8,432
Sydney Coast-Georges River	213	NSW	-491	5,513	4,675	838	1,359	-521	3,585		924	56	128	3,421
Tamar River	318	TAS	-9,636	158,128	132,640	25,488	20,149	5,339	33,040	186	7,680	16,437	21,587	14,233

Basin name	Basin number	State	1996/97 Economic returns	5yr (1992/93 - 1996/97) Gross revenue	5yr (1992/93 - 1996/97) Total costs	5yr (1992/93 - 1996/97) Profit at full equity	Irrigated agriculture 5yr profit at full equity	Dryland agriculture 5yr profit at full equity	Area where lime application, on its own, is the most profitable soil treatment option	Area where gypsum application, on its own, is the most profitable soil treatment option	Area where combined lime/gypsum application is the most profitable soil treatment option1	Area where dryland salinity caused yield loss in 2000	Area where dryland salinity is expected to cause yield loss in 2020	Maximum gross benefit from ameliorating acidic soils
Tambo River	223	VIC	516	21,025	19,033	1,991	1,049	942	2,351	1,075	489			925
Thomson River	225	VIC	-615	128,758	97,619	31,139	14,916	16,223	2,344	20,666	40,854	2,754	3,247	2,929
Todd River	6	NT	-1,453	4,771	6,303	-1,532		-1,532						
Torrens River	504	SA	9,601	51,961	38,127	13,834	11,913	1,921	405	508	203	0	0	372
Torres Strait Islands	928	QLD	-73	6	76	-70		-70						
Towamba River	220	NSW	1,415	10,191	6,140	4,051	768	3,283	4,347		98			618
Towamba River	220	VIC												
Towns River	904	NT	-381	173	506	-333		-333						
Tully River	113	QLD	2,936	31,955	23,654	8,301	1,399	6,902	8,559				39	18,718
Tuross River	218	NSW	2,235	15,698	10,368	5,330	1,723	3,607	6,185		300	14	32	2,745
Tweed River	201	NSW	3,444	66,769	55,342	11,427	563	10,864	19,781		217	14	32	5,577
Upper Murray River	401	NSW	10,045	52,568	29,149	23,420	1,801	21,618	11,621	1,500	1,400	224	1,439	7,096
Upper Murray River	401	VIC	1,390	79,611	65,316	14,295	1,074	13,221	32,677	2,000	9,379	41	58	5,789
VIC River	811	NT	9,131	19,940	10,104	9,837		9,837						336
Wakefield River	506	SA	26,938	63,198	37,057	26,141	4,233	21,908		11,364		1,407	1,407	30
Walker River	902	NT												
Warburton	23	NT												
Warburton	23	SA	-3,911	2,518	5,271	-2,753		-2,753						
Warburton	23	WA												
Warrego River	423	NSW	10,947	34,345	18,607	15,739	13,711	2,028		320	2,031			154
Warrego River	423	QLD	-3,101	53,616	46,701	6,915		6,915		111				52
Warren River	607	WA	20,021	64,435	40,512	23,923	9,999	13,924	27,560		715	15,656	15,656	5,042
Water Park Creek	129	QLD	364	6,760	5,377	1,383	1,057	325	340	113	1,247	23	28	261
Watson River	923	QLD	-560	667	822	-155		-155						
Wenlock River	925	QLD	-1,426	1,781	2,126	-345		-345				199	199	0
Werribee River	231	VIC	1,793	57,941	45,673	12,269	16,186	-3,917	881	7,237	3,910	438	8,389	6,933
Whitsunday Island	123	QLD	48	361	173	188	181	7						
Wildman River	819	NT	255	404	165	239		239						83
Willochra Creek	509	SA	3,864	34,492	26,112	8,379		8,379		936				1
Wimmera-Avon Rivers	415	VIC	128,134	512,667	401,381	111,286	10,380	100,906	14,899	78,565	1,876	53,667	74,688	6,310
Wiso	28	NT	8,246	24,526	16,298	8,229	571	7,658						1

Basin name	Basin number	State	1996/97 Economic returns	5yr (1992/93 - 1996/97) Gross revenue	5yr (1992/93 - 1996/97) Total costs	5yr (1992/93 - 1996/97) Profit at full equity	Irrigated agriculture 5yr profit at full equity	Dryland agriculture 5yr profit at full equity	Area where lime application, on its own, is the most profitable soil treatment option	Area where gypsum application, on its own, is the most profitable soil treatment option	Area where combined lime/gypsum application is the most profitable soil treatment option1	Area where dryland salinity caused yield loss in 2000	Area where dryland salinity is expected to cause yield loss in 2020	Maximum gross benefit from ameliorating acidic soils
Wollongong Coast	214	NSW	1,717	21,757	16,184	5,573	357	5,217	16,690					3,422
Wooramel River	703	WA	-2,596	7,895	8,806	-911		-911						0
Yarra River	229	VIC	2,666	85,819	69,484	16,334	24,458	-8,123	9,492	687	4,404	435	731	115,348
Yarra Yarra Lakes	618	WA	12,816	122,609	101,424	21,184		21,184	115,311			181,766	181,766	4,039
Min	**-**	**-**	**-77,876**	**1**	**0**	**-24,919**	**-198**	**-27,198**	**98**	**104**	**98**	**0**	**0**	**0**
Max	**-**	**-**	**424,047**	**1,647,881**	**1,231,632**	**449,491**	**298,680**	**303,668**	**869,658**	**365,735**	**80,763**	**922,763**	**1,037,539**	**125,440**
Mean	**-**	**-**	**16,535**	**111,756**	**82,906**	**28,851**	**26,659**	**14,142**	**35,377**	**31,117**	**6,744**	**26,325**	**33,530**	**7,729**
Median	**-**	**-**	**748**	**27,610**	**21,457**	**6,194**	**5,688**	**2,715**	**8,767**	**3,020**	**1,916**	**1,967**	**3,787**	**1,716**
Standard Deviation	**-**	**-**	**53,464**	**221,141**	**162,289**	**63,581**	**52,765**	**34,680**	**94,174**	**64,251**	**13,594**	**94,784**	**106,102**	**16,663**
Sum	**-**	**-**	**4,315,516**	**29,168,341**	**21,638,353**	**7,529,989**	**3,838,949**	**3,691,040**	**5,377,240**	**3,173,915**	**782,285**	**3,106,370**	**4,425,962**	**1,584,528**

Table J.4

Basin name	Basin number	State	Maximum gross benefit from ameliorating sodic soils	Maximum gross benefit from ameliorating saline soils	Limiting factor gross benefit	Impact cost of dryland salinity to agriculture from 2000 to 2020	Present value of dryland salinity impact cost to agriculture from 2000 to 2020	Net present value of lime application in areas where lime application is profitable	Net present value of gypsum application in areas where gypsum application is profitable	Net present value of lime and gypsum application in areas where combined lime/gypsum application is profitable6	Local infrastructure cost of salinity and water table rise 2000	Local infrastructure cost of salinity and water table rise 2020
Adelaide River	817	NT	23		283							
Albany Coast	602	WA	8,415	8,555	26,755	1,075	5,965	102,579		8,481	1,711	1,887
Archer River	922	QLD	1		1							
Arthur River	312	TAS			1,066			7,616				
Ashburton River	706	WA										
Avoca River	408	VIC	22,229	171	22,584	313	1,734	539	118,908		74	259
Avon River	615	WA	35,482	41,916	86,521	5,793	32,137	120,056	92	299	11,697	13,053
Baffle Creek	134	QLD	1,261	0	1,662	1	7	1,117	1,313	5,408	0	1
Barkly	29	NT	1,545		1,545							
Barron River	110	QLD	311	174	3,746	242	1,344	26,098	982	1,544	175	575
Barwon River	233	VIC	6,399	722	8,437	2,116	11,738	8,934	1,302	15,732	1,512	4,391
Bathurst And Melville Islands	816	NT										
Bega River	219	NSW			5,413			44,072			1	1
Bellinger River	205	NSW	332	2	11,029	8	44	81,726		20,163	15	33
Benanee	413	NSW	5,150	56	5,150	186	1,035		35,271		100	181
Black River	117	QLD	359		868			3,107	350	1,677		
Blackwood River	609	WA	12,125	10,845	38,305	2,132	11,828	145,025	56	8,332	3,900	4,469
Blyth River	824	NT										
Border Rivers	416	NSW	20,653	2	29,630	102	565	72,299	90,429	101	1	47
Border Rivers	416	QLD	18,638	18	30,775	79	438	1,573	47,135	139,700	4	34
Boyne River	133	QLD	461		466	2	13		192	88		5
Brisbane River	143	QLD	13,451	490	32,166	7	41	81,377	15,215	154,228	398	408
Broken River	404	VIC	46,205	1,189	48,870	5,054	28,039	10,194	315,993	52,093	479	2,287
Broughton River	507	SA	7,690	7,659	15,130	1	4	73	12,128		1,334	1,334
Brunswick River	202	NSW	0	18	25,250	27	151	248,314			1	3
Buckingham River	826	NT										
Bulloo River	11	NSW	83		83							
Bulloo River	11	QLD	334		334							
Bunyip River	228	VIC	4,644		125,496			863,086		332,950		

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Burdekin River	120	QLD	6,647	745	8,514	615	3,411	5,828	17,243	801	72	160
Burnett River	136	QLD	8,362	1,155	11,628	657	3,646	11,225	20,072	16,250	280	812
Burrum River	137	QLD	232	1,209	3,561	777	4,312	14,350	25	781	230	555
Burt	27	NT	16		16							
Busselton Coast	610	WA	713	7,570	16,360			59,078		19,580	2,595	2,595
Calliope River	132	QLD	605	4	608	4	21		523	882	5	19
Calvert River	909	NT	2		2							
Campaspe River	406	VIC	13,464	1,277	16,852	560	3,106	718	81,621	32,225	1,142	2,267
Cape Leveque Coast	801	WA										
Castlereagh River	420	NSW	7,833	64	8,217	185	1,024	6	8,217		40	337
Clarence River	204	NSW	2,818	5	11,063	8	46	49,304	55	11,761	20	46
Clyde River-Jervis Bay	216	ACT										
Clyde River-Jervis Bay	216	NSW	774		2,478			11,673		7,802		
Coal River	303	TAS	628		1,446			4,653	134	5,984		
Coleman River	920	QLD	3		6							0
Collie River	612	WA	1,420	3,090	5,627	1	3	18,095	394	945	1,984	1,984
Condamine-Culgoa Rivers	422	NSW	4,172		4,193			21	1,162			
Condamine-Culgoa Rivers	422	QLD	61,481	1,661	64,415	1,547	8,580	9,988	206,061	3,621	221	505
Cooper Creek	3	NSW	0		0							
Cooper Creek	3	QLD	7,017	0	7,018						0	0
Cooper Creek	3	SA	10		10							
Curtis Island	131	NSW										
Curtis Island	131	QLD	6		6							
Daintree River	108	QLD	1		1,604	6	32	12,889				7
Daly River	814	NT	110		684							
Darling River	425	NSW	6,980	0	7,143	0	0	129	25,956	567	0	18
De Grey River	710	WA										
Denmark River	603	WA	694	412	6,198			41,240		5,214	409	409
Derwent River	304	TAS	1,723	484	3,563	129	714	8,095	426	2,496	341	448
Diamantina River	2	QLD	1,194		1,194						0	0
Diamantina River	2	SA	20		20							

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Don River	121	QLD	2,923		3,314	192	1,064	740	15,906	3,683		18
Donnelly River	608	WA	4	253	1,469			10,241			9	9
Drysdale River	807	WA										
Ducie River	926	QLD			0							
East Alligator River	821	NT	0		2							
East Coast	302	TAS	1,796	52	2,787	14	78	3,592	663	2,852	1,176	1,543
East Gippsland	221	NSW	41		107			375		308		
East Gippsland	221	VIC	30		992			8,561		96		
Embley River	924	QLD										
Endeavour River	107	QLD	108		3,633			4,375		30,296		
Esperance Coast	601	WA	7,187	3,469	11,229	5,749	31,891	7,926	163		392	947
Eyre Peninsula	512	SA	525	761	1,340			1,203	107	11	413	413
Finke River	5	NT	15		15							
Finke River	5	SA	15		15							
Finniss River	815	NT	27		56,413			555,664				
Fitzmaurice River	812	NT	2		106							
Fitzroy River (Qld)	130	QLD	26,149	4,514	31,486	2,559	14,194	7,252	34,002	5,860	488	835
Fitzroy River (Wa)	802	WA	0		0							
Fleurieu Peninsula	501	SA	171	6	178				511		2	2
Flinders River	915	QLD	1,846	10	1,852	29	159		70		1	2
Flinders-Cape Barren Islands	301	TAS	389		389							
Fortescue River	708	WA										
Forth River	315	TAS			7,441			69,942				
Frankland River	605	WA	2,558	604	5,544			19,290		75	277	277
Fraser Island	139	QLD										
Gairdner	21	SA	7,945	1,755	9,365			106	16,038		779	779
Gascoyne River	704	WA			0							
Gawler River	505	SA	8,325	49	9,023			6,732	48,458		19	19
Georgina River	1	NT	474		474							
Georgina River	1	QLD	1,825		1,825							
Georgina River	1	SA	4		4							

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Gilbert River	917	QLD	102		102	0	0					0
Glenelg River	238	SA	1		1							
Glenelg River	238	VIC	7,674	2,473	16,349	3,613	20,044	37,911	2,278	8,890	587	1,712
Goomadeer River	822	NT										
Gordon River	308	TAS										
Goulburn River	405	VIC	49,449	1,459	59,749	4,069	22,573	56,657	329,789	38,497	2,485	5,191
Goyder River	825	NT										
Greenough River	701	WA	1,670	2,745	23,864			153,944			645	645
Groote Eylandt	929	NT										
Gwydir River	418	NSW	31,748		35,121			21,991	163,807	24		
Harvey River	613	WA	1,534	3,992	9,315			47,715	98	1,435	3,138	3,138
Hastings River	207	NSW	343		6,032			47,657	704	1,242		
Haughton River	119	QLD	1,976		2,201	116	646	293	5,876	4,418	0	26
Hawkesbury River	212	NSW	2,693	450	35,450	908	5,035	220,781		78,195	3,941	9,009
Hay River	7	NT	4		4							
Hay River	7	QLD										
Hay River	7	SA	0		0							
Herbert River	116	QLD	1,248	0	10,769	54	299	70,657		3,650	0	47
Hinchinbrook Island	115	QLD										
Holroyd River	921	QLD	2		2							
Hopkins River	236	VIC	24,350	1,529	31,391	7,847	43,531	45,988	15,415	43,223	647	3,630
Hunter River	210	NSW	6,791	1,572	45,260	3,123	17,325	92,590	4,094	292,206	5,498	12,566
Huon River	306	TAS	1,092		76,013			180,296		573,714		
Isdell River	804	WA										
Jacky Jacky Creek	101	QLD			13							
Jardine River	927	QLD										
Jeannie River	106	QLD			722			6,393				
Johnstone River	112	QLD	33	10	38,332	197	1,092	352,398		2,637	3	68
Kangaroo Island	513	SA	847	623	1,352	1	8	102	119		154	155
Karuah River	209	NSW	361		1,990			10,077	157	1,803		
Keep River	810	NT	13		98			383				

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Keep River	810	WA	0		24							
Kent River	604	WA	536	244	3,361			22,185			243	243
Kiewa River	402	VIC	1,144	533	4,533	280	1,555	4,247	103	20,642	331	818
King Edward River	806	WA										
King Island	313	TAS										
King-Henty Rivers	309	TAS			66			409				
Kingston Coast	305	TAS	48		202			325				
Kolan River	135	QLD	769	198	1,786	204	1,131	4,318	179	3,848	73	153
Koolatong River	901	NT										
Lachlan River	412	NSW	30,952	1,046	55,087	2,322	12,881	102,435	41,080	66,526	653	1,791
Lake Bancannia	12	NSW	156		156							
Lake Corangamite	234	VIC	11,244	1,015	13,971	3,392	18,817	16,011	7,288	28,742	567	2,605
Lake Frome	4	NSW	67		67							
Lake Frome	4	QLD										
Lake Frome	4	SA	1,052	7	1,057				58		0	0
Lake George	411	NSW	165	3	226	6	32	113			2	79
Lake Torrens	510	SA	106		106							
Latrobe River	226	VIC	5,128	32	26,537	6	35	166,324	4,848	30,498	8	10
Leichhardt River	913	QLD	232		232							
Lennard River	803	WA										
Limmen Bight River	905	NT	1		1							
Liverpool River	823	NT										
Lockhart River	103	QLD			1,716			16,674				
Loddon River	407	VIC	58,041	2,555	67,012	1,708	9,475	4,875	344,107	88,840	428	723
Logan-Albert Rivers	145	QLD	1,715	9	3,962	1	3	7,989	534	13,181	99	100
Lower Murray River	426	NSW	159		159	0	0				0	0
Lower Murray River	426	SA	42,168	4,910	46,317	3,370	18,697	1,325	353,120		1,413	3,129
Lyndon-Minilya Rivers	705	WA										
Mackay	26	NT	48		48							
Mackay	26	SA										
Mackay	26	WA	21		21							

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Macleay River	206	NSW	1,082		3,665			11,548		97		
Macquarie-Bogan Rivers	421	NSW	19,234	1,331	58,887	2,925	16,226	136,579	32,096	220,976	1,147	3,715
Macquarie-Tuggerah Lakes	211	NSW	446		3,637			2,109		31,695		
Mallee	414	SA	23,778	861	24,535	131	728		178,517		124	475
Mallee	414	VIC	11,823	626	12,177	370	2,054		87,004		246	308
Mambray Coast	508	SA	343	4	345			4	61		9	9
Manning River	208	NSW	620	2	5,738	4	21	31,221		3,196	2	5
Maribyrnong River	230	VIC	785	35	939	143	795	278	374	1,802	80	2,228
Maroochy River	141	QLD	460		17,615			100,301		68,151		
Mary River (Qld)	138	QLD	1,342	9	16,773	17	95	126,667	165	11,647	42	66
Mary River (Wa)	818	NT	19		230							
Mcarthur River	907	NT	4		4							
Mersey River	316	TAS	177		28,081			262,220		6,880		
Millicent Coast	239	SA	22,453	20,985	40,841	12,970	71,953	13	62,889	9,925	1,723	3,829
Millicent Coast	239	VIC	6,966	236	7,035	205	1,138		5,569	266	69	107
Mitchell River (Qld)	919	QLD	514	0	22,442	10	57	202,867	463	4,739	0	3
Mitchell River (Vic)	224	VIC	1,078	7	4,589	2	13	20,774	360	16,389	2	2
Moonie River	417	NSW	120		122				173			
Moonie River	417	QLD	7,028	8	7,037	80	446		9,212		0	2
Moorabool River	232	VIC	4,236	43	15,705	373	2,069	1,524	4,538	127,603	295	1,446
Moore-Hill Rivers	617	WA	3,923	7,832	22,209	892	4,948	83,808			3,234	3,822
Morning Inlet	914	QLD	18		18							
Mornington Island	911	QLD										
Moruya River	217	NSW	11	4	550	11	59	4,001		78	3	6
Mossman River	109	QLD	0	7	182	33	181	941			88	388
Moyle River	813	NT			0							
Mulgrave-Russell Rivers	111	QLD	4		6,188	19	108	53,132				2
Murchison River	702	WA			1,661			9,123				
Murray River (Qld)	114	QLD	62		1,735	6	34	14,298		894		2
Murray River (Wa)	614	WA	4,169	5,444	14,893	4	23	61,125	41	192	6,375	6,375
Murray-Riverina	409	NSW	42,987	729	43,389	5,994	33,255	1,363	266,613	4,739	301	2,250

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Murrumbidgee River	410	ACT	46		181			245			0	10
Murrumbidgee River	410	NSW	55,443	880	126,889	5,853	32,469	457,202	175,573	149,079	2,153	7,339
Myponga River	502	SA	90		90				689			
Namoi River	419	NSW	29,599	132	31,484	320	1,777	2,488	142,580	191	133	308
Nicholson River	912	NT	79		79							
Nicholson River	912	QLD	278		278							
Ninghan	619	WA	426	1,209	1,935			2,186			277	277
Noosa River	140	QLD	85		2,157			15,917		3,257	0	0
Norman River	916	QLD	61		61	0	0					0
Normanby River	105	QLD	15	0	250	0	1	807			0	0
Nullarbor	22	SA										
Nullarbor	22	WA	259		259							
O'Connell River	124	QLD	638	3	3,114	75	415	17,413	42	863	3	30
Olive-Pascoe Rivers	102	QLD			2,696			26,053				
Onkaparinga River	503	SA	3,342		3,494			1,498	29,564	1,324		
Onslow Coast	707	WA										
Ord River	809	NT	27		77							
Ord River	809	WA	67		3,455			20,070		5,105		
Otway Coast	235	VIC	2,119	333	14,186	2,412	13,383	77,582	994	5,842	418	1,272
Ovens River	403	VIC	1,432	731	14,090	611	3,388	65,642	1,773	37,298	531	1,221
Paroo River	424	NSW	4,086		4,090				30,703			
Paroo River	424	QLD	37		41							
Pentecost River	808	WA			0							
Pieman River	310	TAS			279			469				
Pine River	142	QLD	1,235		2,454	0	2	8,141		8,702		20
Pioneer River	125	QLD	488		2,468			13,011	4	636		
Piper-Ringarooma Rivers	319	TAS	1,751	69	9,287	18	98	26,151		46,336	44	58
Plane Creek	126	QLD	3,072	2	9,002	42	234	26,682	3,577	25,638	0	5
Port Hedland Coast	709	WA										
Portland Coast	237	VIC	7,883	199	39,616	2,004	11,118	91,639	2,434	189,774	54	689
Preston River	611	WA	1,063	998	6,792			33,777		19,545	2,980	2,980

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Prince Regent River	805	WA										
Proserpine River	122	QLD	1,543		2,690	1	7	2,222	815	10,792		0
Richmond River	203	NSW	1,031	15	22,328	38	212	182,050	6	8,658	7	16
Robinson River	908	NT	2		2							
Roper River	903	NT	63		64							
Rosie River	906	NT										
Ross River	118	QLD	287		295				1,085		0	0
Rubicon River	317	TAS	1,158		14,125			108,749		29,149		
Salt Lake	24	WA	3,046		3,047	644	3,574					46
Sandy Cape Coast	311	TAS			204			1,615				
Sandy Desert	25	WA										
Settlement Creek	910	NT	2		2							
Settlement Creek	910	QLD	107		107				52			
Shannon River	606	WA	217	1,448	28,004			252,898		8,548	370	370
Shoalhaven River	215	NSW	861		8,277			57,571		3,498		
Shoalwater Creek	128	QLD	603		725			259		1,523		
Smithton-Burnie Coast	314	TAS			55,764			514,908				
Snowy River	222	NSW	666	1	1,621	1	5	4,170			1	1
Snowy River	222	VIC	528		2,201			10,581		2,500		
South Alligator River	820	NT	0		1							
South Coast	146	QLD	225		1,951	0	1	13,143		1,013		627
South Gippsland	227	VIC	9,385	498	28,027	117	650	90,627	4,066	56,720	156	245
South-West Coast	307	TAS			3,380			32,741				
Spencer Gulf	511	SA	3,838	1,213	4,571				8,470	4	674	674
Staaten River	918	QLD	28	0	35	0	2				0	0
Stewart River	104	QLD	21		324			1,512		661		
Stradbroke Island	144	QLD	3		8							
Styx River	127	QLD	1,145		1,200			20	1,780	192		
Swan Coast	616	WA	797	4,098	10,264			40,907		10,314	9,703	9,703
Sydney Coast-Georges River	213	NSW	43	0	3,421	0	2	32,032		671	56	129
Tamar River	318	TAS	3,550	1,287	16,228	350	1,942	64,207	10	47,298	349	458

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Tambo River	223	VIC	359		1,102			566	133	4,503		
Thomson River	225	VIC	9,015	257	10,059	16	87	6,354	12,599	36,957	45	54
Todd River	6	NT	4		4							
Torrens River	504	SA	472		829			3,529	1,639	2,799	0	0
Torres Strait Islands	928	QLD										
Towamba River	220	NSW	10		618			4,294		79		
Towamba River	220	VIC										
Towns River	904	NT										
Tully River	113	QLD	12		18,718	7	37	181,439				0
Tuross River	218	NSW	29	5	2,746	10	54	24,612		114	2	4
Tweed River	201	NSW	12	1	5,577	3	18	48,707		346	1	3
Upper Murray River	401	NSW	861	8	7,363	62	343	44,261	40	1,609	6	150
Upper Murray River	401	VIC	2,435	2	6,599	1	8	12,876	71	8,077	3	4
VIC River	811	NT	328		635							
Wakefield River	506	SA	2,166	263	2,314				5,765		33	33
Walker River	902	NT										
Warburton	23	NT										
Warburton	23	SA	4		4							
Warburton	23	WA										
Warrego River	423	NSW	917		926				1,007	4,730		
Warrego River	423	QLD	1,418		1,464				102			
Warren River	607	WA	1,656	1,366	6,244			29,366		7,322	63	63
Water Park Creek	129	QLD	238		398	0	0	1,369	59	1,468	1	1
Watson River	923	QLD										
Wenlock River	925	QLD		0	0						0	0
Werribee River	231	VIC	6,454	12	10,018	1,011	5,611	3,992	14,128	67,227	51	3,452
Whitsunday Island	123	QLD										
Wildman River	819	NT	3		83							
Willochra Creek	509	SA	1,026		1,027				430			
Wimmera-Avon Rivers	415	VIC	26,161	2,536	32,650	1,320	7,323	31,482	10,424	13,649	1,797	3,198
Wiso	28	NT	189		190							

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Wollongong Coast	214	NSW	0		3,422			28,119				
Wooramel River	703	WA			0							
Yarra River	229	VIC	1,849	12	115,678	7	38	245,143	201	892,307	134	242
Yarra Yarra Lakes	618	WA	1,728	4,880	8,224			11,266			1,778	1,778
Min	**-**	**-**	**0**	**0**	**0**	**0**	**0**	**4**	**4**	**4**	**0**	**0**
Max	**-**	**-**	**61,481**	**41,916**	**126,889**	**12,970**	**71,953**	**863,086**	**353,120**	**892,307**	**11,697**	**13,053**
Mean	**-**	**-**	**4,724**	**1,700**	**10,754**	**985**	**5,466**	**56,267**	**34,213**	**38,109**	**746**	**1,139**
Median	**-**	**-**	**620**	**260**	**2,461**	**91**	**506**	**13,077**	**1,476**	**5,311**	**99**	**158**
Standard Deviation	**-**	**-**	**10,609**	**4,756**	**19,927**	**2,013**	**11,166**	**112,378**	**77,791**	**109,325**	**1,711**	**2,260**
Sum	**-**	**-**	**1,034,556**	**186,995**	**2,559,546**	**100,503**	**557,543**	**8,552,589**	**3,489,714**	**4,420,682**	**88,774**	**150,310**

Table J.5

Basin name	Basin number	State	Present value5 of local infrastructure costs from salinity & rising water tables from 2000 to 2020	Present value of downstream infrastructure cost impacts - 1% increase in salt loads	Present value of downstream infrastructure cost impacts - 5% increase in salt loads	Present value of downstream infrastructure cost impacts - 10% increase in salt loads	Present value of downstream infrastructure cost impacts - 1% increase in turbidity	Present value of downstream infrastructure cost impacts - 5% increase in turbidity	Present value of downstream infrastructure cost impacts - 10% increase in turbidity	Present value of downstream infrastructure cost impacts - 1% increase in sediment loads	Present value of downstream infrastructure cost impacts - 5% increase in sediment loads	Present value of downstream infrastructure cost impacts - 10% increase in sediment loads
Adelaide River	817	NT										
Albany Coast	602	WA	974	304	1,518	3,037				0	2	4
Archer River	922	QLD										
Arthur River	312	TAS										
Ashburton River	706	WA										
Avoca River	408	VIC	1,025	240	1,201	2,401				0	0	1
Avon River	615	WA	7,521	1,106	5,528	11,056				0	1	1
Baffle Creek	134	QLD	4				65	249	479	0	0	0
Barkly	29	NT										
Barron River	110	QLD	2,217				5,399	5,907	6,527	148	454	836
Barwon River	233	VIC	15,974				3,468	4,063	4,781	40	88	149
Bathurst And Melville Islands	816	NT										
Bega River	219	NSW	4				19	95	186	17	18	20
Bellinger River	205	NSW	105				5	26	52			
Benanee	413	NSW	446									
Black River	117	QLD					41	202	395	3	14	29
Blackwood River	609	WA	3,154	1,017	5,084	10,167				0	1	2
Blyth River	824	NT										
Border Rivers	416	NSW	252				5,367	7,169	9,415	9	47	95
Border Rivers	416	QLD	163				2,741	3,129	3,609	641	668	703
Boyne River	133	QLD	25							224	565	990
Brisbane River	143	QLD	58				66,063	69,228	73,109	3,725	12,434	23,321
Broken River	404	VIC	10,033				3,703	4,245	4,916	37	43	51
Broughton River	507	SA	1	1,396	6,978	13,956				30	47	69
Brunswick River	202	NSW	10				4	19	37			
Buckingham River	826	NT										
Bulloo River	11	NSW										
Bulloo River	11	QLD										
Bunyip River	228	VIC					6,565	7,256	8,108	2	9	18

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Burdekin River	120	QLD	488				17,822	19,595	21,789	12,391	13,014	13,794
Burnett River	136	QLD	2,953	1,852	9,260	18,521	15,564	16,559	17,773	1,388	2,216	3,252
Burrum River	137	QLD	1,803				2,556	2,926	3,375	40	135	253
Burt	27	NT										
Busselton Coast	610	WA	0	28	141	282	13	65	128	0	0	1
Calliope River	132	QLD	75							1	5	10
Calvert River	909	NT										
Campaspe River	406	VIC	6,240				3,972	4,441	5,010	333	363	401
Cape Leveque Coast	801	WA										
Castlereagh River	420	NSW	1,653				3,678	3,922	4,220	4	22	43
Clarence River	204	NSW	144				197	524	917	32	159	318
Clyde River-Jervis Bay	216	ACT										
Clyde River-Jervis Bay	216	NSW					40	197	385	1	4	8
Coal River	303	TAS										
Coleman River	920	QLD	0									
Collie River	612	WA	0	857	4,287	8,575	69	339	662	62	68	75
Condamine-Culgoa Rivers	422	NSW		31	153	307	2,800	5,833	9,622	0	2	4
Condamine-Culgoa Rivers	422	QLD	1,577	742	3,709	7,417	8,936	10,686	12,864	1,278	1,297	1,321
Cooper Creek	3	NSW										
Cooper Creek	3	QLD										
Cooper Creek	3	SA					5,514	13,491	23,459	5	25	51
Curtis Island	131	NSW										
Curtis Island	131	QLD										
Daintree River	108	QLD	38				283	417	583	1	6	11
Daly River	814	NT										
Darling River	425	NSW	99	775	3,875	7,750	10,643	12,606	15,049	68	98	135
De Grey River	710	WA										
Denmark River	603	WA	0	106	530	1,061	14	70	138	0	0	0
Derwent River	304	TAS	590									
Diamantina River	2	QLD										
Diamantina River	2	SA										

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Don River	121	QLD	99							1	5	10
Donnelly River	608	WA	0	44	219	437	15	75	148	0	0	0
Drysdale River	807	WA										
Ducie River	926	QLD										
East Alligator River	821	NT										
East Coast	302	TAS	2,034									
East Gippsland	221	NSW					6	28	56			
East Gippsland	221	VIC					18	90	178	0	1	3
Embley River	924	QLD										
Endeavour River	107	QLD					19	92	181	1	3	7
Esperance Coast	601	WA	3,079				7	35	70	0	0	0
Eyre Peninsula	512	SA	0									
Finke River	5	NT										
Finke River	5	SA										
Finniss River	815	NT										
Fitzmaurice River	812	NT										
Fitzroy River (Qld)	130	QLD	1,925				49,442	55,313	62,609	4,451	11,833	21,061
Fitzroy River (Wa)	802	WA										
Fleurieu Peninsula	501	SA					2,351	3,018	3,849	1	4	7
Flinders River	915	QLD	7									
Flinders-Cape Barren Islands	301	TAS										
Fortescue River	708	WA										
Forth River	315	TAS										
Frankland River	605	WA		98	490	981				0	0	0
Fraser Island	139	QLD										
Gairdner	21	SA	0									
Gascoyne River	704	WA										
Gawler River	505	SA	0	5,475	27,376	54,752				18	88	174
Georgina River	1	NT										
Georgina River	1	QLD										
Georgina River	1	SA										

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Gilbert River	917	QLD	0							3	14	28
Glenelg River	238	SA										
Glenelg River	238	VIC	6,238	618	3,088	6,176	49	240	471	1	5	10
Goomadeer River	822	NT										
Gordon River	308	TAS										
Goulburn River	405	VIC	15,012				9,896	10,650	11,565	174	275	402
Goyder River	825	NT										
Greenough River	701	WA								0	0	0
Groote Eylandt	929	NT										
Gwydir River	418	NSW					3,742	4,892	6,326	8	39	79
Harvey River	613	WA	0	4,834	24,169	48,339	17,554	18,607	19,888	17	51	95
Hastings River	207	NSW					58	283	556	3	13	25
Haughton River	119	QLD	145				207	395	630	248	250	253
Hawkesbury River	212	NSW	28,114				686	3,367	6,583	2,207	7,303	13,673
Hay River	7	NT										
Hay River	7	QLD										
Hay River	7	SA										
Herbert River	116	QLD	257				2,109	2,583	3,171	11	54	108
Hinchinbrook Island	115	QLD					15	72	143	0	1	3
Holroyd River	921	QLD										
Hopkins River	236	VIC	16,550	273	1,366	2,731	1,092	1,336	1,637	0	1	2
Hunter River	210	NSW	39,211				173	850	1,661	1,252	3,940	7,301
Huon River	306	TAS										
Isdell River	804	WA										
Jacky Jacky Creek	101	QLD										
Jardine River	927	QLD										
Jeannie River	106	QLD										
Johnstone River	112	QLD	359									
Kangaroo Island	513	SA	3				59	294	588			
Karuah River	209	NSW					26	129	258			
Keep River	810	NT										

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Keep River	810	WA										
Kent River	604	WA	0									
Kiewa River	402	VIC	2,703				21	107	211	0	2	4
King Edward River	806	WA										
King Island	313	TAS										
King-Henty Rivers	309	TAS										
Kingston Coast	305	TAS										
Kolan River	135	QLD	444				368	582	849	173	177	181
Koolatong River	901	NT										
Lachlan River	412	NSW	6,311	1,379	6,894	13,787	14,232	14,916	15,754	19	96	193
Lake Bancannia	12	NSW										
Lake Corangamite	234	VIC	11,306	1,244	6,221	12,441				1	5	10
Lake Frome	4	NSW										
Lake Frome	4	QLD										
Lake Frome	4	SA										
Lake George	411	NSW	428									
Lake Torrens	510	SA										
Latrobe River	226	VIC	12				23,710	25,138	26,860	38	160	313
Leichhardt River	913	QLD										
Lennard River	803	WA										
Limmen Bight River	905	NT										
Liverpool River	823	NT										
Lockhart River	103	QLD										
Loddon River	407	VIC	1,636	670	3,350	6,701	165	347	569	347	352	357
Logan-Albert Rivers	145	QLD	5				7,408	8,021	8,770	168	813	1,619
Lower Murray River	426	NSW	0									
Lower Murray River	426	SA	9,520	22,737	113,683	227,367	60,723	63,990	68,007	10	51	103
Lyndon-Minilya Rivers	705	WA										
Mackay	26	NT										
Mackay	26	SA										
Mackay	26	WA										

Basin name	Basin number	State	Present value5 of local infrastructure costs from salinity & rising water tables from 2000 to 2020	Present value of downstream infrastructure cost impacts - 1% increase in salt loads	Present value of downstream infrastructure cost impacts - 5% increase in salt loads	Present value of downstream infrastructure cost impacts - 10% increase in salt loads	Present value of downstream infrastructure cost impacts - 1% increase in turbidity	Present value of downstream infrastructure cost impacts - 5% increase in turbidity	Present value of downstream infrastructure cost impacts - 10% increase in turbidity	Present value of downstream infrastructure cost impacts - 1% increase in sediment loads	Present value of downstream infrastructure cost impacts - 5% increase in sediment loads	Present value of downstream infrastructure cost impacts - 10% increase in sediment loads
Macleay River	206	NSW					80	395	773	97	278	504
Macquarie-Bogan Rivers	421	NSW	14,244	1,966	9,831	19,661	10,084	10,823	11,723	3,410	3,638	3,922
Macquarie-Tuggerah Lakes	211	NSW					3,794	4,224	4,746	5	26	53
Mallee	414	SA	1,947	202	1,010	2,021				0	1	1
Mallee	414	VIC	345				116	580	1,160			
Mambray Coast	508	SA										
Manning River	208	NSW	16				50	244	478	4	19	37
Maribyrnong River	230	VIC	11,914				2,518	2,846	3,247	3	17	35
Maroochy River	141	QLD					3,528	3,932	4,428	42	177	346
Mary River (Qld)	138	QLD	131				18,607	19,745	21,121	328	1,537	3,047
Mary River (Wa)	818	NT										
Mcarthur River	907	NT										
Mersey River	316	TAS										
Millicent Coast	239	SA	11,686	4,648	23,241	46,483				1	4	7
Millicent Coast	239	VIC	209									
Mitchell River (Qld)	919	QLD	18							1	6	12
Mitchell River (Vic)	224	VIC	2				46	228	447	1	5	10
Moonie River	417	NSW										
Moonie River	417	QLD	8									
Moorabool River	232	VIC	6,384				84	415	812	23	58	100
Moore-Hill Rivers	617	WA	3,263				6	27	54	0	0	0
Morning Inlet	914	QLD										
Mornington Island	911	QLD										
Moruya River	217	NSW	19				4	19	37			
Mossman River	109	QLD	1,666				654	881	1,163	1	7	14
Moyle River	813	NT										
Mulgrave-Russell Rivers	111	QLD	12				420	696	1,030	68	339	678
Murchison River	702	WA										
Murray River (Qld)	114	QLD	12									
Murray River (Wa)	614	WA	0				4,339	5,206	6,249	13	56	109
Murray-Riverina	409	NSW	10,811	8,915	44,575	89,151	51,034	58,227	67,154	549	630	732

Basin name	Basin number	State	Present value5 of local infrastructure costs from salinity & rising water tables from 2000 to 2020	Present value of downstream infrastructure cost impacts - 1% increase in salt loads	Present value of downstream infrastructure cost impacts - 5% increase in salt loads	Present value of downstream infrastructure cost impacts - 10% increase in salt loads	Present value of downstream infrastructure cost impacts - 1% increase in turbidity	Present value of downstream infrastructure cost impacts - 5% increase in turbidity	Present value of downstream infrastructure cost impacts - 10% increase in turbidity	Present value of downstream infrastructure cost impacts - 1% increase in sediment loads	Present value of downstream infrastructure cost impacts - 5% increase in sediment loads	Present value of downstream infrastructure cost impacts - 10% increase in sediment loads
Murrumbidgee River	410	ACT	54				6,782	7,590	8,564	256	411	606
Murrumbidgee River	410	NSW	28,773				22,291	23,568	25,113	3,240	3,511	3,848
Myponga River	502	SA		1,287	6,436	12,872	4,524	4,985	5,548	9	37	73
Namoi River	419	NSW	971	613	3,065	6,130	6,645	7,776	9,181	2,029	2,138	2,275
Nicholson River	912	NT										
Nicholson River	912	QLD										
Ninghan	619	WA	0									
Noosa River	140	QLD								0	1	1
Norman River	916	QLD	0									
Normanby River	105	QLD	0									
Nullarbor	22	SA										
Nullarbor	22	WA										
O'Connell River	124	QLD	149				107	200	315	2	10	20
Olive-Pascoe Rivers	102	QLD										
Onkaparinga River	503	SA		13,361	66,807	133,613	21,917	23,349	25,109	42	180	354
Onslow Coast	707	WA										
Ord River	809	NT										
Ord River	809	WA										
Otway Coast	235	VIC	4,737				3,070	3,486	3,990	4	20	41
Ovens River	403	VIC	3,832				59	289	566	21	40	64
Paroo River	424	NSW					4	19	37			
Paroo River	424	QLD										
Pentecost River	808	WA										
Pieman River	310	TAS										
Pine River	142	QLD	114				15,531	16,504	17,689	182	704	1,355
Pioneer River	125	QLD					2,868	3,233	3,677	130	648	1,295
Piper-Ringarooma Rivers	319	TAS	76									
Plane Creek	126	QLD	24				1,052	1,413	1,863	6	32	65
Port Hedland Coast	709	WA										
Portland Coast	237	VIC	3,527	880	4,402	8,803	38	189	370	0	2	4
Preston River	611	WA	0	722	3,610	7,220	54	267	522	1	5	10

Basin name	Basin number	State	Present value[5] of local infrastructure costs from salinity & rising water tables from 2000 to 2020	Present value of downstream infrastructure cost impacts - 1% increase in salt loads	Present value of downstream infrastructure cost impacts - 5% increase in salt loads	Present value of downstream infrastructure cost impacts - 10% increase in salt loads	Present value of downstream infrastructure cost impacts - 1% increase in turbidity	Present value of downstream infrastructure cost impacts - 5% increase in turbidity	Present value of downstream infrastructure cost impacts - 10% increase in turbidity	Present value of downstream infrastructure cost impacts - 1% increase in sediment loads	Present value of downstream infrastructure cost impacts - 5% increase in sediment loads	Present value of downstream infrastructure cost impacts - 10% increase in sediment loads
Prince Regent River	805	WA										
Proserpine River	122	QLD	0				2,631	3,074	3,608	216	1,081	2,162
Richmond River	203	NSW	50				49	118	205	0	0	0
Robinson River	908	NT										
Roper River	903	NT										
Rosie River	906	NT										
Ross River	118	QLD					20,268	21,654	23,358	964	3,451	6,560
Rubicon River	317	TAS										
Salt Lake	24	WA	254									
Sandy Cape Coast	311	TAS										
Sandy Desert	25	WA										
Settlement Creek	910	NT										
Settlement Creek	910	QLD										
Shannon River	606	WA	0				10	47	94	0	0	0
Shoalhaven River	215	NSW					15	73	144	1	2	4
Shoalwater Creek	128	QLD										
Smithton-Burnie Coast	314	TAS										
Snowy River	222	NSW	4				208	332	484	2	12	23
Snowy River	222	VIC					27	132	259	0	2	4
South Alligator River	820	NT										
South Coast	146	QLD	3,477				8,463	9,190	10,069	62	275	541
South Gippsland	227	VIC	492				3,656	4,061	4,554	5	23	46
South-West Coast	307	TAS										
Spencer Gulf	511	SA	1									
Staaten River	918	QLD	0									
Stewart River	104	QLD										
Stradbroke Island	144	QLD										
Styx River	127	QLD										
Swan Coast	616	WA	3	14,037	70,187	140,373	1,195	2,109	3,205	32	78	136
Sydney Coast-Georges River	213	NSW	403									
Tamar River	318	TAS	604									

Basin name	Basin number	State	Present value5 of local infrastructure costs from salinity & rising water tables from 2000 to 2020	Present value of downstream infrastructure cost impacts - 1% increase in salt loads	Present value of downstream infrastructure cost impacts - 5% increase in salt loads	Present value of downstream infrastructure cost impacts - 10% increase in salt loads	Present value of downstream infrastructure cost impacts - 1% increase in turbidity	Present value of downstream infrastructure cost impacts - 5% increase in turbidity	Present value of downstream infrastructure cost impacts - 10% increase in turbidity	Present value of downstream infrastructure cost impacts - 1% increase in sediment loads	Present value of downstream infrastructure cost impacts - 5% increase in sediment loads	Present value of downstream infrastructure cost impacts - 10% increase in sediment loads
Tambo River	223	VIC					36	175	344	0	2	4
Thomson River	225	VIC	48				789	2,129	3,737	78	249	463
Todd River	6	NT										
Torrens River	504	SA		9,159	45,797	91,593	9,307	10,014	10,873	36	141	273
Torres Strait Islands	928	QLD										
Towamba River	220	NSW					19	93	182	0	1	2
Towamba River	220	VIC										
Towns River	904	NT										
Tully River	113	QLD	2				1,087	1,328	1,625	5	14	25
Tuross River	218	NSW	14				22	109	215	0	2	4
Tweed River	201	NSW	8				193	414	681	34	169	339
Upper Murray River	401	NSW	802				65	152	259	31	34	36
Upper Murray River	401	VIC	5				23	114	225	121	123	127
VIC River	811	NT										
Wakefield River	506	SA	0									
Walker River	902	NT										
Warburton	23	NT										
Warburton	23	SA										
Warburton	23	WA										
Warrego River	423	NSW					4	19	37			
Warrego River	423	QLD										
Warren River	607	WA	0	390	1,948	3,897	22	110	216	0	0	0
Water Park Creek	129	QLD	0				66	322	631	19	93	187
Watson River	923	QLD										
Wenlock River	925	QLD										
Werribee River	231	VIC	18,871				1,831	2,133	2,500	85	226	402
Whitsunday Island	123	QLD										
Wildman River	819	NT										
Willochra Creek	509	SA		103	515	1,030				0	2	3
Wimmera-Avon Rivers	415	VIC	7,773				78	381	745			
Wiso	28	NT										

Basin name	Basin number	State	Present value5 of local infrastructure costs from salinity & rising water tables from 2000 to 2020	Present value of downstream infrastructure cost impacts - 1% increase in salt loads	Present value of downstream infrastructure cost impacts - 5% increase in salt loads	Present value of downstream infrastructure cost impacts - 10% increase in salt loads	Present value of downstream infrastructure cost impacts - 1% increase in turbidity	Present value of downstream infrastructure cost impacts - 5% increase in turbidity	Present value of downstream infrastructure cost impacts - 10% increase in turbidity	Present value of downstream infrastructure cost impacts - 1% increase in sediment loads	Present value of downstream infrastructure cost impacts - 5% increase in sediment loads	Present value of downstream infrastructure cost impacts - 10% increase in sediment loads
Wollongong Coast	214	NSW					8	39	79	12	29	51
Wooramel River	703	WA										
Yarra River	229	VIC	597				44,322	46,718	49,602	171	531	982
Yarra Yarra Lakes	618	WA	0									
Min	-	-	**0**	**28**	**141**	**282**	**4**	**19**	**37**	**0**	**0**	**0**
Max	-	-	**39,211**	**22,737**	**113,683**	**227,367**	**66,063**	**69,228**	**73,109**	**12,391**	**13,014**	**23,321**
Mean	-	-	**2,821**	**2,917**	**14,587**	**29,174**	**5,767**	**6,501**	**7,403**	**356**	**665**	**1,051**
Median	-	-	**144**	**857**	**4,287**	**8,575**	**537**	**866**	**1,394**	**9**	**33**	**52**
Standard Deviation	-	-	**6,219**	**5,013**	**25,065**	**50,129**	**12,140**	**13,025**	**14,199**	**1,343**	**2,143**	**3,466**
Sum	-	-	**341,375**	**102,109**	**510,544**	**1,021,089**	**634,390**	**715,106**	**814,275**	**41,977**	**78,422**	**123,977**

Appendix K Metadata

Metadata – National Soil Treatment Benefit Cost Analysis

Category	Element	Comment
Data	Title	National Soil Treatment Benefit Cost Analysis
	Custodian	CSIRO Land and Water
	Jurisdiction	Australia
Description	Abstract	This dataset contains the outputs of a national benefit cost analysis of lime and gypsum application to manage acidic and sodic soils. The analysis evaluated the net benefits of adopting the soil treatment option in perpetuity and used a private landholder discount rate of 10%. The grids in this dataset include: 1. npvl. The net present value of lime application in $/ha. 2. npvg. The net present value of gypsum application in $/ha 3. npvlg. The net present value of lime and gypsum application in $/ha. 4. npv_max. Maximum NPV of liming and/or gypsum application in $/ha 5. rec. Soil treatment option with the highest net present value. This integer grid identifies which of doing nothing, liming, gypsum application or combined lime and gypsum application has the highest returns.
	Search Word(s)	Benefit Cost Analysis, Soil Treatment, Lime Application, Gypsum Application, Sodic Soils, Acidic Soils
	Geographic Extent Name(s) OR	Australia, the extent of agricultural land with yield constraints from acidic or sodic soils, determined from the Audit's 1996/97 land use map and surfaces of relative yield from sodic and acidic soils produced under the Audit. For all grids, cell size and extent are based on agricultural areas depicted by 1996/97 Land Use of Australia, 1:1 Million, Version 2 Projection: geographic Datum: WGS84 Spheroid: WGS84 Cell size: 0.010 dd
	Geographic Extent Polygon(s)	
Data Currency	Beginning date	1996/97
	Ending date	2001
Data Status	Progress	Complete
	Maintenance and Update Frequency	Not Planned

Category	Element	Comment
Access	Access Constraints	Subject to the terms and condition of the data access and management agreement between the National Land and Water Audit and ANZLIC parties.
	Stored Data Format	Arc/Info grids
	Available Format	Arc/Info grids
Data Quality	Lineage	The data sources include: ▪ The National Land and Water Resource Audit's Profit Function Surface dataset ▪ Gross Benefit surfaces from the Economics of Australian Soil Conditions dataset held by the Audit and produced by CSIRO Land and Water ▪ Relative Yield surfaces from the Economics of Australian Soil Conditions dataset held by the Audit and produced by CSIRO Land and Water ▪ Interviews with private suppliers of lime and gypsum on their costs of application, transport and purchase ▪ Costs of transporting, spreading and purchasing lime compiled under theme five of the National Land and Water Resources Audit. ▪ The pH Buffering Capacity grids produced for the Australian Soil Resource Information System by CSIRO for the Audit.
	Positional Accuracy	Costs of lime and gypsum application in the model were assumed homogenous within each State/Territory. The benefits were determined by assessing increases in profit at full equity resulting from increases to crop/pasture yields caused by the application of lime and/or gypsum. The modelling of profit at full equity, also undertaken in theme 6.1 of the National Land and Water Resources Audit, produced national grids with a 1km pixel resolution. This creates varying degrees of positional accuracy in different locations of Australia. As a general rule, the data should be interpreted at broad regional levels, such as drainage basins.
	Attribute Accuracy	Estimates of lime application, transport and purchase costs were obtained from surveys of industry representatives under theme 5 of the National Land and Water Resources Audit. This was done for each State and Territory of Australia. The spreading and transport costs associated with gypsum application were assumed the same as those incurred in lime application, due to the similar nature of the activities. The attribute accuracy is in-part based on surveys of industry representatives and the Profit Function Data Sets produced under theme 6.1 of the Audit.
	Logical Consistency	The surfaces of net present value were derived from benefit cost analysis of lime/gypsum application. In addition to estimates of application costs, the BCA was linked to the Profit Function Surfaces and gross benefit surfaces also produced under theme 6.1 of the Audit.
	Completeness	The dataset covers the intensively used agricultural regions and the rangelands. The total agricultural area represented in the dataset is equal to 473 million hectares.
Contact Information	Contact Organisation	CSIRO Land and Water

Category	Element	Comment
	Contact Position	Stefan Hajkowicz or Mike Young
	Mail Address	PMB 2
	Suburb or Place or Locality	Glen Osmond
	State	South Australia
	Postcode	5064
	Telephone	08 8303 8419
	Facsimile	08 8303 8582
	Electronic Mail Address	Stefan.Hajkowicz@csiro.au Mike.Young@csiro.au
Additional Metadata	Additional Metadata	Details on how this data was compiled can be found in consulting reports by CSIRO Land and Water to the National Land and Water Resources Audit.
	Metadata data	19 February 2002

Metadata for the Downstream Cost Calculator Model

Category	Model metadata element	Comment
Model	Title	Downstream Cost Calculator
	Custodian	Resource Economics Unit (1) CSIRO Land and Water (2)
	Jurisdiction	1. Western Australia 2. Australia
Description	Abstract	This spreadsheet model is used to determine the downstream costs of salinity, turbidity, erosion and sedimentation to urban and industrial water users. It was produced by the Resource Economics Unit (REU) in Perth and further developed by URS natural resource management consultants and CSIRO Land and Water. It applies a set of infrastructure damage cost functions, developed through theme 6.1 of the National Land and Water Resources Audit, to water use data by State and River Basin. The model determines the present value of costs from marginal increases in water salinity, turbidity and sediment loads over the next 20 years (2000 to 2020). All dollars are given in 1996/97 Australian Dollars. The percentage increase in the water quality parameters is given as an input to the model.
	Search Word(s)	Salinity, Turbidity, Erosion, Sedimentation, Economics, Cost of, Infrastructure damage
Model Currency	Beginning date	1999
	Ending date	2002
Model Status	Progress	Complete
	Maintenance and Update Frequency	No updates currently planned
Access	Access Constraint	Subject to the terms and condition of the data access and management agreement between the National Land and Water Audit and ANZLIC parties.
Model verification	Lineage	This model applies a set of damage cost functions that relate levels of water salinity, turbidity and sedimentation to cost. Water use data is taken from theme one of the National Land and Water Resource Audit. The unavailability of data on water quality trends requires modelling of scenarios for water parameter increases.

Category	Model metadata element	Comment
Model Logic	Data elements	The following list of major variables is given as inputs to the model under the "Assumptions" spreadsheet: 1. The discount rate (number) 2. The time period (years) 3. National increase in river/stream salinity (%) 4. National increase in river/stream turbidity (%) 5. National increase in river/stream sediment loads (%) 6. Use of only river basins deemed to be at risk (Yes/No)
	Constants	Water use per river basin Water use damage cost functions Water quality parameters per river basin (where available)
	Logical Consistency	Data on water use is stored for each river basin and each State/Territory. This is related to marginal cost through a series of damage cost functions developed under theme 6.1 of the National Land and Water Resources Audit.
	Critical data input	The model results are most sensitive to the percentage increases in turbidity, erosion and sedimentation. The results are also sensitive to the discount rate used in calculating the present value of marginal damage costs.
	Data Flow	
	Interpretation	The model results can be interpreted as "what-if" scenarios. By adjusting the percentage increase in water quality and the discount rate the user is able to obtain an estimate of the present value of costs that would be likely to result.
	Limits	The output data is limited by the accuracy of the water use data and the water quality data. A series of assumptions are made in the model as listed on the spreadsheet titled "Assumptions". These should be considered when using the model's results. The results are most sensitive to the values chosen for the discount rate and percentage increases in water quality parameters.
Contact Information	Contact Organisation	CSIRO Land and Water
	Contact Position	Policy and Economic Research Unit
	Mail Address 1	PMB 2, Glen Osmond, SA 5064
	Mail Address 2	
	Suburb or Place or Locality	Glen Osmond
	State or Locality 2	South Australia
	Country	Australia
	Postcode	5064
	Telephone	08 8303 8419

Category	Model metadata element	Comment
	Facsimile	08 8303 8582
	Electronic Mail Address	Stefan.Hajkowicz@csiro.au or mike.young@csiro.au

Metadata for the Downstream Cost Calculator Model

Category	Model metadata element	Comment
Model	Title	Downstream Cost Calculator
	Custodian	Resource Economics Unit (1) CSIRO Land and Water (2)
	Jurisdiction	1. Western Australia 2. Australia
Description	Abstract	This spreadsheet model is used to determine the downstream costs of salinity, turbidity, erosion and sedimentation to urban and industrial water users. It was produced by the Resource Economics Unit (REU) in Perth and further developed by URS natural resource management consultants and CSIRO Land and Water. It applies a set of infrastructure damage cost functions, developed through theme 6.1 of the National Land and Water Resources Audit, to water use data by State and River Basin. The model determines the present value of costs from marginal increases in water salinity, turbidity and sediment loads over the next 20 years (2000 to 2020). All dollars are given in 1996/97 Australian Dollars. The percentage increase in the water quality parameters is given as an input to the model.
	Search Word(s)	Salinity, Turbidity, Erosion, Sedimentation, Economics, Cost of, Infrastructure damage
Model Currency	Beginning date	1999
	Ending date	2002
Model Status	Progress	Complete
	Maintenance and Update Frequency	No updates currently planned
Access	Access Constraint	Subject to the terms and condition of the data access and management agreement between the National Land and Water Audit and ANZLIC parties.
Model verification	Lineage	This model applies a set of damage cost functions that relate levels of water salinity, turbidity and sedimentation to cost. Water use data is taken from theme one of the National Land and Water Resource Audit. The unavailability of data on water quality trends requires modelling of scenarios for water parameter increases.
Model Logic	Data elements	The following list of major variables is given as inputs to the model under the “Assumptions” spreadsheet: 1. The discount rate (number) 2. The time period (years) 3. National increase in river/stream salinity (%) 4. National increase in river/stream turbidity (%) 5. National increase in river/stream sediment loads (%) 6. Use of only river basins deemed to be at risk (Yes/No)

Category	Model metadata element	Comment
	Constants	Water use per river basin Water use damage cost functions Water quality parameters per river basin (where available)
	Logical Consistency	Data on water use is stored for each river basin and each State/Territory. This is related to marginal cost through a series of damage cost functions developed under theme 6.1 of the National Land and Water Resources Audit.
	Critical data input	The model results are most sensitive to the percentage increases in turbidity, erosion and sedimentation. The results are also sensitive to the discount rate used in calculating the present value of marginal damage costs.
	Data Flow	
	Interpretation	The model results can be interpreted as “what-if” scenarios. By adjusting the percentage increase in water quality and the discount rate the user is able to obtain an estimate of the present value of costs that would be likely to result.
	Limits	The output data is limited by the accuracy of the water use data and the water quality data. A series of assumptions are made in the model as listed on the spreadsheet titled “Assumptions”. These should be considered when using the model’s results. The results are most sensitive to the values chosen for the discount rate and percentage increases in water quality parameters.
Contact Information	Contact Organisation	CSIRO Land and Water
	Contact Position	Policy and Economic Research Unit
	Mail Address 1	PMB 2, Glen Osmond, SA 5064
	Mail Address 2	
	Suburb or Place or Locality	Glen Osmond
	State or Locality 2	South Australia
	Country	Australia
	Postcode	5064
	Telephone	08 8303 8419
	Facsimile	08 8303 8582
	Electronic Mail Address	Stefan.Hajkowicz@csiro.au or mike.young@csiro.au

Metadata – 1996/97 Land Use Map

Category	Element	Comment
Data	Title	1996/97 Land Use Map (linked to profit function surfaces)
	Custodian	CSIRO Land and Water
	Jurisdiction	Adelaide, Australia
Description	Abstract	This dataset contains a national grid, of roughly 1km cell size, showing the major forms of agricultural commodity production. The forms of commodity production, classified in the land use map as either dryland or irrigated, include: Agroforestry, Almonds, Apples, Apricots, Avocados, Bananas, Barley, Beef, Canola, Cereals Ex Rice, Cereals For Hay, Cherries, Chick, Peas, Corriander, Cotton, Dairy, Faba Beans, Fennel, Field Peas, Grain Sorghum, Grapes, Lavender, Lemons/Lime, Lentils, Lupins, Macadamia, Maize, Mandarins, Mangoes, Millet, Mung Beans, Mustard, Native Pasture, Nectarines, Non-Cereal Crops For, Nurseries/Flowers, Oats, Oil Poppies, Olives, Oranges, Other Field Beans, Other Sown Pastures, Other Stone Fruit, Other Vegetables, Peaches, Peanuts, Pears, Pineapples, Plums, Potatoes, Pure Lucerne, Pyrethrum, Rambutan, Residual, Rice, Safflower, Sheep, Sown Pasture, Soybeans, Sugar Cane, Sunflower, Tobacco, Triticale, Turf, Vetches and Wheat. The land use map is derived from the 1996/97 land use map of Australia produced by the Bureau of Rural Sciences for the National Land and Water Resources Audit. Some modifications were made to the BRS land use map in order to capture required details on commodity production and allocate pasture to livestock production. The BRS land use map locates over 60 forms of agricultural land use, classified as either dryland or irrigated. Details on the BRS land use map are available in metadata and other supporting documents from the Audit.
	Search Word(s)	Commodity Production, Land Use
	Geographic Extent Name(s) OR	Australia, extent of agricultural land use, including the rangelands. Cell size and extent are based on agricultural areas depicted by 1996/97 Land Use of Australia, 1:1 Million, Version 2 Projection: Geographic Datum: WGS84 Spheroid: WGS84 Cell size: 0.010 dd
	Geographic Extent Polygon(s)	
Data Currency	Beginning date	1996/97
	Ending date	1996/97
Data Status	Progress	Complete
	Maintenance and Update Frequency	Not Planned

Category	Element	Comment
Access	Access Constraints	Subject to the terms and condition of the data access and management agreement between the National Land and Water Audit and ANZLIC parties.
	Stored Data Format	Arc/Info grids
	Available Format	Arc/Info grids
Data Quality	Lineage	This land use map is primarily derived from the 1996/97 Land Use map of Australia (version 2a) produced by the Bureau of Rural Sciences for the National Land and Water Resources Audit. Metadata on the original land use map is available from the Audit office. The main changes are the classification of all pasture land into beef, sheep or dairy based on satellite data and livestock statistics from the Australian Bureau of Statistics. In addition, data on cereal production from the Australian Bureau of Statistics was used to assign wheat to regions with known wheat production, but no record of wheat production in the original land use map. Beef, sheep and dairy land uses were assigned to pasture on a pro rata basis. This involved first determining the number of beef cattle, dairy cattle and sheep per statistical local area (SLA). These numbers were then converted to Dry Sheep Equivalents (DSE) by standard conversions, providing estimates of livestock numbers in commensurable units. The area of pasture within an SLA assigned to each livestock type was proportional to the number of livestock. For example, if 60% of the DSEs within an SLA were dairy, then 60% of the pasture area within the SLA was also assigned to dairy. Cloud adjusted, growing season normalised difference vegetation index (NDVI), derived from satellite images, was used to assign greener (or healthier) pasture first to dairy, then to beef and lastly to sheep.
	Positional Accuracy	Considerable generalisations are made in the land use map in areas of intensive land use, e.g. irrigated areas. These areas are likely to contain numerous land uses within a 1km pixel, yet are represented in the map as a single land use. The nature of these generalisations needs to be considered when using the land use map in intensive land use zones.
	Attribute Accuracy	The categories mapped in the land use map are limited by the commodity types for which production data is available, at the Statistical Local Area level, from the Australian Bureau of Statistics. This excludes some types of land use that are of potential economic significance in certain regions.
	Logical Consistency	
	Completeness	The dataset covers the intensively used agricultural regions and the rangelands. The total agricultural area represented in the dataset is equal to 473 million hectares.
Contact Information	Contact Organisation	CSIRO Land and Water
	Contact Position	Stefan Hajkowicz or Mike Young
	Mail Address	PMB 2

Category	Element	Comment
	Suburb or Place or Locality	Glen Osmond
	State	South Australia
	Postcode	5064
	Telephone	08 8303 8419
	Facsimile	08 8303 8582
	Electronic Mail Address	Stefan.Hajkowicz@csiro.au Mike.Young@csiro.au
Additional Metadata	Additional Metadata	Additional information on how this data was compiled can be found in consulting reports by CSIRO Land and Water, submitted to the National Land and Water Resources Audit.
	Metadata data	19 February 2002

Metadata – Economics of Australian Soil Conditions

Category	Element	Comment
Data	Title	Cost of Salinity to Local Infrastructure
	Custodian	CSIRO Land and Water
	Jurisdiction	Australia
Description	Abstract	This dataset contains 14 national surfaces, represented by 1km grids, relating to the cost of salinity damage to local infrastructrure. The infrastructure cost impacts are limited to those that occur at the location of salinity problem, downstream and other offsite impacts are not covered. All dollar values are given in 1996/97 Australian dollars. Each is described as follows: 1. total2000best: This is the total cost in dollars to all infrastructure (buildings, road, rail and bridges) based on the “best estimate” as described in “the theme 6.1 Audit reports. Costs are estimates of the impact of the current (2000) extent of salinity. This layer is equal to the sum of pop2000best, road2000best, rail2000best and bridg2000best. 2. total2020best : This is the total cost in dollars to all infrastructure (buildings, road, rail and bridges) based on the “best estimate” as described in the theme 6.1 Audit reports. Costs are estimates of the impact of the extent of salinity projected to occur in 2020. This layer is equal to the sum of pop2020best, road2020best, rail2020best and bridge2020best. 3. total2000low: This is the total cost in dollars to all infrastructure (buildings, road, rail and bridges) based on the “low estimate” as described in the theme 6.1 Audit reports. Costs are estimates of the impact of the current (2000) extent of salinity. 4. total2020low: This is the total cost in dollars to all infrastructure (buildings, road, rail and bridges) based on the “low estimate” as described in the theme 6.1 Audit reports. Costs are estimates of the impact of the extent of salinity projected to occur in 2020 5. total2000high: This is the total cost in dollars to all infrastructure (buildings, road, rail and bridges) based on the “high estimate” as described in the theme 6.1 Audit reports. Costs are estimates of the impact of the current (2000) extent of salinity. 6. total2020high: This is the total cost in dollars to all infrastructure (buildings, road, rail and bridges) based on the “high estimate” as described in the theme 6.1 Audit reports. Costs are estimates of the impact of the extent of salinity projected to occur in 2020 7. pop2000best: This is the cost in dollars to the general infrastructure component (buildings etc., derived from population) based on the “best estimate” as described in the theme 6.1 Audit reports. Costs are estimates of the impact of the current (2000) extent of salinity. 8. pop2020best: This is the cost in dollars to the general infrastructure component (buildings etc., derived from population) based on the “best estimate” as described in the theme 6.1 Audit reports. Costs are estimates of the impact of the extent of salinity projected to occur in 2020 9. road2000best: This is the cost in dollars to the road component of infrastructure based on the “best estimate” as described in “the theme 6.1 Audit reports. Costs are estimates of the impact of the current

Category	Element	Comment
		(2000) extent of salinity. 10. road2020best: This is the cost in dollars to the road component of infrastructure based on the “best estimate” as described in “the theme 6.1 Audit reports. Costs are estimates of the impact of the extent of salinity projected to occur in 2020 11. rail2000best: This is the cost in dollars to the rail component of infrastructure based on the “best estimate” as described in the theme 6.1 Audit reports. Costs are estimates of the impact of the current (2000) extent of salinity. 12. rail2020best: This is the cost in dollars to the rail component of infrastructure based on the “best estimate” as described in the theme 6.1 Audit reports. Costs are estimates of the impact of the extent of salinity projected to occur in 2020 13. bridg2000best: This is the cost in dollars to the bridge component of infrastructure based on the “best estimate” as described in the theme 6.1 Audit reports. Costs are estimates of the impact of the current (2000) extent of salinity. 14. bridg2020best: This is the cost in dollars to the bridge component of infrastructure based on the “best estimate” as described in the theme 6.1 Audit reports. Costs are estimates of the impact of the extent of salinity projected to occur in 2020
	Search Word(s)	Salinity, Infrastructure, Costs
	Geographic Extent Name(s) OR	Australia For all grids, cell size and extent are based on agricultural areas depicted by 1996/97 Land Use of Australia, 1:1 Million, Version 2 Projection: geographic Datum: WGS84 Spheroid: WGS84 Cell size: 0.010 dd
	Geographic Extent Polygon(s)	
Data Currency	Beginning date	1996/97
	Ending date	1996/97
Data Status	Progress	Complete
	Maintenance and Update Frequency	Undecided
Access	Access Constraints	Subject to the terms and condition of the data access and management agreement between the National Land and Water Audit and ANZLIC parties.
	Stored Data Format	Arc/Info grids
	Available Format	Arc/Info grids

Category	Element	Comment
Data Quality	Lineage	The data sources for the "Cost of Salinity to Infrastructure" dataset include: (a) Salinity maps from theme two of the National Land and Water Resources Audit. (b) Topo-250K Series 1: Infrastructure for all Australia. AUSLIG (now GeoScience Australia), 2000. For 1:250K scale road, rail and bridge layers (c) CDATA96, ABS 1997 for 1996 Collection district boundaries and population data (d) Cost functions as described in National Land and Water Resources Audit theme 6.1 reports.
	Positional Accuracy	These data sets were derived by combining salinity hazard areas with infrastructure data. The infrastructure maps were primarily derived from Auslig mapping at the 1:250,000 scale. These maps located major roads, rail and bridges. Some infrastructure data was assigned to population, using 1996 census collector districts for population density. The salinity risk regions were defined under theme two of the Audit. These data sources generally enable interpretation of the local infrastructure cost impact grids at the regional level, e.g. river basins. Note that regions mapped as saline were also assumed to have watertable problems.
	Attribute Accuracy	The attribute accuracy is limited by the accuracy of salinity area estimates under theme two of the National Land and Water Resources Audit and the cost impact functions developed through theme 6.1 of the Audit. The cost functions were developed from surveys of local government engineers and road/rail network operators. They determined the additional costs imposed by rising water tables and soil salinity.
	Logical Consistency	Salinity polygons were intersected with population and infrastructure layers to ascertain population numbers, km of road, km of rail and number of bridges that occurred in salt affected areas. Cost functions were then applied to these and the result aggregated to 0.01dd pixels concordant with the BRS land use grid.
	Completeness	Complete
Contact Information	Contact Organisation	CSIRO Land and Water
	Contact Position	Stefan Hajkowicz or Mike Young
	Mail Address	PMB 2
	Suburb or Place or Locality	Glen Osmond
	State	South Australia
	Postcode	5064
	Telephone	08 8303 8419
	Facsimile	08 8303 8582
	Electronic Mail Address	Stefan.Hajkowicz@csiro.au Mike.Young@csiro.au

Category	Element	Comment
Additional Metadata	Additional Metadata	Cost functions used and all assumptions made are detailed in the consulting reports by CSIRO Land and Water to the National Land and Water Resources Audit, theme 6.1.
	Metadata data	18 February 2002

Metadata – Profit Function Surfaces for Five Year Mean (1992/93 to 1996/97)

Category	Element	Comment
Data	Title	Profit Function Surfaces, Averaged for 1992/93 to1996/97
	Custodian	CSIRO Land and Water
	Jurisdiction	Australia
Description	Abstract	This dataset contains a set of national surfaces, represented on a 1km grid, used to determine profit at full equity (PFE) from agricultural production over the five year period 1992/93 to 1996/97. It is based on obtaining mean values over the period for prices and yields. Note that the variable and fixed costs are just given for 1996/97, only the variables relating to yields and prices are based on mean values over the five-year period. All variables used to determine PFE are stored for each 1km grid cell and relate to a single landuse. All dollar values are given in 1996/97 Australian dollars. Profit at full equity is determined as: pfe5yr = (p15yr * q15yr * trn5yr) + (p25yr * q25yr * q15yr) – (qc * q15yr) – ac – (wp * wr) – flc – foc – fdc Where: pfe5yr = Profit at full equity in $/ha/yr p1_5yr = Price of primary product in $ per tonne. q1_5yr = Yield of primary product in tonnes per hectare for crops/horticulture and dry sheep equivalents (DSE) per hectare for livestock trn_5yr = Turn off rate, the portion of livestock sold over the year. For crops this is set to 1. p2_5yr = Price of secondary product, being either only milk ($/litre) or wool ($/kg). For all non-dairy and sheep land uses this equals zero. q2_5yr = Yield of secondary product, being only milk (litres / DSE) or (kg / DSE) qc = Quantity dependent variable costs ($/tonne or $/DSE). These are costs that vary as a function of how much is produced. For 1996/97 only. ac = Area dependent variable costs ($/ha/yr). These are variable costs that are determined by the area of land harvested. For 1996/97 only. wp = Charge for water in $/megalitre. These represent water use charges imposed by water supply agencies. For 1996/97 only. wr = Water requirement of the crop/pasture in megalitres/ha/yr. For 1996/97 only. foc = Fixed operating costs ($/ha/yr). For 1996/97 only. flc = Fixed labour costs ($/ha/yr). This is an imputed labour wage paid to the farmer. For 1996/97 only. fdc = Fixed depreciation costs ($/ha/yr). For 1996/97 only. Another variable also supplied is estimated government support to agriculture in 1996/97 through avenues such as taxation subsidies, research and marketing. It is measured in $/ha/yr and is stored on the grid called “support”.

Category	Element	Comment
		In addition to these surfaces the dataset contains the results of revenue, costs and profit: rev_5yr = Gross revenue ($/ha/yr) tc_5yr = Total costs ($/ha/yr) pfe_5yr = Profit at full equity ($/ha/yr)
	Search Word(s)	Economics, Natural Resources, Agriculture Profit
	Geographic Extent Name(s) OR	Australia, extent of agricultural land use, including the rangelands. Cell size and extent are based on agricultural areas depicted by 1996/97 Land Use of Australia, 1:1 Million, Version 2 Projection: geographic Datum: WGS84 Spheroid: WGS84 Cell size: 0.010 dd
	Geographic Extent Polygon(s)	
Data Currency	Beginning date	1992/93
	Ending date	1996/97
Data Status	Progress	Complete
	Maintenance and Update Frequency	Not Planned
Access	Access Constraints	Subject to the terms and condition of the data access and management agreement between the National Land and Water Audit and ANZLIC parties.
	Stored Data Format	Arc/Info grids
	Available Format	Arc/Info grids

Category	Element	Comment
Data Quality	Lineage	The data sources for the profit function sources include: (a) The Australian Bureau of Statistics statistical local area data on farm-gate prices and regional production. (b) Fixed and variable cost estimates from the Australian Bureau of Agriculture and Resource Economics' ASPIRE package. (c) Satellite data, namely cloud adjusted, growing season normalised difference vegetation index supplied by Environment Australia. (d) Contracted data supplied by ABARE at broad regional levels on costs and returns from broadacre agriculture. (e) State Government gross margin handbooks. (f) Publications on irrigation water use (ABS 2000). (g) Reports from the Industry Commission and Productivity Commission (Productivity Commission 1998, Industry Commission 1996) on support to agricultural industries in Australia. (h) The National Land and Water Resource Audit's 1996/97 landuse map of Australia. (i) Consultation with regional farm management experts. Data from ABS, ABARE, Gross Margin Handbooks and the other publications were matched to the land use map of Australia. Satellite data was used to develop a more detailed land use map representing commodity production and was also used allocate crop/pasture yields. Details on how the profit function surfaces were constructed can be found in reports supplied to the National Land and Water Resources Audit, under theme six "Capacity to Change". References ABS (2000) Water Account for Australia, 1993-94 to 1996-97, Australian Bureau of Statistics, Publication 4610.0, Canberra. Productivity Commission (1998) Trade and Assistance Review 1997-98, Annual Report Series 1997-98, AusInfo, Canberra. Industry Commission (1996) State Territory and Local Government Assistance to Industry, Report No 55, AGPS, Canberra.
	Positional Accuracy	Although stored using a 1km grid the data generally has a positional accuracy relevant to broad regions such as river basins. The grids have been generated from data at varying levels of spatial detail. Satellite data, used to locate land uses and distribute crop/pasture yields, was obtained from grids of roughly 1km pixel size. Other economic data on agricultural production was obtained for statistical local area (SLA) regions and reporting regions used by the Australian Bureau of Agriculture and Resource Economics. Statistics collated for these regions were matched to the 1996/97 land use map of Australia, which is represented on a national 1km grid.

Category	Element	Comment
	Attribute Accuracy	When totalled for the Nation and States the profit function data provides similar estimates of agricultural revenue, costs and returns in 1996/97 as assessed by the Australian Bureau of Statistics and the Australian Bureau of Agriculture and Resource Economics. It is worth noting that since 1996/97 there have been considerable changed to crop/livestock yields and prices. The data cannot be used to derive information on the financial performance of individual farms. It is averaged over regions and represents the economic characteristics of an "average farm".
	Logical Consistency	The surfaces represent variables used to determine profit at full equity according to the formula given above. By subtracting government support from profit at full equity it is possible to obtain an estimate of net economic returns.
	Completeness	The dataset covers the intensively used agricultural regions and the rangelands. The total agricultural area represented in the dataset is equal to 473 million hectares.
Contact Information	Contact Organisation	CSIRO Land and Water
	Contact Position	Stefan Hajkowicz or Mike Young
	Mail Address	PMB 2
	Suburb or Place or Locality	Glen Osmond
	State	South Australia
	Postcode	5064
	Telephone	08 8303 8419
	Facsimile	08 8303 8582
	Electronic Mail Address	Stefan.Hajkowicz@csiro.au Mike.Young@csiro.au
Additional Metadata	Additional Metadata	Some additional grids have been supplied that provide estimates of total costs and revenue. Along with additional information on the grids listed above these are described in Appendix A below. Details on how this data was compiled can be found in consulting reports by CSIRO Land and Water to the National Land and Water Resources Audit.
	Metadata date	15 February 2002

APPENDIX A: ADDITIONAL METADATA ON THE PROFIT FUNCTION DATASETS

- All dollar values are in 1997/97 Australian Dollars
- Unless otherwise indicated, a surface is based on data for the 1996/97 baseline year.
- The 5-year period includes the years 1992/93, 1993/94, 1994/95, 1995/96, 1996/97

Grid	Title	Units	Source	Notes

Grid	Title	Units	Source	Notes
P1	Price of primary product	$/t or $/DSE	ABARE and ABS	This is the local price of the product prior to marketing and transportation costs (i.e. a farm gate price). It is obtained by dividing the local value by production per statistical local area or State.
Q1	Yield of primary product	t/ha or DSE/ha	ABS (SLA level) and NDVI satellite data	Represents the quantity of the primary product produced within the pixel. Determined by dividing production by area of production. NDVI is used to stretch production data such that greener pixels are assigned higher values.
TRN	Turn Off Rate	Ratio	ABARE	This is the portion of livestock sold in the financial year. For all non-livestock forms of production, TRN is set at 1.00
P2	Price of secondary product	$/kg or $/litre	ABS and ABARE	Applies to sheep (wool) and dairy (milk) land uses only. This is a local price as with p1.
Q2	Yield of secondary product	kg/DSE or litres/DSE	ABS and ABARE	Applies to sheep (wool) and dairy (milk) land uses only.
P1_5yr	Price of primary product (5yr mean)	$/t or $/DSE	ABARE and ABS	Same as p1 (above), except mean over 5yrs 1992/93 to 1996/97.
Q1_5yr	Yield of primary product (5yr mean)	t/ha or DSE/ha	ABARE, ABS and NDVI satellite data	Same as q1 (above), except mean over 5yrs 1992/93 to 1996/97.
P2_5yr	Price of secondary product (5yr mean)	$/kg or $/litre	ABS and ABARE	Same as p2 (above), except mean over 5yrs 1992/93 to 1996/97.
Q2_5yr	Yield of secondary product (5yr mean)	kg/DSE or litres/DSE	ABS and ABARE	Same as q2 (above), except mean over 5yrs 1992/93 to 1996/97.
TRN_5yr	Turn Off Rate (5yr mean)	Ratio	ABARE	This is the portion of sheep, beef or dairy animals sold per year relative to the total flock/herd.
QC	Quantity dependent variable costs	$/t or $/DSE	Gross Margin Handbooks, ABARE, Consultation	Costs that vary with the quantity of output produced, eg harvest costs, marginal fertiliser costs. Developed for each land-use category in each of 29 ABARE regions, as they were shown to be undertaken - data is specific for each land use in each ABARE region. Derived from the ABARE ASPIRE package, Gross Margin Handbooks, and Farm Management consultant data.

Grid	Title	Units	Source	Notes
AC	Area dependent variable costs	$/ha	Gross Margin Handbooks, ABARE, Consultation	Production costs that are applied on an area basis but vary between enterprise types. Developed for each land-use category in each of 29 ABARE regions, as they were shown to be undertaken - data is specific for each land use in each ABARE region. Derived from the ABARE ASPIRE package, Gross Margin Handbooks, and Farm Management consultant data
WP	Water price	$/ML	Alexander (2000) ABS (2000) Reuter (2001) Thomas et al. (1999)	Water use rates for each major crop type were determined for each major irrigation area within the each ABARE region. Sourced primarily from the ANCID report Australian Irrigation Water Provider Benchmarking Report.
WR	Water requirement	ML/ha	Alexander (2000) ABS (2000) Reuter (2001) Thomas et al. (1999)	Water prices were determined for each major irrigation area within the each ABARE region. Sourced primarily from ANCID report Australian Irrigation Water Provider Benchmarking Report.
FOC	Fixed operating cost	$/ha	Gross Margin Handbooks, ABARE, Consultation	Production costs that are fixed per unit area for typical farm types (eg. dairy, broad-acre cropping, horticulture). This included land rates, accountant fees, etc.). Developed for each farm category in each of 29 ABARE regions, as they were shown to be undertaken – several land uses may be undertaken within a farm category. Derived from the ABARE ASPIRE package, Farm Management consultant data
FDC	Fixed depreciation cost	$/ha	Gross Margin Handbooks, ABARE, Consultation	Machinery and infrastructure depreciation costs that are fixed per unit area for typical farm types (eg. dairy, broad-acre cropping, horticulture). Developed for each farm category in each of 29 ABARE regions, as they were shown to be undertaken—several land uses may be undertaken within a farm category. Derived from the ABARE ASPIRE package, Farm Management consultant data

Grid	Title	Units	Source	Notes
FLC	Fixed labour cost	$/ha	Gross Margin Handbooks, ABARE, Consultation	Labour costs that are fixed per unit area for typical farm types (eg. dairy, broad-acre cropping, horticulture). Developed for each farm category in each of 29 ABARE regions, as they were shown to be undertaken—several land uses may be undertaken within a farm category. Derived from the ABARE ASPIRE package, Farm Management consultant data.
support	Government support to agriculture	$/ha	Productivity and Industry Commission reports	Direct expenditure on Research Advisory / Extension, Drought assistance, Other and Taxation support on Subsidies and Impact of Tariffs
Pfe97	Profit at Full Equity in 1996/97	$/ha		Pfe97 = Rev97 – Tc97
Pfe5yr	Average Profit at Full Equity over the 5yrs	$/ha		Pfe5yr = Rev5yr – Tc5yr
Rev5yr	Average revenue over the 5yrs	$/ha		Rev5yr = p1_5yr * q1_5yr * trn_5yr + p2_5yr * q2_5yr * q1_5yr Mean values were obtained for p1_5yr, q1_5yr, trn_5yr, p2_5yr, trn_5yr over the five year period.
Tc5yr	Average total costs over the 5yrs	$/ha		tc97 = (q1_5yr * qc) + ac + (wp * wr) + foc + fdc + flc

References

ABS (2000) Water Account for Australia, 1993-94 to 1996-97, Australian Bureau of Statistics, Publication 4610.0, Canberra.

Alexander, P. (2000) Benchmarking Of Australian Irrigation Water Providers, Annual ANCID Conference Towoomba 2000, Australian National Council for Irrigation and Drainage.

Reuter, D. (2001) Nutrient balance in regional farming systems and soil nutrient status, National Land and Water Resources Audit Project Version 1.1, Canberra.

Thomas, J.F., P. Adams, R. Dixon, N. Hall and B. Watson (1999) Water and the Australian Economy, Australian Academy of Technological Sciences and Engineering, Parkville, Victoria.

Metadata – Profit Function Surfaces for 1996/97

Category	Element	Comment
Data	Title	Profit Function Surfaces for 1996/97
	Custodian	CSIRO Land and Water
	Jurisdiction	Australia
Description	Abstract	This dataset contains a set of national surfaces, represented on a 1km grid, used to determine profit at full equity (PFE) from agricultural production in 1996/97. All variables used to determine PFE are stored for each 1km grid cell and relate to a single landuse. All dollar values are given in 1996/97 Australian dollars. Profit at full equity is determined as: PFE = (P1 * Q1 * TRN) + (P2 * Q2 * Q1) – (QC * Q1) – AC – (WP * WR) – FLC – FOC – FDC Where: pfe = Profit at full equity in $/ha/yr p1 = Price of primary product in $ per tonne q1 = Yield of primary product in tonnes per hectare for crops/horticulture and dry sheep equivalents (DSE) per hectare for livestock trn = Turn off rate, the portion of livestock sold over the year. For crops this is set to 1. p2 = Price of secondary product, being either only milk ($/litre) or wool ($/kg). For all non dairy and sheep land uses this equals zero. q2 = Yield of secondary product, being only milk (litres / DSE) or (kg / DSE) qc = Quantity dependent variable costs ($/tonne or $/DSE). These are costs that vary as a function of how much is produced. ac = Area dependent variable costs ($/ha/yr). These are variable costs that are determined by the area of land harvested. wp = Charge for water in $/megalitre. These represent water use charges imposed by water supply agencies. wr = Water requirement of the crop/pasture in megalitres/ha/yr. foc = Fixed operating costs ($/ha/yr) flc = Fixed labour costs ($/ha/yr). This is an imputed labour wage paid to the farmer. fdc = Fixed depreciation costs ($/ha/yr) Another variable also supplied is estimated government support to agriculture through avenues such as taxation subsidies, research and marketing. It is measured in $/ha/yr and is stored on the grid called “support”. In addition to these surfaces the dataset contains the results of revenue, costs and profit: rev97r = Gross revenue ($/ha/yr) tc97 = Total costs ($/ha/yr) pfe97 = Profit at full equity ($/ha/yr)

Category	Element	Comment
	Search Word(s)	Economics Natural Resources Australia Agriculture Profit
	Geographic Extent Name(s) OR	Australia, extent of agricultural land use, including the rangelands. Cell size and extent are based on agricultural areas depicted by 1996/97 Land Use of Australia, 1:1 Million, Version 2 Projection: geographic Datum: WGS84 Spheroid: WGS84 Cell size: 0.010 dd
	Geographic Extent Polygon(s)	
Data Currency	Beginning date	1996/97
	Ending date	1996/97
Data Status	Progress	Complete
	Maintenance and Update Frequency	Not Planned
Access	Access Constraints	Subject to the terms and condition of the data access and management agreement between the National Land and Water Audit and ANZLIC parties.
	Stored Data Format	Arc/Info grids at roughly 1km by 1km grid cell size
	Available Format	Arc/Info grids at roughly 1km by 1km grid cell size

<table>
<tr><th>Category</th><th>Element</th><th>Comment</th></tr>
<tr><td>Data Quality</td><td>Lineage</td><td>The data sources for the profit function sources include:
(a) The Australian Bureau of Statistics statistical local area data on farm-gate prices and regional production.
(b) Fixed and variable cost estimates from the Australian Bureau of Agriculture and Resource Economics’ ASPIRE package.
(c) Satellite data, namely cloud adjusted, growing season normalised difference vegetation index supplied by Environment Australia.
(d) Contracted data supplied by ABARE at broad regional levels on costs and returns from broadacre agriculture.
(e) State Government gross margin handbooks.
(f) Publications on irrigation water use (ABS 2000).
(g) Reports from the Industry Commission and Productivity Commission (Productivity Commission 1998, Industry Commission 1996) on support to agricultural industries in Australia.
(h) The National Land and Water Resource Audit’s 1996/97 landuse map of Australia.
(i) Consultation with regional farm management experts.
Data from ABS, ABARE, Gross Margin Handbooks and the other publications were matched to the land use map of Australia. Satellite data was used to develop a more detailed land use map representing commodity production and was also used allocate crop/pasture yields. Details on how the profit function surfaces were constructed can be found in reports supplied to the National Land and Water Resources Audit, under theme six “Capacity to Change”.

References
ABS (2000) Water Account for Australia, 1993-94 to 1996-97, Australian Bureau of Statistics, Publication 4610.0, Canberra.
Productivity Commission (1998) Trade and Assistance Review 1997-98, Annual Report Series 1997-98, AusInfo, Canberra.
Industry Commission (1996) State Territory and Local Government Assistance to Industry, Report No 55, AGPS, Canberra.</td></tr>
<tr><td></td><td>Positional Accuracy</td><td>Although stored using a 1km grid the data generally has a positional accuracy relevant to broad regions such as river basins. The grids have been generated from data at varying levels of spatial detail. Satellite data, used to locate land uses and distribute crop/pasture yields, was obtained from grids of roughly 1km pixel size. Other economic data on agricultural production was obtained for statistical local area (SLA) regions and reporting regions used by the Australian Bureau of Agriculture and Resource Economics. Statistics collated for these regions were matched to the 1996/97 land use map of Australia, which is represented on a national 1km grid.</td></tr>
</table>

Category	Element	Comment
	Attribute Accuracy	When totalled for the Nation and States the profit function data provides similar estimates of agricultural revenue, costs and returns in 1996/97 as assessed by the Australian Bureau of Statistics and the Australian Bureau of Agriculture and Resource Economics. It is worth noting that since 1996/97 there have been considerable changed to crop/livestock yields and prices. The data cannot be used to derive information on the financial performance of individual farms. It is averaged over regions and represents the economic characteristics of an "average farm".
	Logical Consistency	The surfaces represent variables used to determine profit at full equity according to the formula given above. By subtracting government support from profit at full equity it is possible to obtain an estimate of net economic returns.
	Completeness	The dataset covers the intensively used agricultural regions and the rangelands. The total agricultural area represented in the dataset is equal to 473 million hectares.
Contact Information	Contact Organisation	CSIRO Land and Water
	Contact Position	Stefan Hajkowicz or Mike Young
	Mail Address	PMB 2
	Suburb or Place or Locality	Glen Osmond
	State	South Australia
	Postcode	5064
	Telephone	08 8303 8419
	Facsimile	08 8303 8582
	Electronic Mail Address	Stefan.Hajkowicz@csiro.au Mike.Young@csiro.au
Additional Metadata	Additional Metadata	Some additional grids have been supplied that provide estimates of total costs and revenue. Along with additional information on the grids listed above these are described in Appendix A below. Details on how this data was compiled can be found in consulting reports by CSIRO Land and Water to the National Land and Water Resources Audit.
	Metadata data	18 February 2002

APPENDIX A: ADDITIONAL METADATA ON THE PROFIT FUNCTION DATASETS

- All dollar values are in 1997/97 Australian Dollars
- Unless otherwise indicated, a surface is based on data for the 1996/97 baseline year.
- The 5-year period includes the years 1992/93, 1993/94, 1994/95, 1995/96, 1996/97

Grid	Title	Units	Source	Notes

Grid	Title	Units	Source	Notes
P1	Price of primary product	$/t or $/DSE	ABARE and ABS	This is the local price of the product prior to marketing and transportation costs (i.e. a farm gate price). It is obtained by dividing the local value by production per statistical local area or State.
Q1	Yield of primary product	t/ha or DSE/ha	ABS (SLA level) and NDVI satellite data	Represents the quantity of the primary product produced within the pixel. Determined by dividing production by area of production. NDVI is used to stretch production data such that greener pixels are assigned higher values.
TRN	Turn Off Rate	Ratio	ABARE	This is the portion of livestock sold in the financial year. For all non-livestock forms of production, TRN is set at 1.00
P2	Price of secondary product	$/kg or $/litre	ABS and ABARE	Applies to sheep (wool) and dairy (milk) land uses only. This is a local price as with p1.
Q2	Yield of secondary product	kg/DSE or litres/DSE	ABS and ABARE	Applies to sheep (wool) and dairy (milk) land uses only.
P1_5yr	Price of primary product (5yr mean)	$/t or $/DSE	ABARE and ABS	Same as p1 (above), except mean over 5yrs 1992/93 to 1996/97.
Q1_5yr	Yield of primary product (5yr mean)	t/ha or DSE/ha	ABARE, ABS and NDVI satellite data	Same as q1 (above), except mean over 5yrs 1992/93 to 1996/97.
P2_5yr	Price of secondary product (5yr mean)	$/kg or $/litre	ABS and ABARE	Same as p2 (above), except mean over 5yrs 1992/93 to 1996/97.
Q2_5yr	Yield of secondary product (5yr mean)	kg/DSE or litres/DSE	ABS and ABARE	Same as q2 (above), except mean over 5yrs 1992/93 to 1996/97.
TRN_5yr	Turn Off Rate (5yr mean)	Ratio	ABARE	This is the portion of sheep, beef or dairy animals sold per year relative to the total flock/herd.

Grid	Title	Units	Source	Notes
QC	Quantity dependent variable costs	$/t or $/DSE	Gross Margin Handbooks, ABARE, Consultation	Costs that vary with the quantity of output produced, eg harvest costs, marginal fertiliser costs. Developed for each land-use category in each of 29 ABARE regions, as they were shown to be undertaken - data is specific for each land use in each ABARE region. Derived from the ABARE ASPIRE package, Gross Margin Handbooks, and Farm Management consultant data.
AC	Area dependent variable costs	$/ha	Gross Margin Handbooks, ABARE, Consultation	Production costs that are applied on an area basis but vary between enterprise types. Developed for each land-use category in each of 29 ABARE regions, as they were shown to be undertaken - data is specific for each land use in each ABARE region. Derived from the ABARE ASPIRE package, Gross Margin Handbooks, and Farm Management consultant data
WP	Water price	$/ML	Alexander (2000) ABS (2000) Reuter (2001) Thomas et al. (1999)	Water use rates for each major crop type were determined for each major irrigation area within the each ABARE region. Sourced primarily from the ANCID report Australian Irrigation Water Provider Benchmarking Report.
WR	Water requirement	ML/ha	Alexander (2000) ABS (2000) Reuter (2001) Thomas et al. (1999)	Water prices were determined for each major irrigation area within the each ABARE region. Sourced primarily from ANCID report Australian Irrigation Water Provider Benchmarking Report.
FOC	Fixed operating cost	$/ha	Gross Margin Handbooks, ABARE, Consultation	Production costs that are fixed per unit area for typical farm types (eg. dairy, broad-acre cropping, horticulture). This included land rates, accountant fees, etc.). Developed for each farm category in each of 29 ABARE regions, as they were shown to be undertaken – several land uses may be undertaken within a farm category. Derived from the ABARE ASPIRE package, Farm Management consultant data

Grid	Title	Units	Source	Notes
FDC	Fixed depreciation cost	$/ha	Gross Margin Handbooks, ABARE, Consultation	Machinery and infrastructure depreciation costs that are fixed per unit area for typical farm types (eg. dairy, broad-acre cropping, horticulture). Developed for each farm category in each of 29 ABARE regions, as they were shown to be undertaken—several land uses may be undertaken within a farm category. Derived from the ABARE ASPIRE package, Farm Management consultant data
FLC	Fixed labour cost	$/ha	Gross Margin Handbooks, ABARE, Consultation	Labour costs that are fixed per unit area for typical farm types (eg. dairy, broad-acre cropping, horticulture). Developed for each farm category in each of 29 ABARE regions, as they were shown to be undertaken—several land uses may be undertaken within a farm category. Derived from the ABARE ASPIRE package, Farm Management consultant data.
support	Government support to agriculture	$/ha	Productivity and Industry Commission reports	Direct expenditure on Research Advisory / Extension, Drought assistance, Other and Taxation support on Subsidies and Impact of Tariffs
Pfe97	Profit at Full Equity in 1996/97	$/ha		Pfe97 = Rev97 – Tc97
Rev97	Revenue for 1996/97	$/ha		Rev97 = p1 * q1 * trn + p2 * q2 * q1
Tc97	Total cost in 1996/97	$/ha		tc97 = (q1 * qc) + ac + (wp * wr) + foc + fdc + flc

References

ABS (2000) Water Account for Australia, 1993-94 to 1996-97, Australian Bureau of Statistics, Publication 4610.0, Canberra.

Alexander, P. (2000) Benchmarking Of Australian Irrigation Water Providers, Annual ANCID Conference Towoomba 2000, Australian National Council for Irrigation and Drainage.

Reuter, D. (2001) Nutrient balance in regional farming systems and soil nutrient status, National Land and Water Resources Audit Project Version 1.1, Canberra.

Thomas, J.F., P. Adams, R. Dixon, N. Hall and B. Watson (1999) Water and the Australian Economy, Australian Academy of Technological Sciences and Engineering, Parkville, Victoria.

Metadata – Reporting Regions

Category	Element	Comment
Data	Title	Reporting Regions
	Custodian	CSIRO Land and Water
	Jurisdiction	Australia
Description	Abstract	This dataset contains three national grids, each providing an alternative set of regionalisations for data reporting. The grids have a cell size of roughly 1km by 1km. Each grid cell is coded as belonging to a single region. The three grids include: States. This is a grid of Australia's States and Territories. It contains the State/Territory identifier and the State/Territory name as attributes. Basins. This is a grid of Australia's river basins. It contains the river basin number and name as attributes. Reporting regions. This grid identifies a set of reporting regions that were used in theme 6.1 of the National Land and Water Resources Audit to make generalisations about the economics of natural resource conditions throughout Australia. These datasets can be used in conjunction with the "Profit Function Surfaces", "Local Infrastructure Costs", the "Economics of Australian Soil Conditions" and other spatial datasets produced under theme 6.1 of the Audit. They can be used to quickly derive regional totals for variables such as profit at full equity or production costs. Note that much spatial data from theme 6.1 of the Audit is expressed in units of $/ha. Before deriving regional totals for these data, the $/ha values need to be multiplied by the area of the cells to obtain $/cell values.
	Search Word(s)	Regions Australia, States, Territories, Basins
	Geographic Extent Name(s) OR	Australia, extent of agricultural land use, including the rangelands. For all grids, cell size and extent are based on agricultural areas depicted by 1996/97 Land Use of Australia, 1:1 Million, Version 2 Projection: geographic Datum: WGS84 Spheroid: WGS84 Cell size: 0.010 dd
	Geographic Extent Polygon(s)	
Data Currency	Beginning date	2001
	Ending date	2001
Data Status	Progress	Complete
	Maintenance and Update Frequency	Not Planned

Category	Element	Comment
Access	Access Constraints	Subject to the terms and condition of the data access and management agreement between the National Land and Water Audit and ANZLIC parties.
	Stored Data Format	Arc/Info grids
	Available Format	Arc/Info grids
Data Quality	Lineage	These grids were generated from vector maps. The original vector maps were sourced from the Australian Bureau of Statistics (States and Territories) and the National Land and Water Resources Audit (river basins).
	Positional Accuracy	The grids in this dataset generalise the detail of polygon boundaries available in the vector datasets. They have been created to allow calculation of aggregate statistics for spatial data produced under theme 6.1 of the Audit. The area estimates for these regions will differ to those obtained from vector data.
	Attribute Accuracy	
	Logical Consistency	
	Completeness	The dataset covers Australia's land area.
Contact Information	Contact Organisation	CSIRO Land and Water
	Contact Position	Stefan Hajkowicz or Mike Young
	Mail Address	PMB 2
	Suburb or Place or Locality	Glen Osmond
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	Electronic Mail Address	Stefan.Hajkowicz@csiro.au Mike.Young@csiro.au
Additional Metadata	Additional Metadata	None
	Metadata data	18 February 2002

Metadata – Economics of Australian Soil Conditions

Category	Element	Comment
Data	Title	Economics of Australian Soil Conditions
	Custodian	CSIRO Land and Water
	Jurisdiction	Australia
Description	Abstract	This dataset contains 11 national surfaces, represented by 1km grids, relating to economic opportunities associated with soil condition. All dollar values are given in 1996/97 Australian dollars. There are three sub-types of data in this dataset: relative yields, gross benefits and impact costs. Each is described as follows: 1. Relative yield (RY): This is the yield of the crop or pasture, relative to its full potential expressed as a percentage. It is equal to actual yield divided by potential yield. For example, a crop with an actual yield of 2 t/ha and a potential yield of 4 t/ha has a relative yield of 50%. The relative yield surfaces, measured as a ratio (0 to 1) and represented with a 1km grid, include: ry_salt2000: The relative yield of salinity in the year 2000 (note: this cannot be summed to give estimates of yield loss areas – the yield loss areas are determined by area multipliers for each State as applied to the salinity datasets from theme 2 of the NLWRA) ry_salt2020: The relative yield of salinity in the year 2020 (note: this cannot be summed to give estimates of yield loss areas as above) ry_Acid: The relative yield from soil acidity. ry_esp: The relative yield from soil sodicity. ry_min: The limiting factor relative yield. This is the minimum of ry_salt2000, ry_acid, ry_esp and ry_min. lim_fact: An integer grid indicating which of acidity, sodicity and salinity most limits crop/pasture yield. 2. Gross benefit (GB): The gross benefit is the additional profit at full equity attainable through agricultural production if the yield-limiting factor of salinity, acidity or sodicity were repaired without cost. As such it can be considered an approximate investment ceiling on treating the soil. It is determined only through changes in crop yield as a consequence of changes in soil attributes. The gross benefit grids are measured in $/ha/yr and include: gb97a for soil acidity; gb97e for soil sodicity; gb97s for soil salinity; and gb97m for the limiting factor gross benefit. The limiting factor gross benefit is determined from the minimum relative yield of sodicity, acidity and salinity. 3. Impact cost (IC): This is the decline in agricultural profit at full equity due to worsening dryland salinity severity and extent over the time period 2000 to 2020. It is measured in $/ha/yr. It is determined only through changes in crop yield as a consequence of changes in dryland salinity. Impact cost can be considered the loss in profit at full equity due to worsening salinity over the 20yr time period. The gird of impact cost is: ic97s

Category	Element	Comment
	Search Word(s)	Economics Natural Resources Australia Salinity Sodicity Acidity Soil Treatment
	Geographic Extent Name(s) OR	Australia, extent of agricultural land use, including the rangelands. For all grids, cell size and extent are based on agricultural areas depicted by 1996/97 Land Use of Australia, 1:1 Million, Version 2 Projection: geographic Datum: WGS84 Spheroid: WGS84 Cell size: 0.010 dd
	Geographic Extent Polygon(s)	
Data Currency	Beginning date	1996/97
	Ending date	1996/97
Data Status	Progress	Complete
	Maintenance and Update Frequency	Not Planned
Access	Access Constraints	Subject to the terms and condition of the data access and management agreement between the National Land and Water Audit and ANZLIC parties.
	Stored Data Format	Arc/Info grids
	Available Format	Arc/Info grids

Category	Element	Comment
Data Quality	Lineage	The data sources for the “Economics of Australian Soil Conditions” dataset include: (a) Salinity maps from theme two of the National Land and Water Resources Audit. The original maps were supplied in vector format and delineated areas of “risk”. They were re-interpreted to form surfaces of relative yield. (b) The sodicity classification for the Atlas of Australian Soils (Northcote, K.H. and Skene, J.K.M., 1972) (c) The Australian Soil Resource Information System (ASRIS) produced by CSIRO Land and Water for the National Land and Water Resources Audit (d) Soil test data taken from private soil testing agencies and compiled under theme five of the National Land and Water Resources Audit. (e) The 1996/97 Profit Function Surfaces dataset produced by CSIRO Land and Water for the National Land and Water Resources Audit. (f) A set of relative yield functions for sodicity that relate crop/pasture relative yield to exchangeable sodium percentage for a set of around 30 crop/pasture types. Soil scientists developed these under theme 6.1 of the National Land and Water Resources Audit. (g) An Acidity-Yield model, used to determine the relative yield of crops/pastures to soil acidity developed under theme five of the National Land and Water Resources Audit. (h) A map of commodity production produced under theme six of the National Land and Water Resources Audit and derived from the Audit’s 1996/97 Land Use Map of Australia. References Northcote, K.H. and Skene, J.K.M. (1972), Australian Soils with saline and sodic properties, CSIRO Soil Publication No. 27.
	Positional Accuracy	Although stored using a 1km grid the data generally has a positional accuracy relevant to broad regions such as river basins. The grids have been generated from data at varying levels of spatial detail. Satellite data, used to locate land uses and distribute crop/pasture yields, was obtained from grids of roughly 1km pixel size. Other economic data on agricultural production was obtained for statistical local area (SLA) regions and reporting regions used by the Australian Bureau of Agriculture and Resource Economics. Statistics collated for these regions were matched to the 1996/97 land use map of Australia, which is represented on a national 1km grid. The soil attributes were obtained from modelled surfaces of sodicity and acidity.

Category	Element	Comment
	Attribute Accuracy	When totalled for the Nation and States the profit function data provides similar estimates of agricultural revenue, costs and returns in 1996/97 as assessed by the Australian Bureau of Statistics and the Australian Bureau of Agriculture and Resource Economics. Soil data was derived from modelled surfaces of sodicity and acidity. Some of these models relied on sparsely located point data and relationships between the soil parameter and other predictive variables. The yield impacts of soil salinity were estimated from maps of dryland salinity risk produced under theme 2 of the Audit. It is worth noting that the land use map was used to determine the yield impacts of salinity, acidity and sodicity. The land use map represents each 1km pixel as a single land use. In irrigated and intensively used regions this is a gross generalisation of the actual diversity of land uses that would occur. The data cannot be used to derive information on the financial performance of individual farms. It is averaged over regions and represents the economic characteristics of an "average farm".
	Logical Consistency	The surfaces of gross benefits and impact cost were obtained by performing operations on the Profit Function Surfaces, also supplied under theme 6.1 of the National Land and Water Resources Audit. Relative yield surfaces were matched to the Audit's 1996/97 landuse map of Australia. The relative yield of a crop or pasture was used to determine the economic impact, through a profit function.
	Completeness	The dataset covers the intensively used agricultural regions and the rangelands. The total agricultural area represented in the dataset is equal to 473 million hectares.
Contact Information	Contact Organisation	CSIRO Land and Water
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	Postcode	5064
	Telephone	08 8303 8419
	Facsimile	08 8303 8582
	Electronic Mail Address	Stefan.Hajkowicz@csiro.au Mike.Young@csiro.au
Additional Metadata	Additional Metadata	Some additional information on this dataset is available in the files: Appendix A. About Gross Benefit Appendix B. Gross Benefit Calculations Appendix C. Description of Each Grid Details on how this data was compiled can be found in consulting reports by CSIRO Land and Water to the National Land and Water Resources Audit.

Category	Element	Comment
	Metadata data	18 February 2002

ABOUT GROSS BENEFIT

Gross benefit is the additional profit at full equity attainable if a soil constraint is costlessly "fixed". It is measured in 1996/97 $/ha/yr. It is derived from the profit function surfaces for the 1996/97 baseline year. This directory contains the following Arc/Info grids:

gb97s = Gross benefit for salinity ($/ha/yr)

gb97e = Gross benefit for sodicity ($/ha/yr)

gb97a = Gross benefit for acidity ($/ha/yr)

gb97m = Gross benefit for salinity, acidity and sodicity ($/ha/yr)

GROSS BENEFIT CALCULATIONS

This appendix contains a snippet of the computer code (Avenue Script for Arcview 3.2) that is used to determine the gross benefit surfaces. It refers to variables used to determine profit at full equity. For a description of these variables and their associated surfaces refer to the dataset titled "*Profit Function Surfaces*".

```
'Determine the costs not influenced by q1

oc = (wr * wp) + foc + flc + fdc + ac

'Determine the pfe97 surface

pfe97 = ((p1 * q1 * trn) + (p2 * q2 * q1)) - ((qc * q1) + oc)

'Determine q1 under the different soil constraints.

q1s = q1 / ry_salt2000 'Saline soils

q1e = q1 / ry_esp 'Sodic soils

q1a = q1 / ry_acid 'Acid soils

q1m = q1 / ry_min 'Minimum relative yield of sodicity, acidity and salinity.

'Determine unconstrained PFE in 1996/97 with increased primary yields.

p97s = ((p1 * q1s * trn) + (p2 * q2 * q1s)) - ((qc * q1s) + oc)

p97e = ((p1 * q1e * trn) + (p2 * q2 * q1e)) - ((qc * q1e) + oc)

p97a = ((p1 * q1a * trn) + (p2 * q2 * q1a)) - ((qc * q1a) + oc)

p97m = ((p1 * q1m * trn) + (p2 * q2 * q1m)) - ((qc * q1m) + oc)
```

'Determine gross benefits

gb97s = p97s - pfe97

gb97e = p97e - pfe97

gb97a = p97a - pfe97

gb97m = p97m - pfe97

DESCRIPTION OF EACH GRID

This appendix contains a brief description of each grid contained in the dataset.

- All dollar values are given in Australian 1996/97 dollars.
- All surfaces containing dollar values are derived from profit function data for the 1996/97 baseline year.

Grid	Name	Units	Source Data	Notes
ry_salt2000	Relative yield from salinity in 2000	%	Theme 2 of NLWRA salinity maps	Determined from salinity regions mapped under Theme 2 of the NLWRA. Consultation with those involved in producing the salinity maps allowed estimates of relative yield from maps of risk.
ry_salt2020	Relative yield from salinity in 2020	%	Theme 2 salinity of NLWRA maps	As with ry_salt2000.
ry_esp	Relative yield from sodicity	%	Exchangeable sodium percentage surfaces from Theme 5, land use map and sodicity relative yield functions.	Produced by linking the land use map to a set of sodicity relative yield functions. These functions relate exchangeable sodium percentage to yield.
ry_acid	Relative yield from acidity	%	ASRIS and Acidity Relative Yield Model from Theme 5	Produced by running the acid relative yield model supplied to the NLWRA by Keith Helyar of NSW Agriculture.
nat_esp	National ESP surface	%	ESP surfaces from Theme 5 and maps of sodic soils	ESP = Exchangeable Sodium Percentage.
gb97s	Gross benefit salinity	$/ha/yr	Profit function and relative yield surfaces from this project	Increase in profit at full equity if yield losses associated with salinity were fully recovered without cost
gb97a	Gross benefit acidity	$/ha/yr	Profit function and relative yield surfaces from this project	Increase in profit at full equity if yield losses associated with acidity were fully recovered without cost

Grid	Name	Units	Source Data	Notes
gb97e	Gross benefit sodicity	$/ha/yr	Profit function and relative yield surfaces from this project	Increase in profit at full equity if yield losses associated with sodicity were fully recovered without cost
gb97m	Gross benefit of the limiting factor	$/ha/yr	Profit function and relative yield surfaces from this project	Increase in profit at full equity if yield losses associated with acidity, sodicity and acidity were fully recovered without cost
ic97s	Impact cost of salinity from 2000 - 2020	$/ha/yr	Profit function and relative yield surfaces from this project	The decrease in profit at full equity over the period 2000 to 2020 if no action is taken
lim_fact	Limiting Factor	NA	Relative yield surfaces generated through this project	For each pixel, this integer grid identifies which of salinity, acidity and sodicity most limits crop yield.