B. HENRY

Land Condition Monitoring

Integrating Ground Surveys, Aussie GRASS and Satellite Remote Sensing

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Executive Summary

The Land Condition Monitoring Program (LCMP) was established in 1998 to assess a range of management issues across the agricultural region of South Australia. The potential for integrating ground data of the LCMP's windscreen survey, satellite remote sensing and Aussie GRASS products was identified by South Australia's Soil Conservation Council. Satellite derived NDVI has been used successfully in the past to monitor green vegetation. The Aussie GRASS model is also currently used to monitor growth of forage in the rangelands of Australia.

A relationship was found between the LCMP cropping land survey, Aussie GRASS products Total Pasture Growth, Total Standing Dry Matter and rainfall, and satellite derived NOAA NDVI. Between 70% and 80% of cover can be explained by Aussie grass products TPG, TSDM and rainfall. As the Aussie GRASS model is dependent upon climatic factors, it can also be said that 70-80% of cover can therefore also be explained by climate. The remaining 20-30% of cover could be explained by management practices, which are considered when ranking cover in the windscreen survey. However, this error variance may also be a result of Aussie GRASS not sufficiently calibrated in the cropping regions of South Australia.

With a relationship found between Aussie GRASS and the windscreen survey, cover was modelled for the entire cropping region. This allows for a continuos visualization of cover across State, which is not achievable with survey results alone. Analysis of data much similar to that achieved with the windscreen survey can also be performed on this data, but instead of grouping by zones, grids of 5km pixel size, which provide a finer view of cover, can be used.

With cover modelled by Aussie GRASS products, this research project explored the possibilities of rating detachment by land use and season in order to create continuous maps of EHI. At present more work needs to be done on a accurate method of estimating detachment that takes into account different land management practices across the agricultural region. Wind and water erosion potential maps from the DWLBC Soil and Land Information soil database were investigated for their use in assessing

erosion risk from the EHI. These maps are a better depiction of landscape features than those observed in the windscreen survey.

No relationship was found between NPLR survey data, Aussie GRASS products and satellite remotely sensed NDVI. The NPLR was not included in field surveys used to calibrate the Aussie GRASS model. It is therefore possible that no relationship was found between the LCMP survey data and Aussie GRASSS products, as the model has not been calibrated in the NPLR.

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Acknowledgments

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1 Introduction

1.1 South Australia's Land Condition Monitoring Project (LCMP)

The agricultural industry is an important contributor to South Australia's economic, social and environmental development. To continue this development, sustainable land management is required to protect and maintain our soil and water resources. An important component of sustainable land management is the monitoring of land condition. For this reason the Land Condition Monitoring Program (LCMP) was established in 1998 to assess a range of management issues across the agricultural region of South Australia. The major land uses in these areas include mixed cropping/livestock systems, high rainfall grazing and rangelands. The cropping region is situated south of Goyder's Line (rainfall >250mm/year), and amounts to an area of ~10.8 million ha. The non-pastoral lease rangeland's (NPLR) are generally not suitable for cropping but were included in the survey as they fall outside South Australia's Pastoral Board monitoring jurisdiction. The rangelands encompass 2.5million ha and are dominated by livestock systems. The southeast, Kangaroo Island, Murray irrigated areas, wine growing regions and Mt lofty ranges are not covered in the survey. These areas are considered more resilient to land degradation issues, or are not large enough to suit the windscreen survey methodology of the program.

Windscreen survey technique is slightly different over cropping and NPLR regions, to account for their different land management practices. The main focus of monitoring in both regions is erosion risk. Although the majority of soil erosion is episodic and ephemeral in nature, management methods that promote exposure of the land over extended periods guarantee soil loss at times of severe wind and rainfall events. The program therefore justified that 'erosion over the long term correlates with land exposure and consequent erosion risk' (pg. 2, McCord *et al*, 2000). It is this erosion risk, which is monitored by the windscreen survey. In the NPLR's, the methodology was slightly modified by also including the additional parameters of perennial vegetation type, density and health. Issues that the program's windscreen survey currently monitor include (Mc Cord *et al*, 2000):

- Vegetative and dry residue cover;
- Detachment;
- Wind erosion potential and risk; and
- Water erosion potential and risk.

A rapid field survey methodology was developed by the LCMP, which involves ~6000 sites along predetermined routes in the cropping regions (Figure 1.1). Sites in the NPLR are at fixed locations and number 853. Observers are required to record the rank of several factors including cover, detachment, crop type and growth stage, slope, and burning regimes. Further details on survey methodologies are discussed in Chapter 2 and 3, and can also be found in Mc Cord *et al* 2000, Mc Cord 2000a, and Mc Cord 2000b.

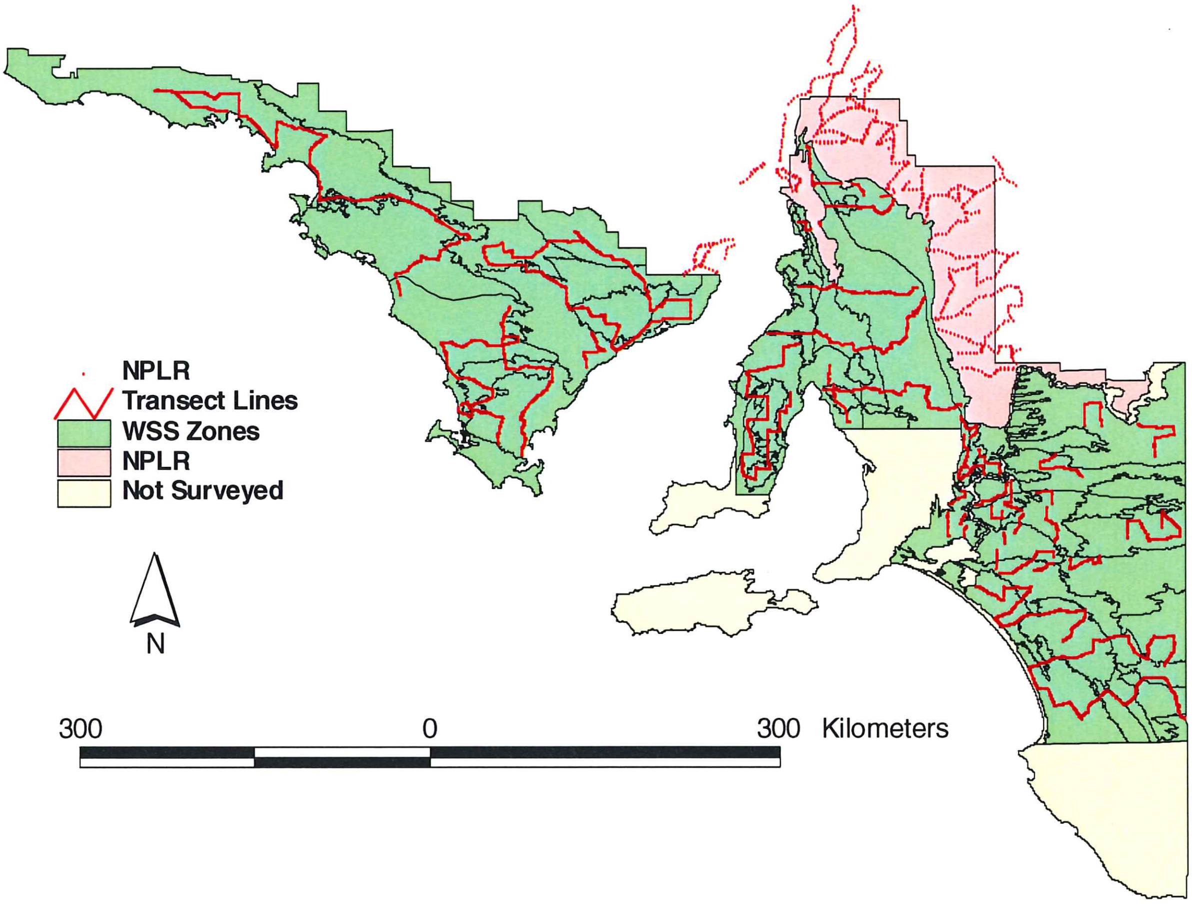

Figure 1.1: LCMP's Transect Roads, NPLR Sites, and Windscreen Survey Zones.

The windscreen survey has been operational for four years, and is able to cover broad regions relatively quickly, measuring solid, objective and repeatable ground data. However, there are limitations to the survey, including (Thomas, 2001):

- Survey sites confined to roadside paddocks with difficult to reach areas not being surveyed;
- It is not known if results can be extrapolated to less accessible locations;
- Inconsistencies in survey timing and surveys conducted during slightly different cropping stages in some areas;
- About 6000 sites in the cropping land and 850 in the NPLR used to represent ~12.5 million ha;
- Limited to a small area along transect roads; and
- Medium temporal repetitions.

1.2 Satellite Remote Sensing and Aussie GRASS

Thomas (2001) investigated the potential of remote sensing techniques to support efforts of the LCMP. Specifically, Thomas used SPOT XS satellite-derived land cover information to determine peak erosion susceptibility in mixed cropping areas prone to water and wind erosion. The use of airborne remote sensing in the NPLR's was also investigated. A recommendation of Thomas' report was the further investigation of NOAA, MODIS and ASTER imagery to aid in the monitoring of South Australia's agricultural region.

Moderate resolution satellite remote sensing provides images that cover broad areas, have a high temporal repetition, and are cost effective. An example of this system is the National Oceanic and Atmospheric Administrations (NOAA) Pathfinder. NOAA imagery has a spatial resolution of 1km, currently uses 6 detectors, and collects images over the entire planet daily. It was developed for remotely determining cloud cover and surface temperature, but its application has extended to other areas including the analysis of green vegetation cover. The normalized difference vegetation index (NDVI) is related to the proportion of photosynthetically absorbed radiation and is calculated from the visible and near infrared channels (1 and 2). NDVI values are dependent on absorption of red light by plant chlorophyll and the reflection of infrared radiation by water-filled leaf cells. As NDVI is correlated with photosynthesis that occurs in the green parts of plant material, the index can be used to estimate green vegetation.

NOAA NDVI images are used to calibrate the Australian Grassland and Rangeland Assessment model (Aussie GRASS). Aussie GRASS is part of the National Climate Variability Program, administered by the Land and Water Resources Research and Development Corporation (LWRRDC). It is a model of pasture and shrubland growth of Australia's rangelands, developed through the integration of Sate and CSIRO models; and climatic and drought analyses. NOAA NDVI data alone cannot be used in providing drought and rangeland monitoring as it has poor relationships with dry pasture biomass, and suffers from data consistency problems (Carter *et al*, 2000). From 1981 to 1994, NOAA NDVI was calculated in ten-day composite periods for the Aussie GRASS model. When the relationship was analysed it was found that the modelled NDVI of Aussie GRASS and the averaged satellite NDVI were highly correlated (R^2=0.84) (Carter *et al*, 2000). This means that the Aussie GRASS model accounts for much of the annual climate driven variability in NDVI (Carter *et al*, 2000). By using the GRASP pasture growth model design, Aussie GRASS is able to simulate growth through the input of a number of variables including:

- Daily rainfall and other climatic information (temperature, radiation, vapour pressure, evaporation);
- Soil type and associated parameters;
- Pasture community and associated parameters;
- Tree basal area; and
- Stocking rate information.

The model was calibrated using both NOAA Pathfinder NDVI imagery and field surveys. In 1999, the South Australian Pastoral Board conducted surveys using the spider mapping technique, to assess grass and forb biomass in the North East, Flinders, Far North-East and North West pastoral districts (Richards *et al*, 2001). 17,900 observations were made which were then used to calibrate the Aussie GRASS model and NDVI data in South Australia.

The Aussie GRASS model extends over the entire continent, dividing it into 0.05-degree pixels (~5km grids). It is run operationally on a monthly basis, using rainfall totals and climatic data supplied by the Bureau of Meteorology. Several products result from the model, and are available within 5-7 days at the end of each month. The Aussie GRASS Extension program (Paull *et al*, 2001) aimed to develop and promote these products to encourage the transfer of technology generated by the Aussie GRASS program. The result was a range of 28 products (mainly maps) that cover each State of Australia and the Northern Territory. The products are grouped as follows:

- Recent Rainfall total and percentile maps for 1, 3, 6, 12 and 24-month periods;
- Current pasture production/condition – total pasture growth for 1, 3, 6, 12 and 24-month periods
- Total standing dry matter and total stranding dry matter percentile map;
- Seasonal climate outlook indicators; and
- Forecast rainfall/pasture condition.

Available on the Aussie GRASS website (http://www.nrm.qld.gov.au/rsc/agrass/) are some of these products, including:

- Recent Rainfall (mm);
- Total Standing Dry Matter (kg DM/ha);
- Total Pasture Growth (kg DM/ha);
- Curing Index; and
- Fire Risk.

For each month of the year beginning 1999 for TSDM, Curing Index and Fire Risk; and 2000 for TPG and total rainfall, these products can be downloaded from the website in compressed ERDAS Imagine format. These images are also available as measurements relative to historical records. To enter the website, a password is required. This is intended so that those accessing information can have an understanding of how the products are produced and how to effectively use them (Hall *et al*, 2001, Paull *et al*, 2001).

1.3 Aims and Objectives

The potential for integrating ground data of the LCMP's windscreen survey, satellite remote sensing and Aussie GRASS products was identified by South Australia's Soil Conservation Council. Satellite derived NDVI has been used successfully in the past to monitor green vegetation. The Aussie GRASS model is also currently used to monitor growth of forage in the rangelands of Australia.

The aims of this research project are:

- To investigate the relationship between the ground-based data of LCMP's windscreen survey, Aussie GRASS products and satellite remote sensing;
- To investigate what variables of the survey show a relationship, and how strong the relationship is; and
- Evaluate possibilities of calibrating the Aussie GRASS model using the ground-based survey.

Through fulfilment of these aims it is hoped to achieve the following objectives:

- Value-add to the LCMP's windscreen survey by visualizing the entire state;
- Value-add to the windscreen survey by providing quantitative information about the representativeness of the sample locations; and
- Value-add to the Aussie GRASS project by evaluating methodologies of using the windscreen survey for ground truthing.

2 Cropping Land, Aussie GRASS and Satellite Remote Sensing

2.1 Monitoring of South Australia's Cropping Regions

The LCMP windscreen survey of cropping lands developed from the need to assess erosion risk in lands cleared for mixed farming of crops and livestock. Within the cropping district, four surveys are conducted each year to coincide with the annual cropping cycle (October, March and May, and June). The entire cropping district was delineated based upon the DWLBC Soil and Land Information soil database and key rainfall isohyets. This resulted in around 45 cropping zones that share similar climate, vegetation and soil attributes (Figure 2.1). Zones where then grouped into regions: Eyre Peninsula, Northern Agricultural District, Murray Lands and the South East. Transect roads were chosen to pass through all zones, covering areas of variability within each.

Within a zone, a minimum of 50-100 sites is surveyed. Each site of a zone is intended to be representative of the typical broad hectare farmland cleared for agriculture. For these reason anomalies such as headlands, watering troughs, firebreaks and tracks are avoided. A sample site is an imaginary 200m square, beginning 10m inside the road and 50m beyond each internal subdivision fence. To date, there are a total of about 6000 sites surveyed. Sites are not fixed and geo-coordinates not taken on surveying due to time, infrastructure and monetary constraints of the LCMP.

There are several factors monitored by the cropping windscreen survey. They include:

- Dune Presence;
- Cropping Phase;
- Topographic Rating (Wind and Water);
- Erosion (Wind and Water Severity);
- Detachment Rating;
- Cover Rating; and
- Burn.

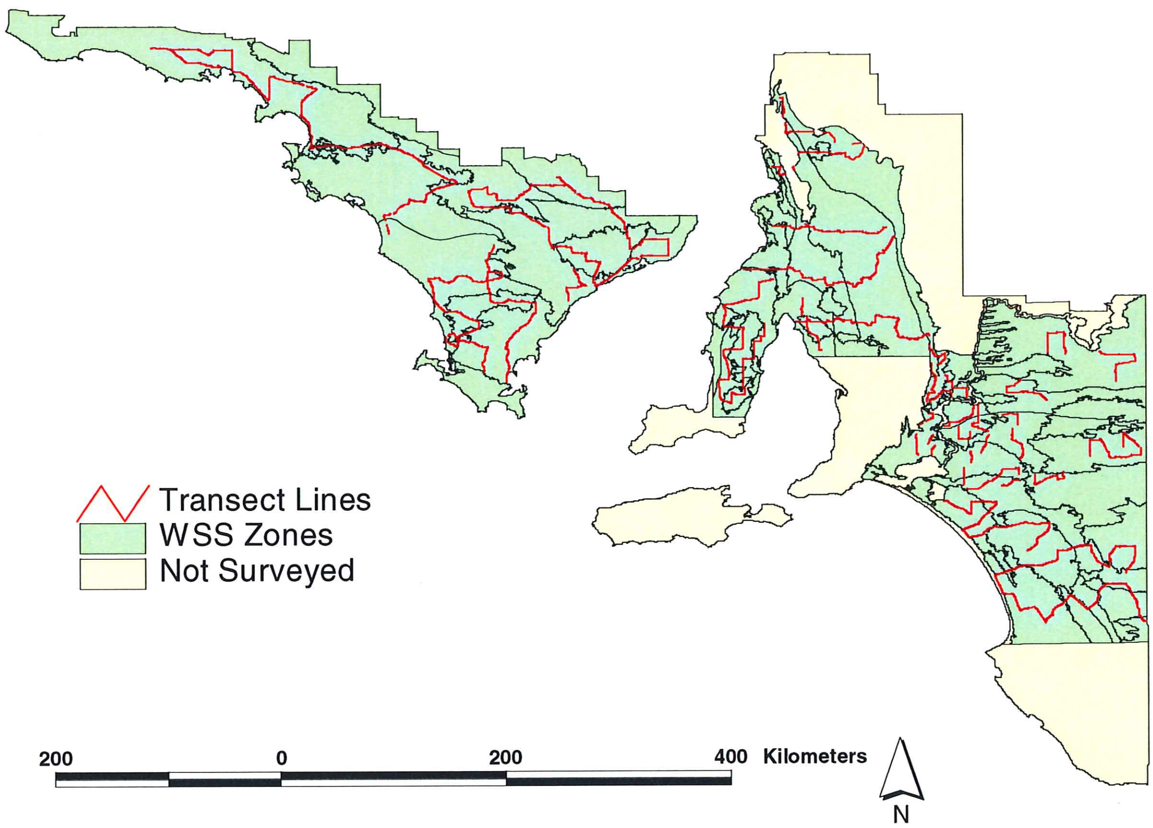

Figure 2.1: Zones and Transect lines of the LCMP Windscreen survey.

Further details of these variables and the parameters that dictate them can be found in McCord, A. *et al*, 2000 and McCord, A. 2000a. The recording sheet used to transcribe each factors value is given in Appendix 1. After completion of a survey the recording sheet is sent to the Project Manager, where it is imported to the Microsoft Access® database.

2.1.1 LCMP's Cropping Survey, Aussie GRASS and Satellite Remote Sensing

The LCMP's cropping survey factor cover rating is defined as the combined dry and green material protecting the soil surface. A site is given a rating between 1 (representing residues knee high or greater) and 8 (representing nil cover). To ensure consistency across time and the state, surveyors are required to use a monitoring manual (Mc Cord, 2000a) and photo standards when in the field. Of all factors monitored in the survey, cover rating is the only related to vegetation density and abundance. For this reason the relationship between cover rating, Aussie GRASS and satellite remote sensing was investigated in this research project.

The GIS package used in the analysis was Arc View GIS 3.2a, a program developed and distributed by the Environmental Systems Research Institute (ESRI). For a spatial analysis between Aussie GRASS products, satellite images and survey data, several modifications were needed of the Microsoft Access® cropping database. As sites monitored in the survey are not geo-referenced, the mean value of cover across zones was used in the analysis.

For all surveys carried out from March 2000 (total=15), the mean cover rating of each zone was calculated in Microsoft Excel®. The results of all years were compiled in spreadsheets displaying the year of survey, month of survey, date, zone, region, and mean cover rating (Appendix 2).

2.1.1.1 Aussie GRASS and Cover Rating

Available on the Aussie GRASS website (http://www.nrm.qld.gov.au/rsc/agrass/) are several products developed by the program. These include maps of:

- Rainfall (mm);
- Total Standing Dry Matter (kg DM/ha);
- Total Pasture Growth (kg DM/ha);
- Curing Index; and
- Fire Risk.

The three Aussie GRASS products of Rainfall, TPG and TSDM were considered most likely of all Aussie GRASS products to have a relationship with cropping survey factor cover. For each month of the year beginning 2000, TPG, TSDM and total rainfall measurements were downloaded from the Aussie GRASS website in compressed ERDAS Imagine format. The images were converted into a raster format that can be imported and analysed in the program Arc View 3.2a. The Aussie GRASS products are projected in geographic coordinates (lat/lon) and with map datum of WGS 84. Grids of rainfall have 10km pixel size, and TPG and TSDM 5km. For ease of analysis between products, rainfall grids were converted to a cell size of 5km.

As the windscreen survey is conducted along transect roads and sites are not geo-referenced or revisited, it was those roads that were used spatially represent mean values of cover rating. Using the zones delineated by the windscreen survey as their value, transect lines were converted to a grid of 5km (Figure 2.2). For each survey (total=15) the mean value of Aussie GRASS products were calculated for each zone at both the month the survey was performed, and also the month prior. Within the GIS package the mean value of rainfall, TPG and TSDM was calculated for the grid of combined transect lines for each zone. The calculated output was exported to Microsoft Excel®, and appended to the mean covering rating data collated from the Microsoft Access® cropping database. The result was a spreadsheet with the zone number, region, date, month of survey, mean cover rating, and mean TPG, TSDM and Rainfall values (Appendix 2). This spreadsheet was imported into the statistical program GenStat for Windows 6th Edition for analysis. The variables analysed for their relationship included:

- Zone (1, 2, 3...);
- Region (EP, ML, NAD, SE);
- Month of Survey (March, May, June, October);
- Month Prior to Survey (February, April, May, September);
- Mean Cover Rating;
- TPG (Aussie GRASS);
- TSDM (Aussie GRASS); and
- Rainfall (Aussie GRASS).

The main statistical designs used in analysis were simple linear regressions and multiple linear regressions. Regression is a parametric procedure, which assumes multivariate normality and a linear relationship between variables. The fundamental statistic used in regression is the F-test of difference of means. The F-test grows to be less reliable as sample size decreases, group sample sizes become more divergent, or the number of factors increases. In this research project continuous variables were analysed, and grouped by factors. When two variables are related, regression analysis is most commonly used to predict the value of one variable from the value of another. 1st order simple and multiple linear regressions were applied to windscreen survey variables and Aussie GRASS products TPG, TSDM and Rainfall. Regression analysis was also used on assessing the relationship between WSS and remotely sensed imagery.

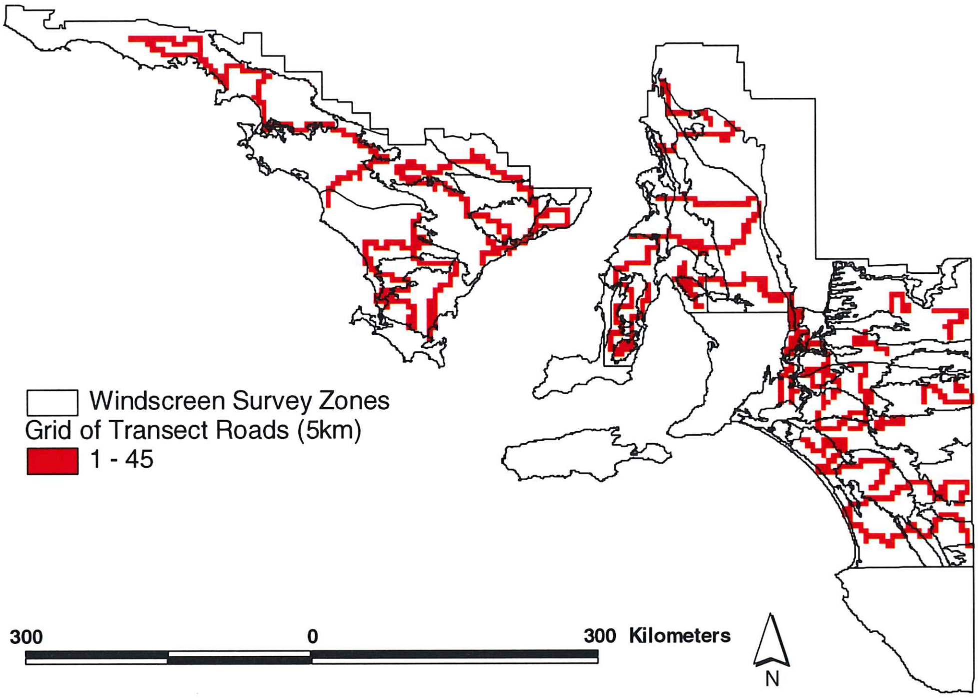

Figure 2.2: Transect Roads of Windscreen Survey After Conversion to a Grid of 5km Pixel size.

2.1.1.2 NDVI and Cover Rating

Remotely sensed NOAA AVHRR images were kindly supplied by the Queensland Centre for Climate Applications, Climate Impacts and Natural Resource Systems, Department of Natural Resources and Mines. They came in ERDAS Imagine 16 bit file format, and were converted to raster datasets. What resulted from the conversion were the following 8 separate layer grids for each image file:

- Band 1 Reflectance AVHRR;
- Band 2 Reflectance AVHRR;
- Satellite Azimuth;
- Satellite Zenith;

- Solar Azimuth;
- Solar Zenith;
- NDVI; and
- Cloud Mask.

The NOAA data was projected in geographic coordinates (lat/lon), with map datum of WGS 84 and pixel size 1km. Mapping accuracy is generally ±2km, although worse at the edge of the scan line when pixel size blows out. When georegistration errors occur due to timing errors in satellite navigation, mapping accuracy can be up to ± 10 km. For these reasons, the same grid of transect lines (5km pixel) as used to extract Aussie GRASS product information, was used in NOAA analysis.

As with the Aussie GRASS products, the NDVI was analysed for its relationship with cover rating. To achieve this, the NDVI grid was imported into the GIS package and the mean NDVI for the combined transect lines in each zone calculated. From the images obtained by the Queensland Department of Natural resources and Mines, those with the least cloud cover as determined by the mask contained within each file were used in the analysis. Unlike Aussie GRASS data, the NDVI images were collected on or near the exact date of surveying.

For each survey (total=15) the mean NDVI along combined transects for each zone were calculated. The calculated output was exported to Microsoft Excel®, and appended to the mean covering rating data collated from the Microsoft Access® cropping database. The result was a spreadsheet of zone number, region, date, month of survey, mean cover rating, and NDVI value (Appendix 3). The spreadsheet was imported into the statistical package, and the following variables analysed for their relationship:

- Zone (1, 2, 3…);
- Region (EP, ML, NAD, SE);
- Month of Survey (March, May, June, October); and
- NDVI.

2.2 Results

Several different relationships between LCMP's cover rating, Aussie GRASS products and NOAA AVHRR NDVI were analysed, and the results given in Table 2.1. Where the statistical design included groups, the month of survey was used as a factor. Zones and regions were also used as grouping factors in the analysis, with no significant result. From Table 2.1, there is a strong relationship (%VAR 71.1, 70.0) between the three Aussie GRASS products (TSDM, TPG, Rainfall) and the variable cover rating when grouped by month of survey. It is therefore possible that the equations resulting from the analysis could be used to model cover over the cropping district of South Australia at each month of survey, using the three products of Aussie GRASS (Table 2.2 and 2.3).

To test the model developed, the same spatial and statistical method as previous was used to analyse cover, rainfall, TPG and TSDM data of years 2000, 2002 and 2003. The resulting equations were then used to test the model against the remaining 2001 survey dataset. The map calculator function of Arc View 3.2a allowed the model to be input through the March, May, June and October 2001 Aussie GRASS products grids of the month the survey was conducted. As before, the mean cover rating of combined transect lines within each zone were calculated within the GIS package. The results were exported into a Microsoft Excel® spreadsheet, where they were appended to the mean value of cover recorded by the LCMP's 2001 windscreen survey. A regression analysis was conducted on the combined datasets, resulting in a R^2 of 0.8344 (Figure 2.3). With the original relationship exhibiting a high %VAR, and when tested a very high R^2, the model was concluded to be a satisfactory measurement of cover.

With the model tested and concluded to be satisfactory the cover rating over LCMP's 45 zones as predicted by the model, was calculated for each survey (total=15). The map calculator function of Arc View 3.2a allowed the regression equation to be input through each Aussie GRASS product, for all months and years of the survey. Results of 2000 are displayed in Figure 2.4, 2.5, 2.6 and 2.7 and the remaining in Appendix 4. To compare the results between modelled and actual cover rating, the mean cover rating of combined transect lines within each zone was calculated using the GIS package. The results were exported into a Microsoft Excel® spreadsheet, where they were combined with the mean value of cover recorded by the LCMP's windscreen survey. A regression analysis was conducted on the combined datasets, resulting in a R^2 of 0.7191 (Figure 2.8).

Dependent Variable	Independent Variable	Statistical Design	% Variance Accounted For (%VAR)
Cover Rating	TSDM	SLR	26.5
Cover Rating	TPG	SLR	15.8
Cover Rating	Rainfall	SLR	1.1
Cover Rating	TSDM+Rainfall	MLR	32.4
Cover Rating	TSDM+Rainfall +Seasonality (month of survey)	MLR with Groups	66.0
Cover Rating	TSDM+Rainfall+TPG +Seasonality (month of survey)	MLR with Groups	**71.1**
Cover Rating	TSDM+Rainfall+TPG +Seasonality (month prior to survey)	MLR with Groups	70.0
Cover Rating	NDVI	SLR	60.2

SLR – Simple Linear Regression
MLR – Multiple Linear Regression

Table 2.1: Summary of Relationships Investigated between Cover Rating (LCMP), Aussie GRASS Products and NOAA AVHRR NDVI.

Season	Equation %VAR 71.1
March	4.518+(-0.000977*rainfall)+(0.002029*TPG)+(-0.000549*TSDM)
May	5.056+(-0.001675*rainfall)+(0.001476*TPG)+(0.000187*TSDM)
June	5.317+(-0.000782*rainfall)+(0.002080*TPG)+(-0.000012*TSDM)
October	3.704+(-0.000557*rainfall)+(0.000586*TPG)+(-0.000557*TSDM)

Table 2.2: Equations to Predict Cover Rating from Aussie GRASS Products TSDM, TPG and Rainfall (month of survey) Within Seasons.

Season	Equation %VAR 70.0
March	3.994+(0.001776*rainfall)+(-0.00147*TPG)+(-0.000308*TSDM)
May	4.668+(-0.000565*rainfall)+(0.001559*TPG)+(-0.000123*TSDM)
June	5.287+(-0.000435*rainfall)+(0.001010*TPG)+(0.000068*TSDM)
October	4.096+(-0.001975*rainfall)+(0.001149*TPG)+(-0.001092*TSDM)

Table 2.3: Equations to Predict Cover Rating from Aussie GRASS Products TSDM, TPG and Rainfall (month prior to survey) Within Seasons.

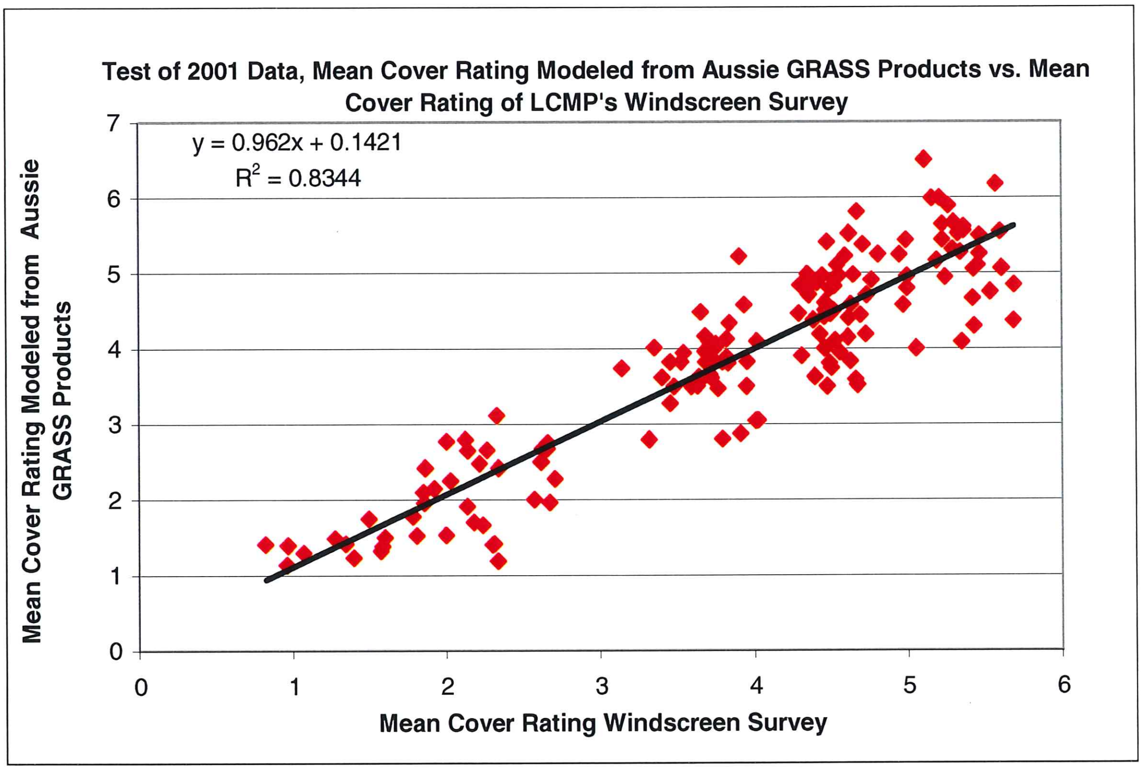

Figure 2.3: Test of 2001 Data, Mean Cover Rating Modelled from Aussie GRASS Products vs. Mean Cover Rating of LCMP's Windscreen Survey

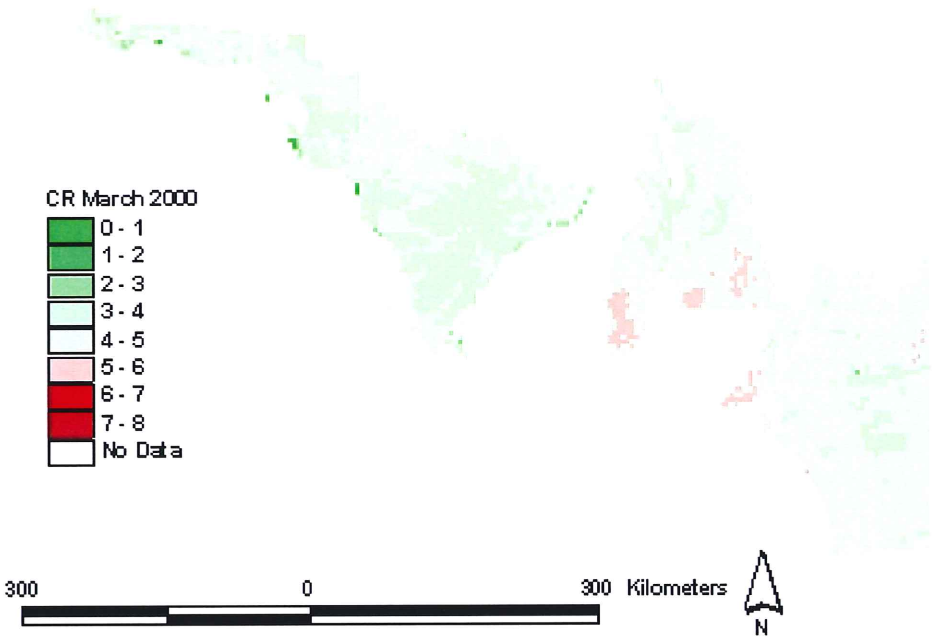

Figure 2.4: Cover Rating Modelled from Aussie GRASS Products, March 2000

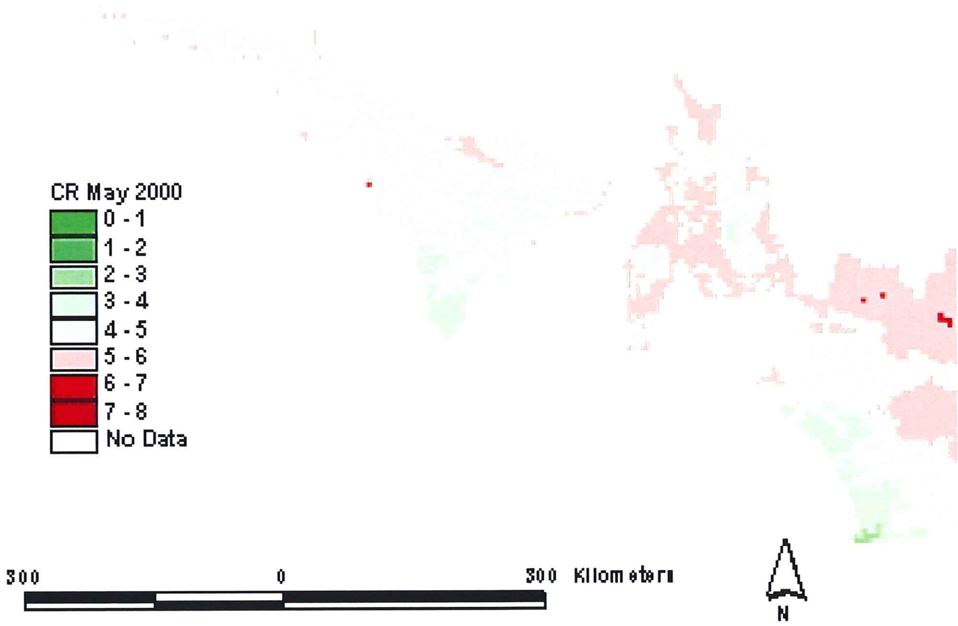

Figure2.5: Cover Rating Modelled from Aussie GRASS Products, May 2000

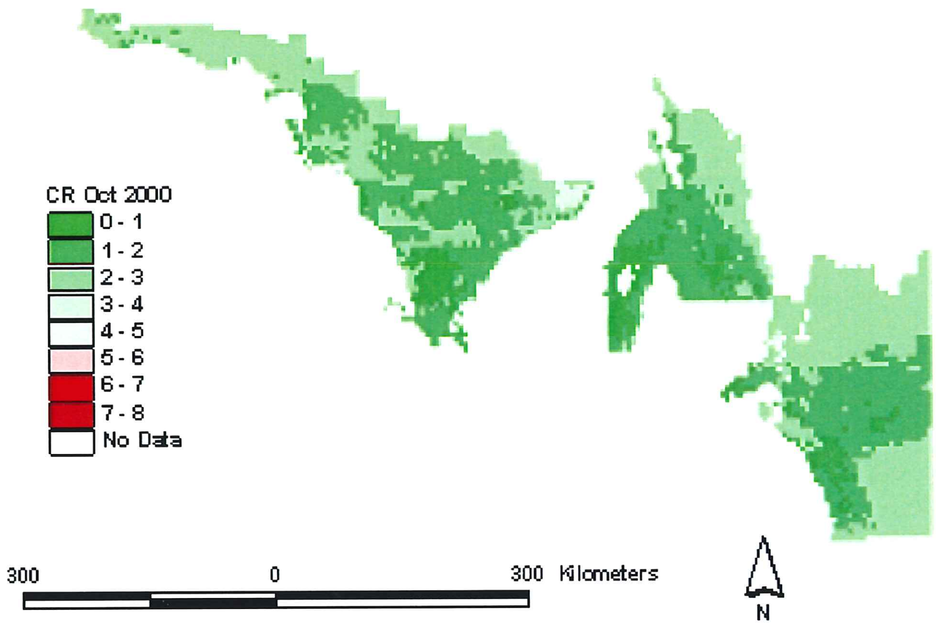

Figure 2.6: Cover Rating Modelled from Aussie GRASS Products, June 2000

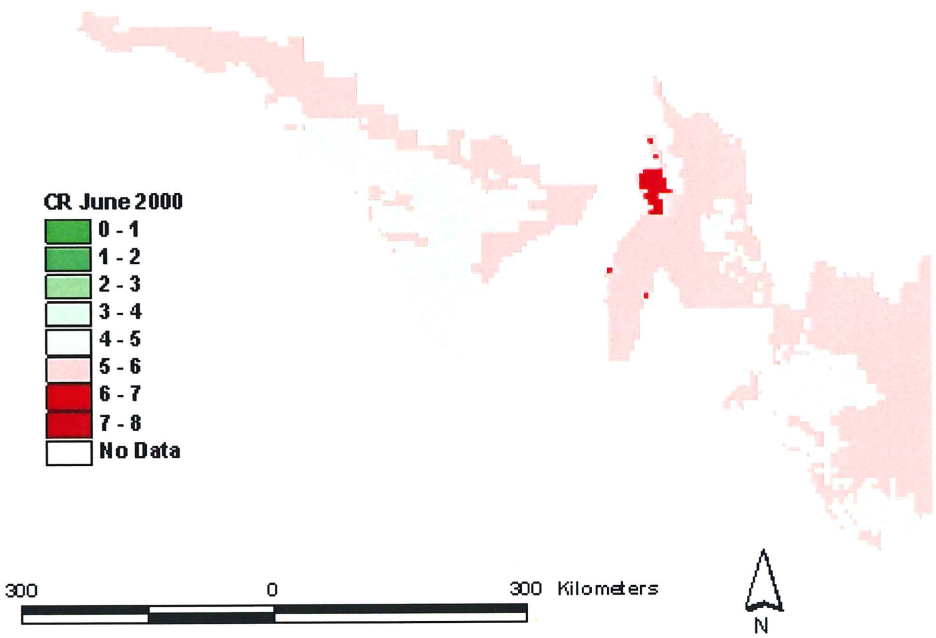

Figure2.7: Cover Rating Modelled from Aussie GRASS Products, October 2000

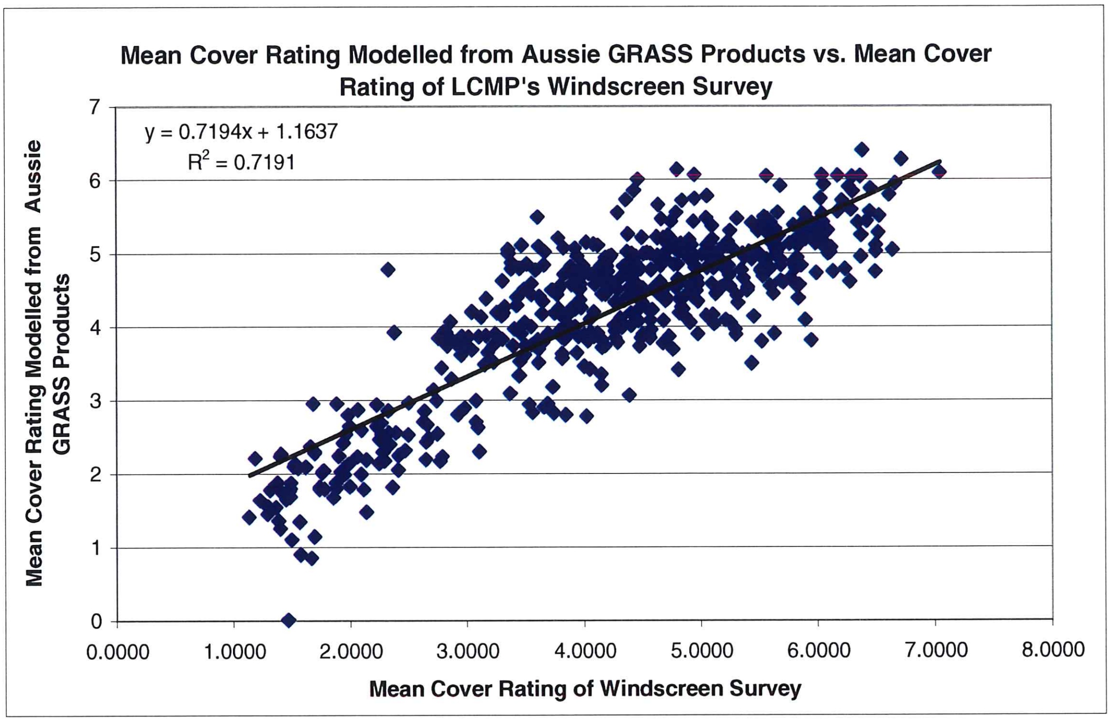

Figure 2.8: Mean Cover Rating Modelled from Aussie GRASS Products vs. Mean Cover Rating of LCMP's Windscreen Survey

A further application resulting from the modelling of cover is the ability to analyse the representativeness of transect roads delineated by the LCMP. By using the map calculator function of Arc View3.2a, the Aussie GRASS modelled value of cover was subtracted from the survey observed rating of cover. Where a negative result occurs, the cover rating observed on ground is less than that of cover modelled. When the value is positive, the cover rating on ground is greater than that modelled by Aussie GRASS. Images of the composite residual analysis of years 2000, 2001, 2002 and 2003 are given in Figures 2.9, 2.10, 2.11 and 2.12. The greater a cell is from 0, the less the relationship between modelled and observed cover. In some regions it is observed that transects lines consistently diverge >2 units from 0 (Figure 2.13). This could mean that these transects do not truly represent the zone that they monitor, or the model inadequately models covering these areas.

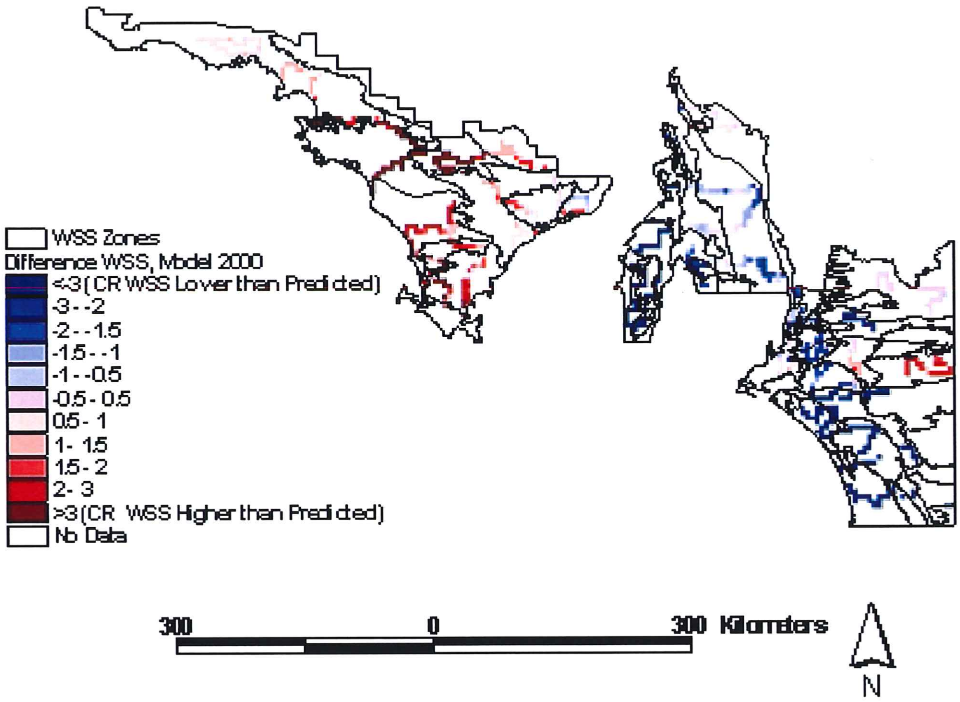

Figure 2.9: Residual Analysis of Cover, 2000

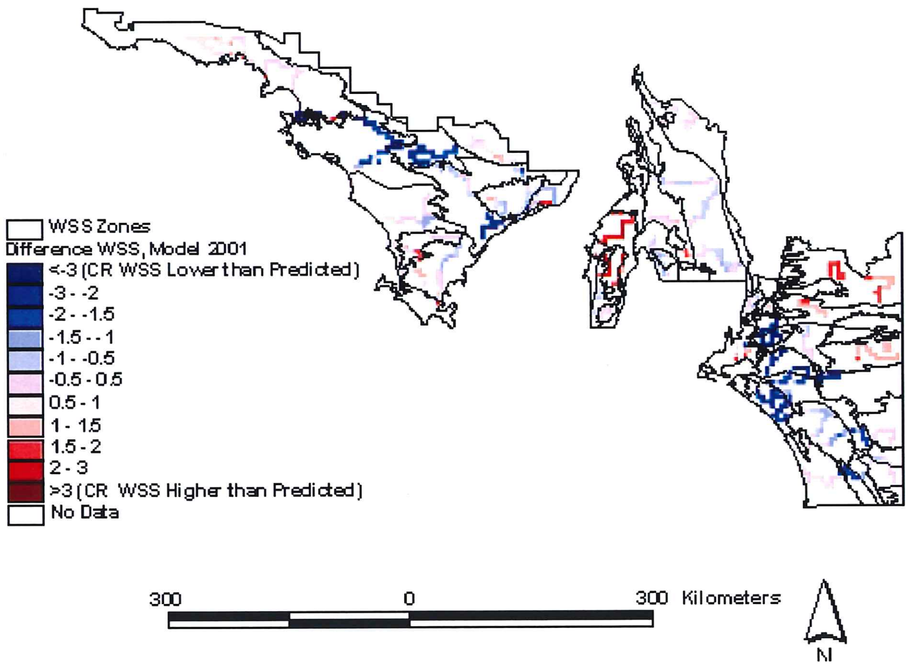

Figure 2.10: Residual Analysis of Cover, 2001

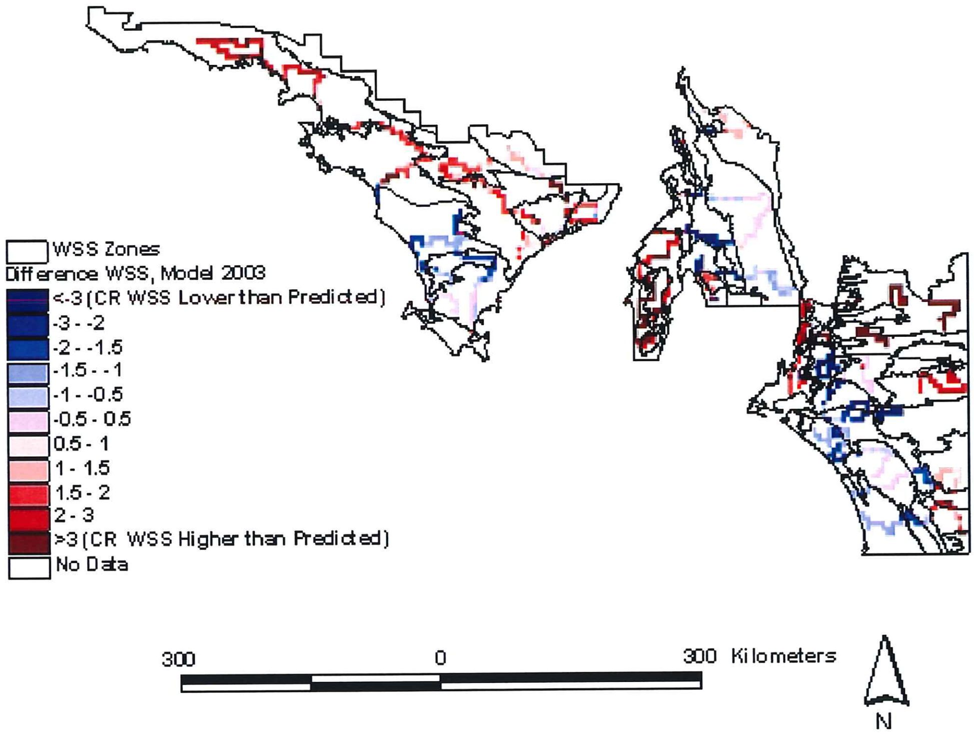

Figure 2.11: Residual Analysis of Cover, 2002

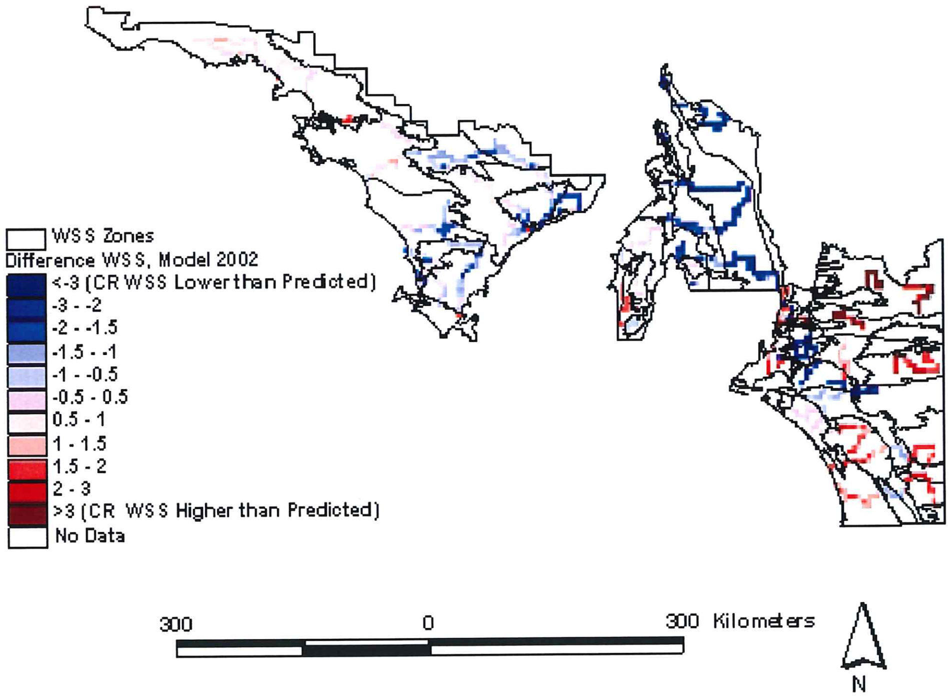

Figure 2.12: Residual Analysis of Cover, 2003

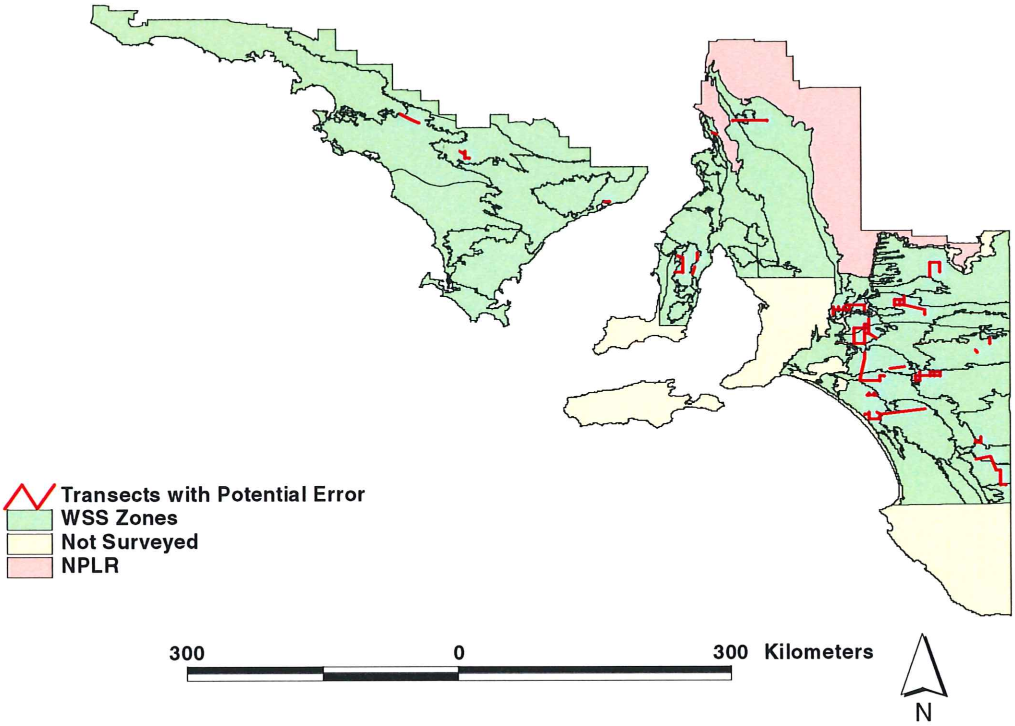

Figure 2.13: Transects of Potential Error Identified from Residual Analysis of Cover (2000, 2001, 2002 and 2003)

2.3 Discussion

2.3.1 Cover Rating, Aussie Grass and NDVI

In this research project, the relationship between the LCMP's cropping land windscreen survey, Aussie GRASS and satellite remotely sensed images were investigated. A strong relationship was found between the survey factor cover rating and Aussie GRASS products TSDM, TPG and Rainfall. The NDVI of NOAA AVHRR was also found to have a relationship with cover. A conceptual summary of these relationships is given in Figure 2.14.

From the statistical analysis, between 70% and 80% of cover can be explained by Aussie GRASS products. The Aussie GRASS model is dependent upon climatic factors to predict the growth of grass, therefore it can also be inferred that 70 – 80% of cover is also explained by climate. The aim of the LCMP's cropping land windscreen survey is to assess erosion risk resulting from management practices. For this reason, cover is not only determined in the survey by plant vigour, but by the management practices that influence it. The "error variance" of 20-30% could be a result of variables not included in the Aussie GRASS model, which are observed in the survey. These include:

- Management practices;
- Soil variability or
- Natural variability.

The "error variance" could also be explained by faults in the Aussie GRASS model and/or the climate data used to generate its outputs.

The Aussie GRASS model was calibrated using NOAA Pathfinder NDVI imagery. A strong relationship was found between the modelled NDVI and the NOAA AVHRR averaged NDVI, with Aussie GRASS able to account for much of the annual climate driven variability in NDVI. Further parameters than green vegetation cover are used in the pasture growth model however, which is consistent with the relationship between NDVI and LCMP's cover. NDVI has a relationship with cover of %VAR 62, less than that between the Aussie GRASS products.

A strong relationship was also found between the three Aussie GRASS products and cover, when grouped by the month prior to LCMP's windscreen survey (%VAR 70.0). This indicates potential for cover to be modelled using Aussie GRASS data from the month before time of survey i.e. cover can be modelled before the survey is conducted. At present, this has little application because Aussie GRASS products are posted on their website a few days after the month of analysis which coincides when the survey is run (first week of the month). However, the development team behind Aussie GRASS are currently working on models that predict grass growth 1, 2 and 3 months before the actual event. On completion of these models, it may be possible for cover rating too to be predicted 1, 2, and 3 months prior to the ground survey. This has some application to the survey methodology, including:

- Zones at risk of poor cover can be predicted before the survey, and the number of sites monitored increased;
- Zones with little risk of poor cover can be predicted, and sites monitored decreased.

This ultimately will improve the monitoring capability of the windscreen survey, and reduce the unnecessary expense of conducting ground surveys where there is little need.

A residual analysis between modelled and LCMP's observed cover was also performed. This can allow for the representativeness of transect roads delineated by the LCMP to be analysed. In some regions it is observed that transects lines consistently diverge >2 units from 0. This could mean either that these transects do not truly represent the zone that they monitor, or the model fails in those areas.

The major result of this research project is the establishment of a strong relationship between Aussie GRASS and the cropping windscreen survey. Cover as monitored by the survey, is explained to a certain degree by the Aussie GRASS products TPG, TSDM and Rainfall. Using the equations of Table 2.2, cover was modelled across the agricultural zone of South Australia. The LCMP uses sites along transect roads to estimate factors of land condition, which are then extrapolated to the zone, region and state levels. With the model developed in this current research project, continuous estimation and visualization of cover is now possible.

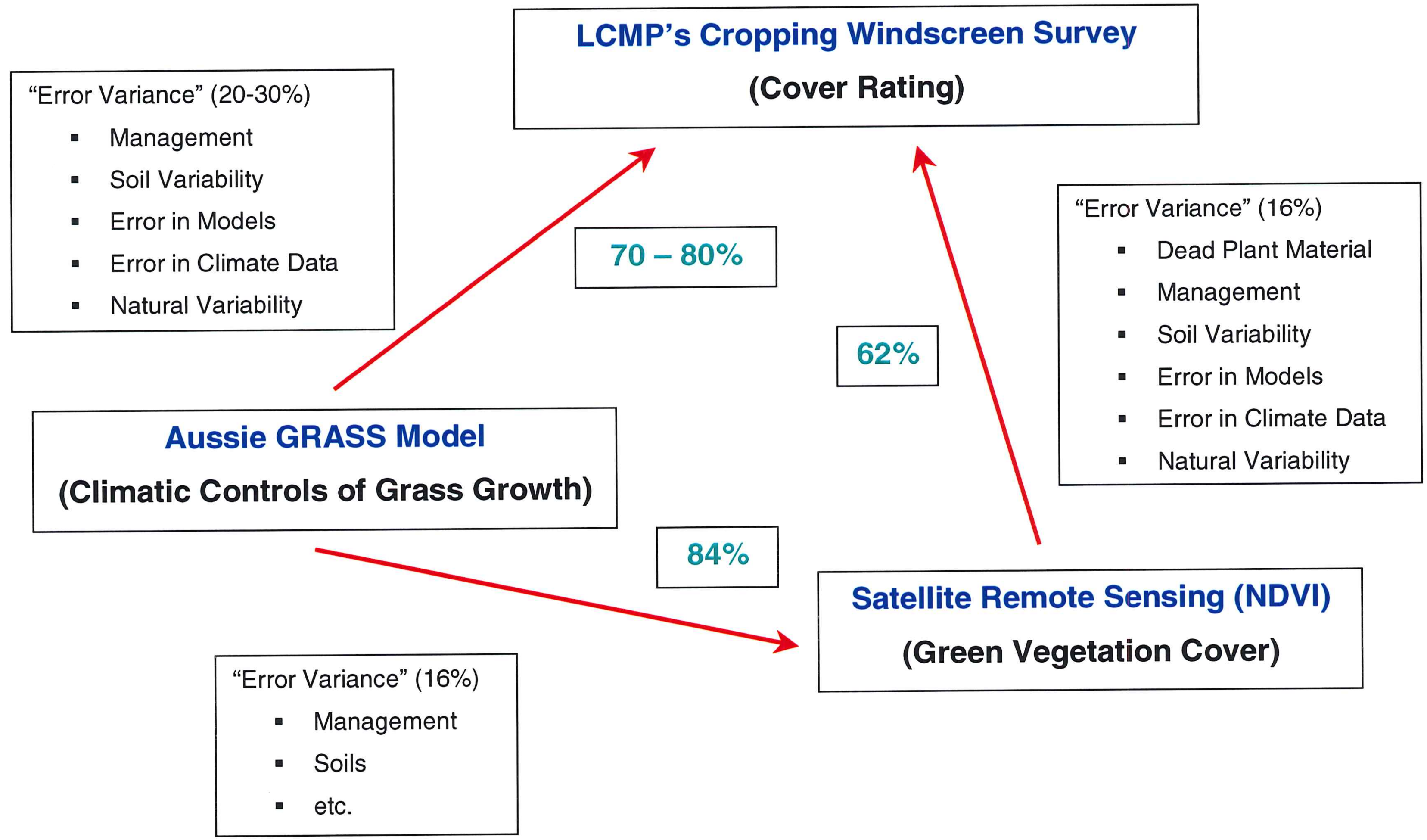

Figure 2.14: Conceptual Summary of Relationships Between LCMP's Cropping Windscreen Survey, Aussie GRASS Model and Satellite Remote Sensing

2.3.2 Future Research

The aim of the LCMP's cropping land windscreen survey is to assess erosion risk resulting from management practices. For this reason, cover rating is not only determined in the survey by plant vigour, but by the management practices that influence it. Erosion risk as defined by the LCMP, is considered largely to be a function of cover and detachment. Detachment is also measured in the survey and is defined as the surface disturbance by cultivation or grazing. Thus, detachment is solely dependent on land management. To monitor erosion risk at each site, the erosion hazard index (EHI) was developed by the program. It is used to calculate the proportion of land at risk of erosion at the zone, region and state level, and to assess the trend in erosion risk over time. Given the time constraints of this current research project, a working model of erosion hazard index was not possible. However, the following chapter discusses ideas and infrastructure requirements that would assist in furthering this research possibility.

2.3.2.1 Erosion Hazard Index

Current analysis of the LCMP's cropping land windscreen survey is achieved through a menu system programmed within the Microsoft Access® database. It's most useful function is to discriminate the proportion of land at risk of erosion at the zone, region and state level, and to assess the trend in erosion risk over time. Erosion risk is considered largely to be a function of cover and detachment, and are therefore both measured in the cropping windscreen survey. For each site an index of erosion hazard was derived:

Erosion Hazard Index (EHI) = Cover Rating × Detachment Rating

Detachment rating is a measure of the apparent surface disturbance as a result of cultivation and/or grazing practices. Its value ranges from 1 to 3, with 1 representing no significant disturbance and 3, complete soil disturbance. Further details on detachment rating can be found within McCord, 2000a.

In this current research project, detachment rating for each month of the survey (March, May, June, October) was estimated from the 'South Australian Land Use 2002' database (Department of Water, Land and Biodiversity Conservation, Soil and Land Information). The land use map depicts different land management practices eg. livestock grazing, mallee woodland, irrigated sown grasses, crop/grazing rotation etc. It was assumed that soil management and therefore detachment is dependent on land use and month of survey. This method of ranking detachment did not account for changes in land management practices across regions and over time. The land use map was converted to a grid of pixel size 5km (Figure 2.15), the same as that of the Aussie GRASS derived model of cover. For each season of the survey, the rating of detachment was estimated based upon historic cultivation and grazing practices (Figure 2.16).

With cover rating modelled from Aussie GRASS products, and detachment rating determined for each season by land use, a continuous estimate of EHI can be achieved. By using the map calculator function of Arc View 3.2a, the modelled cover rating of each month for each year was multiplied by its concurrent detachment rating. The resultant erosion hazard indices of 2000 are displayed in Figures 2.17, 2.18, 2.19 and 2.20, and the remaining years in Appendix 5.

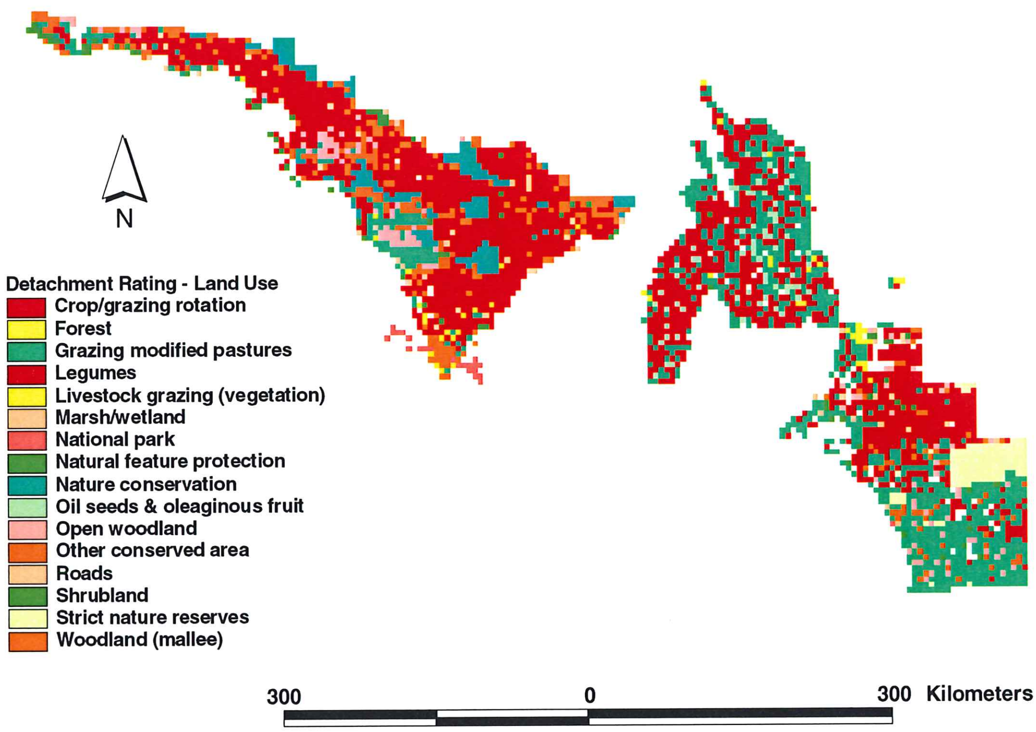

Figure 2.15: Land Use Map Converted to Grid of 5km Pixel Size

Figure 2.16: Detachment Rating as Determined by Land Use, for Seasons March, May, June and October.

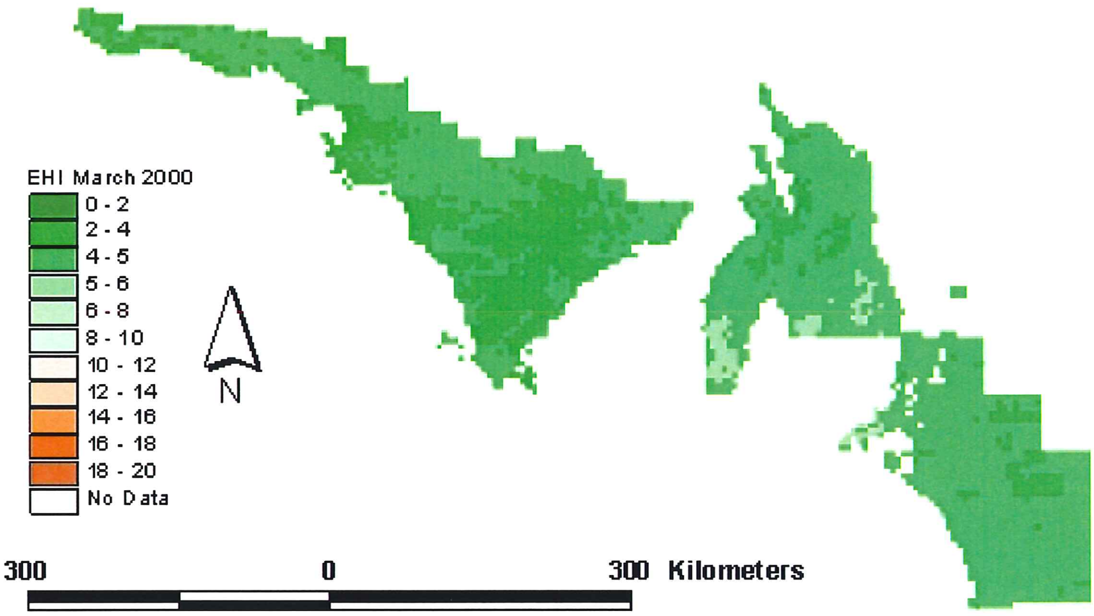

Figure 2.17: Erosion Hazard Index (EHI), March 2000.

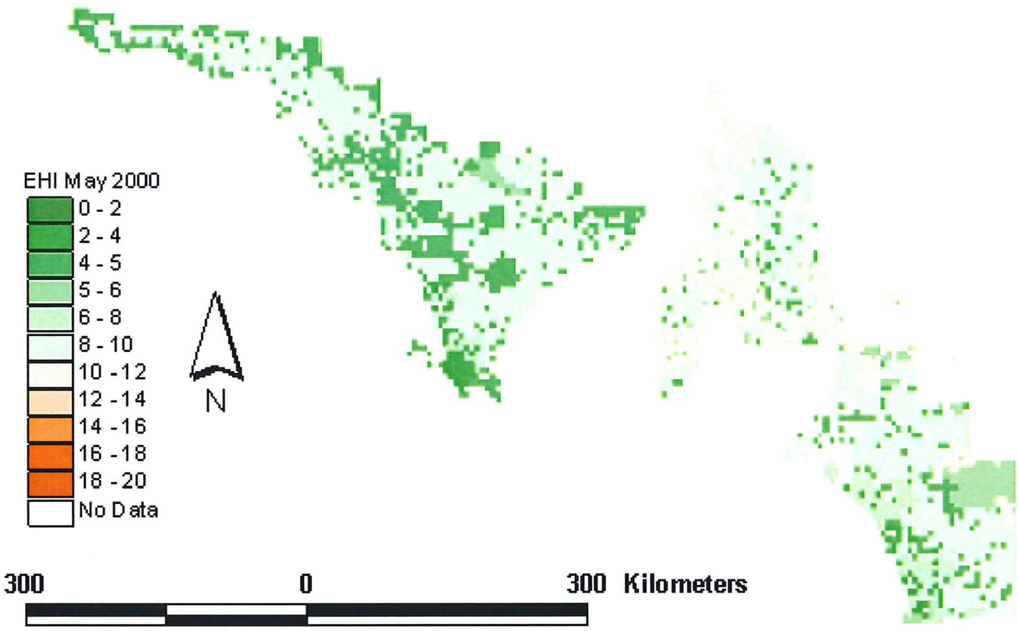

Figure2.18: Erosion Hazard Index (EHI), May 2000.

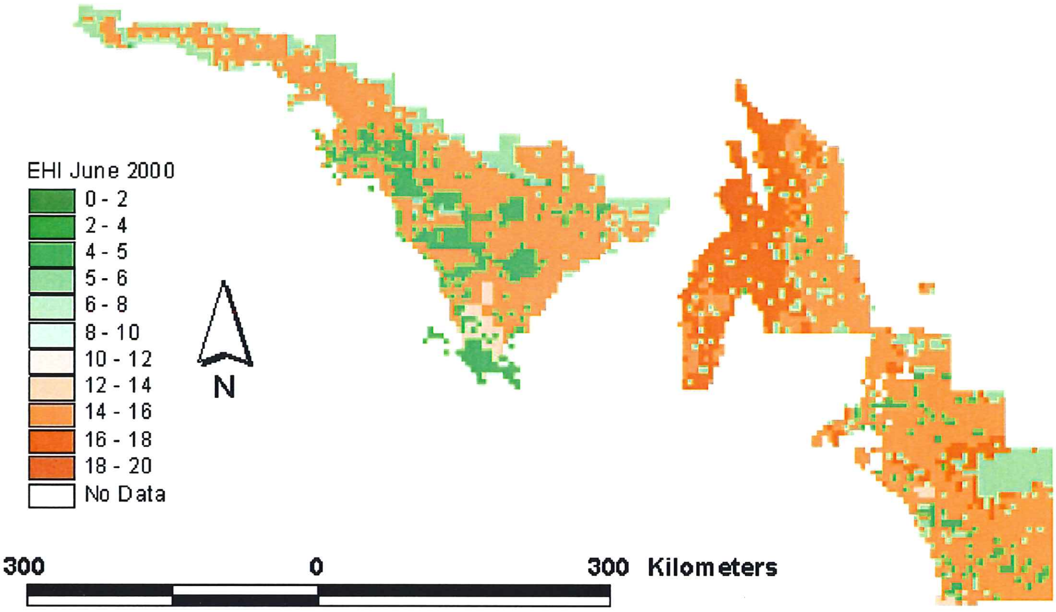

Figure 2.19: Erosion Hazard Index (EHI), June 2000

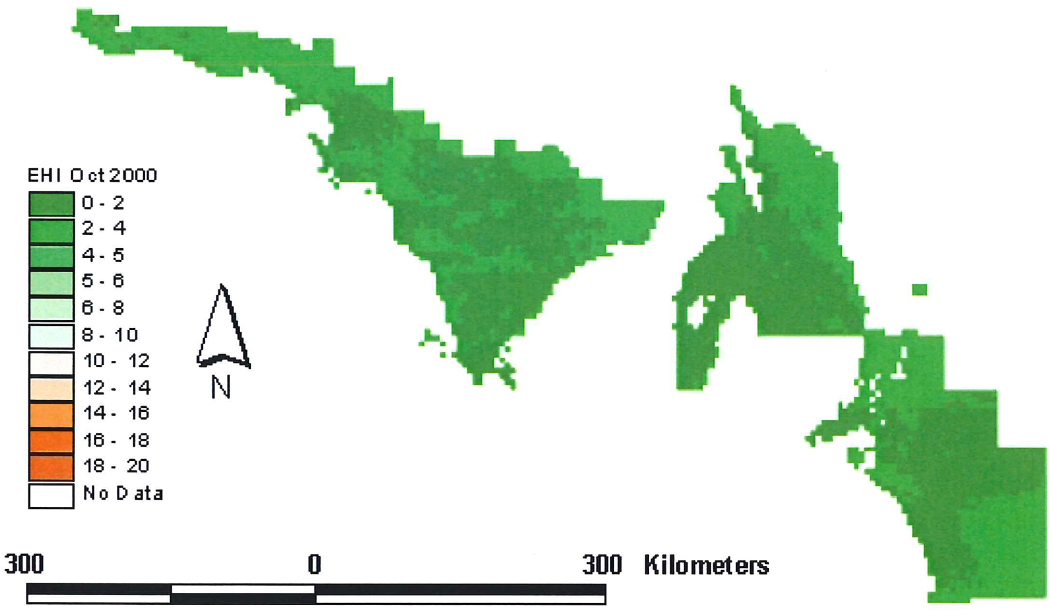

Figure 2.30: Erosion Hazard Index (EHI), October 2000

To compare the results between modelled EHI and that monitored by the cropping windscreen survey, the mean EHI of combined transect lines within each zone were calculated using the GIS package. The results were exported into a Microsoft Excel® spreadsheet, where they were appended to the mean value of EHI recorded by the LCMP's windscreen survey. A regression analysis was conducted on the combined datasets, resulting in a R^2 of 0.5765 (Figure 2.21). As there is a significant relationship between cover and Aussie GRASS (%VAR 71.1), this relatively low R^2 value is most likely a result of inadequate estimation of detachment. Detachment rating was assumed to be a function of land use and month of survey, and did not account for changes in land management practices across regions and over time. Further research in this area would better determine detachment rating. Land use maps would still be vital in delineating detachment in the agricultural zone, but more needs to be known of the different land management practices across regions.

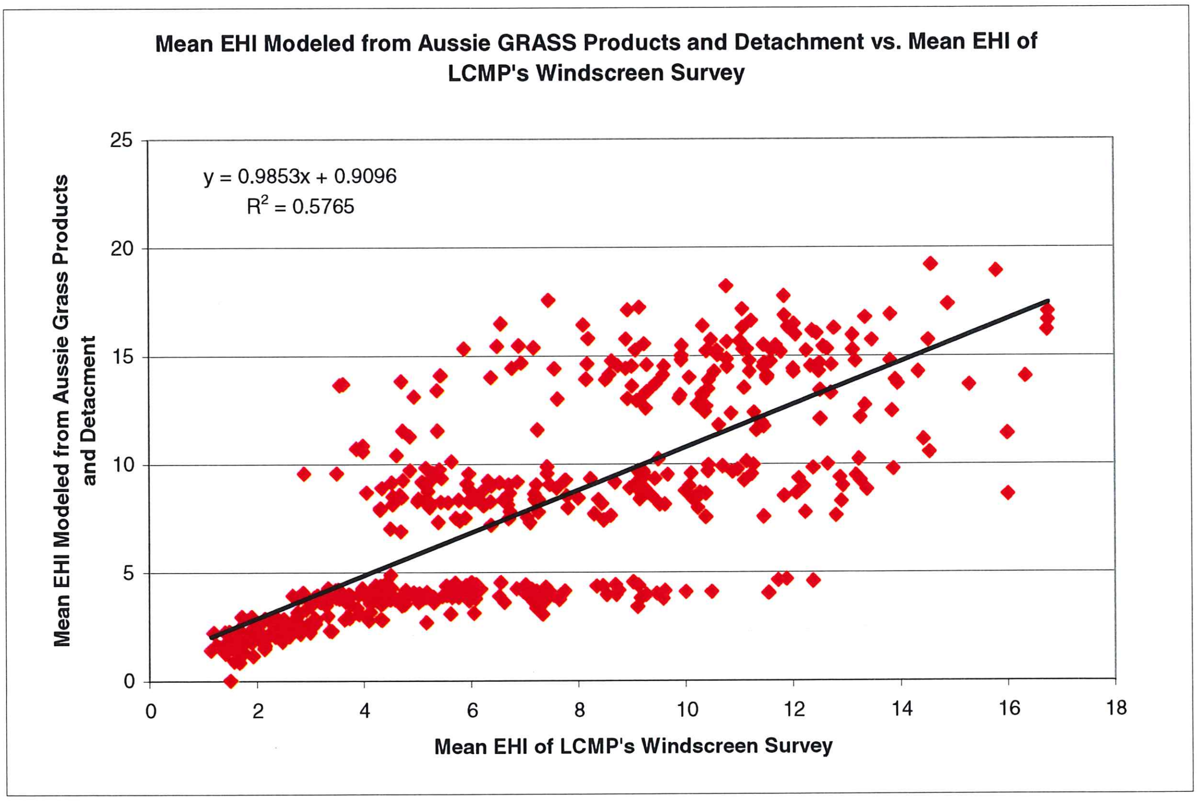

Figure 2.21: Mean EHI Modelled from Aussie GRASS Products and Detachment vs. Mean EHI of LCMP's Windscreen Survey

2.3.2.2 Water and Wind Erosion Risk

Using EHI, the LCMP developed a process to determine the proportion of sites at risk of wind and water erosion. Two measurements of topography are recorded during the survey: topographic rating wind and topographic rating water. Wind erosion is considered to be a function of land type (soil and slope) and water erosion a function of slope. For wind erosion an increasing topographic rating means that land is increasingly sandy and exposed. For water erosion, an increasing topographic rating coincides with increasing slope. Each survey site is given a topographic rating of water and wind. Using the menu system programmed within the database, EHI and the topographic ratings calculate the number of sites at risk of moderate to high water and wind erosion. This is then extrapolated to the state, regional and zone risk levels. Further details of methodology can be found in Mc Cord, *et al* 2000, and Mc Cord, 2000a.

In this research project, water and wind erosion potential factors of the DWLBC Soil and Land Information soil database were used in a similar way to that of the windscreen surveys' topographic ratings. The potential of water and wind erosion factors of DWLBC are a function of slope and the erodibility of soil landscape map units. They are rated from 1 – 7 (water erosion potential) and 1-6 (wind erosion potential). This categorization system is similar to that of the topographic variables of water and water erosion risk in the LCMP cropping survey. In the program, ratings are from 1 through 5 and are determined through fewer variables than in the soil database. Following a similar progressive categorization system of the LCMP, tables were made of EHI water and EHI wind against the erosion potential factors of the soil database (Figure 2.22).

For analysis between grids of EHI and the soil database factors of potential water and wind erosion, the latter were converted into 5km grids (Figures 2.23 and 2.24). Cells of nil, slight and moderate water and wind erosion in the EHI grids were isolated using the GIS package (Figures 2.25-2.32 for 2000 and the remaining in Appendix 6). The result was continuous maps of the risk of water and wind erosion across the State.

DWLBC Water Erosion Potential	EHI Water			
	<7	7-9	10-12	>12
1	Nil	Nil	Nil	Nil
2	Nil	Slight	Slight	Moderate
3	Nil	Slight	Moderate	Moderate
4	Nil	Moderate	Moderate	High
5	Nil	Moderate	High	High
6	Slight	High	High	High
7	Moderate	High	High	High

DWLBC Wind Erosion Potential	EHI Wind			
	<6	6-10	11-16	>16
1	Nil	Nil	Nil	Nil
2	Nil	Slight	Slight	Moderate
3	Nil	Slight	Moderate	High
4	Nil	Moderate	High	High
5	Slight	Moderate	High	High
6	Moderate	High	High	High

Figure 2.22: Erosion risk categorized by DWLBC Soil Landscape Maps Wind and Water Erosion Potential

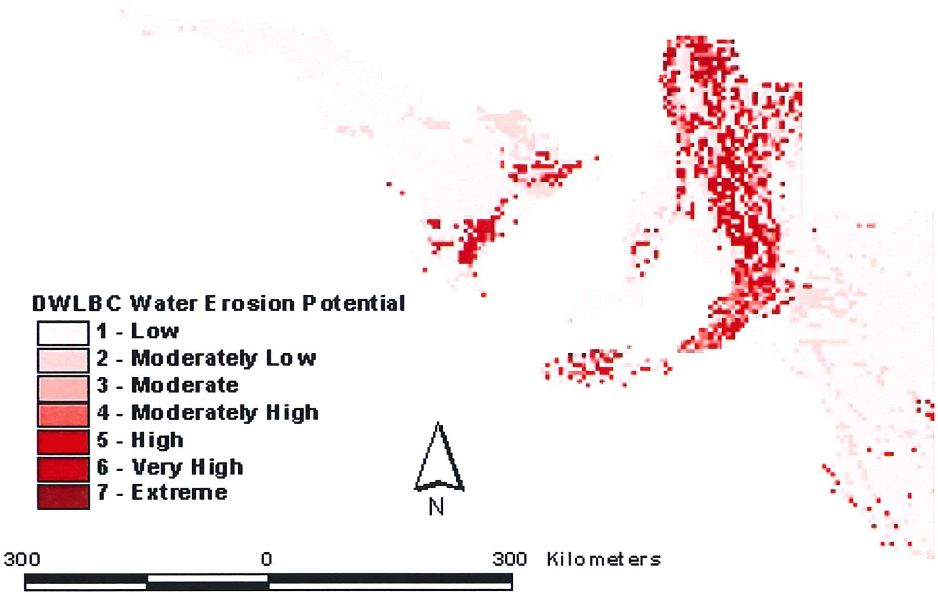

Figure 2.23: DWLBC Soil Landscape Map of Water Erosion Potential Converted to Grid of 5km Pixel Size.

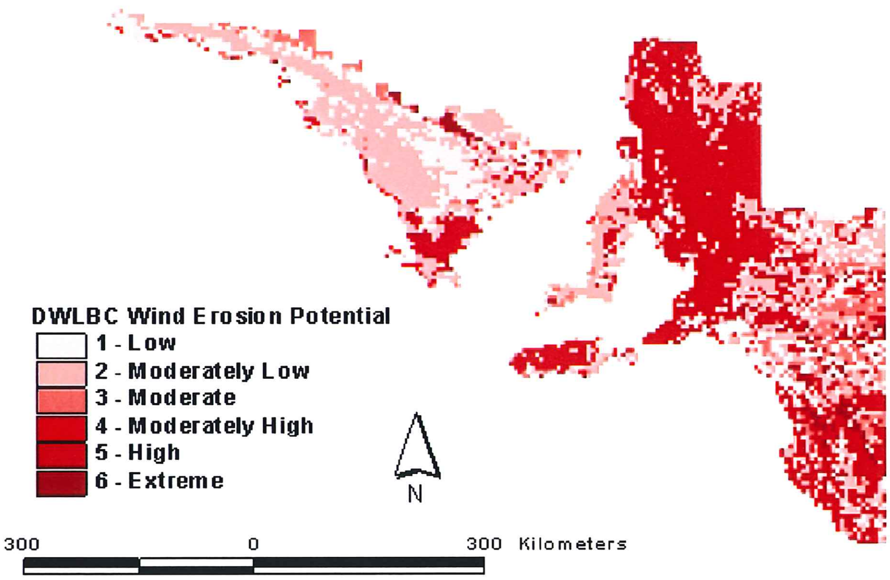

Figure 2.24: DWLBC Soil Landscape Map of Wind Erosion Potential Converted to Grid of 5km Pixel Size.

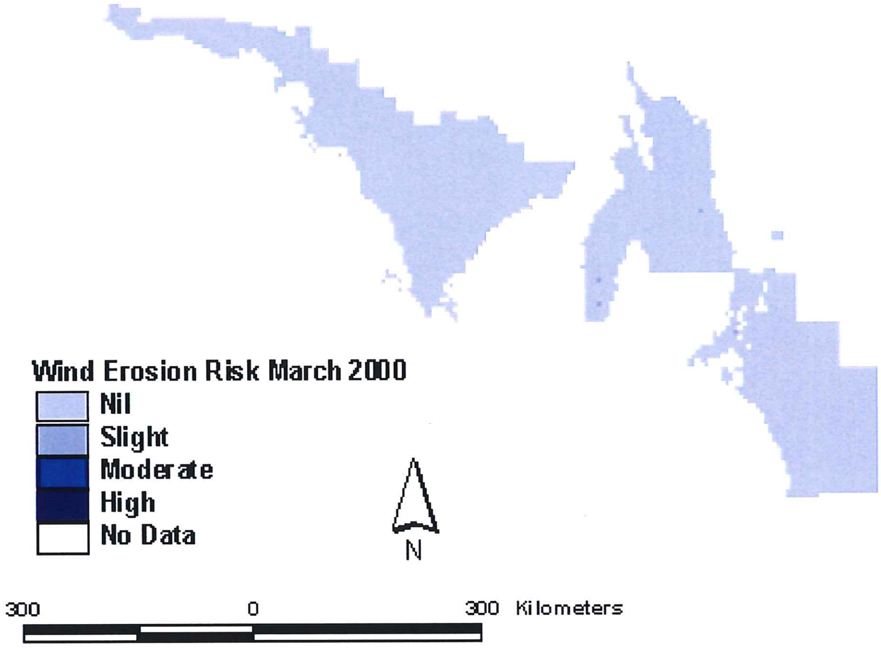

Figure 2.25: Wind Erosion Risk, March 2000

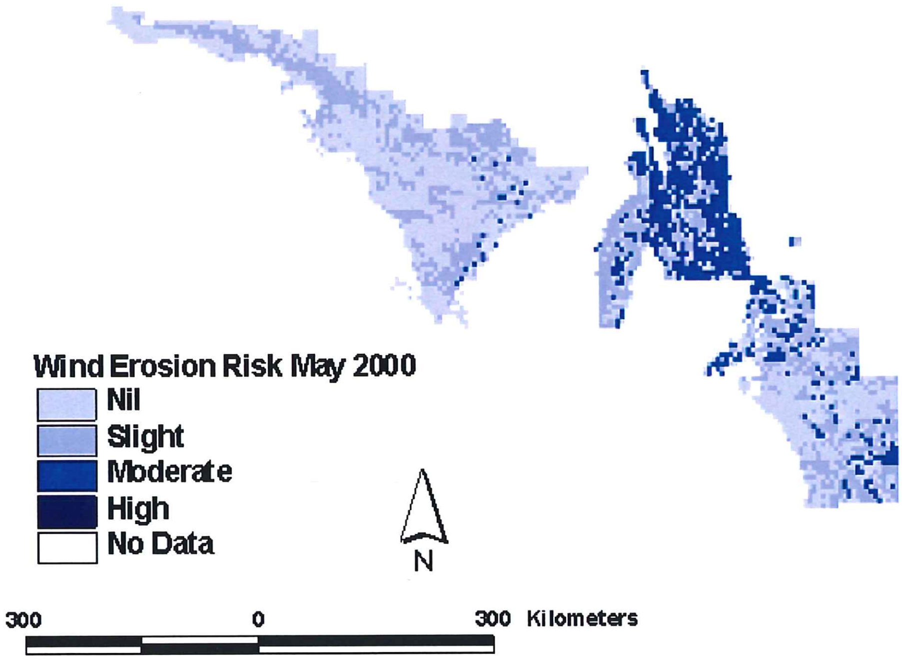

Figure 2.26: Wind Erosion Risk, May 2000

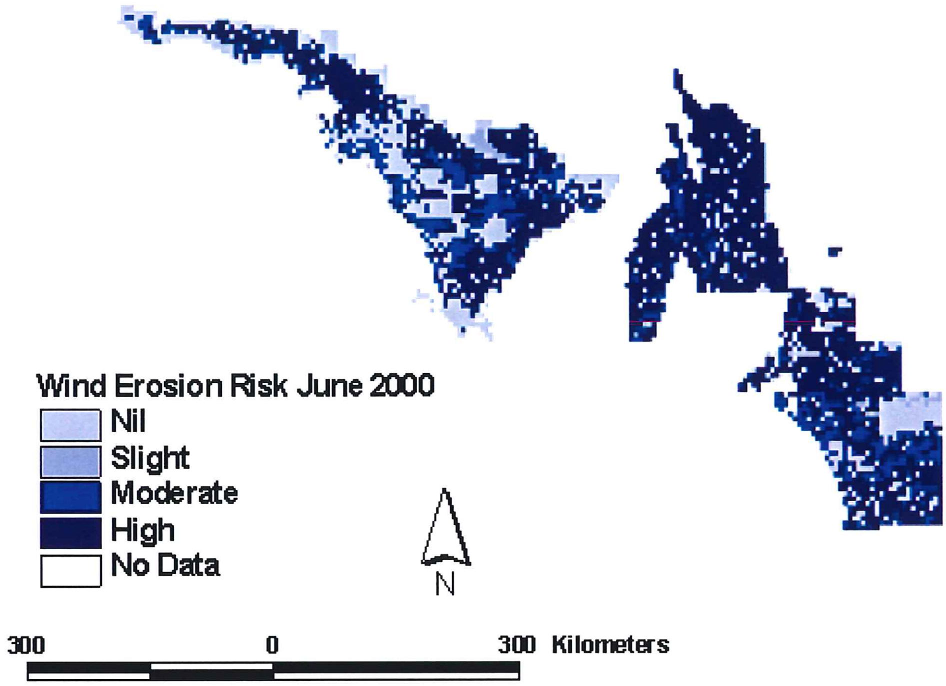

Figure 2.27: Wind Erosion Risk, June 2000

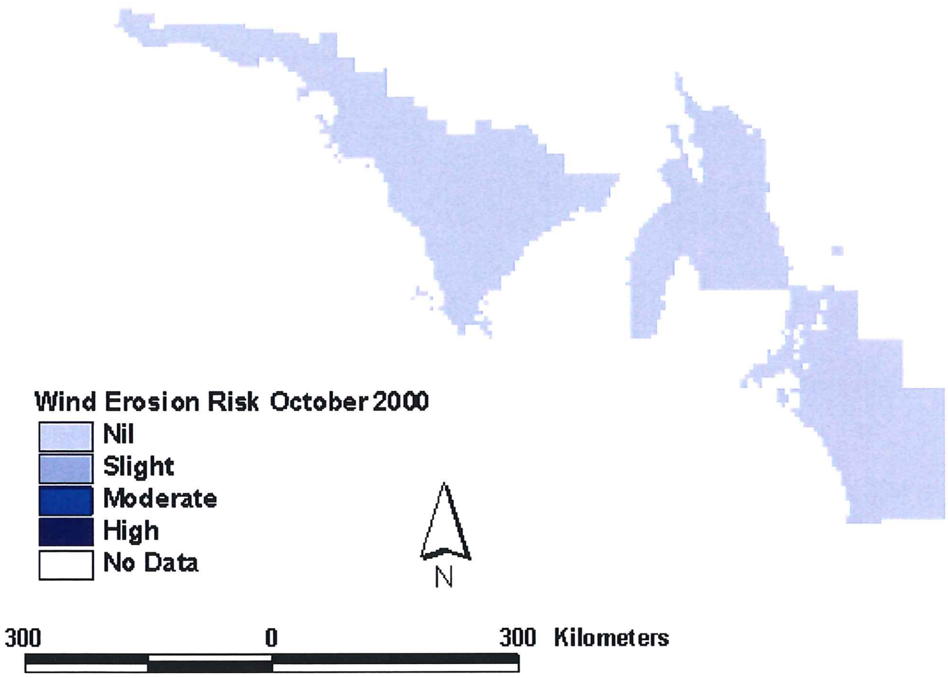

Figure 2.28: Wind Erosion Risk, October 2000

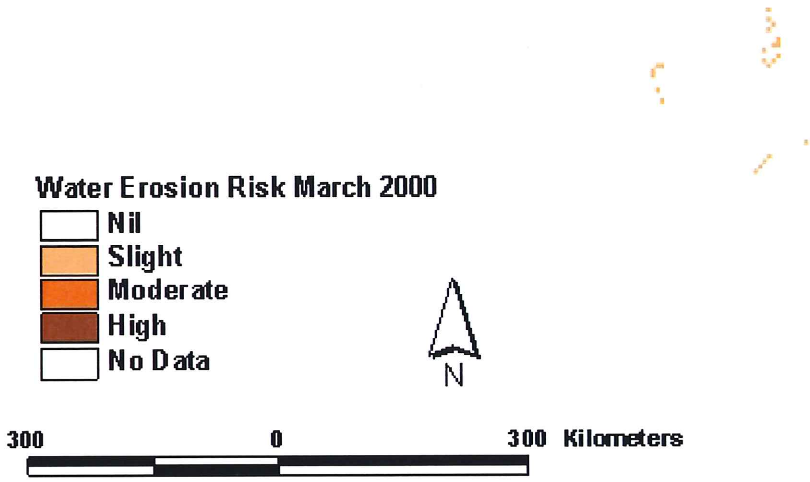

Figure 2.29: Water Erosion Risk, March 2000

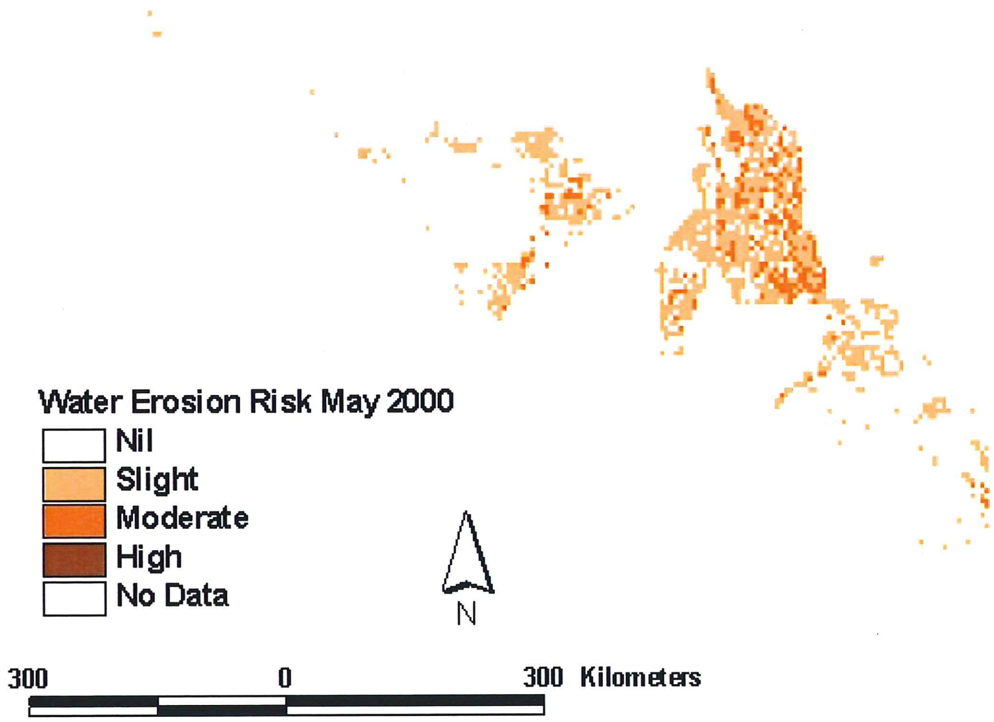

Figure 2.30: Water Erosion Risk, May 2000

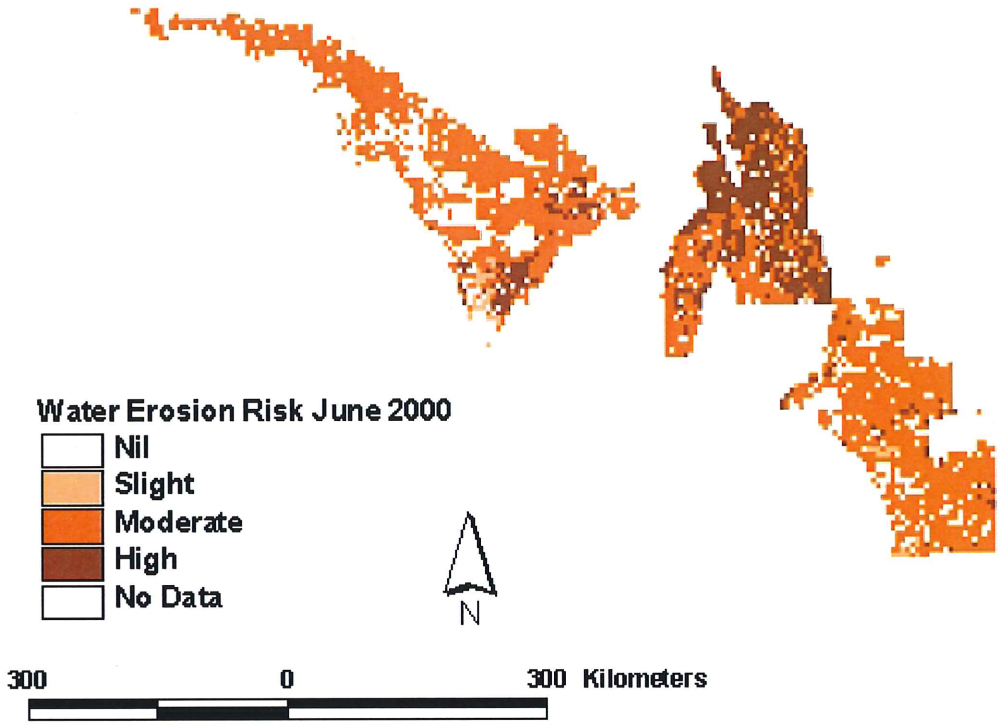

Figure 2.31: Water Erosion Risk, June 2000

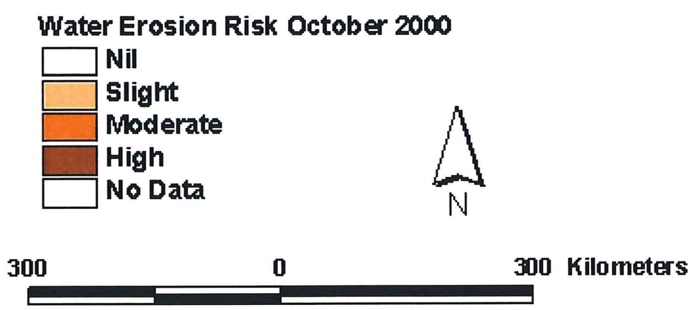

Figure 2.32: Water Erosion Risk, October 2000

2.3.2.3 Development of EHI, Water and Wind Erosion Risk

The aim of the LCMP's cropping and windscreen survey is to assess erosion risk resulting from management practices. Erosion risk as defined by the LCMP, is considered largely to be a function of cover and detachment. With cover modelled by Aussie GRASS products, this current research project explored the possibilities of rating detachment by land use and season in order to create a continuous prediction of the EHI. At present more work needs to be done on a more accurate method of estimating detachment that takes into account different land management practices across the agricultural region.

Wind and water erosion potential maps from the DWLBC Soil and Land Information soil database were investigated for their use in assessing erosion risk from the EHI. These maps are a more accurate depiction of landscape features than those observed in the windscreen survey. Future research should focus on replacing the survey variables of wind and water erosion potential with those of the database.

3 Non Pastoral Lease Rangelands, Aussie GRASS and Satellite Remote Sensing

3.1 Monitoring of South Australia's Non Pastoral Lease Rangelands

The survey methodology used by the LCMP in the NPLR's is similar to that of the cropping region. Several changes were made in order to suit the different management practices and environment of the rangelands. In 1999 geological, topographic and key rainfall isohyets were used to define 9 zones in the region; Middleback, Tent Hill, Parachilna, Flinders, Willochra, West Yunta, East Yunta, Murkaby, Morgan and Mt. Remarkable. These 9 zones aided in the delineation of transect routes along roads of the survey. As in cropping lands, a sample site is an imaginary 200m square area 10m inside the roadside fence. However, sites are at a fixed location 5km along the designated transects (Figure 3.1). These sites are revisited once a year in April, when soil erosion is considered to be at its peak.

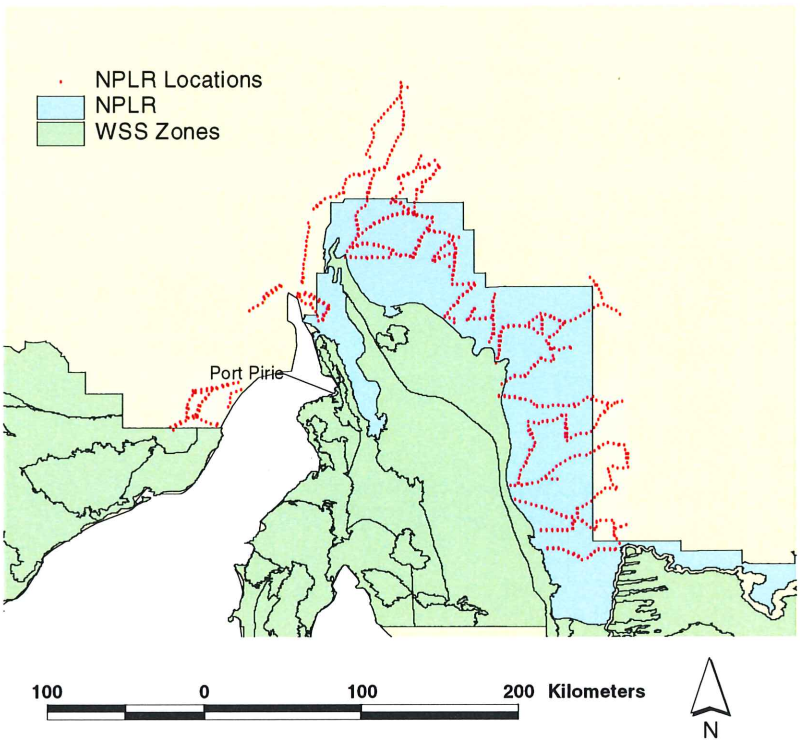

Figure 3.1: Extent of Non Pastoral Lease Rangelands and Monitored Survey Sites

Sites, like transect lines, were chosen to represent the typical broad hectare land practices of the rangelands (McCord *et al*, 2000). For this reason, anomalies such as headlands, watering troughs, tanks, tracks, sheds and houses were avoided. Within each of the 9 zones, 50-100 sites were selected and a GPS reading taken. A GPS reading generally represents two sites, one at either side of the transect road. Digital photographs were taken at each site to aid in their revisit and monitoring process. The NPLR survey began in 1999 with 749 sites, and to date 853 are revisited annually. There are several indicators monitored by the NPLR survey, including:

- Tree Shrub Species Present (up to 3 species, in order of dominance);
  - Severity of Grazing
  - Density
- Native Grass Species Present (up to 3 species, in order of dominance);
  - Severity of Grazing
  - Density
- Chenopod Species Present (up to 3 species, in order of dominance);
  - Severity of Grazing
  - Density
- Lichen/Biocrust Groundcover;
- Cover Rating;
- Forage Rating.

Further details on these variables and the parameters that dictate them can be found in McCord, A. *et al*, 2000 and McCord, A. 2000b. The above data is entered on recording sheets (Appendix 7), along with the date, site ID, and zone name. After completion of a survey, the recording sheet is sent to the Project Manager where it is compiled in a Microsoft Access® database.

The NPLR survey is aimed at monitoring several environmental management issues. Firstly, each indicator is individually assessed to 'establish trends over time in their presence and vigour' (pg. 13, McCord *et al*, 2000). When all indicators are combined, the contribution of the types of cover on soil surface protection is established. This is then used to assess the proportion of sites with perennial and annual species erosion protection and the proportion of unprotected sites, in the 9 zones and the entire region (Mc Cord *et al*, 2000).

3.1.1 NPLR, Aussie GRASS and Satellite Remote Sensing

In this current research project the relationship between the NPLR indicators low bush density, tree shrub density and cover, Aussie GRASS products and satellite remote sensing was investigated. The above NPLR indicators are related to vegetation abundance and were therefore thought likely to be related to Aussie GRASS products and NDVI.

The GIS package used in the analysis was Arc View GIS 3.2a. For a spatial analysis between Aussie GRASS products, NDVI images and NPLR survey data, sites were needed in map form that could be imported to the GIS package. To do this, the results for all years beginning 1999 were exported into a Microsoft Excel® spreadsheet. The spreadsheet was then imported into Arc View 3.2a where a new map of NPLR sites and their surveyed results was created (Figure 3.1).

3.1.1.1 Aussie GRASS and Non Pastoral Lease Rangelands

Aussie GRASS TPG, TSDM and Rainfall grids of the month April beginning 2000 were imported into Arc View 3.2a. The extension 'Get Grid Value Extension (v2)' was used to write underlying grid values of the Aussie GRASS product to the NPLR windscreen survey shapefile (Figure 3.2). The result was a spreadsheet with the survey results and TPG, TSDM and Rainfall data associated with each site at month of survey (Appendix 8).

3.1.1.2 NDVI and Non Pastoral Lease Rangelands

From the images obtained by the Queensland Department of Natural Resources and Mines, those with the least cloud cover as determined by the mask contained within each file were used in the analysis (further information can be found in Chapter 2.2.3). Unlike Aussie GRASS data, the NDVI images used in analysis were collected on or near the exact date of surveying The method of extracting NDVI values coinciding with windscreen survey sites is the same as that used with Aussie GRASS products. The extension 'Get Grid Value Extension (v2)' wrote underlying NDVI grid values to the NPLR windscreen survey shapefile. The result was a spreadsheet with the site ID, survey results and NDVI data coinciding with that survey (Appendix 9).

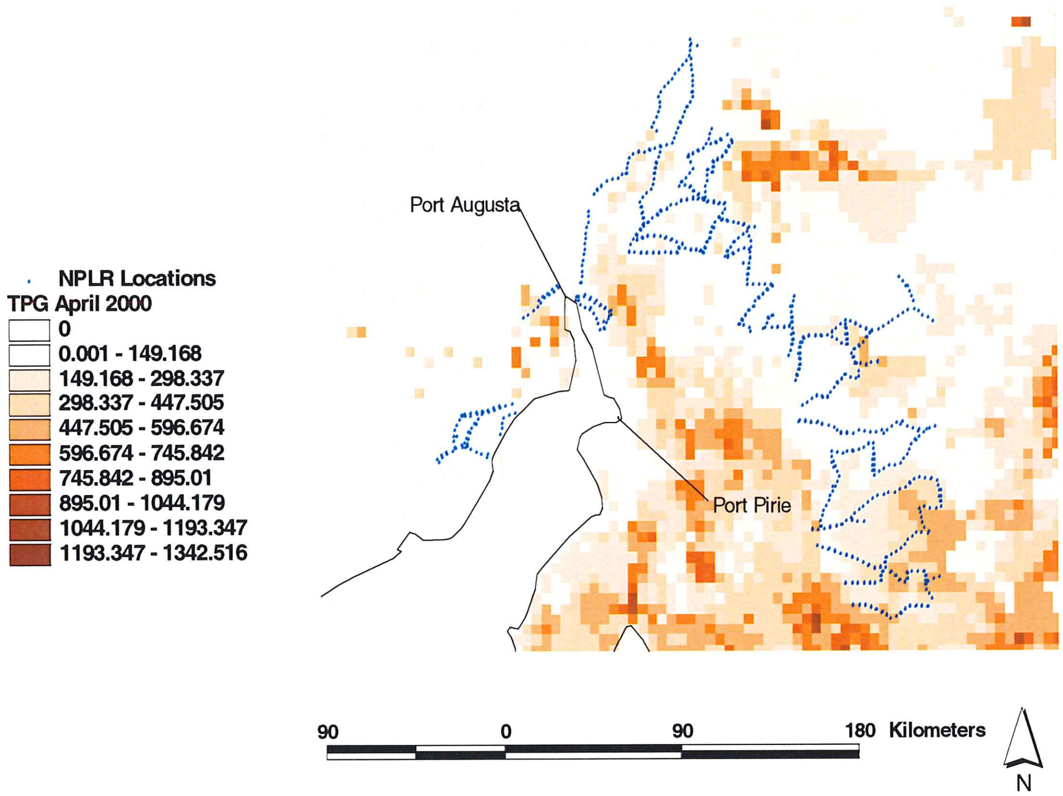

Figure 3.2: Aussie GRASS Product (Total Pasture Growth, April 2000) Overlaid by Non Pastoral Lease Rangelands Sites

NDVI derived from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument were also to be used in the analysis. On georectification of several images however there were several problems. The ASTER scenes investigated were not radio-metrically calibrated and cross image illumination correction was therefore needed. Due to time constraints of this research project, correction was not possible and the analysis not conducted.

3.2 Results and Discussion

The spreadsheets of NPLR windscreen survey results and their coinciding Aussie GRASS product and NOAA AVHRR NDVI values were imported into the GenStat vs. 6 statistical package. Several different statistical designs were applied on the data, including 1st and 2nd order simple linear regression, and multiple linear regressions. Information from the DWLBC Soil and Land Information soil database was also imported into the spreadsheet, to investigate the relationship between survey results and topography and soil information. Several different relationships were analysed, with the results given in Table 3.1. Many different relationships were tested, with none exhibiting a %VAR greater than 15. Therefore, no detectable relationship between factors of the NPLR survey, soil information, Aussie GRASS products and remotely sensed NDVI was found.

Dependent Variable	**Independent Variable**	**%Variance Accounted For (%VAR)**
Cover Rating	TSDM	0.2
Cover Rating	TPG	0.3
Cover Rating	Rainfall	0
Cover Rating	SLU	2.1
Cover Rating	TSDM+TPG+Rainfall	0.9
Cover Rating	TSDM+TPG+Rainfall+SLU	2.1
Low Bush Density	TSDM	0
Low Bush Density	TPG	0
Low Bush Density	Rainfall	0.1
Low Bush Density	SLU	0
Low Bush Density	TSDM+TPG+Rainfall	0.2
Low Bush Density	TSDM+TPG+Rainfall+SLU	4.7
Tree Shrub Density	TSDM	0.3
Tree Shrub Density	TPG	0
Tree Shrub Density	Rainfall	0
Tree Shrub Density	SLU	0
Tree Shrub Density	TSDM+TPG+Rainfall	0.2
Tree Shrub Density	TSDM+TPG+Rainfall+SLU	15
Cover Rating	NOAA AVHRR NDVI	<1
Low Bush Density	NOAA AVHRR NDVI	<3
Tree Shrub Density	NOAA AVHRR NDVI	<3

Table 3.1: The Results of NPLR Survey, Aussie GRASS Products, NDVI and Soil Information Statistical Analysis

There are several possible reasons for the lack of relationship, including:

- Aussie GRASS products and NDVI imagery have pixel sizes (5km and 1km respectively) to broad to detect changes in on ground variability of NPLR survey;
- Aussie GRASS products contain errors when modelling NPLR's; and/or
- NPLR data is not representative of the area it surveys.

Aussie GRASS products and NDVI imagery have pixel sizes of 5km and 1km respectively. NPLR survey data however, is measured in 200m square plots. Figure 3.3 displays an ASTER image overlayed by the NPLR survey points in the southern Flinders Ranges. The grid represents the pixel size of Aussie GRASS products. What can be observed is that Aussie GRASS products cannot adequately model small changes in variability observed on ground by the NPLR survey, as its pixel size is too broad. The same can be found for NOAA NDVI data.

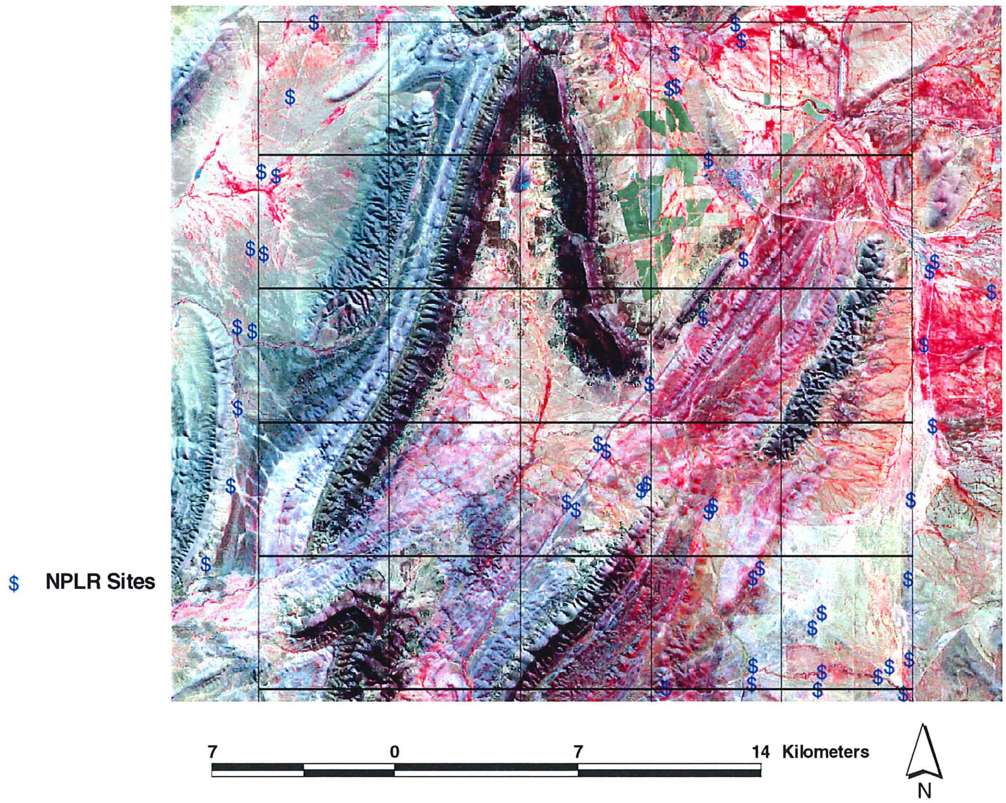

Figure 3.3: NPLR Survey Points Overlayed by Aussie GRASS Grid

Aussie GRASS was not only calibrated by NOAA NDVI imagery, but also ground surveys. A spider mapping technique was used to collect pasture biomass, edible bush biomass and tree/shrub basal area data in South Australia's North-East, Flinders, Far North-East and North West pastoral districts (Richards *et al*, 2001). The NPLR was not included as it falls outside the jurisdiction of the Pastoral Board who conducted the survey. As no data was collected in the NPLR, the Aussie GRASS model has not been calibrated in this area. Therefore it is possible that no relationship was found between the LCMP survey data and Aussie GRASSS products, as the model has not been calibrated in the NPLR. With permission of the LCMP manager, results of the NPLR survey were sent to Climate Impacts & Natural Resource Systems, Queensland Centre for Climate Applications, where its potential for calibrating the Aussie GRASS will be investigated.

A further possible reason for no relationship found between the three investigated, is that NPLR data is not representative of the rangelands it surveys. Figure 3.4 (a) is of an ASTER image overlayed by NPLR survey points in the southern Flinders Ranges (~530km^2). Figure 3.4 (b) is of a few NPLR survey points in (a) and their extent (200m*200m). A large amount of variability is observed within (a), which may not be detected within the survey sites (b). This observation can be extended to the entire area surveyed by the LCMP (~25000km^2). Survey sites are confined to roadside paddocks, with areas that are inaccessible not surveyed at all (Thomas, 2001). This creates bias, and therefore may not be an effective method for monitoring an entire region.

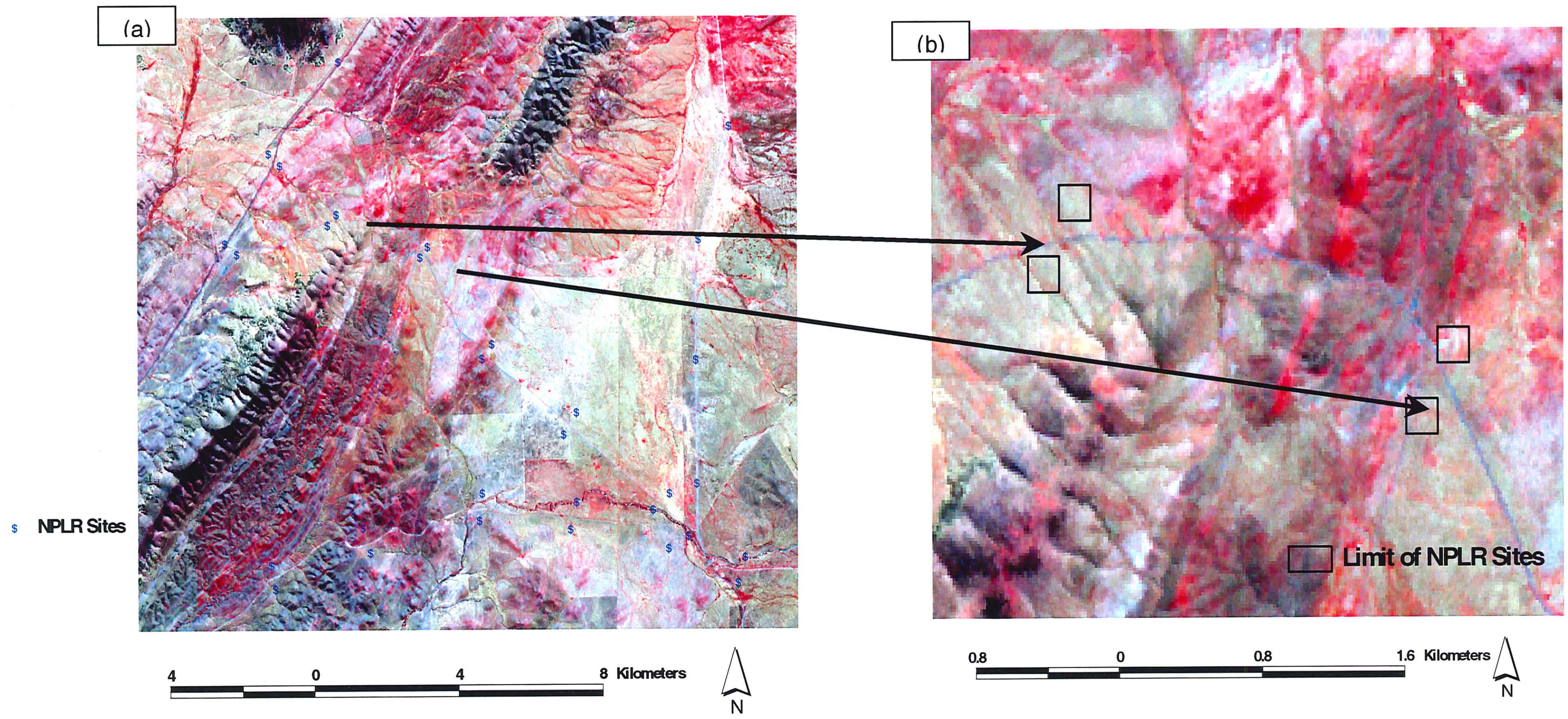

*Figure 3.4: ASTER Image Overlayed by NPLR Survey Points. Figure 3.5 (a) is of an ASTER image overlayed by NPLR survey points in the southern Flinders Ranges (~530km^2). Figure 3.5 (b) is of a few NPLR survey points in (a) and their extent (200m*200m). A large amount of variability is observed within (a), which may not be detected within the survey sites (b).*

4 Conclusions and Recommendations

The potential for integrating the ground surveys of the LCMP's windscreen survey, satellite remote sensing and Aussie GRASS products was identified by South Australia's Soil Conservation Council. In this research project a relationship was found between the cropping land survey, Aussie GRASS products TPG, TSDM and rainfall, and satellite derived NOAA NDVI. However, no relationship was found between the NPLR survey Aussie GRASS and NDVI.

Between 70% and 80% of cover can be explained by Aussie grass products TPG, TSDM and rainfall. As the Aussie GRASS model is dependent upon climatic factors, it can also be said that 70-80% of cover can therefore also be explained by climate. The remaining 20-30% of cover could be explained by management practices, which are considered when ranking cover in the windscreen survey. However, this error variance may also be a result of Aussie GRASS not sufficiently calibrated in the cropping regions of South Australia. For this reason with permission from the LCMP Project Manager results of the cropping windscreen survey were sent to the Climate Impacts and Natural Resource Systems, Queensland Centre for Climate Applications where they will be investigated for their possible use in calibrating the Aussie grass model.

A significant relationship between satellite derived NDVI and the cropping land windscreen survey was also found. The relationship was less strong than that between Aussie GRASS and the survey, which was expected as NDVI measures only green vegetation cover.

With a relationship found between Aussie GRASS and the windscreen survey, cover was modelled for the entire cropping region. This allows for a continuos visualization of cover across the State, which is not achievable with survey results alone. Analysis of data much similar to that done in the windscreen survey can also be performed on this data, but instead of grouping by zones, grids of 5km pixel size which provide a finer view of cover can be used.

A residual analysis between modelled cover and the LCMP's observed cover was also performed. This analysis was able to identify particular transects which consistently diverged from the modelled cover. This could mean that those transects may not truly represent the zone that they monitor or the model fails in those areas.

With cover modelled by Aussie GRASS products, this research project explored the possibilities of rating detachment by land use and season in order to create continuous maps of EHI. At present more work needs to be done on an accurate method of estimating detachment that takes into account different land management practices across the agricultural region. Wind and water erosion potential maps from the DWLBC Soil and Land Information soil database were investigated for their use in assessing erosion risk from the EHI. These maps are a better depiction of landscape features than those observed in the windscreen survey. Future research should focus on replacing the survey variables of wind and water erosion potential with those of the database.

No relationship was found between NPLR survey data, Aussie GRASS products and satellite remotely sensed NDVI. This could be the result of three factors:

- Aussie GRASS products and NDVI imagery have pixel sizes (5km and 1km respectively) to broad to detect changes in on ground variability of NPLR survey;
- Aussie GRASS products contain errors when modelling NPLR's; and/or
- NPLR data is not representative of the area it surveys.

The NPLR was not included in filed surveys used to calibrate the Aussie GRASS model. It is therefore possible that no relationship was found between the LCMP survey data and Aussie GRASSS products, as the model has not been calibrated in the NPLR. With permission of the LCMP Project Manager, results of the NPLR survey were sent to Climate Impacts & Natural Resource Systems, Queensland Centre for Climate Applications, where its potential for calibrating the Aussie GRASS will be investigated.

4.1 Future Research

Below are listed future research possibilities that we have identified whilst completing this project:

- Modelling cover of those months not included in the survey was not investigated in this research project. Further research in this area should result in cover being predicted for all months of the year, opposed to the current four.
- The development team behind Aussie GRASS are currently working on models that predict grass growth 1, 2 and 3 months before the actual event. On completion of these models, it may be possible for cover rating too to be predicted 1, 2, and 3 months prior to the ground survey.
- With cover modelled by Aussie GRASS products, this current research project explored the possibilities of rating detachment by land use and season in order to create a continuous prediction of the EHI. At present more work needs to be done on a more accurate method of estimating detachment that takes into account different land management practices across the agricultural region. This could be achieved through the use of satellite remote sensors with higher spatial and spectral resolution.
- Thomas (2001) identified emerging new remote sensing technologies that could be used to aid in land condition monitoring. This research project also identifies the potential of satellite sensors such as MODIS, which has a 500m spatial resolution, in monitoring of land condition within South Australia's agricultural region.

References

Carter, J.O., Hall, W.B., Brook, K.D., McKeon, G.M., Day, K.A. and Paull, C.J. (2000). *Aussie GRASS: Australian grassland and rangeland assessment by spatial simulation.* In 'Applications of seasonal climate forecasting in agricultural and natural ecosystems - the Australian experience' (ed G. Hammer, Nicholls, N. and Mitchell, C.), pp. 329-49. Kluwer Academic Press, Netherlands.

Carter, J.O., Bruget, D., Hall, W.B., and Collett, L. *Using Satellite Data to Calibrate a Continental Scale Spatial Model of Pasture Production.* In 11th ARSPC.

Hall, W., Bruget, D., Carter, J., McKeon, G., Yee Yet, J., Peacock, A., Hassett, R. and Brook, K. (2001). *The Aussie GRASS Final Report.* Queensland Department of Natural Resources and Mines, Brisbane.

McCord, A. (2000b). *State Survey Monitoring Manual: Non-Pastoral Lease Rangelands.* Primary Industries and Resources South Australia, Adelaide.

McCord, A. (2000a). *State Survey Monitoring Manual: Cropping.* Primary Industries and Resources South Australia, Adelaide.

McCord, A, Thomas, M., Graham, G. and Davis, S. (2000). *A Description of key Land Condition Monitoring Methodology used in South Australia from 1999-2000.* Primary Industries and Resources South Australia, Adelaide.

Paull, C., Cliffe, N. and Hall, W. (2001). *The Aussie GRASS Extension sub-project Final Report.* Queensland Department of Primary Industries, Brisbane.

Richards, R., Watson, I., Bean, J., Maconochie, J., Clipperton, S., Beeston, G., Green, D. and Hacker, R. (2001). *The Aussie GRASS Southern Pastures sub-project Final Report*. Queensland Department of Natural Resources and Mines, Brisbane.

Thomas, M. (November, 2001). *Remote Sensing in South Australia's Land Condition Monitoring Project*. DWLBC Sustainable Resources Land Information Group, Adelaide.

Appendix 1: Data recording sheet used in monitoring of cropping lands

Cropping districts field survey recording sheet (with example data)

LAND CONDITION RECORDING SHEET - CROPPING														
Date	Trans #	Zone #	Site #	Dune Pres.	Current PHASE f.cf.c.p	TOPOG Rating WIND	TOPOG Rating WATER	EROSION Wind Severity	EROSION Water Severity	DETACH Rating	COVER Rating	BURN	COMMENTS	REGION ep nad
dd/mm/yyyy				d, n	s.gl.ca	(1-5)	(1-5)	(1-5)	(1-5)	(1-3)	(1-8)	n/mb/pb/cb	eg. Pests.claying	ml se
10/05/2001	9	34	201	n	p	1	1	1	1	1	2	n		ml
10/05/2001	9	34	202	n	p	1	1	1	1	1	2	n		ml
10/05/2001	9	34	203	n	p	1	1	1	1	1	2	n		ml
10/05/2001	9	34	204	n	p	1	1	1	1	1	3	n		ml
10/05/2001	9	34	205	n	c	1	1	1	1	1	1	n		ml
10/05/2001	9	34	206	n	p	1	1	2	1	1	2	n		ml
10/05/2001	9	34	207	n	p	1	1	1	1	1	3	cb		ml
10/05/2001	9	34	208	n	p	1	1	1	1	1	3	n		ml
10/05/2001	9	34	209	n	p	1	1	1	1	1	3	n		ml
10/05/2001	9	34	210	n	p	1	1	1	1	1	3	n		ml
10/05/2001	9	34	211	n	p	1	1	1	1	1	2	n		ml
10/05/2001	9	34	212	n	p	1	1	1	1	1	3	n		ml
10/05/2001	9	34	213	d	p	4	1	1	1	1	2	n		ml
10/05/2001	9	34	213	n	p	2	1	1	1	1	2	n		ml
10/05/2001	9	34	214	d	p	4	1	2	1	1	2	n	clayed	ml
10/05/2001	9	34	214	n	p	2	1	1	1	1	2	n		ml
10/05/2001	9	34	215	d	c	4	1	1	1	1	1	n		ml
10/05/2001	9	34	215	n	c	2	1	1	1	1	1	n		ml
10/05/2001	9	34	216	n	p	1	1	1	1	1	2	n		ml
10/05/2001	9	34	217	d	p	4	1	1	1	1	2	n	clayed	ml
10/05/2001	9	34	217	n	p	2	1	1	1	1	2	n		ml
10/05/2001	9	34	218	d	p	4	1	2	1	1	2	n		ml
10/05/2001	9	34	218	n	p	2	1	1	1	1	2	n		ml
10/05/2001	9	34	219	d	p	4	1	1	1	1	2	n		ml
10/05/2001	9	34	219	n	p	2	1	1	1	1	2	n		ml
10/05/2001	9	34	220	d	p	4	1	3	1	1	2	pb		ml
10/05/2001	9	34	220	n	p	2	1	1	1	1	2	cb		ml
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10/05/2001	9	34	226	n	p	2	1	1	1	1	3	mb		ml
10/05/2001	9	34	227	n	p	2	1	1	1	1	3	n		ml
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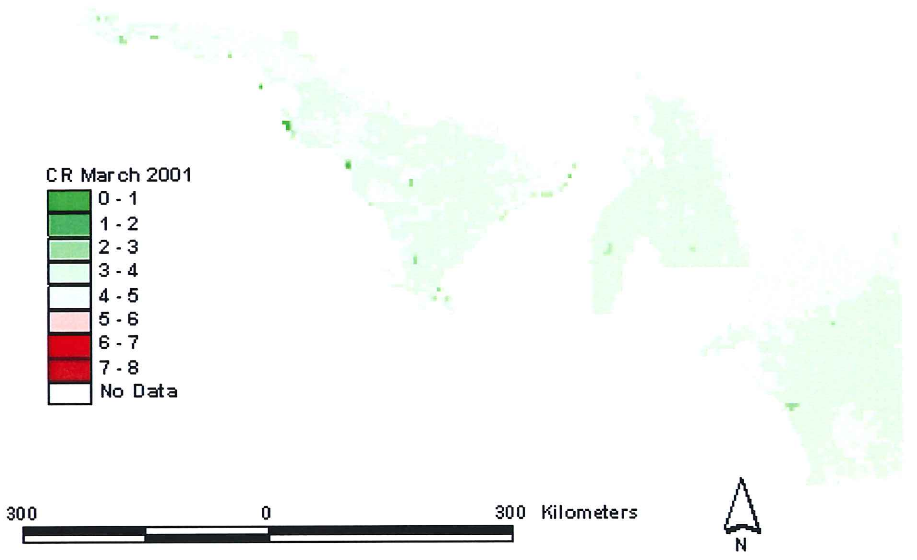
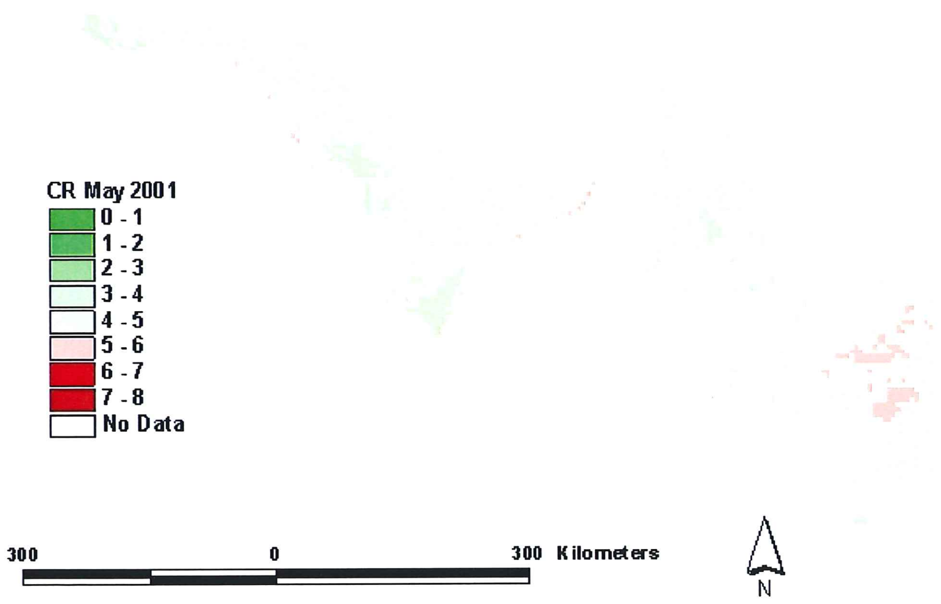
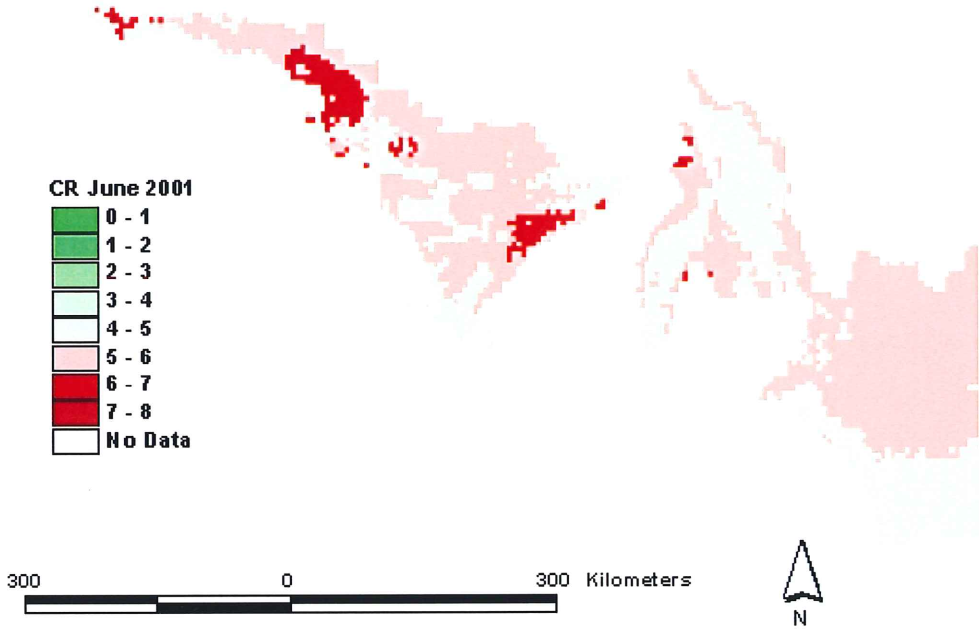
Appendix 4: Cover Rating Modelled using Aussie GRASS Products, March 2001 – June 2003



Cover Modelled from Aussie GRASS Products, March 2001.



Cover Modelled from Aussie GRASS Products, May 2001.



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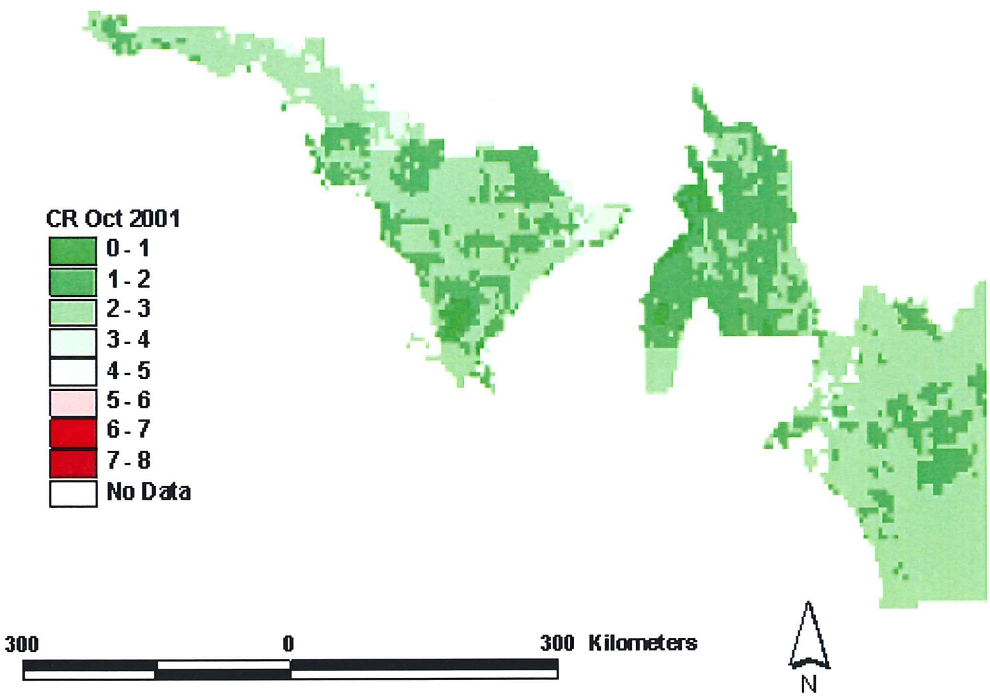
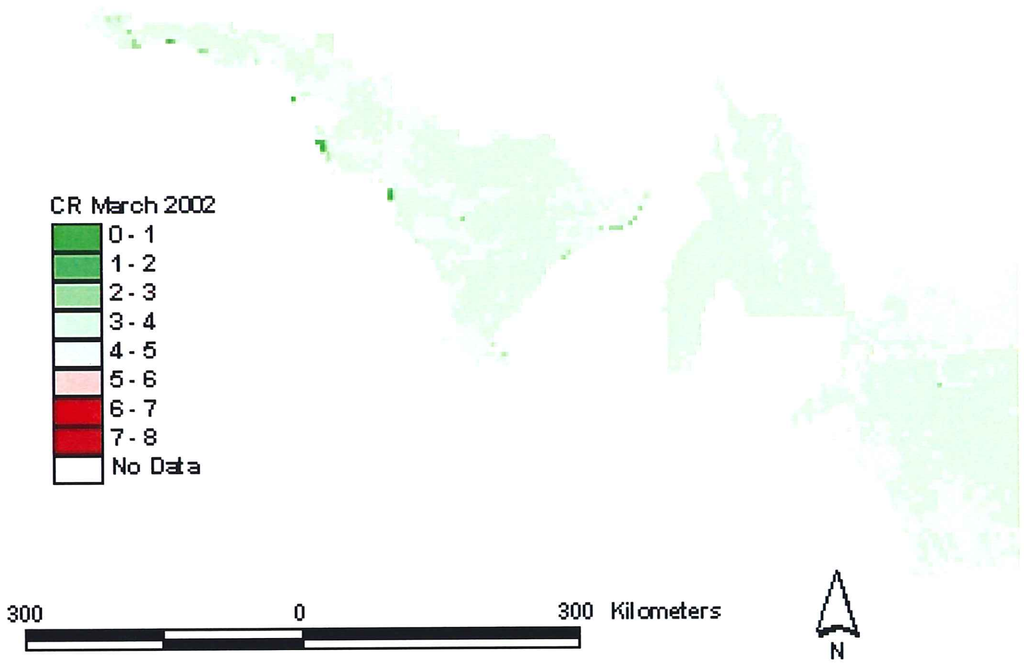


Cover Modelled from Aussie GRASS Products, October 2001.



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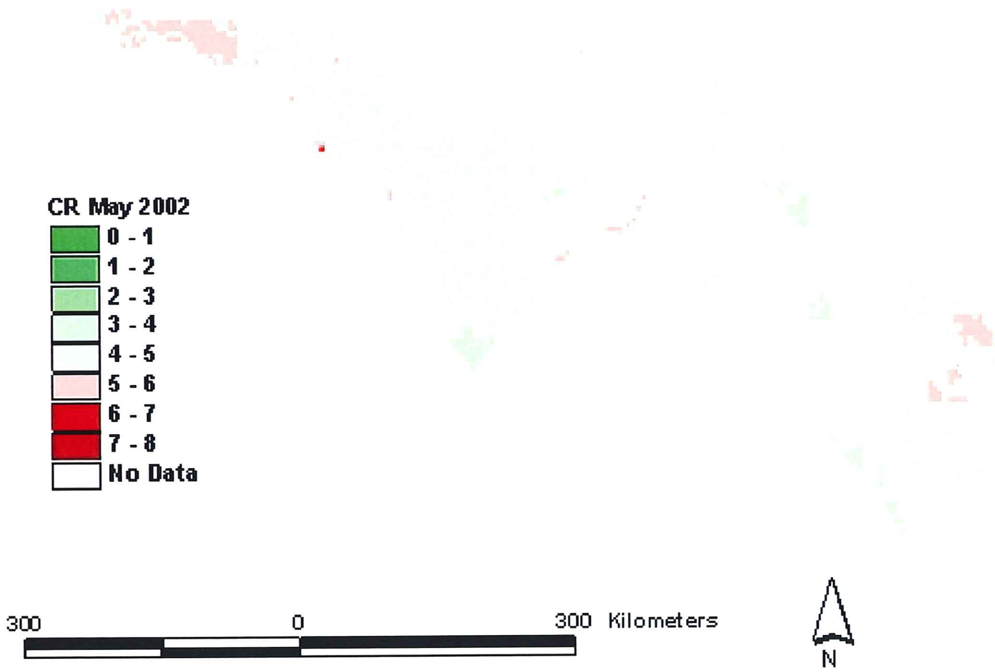

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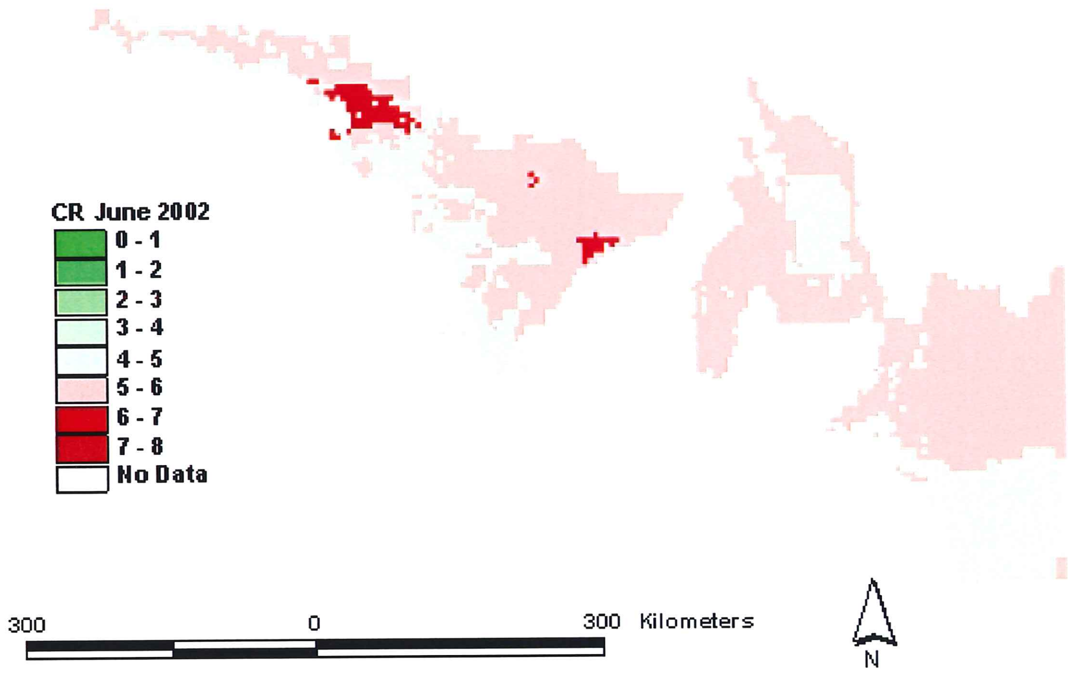

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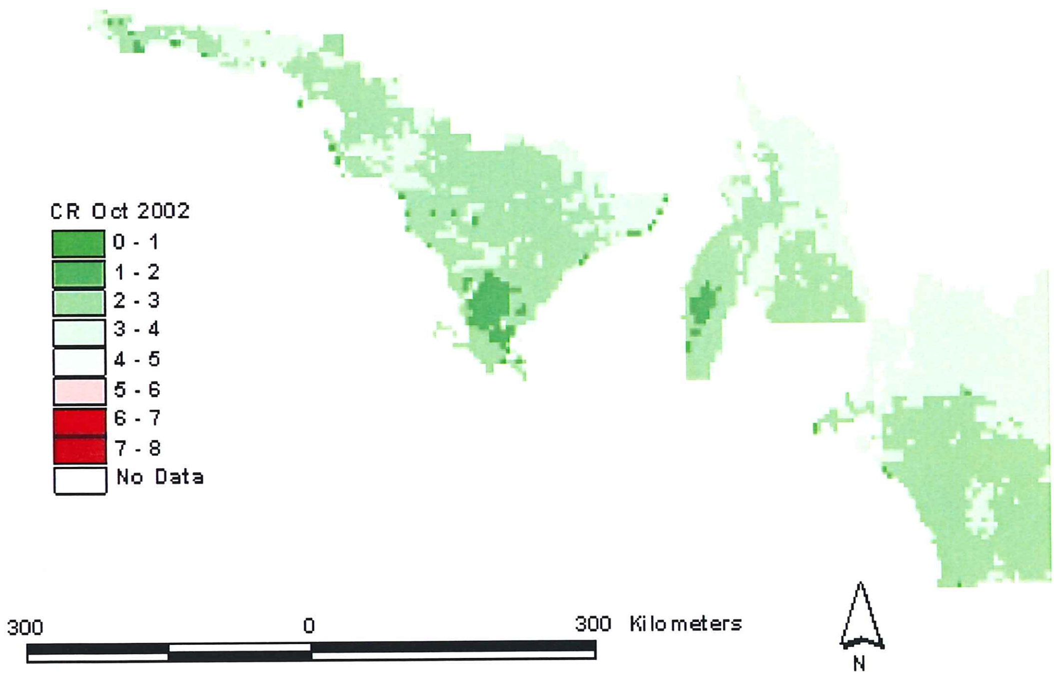

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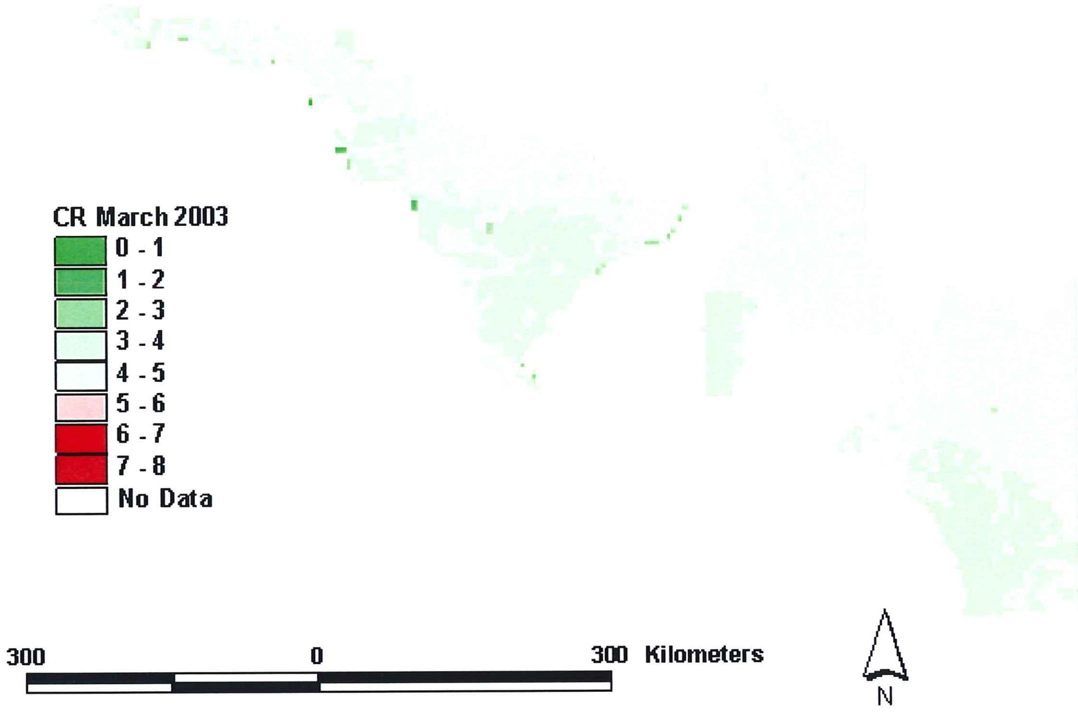

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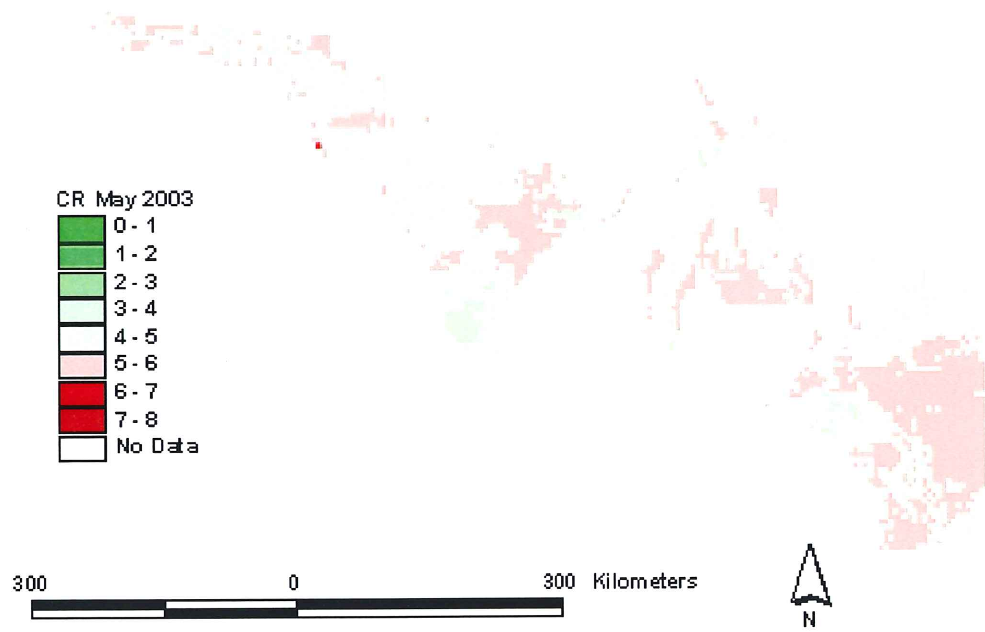

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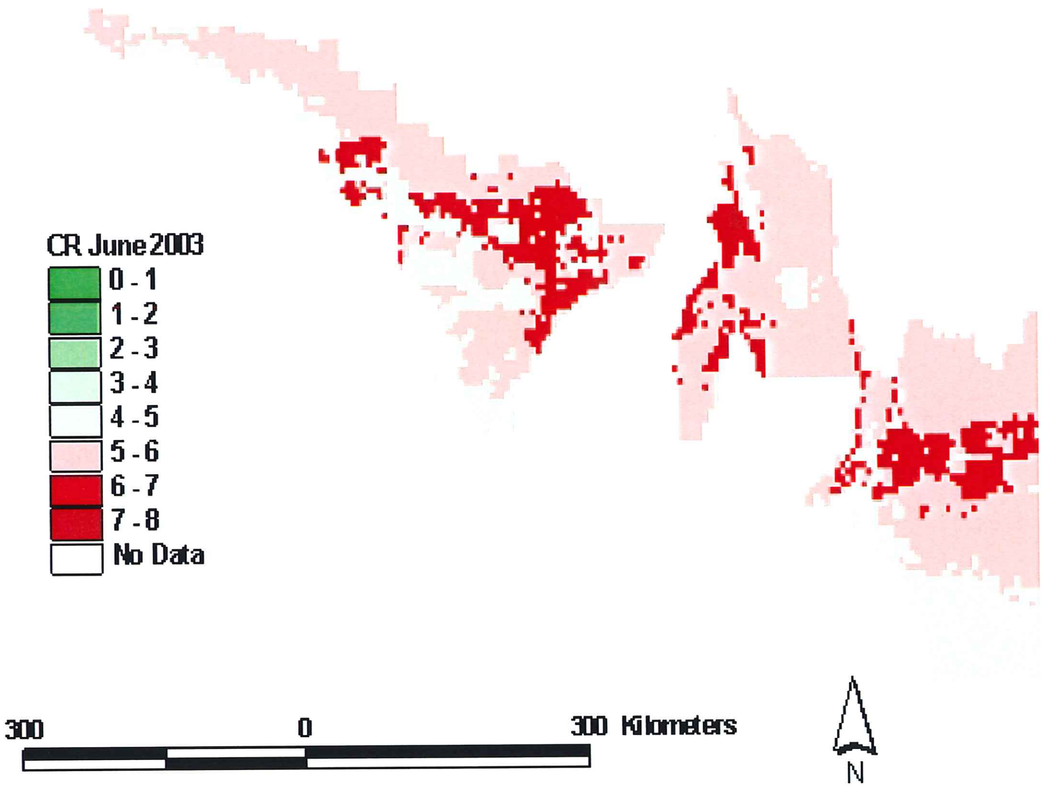
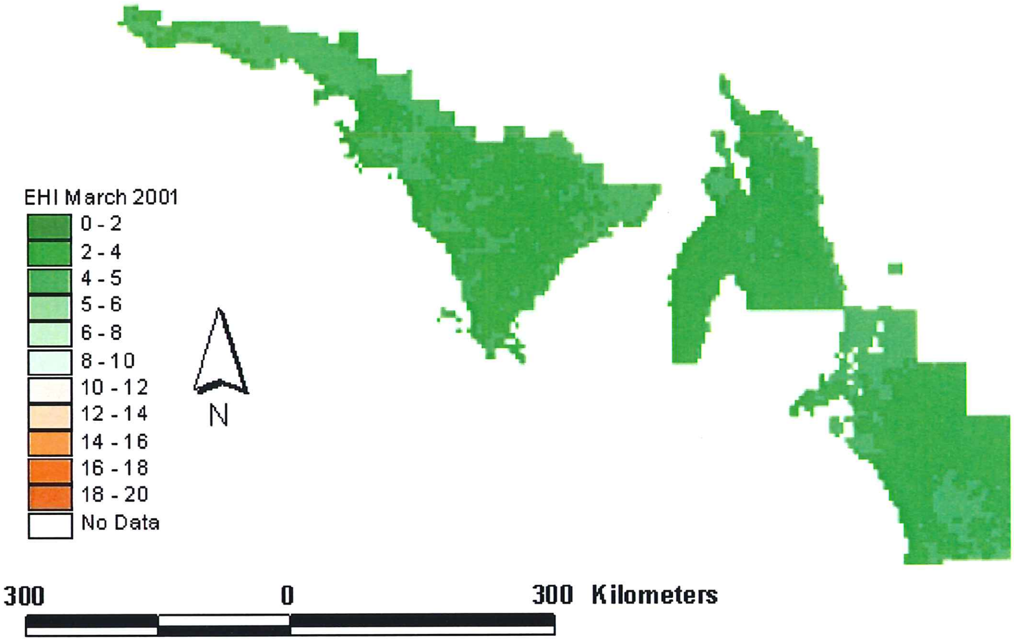


Cover Modelled from Aussie GRASS Products, June 2003

Appendix 5: Erosion Hazard Index, March 2001 – June 2003



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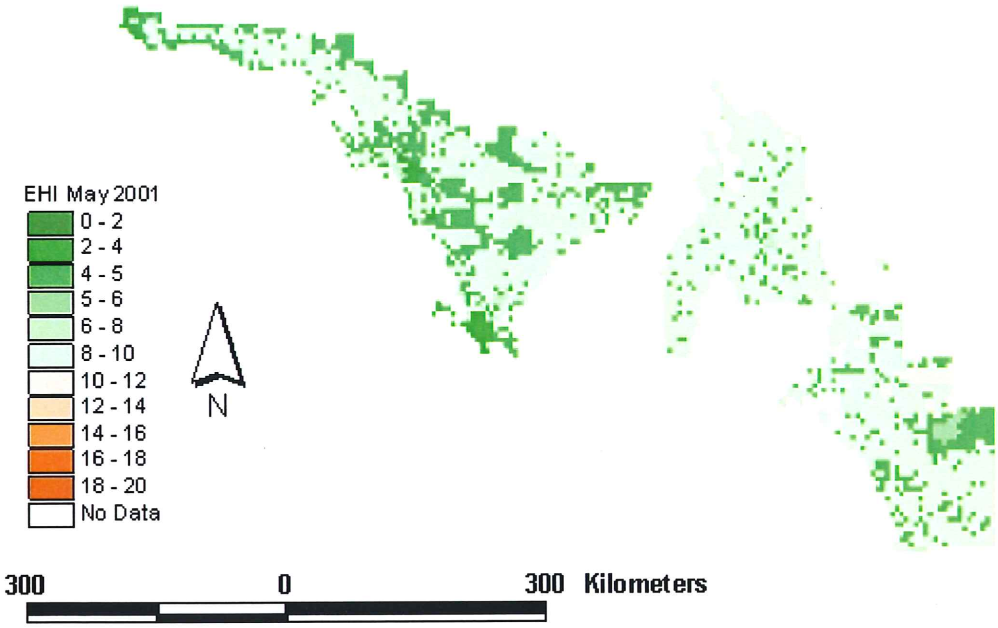

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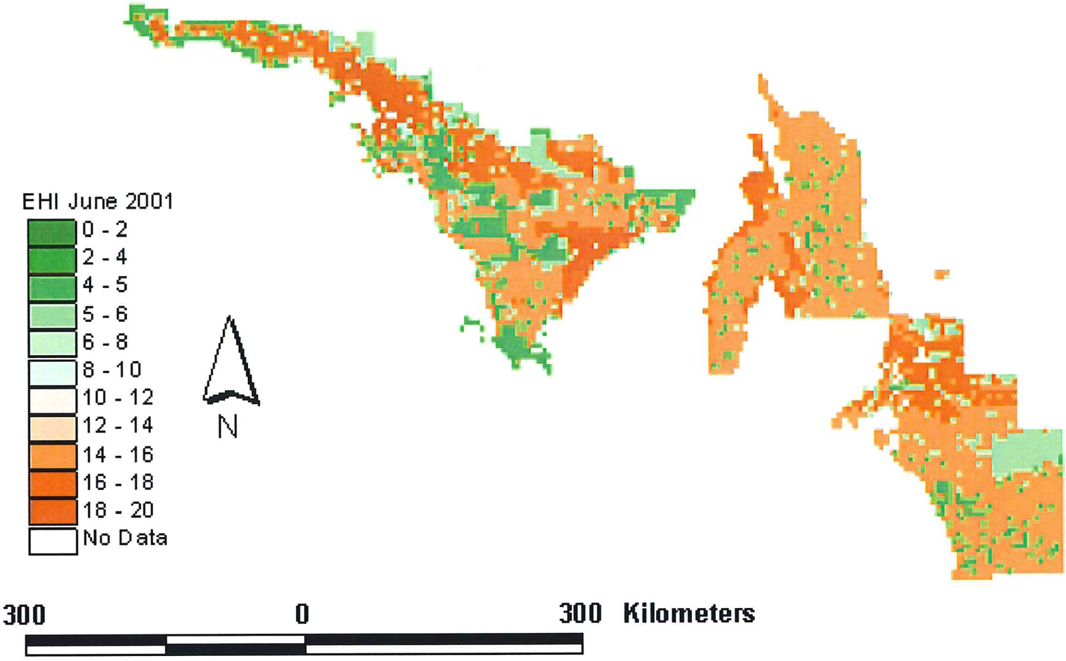
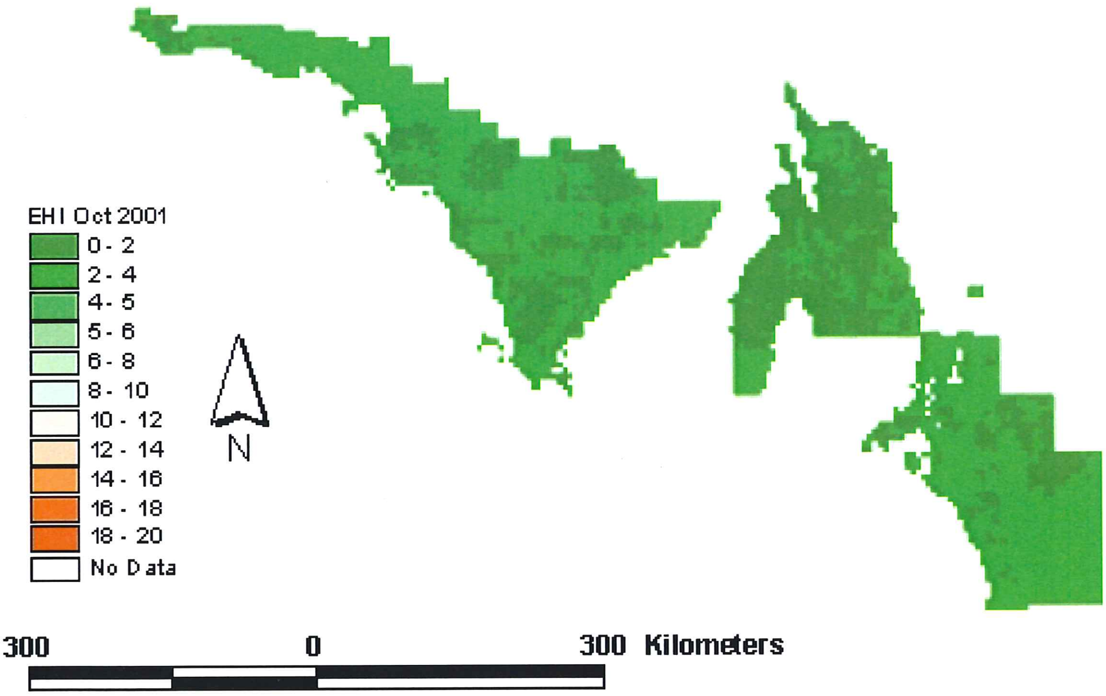


Erosion Hazard Index, June 2001



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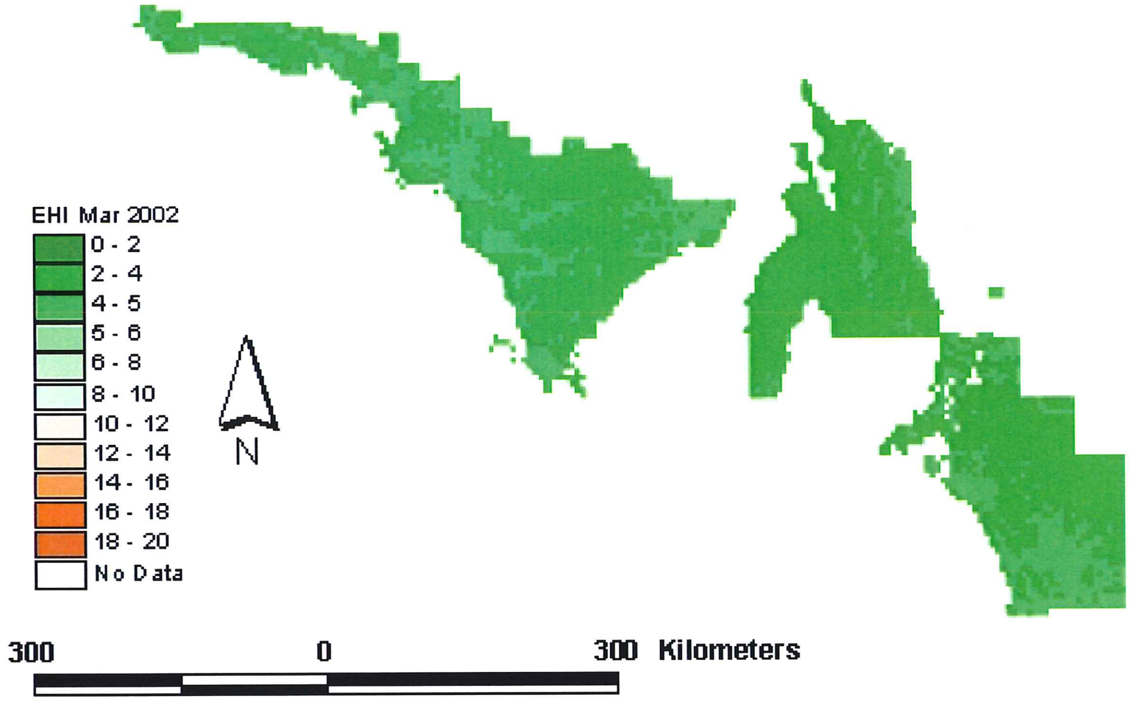

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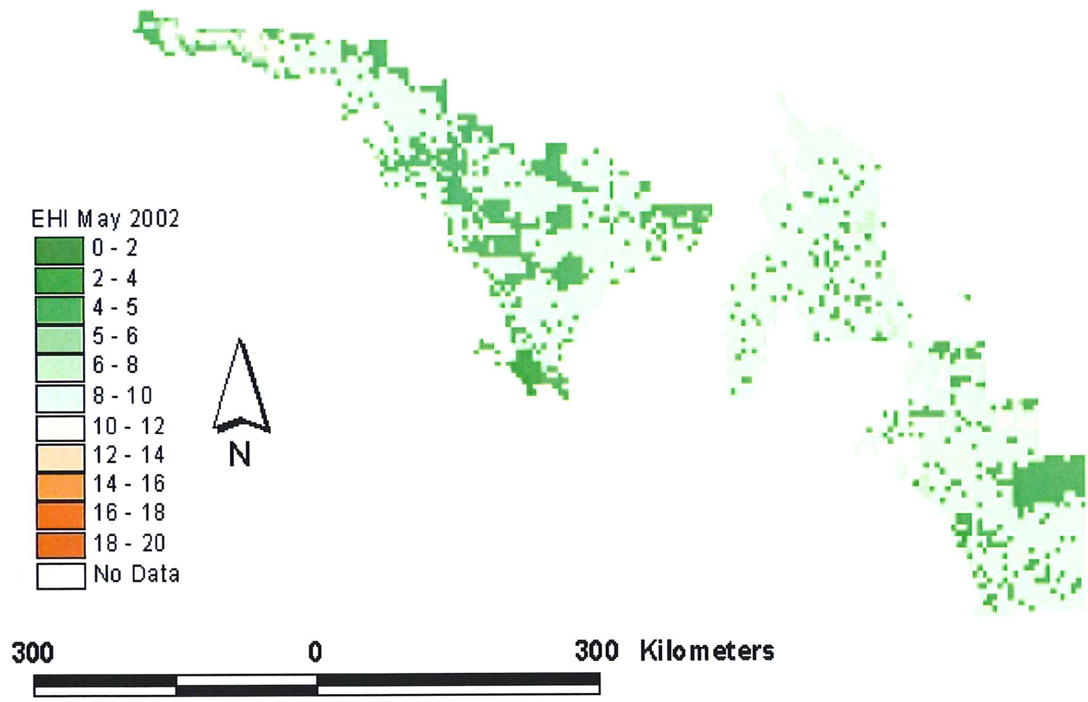

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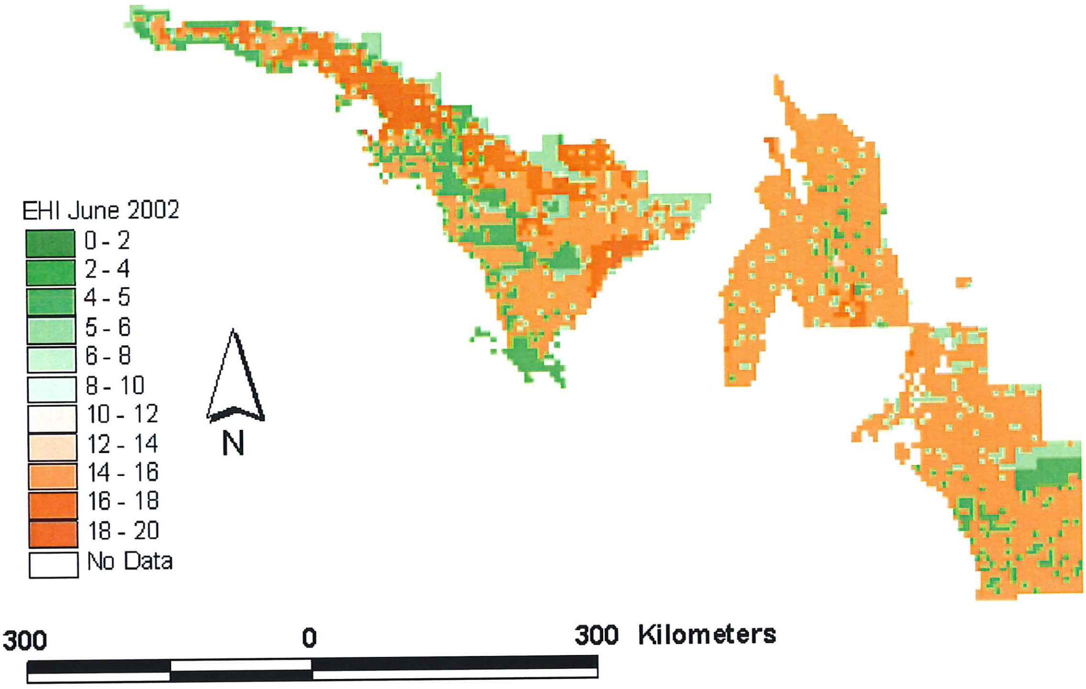

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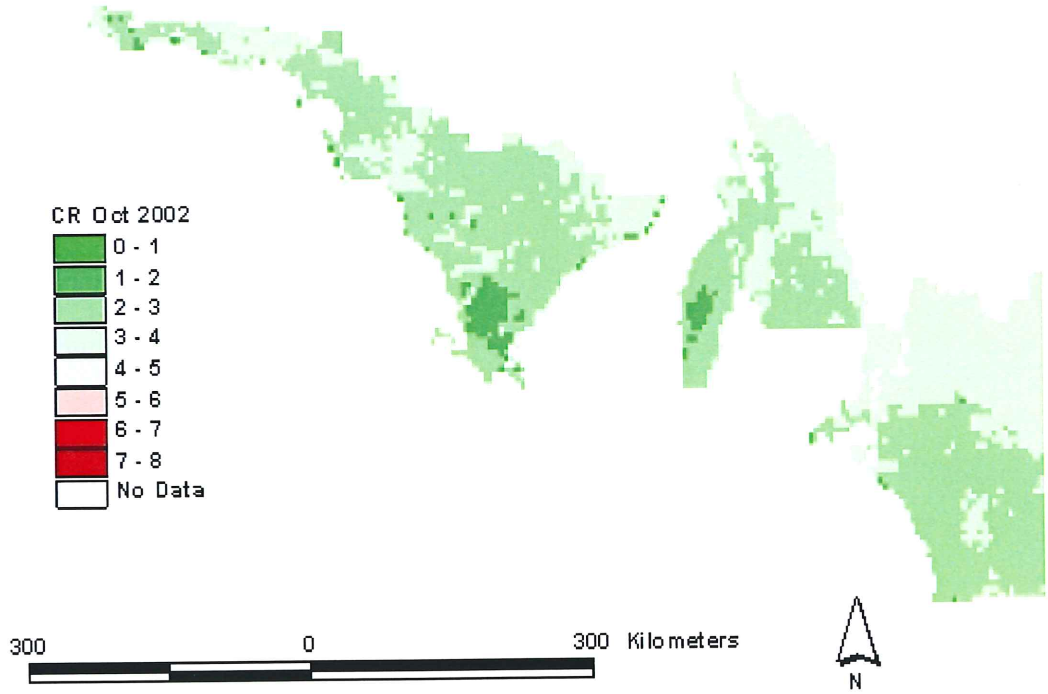

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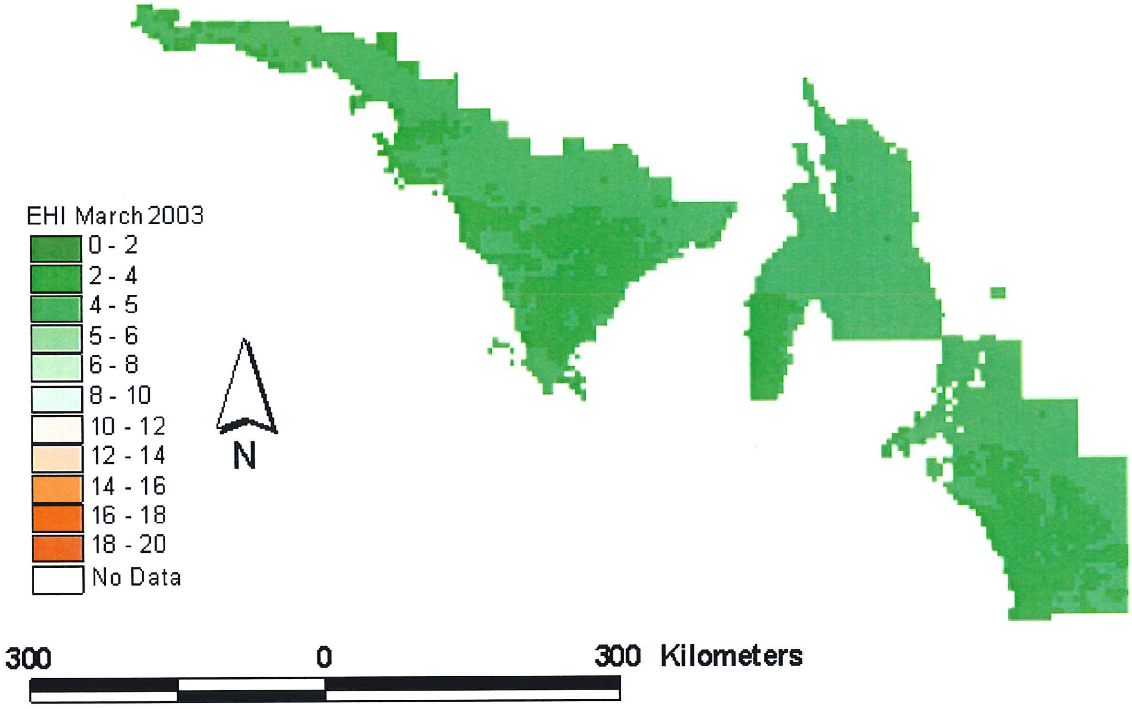

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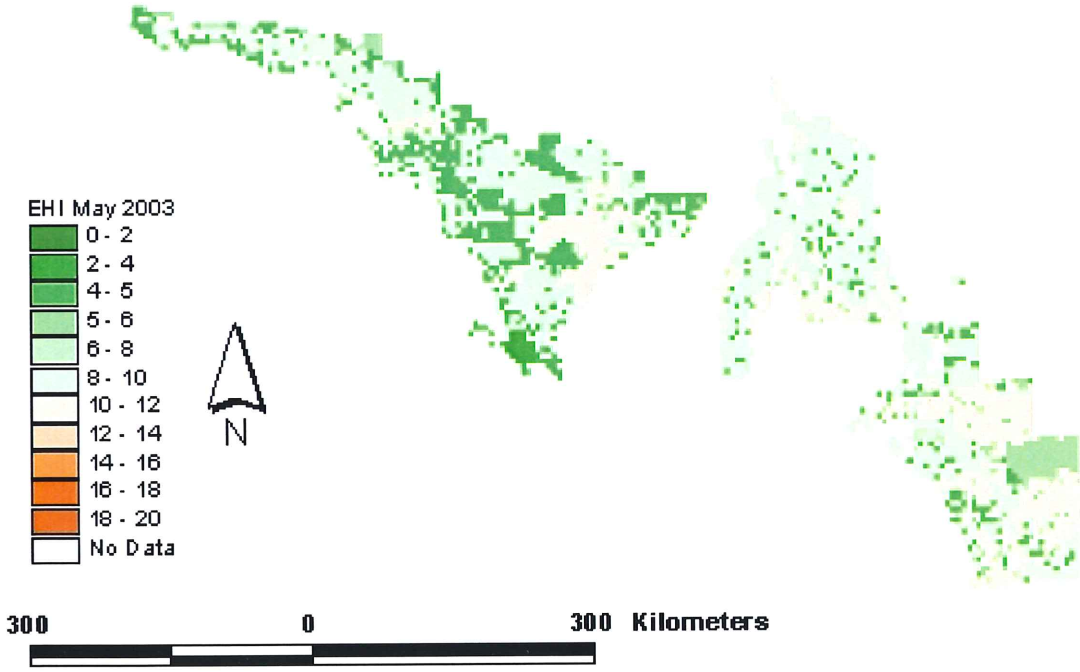

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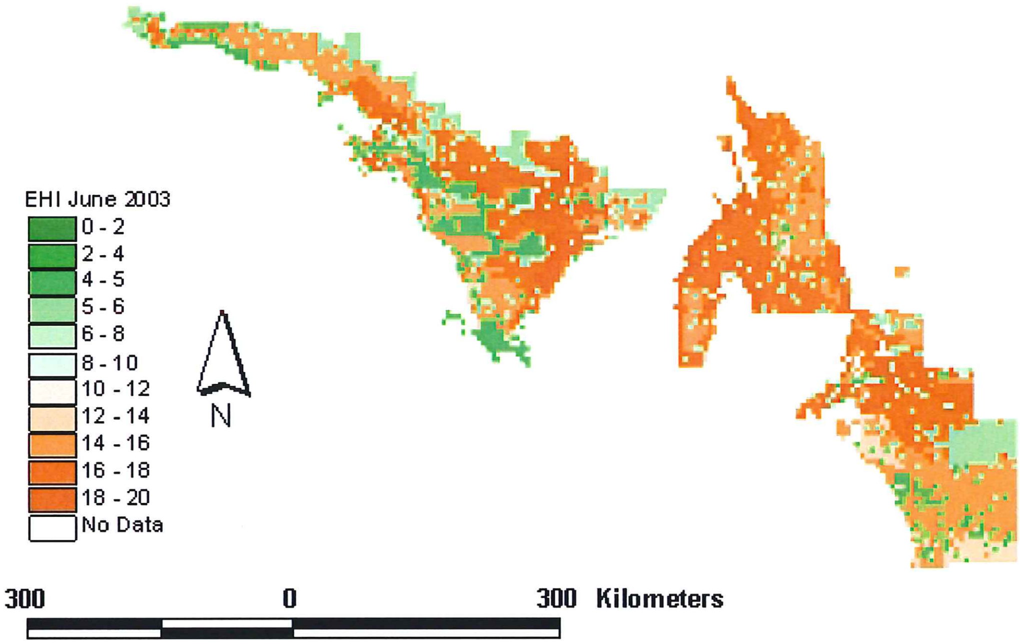
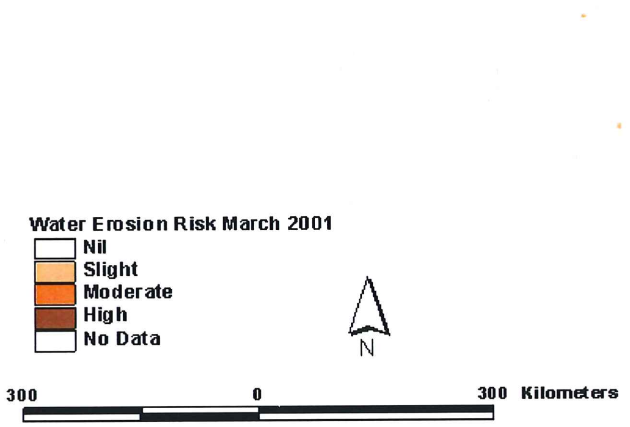


Erosion Hazard Index, June 2003

Appendix 6: Modelled Wind and Water Erosion Risk, March 2001 – June 2003



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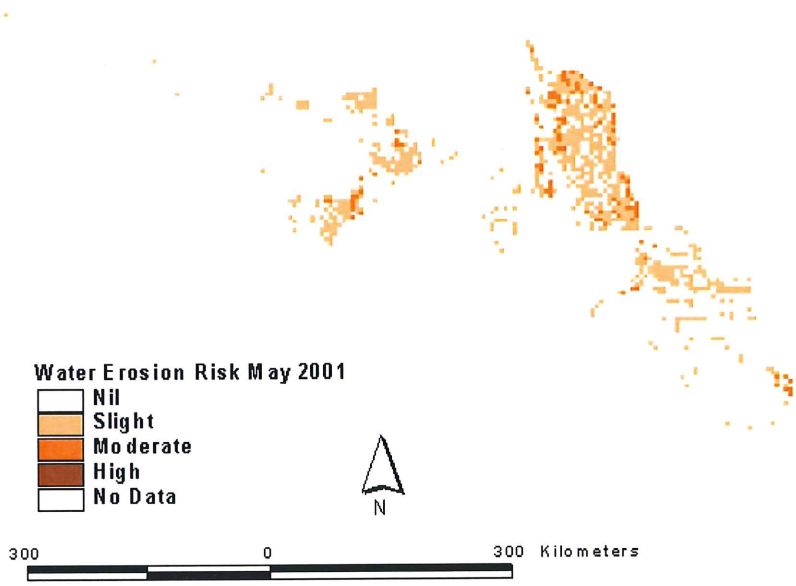

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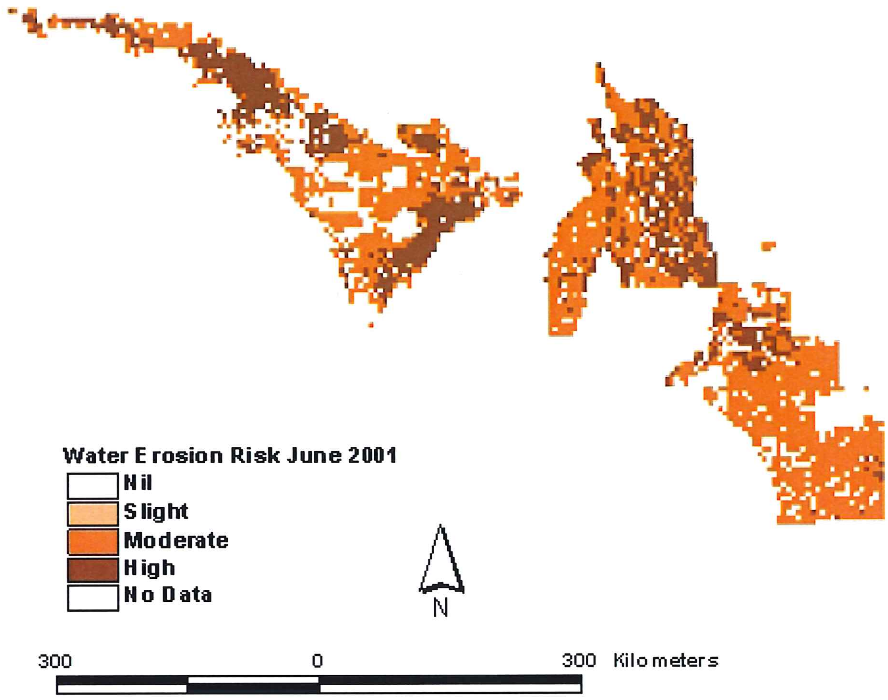

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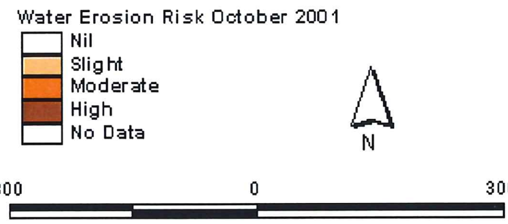

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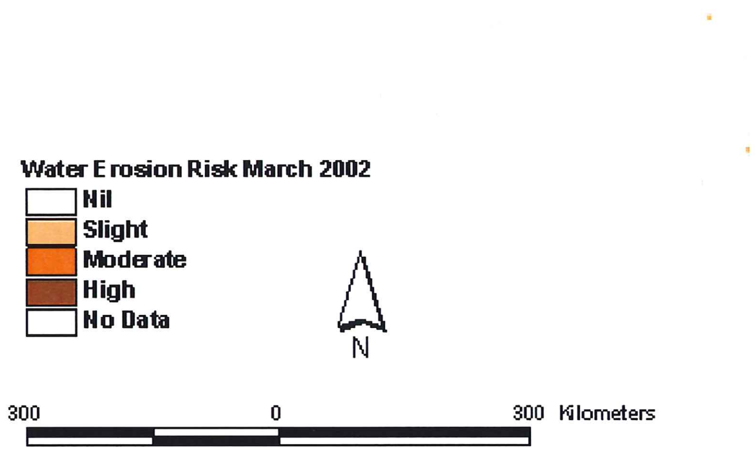

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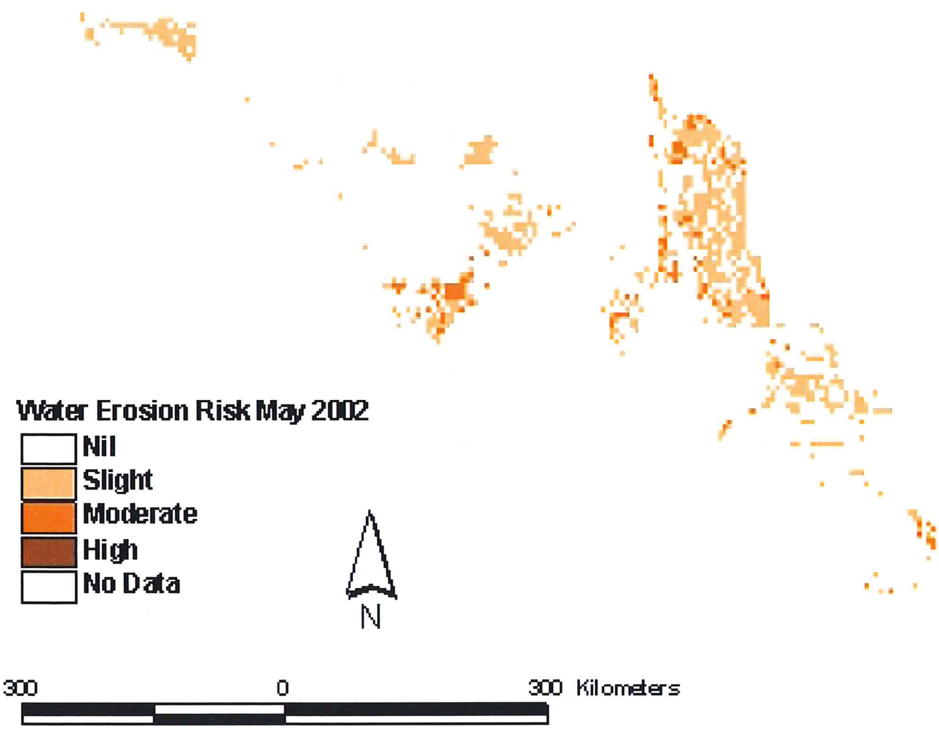

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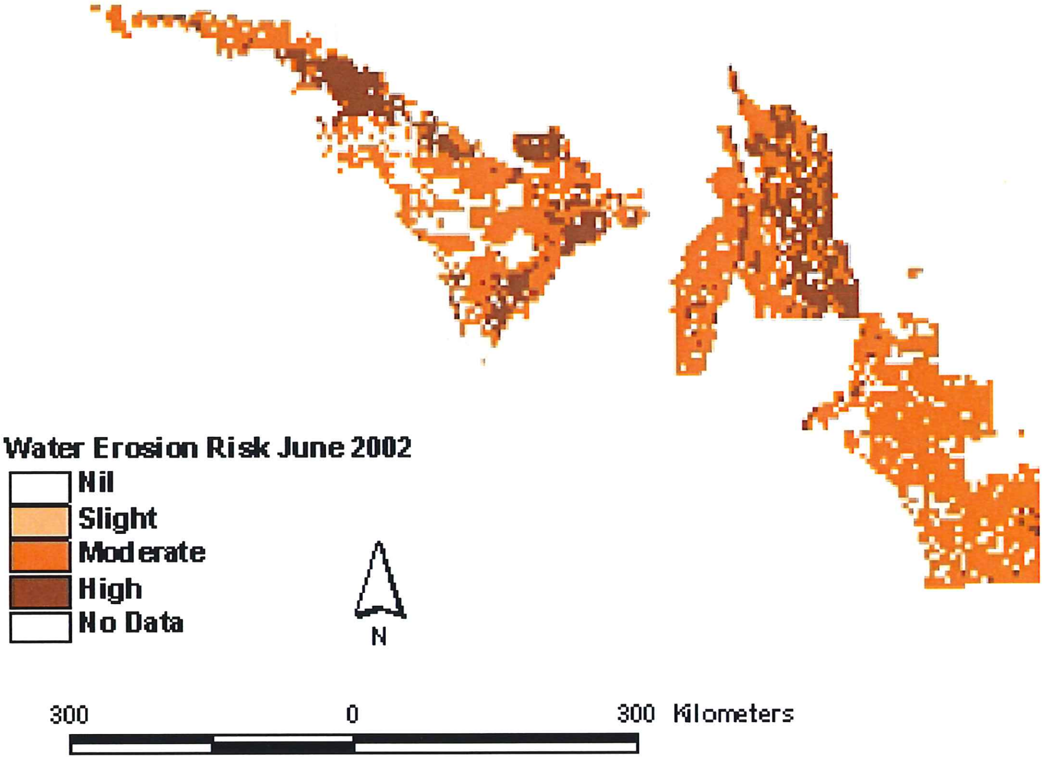

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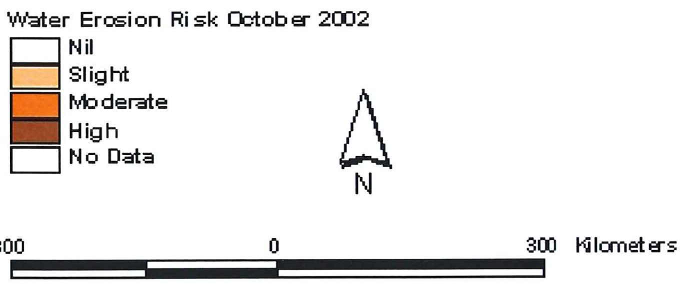

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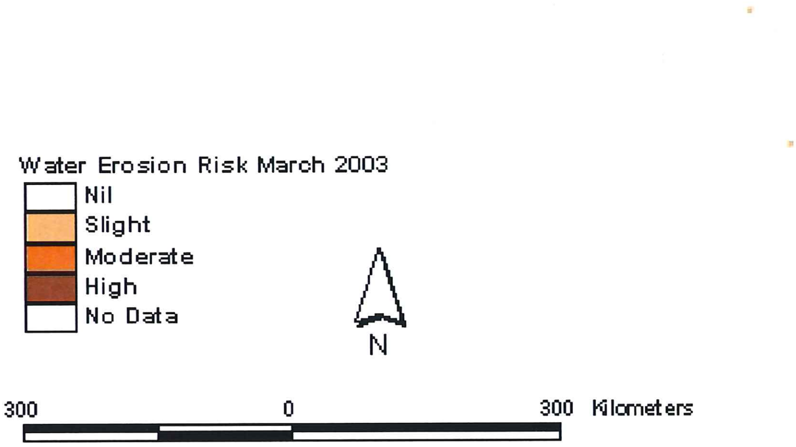

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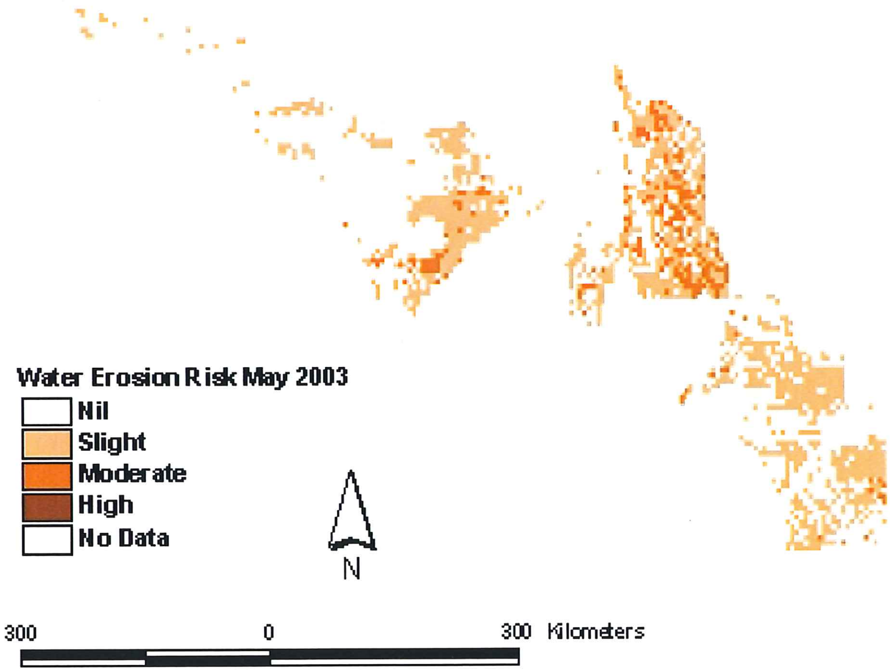

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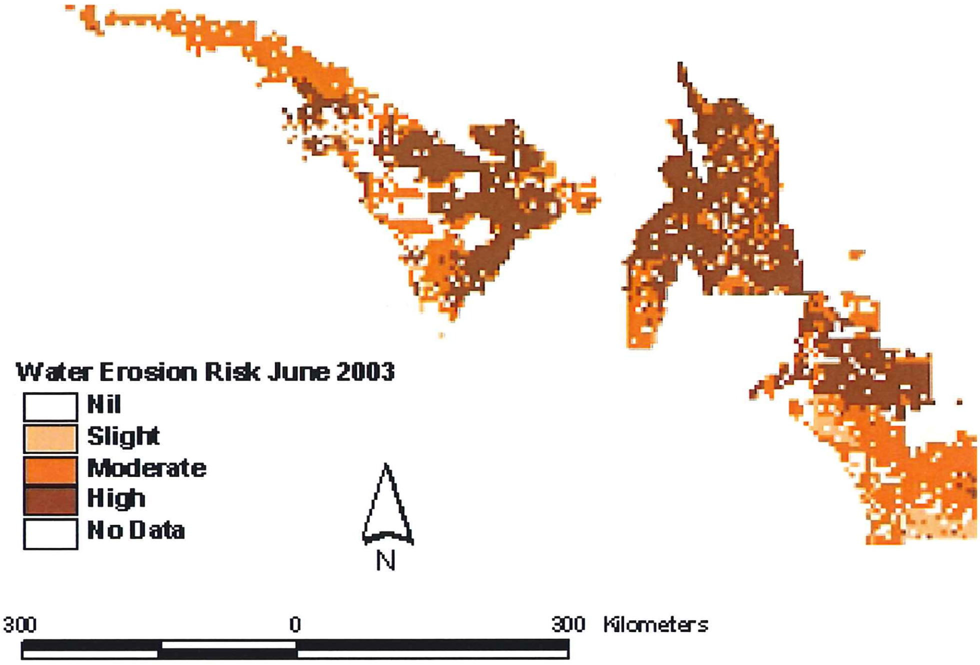

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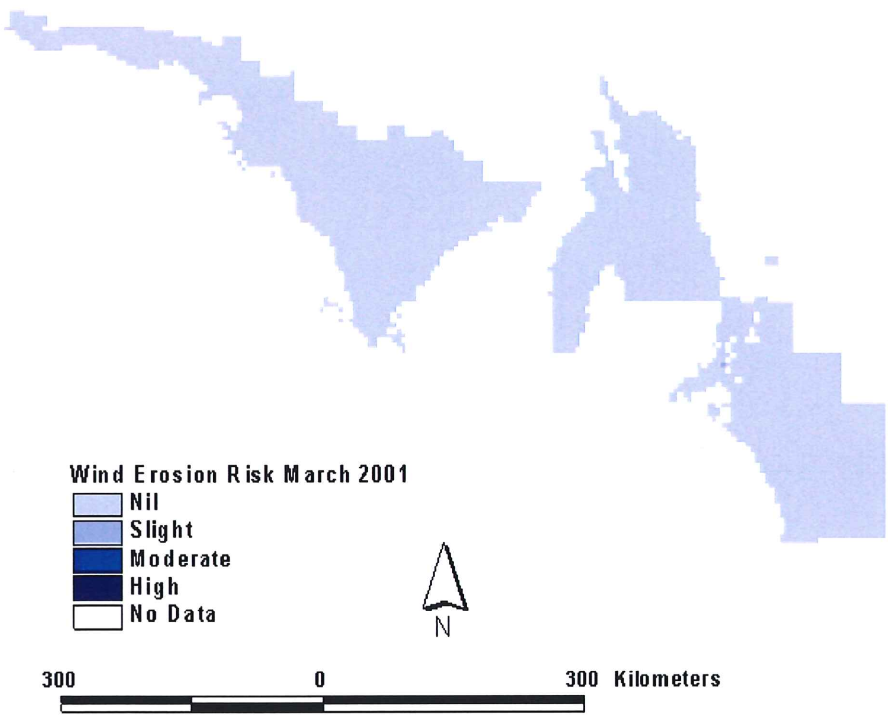

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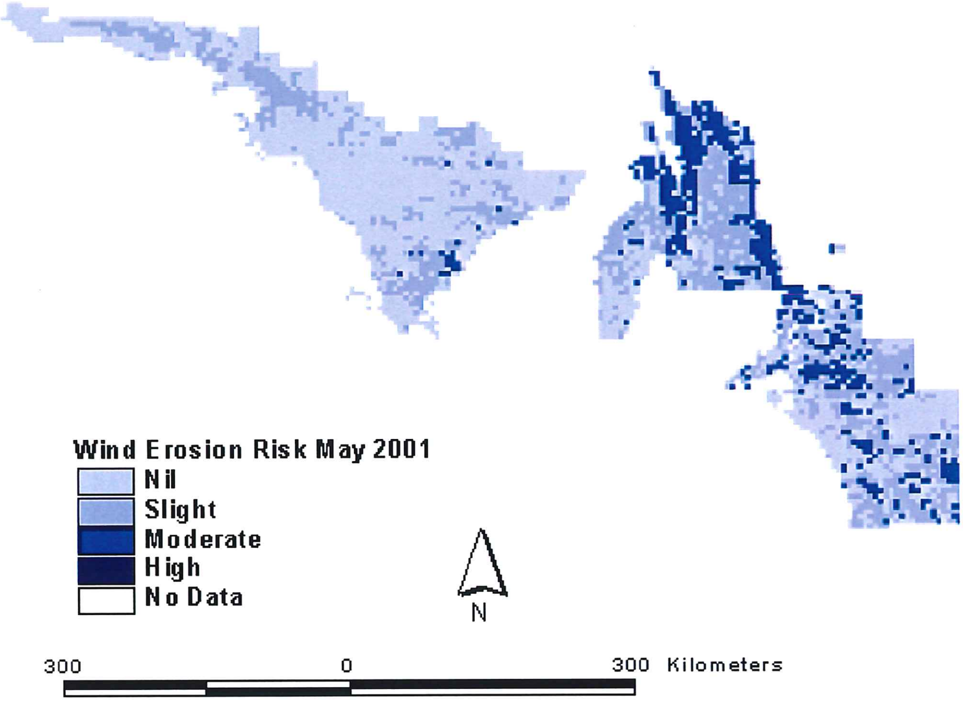

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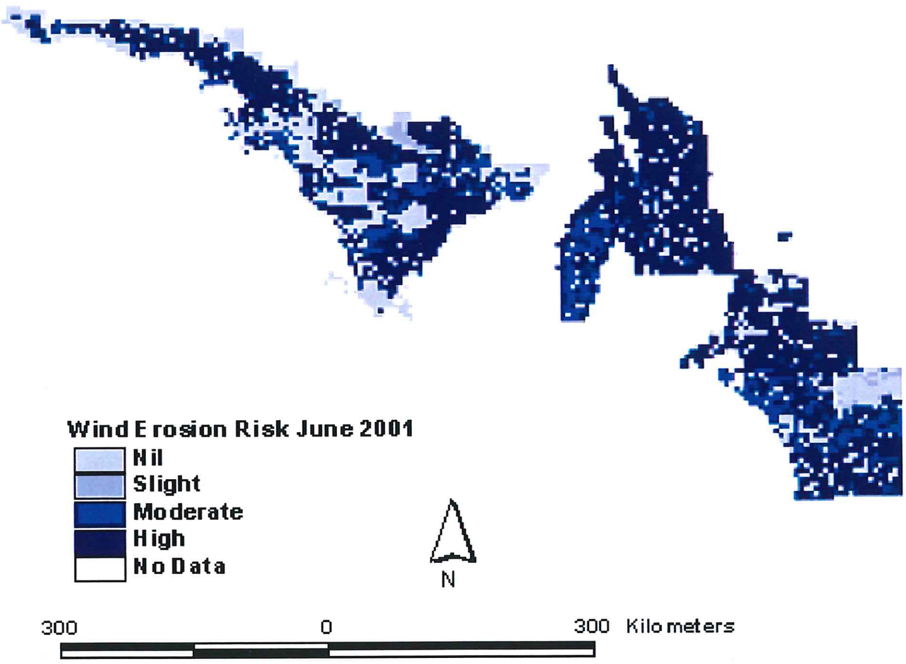

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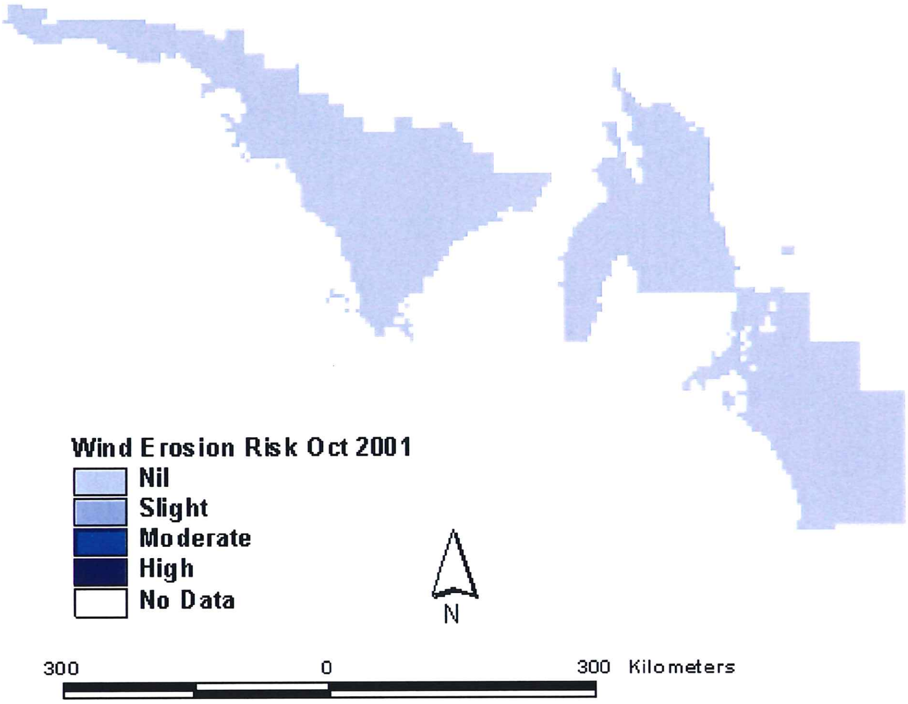

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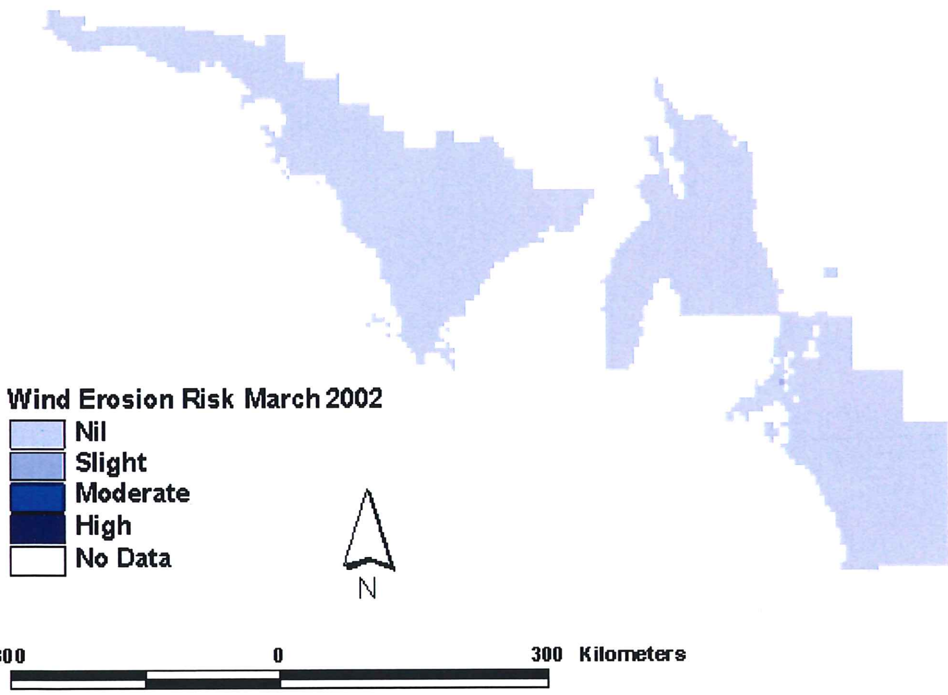
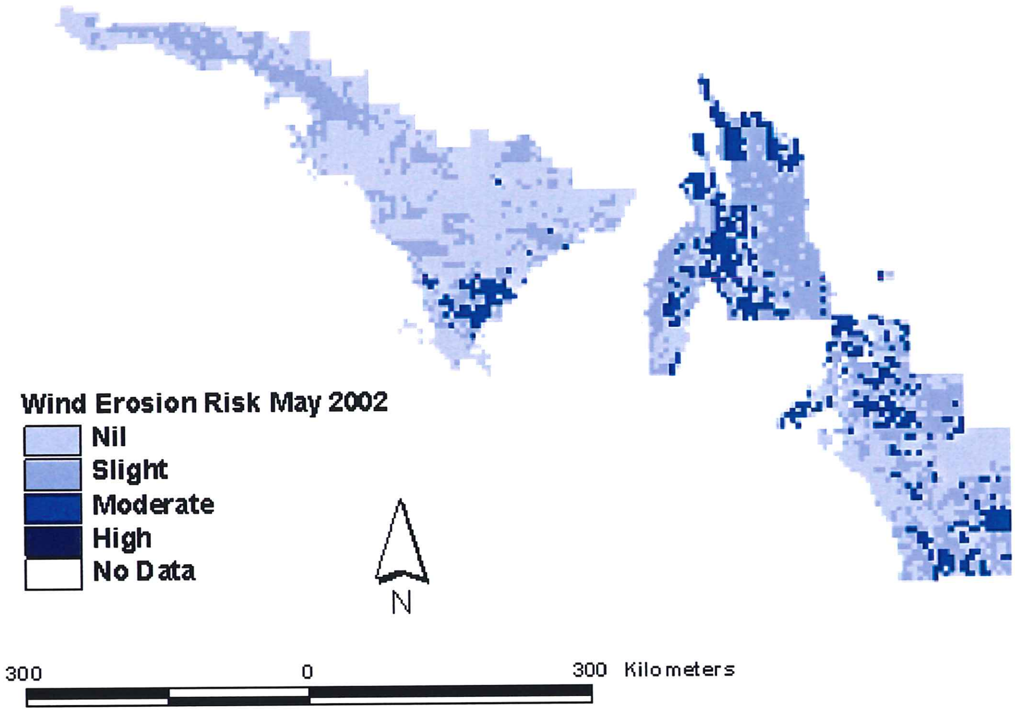
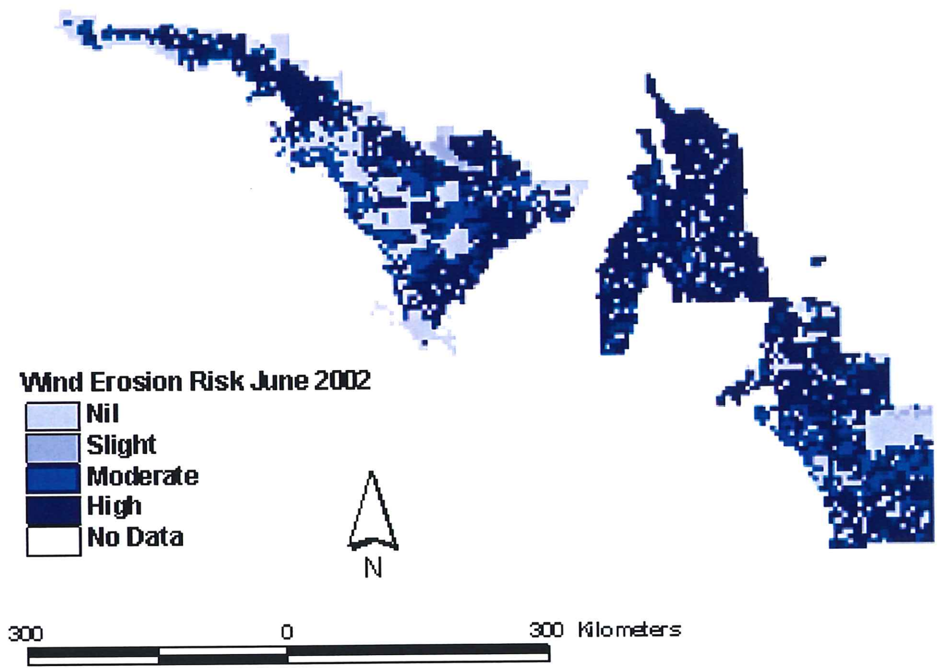


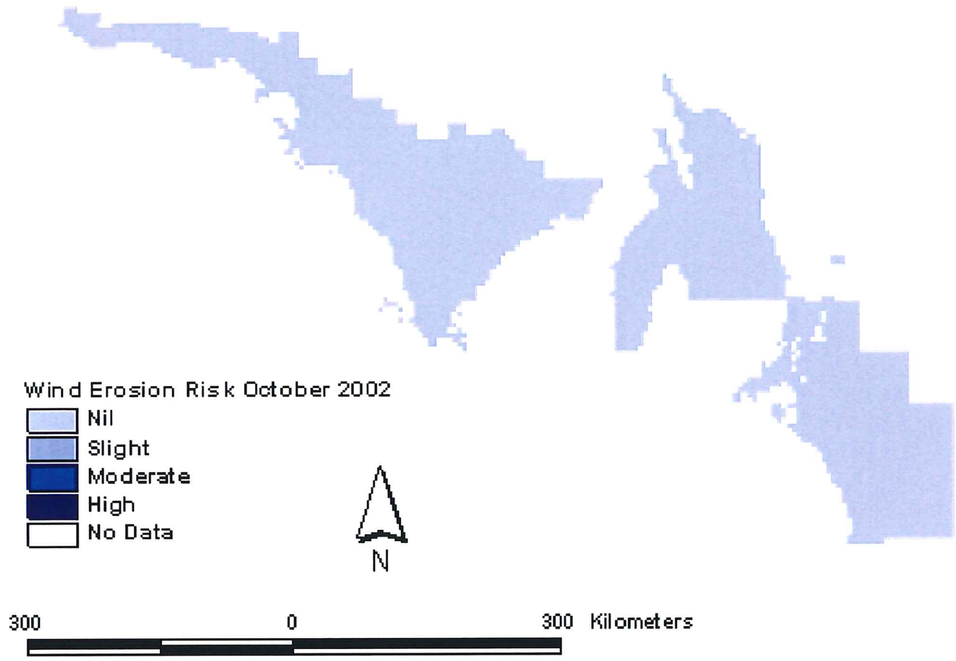
Modelled Wind Erosion Risk, March 2002



Modelled Wind Erosion Risk, May 2002



Modelled Wind Erosion Risk, June 2002



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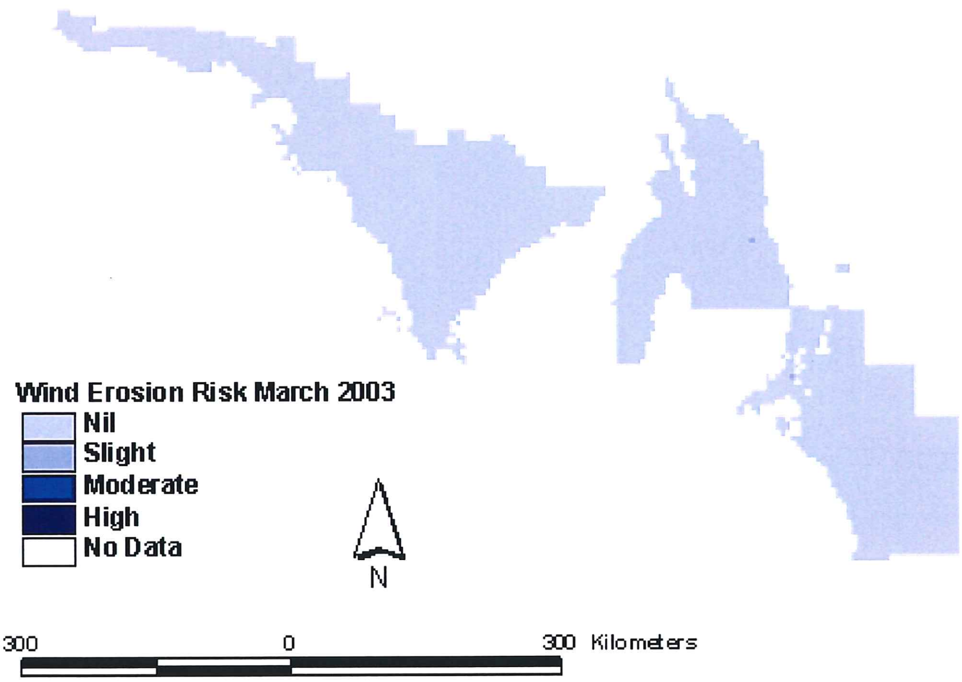
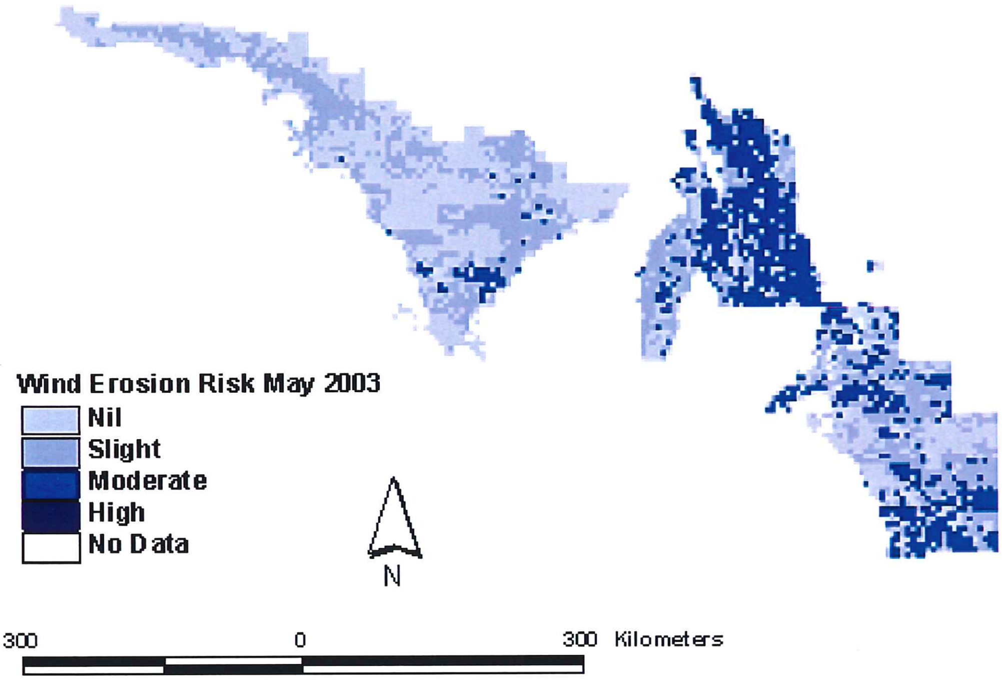
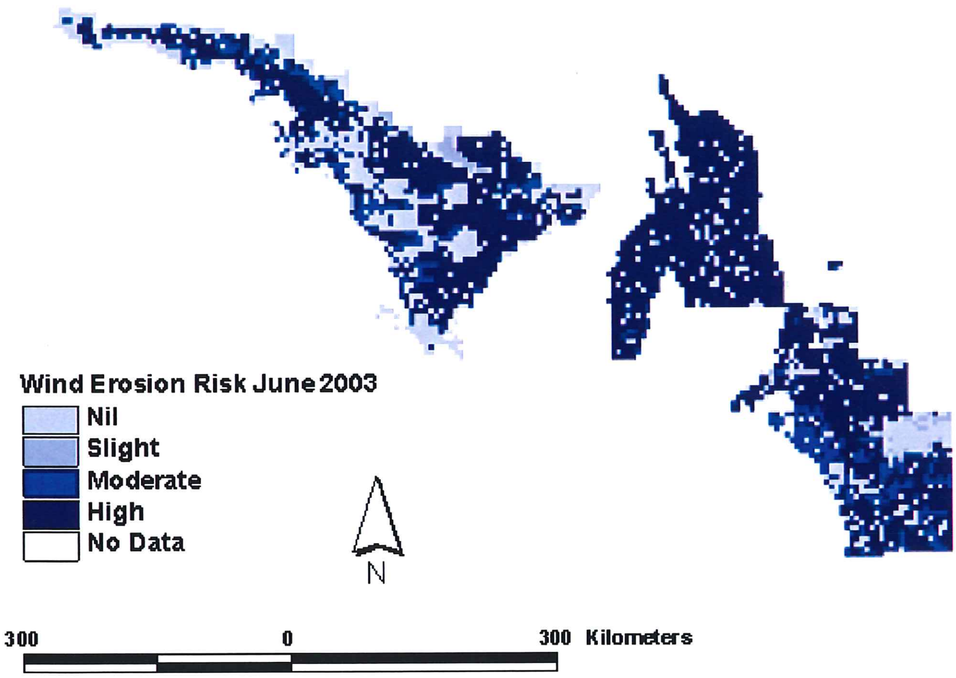


Modelled Wind Erosion Risk, March 2003



Modelled Wind Erosion Risk, May 2003



Modelled Wind Erosion Risk, June 2003

Appendix 7: Data recording sheet used in monitoring of NPLR's

Non pastoral lease rangelands district field survey recording sheet

LAND CONDITION RECORDING SHEET - NON-PASTORAL LEASE RANGELANDS

Date: ... ...

SiteID	SITE CHARACTERISATION			DETACH	TREES/SHRUBS			CHENOPOD BUSHES				NATIVE GRASS			LICHEN	COVER		WIND	SHEET RILL	OLD GULLY	NEW GULLY
	TopoR Wind	TopoR Water	Gully Depth	Rating		Graz	Dens		Graz	Dens	Heal		Graz	Dens		Rating	Forage	Sev.	Sev.	Stab.	Stab.
1-853	1-5	1-5	1-3	1-3	Species	1-3	1-7	Species	1-3	1-7	1-4	Species	1-3	1-7	0-1	1-8	1-3	1-5	1-5	1-5	1-5