Supplementary materials

Part A: The PROLAND model

The *Prosopis* spp. land-use trade-off model (the PROLAND model) was constructed for the purposes of this study. This system dynamics model consists of 10 sub-models, namely i) the land-use sub-model, ii) the yield growth factor sub-model, iii) the raisins farming sub-model, iv) the table grape farming sub-model, v) the citrus farming sub-model, vi) the establishment cost sub-model, vii) the clearing cost sub-model, viii) the carbon sequestration lost sub-model, xi) the water savings sub-model, and x) the net present value sub-model. Part B provides the parameters (exogenous variables) used within the model, and the respective equations used to derive the endogenous variables, while Part C presents the model validation process conducted.

The land-use sub-model

This sub-model models the invaded area that is cleared of *Prosopis* spp. and then converted into various land-use options. The land-use sub-model consists of five stock variables, namely i) the area invaded by *Prosopis* spp., ii) the area restored to table grapes (viz. Prime white seedless cultivar), iii) the area restored to raisins (viz. Golden sultana cultivar), iv) the area restored to citrus (viz. Eureka lemon cultivar), and v) the area restored to natural vegetation (called conservation in the model). The area invaded by *Prosopis* spp. is increased by the re-growth of *Prosopis* spp., which is influenced by the spread rate thereof, the agricultural land-use plantings (i.e. table grape, raisins and citrus plantings) and the area invaded. Furthermore, the area invaded is reduced through clearing operations, which are influenced by clearing budget (and hence employment in person-days). With respect to the other stocks (i.e. area restored to table grapes, citrus, raisins and conservation), they only have inflows, as shown in Figure A1. These inflows are influenced by the proportion assigned to each land-use option, time, the clearance of *Prosopis* spp., and the proportion of and maximum area assigned to each land-use option post-clearing

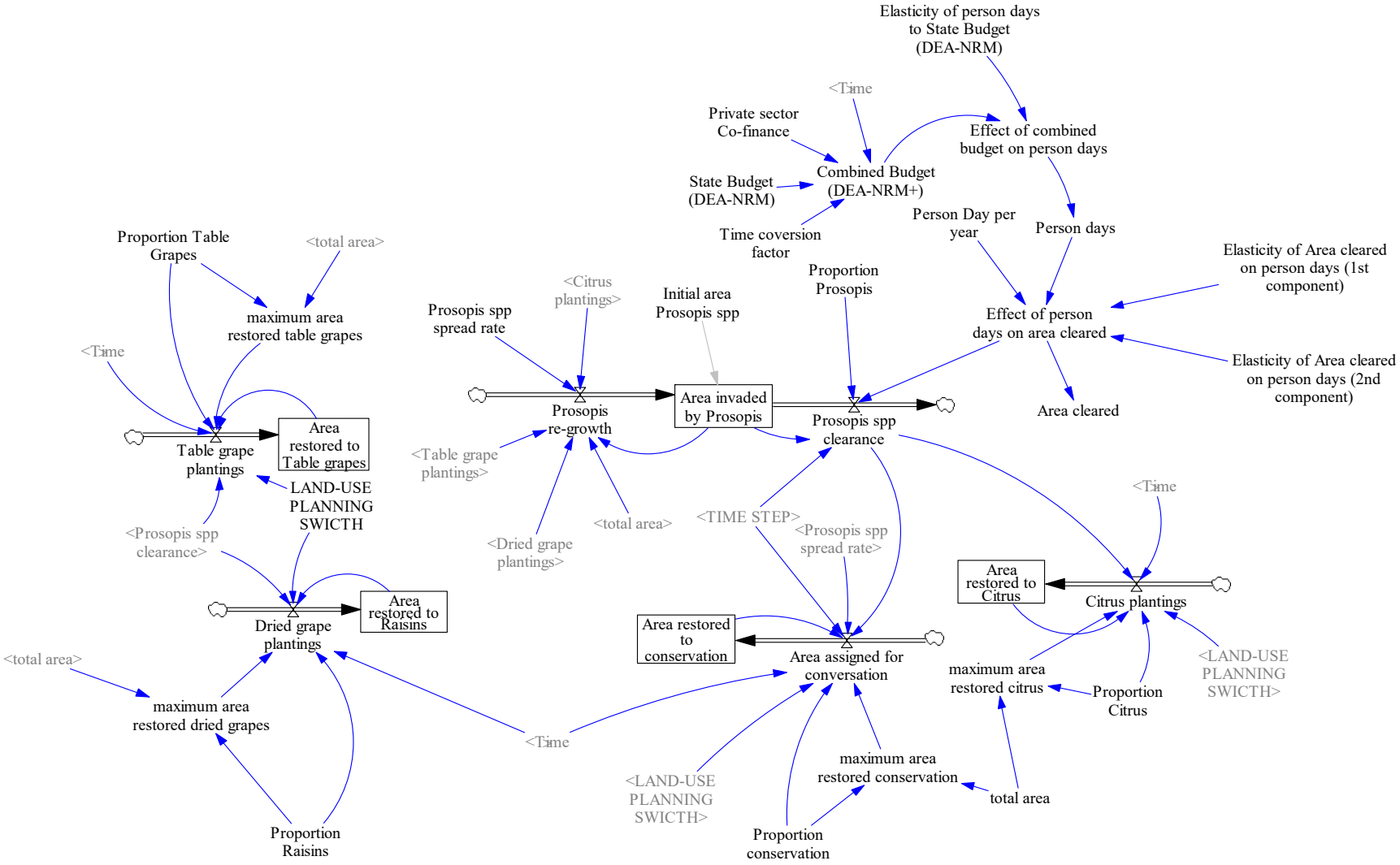

Figure A1: Land-use sub-model of the PROLAND model
Source: Own analysis

Yield growth factor sub-model

This sub-model establishes the growth in the yield of agricultural land-use options considered for the purposes of this study. For the table grapes (i.e. Prime white seedless) and raisins (Golden sultanas) land-use options, the first marketable harvest is realised in the third year after planting, with only 30% of the maximum possible yield being harvested (Moelich, personal communication 2017[1]). In the fourth year, the yield harvested increases to 70%, and finally to 100% from the fifth year onward when all vines have matured (Moelich, personal communication 2017). As a result, for the first two years after planting the yield will be zero. With respect to the citrus (Eureka lemons) land-use option, the first marketable harvest is also realised in the third year after planting, with only 15% of maximum possible yield being harvested (Cronje, personal communication, 2017[2]). Thereafter, 30%, 60%, 85% and 100% of the maximum possible yield is achieved in the fourth, fifth, sixth and, finally, the seventh year and onward respectively (Cronje, personal communication 2017). This sub-model is imperative in order to distinguish the yield emanating from the citrus trees, which in this case are planted at different points in time. Since the citrus tree plantings are determined by the portion of *Prosopis* spp. cleared within a given point in time, the yield growth for the total trees planted differs significantly, with those planted first starting to yield fruit while the rest follow suit only later. Thus the yield area for all the agricultural land-use options is determined by the plantings per annum and the accumulation of plantings (i.e. the stocks) per given time, *inter alia* the proportion of the growth yield based on the age of the agricultural plants post-planting. For illustrative purposes, only the yield growth factor sub-model of table grapes is shown in Figure A2 below. The yield growth factor model for raisins looks basically the same, while that of citrus runs for seven years, since citrus trees take seven years to reach the maximum possible yield.

[1] Mr Dawie Moelich is an experienced horticulturist working as a technical and market access manager for the South African Table Grape Industry (SATI).

[2] Dr Paul Cronje is an experienced horticulturist working as researcher for Citrus Research International (CRI) in partnership with the Department of Horticultural Science of Stellenbosch University.

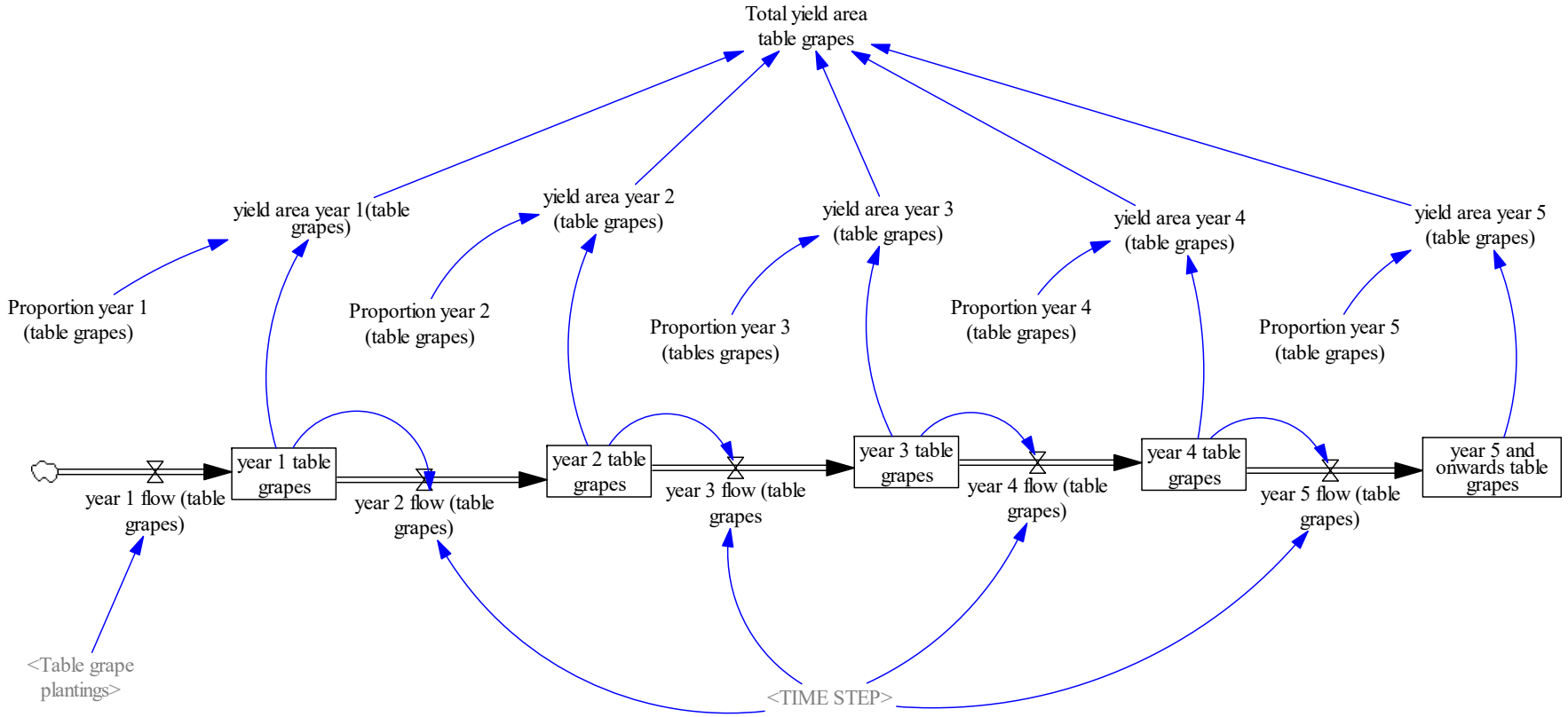

Figure A2: Yield growth factor sub-model for table grapes

Source: Own analysis

Raisins sub-model

In this study it was assumed that the land restored to all land-use options would be apportioned equally on a pro rata basis subject to each scenario under investigation. This sub-model models the enterprise budget for the raisins (viz. Golden sultanas) land-use option. The yield for raisins is determined by the total yield area for raisins (based on the yield growth factor sub-model explained earlier), the dry mass proportion and the respective yield per hectare. The dry mass proportion (i.e. 40%) is imperative to the net weight of the fresh Golden sultanas after drying. The gross revenue for raisin farming is then determined by the product of the total yield from raisins and the respective price per ton. The gross revenue is apportioned in a two-part structure, consisting of export market sales and local market sales. The net revenue from raisin farming is then derived by subtracting the fixed costs and overhead costs, and the directly attributable variable costs and indirectly attributable variable costs, from the gross revenue. The raisin farming sub-model is shown in greater detail in Figure A3.

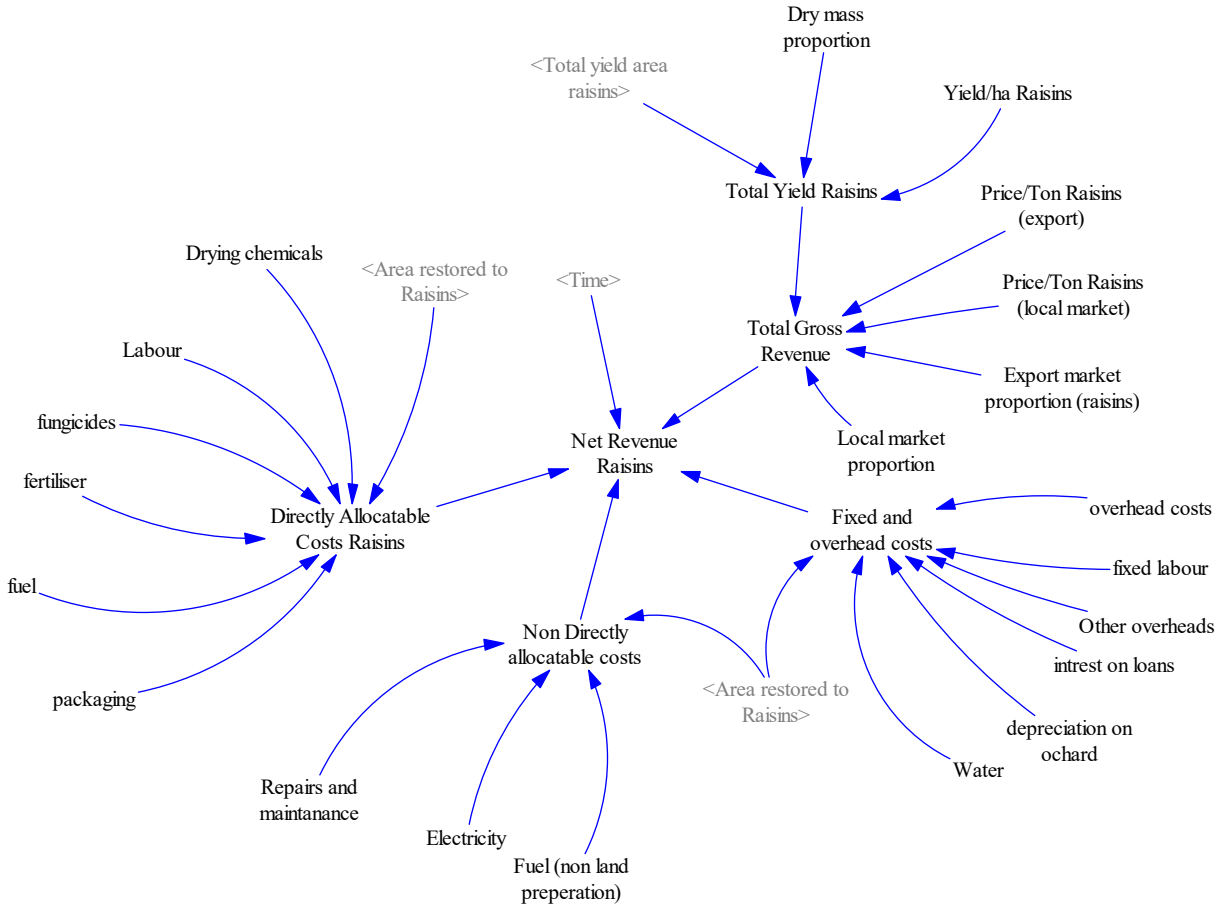

Figure A3: The raisin farming sub-model of the PROLAND model
Source: Own analysis

Table grape farming sub-model

This sub-model models the table grape (Prime white seedless) land-use enterprise budget. Similar to the raisins farming sub-model, the yield of table grapes is influenced by the yield per hectare and the total yield area of table grapes (based on the yield growth factor sub-model). The gross revenue from table grape farming is a function of the price per ton and the total yield of table grapes. The gross revenue is also apportioned in a two-part structure, consisting of export market sales and local market sales. All total production costs are then subtracted from the gross revenue in order to get the net revenue from table grapes (i.e. profit or loss). The table grape farming land-use model is shown in detail in Figure A4.

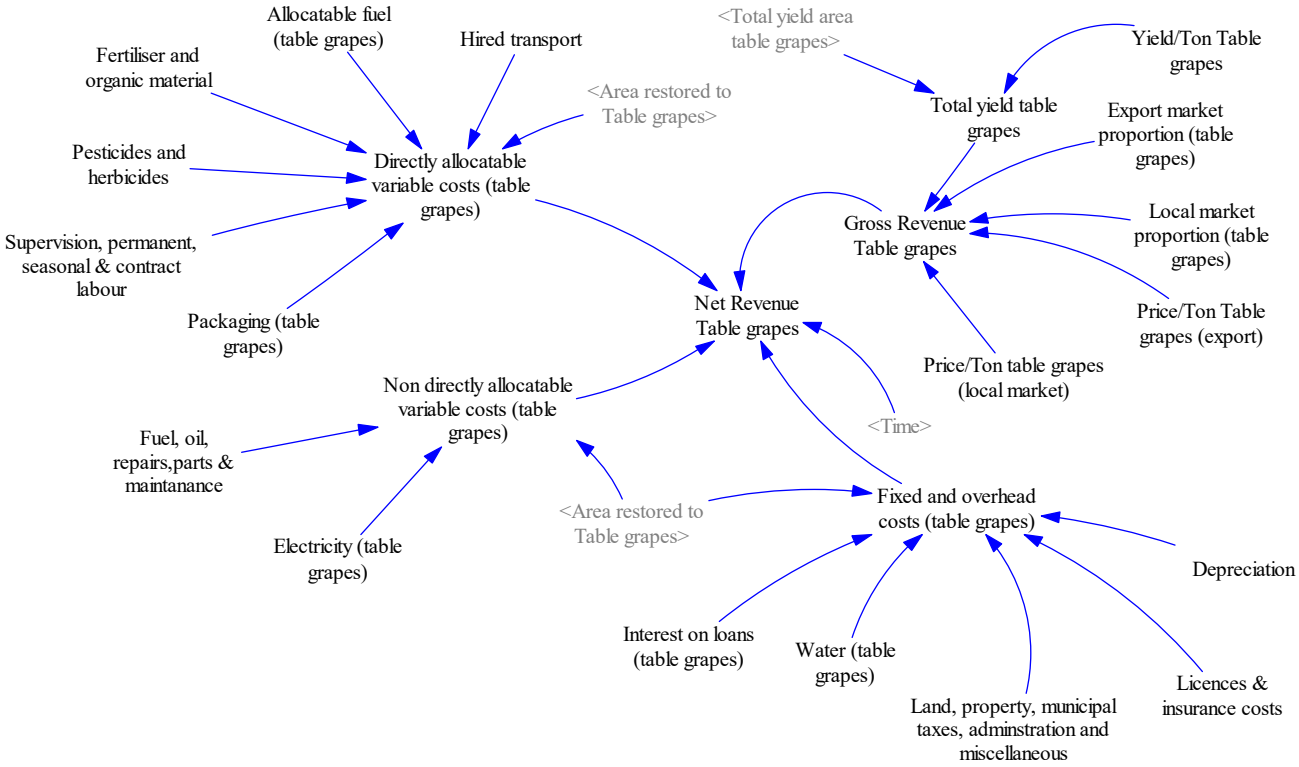

Figure A4: Table grape farming sub-model of the PROLAND model
Source: Own analysis

Citrus sub-model

This sub-model models the farm budget of the citrus (Eureka lemons) land-use option. The total yield is a function of the total yield area (based on the yield growth factor sub-model) and the yield per hectare. The gross revenue of citrus is then determined by multiplying the price per ton of citrus and the total citrus yield. The net revenue of citrus is then derived by subtracting all the costs (i.e. the directly and indirectly attributable variable costs and the fixed and overhead costs for citrus) from the gross revenue value of citrus. The citrus farming sub-model is shown in Figure A5.

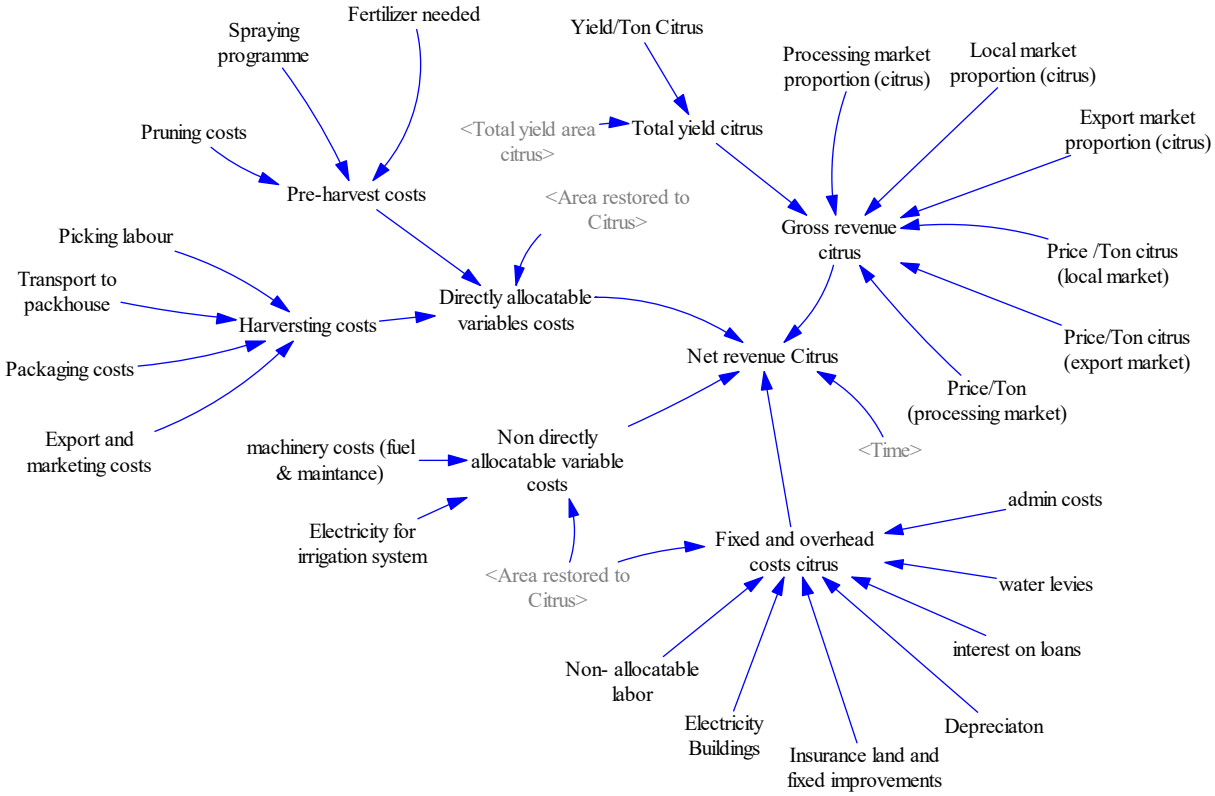

Figure A5: The citrus farming sub-model of the PROLAND model
Source: Own analysis

Establishment cost sub-model

The establishment cost sub-model models the initial investment required in order to undertake the various land-use options considered for the purposes of this study. The establishment costs for all the land-use options are then aggregated to give the total establishment cost that is incurred as a once-off event. The establishment cost sub-model is illustrated in Figure A6.

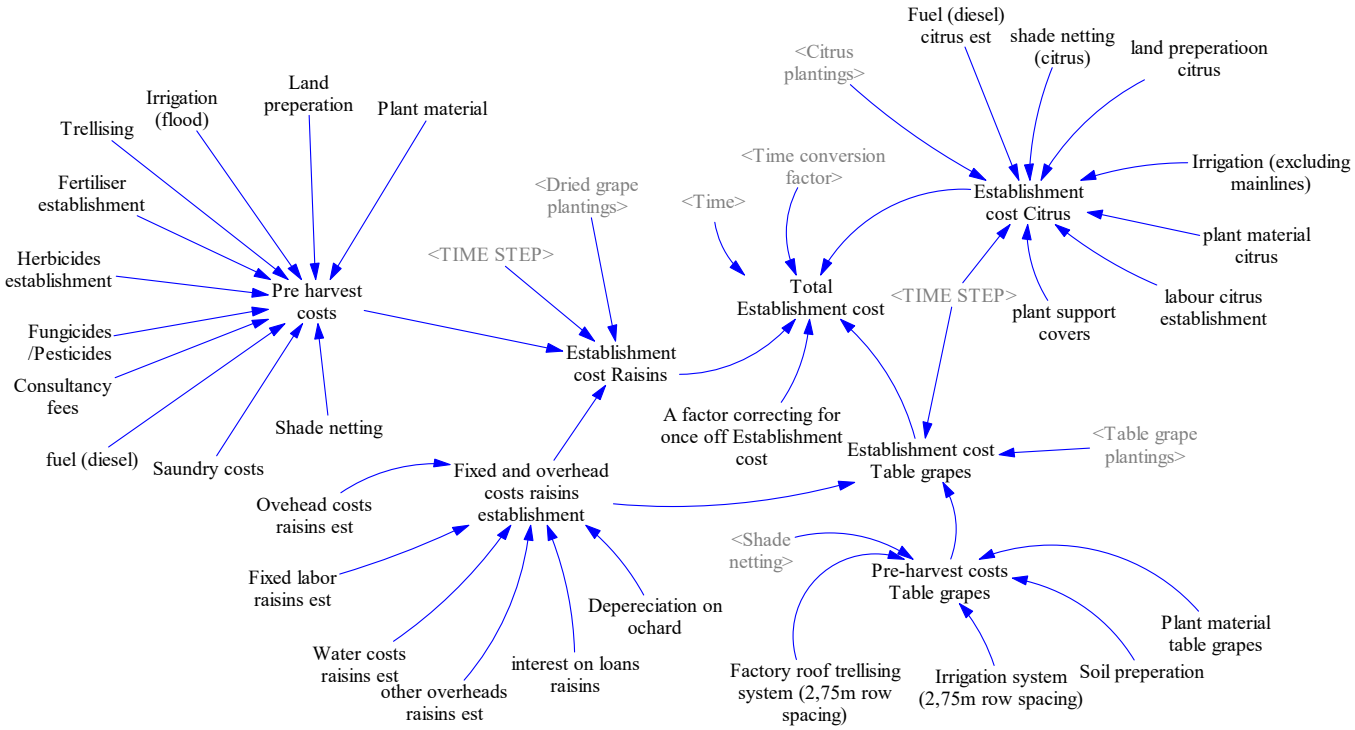

Figure A6: Establishment cost sub-model of the PROLAND model
Source: Own analysis

Clearing cost sub-model

The clearing cost sub-model involves the modelling of the total clearing costs incurred to clear *Prosopis* spp. from the study site. The unit clearing cost is a function of the total budget for clearing *Prosopis* spp. within the sites and the annual clearance of *Prosopis* spp. The budget refers to the total amount of money invested by the DEA: NRM to clear *Prosopis* spp. from within the water management areas of Onseepkans (D81E) and Pella (D81G). The clearing cost sub-model is shown in Figure A7.

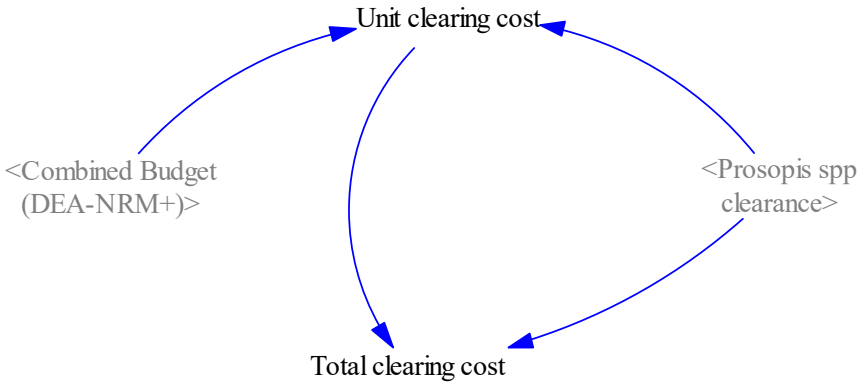

Figure A7: Clearing cost sub-model of the PROLAND model
Source: Own analysis

Carbon sequestration sub-model

The carbon sequestration sub-model establishes the net value of carbon sequestered and stored that is lost as a result of clearing *Prosopis* spp. *Prosopis* spp. sequester and store carbon from the atmosphere as a result of photosynthesis. Thus, through clearing there is an opportunity cost involved due to the loss of both historic as well as potential future carbon sequestration capability. The carbon sequestration potential is derived as the product of the *Prosopis* spp. biomass, the net dry mass conversion ratio of *Prosopis* spp., the clearance of *Prosopis* spp., and the CO_2 (carbon dioxide) to carbon ratio. As a result of the re-growth of *Prosopis* spp., there is a marginal corresponding benefit due to carbon sequestered and stored. This is then subtracted from the carbon sequestered, stored and removed to get the net carbon sequestered, stored and removed. The value of net carbon sequestered and stored that is removed is then calculated by multiplying the net carbon removed and the unit price of carbon. The carbon sequestration sub-model is shown in Figure A8.

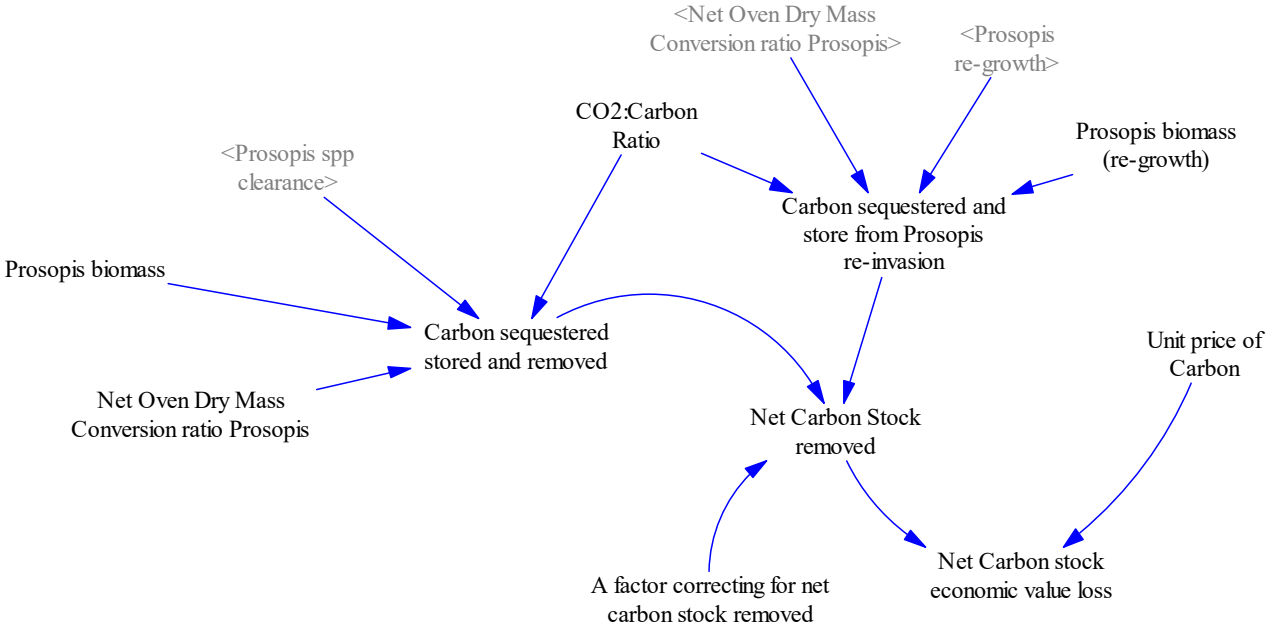

Figure A8: Carbon sequestration sub-model of the PROLAND model
Source: Own analysis

Water consumption sub-model

This sub-model establishes the water reduction caused through invasion by *Prosopis*. As a result of clearing *Prosopis*, the water that was previously consumed by these IAPs is saved and becomes available, therefore augmenting the water supply of the Orange River. The water that is used by the trees is derived as the product of water reduction per hectare by *Prosopis* spp. and the clearance thereof. The monetary economic value of water that is saved as a result of clearing operations is then calculated by multiplying the unit value of water and the water use that has been released. The water consumption sub-model is shown in Figure A9.

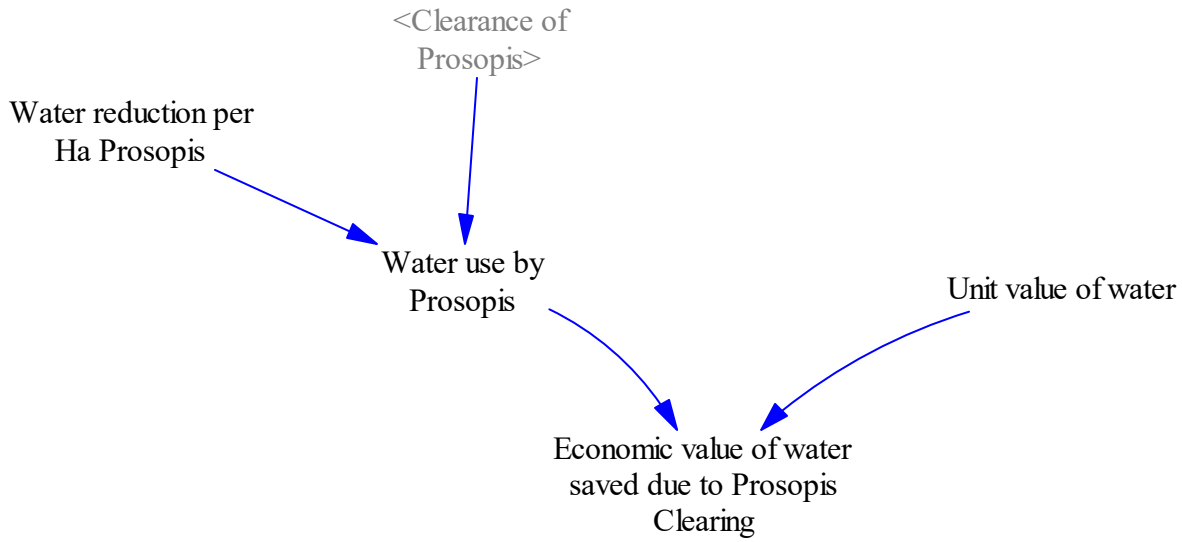

Figure A9: Water consumption sub-model of the PROLAND model
Source: Own analysis

NPV sub-model

This sub-model captures the private (and social) benefits and costs of *Prosopis* spp. clearing operations by calculating the net present value of the operations. In order to assess the feasibility of clearing *Prosopis* spp. and restoring the land cleared to active land-use options, the net present value method was used for the purposes of this study. The net present value is a method of determining the feasibility of a project (or investment) through discounting the net difference between the annual benefits realised and annual costs incurred by a specific discount rate over a given period of time. The net present value formula used for the purpose of this study is shown in the equations below:

$$NPV = \sum_{T=1}^{T} \frac{B_t}{(1+r)^t} - C_t \quad (1)$$

where:
B_t = total annual benefits realised during the year t over a given time period (2)
C_0 = total annual costs incurred during year t over a given time period (3)
r = discount rate (4)
and t = year of cost (5)

The NPV sub-model is illustrated in Figure A10.

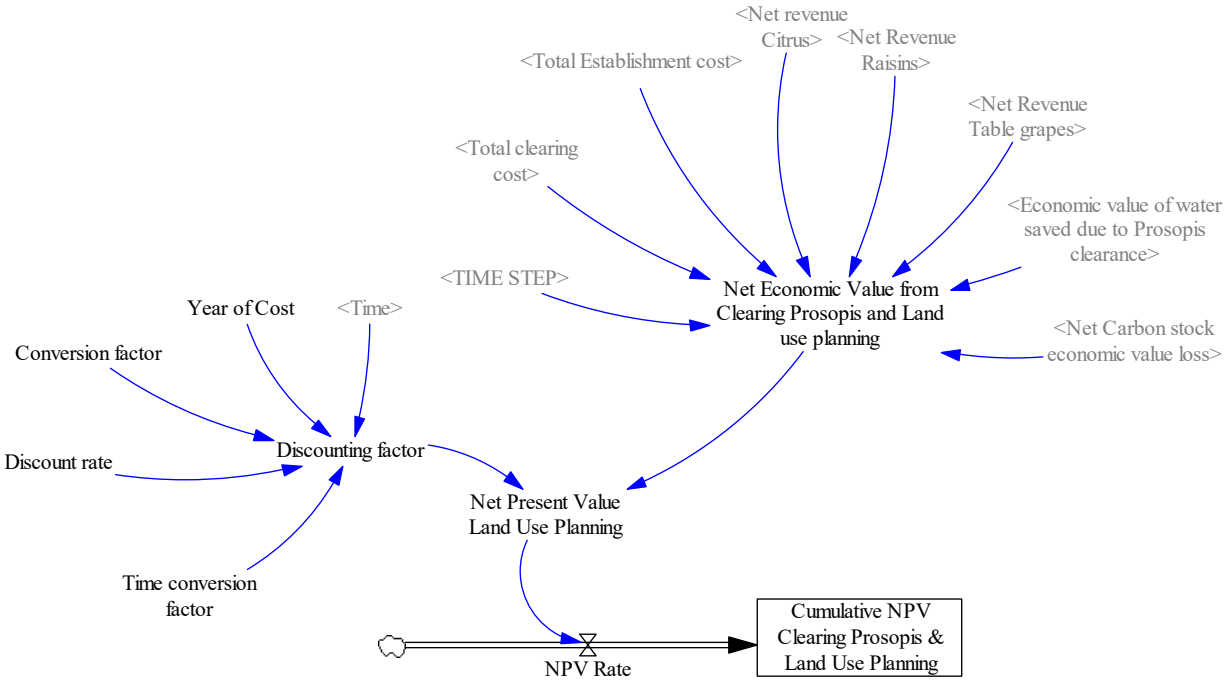

Figure A10: NPV sub-model of the PROLAND model
Source: Own analysis

PART B: PROLAND model parameters and equations

Parameters of land-use sub-model				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Elasticity of area cleared on PD (1st component)	-3e-006	ha/PD	Own calculation	
Elasticity of area cleared on PD (2nd component)	0.0487	ha/PD	Own calculation	
Elasticity of PD to state budget	0.0041	PD/R	Own calculation	
Initial *Prosopis* spp.	9 097.64	ha	DEA: NRM (2016)	
Land-use planning switch	0	Dmnl	Policy variable	
Person day per year	1	PD/year	DEA: NRM (2016)	
Private sector co-finance	1	Dmnl	Policy variable	
Proportion citrus	0.25	Dmnl	Model assumption	
Proportion conservation	0.25	Dmnl	Model assumption	
Proportion *Prosopis*	1	Dmnl	Model assumption	
Proportion raisins	0.25	Dmnl	Model assumption	
Proportion table grapes	0.25	Dmnl	Model assumption	
Prosopis spp. spread rate	0.1075	Dmnl/year	Versfeld (1993) and Vorster (1977), also cited in Van Wilgen & Le Maitre (2013)	Based on a number of studies in South Africa
State budget (DEA: NRM)	Lookup	ZAR/year	DEA: NRM (2016)	
Time	Internally defined in model	year		
Time conversion factor	1	year		
Time step	Internally defined in model	year		

Equations for land use sub-model				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Combined budget (DEA: NRM+)	"Private sector co-finance"*"State budget (DEA:NRM)"(Time/Time conversion factor)	ZAR/year	Own calculation	
Effect of combined budget on PD	"Elasticity of person days to state budget (DEA:NRM)"*"Combined budget (DEA:NRM+)"	PD/year	Own calculation	
Person days	Effect of combined budget on person days + 427.12	PD/year	Own calculation	
Effect of person days on area cleared	(("Elasticity of area cleared on person days (1st component)"*	ha/year	Own calculation	

	(Person days*Person days))/ Person days per year)+("Elasticity of area cleared on person days (2nd component)"*Person days)			
Area cleared	Effect of person days on area cleared - 34.458	ha/year	Own calculation	
Prosopis spp. clearance	MIN((Effect of person days on area cleared*Proportion Prosopis)-34.458, Area invaded by Prosopis/TIME STEP)	ha/year	Own calculation	
Area invaded by Prosopis	INTEG("*Prosopis* spp. re-growth"-*Prosopis* spp. clearance)	ha	Own calculation	
"*Prosopis* spp. re-growth"	(Area invaded by Prosopis* *Prosopis* spp. spread rate)+(Area restored to conservation**Prosopis* spp. spread rate)	ha/year	Own calculation	
Table grape plantings	IF THEN ELSE(Time<2016, "LAND-USE PLANNING SWITCH"*Proportion table grapes**Prosopis* spp. clearance, Proportion table grapes **Prosopis* spp. clearance)	ha/year	Own calculation	
Area restored to table grapes	INTEG(Table grape plantings)	ha	Own calculation	
Dried grape (raisin) plantings	IF THEN ELSE(Time<2016, proportion raisins**Prosopis* spp. clearance*"LAND-USE PLANNING SWITCH", Proportion raisins**Prosopis* spp. clearance)	ha/year	Own calculation	
Area restored to raisins	INTEG(Dried grape (raisins) plantings)	ha	Own calculation	
Area restored to conservation	INTEG(Area assigned for conservation)	ha	Own calculation	
Area restored to citrus	INTEG(Citrus plantings)	ha	Own calculation	
Citrus plantings	IF THEN ELSE(Time<2016, Proportion citrus**Prosopis* spp. clearance*"LAND-USE PLANNING SWITCH", Proportion citrus**Prosopis* spp. clearance)	ha/year	Own calculation	

Area assigned for conservation	(Proportion conservation* *Prosopis* spp. clearance)-(Area restored to conservation**Prosopis* spp. spread rate)	ha/year	Own calculation	
Parameters of raisin farming sub-model				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Drying chemicals	714.12	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Labour	13 156.1	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Fungicides	1 941.44	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Fertiliser	3 719.86	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Fuel	4 960.96	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
packaging	0	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Repairs and maintenance	3 056	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Electricity	0	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
"Fuel (non-land preparation)"	2 360.5	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Water	2 344.43	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Depreciation on orchard	11 055.5	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures

Interest on loans	2 579.79	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Other overheads	16 163	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Fixed labour	14 251	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA, 2017) based on the Hortgro and VinPro figures
Overhead costs	46 397	R/ha	Hortgro (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Export market proportion (raisins)	0.87	Dmnl	Based on Hortgro (2016)	
Local market proportion	0.13	Dmnl	Based on Hortgro (2016)	
"Price/ton raisins (export)"	30 765	R/Ton	Hortgro (2015), DAFF (2016), NAMC (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro, DAFF, NAMC and VinPro figures
"Price/ton raisins (local market)"	19 747.4	R/Ton	Hortgro (2015), DAFF (2016), NAMC (2015) & VinPro (2016	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro DAFF, NAMC and VinPro figures
"Yield/ha raisins"	22	Ton/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Equations for raisin farming sub-model				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Total yield raisins	Area restored to raisins*"Yield/ha raisins"	Ton	Own calculation	
Area restored to raisins	INTEG(Dried grape plantings)	ha	Own calculation	
Total gross revenue	"Price/ton raisins"*Total yield raisins	R/year	Own calculation	
Fixed and overhead costs	(Depreciation on orchard+ Fixed labour + Interest on loans + Other overheads + Overhead costs+ Water)*Area restored to raisins	R/year	Own calculation	
Net revenue raisins	IF THEN ELSE(Time>2017, Total gross revenue-Directly allocatable costs raisins-Fixed and overhead costs-Non-directly allocatable costs, 0)	R/year	Own calculation	

Non-directly allocatable costs	(Electricity + "Fuel (non-land preparation)"+Repairs and maintenance)*Area restored to raisins	R/year	Own calculation	
Directly allocatable costs raisins	(Drying chemicals + Fertiliser + Fuel + Fungicides + Labour + Packaging)*Area restored to raisins	R/year	Own calculation	
Parameters of table grape farming sub-model				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Fuel, oil, repair, parts and maintenance	24 041	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
Electricity (table grapes)	9 475	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
"Packaging (table grapes)"	0	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
Supervision, permanent, seasonal and contract labour	135 559	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
Pesticides and herbicides	22 255	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
Fertiliser and organic material	9 808	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
Allocatable fuel (table grapes)	4 961	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
Hired transport	1 239	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
Licences and insurance	805	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)

Interest on loans (table grapes)	2 580	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
Water (table grapes)	1 305	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
Land, property, municipal taxes, administration and miscellaneous	7 284	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
Electricity table grapes	1 580	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
Water cost	1 257	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
Depreciation	28 956	R/ha	SATI (2015) & VinPro (2016	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
Export market proportion (table grapes)	0.93	Dmnl	Based on SATI (2015) and verified by experts	
Local market proportion (table grapes)	0.07	Dmnl	Based on SATI (2015) and verified by experts	
"Price/ton table grapes (export)"	21 195.2	R/Ton	SATI (2015) & VinPro (2016	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
"Price/ton table grapes (local market)"	13 808.3	R/Ton	SATI (2015) & VinPro (2016	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
"Yield/ton table grapes"	22	Ton/ha	SATI (2015) & VinPro (2016	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
Equations for table grape farming sub-model				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Direct costs	Fertiliser table grapes + Herbicide control + Organic material + Pesticide control + Repair and binding material + Seed	R/ha	Own calculation	
Total cash expenditures	Direct costs + Fixed improvements + General	R/ha	Own calculation	

	expenditure + Labour requirements + Mechanisation costs			
Labour requirements	Permanent labour + Seasonal and contract workers + Supervision	R/ha	Own calculation	
General expenditure	Admin expenses + Electricity table grapes + Taxes + Water cost	R/ha	Own calculation	
Fixed improvements	Insurance + Repair and maintenance	R/ha	Own calculation	
Mechanisation costs	Fuel costs + Hired transport + Licences and insurance + "Repair, parts and maintenance"	R/ha	Own calculation	
Provision for renewal	Fixed improvements provisions + Loose assets provisions + Vineyards	R/ha	Own calculation	
Net revenue table grapes	IF THEN ELSE(Time>2017, Gross revenue table grapes-Total production cost, 0)	R/year	Own calculation	
Gross revenue table grapes	"Price/ton table grapes"*Total yield table grapes	R/year	Own calculation	
Total yield table grapes	Area restored to table grapes* "Yield/ton table grapes"	Ton/year	Own calculation	
Total production cost	(Provision for renewal + Total cash expenditures)*Area restored to table grapes	R/year	Own calculation	
Parameters of citrus farming sub-model				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Fertiliser needed	4 792.95	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Spraying programme	17 299.3	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Pruning costs	71.38	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Picking labour	10 042.5	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts

Transport to packhouse	3 095.24	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Export and marketing costs	31 980	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
"Machinery costs (fuel & maintenance)"	26 145.2	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Electricity for irrigation system	2 126.17	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
"Non-allocatable labour"	19 184	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Electricity buildings	1 856	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Insurance land and fixed improvements	1 345	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Depreciation	6 000	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Interest on loans	1 200	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Water levies	560.75	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Admin costs	3 000	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Processing market proportion (citrus)	0.29	Dmnl	Based on CGA (2016) and verified by experts	
Local market proportion (citrus)	0.04	Dmnl	Based on CGA (2016) and verified by experts	
Export market proportion (citrus)	0.67	Dmnl	Based on CGA (2016) and verified by experts	

"Price/ton citrus (export market)"	14 097.6	R/ton	Based on CGA (2016) and verified by experts	Conservative estimates based on CGA (2016) adjusted for inflation using the PPI index for agriculture based on StatsSA (2017)
"Price/ton citrus (local market)"	8 568.3	R/ton	Based on CGA (2016) and verified by experts	Conservative estimates based on CGA (2016) adjusted for inflation using the PPI index for agriculture based on StatsSA (2017)
"Price/ton citrus (processing market)"	1 582.09	R/ton	Based on CGA (2016) and verified by experts	Conservative estimates based on CGA (2016) adjusted for inflation using the PPI index for agriculture based on StatsSA (2017)
"Yield/ton citrus"	65	Ton/ha	Consultation with anonymous citrus farmers and verified by experts	Conservative estimates based on consultation with anonymous farmers and experts, and CGA (2016)
Equations for citrus farming sub-model				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
"Pre-harvest costs"	Fertiliser needed + Pruning costs + Spraying programme	R/ha	Own calculation	
Harvesting costs	Export and marketing cost + Packaging costs + Picking labour + Transport to packhouse	R/ha	Own calculation	
Directly allocatable variables costs	(Harvesting costs + "Pre-harvest costs")*Area restored to citrus	R/year	Own calculation	
Non-directly allocatable variable costs	(Electricity for irrigation system + "Machinery costs (fuel & maintenance)")*Area restored to citrus	R/year	Own calculation	
Fixed and overhead costs citrus	Admin costs + Depreciation + Electricity buildings + Insurance land and fixed improvements + Interest on loans + "Non-allocatable labour" + Water levies)*Area restored to citrus	R/year	Own calculation	
Net revenue citrus	IF THEN ELSE(Time>2018, Gross revenue citrus-Directly allocatable variables costs-Fixed and overhead costs citrus-Non-directly allocatable variable costs, 0)	R/year	Own calculation	

Gross revenue citrus	"Price/ton citrus"*Total yield citrus	R/year	Own calculation	
Total yield citrus	Area restored to citrus*"Yield/ton citrus"	Ton/year	Own calculation	
Parameters of establishment cost sub-model				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Plant material	36 734.7	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Land preparation	17 221.6	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
"Irrigation (flood)"	10 119.4	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Trellising	87 937	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Fertiliser establishment	4 316.87	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Herbicides establishment	559.13	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
"Fungicides/pesticides"	516	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Consultancy fees	1 090.7	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
"Fuel (diesel)"	3 598.16	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Sundry costs	1 226.18	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Shade netting	160 000	R/ha	Consultation with experts	

Overhead costs raisins (establishment)	59 164	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Fixed labour raisins (establishment)	20 097.6	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Water costs raisins (establishment)	2 344.43	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Other overheads raisins (establishment)	16 163	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Interest on loans raisins	9 500.56	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
Depreciation on orchard	11 055.5	R/ha	Hortgro (2015) & VinPro (2016)	Conservative estimates adjusted for inflation to current prices using the Jan 2017 PPI index for agriculture (StatsSA 2017) based on the Hortgro and VinPro figures
"Factory roof trellising system (2,75 m row spacing)"	69 926	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
"Irrigation system (2,75 m row spacing)"	23 281	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
Soil preparation	21 000	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
Plant material table grapes	36 734.7	R/ha	SATI (2015) & VinPro (2016)	Conservative estimates based on the SATI and VinPro figures adjusted to inflation using the PPI index for January 2017 (StatsSA 2017)
Shade netting	160 000	R/ha	Consultation with experts	
Plant support covers	1 000	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Labour citrus establishment	10 000	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts

Plant material citrus	45 000	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
"Irrigation (excluding mainlines)"	30 000	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Shade netting (citrus)	200 000	R/ha	Consultation with experts	
Land preparation citrus	35 000	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
"Fuel (diesel) citrus establishment"	120	R/ha	Consultation with anonymous citrus farmers and experts	Conservative estimates based on consultation with anonymous farmers and experts
Parameters of establishment cost sub-model				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Pre-harvest costs	Consultancy fees + Fertiliser establishment + "Fuel (diesel)" + "Fungicides/pesticides" + Herbicides establishment + "Irrigation (flood)" + Land preparation + Plant material + Sundry costs + Trellising	R/ha	Own calculation	
Fixed and overhead costs raisins establishment	Depreciation on orchard + Fixed labour raisins establishment + Interest on loans raisins + Other overheads raisins est + Overhead costs raisins establishment + Water costs raisins est	R/ha	Own calculation	
"Pre-harvest costs table grapes"	"Factory roof trellising system (2,75 m row spacing)" + "Irrigation system (2,75 m row spacing)"+ Plant material table grapes + Soil preparation	R/ha	Own calculation	
Establishment cost table grapes	(Fixed and overhead costs raisins establishment + "Pre-harvest costs table grapes")*Area restored to table grapes	R/year	Own calculation	

Establishment cost raisins	(Fixed and overhead costs raisins establishment + Pre-harvest costs)*Area restored to raisins	R/year	Own calculation	
Establishment cost citrus	Area restored to citrus*("Fuel (diesel) citrus establishment" + "Irrigation (excluding mainlines)" + Labour citrus establishment + Land preparation citrus + Plant material citrus + Plant support covers)	R/year	Own calculation	
Total establishment cost	(Establishment cost citrus + Establishment cost raisins + Establishment cost table grapes)* A factor correcting for once-off establishment cost (Time/Time conversion factor)	R/year	Own calculation	
Equations for clearing cost sub-model				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Unit clearing cost	"Combined budget (DEA: NRM+)"/*Prosopis* spp. clearance	R/ha	Own calculation	
Total clearing cost	*Prosopis* spp. clearance*Unit clearing cost	R/year	Own calculation	
Carbon sequestration sub-model parameters				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Prosopis spp. biomass	45	Ton/ha	Mugido *et al*. (2014)	Conservative estimates
Prosopis spp. biomass (re-growth)	4.5	Ton/ha	Mugido *et al*. (2014) and consultation with experts	Conservative estimates, it takes 10 years for *Prosopis* spp. trees to reach maximum biomass, as a result this was divided by 10 years to apportion for biomass emanating from re-invasion per annum
Net oven dry mass conversion ratio Prosopis	0.45	Dmnl	Thomas & Martin (2012)	55% moisture is removed from cleared biomass to be left with the 45% oven dry mass.
"CO2:Carbon ratio"	3.6667	Dmnl	Thomas & Martin (2012)	3.6667 is the ratio of CO_2 over carbon
A factor correcting for net carbon stock removed	0.5	Dmnl	Policy variable	
Unit price of carbon	120	R/ton	National Treasury (2013)	

Equations for carbon sequestration sub-model				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Carbon sequestration *Prosopis*	*Prosopis* biomass**Prosopis* spp. clearance*Net oven dry mass conversion ratio Prosopis* "CO2:Carbon ratio"	Ton/year	Own calculation	
Carbon sequestered and stored from *Prosopis* re-invasion	"CO2:Carbon Ratio"*"*Prosopis* biomass (re-growth)"*"*Prosopis* re-growth"*Net oven dry mass conversion ratio *Prosopis* units: Ton/year	Ton/year	Own calculation	
Net carbon stock removed	(Carbon sequestered stored and removed-"Carbon sequestered and stored from *Prosopis* re-invasion")*A factor correcting for net carbon stock removed	Ton/year	Own calculation	
Net carbon stock economic value loss	Net carbon stock removed*Unit price of carbon	R/year	Own calculation	
Parameters of water consumption sub-model				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Water reduction per ha *Prosopis* spp.	1 203.7	m^3/ha	Le Maitre *et al*. (2015)	An estimate for the whole country
Unit value of water	2	R/m^3	Consultation with anonymous farmers and experts	Conservative estimate for the Orange River irrigation water
Equations for water consumption sub-model				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Water use by *Prosopis*	*Prosopis* spp. clearance*Water reduction per ha *Prosopis*	m^3/year	Own calculation	
Economic value of water saved due to *Prosopis* clearance	Unit value of water*Water use by *Prosopis*	R/year	Own calculation	
Parameters of NPV sub-model				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Time conversion factor	1	year	Policy variable	
Conversion factor	1	Dmnl	Policy variable	
Discount rate	0.06	Dmnl	Policy variable	Based on National Treasury rates

Year of cost	Lookup	Dmnl	Policy variable	
Equations for NPV sub-model				
Description	**Formula/value**	**Unit**	**Reference**	**Comment**
Discounting factor	((Conversion factor + Discount rate)^Year of cost((Time/Time conversion factor)))	Dmnl	Own calculation	
Net economic value from clearing *Prosopis* and land-use planning	(Economic value of water saved due to *Prosopis* clearance + ((Net revenue citrus + Net revenue raisins + Net revenue table grapes)/TIME STEP)) - (Total clearing cost + Net carbon stock economic value loss + Total establishment cost)	R/year	Own calculation	
NPV rate	Net present value land use planning * 1	R/year	Own calculation	
Net present value land-use planning	Discounting factor*Net economic value from clearing *Prosopis* and land use planning	R/year	Own calculation	
"Cumulative NPV clearing *Prosopis* & land use planning"	INTEG(NPV Rate)	R	Own calculation	

PART C: Model validation

The PROLAND model was tested through a triple-pronged validation process consisting of i) model debugging, ii) model verification, and iii) model validation. During the model debugging stage, all errors were traced and corrected in order to prevent the PROLAND model from failing to simulate the various scenarios properly. Among the bugs traced and rectified were unit errors, negative stocks and floating point overflows. During the model verification stage, the model parameters were checked for any noticeable faults based on Forrester and Senge (1980), and these were addressed accordingly after having checked for unit consistency and numerical accuracy based on Sterman (2000). Lastly, the model underwent a model validation process. According to Sterman (2000), the model validation process is imperative in order to increase the confidence in the developed model, *inter alia* the robustness of the results emanating from the simulation of various scenarios. The model validation stage was two pronged, consisting, firstly, of direct structural tests to assess the validity of the model structure in comparison with the reference mode based on prior knowledge of the real-world system being modelled. Secondly, the model underwent extreme condition testing, which subjected the model to extreme policies, shocks and parameters as recommended by Sterman (2000). The extreme condition tests conducted for the purposes of this study are shown in Figure A11 below, thereby confirming the validity of the PROLAND model.

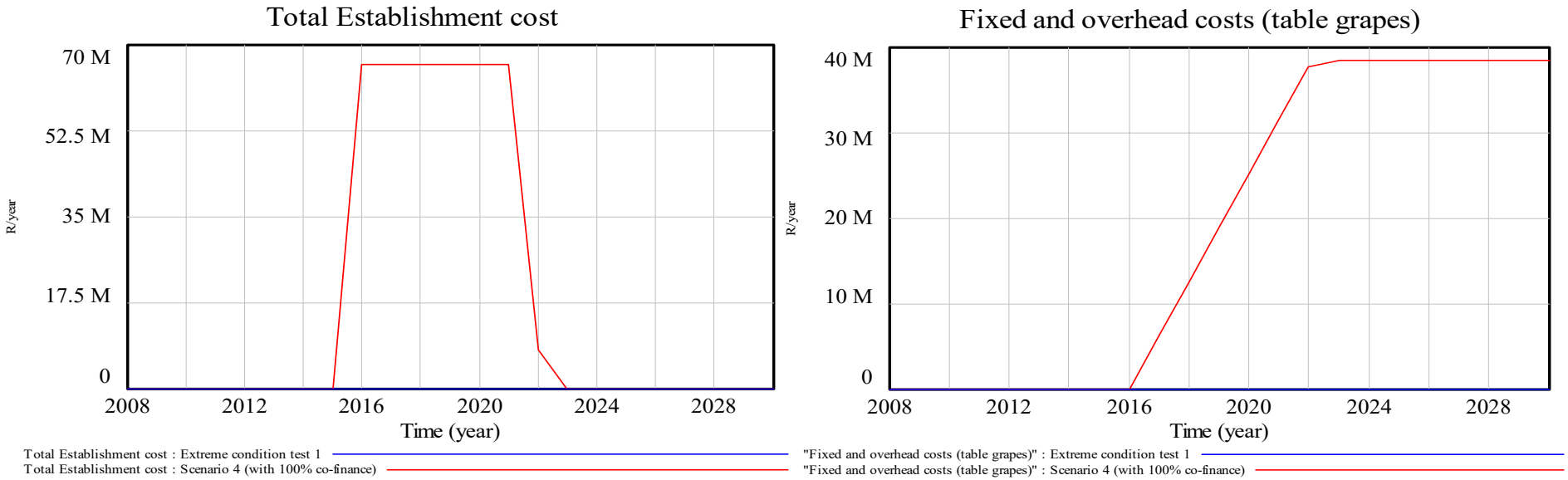

Figure A11: Extreme condition tests for the PROLAND model
Source: Own analysis

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