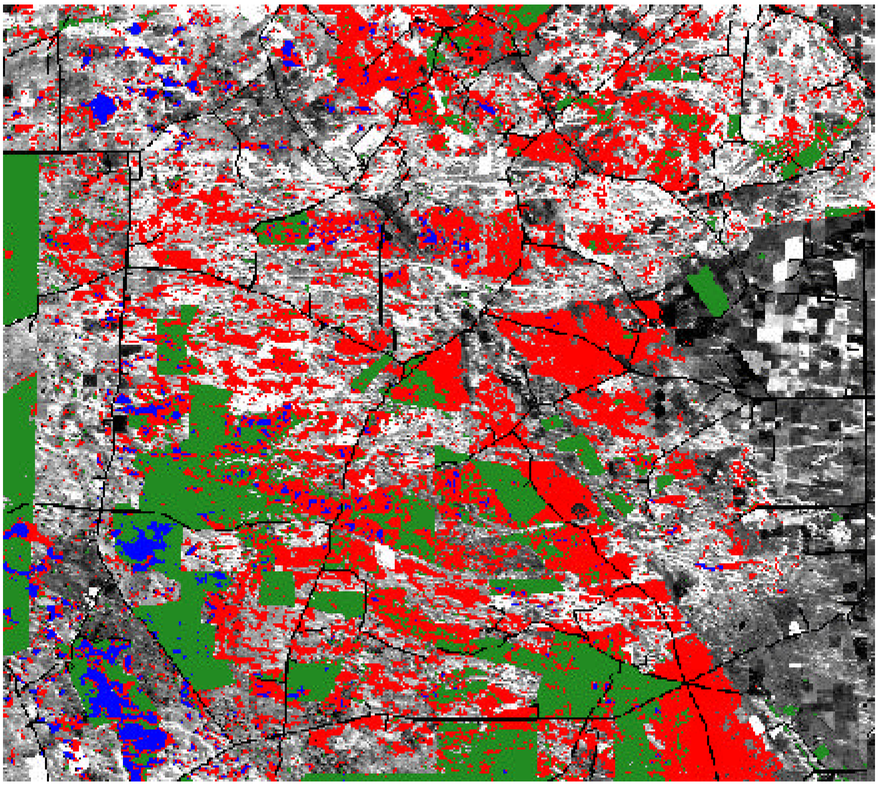
Mapping Salinity in the Upper South East Catchment

in South Australia

A report from the LWWRDC project
Mapping Dryland Salinity (CDM2)



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Summary

This report summarises the South Australian component of a project funded by the Land and Water Resources Research and Development Corporation (LWRRDC) on “Mapping Dryland Salinity” (CDM 2). The aims of the overall study are:

- to map the extent and severity of dryland salinity in three catchments using multi-temporal Landsat TM data; and
- to provide guidelines to support the use of the approach nationally.

The findings for the Upper South East catchment in South Australia are described in this report. The methodology used has been extended to include digital elevation data as well as Landsat TM imagery in the processing, since information derived from elevation data has been found to improve salinity mapping accuracy in Western Australia.

A salinity map has been produced for 90% of the Upper South East catchment using Landsat TM data from August and October 1992 and September 1997 and digital elevation data. Only small samples from this map will be presented here. Full salinity maps can be obtained from Primary Industries South Australia. 195 240 hectares of agricultural land have been mapped as salt-affected in 1997. This is approximately 15% of the catchment.

A quantitative error assessment in the northern part of the catchment shows that 75% of all salt-affected sites are being detected. Qualitative feedback from local experts suggests that all the severe salt-affected land is being mapped, but that the amount of marginally salt-affected land is being under-estimated. The marginally saline areas are supporting a very good cover of salt-tolerant grasses such as puccinellia and tall wheat grass that is adequate for grazing but sub-clover species that are not salt-tolerant will not grow. Many such areas are being detected, but their extent is not being accurately mapped. The error assessment also shows that 7% of other areas of low productivity are also being mapped as salt-affected. These are typically areas associated with waterlogging which also leads to a decline in productivity.

A qualitative assessment of the salinity map in the southern part of the catchment shows that salt-affected land is being considerably over-estimated. On the flats, there is very little discrimination between salt-affected and not salt-affected areas in the Landsat TM image data used in this study. The flats are saline discharge areas through the summer months, but act as recharge areas through the winter months. During the early parts of the growing season, the available ground water is fresh. Closer to the time of plant maturity, the system becomes saline, and plant growth and seed development is affected. The timing of the transition depends on climate patterns.

The study has demonstrated that Landsat TM images can be used, together with digital elevation data, to map salinity in the northern part of the catchment. Landsat TM images cannot be used to map salinity in areas similar to the southern part of the catchment where the salinity status is not a relatively constant factor throughout the growing season. The value of the elevation data comes from the ability to assign a more appropriate condition label to poor condition land in parts of the landscape that are not prone to salinity, such as bare hilltops or slopes.

The Upper South East Water Conservation and Drainage Advisory Committee has been informed of the results and the potential of the approach to be used as a monitoring tool to assess the effect of any changes to vegetation productivity in appropriate areas.

The findings in New South Wales and Victoria have been reported separately and a summary report comparing the results in each state with those for Western Australia has also been prepared.

Introduction

In August 1993, the Land and Water Resources Research and Development Corporation (LWRRDC) in collaboration with the Murray Darling Basin Commission, the Department of Primary Industries and Energy, and the States reviewed remote sensing with respect to dryland salinity, its research, development, and impact on land management in Australia. Three workshops were held. The most relevant of these was 'The Use of Remote Sensing in Saline Discharge Identification'. At this workshop, through a process of review and discussion, specific objectives were established for various methods of remote sensing for farm, catchment and regional scales. The emphasis was on the identification of methods / approaches which can be applied now.

The workshop concluded that the use of multi-temporal Landsat TM imagery was appropriate for mapping dryland salinity at regional (~500 000 ha area) and catchment (~30 000 ha area) scales. The current project was supported by LWRRDC to assess the transferability of methodology developed in Western Australia to other parts of Australia and to develop national guidelines for the application of the approach.

The original aims of the study were:

- to map the extent and severity of dryland salinity in three catchments using multi-temporal Landsat TM data; and
- to provide guidelines to support the use of the approach nationally.

During the course of the project, it was recognised, from work being carried out concurrently in Western Australia, that including digital elevation and using images from consecutive seasons rather than multiple images within a season improves the accuracy of the salinity maps. Images from another season have been acquired for two of the three regions considered. However, due to cloud cover constraints, the seasons are not consecutive.

The areas chosen for the study were:

- the Upper South East catchment in South Australia;
- the Lodden-Campaspe catchment in Victoria; and
- the Liverpool Plains catchment in New South Wales.

Each is a LWRRDC focus catchment with different land types and land use characteristics. The findings in New South Wales and Victoria will be reported separately and a summary report comparing the results in each state with those for Western Australia has also been prepared.

2. The Study Area

The study area is 680,000 ha in the South East of South Australia, approximately 250km south east of Adelaide. The approximate location is shown in figure 1. It abuts the coast in the west and the Tintinara, Keith, Padthaway and Naracoorte roads in the east. The northern boundary is the Woods Well and Tintinara roads, and the southern boundary is the Kingston SE, Lucindale to Naracoorte Road and railway. Figure 2 shows the September 1997 Landsat TM image of the region. The catchment boundary is shown in yellow.

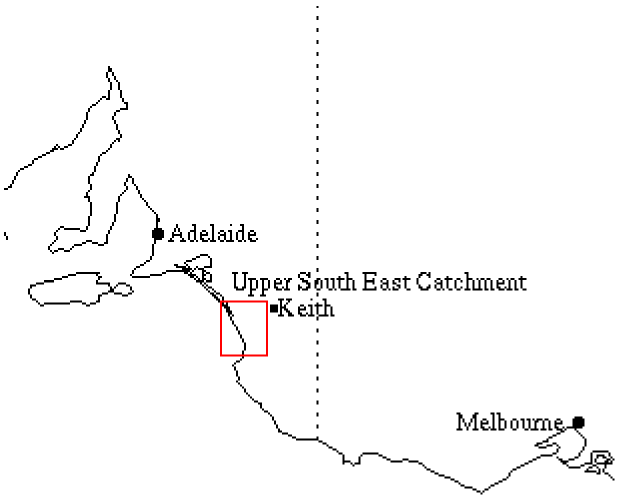

Figure 1: Location map showing the Upper South East catchment.

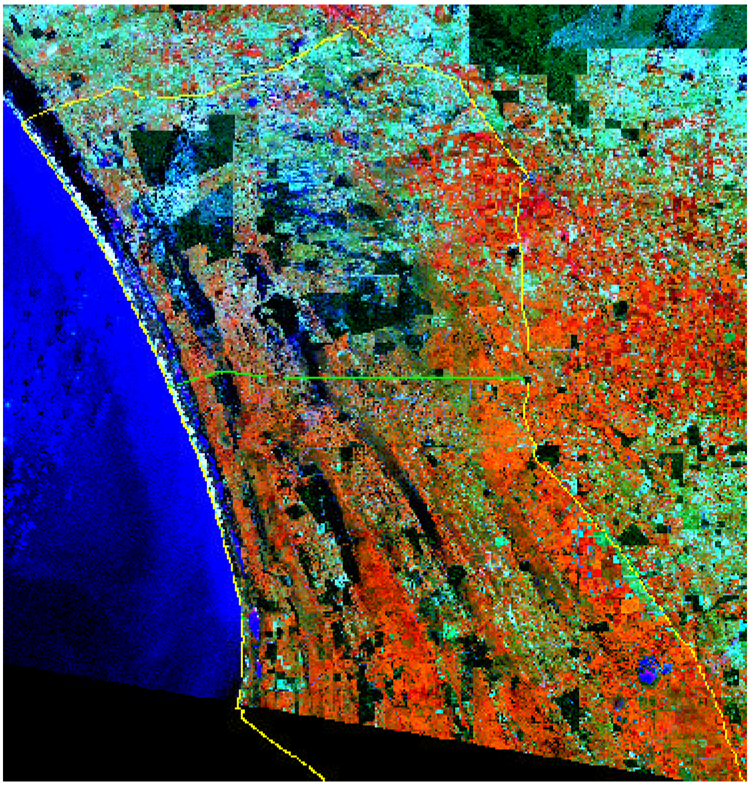

Figure 2: September 1997 Landsat TM image, bands 3, 5 and 4 in BGR. Shades of red and orange indicate good green vegetation cover. Shades of green and blue indicate less vegetation cover, through to sand dunes in white. The dark areas are remnant vegetation and the ocean appears as blue.

A gently westwardly sloping basement of limestone is overlain with north-south trending remnant coastal dunes. In the northern part of the catchment (above the green line in figure 2), a jumbled dune system exists. In the southern part of the catchment, a well-defined dune system exists. Ground water flow is east to west, with surface water generally originating in the south and flowing north.

There are significant stands of remnant vegetation and swamps in the study area. The most common land use is grazing using improved pastures for cattle and sheep. Saltland agronomy has become extensive in recent times and is reflected in the greater green vegetation cover in the southern part of the catchment (more red below the green line in the image in figure 2). Cropping is intensive on the eastern margin of the study area (more red near the yellow line in figure 2).

Surface soils were initially of low salinity due to winter leaching. The spread of agricultural development caused a more frequent and extensive downstream transfer of water along the watercourses, resulting in inundation and waterlogging. Loss of plant cover due to flooding or increased grazing results in decreased cover during summer and reduced water use, thus allowing increased groundwater evaporation at the surface, with consequent salinisation. Important factors determining the local extent of land salinisation include soil profile and capillary characteristics, groundwater salinity and local topography (Upper South East Dryland Salinity and Flood Management Plan).

Increased recharge following European settlement and large-scale clearing has contributed to raising the water table. Other factors also contribute, such as surface drains and the interaction of surface and groundwater. The net effect has been increasing areas of saline and waterlogged land with decreased productivity.

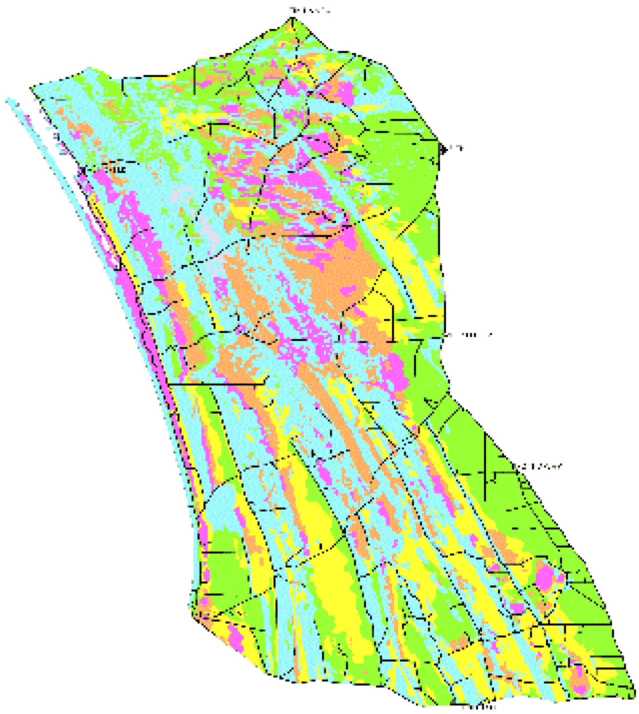

Figure 3: 1992 salinity map from airphoto interpretation and field survey. The colours are:

light blue: most land is not saline in 1992 and not at risk
green: most land is not saline in 1992, but is at risk
yellow: most land is mildly to moderately saline in 1992
orange: most land is moderately to highly saline
dark pink: most land is very highly saline
light pink: wetlands

Figure 3 shows the generalised land salinity categories derived from detailed mapping conducted in 1992. This map was created as part of the Upper South East Dryland

Salinity and Flood Management Plan. The map was formed from the interpretation of 1:40000 airphotos and field inspection. The salinity status (high, moderate, mild or at risk) of land systems was mapped and consequently it has errors at a local scale.

3. Image, Ancillary and Ground Data

The Landsat TM images used in this study are:

24 August 1992
11 October 1992
30 December 1992
24 September 1997

The sequence of images through the 1992 growing season was the most recent cloud-free sequence available at the commencement of the project in late August 1994. This sequence of images is expected to have good contrast between the very green, wet and high-growth period in spring and mid-summer when most of the perennial vegetation will have dried out. 1992 was a wet year with about double the average rainfall for June and July, with August being average. In August, much of the southern portion of the study area was covered by surface water affecting plant production, and flowing slowly north. By October, the surface water would have reached its most northerly extent. Surface water and saline groundwater in the root zone induces stress on plants, which can be observed in the imagery. In mid-summer, the surface water has receded to lakes, and pastures take on their summer characteristics of drying out.

The September 1997 image was added to the processing at a later stage to provide a more recent look at the area and to provide data from another season to allow some discrimination between management and land condition effects. The 1997 season was considered more average in terms of rainfall.

Digital height data were acquired for this project as 2m contours from Primary Industries South Australia (PISA). These data were gridded to form a digital elevation model (DEM) over the study area, from which landform units, such as hilltops, slopes and broad flat basins, were derived using water accumulation models. These procedures are described in Caccetta (1996).

Roads have been obtained digitally from PISA. Image pixels along these boundaries are spectrally mixed and have been labelled as saline in previous mapping exercises.

Ground information has been provided in three stages. Early in the project, eight farms were visited to obtain farm plans which describe the 1992 cropping and pasture program and the locations of salt-affected sites. The farms were predominantly in the northern part of the catchment. Some farm maps were drawn to scale and others just sketched. Training sites were difficult to locate because the satellite response within a paddock was often non-uniform and showed more variation than the farm manager had indicated.

Additional ground data were provided by field officers from PISA in December 1997. This provided information about the extent of salinity in representative areas in the northern part of the catchment in 1997. Sites were located directly onto prints of the September 1997 image.

In April 1998, additional validation sites were obtained in the both the northern and southern parts of the catchment. The sites in the northern part of the catchment were used to assess the salinity maps produced at that stage. The sites from the southern part of the catchment were used to reprocess the data to correct the observed problems with the salinity maps for that part of the catchment.

4. Salinity Mapping Methodology

The steps used by CSIRO to produce the salinity maps described in section 5 of this report are listed below. This is the standard methodology being used for salinity mapping work in Western Australia, except that image data from consecutive seasons is not available. More details on the methodology can be found in Furby et al (1995).

1. Co-register the images to a common map base (here, AMG coordinates at 30m pixel size). This allows ground sites to be traced through time and the satellite data to be compared to the ancillary map data, such as the DEM.

2. Calibrate the image data from different dates to a reference image so that digital counts from different image dates can be compared (Furby et al, 1996).

3. Locate ground sites of all the major cover types in each of the images.

4. Stratify the study area into zones within which there are no marked regional variations in rainfall, land-use types or rotations, geology, predominant soil types or visible patterns in the image. If there are strong differences between these zones, they should be processed separately.

5. Apply discriminant analysis procedures, in particular canonical variate analyses (Campbell and Atchley, 1981), to the training data to examine the separation of ground cover types in the TM spectral data and to determine which image dates are most appropriate and to define sensible spectral groupings of ground cover types.

6. Apply neighbourhood-modified maximum likelihood classification techniques (Campbell and Wallace, 1989) to the best individual image dates. This produces probabilities of belonging to each of the major cover classes on each date for each pixel in the images.

7. Combine the cover class probabilities from each date with position in the landscape – hill, slope, valley floor – to calculate the probability of each pixel being salt-affected. A conditional probability network has been used for these calculations (Caccetta et al 1995).

8. Post-processing to remove obvious errors in the final salinity maps such as roads being labelled as salt-affected.

Although an obvious stratification of the study area could be made into northern and southern zones, see figure 2, this was not done until the final stages of the analyses as adequate ground data for the southern part of the catchment were not obtained until April 1998.

In its simplest form, a conditional probability network (CPN) can be thought of as specifying a set of links between related datasets and a set of rules governing how those datasets are combined. The network used in this study is shown below.

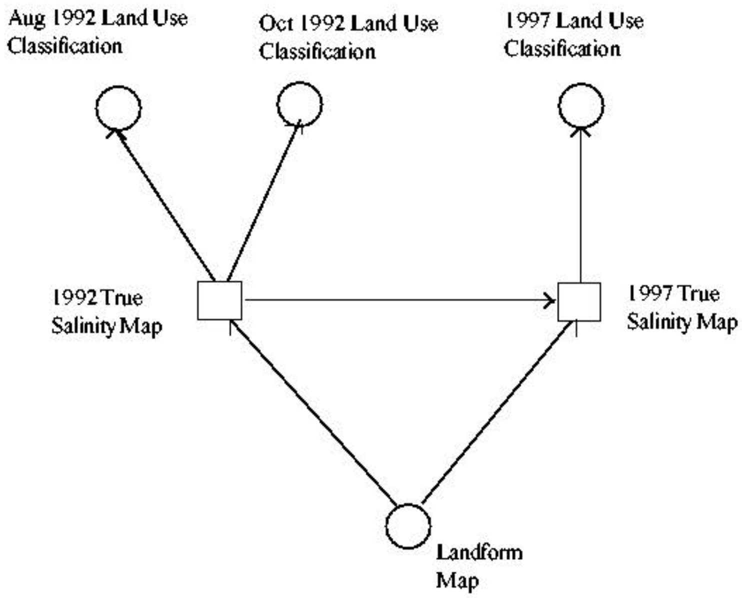

Figure 4: The conditional probability network used to produce the salinity map.

Underlying the model are the true salinity maps at each available image date (square boxes). It is these maps that are being estimated. At each image date, land-use / condition classification images (upper circles) have been formed. They are a realisation of the true salinity map. With sufficient ground data, the error rates between the true salinity maps and the land condition classifications can be estimated. There are also relationships between the true salinity maps. If it is known that an area is salt-affected at one point in time, it can be assumed that it will continue to be salt-affected in the following seasons with high probability. Also there may be some information on how likely an area is to change from non-saline to saline over a five-year interval. Similarly there is a relationship between landform (lower circle) and the true salinity maps. If the landform type of an area is known, a statement can be made about how likely it is to be salt-affected.

Each of the arrows in the diagram represents a relationship between the data sources. The exact nature of the relationships can be specified by expert knowledge; can be derived from ground training data; or can be estimated from the datasets themselves.

Conditional probability networks differ from a simple intersection of two or more data layers in two ways. Firstly, the probabilities of belonging to each land-use / condition class are the inputs to the model, not class labels. This allows a measure of uncertainty in the class label to be included in the calculations. For example, consider two sites, both labelled as salt-affected by the land-use classification. Suppose the first site has a probability of being salt-affected of 0.95 and a probability of having poor cover for other reasons of 0.05. Suppose the second site has a probability of being salt-affected of 0.60, a probability of being in poor condition of 0.30 and a probability of being in good condition of 0.10. We might have more confidence that the first site is salt-affected than the second site and want to incorporate this into the rules.

Secondly, the rules themselves are expressed in terms of probabilities, not hard yes-no rules. For example, salinity in this region is relatively rare above the valley floors. However, higher in the landscape a natural barrier to water flow, such as a road, might exist causing an area of salinity behind the obstruction. In this case, while the probability of salinity in the higher regions will be low, it is not zero.

The post-processing performed on the salinity maps was designed to correct three problems observed during the assessment phase of the project. A number of marshy areas were being labelled as salt-affected. These areas tend to be covered by shallow water all year round. Although the water is saline, the field officers thought it would be better to label these areas as water to avoid confusion with areas actively under agriculture. A water mask was calculated directly from the September 1997 image and all pixels labelled as water in this mask, were relabelled as water in the final salinity map.

Another problem observed was that several areas at the eastern fringe of the study area were incorrectly being labelled as salt-affected. Although productivity in these areas is consistently low, the cause of the problem is waterlogging not salinity. In the eastern part of the catchment, the ground water table is lower and salinity is still a very rare problem; however, waterlogging by fresh water is common. With the help of field officers, a “line” was defined, east of which salinity is rare. Areas east of this line that were labelled as salt-affected in the salinity map were relabelled as waterlogged.

The final correction was to mask pixels along roads with a roads overlay. These pixels are typically a mixture of road (bitumen, gravel or soil), roadside verge and associated vegetation and tracks along the inside edge of paddocks. They tend to be labelled as salt-affected due to a lack of vegetation cover.

5. Results

Figure 5 shows the salinity map produced for a typical region in the northern part of the catchment. Table 1 shows the assessment of the map for the northern part of the catchment only against independent validation data collected in April 1998. The figures in the table are numbers of pixels assigned to each class.

The figures in table 1 show that 75% of salt-affected sites are being detected and 7% of other poor-condition, non-saline sites are being labelled as salt-affected.

The “mixed” class represents poor condition areas where the spectral information was unable to discriminate between salinity and other causes of low productivity. This class is still split between saline and non-saline sites. For the purposes of the summary figures above, it has been assumed to be non-saline.

Table 1: Assessment of Salinity Map – Northern Zone

Salinity Map Label	Salt-affected Reference Sites	Poor Condition Reference Sites
Water	531	0
Bush	2338	4962
Salt	48491	1799
Mixed	4490	5781
Bare	1521	1310
Non-saline crop/pasture	8221	7179
Waterlogging	0	3723

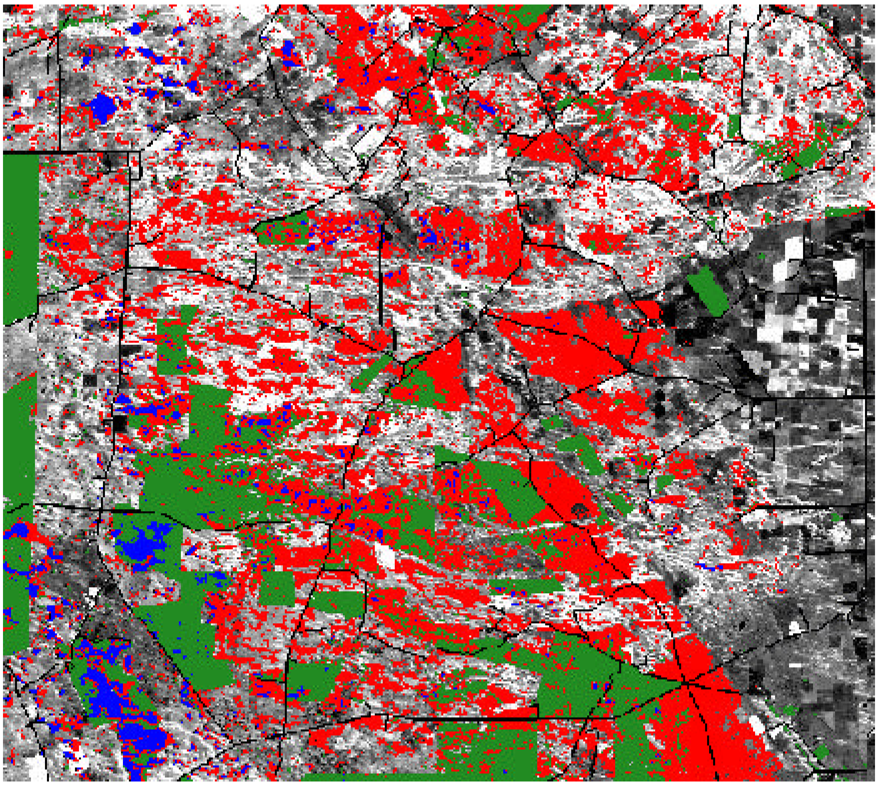

Figure 5: 1997 salinity map for a region in the northern part of the catchment.

- **red is salt-affected land**
- **green is bush**
- **blue is surface water**
- **black is major roads**
- **shades of grey are non-saline land, dark indicates good cover, bright indicates poor cover or bare soil**

The salt-affected reference sites include severe, moderate and marginally salt-affected sites as well as some of the saline marshes. The marginally salt-affected sites tend to have a very good cover of salt-tolerant species such as puccinellia and tall wheat grass. Qualitative feedback from field officers suggests that almost all of the severe and moderately salt-affected areas are being mapped, but that the extent of many marginally saline areas is being under-estimated and some areas are being missed completely.

This accords with the experience in several salinity mapping projects in Western Australia.

Some of the salt-affected reference sites from near the saline marshes are covered in remnant vegetation, rather than cleared for agriculture. There is a spectral overlap between some of these sites and bush sites that appear thin for other reasons, such as fires within reserves. For this reason, some of the salt-affected sites within the larger remnants are labelled as bush. The use of summer images to better discriminate the condition of remnant vegetation has not been investigated in this study.

The non-saline reference sites include some bush sites as well as several sites in relatively poor condition due to causes other than salinity, primarily waterlogging. The easily separable good-condition cover types are not well represented in the non-saline reference sites. Given this bias in the reference sites, 7% is not an unacceptably high commission error rate.

Figure 6 shows a sample of the same salinity map for a region in the southern part of the catchment. Table 2 shows the assessment of the map for the southern part of the catchment against independent validation data collected in April 1998.

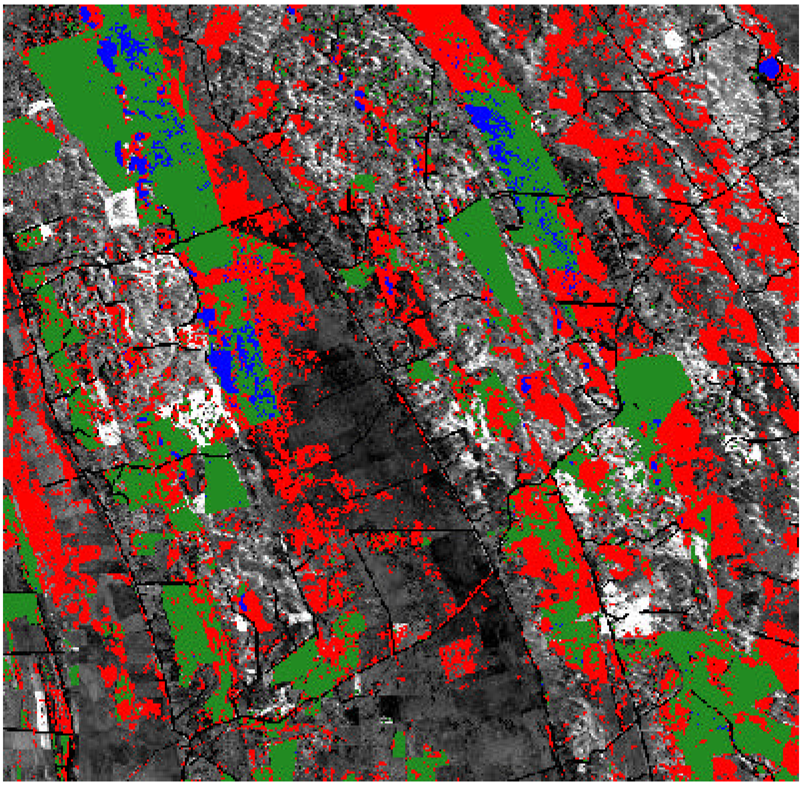

Figure 6: 1997 salinity map for a region in the southern part of the catchment.

- **red is salt-affected land**
- **green is bush**
- **blue is surface water**
- **black is major roads**
- **shades of grey are non-saline land, dark indicates good cover, bright indicates poor cover or bare soil**

Table 2: Assessment of Salinity Map – Southern Zone

Salinity Map Label	Salt-affected Reference Sites	Poor Condition Reference Sites
Water	58	0
Bush	1355	250
Salt	6872	107
Mixed	1049	86
Bare	4	145
Non-saline crop/pasture	6146	1857
Waterlogging	0	129

These figures show that only 44% of salt-affected sites are being detected and 4% of other poor-condition, non-saline sites are being labelled as salt-affected. These figures improve if the “mixed” class is considered to be saline.

In contrast to the northern part of the catchment, the southern part consists of large flat areas that are mostly marginally saline. The flat areas act as discharge zones during the summer months and as recharge zones during the winter months. Early in the growing season, the flats are a freshwater system. As the plants get closer to maturity, and the system dries out, the soil salinity increases affecting vegetation cover and seed production. Salt-tolerant species become more common in these areas as seed production of the salt-sensitive species is reduced. Typically the severely saline areas have a very good cover of salt-tolerant grasses but will not support sub-clover species which are not salt-tolerant. An example of such an area is the dark grey region in the centre of figure 6.

At the time the initial salinity map was formed, there were no adequate training data from the southern part of the catchment so it is not surprising that the accuracy is poor. The validation data have been used to retrain the classifiers for the southern part of the catchment. Figure 7 is the resultant salinity map. Most of the broad flat valleys are classified as salt-affected. Compared to the training data, 93% of the salt-affected land is detected. This is an overly optimistic estimate given that the data are no longer independent of the salinity map, but it does show that the new salinity map has addressed many of the problems in the original version.

A qualitative assessment of the salinity map in the southern part of the catchment shows that salt-affected land is now being over-estimated. Almost all of each flat area is being labelled as salt-affected; however, there are parts of these flats that are not yet salt-affected at all. Salinity only affects vegetation cover in this region in late spring and through the summer months. During winter and early spring, the flat areas have a uniformly excellent vegetation cover of both salt-tolerant and salt-sensitive species, and are more productive than the non-saline areas higher in the catchment. On the flats, there is very little discrimination between salt-affected and not salt-affected areas in the Landsat TM image data used in this study.

Using the training data from the northern part of the catchment, some of the more severely salt-affected land can be mapped; however, an accurate map cannot be produced showing the current extent of all salt-affected areas in the southern part of the catchment.

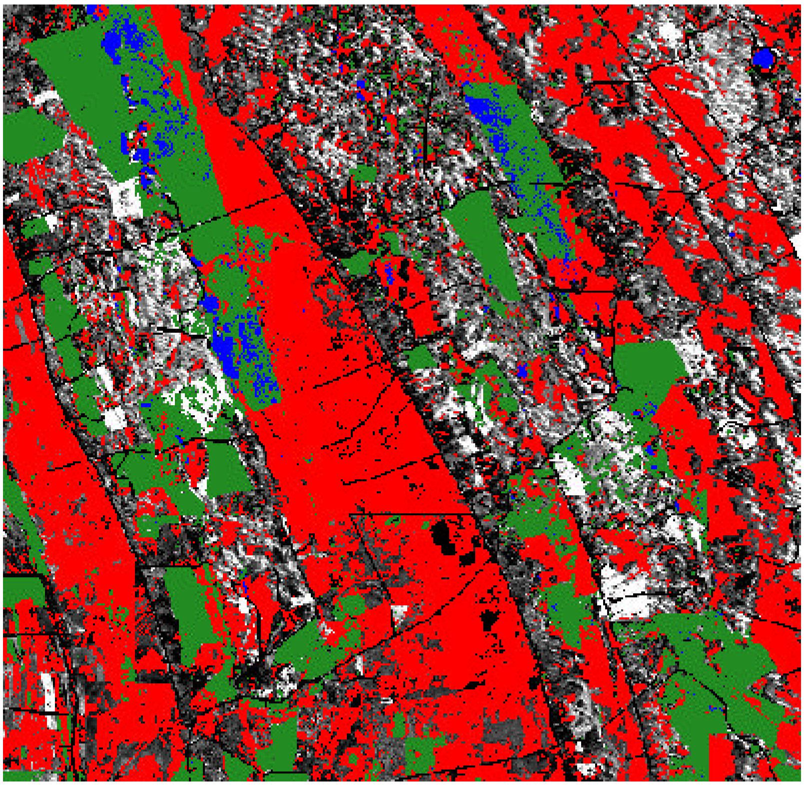

Figure 7: Improved 1997 salinity map for a region in the southern part of the catchment.

- **red is salt-affected land**
- **green is bush**
- **blue is surface water**
- **black is major roads**
- **shades of grey are non-saline land, dark indicates good cover, bright indicates poor cover or bare soil**

6. The Contribution of the Elevation Data

The results presented so far have used the digital elevation data as one of the data sources. This dataset was outside the original scope of the project. To assess its effect on the accuracy of the salinity mapping in this catchment, a comparison was made by running the CPN model without the landform information. The table below shows the accuracy assessment for the northern part of the catchment. The figures in the table can be compared directly to the figures in table 1.

The figures show that 74% of salt-affected reference areas are detected in the salinity map formed without landform information (75% with landform); the commission errors have increased from 7% to 8.5%.

Table 3: Assessment of 'No Landform' Salinity Map – Northern Zone

Salinity Map Label	Salt-affected Reference Sites	Poor Condition Reference Sites
Water	531	0
Bush	2151	4935
Salt	48514	2113
Mixed	7614	8645
Bare	1396	1248
Non-saline crop/pasture	5386	4588
Waterlogging	0	3225

In the salinity map formed without landform, more pixels have been allocated to the "mixed" class. This class represents areas with poor vegetation cover where the spectral information cannot discriminate between salinity and causes of low productivity. By including landform information, the proportion of the image assigned to this mixed class is considerably reduced.

The value in using landform information comes from the ability to assign a more appropriate condition label to poor condition land in parts of the landscape that are not prone to salinity, such as bare hilltops or slopes.

7. Conclusions

This study has shown that salinity can be mapped to an adequate accuracy in the northern part of the Upper South East catchment. A quantitative error assessment showed that 75% of all salt-affected sites are being detected. Qualitative feedback from local experts suggests that all the severe salt-affected land is being mapped, but that the amount of marginally salt-affected land is being under-estimated. The marginally saline areas are supporting a very good cover of salt-tolerant grasses such as puccinellia and tall wheat grass that is adequate for grazing but sub-clover species that are not salt-tolerant will not grow. Many such areas are being detected, but their extent is not being accurately mapped. The error assessment also shows that 7% of other areas of low productivity are also being mapped as salt-affected. These are typically areas associated with waterlogging which also leads to a decline in productivity.

A qualitative assessment of the salinity map in the southern part of the catchment shows that salt-affected land is being considerably over-estimated. On the flats, there is very little discrimination between salt-affected and not salt-affected areas in the Landsat TM image data used in this study. The flats are saline discharge areas through the summer months, but act as recharge areas through the winter months. During the early parts of the growing season, the available ground water is fresh. Closer to the time of plant maturity, the system becomes saline, and plant growth and seed development is affected. The timing of the transition depends on climate patterns.

The study has demonstrated that Landsat TM images can be used, together with digital elevation data, to map salinity in areas similar to the northern part of the Upper South East catchment. Landsat TM images cannot be used to map salinity in areas similar to the southern part of the catchment where soil salinity varies from negligible to potentially quite high throughout a full growing season. The mapping process described here uses individual Landsat TM images to identify areas of low productivity. Images from the time of maximum green vegetation cover are used to provide maximum discrimination between areas of high and low productivity. The multi-temporal sequence and the ancillary data are used to identify areas of persistent low productivity most likely to be associated with salinity. The processes driving salinity in the southern part of the catchment are such that productivity is not affected until later in the growing cycle so salt-affected land is not necessarily associated with a loss in productivity, making salinity difficult to map using single-scene Landsat TM data. Later in the growing cycle, when salinity is a factor governing plant maturity and seed development, there is less discrimination between good and poor vegetation cover.

The study has also shown that elevation data, processed to identify landform units, such as hilltops, slopes and valleys, contributes to the accuracy of the salinity maps produced. The value of elevation data comes from the ability to assign a more appropriate condition label to poor condition land in parts of the landscape that are not prone to salinity, such as bare hilltops or slopes.

The Upper South East Water Conservation and Drainage Advisory Committee has been informed of the results and of its potential to be used as a monitoring tool to assess the effect of any changes to vegetation productivity in appropriate areas.

Continuing work in the Upper South East catchment by PISA will attempt to assign severity labels (high, moderate-high, moderate and marginal) to the areas that have been mapped as salt-affected.

8. References

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