Assessing South Australian carbon offset supply and policy for co-beneficial offsets: Technical estimation of carbon supply

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Contents

Figures

Tables

1 Emission reduction fund (ERF) methods

1.1 Overview

This report pertains to the data and methodologies employed in the Goyder Institute for Water Research project: *Assessing South Australian carbon offset supply and policy for co-beneficial offsets.* This document and the herein referenced data achieve the objective of estimating the technical supply of carbon in South Australia (SA) using ERF and non-ERF methods.

Three ERF methods from the vegetation management sector and one ERF method from the agricultural sector were modelled. Each ERF method specifies a range of project mechanisms that a landholder can undertake to earn Australian Carbon Credit Units (ACCUs). Only project mechanisms with available biophysical and land use data were considered.

ERF methods and project mechanisms have strict eligibility requirements. Using generalised land use mapping data (DPTI, 2016) in ArcGIS, eligible land for each project mechanism was determined based on land use characteristics, current native vegetation cover and annual rainfall.

A sample grid of 10 km intervals was applied across SA. Sample points falling within eligible land were identified. Sample points within non-eligible land but within the nominal agricultural zone were also noted for future analysis. The latitudes and longitudes of the points identified in the eligible land and nominal agricultural zone are the points for which carbon sequestration was estimated.

For vegetation management methods, the 2016 version 2.0 of the Federal Government's Full Carbon Accounting Model (FullCAM) (available: https://www.environment.gov.au/climate-change/climate-science-data/greenhouse-gas-measurement/land-sector) was used to estimate the cumulative carbon sequestration over a project timeframe of 100 years. FullCAM was run for the sample points in eligible and non-eligible land for all appropriate tree species. FullCAM technical specifications are provided in DoEE (2016b).

For agricultural methods, the 2015 version 4.0 of the Federal Government's Carbon Farming Initiative Mapping Tool (CFI Mapping) (available: http://www.environment.gov.au/climate-change/government/emissions-reduction-fund/cfi/reforestation-tools) was used to estimate the annual sequestration rate of carbon in soil for each sample point for three carbon soil sequestration actions. The CFI Mapping Tool reports carbon sequestration as a rate (tC/ha/year). To match the FullCAM output, annual rates were summed (assuming a linear trajectory) to generate a cumulative soil carbon sequestration time-series over 100 years. The CFI Mapping Tool technical specifications are provided in DoE (2015b).

Both FullCAM and CFI Mapping Tool results were exported as *.csv* files to be used in the economic analysis. An example of the output file formats in Appendix B. A file naming key is also included for each method in the data delivery.

A range of spatial data sources were used to determine the applicability of the ERF methods to areas of SA. Table 1 details data inputs and their source.

Table 1. Key data inputs used in the ERF modelling.

Data	Use	Source
Generalised 2016 land use mapping	Determine eligible ERF areas	DPTI (2016)
Rainfall mapping	Determine Mallee planting regions	Trevor Hobbs (DEW)
NRM layer	Reporting	DEWNR (2012)
10 km grid	Identify sample points for FullCAM	Dr. Courtney Regan (The University of South Australia)
Forestry layer	Determine current area of plantation forests	DAWR (2013)
Permits for Mallee rolling	Determine eligible area for human induced regeneration method	Russell Seaman (DEW)

1.2 Selection of ERF methodologies

Four ERF methods were chosen based on their applicability to SA. Each ERF method was selected in consultation with, and ratified by, the project advisory committee comprised of Russell Seaman, Graham Green, Brita Pekarsky, Louisa Perrin and Murray Townsend during a joint meeting held at the Department for Environment and Water (DEW) on 28th November 2017.

Each ERF method prescribes a range of on-land activities called *project mechanisms* that can be undertaken to earn ACCUs. The methods and the subsequent project mechanisms considered in this project are shown in Table 2. The parameter FullCAM and CFI Mapping Tool parameter settings for each ERF method shown below are described in Section 1.1.6, 1.1.7 and 1.1.8 for further reference.

Table 2. ERF methodologies.

Sector	ERF Method	Project Mechanism
Vegetation Management	Reforestation by Environmental or Mallee Plantings	Mallee revegetation* Mixed environmental planting revegetation*
	Plantation Forestry	New commercial plantation forestry* Conversion of short-run plantations to long-run plantation Maintain existing plantations established under previous ERF method
	Human-induced Regeneration of a Permanent Even-aged Native Forest	The exclusion of livestock and the taking of reasonable steps to keep livestock excluded* The management of the timing, and the extent, of grazing The management, in a humane manner, of feral animals The management of plants that are not native to the project area The implementation of a decision to permanently cease the mechanical or chemical destruction, or suppression, of regrowth*
Agriculture	Estimating Sequestration of Carbon in Soils Using Default Values	Increasing biomass yields through sustainable intensification* Converting land under crops to pasture* Retaining crop residue in field rather than burning or bailing.

** considered in this project*

1.3 Determining ERF eligible land in South Australia

Each ERF method has different and strict eligibility requirements for where project mechanisms can be implemented. These are based on:

- Current and/or historic land use.
- Current and/or historic forest cover.
- Productive ability to attain forest cover.
- Annual rainfall.
- Soil type and condition.

The key eligibility requirements for the selected ERF methods are shown in Table 3. In addition to the requirements set out in Table 3, the project must also be within Australia, excluding external territories, and be in an area for which FullCAM or CFI Mapping Tool data exists.

Table 3. ERF method eligibility requirements.

ERF method	Project mechanism	Eligibility Rrequirements
Reforestation by Environmental or Mallee Plantings	Mixed environmental planting revegetation	• Land must not contain woody biomass that would need to be cleared for revegetation to occur, except in the case of prescribed weed species • Land must be clear of forest cover for at least five previous years • Trees on project land must be the potential to attain a height of 2m and a crown cover of at least 20%
	Mallee revegetation	• In addition to all as above, Mallee plantations must only be established in regions with long-term average rainfall of 600mm/year or less
Plantation Forestry	New commercial plantation forestry	• Land must not have been used for plantation forestry for at least seven previous years • Land must be within a national plantation inventory region
	Conversion of short-run plantations to long-run plantations	• Land must not be part of another forestry offsets project • If a rotation of plantation forest is underway, it must be a short rotation and no thinning or pruning must have occurred • If a rotation of plantation forest had occurred in the previous seven years, the rotation must have been a short rotation • Land must have only been used for plantation forestry for at least the previous seven years • Land must be within a national planting inventory region
Human-induced Regeneration of a Permanent Even-aged Native Forest	The implementation of a decision to permanently cease the mechanical or chemical destruction, or suppression, of regrowth.	• Land is not conservation land • Land must have been used or managed in a way that suppressed the development of forest cover either through livestock grazing, feral animals, plants not native to the area, or mechanical or chemical destruction/suppression of regrowth • Land did not have forest cover at any time during the baseline period (e.g. before stock exclusion occurred)
Estimating Sequestration of Carbon in Soils Using Default Values	Increasing biomass yields through sustainable intensification	• Land must be agricultural land which has been cropped, grazed or fallowed at least once in the previous five years • Land must have deficient soil that can be improved by undertaking two specified management actions
	Converting land under crops to pasture	• Land must be under crops and/or bare fallowed for at least five years before conversion to pasture
	Retaining crop residue in field rather than burning or bailing	• Land must be agricultural land which has been cropped, grazed or fallowed at least once in the previous five years • No burning or bailing can occur on land more than once every five years while the area is under crops

<u>Sources:</u> DoE (2015a), DoE (2015b), DoEE (2016a), Frydenberg, J. (2017)

As a result of the eligibility requirements, ERF methods and project mechanism can only be applied in certain regions of SA. The land where these methodologies are applicable is referred to as *eligible land.* The type of eligible land for each ERF method is summarised in Table 4.

Table 4. Type of land eligible for ERF method project mechanisms.

ERF method project mechanisms	Type of land	Rainfall restrictions	Land use restriction
Mixed environmental plantings revegetation	Agriculture, horticulture, livestock	N/A	Exclude already natively vegetated lands
Mallee revegetation	Agriculture, horticulture, livestock	<600 mm/year	Exclude already natively vegetated lands
New commercial forestry	National plantation forestry inventory regions	N/A	Exclude existing plantation forestry or natively vegetated lands
Short-run to long-run forestry conversion	Commercial forestry within national plantation forestry inventory regions	N/A	Only applies to existing commercial forestry
Cease the mechanical or chemical destruction, or suppression, of regrowth.	Agriculture with permit for native vegetation destruction	N/A	N/A
Increasing biomass yields	Agriculture, horticulture, livestock ('nominal agricultural zone')	N/A	N/A
Converting crops to pasture			
Retaining crop residue			

Sources: DoE (2015a), DoE (2015b), DoEE (2016a), Frydenberg, J. (2017).

The total area eligible for each ERF method project mechanism by natural resources management (NRM) region is summarised in Table 5 and shown graphically in Figures 1 to Figure 5. A map of NRM regions and rainfall zones in SA is provided in Appendix A.

Table 5: ERF methods eligible areas.

NRM region	Total land ('000 ha)	Eligible Land ('000 ha) [% of NRM region]							
		Revegetation		Plantation forestry		Human-induced regeneration	Estimated soil carbon sequestration using default values		
		Mixed species environmental	Mallee	New commercial	Conversion of short-run to long-run	Ceasing mechanical destruction of regrowth	Sustainable intensification	Conversion to pasture	Retaining crop residue
SA Arid Lands	52,164	194 [0.3%]	194 [0.3%]	0 [0.0%]	0 [0.0%]	0 [0.0%]	1748.3 [3.3%]		
Alinytjara Wilurara	28,119	0.01 [0.0%]	0.01 [0.0%]	0 [0.0%]	0 [0.0%]	0 [0.0%]	1,319 [4.6%]		
SA Murray Darling Basin	5,647	2,952 [52.3%]	2,560 [45.3%]	13.5 [0.25%]	0 [0.0%]	2.9 [0.05%]	3,915 [75.5%]		
Northern & Yorke	3,463	1,993 [57.5%]	1,291 [37.2%]	0.0* [0.0%]	12.1 [0.35%]	0.2 [0.01%]	3,437.8 [99.2%]		
Eyre Peninsula	5,184	3,666 [70.7%]	3,666 [70.7%]	0 [0.0%]	0 [0.0%]	9.1 [0.18%]	5,184 [100%]		
Kangaroo Island	440	86 [19.6%]	74 [16.8%]	86 [19.6%]	10.8 [2.4%]	3.5 [0.81%]	440 [100%]		
Adelaide & Mt Lofty Ranges	664	270 [40.7%]	184 [27.7%]	13.5 [2.04%]	14.9 [2.2%]	0 [0.0%]	604 [90.9%]		
South East	2,686	1,634 [60.8%]	1,358 [50.5%]	249 [9.28%]	141.9 [5.2%]	19 [0.71%]	2,686 [100%]		
Total South Australia	98,424	10,799 [10.9%]	9,330 [9.48%]	362 [0.36%]	179 [0.18%]	35 [0.04%]	19,230 [19.5%]		

**Note, although part of the Northern & Yorke NRM is covered by the National Plantation Forestry Inventory Region, it does not have area that meets the rule of thumb of >650mm/year rainfall in forestry zones, see Figure 2 below.*

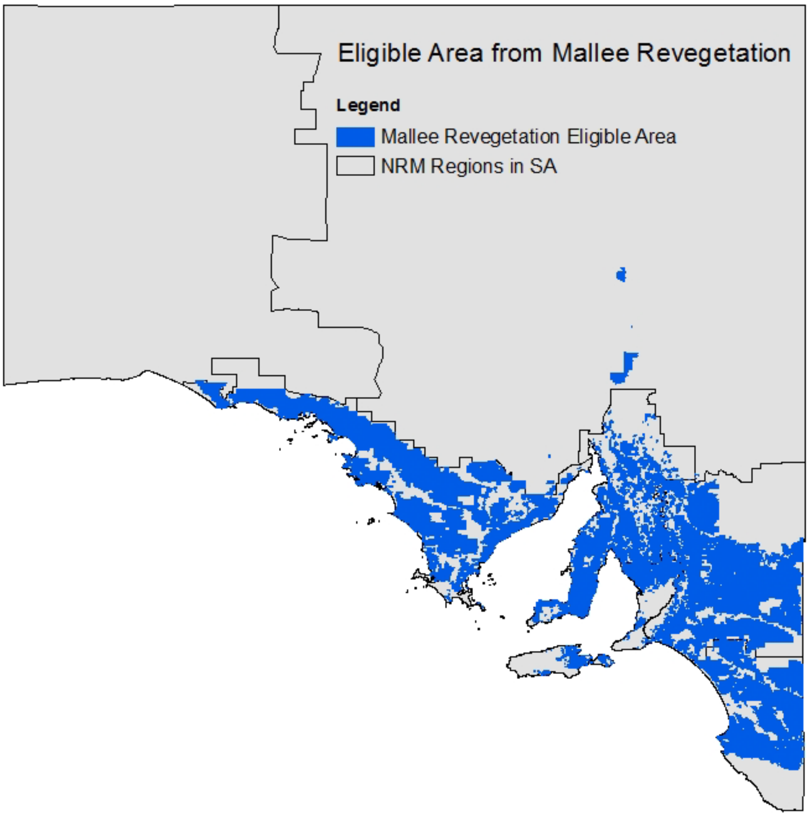


Figure 1: Area eligible for Mallee revegetation in South Australia, under the review criteria (see section 1.4).

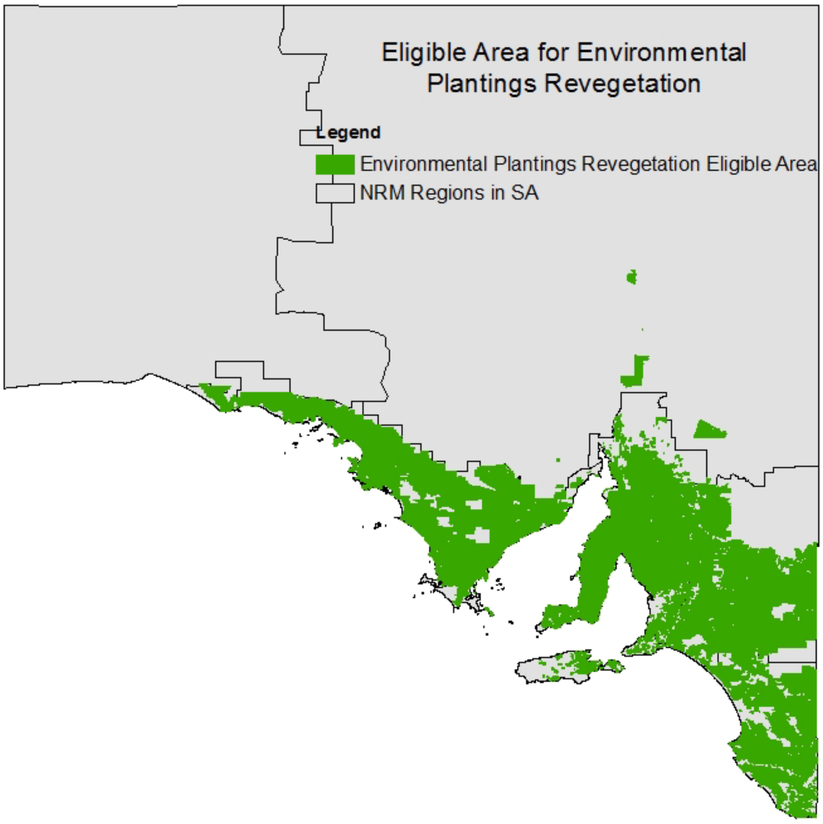


Figure 2: Area eligible for Mallee mixed environmental plantings in South Australia, under the review criteria (see section 1.4).

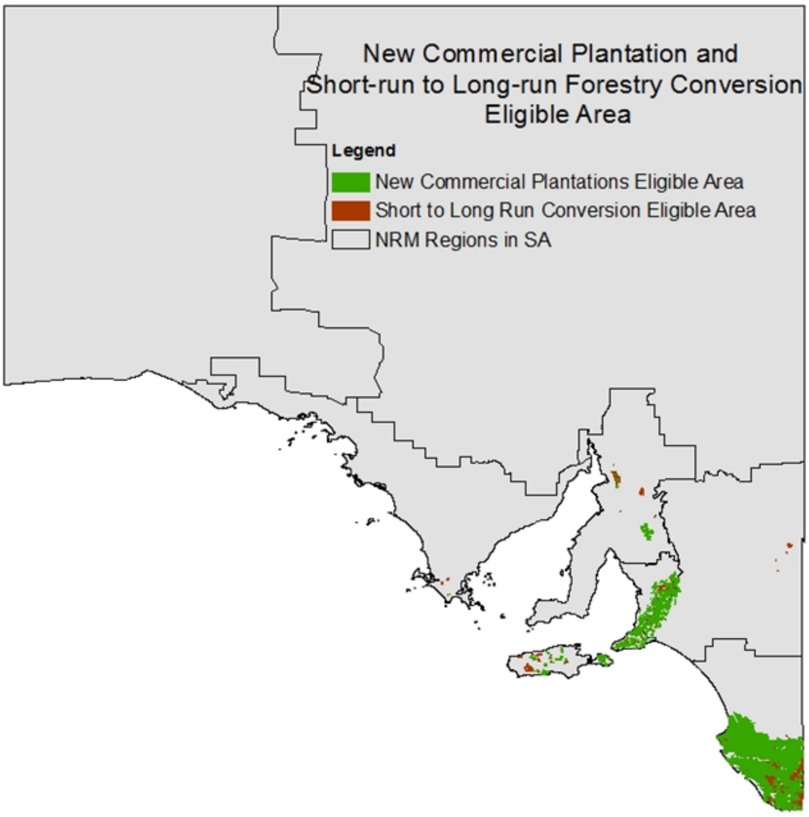


Figure 3: Area eligible for plantation forestry (new commercial plantations eligible area and short to long run conversion eligible area) in South Australia, under the review criteria (see section 1.4).

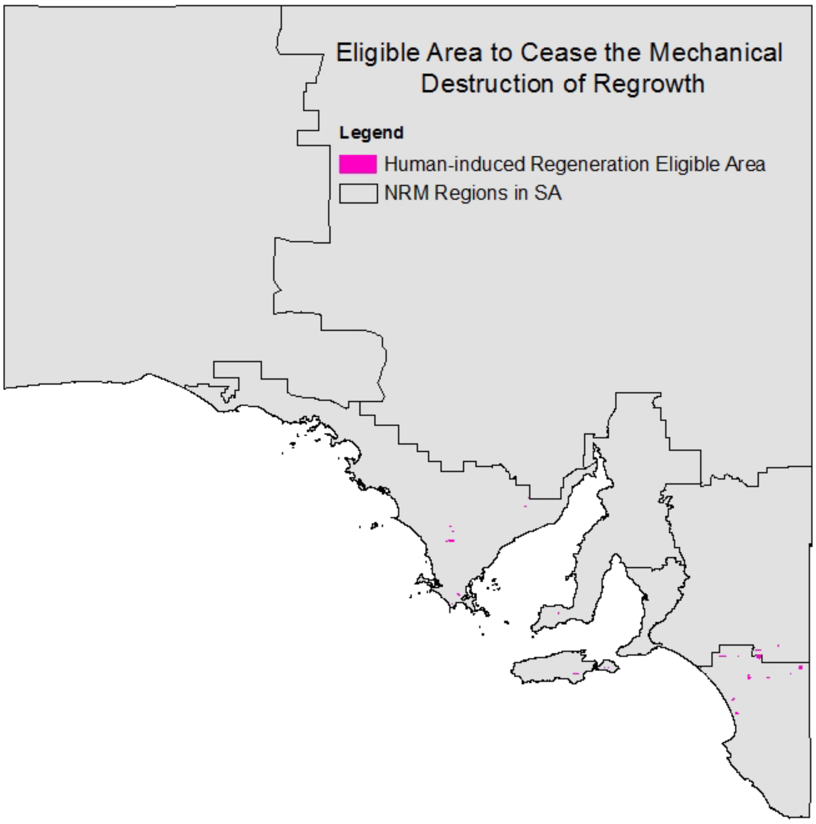


Figure 4: Area eligible for human-induced regeneration (i.e. eligible area to cease the mechanical destruction of regrowth) in South Australia, under the review criteria (see section 1.4).

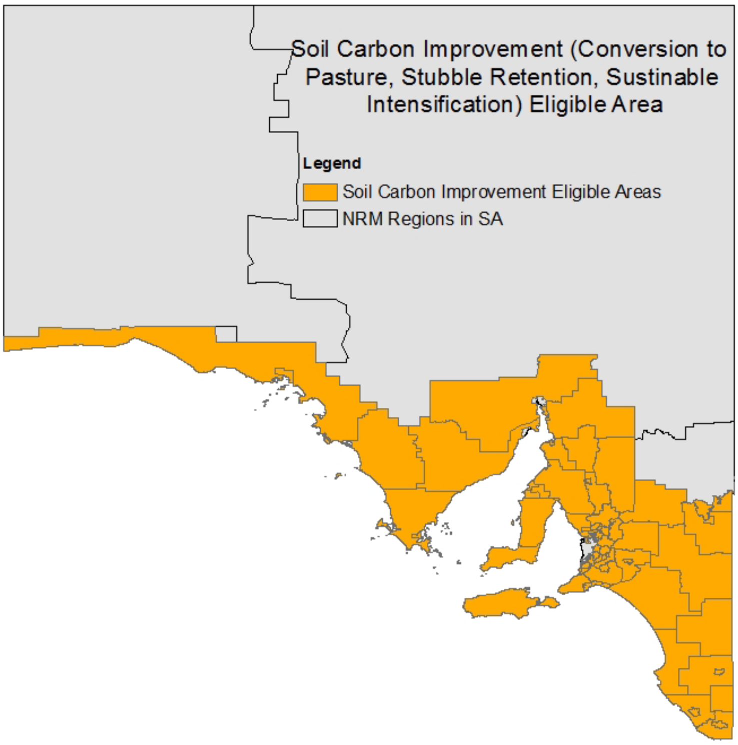


Figure 5: Area eligible for soil carbon improvement in South Australia, under the review criteria (see section 1.4).

Since the National Plantation Forestry Inventory Region outline was unavailable as a shapefile, the eligible area for new plantation forestry was estimated using the average annual rainfall zone of greater than 650 mm/year (rainfall code 700 in the data, see Appendix A). The available JPEGs of the National Plantation Forestry Inventory Region was compared to the 650 mm/year rainfall zone and it was determined it was an acceptable approximation of the area, as shown in Figure 6. Note that only the South Australian area of the Green Triangle (shown in right pane of Figure 6) is considered in the current project.

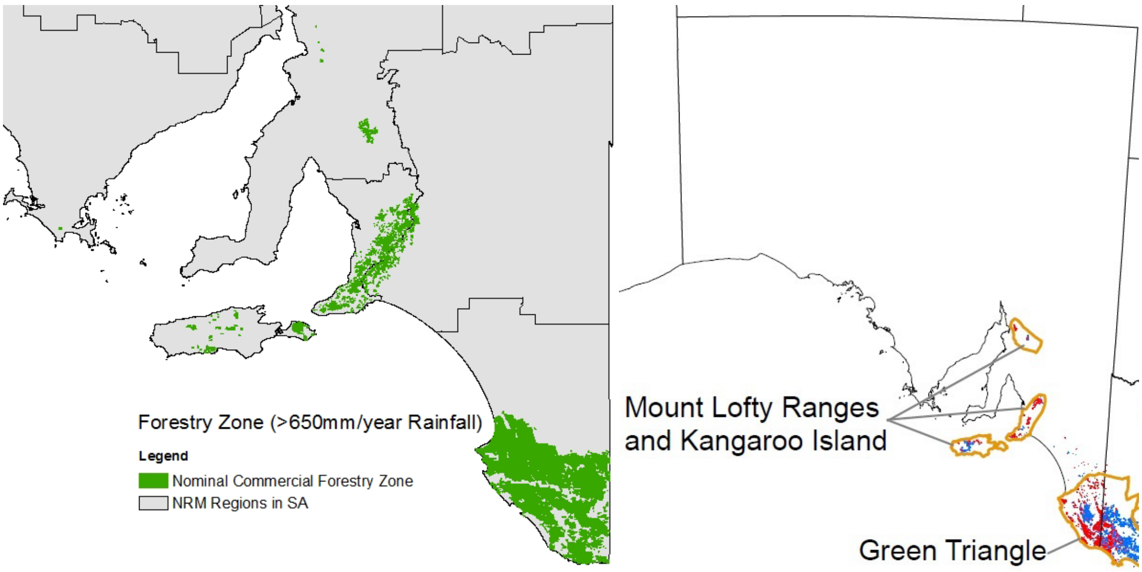
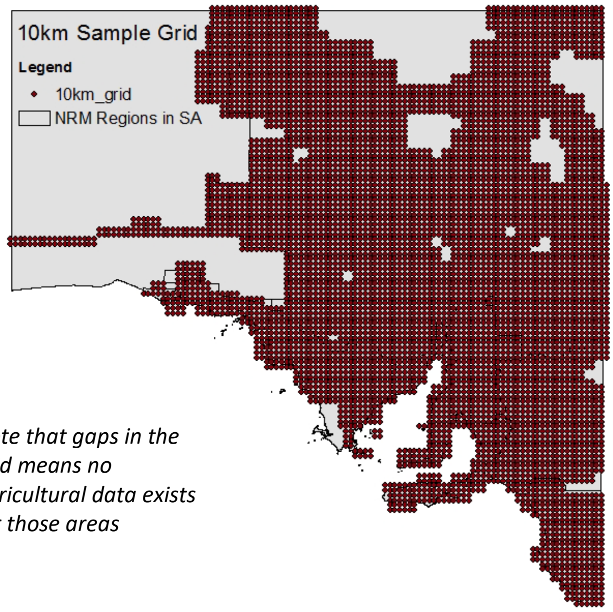


Figure 6: Nominal forestry zone considered in this project compared to the national forestry inventory regions.

1.4 Sampling points in ArcGIS

FullCAM is a point model that draws biophysical data throughtout a 250 m square area. As a landholder, the point chosen to model in FullCAM would be the centroid of the Carbon Estimation Area (CEA) (farm area to be converted to vegetation/soil carbon area). Because we were interested in the carbon sequestration potential across all of SA, a sample grid of 10 km increments across the SA landscape was applied in ArcGIS.

The uniform 10 km grid was provided by The University of South Australia (Dr. Courtney Regan). The grid points were obtained from a raster image of agricultural profit data, such that each point corresponds to a land use and profitability. In some regions there was a gap in agricultural data and this manifests as a gap in the grid (see for example near Cummins, Eyre Peninsula). The 10 km grid is shown in Figure 7.



Note that gaps in the grid means no agricultural data exists for those areas

Figure 7 10 km sample grid.

Identifying sample points from the 10 km grid to be run in FullCAM had two steps. First, samples were taken at 10 km increments across all the eligible land for each ERF method. This resulted in a sample of points to run through FullCAM in eligible land only. Second, samples were taken in 10 km increments across the total nominal agricultural zone (e.g. all of SA excluding non-ERF eligible land in the SA Arid Lands and Alinytjara Wilurara NRM regions). This resulted in an estimate of the total *hypothetically* available land able to be engaged in an ERF method project mechanism if current land use was ignored. The difference in sampling area for the two approaches is shown in Figures 8a and 8b.

Figure 9 shows a close up example of the sample points (from both the 'all land' and 'eligible land' sample) is provided in Figure 10 in the South East NRM. Note that the sampling density is difficult to show on a map of SA so an isolated NRM example is shown.

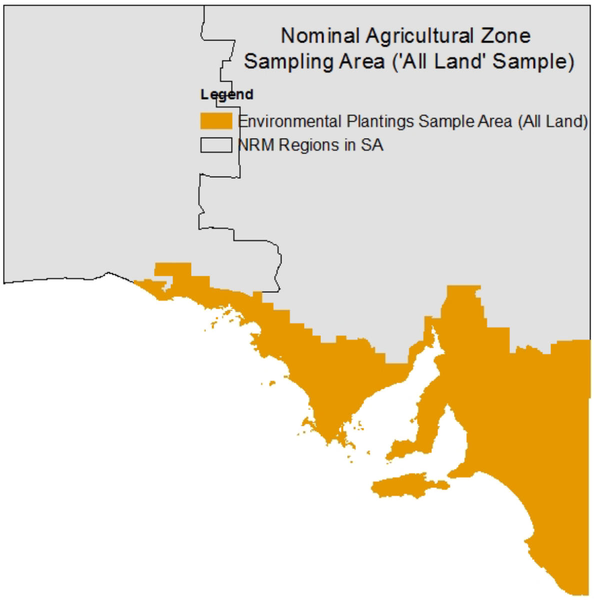


Figure 8a: Sample areas for mixed environmental planting method: 'All Land' sample area.

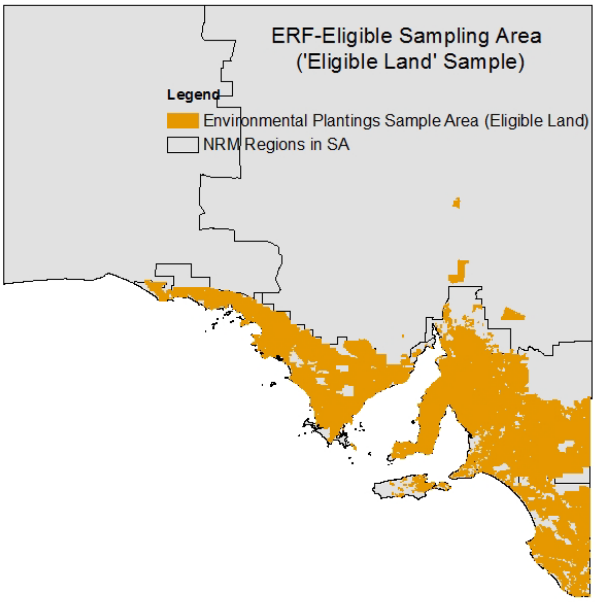


Figure 8b: Sample areas for mixed environmental planting method: 'Eligible Land' sample area.

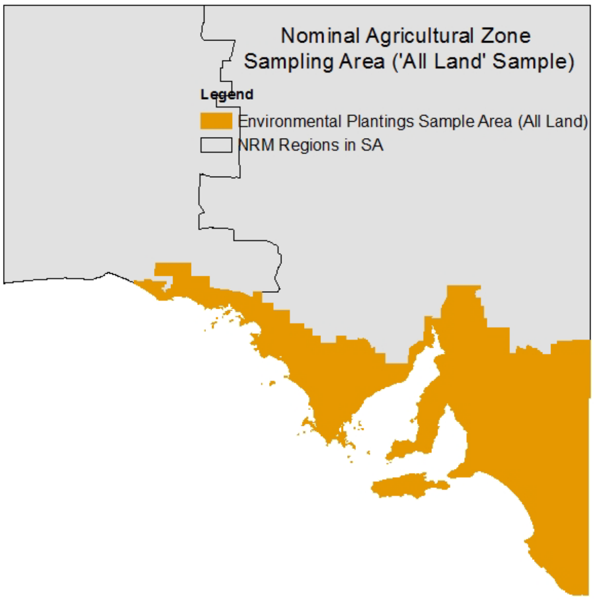


Figure 9a: Sample areas for mixed environmental planting method: 'All Land' sample area.

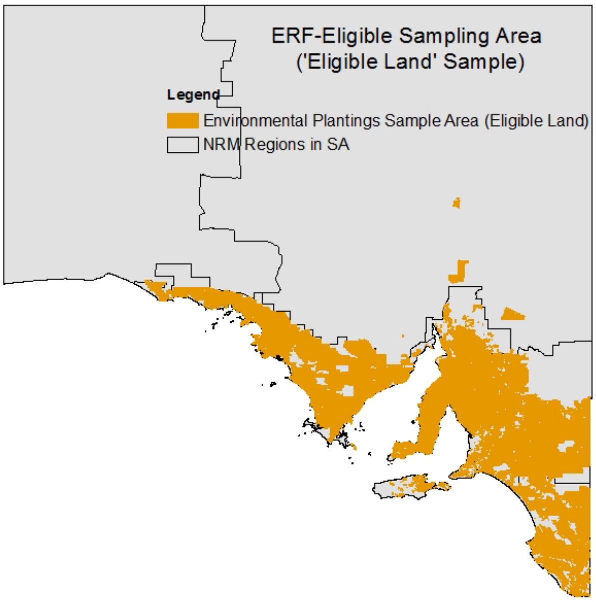


Figure 8b: Sample areas for mixed environmental planting method: 'Eligible Land' sample areas.

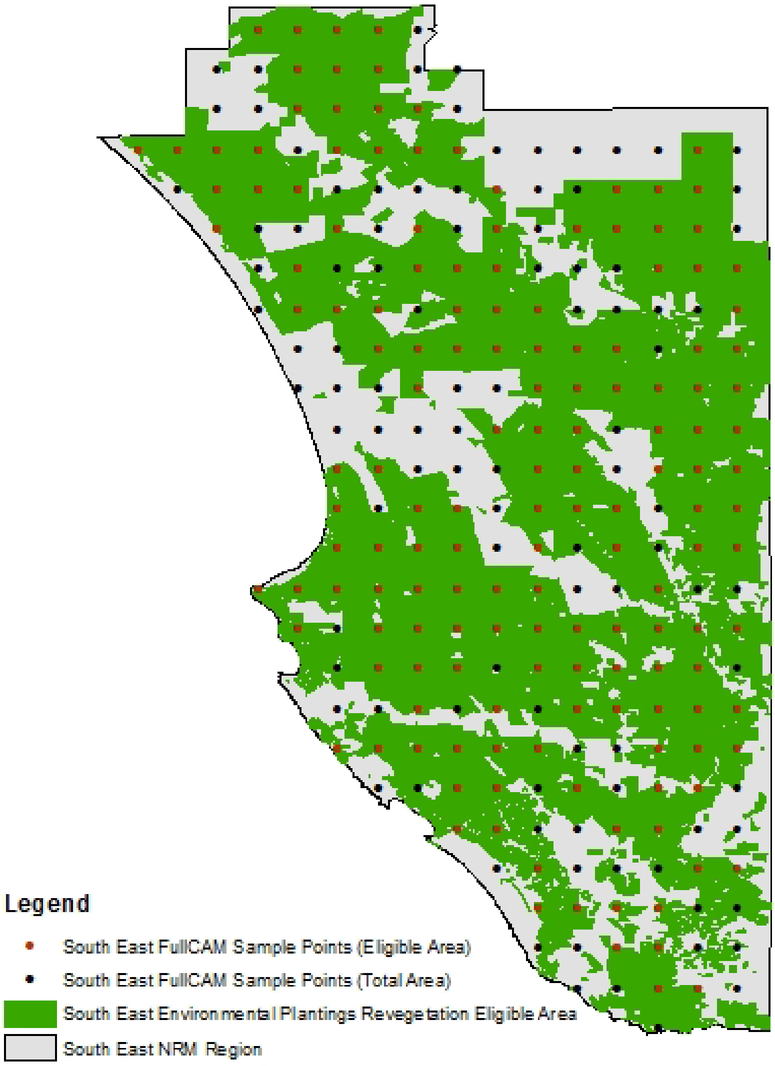


Figure 9: Example of 10 km FullCAM sample points in the South East.

Sampling in 10 km increments across the nominal agricultural zone was time consuming, but running FullCAM for these points had the following three benefits:

1) Allowing informed estimates of added carbon benefits in the case of future land use change to be made, such as in the case of new land becoming available for agriculture/livestock/ horticulture (and hence will become ERF eligible).
2) Capturing carbon sample points that may have fallen just outside of eligible area (e.g. other side of the farm fence). This is a particularly useful approach in NRM Regions such as the Adelaide and Mount Lofty Ranges NRM Region where the land parcels are small and interspersed with non-ERF-eligible areas. An example of how this applies is shown in Figure 11.
3) Developing state-wide maps of carbon sequestration potential to be developed to identify carbon sequestration hotspots that may or may not be eligible under the current ERF methods. An example is shown in Figure 12.

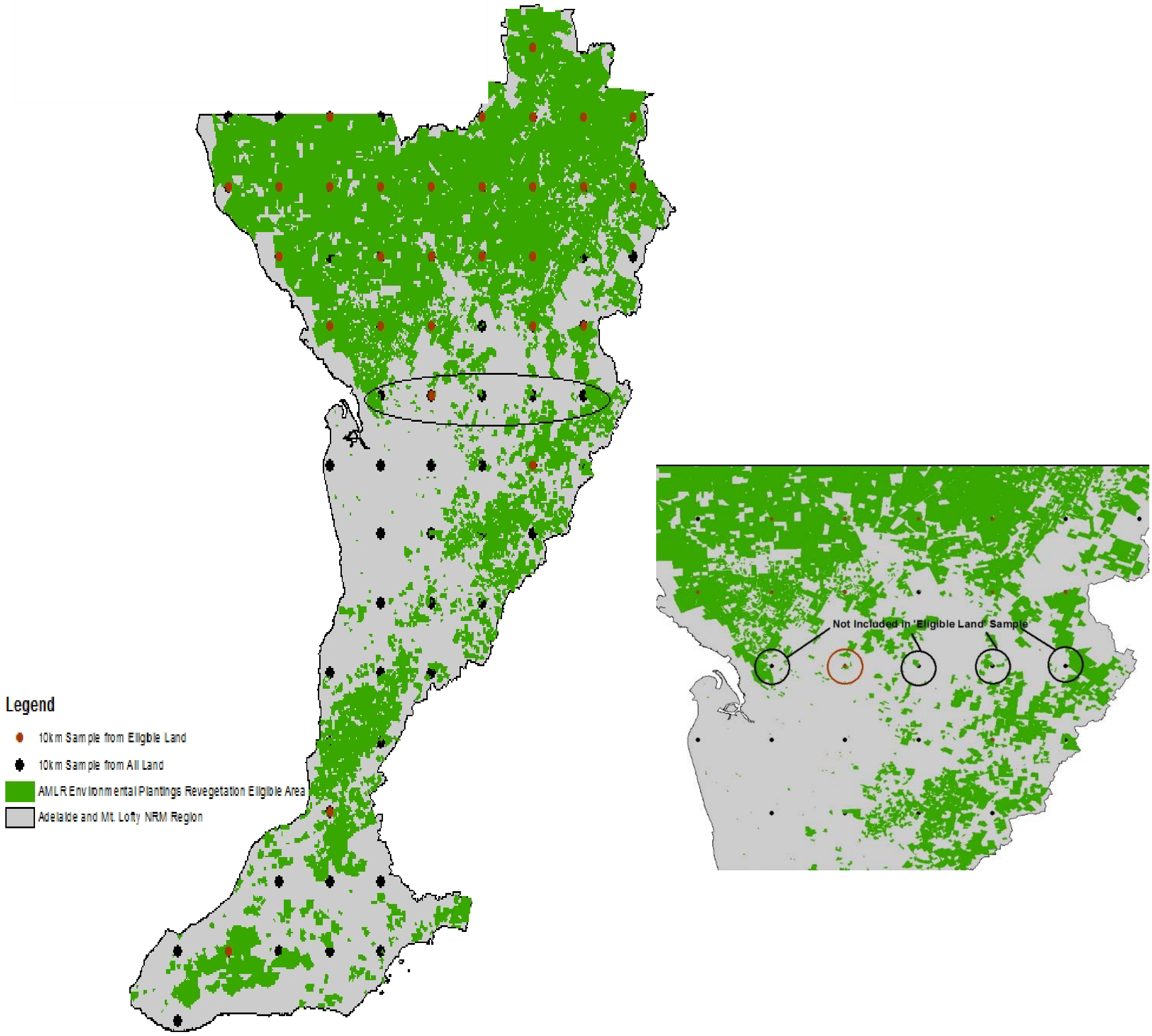


Figure 10: Adelaide and Mount Lofty Ranges NRM region sampling. Right pane shows possible issues of sampling strictly only in ERF-eligible area in areas that contains small land parcels. All points sampled in 'all land' sampling approach to overcome this.

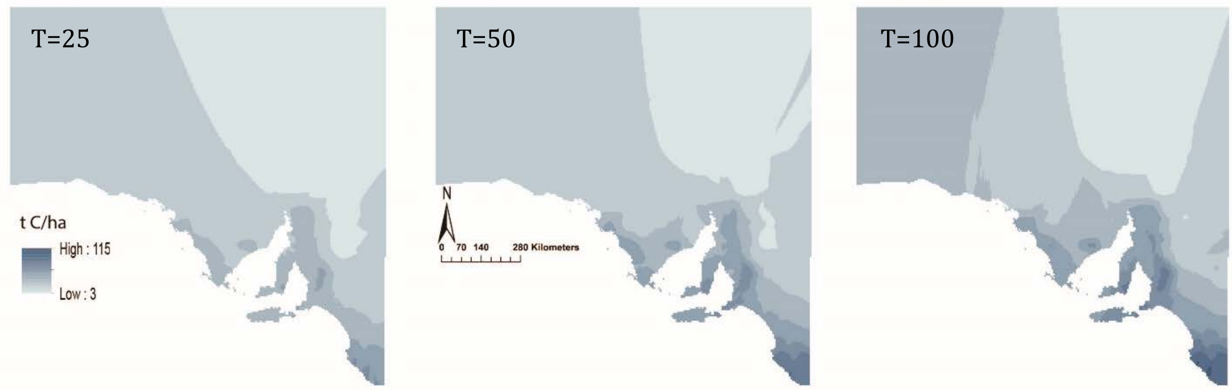


Figure 11: Map of carbon sequestration potential across SA for Mallee revegetation at 25, 50 and 100 Years since planting.

Because of the uniform sampling approach, the number of 'eligible land' sample points per NRM Region was proportional to the volume of eligible area in each NRM Region. For the 'all land' sample approach, the number of points is proportional to the total area in each NRM Region, excluding SA Arid Lands and Alinytjara Wilurara NRM Regions. The number of sample points across in the eligible area and across the wider landscape is shown in Table 6.

Table 6: FullCAM sample points in eligible areas.

ERF method	Project mechanism	Number of sample points in eligible land (10 km grid)	Number of sample points in All Land (10 km grid)
Reforestation by Environmental or Mallee Plantings	Mixed environmental planting revegetation	1,012	1,697
	Mallee revegetation	876	1,510
Plantation Forestry*	New commercial plantation forestry	83	178
	Short-run to long-run conversion	75	178
Human-induced Regeneration**	Cease the mechanical or chemical destruction or suppression of regrowth.	32****	N/A
Sequestration of Carbon in Soils Using Default Values***	Sustainable intensification	1,699	1,699
	Converting crops to pasture		
	Retaining crop residue in field		

**For plantation forestry 'all land' refers to land within national plantation forestry inventory region zones, irrespective of current land use).*

***Based on the maps available (provided by DEW) there is a very small area of land available for this method (0.04%) and eligible land parcels are widely distributed across SA. We have no further information to expand sampling to a more generalised area, so no 'all land' sample was taken. If future carbon estimates for this method are required, a possible sample area could be the intersection between native scrub and livestock/grazing zoned areas (most likely in the southern rangelands).*

****Soil carbon improvements eligibility coincides with the nominal agricultural zone (e.g. all SA excluding Arid Land and Alinytjara Wilurara).*

*****This is a very small sample (reflecting the small volume of land available for this project mechanism). The sample points are widely distributed across SA. It is therefore important not to generalise based on this sample. It is not representative of rainfall, soil, or land use. Caution should be used when making conclusions or policy recommendations based on this sample.*

1.5 Selecting tree species to be modelled in FullCAM and CFI mapping tool

In SA, there are roughly 25-30 tree species programed into FullCAM. There are general species groupings (e.g. Mallee woodland and shrubland) and species with specific calibrations (e.g. *Eucalyptus kochii*). Tree species with specific calibrations are only eligible in certain regions of Australia.

In this project, there was a choice of tree species for the *Environmental and Mallee Revegetation* method and the *Plantation Forestry* method. In the other method (human-induced regeneration), there was a single tree species specified in the FullCAM guidelines. A summary of where each species model was applied in South Australia is shown in Table 7**.** and explained below.

Table 7: Revegetation species for vegetation ERF methods.

<table>
<tr><th colspan="2" rowspan="2">ERF Method project mechanisms</th><th colspan="8">NRM region</th></tr>
<tr><th>SAAL</th><th>AW</th><th>SAMDB</th><th>N&Y</th><th>EP</th><th>KI</th><th>AMLR</th><th>SE</th></tr>
<tr><td rowspan="2">Revegetation</td><td>Mixed Environmental Plantings</td><td>Mixed species environmental planting
Mixed species environmental temperate</td><td>N/A</td><td colspan="4">Mixed species environmental planting
Mixed species environmental temperate</td><td colspan="2">Mixed species environmental temperate</td></tr>
<tr><td>Mallee Revegetation</td><td colspan="8">Mallee woodland and shrubland revegetation</td></tr>
<tr><td rowspan="2">Plantation forestry</td><td>New Plantation Forestry</td><td>N/A</td><td>N/A</td><td colspan="2">Eucalyptus globulus
Eucalyptus tall open forest
Pinus radiata</td><td>N/A</td><td colspan="3">Eucalyptus globulus
Eucalyptus tall open forest
Pinus radiata</td></tr>
<tr><td>Conversion to Long-run Rotation*</td><td>N/A</td><td>N/A</td><td colspan="2">Eucalyptus globulus</td><td>N/A</td><td colspan="3">Eucalyptus globulus</td></tr>
</table>

**The tree species able to be presumed to have a short-rotation (and hence eligible for conversion to long-run rotations) is specified in Schedule 1, Part 1 of the Plantation Forestry ERF legislation. For SA, only Eucalypts globulus. Other species require additional evidence to be provided by the land holder in order to make the project eligible for ACCUs.*

1.5.1 ENVIRONMENTAL AND MALLEE REVEGETATION TREE SELECTION

For SA, FullCAM has two environmental plantings models:

- Mixed species environmental planting *(general species grouping)*
- Mixed species environmental planting temperate *(specific calibration)*

The carbon sequestration technical advisor from DEW strongly recommended using the specific temperate calibration (T Hobbs, pers comm.). This is because the general environmental planting is a very old calibration set from >15 years ago based on a model of Tasmanian Blue Gums. The specific temperate calibration is more recent and more accurate. However, the mixed species environmental planting temperate is only eligible in temperate regions and can only be modelled in FullCAM within these regions. These areas are shown in Figure 13. As shown, the temperate specific calibration is only applicable is some parts of SA. In all other regions (where the method is eligible to be applied), the general species model was used. This introduced the complication that two separate tree species models have been used in the same method, however there was no way to avoid this issue and there were no overall implications on the accuracy of the carbon estimates. Note that the specific temperate and general species model has different planting configuration options. Further discussion on this issue is provided in Section 1.1.7.

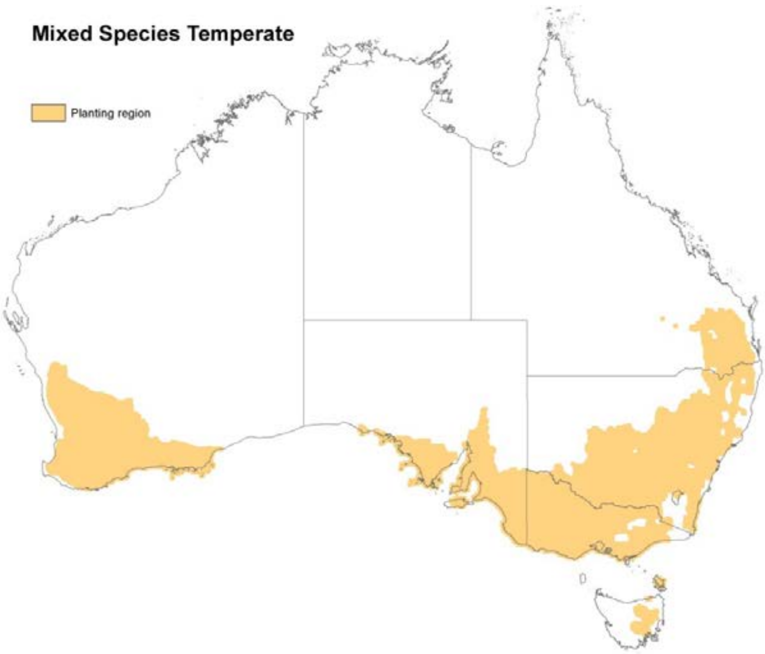


Figure 12 Mixed environmental species temperate planting regions. Source: DoEE, 2016.

For Mallee plantings, FullCAM has four models for SSA:

- Mallee *Eucalypt kochii (specific calibration).*
- Mallee *Eucalypt loxophleba lissophloia (specific calibration).*
- Mallee *Eucalypt polybractea (specific calibration).*
- Mallee woodlands and shrublands (*general calibration).*

As with the environmental plantings, specific calibration Mallee species are only applicable in certain areas. This is shown in Figure 14. As can be seen, the distribution of planting regions is different but overlapping between each Mallee species. This raises the question of which Mallee species should be modelled where. However, the species of Mallee with specific tree species are not indigenous to SA but rather are indigenous to Western Australia (P O'Connor, University of Adelaide, pers. comm.). It was further known that the specific Mallee calibrations are calibrated for WA soils and rainfall and are thus unlikely to be accurate in a SA context. It was therefore decided that the general Mallee calibration (Mallee woodlands and shrublands) would be applied across all regions of SA eligible for Mallee revegetation.

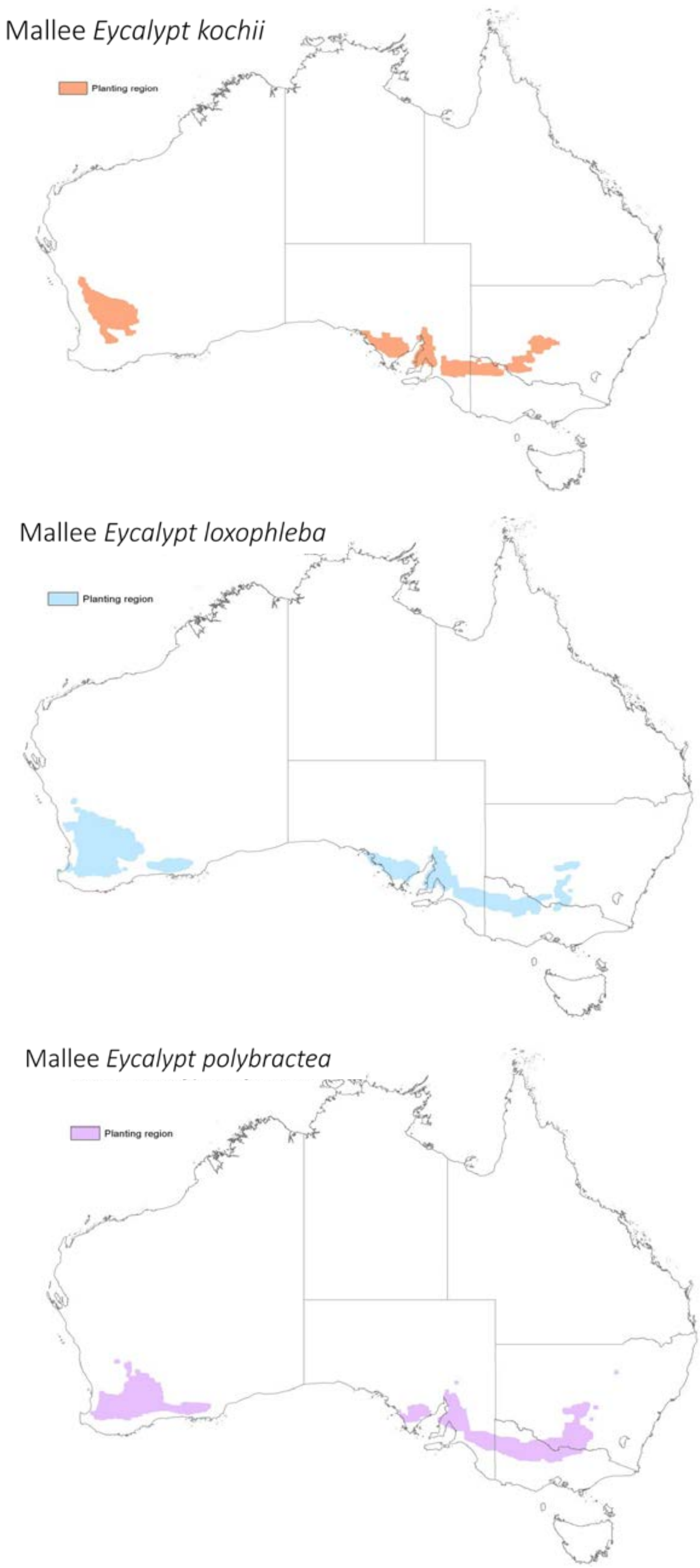


Figure 13 Mallee specific calibration planting regions. Source: DoEE (2016b)

1.5.2 PLANTATION FORESTRY TREE SPECIES SELECTION

For plantation forestry in SA a number of tree species can be selected, however only the following FullCAM options are viable commercial plantations in SA:

- *Eucalyptus globulus.*
- *Pinus radiata.*
- Tall open *Eucalyptus* forest.

Importantly, it was not known what specie(s) comprises the *Tall open Eucalyptus forest* model. DEW confirmed that a description cannot be provided (T Hobbs, pers. comm.), nor was any detail provided in the legislation or explanatory statements. It was therefore decided that although this tree species classification was vague, it was the best choice from the list of possible models within FullCAM.

Although not possible because of limitations provided by FullCAM, it was also envisioned that the Plantation Forestry method would be explored with plantations of Sugar Gum and Spotted Gum.

The three species available to be run in FullCAM for SA are run in across the whole National Plantation Forestry Inventory Region in SA.

1.6 Planting configurations

Each tree species has a choice of planting configurations and tree densities. It appeared that specific calibration tree species have more detailed planting configurations to model, while general species grouping have only ‘revegetation’ or ‘clearing’. The planting configurations modelled are shown in Table 8.

For the environmental planting temperate species (which has a lot of possible planting regimes), the planting regime was chosen to reflect observed stocking densities (~600trees per hectare) and proportion tree cover (88% tree) for typical environmental plantings (Hobbs et al., 2010).

Table 8 Planting regimes for modelled tree species.

Tree species	Planting regime and configuration
Mixed species environmental planting temperate	Geometry block, stocking 500-1500, prop tree >=0.75
Mixed species environmental planting	1970-present, all plantation medium, non-commercial planting, no prunes (1 – recommended)
Mallee woodlands and shrublands	Revegetation
Eucalyptus globulus	1998-present, SA plantation medium, no thins, no prunes (1 – recommended)
Pinus radiata	1984-present, SA plantation medium, 4 thins, no prunes (1)
Eucalyptus tall open forest	Revegetation

Note, when the planting regime specifies events such as pruning or thinning, these are removed from the time-series in the events tab. This is to ensure observations of all species occur with the same events (e.g. no thins, no prunes, no fire, no clearing etc.).

1.7 Running FullCAM and using the CFI Mapping Tool

FullCAM was used to estimate carbon sequestration in vegetation over time. Once the sample points were identified[1] across the landscape and in eligible land, the latitudes and longitudes were run through FullCAM. Each latitude and longitude were entered manually. Each sample point was run for every applicable method and tree species in FullCAM. FullCAM outputs a 100 year time series of cumulative tonnes of carbon sequestered per hectare (tC/ha), beginning on January 1st 2018 and ending December 31st 2118.

FullCAM also outputs a number of variables (selected by the user) over the 100 years. For each sample point, the following variables were output:

- Carbon mass of trees (tC/ha).
- Carbon mass of debris (tC/ha).
- Carbon mass of soil (tC/ha).
- Carbon mass complete (tC/ha).
- CH_4 emitted due to fire (tCH_4/ha).
- Carbon mass of complete forest (tC/ha).
- Carbon mass on-site forest (tC/ha).
- Carbon mass of aboveground forest (tC/ha).
- Carbon mass of belowground forest (tC/ha).
- Carbon mass of forest debris.
- N_2O emitted due to fire (tN_2O/ha).

Because no fire events were modelled (see Section 1.3.2), N_2O and CH_4 emitted due to fire should always read zero. In addition, for plantation forestry carbon mass of forest products (tC/ha) was an ouput. Because no harvest events were modelled, this variable should always read zero.

Of the above outputs, the most important are carbon *mass of trees* and *carbon mass of debris.* Generally speaking, it is the carbon sum of these two variables that translates into Australian Carbon Credit Units (ACCUs). This is explained in Section 1.1.10.

For the variables listed above, the time-series was exported from FullCAM as a *.csv* file. The file was saved with a naming convention to represent which species has been run and at which location. The file naming key is included in each folder of data outputs (see Appendix B and data files). An example of the FullCAM process and data output is shown in Figure 15.

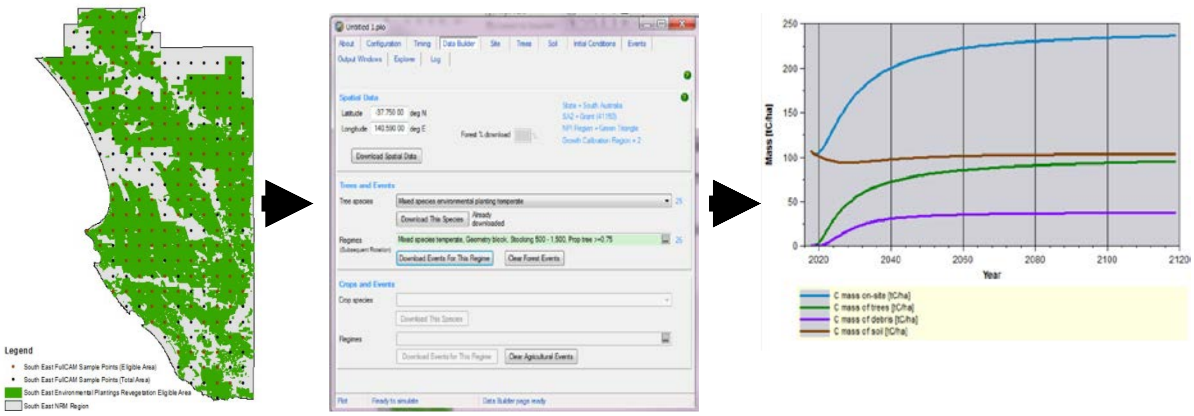


Figure 14 Running FullCAM: an illustrative example of the FullCAM process and data output

[1] To identify sample points, the relevant data layers needed are: SA NRM zones, rainfall zones, generalized land use layer, 10 km sampling grid. A table providing further detail of required spatial input files for each ERF and non-ERF method is provided in Appendix B.

The Carbon Farming Initiative (CFI) Mapping Tool was used to estimate annual soil carbon sequestration rates. The CFI Mapping Tool assigns annual soil sequestration rates to areas of land based on the modelled project mechanism (e.g. stubble retention). The soil carbon sequestration rates in SA based on the CFI Mapping Tool are shown in Figure 16 to 18.

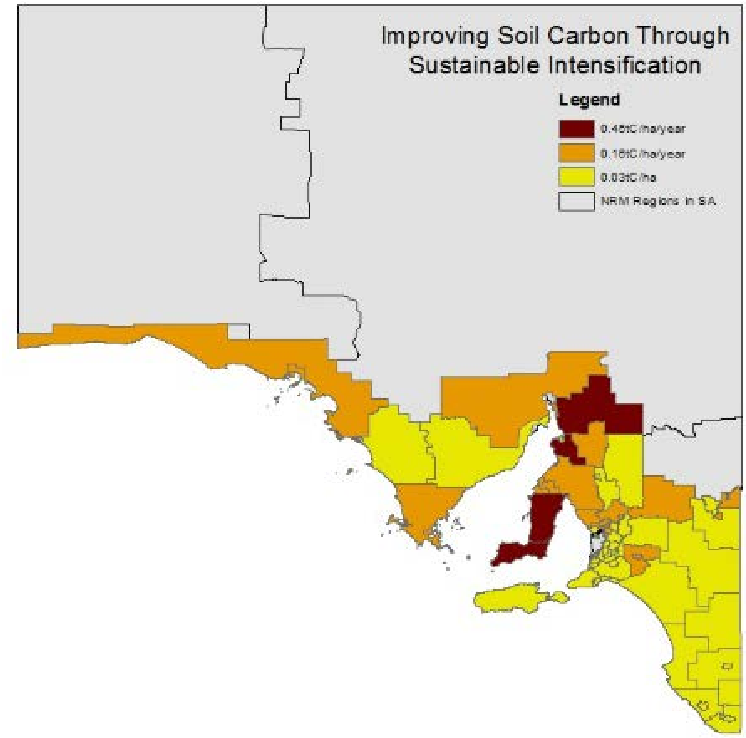


Figure 15 Soil carbon sequestration rates for sustainable intensification in eligible regions of SA

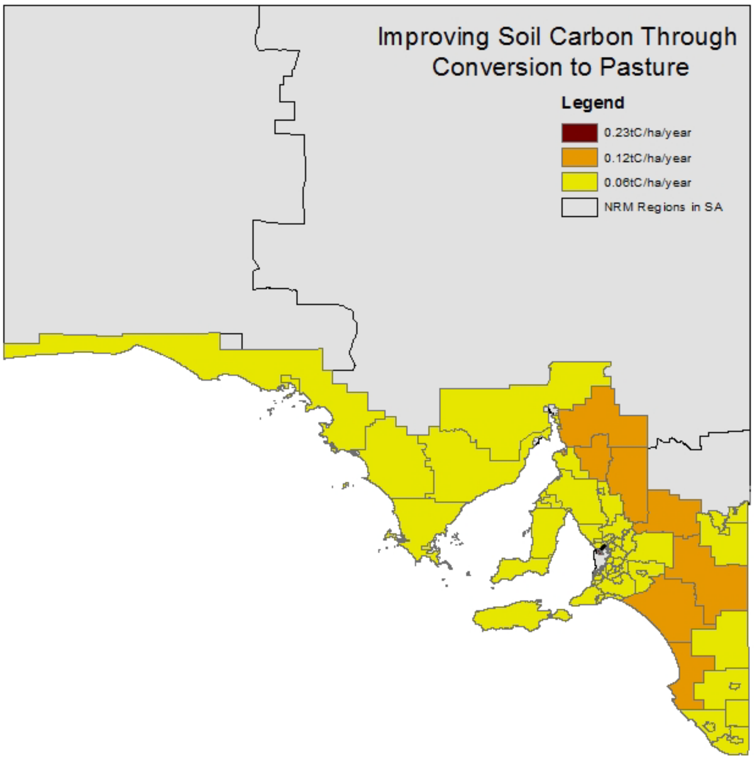


Figure 16 Soil carbon sequestration rates for conversion to pasture in eligible regions of SA

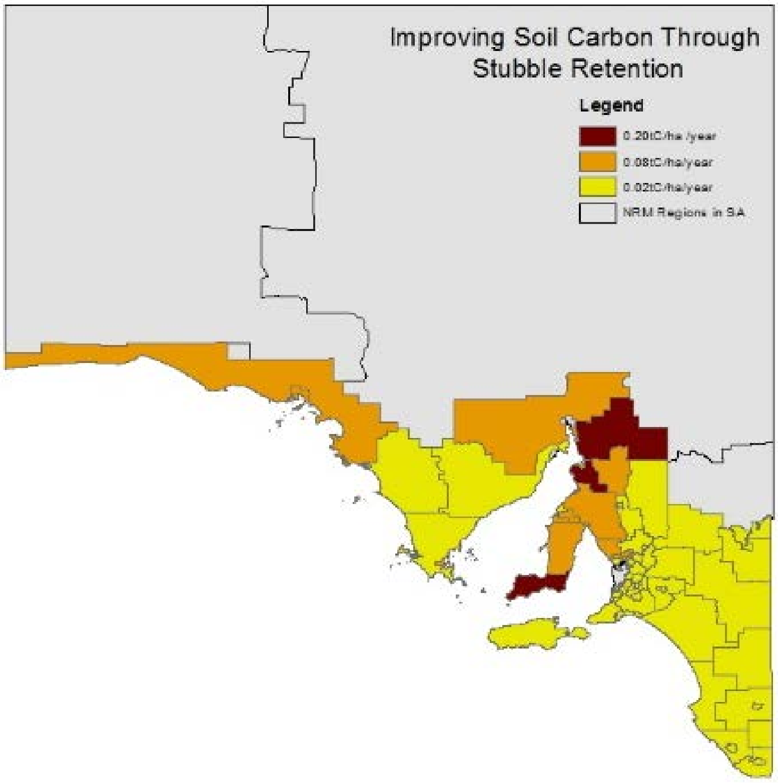


Figure 17 Soil carbon sequestration rates for stubble retention in eligible regions of SA

Since all the agricultural and vegetation carbon sequestration estimates are in point form, it was necessary to attach the carbon sequestration rates the data from the CFI Mapping Tool shapefiles to the sample points within each region and each project mechanism. This was also necessary for comparison with agricultural profits at each sample point. In addition, the CFI Mapping Tool expressed carbon sequestration rates as annual tonnes of carbon sequestered each year (tC/ha/year) rather than in a cumulative time-series format (as is the case for vegetation carbon sequestration estimates). Therefore, to ensure all data was delivered in the same format, the annual carbon sequestration rates were summed over a 100 year time series, beginning January 1st 2018, to match the output from FullCAM.

The soil carbon sequestration time-series were saved as *.csv* files labelled by project mechanism and location. An example of file naming convention in the results files is shown in Appendix B. A file naming key is also included for each method in the data delivery.

Overall, for all vegetation and soil carbon sequestration methods, this process results in 8,692 data points in the carbon sequestration time-series, 7,175 of which are in eligible areas. This is summarised in Figure 19.

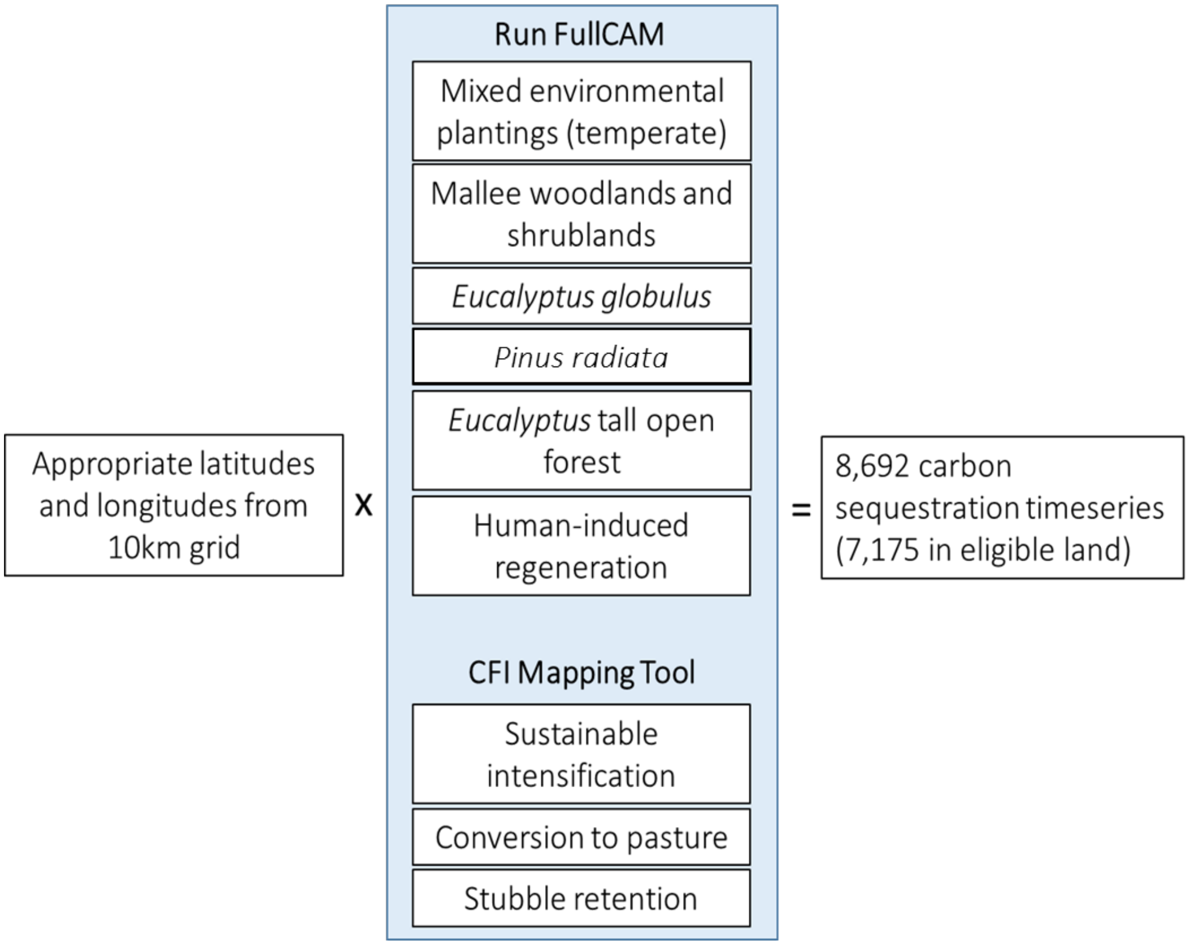


Figure 18 Process of running FullCAM and assigning values from CFI mapping tool

Once all sample points were spatially analysed in ArcGIS and run through FullCAM or the CFI Mapping tool, the carbon sequestration estimates were then attached to the 10 km grid sample points via their unique identifiers. At the end of this process, each point will therefore contain data regarding location (latitude/longitude, NRM Region), agriculture (land use, profit) and carbon sequestration estimates (carbon sequestration over time in vegetation/soil). This is the data that is used for the economic analysis.

1.8 Discounting carbon sequestration for 25 year permanence periods

Landholders engaging with soil or vegetation based sequestration projects are subject to permanence obligations of 25 and 100 years. A permanence obligation means that the carbon sequestered as part of a project must be maintained for the nominated amount of time (25 or 100 years). For example, once a landholder has decided to engage in a project, the landholder cannot then clear the forest for wood products. Once a permanence period has been nominated, it cannot be changed.

If a landholder nominates a 25 year permanence period, then that project will be subject to a 20% reduction in the number of carbon credits (ACCUs) issued that that project (ERF, 2017). The value of the non-paid out ACCUs (20% not paid to the landholder) is designed to cover the cost to the government of replacing the carbon when the 25 year permanence period ends and the landholder clears the land, for example.

In addition, for a 25 year permanence period, the government implements a 5% risk of reversal buffer (RRB). The RRB is an 'insurance scheme' implemented to protect the government against temporary losses of carbon stocks due to natural and man-made events in 25 year projects (e.g. bush fire, deliverate destruction of forest) (ERF, 2015).

This means that for a 25 year permanence obligation, the landholder will only be paid 75% of the carbon credits sequestered in the project. For example, if after 100 years a farmer sequesters 100tC/ha, he will only be paid 75 ACCUs.

1.9 Calculating ACCUs from FullCAM and CFI mapping output

FullCAM and the CFI Mapping Tool output data in the form of tC/ha. ACCUs are paid on the basis of tCO_{2e}. The method explanatory statements provide details of how to convert FullCAM outputs into ACCUs.

Importantly, not all FullCAM variable outputs convert to ACCUs. Importantly, ACCUs are not paid for the complete carbon mass of the forest or the carbon mass in the soil for vegetation methods. ACCUs are only paid for the CO_{2e} in the carbon mass of trees and carbon mass of debris for native vegetation methods, net any emissions due to fire or on-land fuel emissions. For commercial forestry, the carbon mass of products is also accounted for, net any emissions due to fire or on-land fuel emissions. For soil carbon methods, the emissions calculations are complex due to the number of fuel-intensive on land activities associated with improving biomass yields or converting crops to pasture. Care should be taken to examine the legislation to decide how to account for these various emissions sources (which would reduce the number of ACCUs paid).

Further details and calculation guidelines of how ACCUs are calculated is provided in the final section of the legislation for each determination.

2 Non-Emission reduction fund methods

2.1 Overview

Three non-ERF methods were developed and modelled in this project, all of them form the vegetation management sector. These are: a) Drooping Sheoak restoration; b) woodlands restoration; and c) carbon sequestration in the southern Rangelands.

The non-ERF methods were selected on criteria based on existing conservation targets and applicability to SA. The non-ERF methods developed do not meet requirements under the current legislation due to inability to reach 20% forest cover at 2 m and also due to their placement outside of eligible land uses.

To the greatest degree possible, the same procedure to determine eligible land and identify sample points was applied to the non-ERF methods as was to the ERF methods described in Section 1.1.

However, because there are no eligibility requirements placed on the non-ERF methods, the area estimates were approximate only and should be updated when DEW is able to provide spatial data surrounding their targeted conservation actions.

For the sake of comparability to the ERF method data, it was advantageous to use existing tools. Therefore, the 2016 version 2.0 of the Federal Government's Full Carbon Accounting Model (FullCAM) (available: https://www.environment.gov.au/climate-change/climate-science-data/greenhouse-gas-measurement/land-sector) was used for the two vegetation management non-ERF methods: *Drooping Sheoak restoration* and *Woodlands restoration*. Results were outputted as cumulative carbon sequestration over a project timeframe of 100 years. FullCAM technical specifications are provided in DoEE (2016b).

For carbon sequestration in the southern Rangelands, the model of Hobbs et al. (2016) was used to estimate carbon storage in native tree species at 25, 45 and 65 years since project commencement for a range of tree covers.

All non-ERF data is outputted as .csv files with one file per sample point, ready to be input into the economic analysis. An example of file naming convention in the results files is shown in Appendix B. A file naming key is also included for each method in the data delivery.

2.2 Data

Table 9 Key data inputs for non-ERF development and modelling

Data	Use	Source
Generalised 2016 land use mapping	Determine non-ERF applicable areas.	DPTI (2016)
Rainfall mapping	Apply rainfall restrictions for southern rangelands non-ERF method.	Trevor Hobbs (DEW)
NRM layer	Reporting.	DEWNR (2012)
10 km grid	Identify sample points for rangelands case study and SA biophysical attributes.	Dr. Courtney Regan (The University of South Australia)
Rangelands mapping	Map rangelands regions.	Australian Rangelands Boundaries (2000)

2.3 Selection of non-ERF methodologies

Due to the biophysical and climate characteristics of SA, less than 20% of the total area was eligible for inclusion in the ERF methods discussed in Section 1.1. This means that roughly 78 million hectares was not eligible for the vegetation or soil ERF methodologies investigated in this project. As a result, it was beneficial to explore potential carbon sequestration methods that may be applicable in SA but are not currently recognised at a national scale.

To that end, three non-ERF methods were developed and analysed. These methods were chosen based on two primary criteria:

- Existing conversion targets and actions in SA.
- Targeting areas with carbon sequestration potential that do not qualify as eligible for current ERF methods.

The three non-ERF carbon sequestration methods are shown in Table 10. The three non-ERF methods were selected in consultation with, and ratified by, the project advisory committee.

Table 10 also sets out why the proposed non-ERF method does not classify as eligible under the current legislation.

Table 10 Proposed non-ERF methods

Sector	Proposed non-ERF method*	Proposed Project Mechanism (*considered in this project)	What makes it Non-ERF?	Relevance to SA
Vegetation Management	Revegetation of Drooping Sheoak on Kangaroo Island	*Casuarina* forest revegetation	Does not meet 20% cover at 2 m condition (sparsely populated)	Conservation priority
	Grassy Woodlands Regeneration in the Mount Lofty Ranges	*Eucalyptus* woodlands natural regeneration measures	Does not meet 20% cover at 2 m condition (sparsely populated)	Conservation priority
	Carbon Sequestration in the Southern Rangelands	Environmental plantings in sandy soil, moderate to low rainfall zones	Has existing native remnant vegetation, does not meet 20% cover at 2 m condition	Large area of land
Agriculture	Clay spreading	Spreading clay in agricultural soils to increase yield productivity	Unknown	Large area of land

**Note, clay spreading sSpreading clay in agricultural soils to increase yield productivity) was originally included as a non-ERF method but is instead now being considered as a potential co-benefit case study, on the advice of the project advisory committee.*

2.4 Determining land available for implementation of non-ERF methods

Unlike ERF methods, there are were no eligibility requirements for the proposed non-ERF methods. The non-ERF methods were therefore applied in the most appropriate region for each method. The type of land, rainfall zone and any restrictions that apply to the non-ERF methods are shown in Table 11.

Table 12 shows the area of applicable land by NRM for each non-ERF method. This is shown graphically in Figure 20.

Table 11 Type of land applicable for non-ERF methods

Non-ERF Method	Type of land	Rainfall restrictions	Land use restrictions
Revegetation of Drooping Sheoak on Kangaroo Island	Conservation, agriculture, horticulture, livestock*	N/A	Exclude already natively vegetated lands
Grassy Woodlands Regeneration in the Mount Lofty Ranges	Conservation, agriculture*		Exclude already natively. vegetated lands
Carbon sequestration in the Southern Rangelands	Agriculture fringe	250-350 mm/year	N/A

**This land use is an assumption. Drooping sheoak restoration on Kangaroo Island is a DEW restoration priority and it is anticipated that there may be some data availability regarding the specifically targeted sites. However, this has not yet been made available*

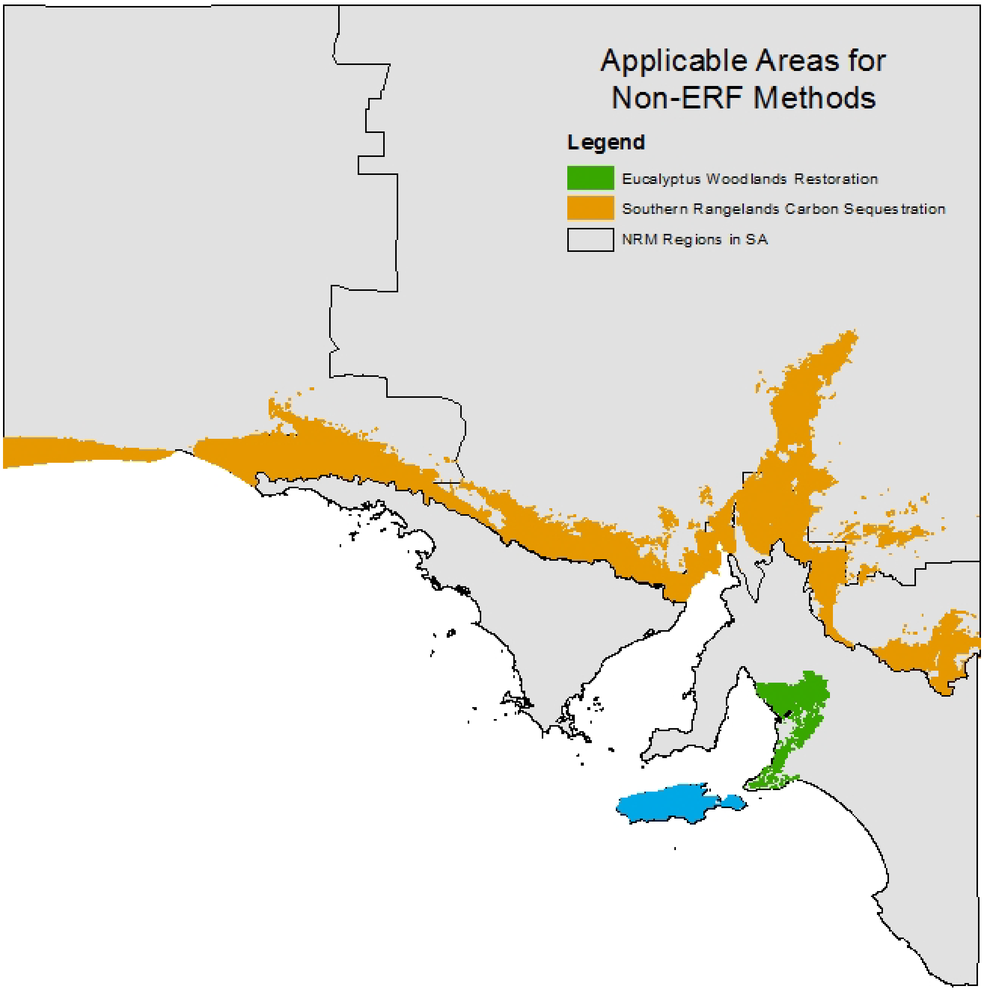


Figure 20 Applicable areas for non-ERF methods

Table 12 Non-ERF methods applicable areas

		Eligible Land ('000 ha) [% of NRM region]		
NRM region	**Total land ('000 ha)**	**Drooping sheoak restoration ki**	**Woodland restoration Mt Lofty ranges**	**Southern Rangelands Carbon Sequestration**
SA Arid Lands	52,164	0 [0.0%]	0 [0.0%]	Exact area to be determined
Alinytjara Wilurara	28,119	0 [0.0%]	0 [0.0%]	19.9 [0.07%]
SA Murray-Darling Basin	5,647	0 [0.0%]	0 [0.0%]	Exact area to be determined
Northern & Yorke	3,463	0 [0.0%]	0 [0.0%]	0 [0.0%]
Eyre Peninsula	5,184	0 [0.0%]	0 [0.0%]	Exact area to be determined
Kangaroo Island	440	440? Exact area unknown*	0 [0.0%]	0 [0.0%]
Adelaide and Mt Lofty Ranges	664	0 [0.0%]	664? Exact area unknown*	87 [13.1%]
South East	2,686	0 [0.0%]	0 [0.0%]	0 [0.0%]
Total South Australia	98,424	<440 [0.44%]	<664 [0.67%]	

**The spatial extend of these non-ERF methods is currently unknown.*

2.5 Sampling points in ArcGIS

The same sampling methodology used for the ERF methods was applied for the sampling across applicable land for the non-ERF methods. Due to the lack of spatial data outlining the extent of restoration activities in Kangaroo Island (Drooping sheoak revegetation) and the Mount Lofty Ranges (Woodlands regeneration), the sampling extent was taken to be the total NRM Regions of Kangaroo Island and Adelaide and Mount Lofty Ranges, respectively. For the southern Rangelands method, points were sampled only from the applicable area.

2.6 Approach used to estimate carbon sequestration for non-ERF methods

The non-ERF methods do not come under current legislation and therefore there is no prescribed way to estimate the carbon sequestration. Where possible, it is advantageous to use existing tools and data. As a result, two non-ERF methods are estimated using FullCAM and the other using an existing model provided by DEW, as shown in Table 13.

Table 13 Carbon estimation methods for the non-ERF methods

Non-ERF Method	Carbon Estimation Approach
Revegetation of Drooping Sheoak on Kangaroo Island	FullCAM
Grassy Woodlands Regeneration in the Mount Lofty Ranges	FullCAM
Carbon Sequestration in the Southern Rangelands	Hobbs et al. 2016

2.6.1 USING FULLCAM FOR MODELLING DROOPING SHEOAK AND GRASSY WOODLANDS CARBON SEQUESTRATION

For the Revegetation of Drooping sheoak on Kangaroo Island and Grassy woodlands regeneration in the Mount Lofty Ranges it was possible to use FullCAM to estimate the carbon sequestration time series.

FullCAM has programmed tree species that is applicable for these two non-ERF methods. The same FullCAM procedure outlined in Section 1.1.8 is used for the non-ERF methods. However, because the planting configuration of the Drooping Sheoak revegetation is largely unknown, both natural regeneration and woodlot stocking planting regimes were used.

For the Mount Lofty Ranges grassy woodlands restoration, the mixed environmental plantings model was used. Note that in the Mount Lofty Ranges region it is acceptable to use the *environmental planting temperate* model which would yield higher carbon estimates. However, this was not done because the regeneration of grassy woodlands in the Mount Lofty Ranges is comparable to a human-induced regeneration method. This is the case because it does not require any new plantings but rather management of existing conservation or mixed conservation/agriculture areas to allow natural regrowth. In the legislation for the human-induced regeneration method, it is specifically detailed that the *mixed environmental planting temperate* model not be used. Due to the comparability between the methods, this restraint was also observed when modelling woodlands regeneration.

Table 14 shows the vegetation and planting configurations for the two non-ERF methods using FullCAM. The same procedure for running FullCAM for the ERF methods is applied to using FulLCAM for the non-ERF methods. This approach is outlined in Section 1.18.

Table 14 Tree species and planting configurations for two non-ERF methods

Non-ERF method	Estimation method	Tree species	Planting regime
Revegetation of Drooping Sheoak on Kangaroo Island	FullCAM	Casuarina forest and woodlands	Natural regeneration Revegetation, normal stocking
Grassy Woodlands Regeneration in the Mount Lofty Ranges	FullCAM	*Eucalyptus* woodland	Natural regeneration

2.6.2 USING HOBBS ET AL 2016 MODEL TO ESTIMATE CARBON SEQUESTRATION IN THE SOUTHERN RANGELANDS

Hobbs et al. 2016 has developed a carbon sequestration model built on allometric models based on the destructive sampling and measurement of trees across SA. The model estimates the carbon sequestration of the tree species most likely present in each area, therefore representing the indigenous vegetation rather than modelling a specific tree species (as with FullCAM). The outputs from the model represent the carbon stored in vegetation at 25, 45, 65 years and mature periods of vegetation growth.

Note that the outputs from this model are not an annual time series, and so require different treatment in the economics compared to the other carbon estimate points. For the 10 km sample grid, carbon sequestration data from Hobbs' existing spatial data output was attached to the grid. The points located in the Southern Rangelands region were selected and carbon sequestration values at 25, 45 and 65 years for 10%, 50% and 88% tree cover were output for each sample point in the area of interest. Note that because we are interested in carbon sequestration vegetation that does not meet Kyoto conditions (20% at 2 m), the most applicable output from Hobbs et al. 2016 is the 10% tree coverage. The 10 km grid used by Hobbs et al. 2016 and the 10 km grid used for sampling in other methods lines up geographically but do not have the same unique identifiers. This has no implication of the validity of the results, but important to note when mapping data back into ArcGIS.

3 Future work

There are additional aspects of the technical supply of carbon work that would be desirable but are beyond the scope of this project. In particular, although *climate scenario analysis* and *fire risk analysis* are not included in current ERF methods, additional projects to include them would enhance the value and aid in more realistic accounting for key risks.

3.1 Climate scenario analysis

FullCAM and the CFI Mapping Tool output results are based on biophysical parameters representative of the current (historic) climate scenario. It is expected that the rate of climate sequestration will be affected by changes in climate variables. The impact of climate change on sequestration rates is not easily modelled in FullCAM. As a result, climate scenario analysis in the context of FullCAM would require a substantial additional project.

3.2 Fire risk analysis

Planting vegetation to sequester carbon means that there is more fuel available for wildfire. FullCAM doesn't account for fire emissions, though conceptually it should be deducted from the total amount of carbon credit payments for a project (e.g. *CO_2 – fire emissions = ACCUs*).

Fire can be modelled as an 'event' in FullCAM. However, this was not done in the project because data was not available regarding fire frequency or severity and there is large uncertainty in future projections. This would require a substantial new project. Data for such a project could possibly be sourced from relevant government departments. A feasible approach might be to spatially identify risk areas and target the modelling to those regions. For example, fire risk may be a particularl concern in low/moderate rainfall regions with mixed environmental plantings (e.g. bush) near townships or cities.

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Appendix A: NRM regions and rainfall zones in South Australia

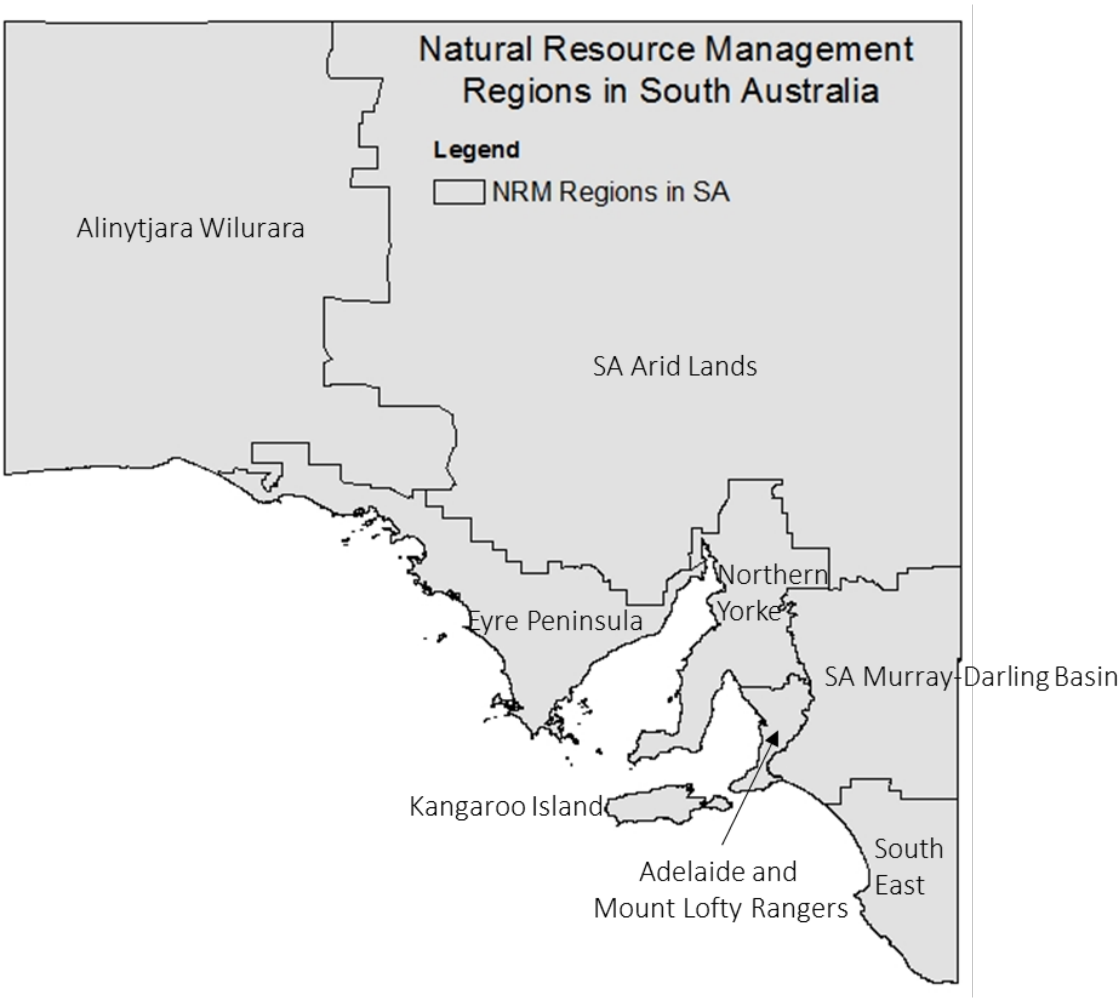

Figure A.1 Natural resource management areas in South Australia

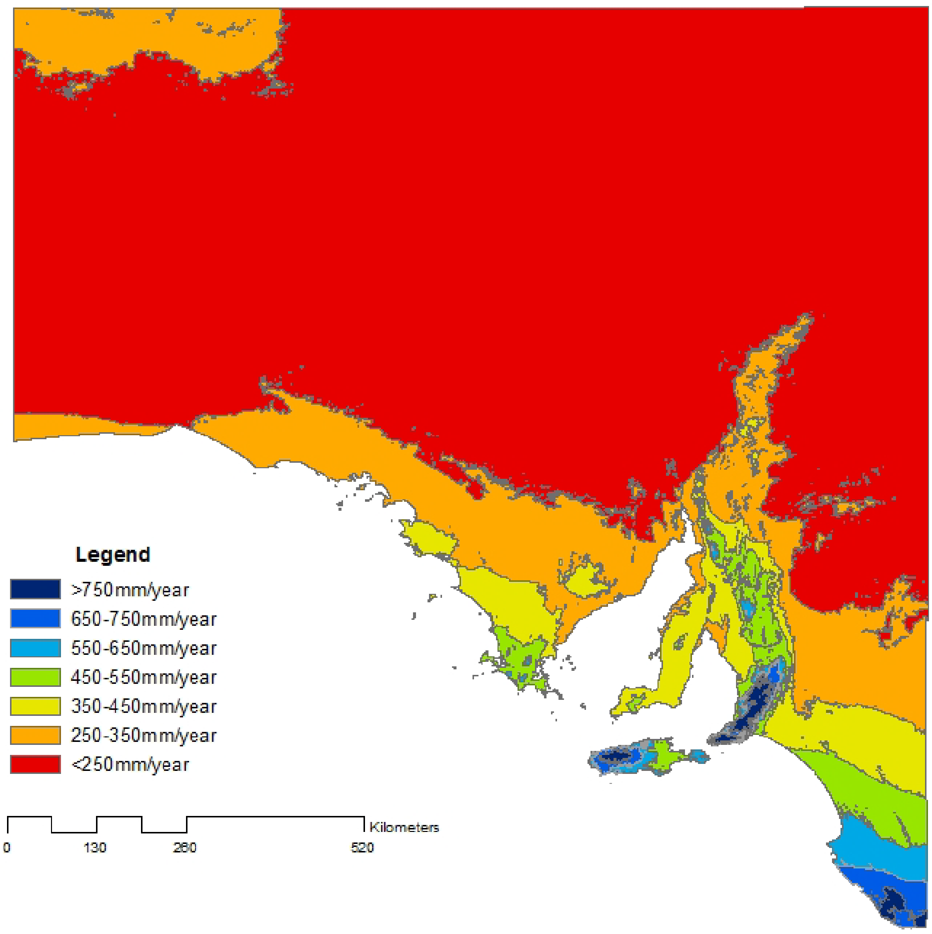

Figure A.2 Rainfall zones in South Australia

Appendix B: File inputs, outputs and file naming conventions

ERF/ Non-ERF method	Project mechanism	Spatial input files needed	Output file examples	Output file interpretation
Reforestation by Environmental or Mallee Plantings	Mixed environmental planting revegetation	-NRM layer -Rainfall layer -Generalised land use layer -10 km sample grid	E_138.19,-35.55	Mixed environmental plantings temperate, location in Mt. Lofty
	Mallee revegetation		MWS_136.89, -32.25	Mallee Woodlands and Shrublands, location in Northern & Yorke
Plantation Forestry	New commercial plantation forestry		NP_EG_136.92, -35.78	New plantation of *Eucalyptus globulus,* location in Kangaroo Island
	Conversion of short-run plantations to long-run plantations	-As above -Forestry layer	CP_EG_139.92, -37.33	Conversion plantation, *Eucalyptus globulus,* location in South East
Human-induced Regeneration of a Permanent Even-aged Native Forest	The implementation of a decision to permanently cease the mechanical or chemical destruction, or suppression, of regrowth.	-NRM layer -Rainfall layer -Permit holder's layer	HIR_135.59, -33.97	Human induced regeneration, location in Eyre Peninsula
Estimating Sequestration of Carbon in Soils Using Default Values	Increasing biomass yields through sustainable intensification	-NRM layer -Rainfall layer -CFI Mapping Tool spatial layer -10 km sample grid	SI_136.09, -32.25	Sustainable intensification, location in Alinytjara Wilurara
	Converting land under crops to pasture		CP_136.09, -32.25	Conversion to pasture, location in Alinytjara Wilurara
	Retaining crop residue in field rather than burning or bailing		SR_136.09, -32.25	Stubble retention, location in Alinytjara Wilurara
Revegetation of Drooping Sheoak on Kangaroo Island*	*Casuarina* forest revegetation.	-NRM layer -Rainfall layer -10 km sample grid	CFW_136.59, -35.75	Casuarina forest and woodlands, location in Kangaroo Island
Grassy Woodlands Regeneration in the Mount Lofty Ranges *	*Eucalyptus* woodlands natural regeneration measures.		EWR_138.19, -35.55	Eucalyptus woodlands restoration, location in Mount Lofty ranges
Carbon Sequestration in the Southern Rangelands	Environmental plantings in sandy soil, moderate to low rainfall zones.	-as above and -SA rangelands layer	Southern_rangelands_10%tree _cover	Native vegetation growth in the southern Rangelands (250-350mm/year) for 10% tree cover

**Current extent of re-vegetation of Drooping Sheoak on Kangaroo Island or Grassy Woodlands Regeneration in Mount Lofty Ranges is unknown. Additional spatial layers may be required as further understanding of the spatial extent of this non-ERF method is decided. Currently, the sampling is carried out across the whole NRM Region containing the applicable land. This can be refined in future data processing.*

The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department for Environment and Water, CSIRO, Flinders University, the University of Adelaide, the University of South Australia, and the International Centre of Excellence in Water Resource Management.