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Minimising costs of environmental service provision: water-yield, salt-load and biodiversity targets with new tree planting in Simmons Creek Catchment, NSW, a dryland farming/grazing area

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Abstract: Although dryland farming and grazing have been practiced for over 130 years in the 17,000 ha Simmons Creek catchment without surface salinity problems, the area has been identified as a significant source of salt seepage to Billabong Creek in the NSW Murray catchment. Groundwater movement and salinity levels are spatially heterogenous at Simmons Creek. Groundwater of the upper catchment is relatively fresh and seemingly unconnected with the highly saline groundwater of the lower catchment. However, fresh surface water does flow from the upper to the lower catchment. This spatial diversity provokes the question of where high-water-use forest habitats might be placed to achieve different combinations of environmental services (greater water yield, lower stream salinity and greater biodiversity) at least cost. Agro-forestry and or carbon sequestration benefits are not considered here. This paper presents methods and preliminary calculations of land use changes for least-cost delivery of these environmental service targets.

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1. Introduction

The question posed in this study is: where can forest habitats be established in the Simmons Creek catchment to benefit the Billabong Creek by reducing salt exports and minimizing reductions in water yields. 'Least cost' means the sum of direct costs of forest establishment and maintenance, and the opportunity costs of reduced net present values of productive farming or grazing lands. The external costs and benefits of altering mean catchment water yields and salt loads flowing to downstream water users are not explicitly calculated within the model, but are handled as environmental service target constraints, along with target areas of forest habitat. This defines an optimisation problem, the aim of which is to provide specific answers to the questions of 'where' forest habitats could be located to incur least cost in reducing salt-loads. The results must detail the hectares of new forest habitat to displace current land uses on each soil type in each sub-catchment at least cost, given specific catchment-level target constraints on forest habitat area, water yield and salt load. In short, the aim of this paper is to suggest how it is possible to find the "minimum costs for a menu of ecosystem service combinations: catchment forest habitats, water-yields and salt-loads".

Increasing the area of forest habitat reduces water yield. We show estimates of the effects of adding to total within-catchment cost the downstream losses due to significantly reduced stream volume. However, we do not calculate the smaller benefits likely from the associated improvements in water quality (reduced salt concentration). Neither are agro-forestry nor carbon sequestration benefits considered here. These require development in subsequent analyses, as do the initial, simplifying assumptions on hydrology used in the present analysis.

2. Methods

This project proceeds from four bases: (1) hydrological and soil information from regional surveys and analyses of the study area; (2) economic and land use information from local farmer engagement; (3) one dimensional modelling of plant growth, water use, evaporation, deep drainage and runoff, given the weather and soils of the study area and information on farming systems provided by the local land managers; and (4) a NSW DPI model that integrates this information to calculate minimum-cost changes in land use to attain each of a range of specified targets of forest habitat area in the catchment and future mean water-yields and salt-loads from the catchment.

2.1 Hydrological and soil information: CSIRO surveys and analyses of the study area

This study has built upon considerable information developed earlier by CSIRO, in particular:

Cresswell, H. *et al.* 2002. *Generation and Delivery of Salt and Water to Streams*. Project CLW28 Final report to Land and Water Australia. CSIRO Land and Water, Canberra…. to which are attached the following:

Appendix A. *Land resource survey for the Simmons Creek Sub-catchment, Billabong Creek, NSW.* By Hook, McKenzie, McPherson, Glover and Aldrick.

Appendix B. *Groundwater and Salinity Processes in Simmons Creek Sub-catchment, Billabong Creek, NSW.* By English, Richardson, and Stauffacher.

Appendix C. *Putting farming systems models in a catchment framework.* By Gallant, Paydar

Appendix D. *Billabong Land Information System (BLIS).* By McKenzie, Gregory, Jacquier and Cresswell

The conceptual model of catchment hydrology used in the present paper is very simple and will benefit from revision. The key simplifying assumptions are:

- The Simmons Creek has 13 sub-catchments. Five are in the upper part of the catchment and exhibit different hydrological behaviour to the eight in the lower part of the catchment.

- In the upper Simmons Creek, groundwater is assumed to be unconnected with that of the lower catchment and, therefore, disconnected from Billabong Creek. It is thought, in reality, the upper catchment's groundwater fluxes are very slow and insignificant in the time frames we are considering relative to surface water fluxes and groundwater fluxes out of the lower part of the catchment.

- Surface runoff is fresh at the salinity of rainfall.

- Fresh surface water from the upper catchment does reach Billabong Creek directly, but by a combination of surface and sub-surface channels. This is consistent with the fact that fresh water seeps are observed joining Billabong Creek, as well as saline seeps of different concentrations.

- Each sub-catchment of the lower catchment is assumed to have groundwater of a unique and uniform salt concentration. These were set at concentrations visually judged to represent the diverse salinity contours depicted in Figure 1.b.

- Deep drainage in any sub-catchment in the lower catchment is assumed to engage the salty groundwater. However, 86% of the baseflow to Billabong Creek is assumed fresh and 14% is assumed to be at salt water concentration of the groundwater of that sub-catchment. This 14% mixing value was estimated as it delivers a weighted total salt load close to the nominal value of 10,000 t/year

The true hydrologic reality of the area is certainly far more complex, particularly in its spatial and temporal dynamics. For the moment, we proceed with this simple model. Though it is far from perfect, it allows us to calculate approximate water and salt balances under different land use configurations. The geographical characteristics of the region are shown in Figure 1 and the conceptual model of hydrology, as described above, is drawn in Figure 2.

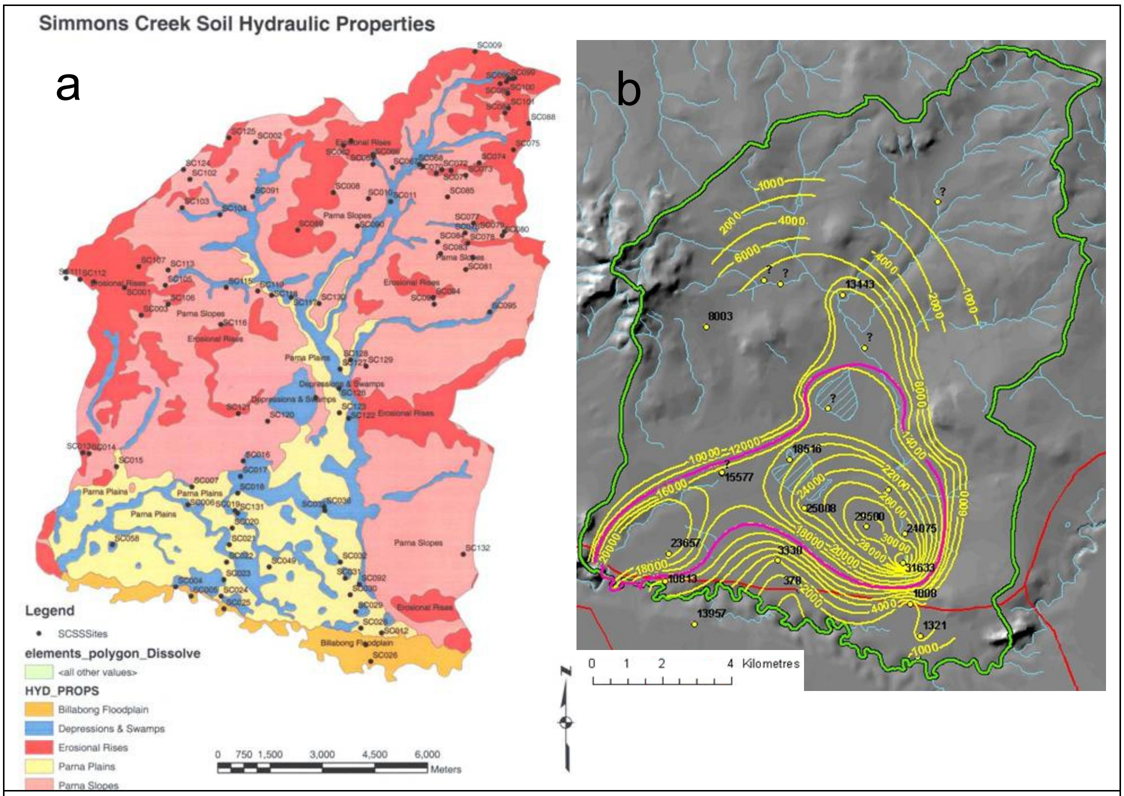

Figure 1. Geophysical descriptions of Simmons Creek catchment by CSIRO Land & Water: (a) soils, (b) groundwater salinity. Source: Cresswell *et al*. 2002

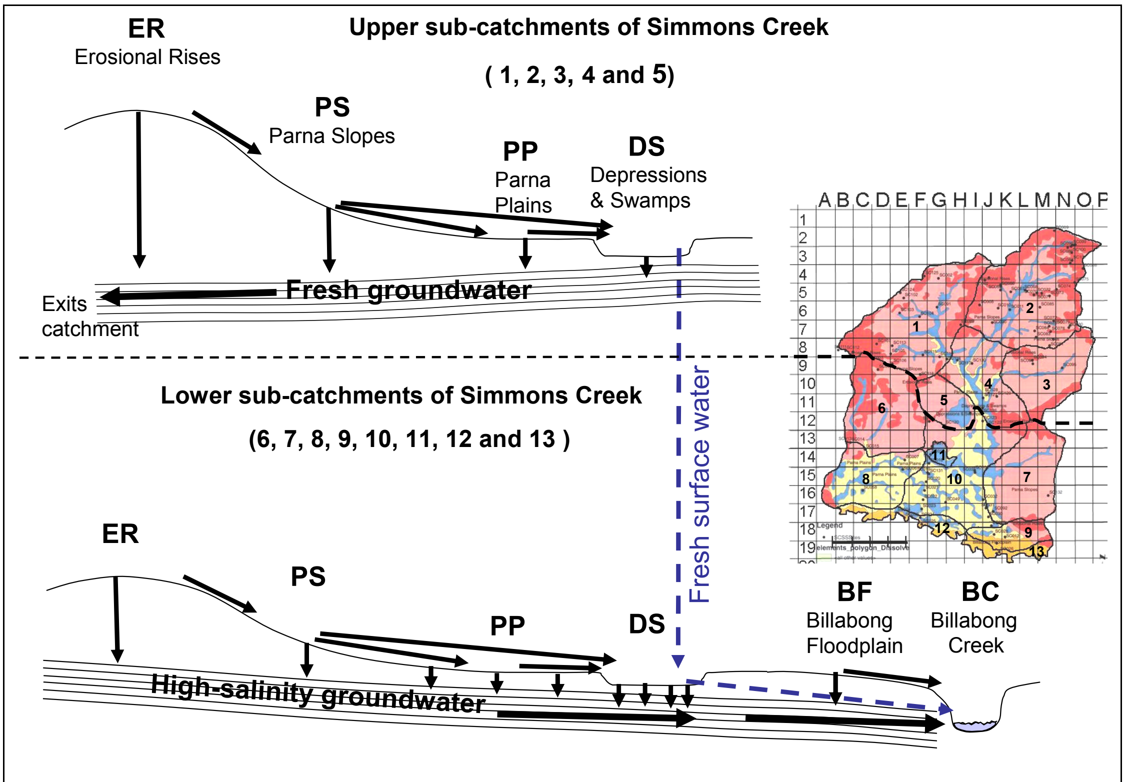

Figure 2. Schematic of hydrology assumptions taken in this analysis

2.2 Economic and land use information from local farmer engagement

The following steps were taken to refine landuse information available in the form of satellite imagery and regional gross margin budgets.

- (April 2006) A meeting was held at Culcairn with NSW DPI and CSIRO L&W staff and four leading farmers (key land managers) from the study area. Discussion centred on gaining from the latter a clearer picture their farming systems. They all agreed to individual follow-up meetings with Nordblom to look at costs of production, livestock management, etc., information needed for economic analysis of the Simmons Creek area.

- (May 2006) Created crop/pasture rotation budgets for three farming systems typical of the Simmons Creek area, according to discussions at Culcairn (April 2006) and with reference to NSW DPI extension material. The budgets were for 'Low-Input Traditional' pasture-cropping rotations, and 'Current high-input cropping-pasture rotations on better-drained red soils' and 'Current high-input cropping-pasture rotations on soils subject to water-logging'. Prepared maps of the area to support the farmer survey work ahead.

- (June 2006) Scanned the CSIRO map of soils for the study area and traced Simmons Creek catchment and sub-catchment boundaries (Figure 2). Created a mosaic of un-dated Google Map images of the study area, overlaid with catchment and sub-catchment boundaries from the CSIRO map (Figure 3). Overlayed both maps with a 1 km square grid.

- (July 2006) Created a data base to cross-tabulate soils and land uses of the 13 sub-catchments of Simmons Creek (170 km^2) on a 1 km grid.

- (July 2006) Interviewed the four key land managers participating in the project, two times each. The first interviews were to review and correct crop rotation budgets (land uses 7, 8 and 4 in Table 4 Table 1). A second round of interviews identified the landuse of each paddock. The key land managers coded four 'waterlogged land' uses, (1) native and (2) introduced permanent pastures, (3) low input and (4) high input crop / pasture rotations; four 'well-drained land' uses (5, 6, 7 and 8, corresponding to 1, 2, 3 and 4 above); and (9) for trees, directly onto Google Map satellite images (Figure 3).

Table 1. Land use classes in Simmons Creek catchment.

Land use code	Current Land Use	Approx. total area (ha)	Budget and productivity references:
1	Native Pasture, Water Logged	665	Appendix 1
2	Introduced Pasture, Water Logged	495	Appendix 2
3	Low Input Rotation, Water Logged	1,186	Appendix 3
4	High Input Rotation, Water Logged	1,739	Appendix 4
5	Native Pasture, Well Drained	931	Appendix 5
6	Introduced Pasture, Well Drained	463	Appendix 6
7	Low Input Rotation, Well Drained	3,541	Appendix 7
8	High Input Rotation, Well drained	8,247	Appendix 8
9	Trees	545	Appendix 9

Source: Compiled by Nordblom from CSIRO soils map and un-dated Google Map images used in local farmer interviews, July 2006

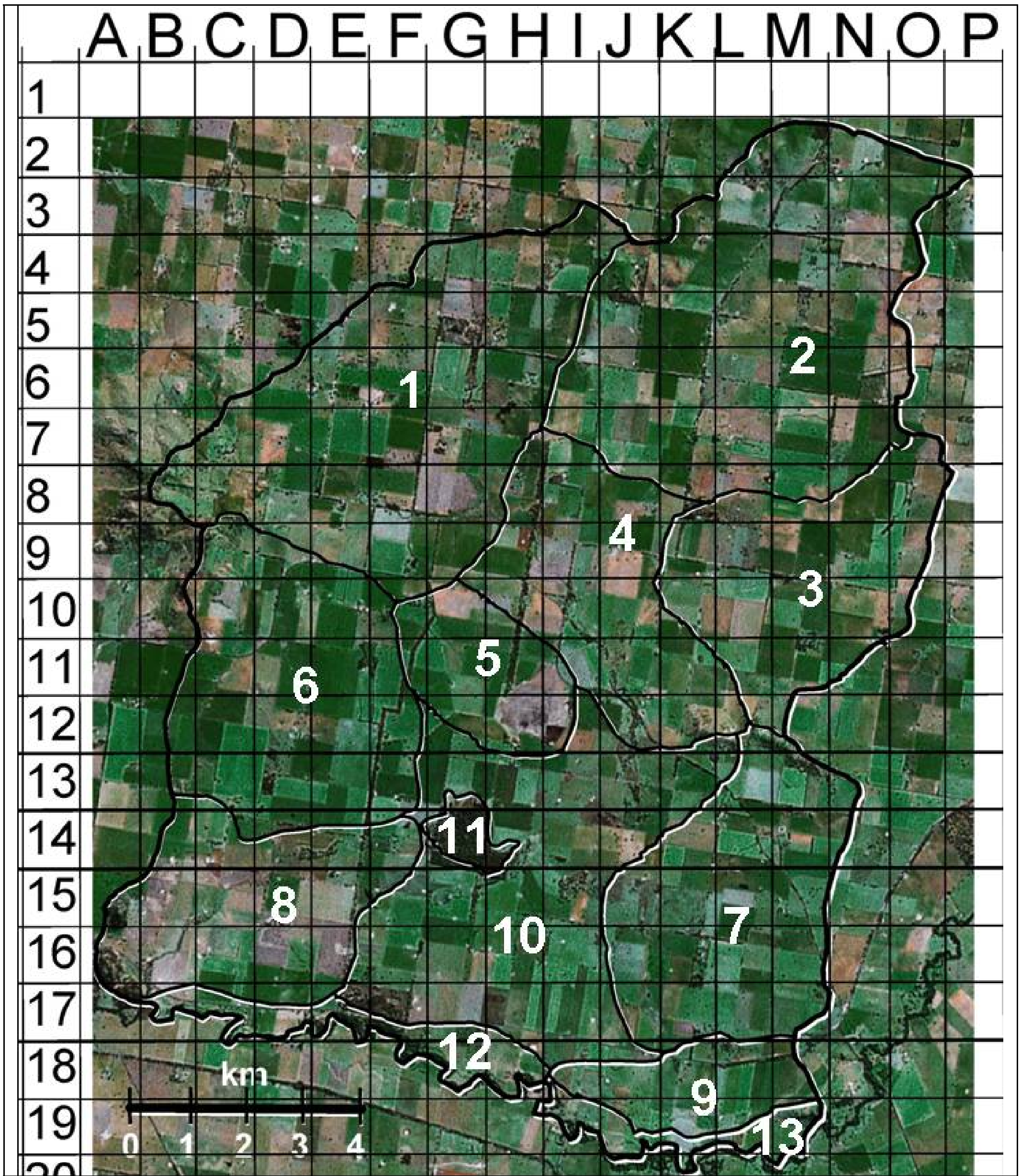

Figure 3. Mosaic of Google Map satellite images of Simmons Creek in which individual paddocks may be distinguished, overlain by 1 X 1 km grid and sub-catchment boundaries. White labels designate sub-catchments 1 to 13

- (July 2006) These paddock-by-paddock indications of land use were then visually cross-tabulated with the soils map for each 1 km square. Cross-tabulations in the data base were aggregated at the sub-catchment level (Table 2). These comprise the current land use 'constraint' vectors for our sub-catchment economic analyses, the results of which we then used in catchment-level economic analyses, following Nordblom *et al.* (2006).

Table 2. Summary of land use by soil and by sub-catchment of Simmons Creek

	Current configuration of private land use in sub-catchments of Simmons Creek													
	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	SC11	SC12	SC13	Total
Erosional Rises	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)
Native Past, Well Drained	100	125	48	69	0	139	54	50	2	18	0	0	25	**630**
Introduced Past, Well Drained	72	0	0	0	0	0	0	10	0	0	0	0	0	**82**
Low Input Rot., Well Drained	512	543	0	10	7	0	27	0	0	49	0	0	0	**1148**
High Input Rot., Well drained	301	482	239	180	41	509	58	37	116	22	0	0	0	**1985**
Existing Trees	5	10	8	10	3	11	0	20	5	0	0	0	0	**72**
Parna Slopes														
Native Past, Water Log'd	0	0	0	0	3	0	28	0	0	0	2	0	0	**33**
Introduced Past, Water Log'd	0	0	0	0	0	0	30	0	0	10	0	0	0	**40**
Low Input Rot., Water Log'd	125	186	0	10	0	0	14	0	0	34	0	0	0	**369**
High Input Rot., Water Log'd	5	20	0	48	35	8	40	0	0	162	0	0	0	**318**
Native Past, Well Drained	0	36	58	47	16	18	20	5	1	0	0	0	0	**201**
Introduced Past, Well Drained	0	45	0	24	0	12	2	1	0	0	0	0	0	**84**
Low Input Rot., Well Drained	563	699	0	98	49	6	507	26	0	6	2	0	0	**1956**
High Input Rot., Well drained	795	657	1046	457	308	1011	653	90	80	168	0	0	0	**5265**
Existing Trees	17	11	5	19	17	23	19	2	0	0	0	0	0	**113**
Parna Plains														
Native Past, Water Log'd	0	0	0	0	8	0	15	12	0	47	0	0	0	**82**
Introduced Past, Water Log'd	0	0	0	25	0	0	0	35	0	97	0	0	0	**157**
Low Input Rot., Water Log'd	0	0	0	25	0	0	24	203	0	152	0	0	0	**404**
High Input Rot., Water Log'd	0	1	0	43	3	0	65	274	0	297	0	12	0	**695**
Native Past, Well Drained	0	0	0	15	0	0	0	0	0	16	0	41	0	**72**
Introduced Past, Well Drained	0	0	0	0	0	0	1	85	0	194	0	0	0	**280**
Low Input Rot., Well Drained	23	0	0	30	0	0	3	158	0	115	0	40	0	**369**
High Input Rot., Well drained	7	0	3	28	0	16	0	68	114	311	0	24	2	**573**
Existing Trees	0	0	0	2	0	2	0	4	0	23	6	4	0	**41**
Depressions & Swamps														
Native Past, Water Log'd	20	44	0	24	133	15	73	47	13	164	10	22	0	**565**
Introduced Past, Water Log'd	107	0	0	40	2	0	0	54	0	105	0	0	0	**308**
Low Input Rot., Water Log'd	55	149	0	56	0	0	12	40	0	68	3	33	0	**416**
High Input Rot., Water Log'd	55	65	53	149	1	53	38	109	27	139	0	0	0	**689**
Existing Trees	38	21	0	22	2	0	0	27	0	81	88	23	0	**302**
Billabong Floodplain														
High Input Rot., Water Log'd	0	0	0	0	0	0	0	0	0	0	0	0	37	**37**
Native Past, Well Drained	0	0	0	0	0	0	0	1	0	0	0	8	4	**13**
Introduced Past, Well Drained	0	0	0	0	0	0	0	0	0	0	0	0	7	**7**
Low Input Rot., Well Drained	0	0	0	0	0	0	0	0	0	0	0	65	0	**65**
High Input Rot., Well drained	0	0	0	0	0	0	0	0	164	0	0	98	162	**424**
Existing Trees	0	0	0	0	0	0	0	0	0	0	0	12	5	**17**
Sub-catchment areas (ha)	**2800**	**3094**	**1460**	**1431**	**628**	**1823**	**1683**	**1358**	**522**	**2278**	**111**	**382**	**242**	**17812**

* Source: compiled by Nordblom, July 2006, from land manager interviews using satellite images and CSIRO soils map.

2.3. Modelling of plant growth and agricultural hydrology of farming systems.

Five land uses were modelled (Table 3) on the five significant soil types found in Simmons Creek (Cresswell *et al*., 2002). This was undertaken as a series of one-dimensional modelling runs, i.e., there was no interaction between soil types such as runoff, run-on or waterlogging. The APSIM model (McCown *et al*., 1996) was used for this exercise and was run for a period of 114 years 1891 – 2005, using weather data derived from historical climate data for 1889 to 2005, obtained from the SILO patched point data base (www.bom.gov.au/SILO) for the Walbundrie station (Station No 074115, 35.69ºS, 146.72ºE).

Table 3. Land uses modelled with the APSIM plant growth model	
Landuse	Description
Native Pasture	Continuous Native Pasture
Improved Pasture	Continuous Phalaris Sub Clover Pasture
Low input rotation	Oats Wheat Lupins Pasture Pasture Pasture Pasture Pasture Pasture Pasture
High input rotation	Wheat Triticale Canola Wheat Lupin Pasture Pasture Pasture Pasture

The APSIM model runs on a daily time step but the results are presented as mean annual values over the 114 years of simulation (Table 4).

Table 4. Runoff, deep drainage and 30-year NPVs of current land uses calculated for Simmons Creek*

Soil / landform	Code **	Mean annual runoff (mm)	Mean annual deep drainage (mm)	Mean annual biomass production (t/ha)	Net Present Value (NPV $/ha)
Erosional	5	18	99	2710	918
Rises	6	16	81	4812	1372
(ER)	7	14	84	4879	1732
	8	18	65	9391	6085
	9	10	0	-	-67
Parna	**1**	15	113	2795	**947**
Slopes	**2**	14	100	4067	**1160**
(PS)	**3**	12	139	3958	**1405**
	4	16	106	3184	**2063**
	5	15	96	3702	**1254**
	6	14	80	5407	**1542**
	7	12	85	5734	**2036**
	8	16	72	9388	**6083**
	9	9	3	-	-67
Parna	1	17	97	2303	780
Plains	2	16	84	3735	1065
(PP)	3	14	131	3427	1217
	4	18	94	3024	1960
	5	17	77	3050	1033
	6	16	62	4965	1416
	7	14	69	4966	1763
	8	18	58	8918	5778
	9	11	0	-	-67
Depres-	1	18	95	2887	978
sions &	2	16	83	4158	1186
Swamps	3	14	133	4141	1470
(DS)	4	19	93	3289	2131
	9	11	1	-	-67
Billabong	4	25	92	2741	1776
Floodplain	5	23	83	2920	989
(BF)	6	20	64	4987	1422
	7	17	67	5303	1883
	8	25	60	8082	5236
	9	11	0	-	-67

* **Source:** runoff and drainage values compiled by Iain Hume using APSIM results of Enli Wang for the 114-year period (1892-2005); NPVs are based on Parna Slope soil budgets in Appendices 1 to 8, and adjusted for APSIM-calculated biomasses relative to those for Parna Slope soil (**bold type** here). The exceptions are the NPVs of new forest habitats, considered here to have the same per hectare direct costs for establishment (-$1140) and pest control (-$67) on all soils in the study area.
** see Table 1 for land use codes

Waterlogging was assumed to reduce income by depressing growth and therefore harvestable yield. The water balance was adjusted to account for this by (1) reducing the modelled estimate of transpiration by the same proportion as income was reduced by waterlogging and (2) adding this “un-transpired” water to drainage. This is a justifiable approach since these waterlogged soils are likely to be in the lowest parts of the landscape where surface drainage is poor.

2.4. Bioeconomic Modelling.

A NSW DPI model integrates the physical, biological and economic information to calculate minimum-cost changes in land use to attain each of a range of specified targets of forest habitat area in the catchment and future mean water-yields and salt-loads from the catchment.

Gross margins of each of the land uses were estimated for the Parna Slopes, the most common soil/landform in the catchment (Table 2). The farmers' estimates of yield loss (compare Appendices 8 and 4) were used to account for lost production under waterlogged conditions. NPVs for each land use on the Parna Slopes soil were calculated using the annual average gross margins, given in Appendices 1 to 8. Assuming these values would hold for each year to a planning horizon of 30 years, the present value for each year was discounted at 7 per cent.

APSIM-modelled estimates of biomass production for each soil type were used to adjust the Gross Margin and Net Present Value (NPV) levels of soils other than the base-line Parna Slopes. The NPV of each farming system on each soil type was calculated as the product of the NPV of that land use on the Parna Slopes (**bold type** in Table 4) and the ratio of biomass productivity on that soil to that of the Parna Slopes.

Trees already in the catchment are retained but incur annual expenditures of \$5/ha for pest control, the discounted NPV of which for the current year to 30 years in the future is -\$67/ha. Any new areas of trees, to provide forest habitat, were assumed to have similar pest control requirement in addition to a one-off establishment cost of \$1140/ha, regardless of soil type. All land uses, other than tree areas, are assumed to provide different levels of livestock grazing resources, valued at \$25/DSE, where DSE refers to 'Dry Sheep Equivalents'. In some cases, grazing value is available from permanent or annual pastures. In the case of crop/pasture rotations, crop residue such as standing stubble, leaves and fallen grain, also provide summer grazing.

The APSIM Modelling estimated for each land use surface water runoff and deep drainage (Table 4, in mm/year). Salt-loads were calculated as weighted sums: surface runoff at rainwater salinity (5.25 ppm), plus deep drainage times a mixing factor times groundwater salinity (Table 5).

In this preliminary analysis we discover where current land use could be replaced with forest habitat to achieve future catchment water-yield and salt-load targets at least cost. The problem is posed in a linear programming framework similar to that described by Nordblom *et al.* (2006). The difference here is that surface runoff and deep drainage values are based on APSIM calculations, while the earlier model used modified Zhang (2001) and, here, we are only considering changing from current land-use to forest habitat. No other switching among land uses is considered here.

Table 5. Simmons Creek surface and groundwater salinity assumptions by sub-catchment with mixing proportions

	Groundwater salinity			
	EC	Concentration	Local surface runoff salinity	Deep drainage mix***
Sub-catch*	(µS/cm)	(ppm, w/w)**	(ppm, w/w)**	(proportion)
1	-	-	5.25	-
2	-	-	5.25	-
3	-	-	5.25	-
4	-	-	5.25	-
5	-	-	5.25	-
6	10,000	6,250	5.25	0.14
7	15,000	9,375	5.25	0.14
8	20,000	12,500	5.25	0.14
9	2,000	1,250	5.25	0.14
10	25,000	15,625	5.25	0.14
11	24,000	15,000	5.25	0.14
12	10,000	6,250	5.25	0.14
13	1,000	625	5.25	0.14

* Sub-catchments 1-5 comprise the upper catchment; the others comprise the lower catchment with salty groundwater. Refer to Figures 2 and 3

** ppm = 0.625 EC (electrical conductivity)

*** proportion of deep drainage delivering full concentration of salty ground-water to Billabong Creek, calibrated to deliver approx. 10,000 t/year

2.4.1. Sub-catchment Linear Programming model

The sub-catchment LP model, each current land use / soil combination has characteristic values in the constraint rows for water-yield (Table 4) and salt-load (using Table 5), and an NPV value (from Table 4) in the objective row. New forest habitat areas were assumed to have the same water-yield and salt load characteristics as existing tree areas, but have both establishment and pest control costs represented in the objective row. Each current land use / soil combination in a particular sub-catchment (Table 4) is constrained in the future to either continued current use, new forest habitat, or some combination of these. The model is solved to maximise sub-catchment NPV, subject to the additional constraint that new forest habitat area is a fixed value.

The model is solved first with new forest area set at zero, to find the sub-catchment NPV, water-yield (W) and salt-load (S) given the current land use configuration. It is solved again with new forest habitat area set at 200 ha and the resulting NPV, W, S and all land use levels recorded. The 200 ha of new forest will have been allocated to land currently in other uses, such that opportunity costs are minimised. The model is solved with successive 200 ha-increments, and results recorded for each, until the sub-catchment area is filled with trees (old and new), or nearly so. This process is repeated for each of the sub-catchments.

2.4.2. Aggregate Catchment-Level Model

The results of all the sub-catchment runs, each with different levels of new forest habitat, are then combined in an aggregate catchment-level model. This is set to maximise catchment NPV, subject to a specified lower level of salt-load reaching Billabong Creek. In the Catchment Level Model a particular sub-catchment may have half its total area in the current land use configuration and half in a new configuration that involves some proportion of new forest habitat. Starting with the salt-load, associated with current land use, catchment annual salt-load was reduced in decrements of 1000 t and the model solved to identify the NPV-maximising land use configuration. Water-yields, salt-loads and areas of new forest habitat associated with the solution are reported at each step.

Tabular summaries and some detailed examples are given in the 'Results' section (Tables 6, 7 & 8). Also a graphical summary of the trade-offs between area of new forest habitat and total cost per hectare of habitat is provided (Figure 4). The total costs include opportunity costs of displacement of profitable crops and pastures, direct costs of establishing and maintaining new forest habitat, and downstream losses expected due to reduced water-yields.

3. Results

The details of optimal placement of new forest habitat areas among sub-catchments in order to attain specified salt-load reduction at least cost from the current level of 9542 t/year at the catchment-level are given as examples here for two cases: reduction to 6000 t/year (Table 6) and to 1000 t/year (Table 7).

Notice that no sub-catchments in the upper catchment enter are planted to new forestry habitats, neither do sub-catchments 9, 11 nor 13 enter the solutions (Table 7).

Reducing salt-load to 6000 t/year calls for new forest habitat only in sub-catchments 8 and 10 (Table 6). However, an extreme reduction in salt-load to 1000 t/year will require new forest habitats covering over 6000 ha in sub-catchments 6, 7, 8, 10 and 12 (Table 7). In each case, these results offer 'best results for the money'… but the costs are substantial. Catchment NPV falls from the current $64 million to only $37 million for the most extreme reduction. Likewise, water yields drop from 9392 to only 3654 ML/year. These catchment-level tradeoffs are shown across all 1000 t/year decrements in salt-load in Table 8.

The incremental cost of each ha of forest habitat is initially high, plateaus and then rises (Figure 4). This reflects the model's objective of maximising NPV given each set of constraints. Land giving the best salt-load reductions in terms of opportunity cost is selected for new forest habitat first. As the locations providing such advantages are used up, more productive land, with less cost-effective capacity to reduce salt-loads, is drawn into forest habitat use.

Table 6. Detailed results for catchment target of reducing salt-load to 6000 t/yr at least cost

	NPV	W	S	NFH										
	($K)	(ML)	(t/yr)	(ha)										New
	59822	7592	6000	1750										Forest
	Optimal location of new forest habitat in sub-catchments of Simmons Creek													Habitat
	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	SC11	SC12	SC13	areas
Erosional Rises	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)
Native Past, Well Drained	0	0	0	0	0	0	0	**50**	0	**18**	0	0	0	**68**
Introduced Past, Well Drained	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Low Input Rot., Well Drained	0	0	0	0	0	0	0	0	0	**49**	0	0	0	**49**
High Input Rot., Well drained	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Parna Slopes														
Native Past, Water Log'd	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Introduced Past, Water Log'd	0	0	0	0	0	0	0	0	0	**10**	0	0	0	**10**
Low Input Rot., Water Log'd	0	0	0	0	0	0	0	0	0	**34**	0	0	0	**34**
High Input Rot., Water Log'd	0	0	0	0	0	0	0	0	0	**94**	0	0	0	**94**
Native Past, Well Drained	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Introduced Past, Well Drained	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Low Input Rot., Well Drained	0	0	0	0	0	0	0	0	0	**3**	0	0	0	**3**
High Input Rot., Well drained	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Parna Plains														
Native Past, Water Log'd	0	0	0	0	0	0	0	**12**	0	**47**	0	0	0	**59**
Introduced Past, Water Log'd	0	0	0	0	0	0	0	**35**	0	**97**	0	0	0	**132**
Low Input Rot., Water Log'd	0	0	0	0	0	0	0	**201**	0	**152**	0	0	0	**353**
High Input Rot., Water Log'd	0	0	0	0	0	0	0	0	0	**173**	0	0	0	**173**
Native Past, Well Drained	0	0	0	0	0	0	0	0	0	**16**	0	0	0	**16**
Introduced Past, Well Drained	0	0	0	0	0	0	0	0	0	**194**	0	0	0	**194**
Low Input Rot., Well Drained	0	0	0	0	0	0	0	0	0	**86**	0	0	0	**86**
High Input Rot., Well drained	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Depressions & Swamps														
Native Past, Water Log'd	0	0	0	0	0	0	0	**47**	0	**164**	0	0	0	**211**
Introduced Past, Water Log'd	0	0	0	0	0	0	0	**54**	0	**105**	0	0	0	**159**
Low Input Rot., Water Log'd	0	0	0	0	0	0	0	0	0	**68**	0	0	0	**68**
High Input Rot., Water Log'd	0	0	0	0	0	0	0	0	0	**38**	0	0	0	**38**
Billabong Floodplain														
High Input Rot., Water Log'd	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Native Past, Well Drained	0	0	0	0	0	0	0	**1**	0	0	0	0	0	**1**
Introduced Past, Well Drained	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Low Input Rot., Well Drained	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
High Input Rot., Well drained	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
New Forest Habitat (ha)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**400**	**0**	**1350**	**0**	**0**	**0**	**1750**

Table 7. Detailed results for catchment target of reducing salt-load to 1000 t/yr at least cost

	NPV	W	S	NFH									
	($K)	(ML)	(t/yr)	(ha)									New
	36860	3654	1000	6371									Forest
	Optimal location of new forest habitat in sub-catchments of Simmons Creek												Habitat
	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	SC11	SC12	SC13	areas
Erosional Rises	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)
Native Past, Well Drained	0	0	0	0	0	139	54	50	0	18	0	0	0	261
Introduced Past, Well Drained	0	0	0	0	0	0	0	10	0	0	0	0	0	10
Low Input Rot., Well Drained	0	0	0	0	0	0	27	0	0	49	0	0	0	76
High Input Rot., Well drained	0	0	0	0	0	104	0	0	0	0	0	0	0	104
Parna Slopes														
Native Past, Water Log'd	0	0	0	0	0	0	28	0	0	0	0	0	0	28
Introduced Past, Water Log'd	0	0	0	0	0	0	30	0	0	10	0	0	0	40
Low Input Rot., Water Log'd	0	0	0	0	0	0	14	0	0	34	0	0	0	48
High Input Rot., Water Log'd	0	0	0	0	0	8	40	0	0	162	0	0	0	210
Native Past, Well Drained	0	0	0	0	0	18	20	5	0	0	0	0	0	43
Introduced Past, Well Drained	0	0	0	0	0	12	2	1	0	0	0	0	0	15
Low Input Rot., Well Drained	0	0	0	0	0	6	507	26	0	6	0	0	0	545
High Input Rot., Well drained	0	0	0	0	0	1000	647	22	0	16	0	0	0	1685
Parna Plains														
Native Past, Water Log'd	0	0	0	0	0	0	15	12	0	47	0	0	0	74
Introduced Past, Water Log'd	0	0	0	0	0	0	0	35	0	97	0	0	0	132
Low Input Rot., Water Log'd	0	0	0	0	0	0	24	203	0	152	0	0	0	379
High Input Rot., Water Log'd	0	0	0	0	0	0	65	274	0	297	0	0	0	636
Native Past, Well Drained	0	0	0	0	0	0	0	0	0	16	0	41	0	57
Introduced Past, Well Drained	0	0	0	0	0	0	1	85	0	194	0	0	0	280
Low Input Rot., Well Drained	0	0	0	0	0	0	3	158	0	115	0	40	0	316
High Input Rot., Well drained	0	0	0	0	0	16	0	68	0	311	0	0	0	395
Depressions & Swamps														
Native Past, Water Log'd	0	0	0	0	0	15	73	47	0	164	0	22	0	321
Introduced Past, Water Log'd	0	0	0	0	0	0	0	54	0	105	0	0	0	159
Low Input Rot., Water Log'd	0	0	0	0	0	0	12	40	0	68	0	33	0	153
High Input Rot., Water Log'd	0	0	0	0	0	53	38	109	0	139	0	0	0	339
Billabong Floodplain														
High Input Rot., Water Log'd	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Native Past, Well Drained	0	0	0	0	0	0	0	1	0	0	0	8	0	9
Introduced Past, Well Drained	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Low Input Rot., Well Drained	0	0	0	0	0	0	0	0	0	0	0	56	0	56
High Input Rot., Well drained	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New Forest Habitat (ha)	0	0	0	0	0	1371	1600	1200	0	2000	0	200	0	6371

Table 8. Catchment-level tradeoffs, Simmons Creek					
		Net Present Value			New Forest
Salt-load	Water-yield	($ million)	($ million)	Salinity	Habitat
(t/year)	(ML/year)	**within**	**in - out ****	(ppm)	(ha)
9542 *	**9392 ***	**$64.3 ***	**$64.3**	**1016 ***	**0 ***
9000	9128	$63.8	$63.4	986	256
8000	8622	$62.7	$61.5	928	723
7000	8080	$61.4	$59.4	866	1247
6000	7592	$59.8	$57.1	790	1750
5000	6993	$58.1	$54.5	715	2363
4000	6284	$56.0	$51.3	637	3092
3000	5484	$52.7	$46.9	547	4015
2000	4789	$47.4	$40.5	418	4891
1000	3654	$36.9	$28.3	274	6371
* calculated current levels			Source: compiled by authors		
'** includes downstream cost of lower water yield					

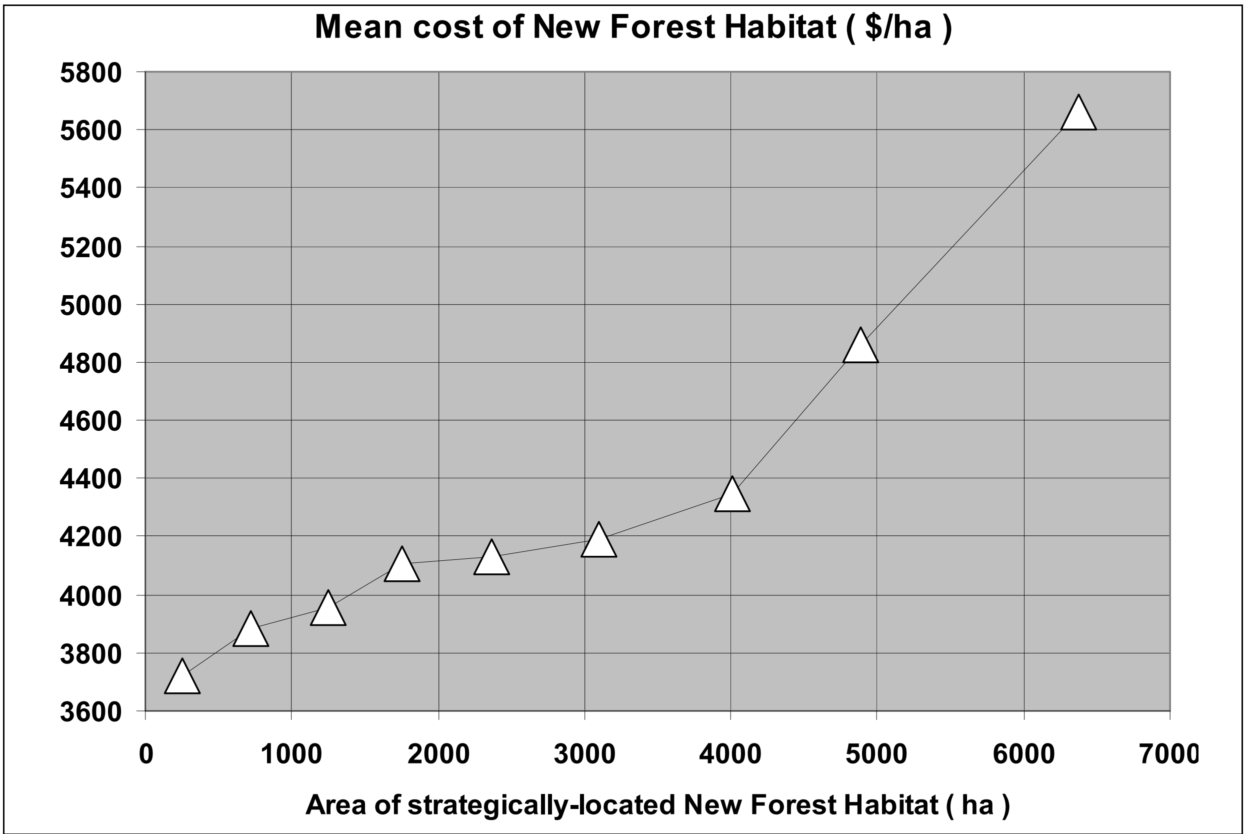

Figure 4. Costs (in-catchment and downstream) of new forest habitat

4. Discussion

There are a number of reasons why some sub-catchments are not selected for planting with new forest habitat:

- The model will allow establishment of new forest habitats only where trees are not already present. Since sub-catchment 11 is currently a heavily forested area (Table 3) new forest habitat is not called for here.

- Sub-catchments 9 and 13 have the lowest concentrations of salt in their groundwater compared with others in the lower catchment (Table 5). They also support large areas of the most profitable land uses: high input crop/pasture rotations on well drained soil. New forest habitats in these areas would be most expensive in terms of opportunity costs and reduced water yields and least effective in reducing river salt-loads.

- The reason no new native forest habitat is called for in the upper catchment is due to our assumption that only fresh water flows from that area and that this does not engage the salty groundwater of the lower catchment. Refinement of our simplified hydrology model may well include more mixing of waters in our subsequent analyses.

Tradeoffs occur between catchment water-yield, salt-load, NPV and the area of new forest habitat areas (Table 8). These are worthy of further comment.

- The model chooses the least-opportunity-cost combinations of sub-catchment (and associated groundwater salinity), soil and land use to achieve a reduced salt-load target by substituting new forest habitat for old land uses. The first decrements in salt-load (say to 9000 and 8000 t/year) come at relatively modest cost in terms of reduced catchment NPV (Table 8). Subsequent reductions are increasingly expensive in absolute terms and in terms of cost per hectare of habitat (Figure 4), because increasingly valuable land uses are being displaced.

- In addition to the direct costs of establishing a forest area, we must deal with several-fold larger opportunity costs… the lost opportunities for profitable employment of the land. When we add to these costs the consideration of likely downstream losses borne by people dependent on continued stream flow volumes, the supply of which would be reduced by large-scale upstream tree planting, the picture looks worse (Table 8). Here, for the sake of discussion we used a rough figure of $1,500/ML for the value of Billabong Creek water in a permanent trade.

- Costs are not linked in a linear way to the incremental increase in the area of new forest habitat (Table 8, Figure 4).

- Water yield from forests is commonly of better quality than from cleared catchments. This is particularly the case when sites for forest plantations are selected explicitly to reduce salt-loads, as we have done. With less than half of Simmons Creek catchment planted to forest, in the most effective places, salt load may be reduced from 9,542 t/year to 1000 t/year, with a commensurate reduction in water-yield from 9392 to 3654 ML/yr. As a consequence of salt sources being targeted in this process the proportional reduction in salt (89%) was far greater than the proportional reduction in water yield (61%). This is expressed by large reductions in the over all salinity concentration of the catchment's water yield, from over 1000 ppm to less than 300 ppm (Table 8). If we had instead focussed forest establishment on the fresh water sources, such as the upper catchment, quite the opposite result would be obtained with regard to water quality, though water yields would be similarly reduced.

General discussion points:

- Where opportunity costs of a land use change are "just covered" as we have assumed in this analysis, one should expect very few land managers to actually change land use. Therefore, to encourage change, bids for ecosystem services would have to be considerably higher than the minimum cost figures we have calculated here.

- The precise locations of "best" new forest habitat areas (Tables 6 and 7), beg the question of how a program might be achieved on the ground. The sub-catchment-specific identification of locations is due to relative cost effectiveness in achieving catchment-level aims of reduced salt-loads. Presumably, programs would focus on only those sub-catchments, soils and land uses identified by the model. Because the land is in private ownership, decisions by landowners on whether to participate will depend on their private assessments of costs and benefits. The current soil-specific land uses in those sub-catchments, which are shifted to new forest habitat by the model, are based on our profitability assumptions (Table 4). These may provide a rough predictor of the relative bids that may be received in a sub-catchment / state-specific tender process for ecosystem services.

- The two key target constraints in this study; the 'area of new forest habitat' and the 'catchment salt-load' of the whole catchment are likely more desirable to people living outside the catchment than to landowners within the catchment. Greater areas of protected habitat may be desired by the wider society, while lower salt-loads may be desired by riparian water users along the course of Billabong Creek, below Simmons Creek, though the large accompanying reductions in water-yield would likely be seen as a disadvantage.

5. Conclusions.

- The methods applied here can be used elsewhere to glean information on current land use and the associated economic characteristics, benefiting from the help of experienced local land managers (farmers).

- Even if our budget calculations for current land uses, and costs of new forest habitats, are correct, project costs for actually implementing such reforestation plans would likely far exceed the break-even solutions we have identified. Changing land use from an integrated crop-livestock system, to one in which stock-excluded habitat areas have a major presence, would require considerable lifestyle changes for some rural residents. We should not expect such changes to be accepted automatically or quickly.

- We have explored only changing to forest habitat. There are many other trajectories that land changes may take and the economic and hydrologic consequences of intensified farming systems with greater areas of summer-active forage crops, such as lucerne and cowpea, warrant exploration.

- We have shown it is possible to quantify the tradeoffs among the upstream options for minimum-cost land use changes, such as provision of new forest habitat areas, to deliver targeted future mean river water-yield / salt-load mixes. While we are confident this provides a broad illustration of such tradeoffs, we caution readers that the simple hydrology model we have used must limit our confidence in the precise numerical accuracy of the results.

- If it is possible, also, to quantify down-stream demand for water and water quality, this opens the way for quantifying the full costs of providing new areas of forest habitat, agro-forestry and/or carbon sequestration plantations.

It is possible to quantitatively explore options for linking down-stream demand with upstream supply of water, water quality and forest benefits. Correct anticipation of the distributions of costs and benefits is key to correctly anticipating the main effects of any new incentive program for strategic targeting (or limiting) re-vegetation.

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Appendices Ten-year gross-margin budgets follow, as listed in Table 1 (page 5):

Appendix 1.	Native pastures on soils subject to water logging											
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	10-year
Simmons Creek					Annual pasture (sub-clover, annual grasses)							totals
	Operation				$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha
Fertilizer												
Pasture - fert 2yrs in 10		$7				$7						$7
weed spray 3yrs in 10		$8				$8				$8		$24
insect control 2yrs in 10		$10				$10						$20
Total 10-year costs ($/ha)		$18	$0		$0	$18	$0	$0		$8	$0	**$44**
Pasture Productivity												
Poorest year DSE/ha		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	5.00
Typical year DSE/ha		**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**30.00**
Best year DSE/ha		7	7	7	7	7	7	7	7	7	7	70.00
Pasture gross margin	**$25**											
((Typical DSEs x $25) - costs)		$57	$75	$75	$75	$57	$75	$75	$75	$67	$75	**$706**
Rotation Gross Margin	= (Pasture Gross Margins)**/10 years** ($/ha/yr)											**$71**

Appendix 2.	**Introduced pastures on water logged soils**											
		Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**10-year**
Simmons Creek	Pasture:						**Permanent pasture of sub-clover and phalaris**					**totals**
	Operation						$/ha	$/ha	$/ha	$/ha	$/ha	**$/ha**
Land Preparation												
weed control & insect control yr1		$27										**$27**
Fertilizer												
Pasture -					$12				$12			**$24**
Sowing												
sub & phalaris		$60										**$60**
weed control - maintenance				$8			$8			$8		**$24**
insect control - maintenance				$9			$9			$9		**$27**
Total 10-year costs ($/ha)		$87		$17	$12		$17		$12	$17		**$162**
Pasture Productivity												
Poorest year DSE/ha		1	1	1	1	1	1	1	1	1	1	10
Typical year DSE/ha		**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**40**
Best year DSE/ha		8	8	8	8	8	8	8	8	8	8	80
Pasture gross margin	**$25**											
((Typical DSEs x $25) - costs)		$40	$100	$83	$88	$100	$83	$100	$88	$83	$100	**$865**
Rotation Gross Margin	= (Pasture Gross Margins)**/10 years** ($/ha/yr)											**$87**

Appendix 3.	'Low input traditional' on soils subject to water-logging... focussed on wool and fat lambs (30% of merino ewes joined to terminal sires)											
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	10-year
Simmons Creek		Oats	Wheat	Triticale	Annual pasture (sub-clover, annual grasses)							totals
	Operation	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha
Land Preparation												
Crops	2-3 cultivations annually	$8	$15	$15								$37
Fertilizer												
Pasture	10kg P/ha, one year in 10				$7							$7
Crop	50 kg N / ha in spring of wet years	$0	$25	$25								$50
Sowing												
Oats		$21										$21
Wheat	60-80 kg/ha		$50									$50
Triticale	80 kg/ha			$66								$66
Sub-clover	undersown - seed and dressing cost				$28							$28
Post emegence												
broad leaf & grass weed control		$10	$28	$16								$54
1 x Soil herbicide		$6	$6	$6								$18
Insecticide					$4		$4		$4		$4	$16
Harvest												
Oats (80%), Wheat, Triticale	harvest and carting costs	$30	$48	$45								$123
Oat (about 15%)	haymaking and carting	$26										$26
Total 10-year costs ($/ha)		$101	$172	$173	$39		$4		$4		$4	**$496**
Crop Yield	Poorest year T/ha	0.5	0.8	1.2								
	Typical year T/ha	**1.2**	2	2.3								
	Best year T/ha	1.7	3.5	3.8								
crop sales price ($/T)		**115**	**160**	**135**								
X typical yield =		**138**	**320**	**311**								**$769**
Crop Gross Margin =	((yield x sale price) - costs)/ha	**38**	**149**	**138**								**$324**
Pasture Productivity	Poorest year DSE/ha	0	0	0	2	2	2	2	2	2	2	14.00
include 5% of oats	**Typical year DSE/ha**	**1**	**1**	**1**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**31.00**
	Best year DSE/ha	2	2	2	10	10	10	10	10	10	10	76.00
Pasture gross margin	**$25**											
	((Typical DSEs x $25) - costs)	$25	$25	$25	$61	$100	$96	$100	$96	$100	$96	**$724**
Rotation Gross Margin	= (Crop + Pasture Gross Margins)/**10 years** ($/ha/yr)											**$105**

Appendix 4.	**'High Input Rotation'** **on soils subject to water-logging**											
		Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**10-year**
Simmons Creek	Crop or Pasture:	**Canola**	**Wheat**	**Triticale**	**Canola**	**Triticale**	**Perm. pasture: sub-clover & phalaris**					**totals**
	Operation	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	**$/ha**
Land Preparation												
Crop following pasture, heavy graze + 2 knockdown sprays + cultivation		41										**$41**
Crop following crop, direct drilled with cereal stubbles burnt			32	38	40	38						**$148**
Pastures in final year spray topped for grass weeds (take-all risk)											12	**$12**
Soil amendments	Lime **2.5 T/ha** each 10 years	180										**$180**
	Gypsum **2.5 t/ha** each five years on water-logged soils	50					50					**$100**
Fertilizer												
Crop	100 kg MAP/ha at sowing	65	55	43	65	65						**$293**
Pasture	Pasture - 24 kg P/year (as 125 kg SSP)						60		60		60	**$180**
Sowing												
Wheat	80 kg/ha. Typically Janz types @ 80 kg/ha		63									**$63**
Canola	90% of crop is mainseason TT canola	22			22							**$44**
Triticale	100 kg/ha			60		60						**$120**
Sub-clover & Phalaris	Sub-clover undersown						28					**$28**
Post emegence												
Fungicides	for stripe rust in wheat, blackleg in canola	12	10		12		5					**$39**
Herbicides	for grass weeds in cereals, broadleaf in canola	39	12				18					**$69**
Fertilizer top-dress		30	30	30	30	30	65		65		65	**$345**
Harvest												
Canola, Wheat, Triticale	harvest and carting costs	108	55	45	108	45						**$361**
Pasture hay	haymaking and carting											
Total 10-year costs ($/ha)		547	257	216	277	238	226	0	125	0	137	**$2,023**
Crop Yield	Poorest year T/ha	0.8	1.5	1.5	0.8	1.5						
	Typical year T/ha	2	3	2.8	2	2.8						
	Best year T/ha	2.8	4.5	4.2	2.8	4.2						
crop sales price ($/T)		**300**	**160**	**135**	**300**	**135**						
X typical yield =		600	480	378	600	378						**$2,436**
Crop Gross Margin =	((yield x sale price) - costs)/ha	53	224	162	323	140						**$902**
Pasture Productivity	Poorest year DSE/ha	1	1	1	1	1	2.5	2.5	2.5	2.5	2.5	$18
	Typical year DSE/ha	**2**	**2**	**2**	**2**	**2**	**7**	**7**	**7**	**7**	**7**	$45
	Best year DSE/ha	4	4	4	4	4	12.5	12.5	12.5	12.5	12.5	$83
Pasture gross margin	**$25**											
	((Typical DSEs x $25) - costs)	$50	$50	$50	$50	$50	-$51	$175	$50	$175	$38	**$637**
Rotation Gross Margin	= (Crop + Pasture Gross Margins)**/10 years** ($/ha/yr)											**154**

Appendix 5.	NATIVE PASTURE COSTS AND PRODUCTIVITY,on well-drained soils										
		Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**10-year**
Simmons Creek					**Annual pasture (sub-clover, annual grasses)**							**totals**
	Operation				$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	**$/ha**
Fertilizer												
Pasture - fert 3yrs in 10		7				7				7		$14
weed spray 3yrs in 10		8				8				8		$24
insect control 2yrs in 10		9				9				9		$27
Total 10-year costs ($/ha)		17	0	0	0	24	0	0	0	24	0	**$65**
Pasture Productivity												
Poorest year DSE/ha		1	1	1	1	1	1	1	1	1	1	$10
Typical year DSE/ha		**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**$40**
Best year DSE/ha		9	9	9	9	9	9	9	9	9	9	$90
Pasture gross margin	**$25**											
((Typical DSEs x $25) - costs)		83	100	100	100	76	100	100	100	76	100	**$935**
Rotation Gross Margin	= (Pasture Gross Margins)**/10 years** ($/ha/yr)											**$94**

Appendix 6.	**INTRODUCED PERMANENT PASTURE COSTS AND PRODUCTIVITY, well-drained soils**											
		Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**10-year**
Simmons Creek	Crop or Pasture:						**Lucerne**	**Lucerne**	**Lucerne**	**Lucerne**	**Lucerne**	**totals**
	Operation						$/ha	$/ha	$/ha	$/ha	$/ha	**$/ha**
Land Preparation								0				
Soil amendments	Lime 2.5 T/ha each 10 years			180								**$180**
Fertilizer												
Pasture												
Pasture - 24 kg P/ every 2 years (as 125 kg SSP)			60		60		60		60		60	**$300**
Sowing												
Lucerne		120										**$120**
												$0
												$0
Total 10-year costs ($/ha)		**120**	**60**	**180**	**60**		**60**		**60**		**60**	**$600**
Pasture Productivity	Poorest DSE/ha	2	2	2	2	2	2	2	2	2	2	$20
	Typical DSE/ha	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**$70**
	Best DSE/ha	12	12	12	12	12	12	12	12	12	12	$120
Pasture gross margin	**$25**											
((Typical DSEs x $25) - costs)		55	115	-5	115	175	115	175	115	175	115	**$1,150**
Rotation Gross Margin	= (Crop + Pasture Gross Margins)**/10 years** ($/ha/yr)											**$115**

Appendix 7.	**'Low input traditional' on better-drained red soils...** focussed on wool and fat lambs (30% of merino ewes joined to terminal sires)											
		Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**10-year**
Simmons Creek		**Oats**	**Wheat**	**Triticale**	**Annual pasture (sub-clover, annual grasses)**							**totals**
	Operation	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	**$/ha**
Land Preparation												
Crops	2-3 cultivations annually	$8	$15	$15								$37
Fertilizer												
Pasture	10kg P/ha, one year in 10				$7							$7
Crop	50 kg N / ha in spring of wet years	$0	$25	$25								$50
Sowing												
Oats		$21										$21
Wheat	60-80 kg/ha		$50									$50
Triticale	80 kg/ha			$66								$66
Sub-clover	undersown - seed and dressing cost				$28							$28
Post emegence												
broad leaf & grass weed control		$10	$28	$16								$54
1 x Soil herbicide		$6	$6	$6								$18
Insecticide					$4		$4		$4		$4	$16
Harvest												
Oats (80%), Wheat, Triticale	harvest and carting costs	$30	$48	$45								$123
Oat (about 15%)	haymaking and carting	$26										$26
Total 10-year costs ($/ha)		$101	$172	$173	$39		$4		$4		$4	**$496**
Crop Yield	Poorest year T/ha	0.5	0.8	1.2								
	Typical year T/ha	**1.5**	2.2	2.7								
	Best year T/ha	1.7	3.5	3.8								
crop sales price ($/T)		**$ 115.00**	**$ 160.00**	**$ 135.00**								
X typical yield =		**$ 172.50**	**$ 352.00**	**$ 364.50**								**$ 889.00**
Crop Gross Margin =	((yield x sale price) - costs)/ha	**$ 72.00**	**$ 180.50**	**$ 192.00**								**$ 444.50**
Pasture Productivity	Poorest year DSE/ha	0	0	0	2	2	2	2	2	2	2	14
include 5% of oats	**Typical year DSE/ha**	**1**	**1**	**1**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**45**
	Best year DSE/ha	2	2	2	10	10	10	10	10	10	10	76
Pasture gross margin	**$25**											
	((Typical DSEs x $25) - costs)	$25	$25	$25	$111	$150	$146	$150	$146	$150	$146	**$1,074**
Rotation Gross Margin	= (Crop + Pasture Gross Margins)**/10 years** ($/ha/yr)											**$152**

Appendix 8.	**'High Input Rotation' on better-drained red soils**											
		Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**10-year**
Simmons Creek	Crop or Pasture:	**Wheat**	**Canola**	**Wheat**	**Wheat**	**Lupin**	**Lucerne**	**Lucerne**	**Lucerne**	**Lucerne**	**Lucerne**	**totals**
	Operation	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	**$/ha**
Land Preparation												
Crop following Lucerne, heavy graze + 2 knockdown sprays + cultivation		$41										**$41**
Pastures in final year spray topped for grass weeds (take-all risk)											$12	**$12**
Crop following crop, direct drilled with cereal stubbles burnt			$40	$32	$32	$10						**$114**
Soil amendments	Lime 2.5 T/ha each 10 years						**$180**					**$180**
	Gypsum for Canola – 0.5 t/ha											
Fertilizer												
Crop	100 kg MAP/ha at sowing	$55	$65	$55	$55	$39						**$269**
Pasture	Pasture - 24 kg P/year (as 125 kg SSP)						$60	$60	$60	$60	$60	**$300**
Sowing												
Wheat	80 kg/ha. Typically Janz types @ 80 kg/ha	$63		$63	$63							**$188**
Canola	90% of crop is main-season TT canola		$22									**$22**
Lupin	60-80 kg/ha					$63						**$63**
Lucerne	Undersown in final crop year					$62						**$62**
Post emegence												
Fungicides/insecticides	for stripe rust in wheat, blackleg in canola	$10	$12	$10	$10	$14	$6	$6	$6	$6	$6	**$86**
Herbicides	for grass weeds in cereals, broadleaf in canola	$12	$39	$12	$12	$44						**$119**
Fertilizer top-dress	Crops - 50 kg N / ha	**$50**	**$50**	**$50**	**$50**	**$50**						**$250**
Harvest												
Wheat, Canola, Lupin	harvest and carting costs, insurances	**$108**	**$108**	**$108**	**$108**	**$108**						**$540**
Lucerne	haymaking and carting per 1t DM/Year						$60	$60	$60	$60	$60	**$300**
Total 10-year costs ($/ha)		**$339**	**$336**	**$330**	**$330**	**$390**	**$306**	**$126**	**$126**	**$126**	**$138**	**$2,546**
Crop Yield	Poorest T/ha	2	1	1.8	1.6	1						
	Typical T/ha	**4.5**	**2**	**4**	3.8	1.8	**4**	**4**	**4**	**4**	**4**	
	Best T/ha	6	**2.5**	5.5	5	2.6						
crop sales price ($/T)		**$160**	**$300**	**$160**	**$160**	**$270**	**$180**	**$180**	**$180**	**$180**	**$180**	
X typical yield =		$720	$600	$640	$608	$486	$720	$720	$720	$720	$720	$6,654
Crop Gross Margin =	((yield x sale price) - costs)/ha	$382	$264	$311	$279	$96	$414	$594	$594	$594	$582	**$4,109**
Pasture Productivity	Poorest DSE/ha	0.5	0.5	0.5	0.5	0.5	3	3	3	3	3	18
	Typical DSE/ha	**2**	**2**	**2**	**2**	**2**	**8**	**8**	**8**	**8**	**8**	**50**
	Best DSE/ha	4	4	4	4	4	16	16	16	16	16	100
Pasture gross margin	**$25**											
	((Typical DSEs x $25) - costs)	$50	$50	$50	$50	$50	-$106	$74	$74	$74	$62	**428**
Rotation Gross Margin	= (Crop + Pasture Gross Margins)**/10 years** ($/ha/yr)											**454**