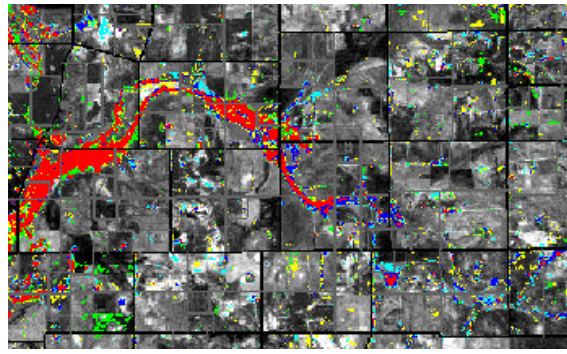
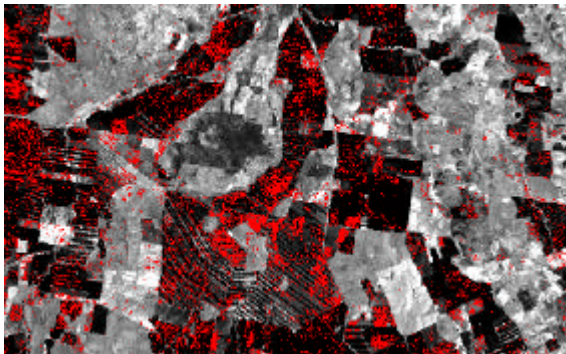
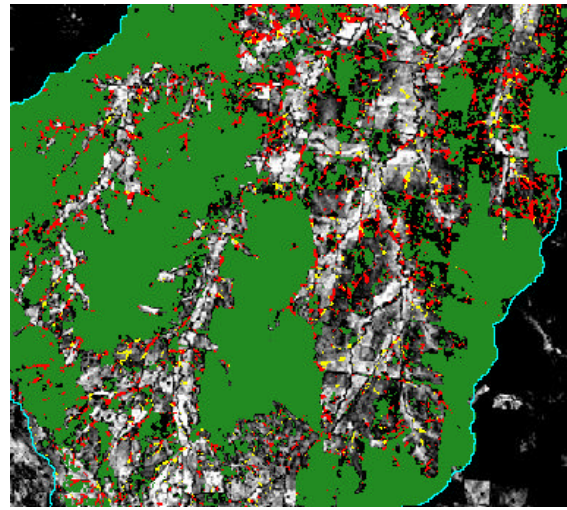
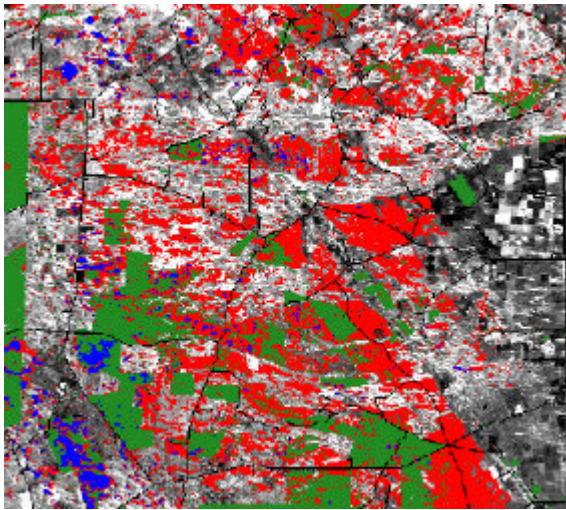


# Mapping Dryland Salinity in Selected Catchments Across Australia

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



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## Summary

This report summarises the findings 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 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.

This report describes the findings for the three eastern states catchments and compares them to typical results for catchments in Western Australia. The methodology used has been extended to include digital elevation data and Landsat TM imagery in the processing for two of the three catchments, since information derived from elevation data has been found to improve salinity mapping accuracy in Western Australia.

The salinity maps for the Western Australian catchments and for the northern part of the Upper South East catchment in South Australia are adequate for use by catchment groups and field officers for making decisions on how to allocate resources and manage the land. These salinity maps are formed from image data from two or three consecutive years (separate years in South Australia) and landform units - hilltops, slopes and valleys - derived from the digital elevation data.

In the Liverpool Plains catchment, a strategy has been developed that will lead to an adequate salinity map of the area. The approach requires at least five or six images over a two-year period to allow for both winter and summer cropping cycles. Since more satellite images are required, the mapping cost will be higher.

The salinity maps produced for the Loddon-Campaspe catchments and the southern part of the Upper South East catchment are not adequate.

The salinity mapping failed in the southern part of the Upper South East catchment due to the different salinity process operating there. Unlike the other catchments, salinity only affects plant growth during the latter part of the growing season. The system is fresh during the early growth stages during winter and becomes progressively saline by summer. This only affects plants at or near maturity and in the seed development phase.

Better training data and images from at least three consecutive seasons may improve the salinity mapping accuracy in the Loddon-Campaspe region. It is unlikely that the process will be able to adequately discriminate between waterlogged and saline areas on a consistent basis when spiny rush is the dominant vegetation cover.

The ingredients of a successful salinity mapping process have been found to be:

- satellite images from consecutive growing seasons;
- digital elevation data;
- good, representative ground data;
- active collaboration with field officers in the area being mapped;
- appropriate data integration methods; and
- skilled data analysts.

With these ingredients in place, salinity can be mapped in regions where it causes a decrease in productivity at the time(s) of maximum green vegetation cover and is one of the more common causes of productivity decline.

## 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. A workshop on 'The Use of Remote Sensing in Saline Discharge Identification' was held. 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 (CDM2) was supported by LWRRDC to assess the transferability of the 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.

The areas chosen for the study were:

- the Upper South East catchment in South Australia;
- the Loddon-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.

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 would improve the accuracy of the salinity maps. Digital elevation data have been included in the analyses for the Upper South East and Loddon-Campaspe catchments. Images from another season were also obtained for these two catchments; however, it was not possible to obtain data for the season prior to or following the original image dates.

This report summarises the findings in each of the three LWRRDC focus catchments and compares the results with work in the Ninan, Xantippe and Ryan's Brook catchments in Western Australia. From these comparisons, general recommendations for the applicability of this methodology across Australia are presented.

More detailed reports on the salinity mapping in each catchment have also been prepared. They are:

- Furby et al (1998) for the Upper South East catchment
- Furby (1998) for the Loddon and Campaspe catchments
- McGowen (1995) for the Liverpool Plains catchment
- Furby et al (1995) for the Ninan and Xantippe catchments
- Evans and Kiiveri (1998) for the Ryan's Brook catchment

## 2. Salinity Mapping Methodology

The steps used to produce the salinity maps for each catchment are listed below. This is the standard methodology being used for salinity mapping work in Western Australia. More details on the methodology can be found in Furby et al (1995).

1. Co-register the images to a common map base. This allows ground sites to be traced through time and the satellite data to be compared with 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, determine which image dates are most appropriate and 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 is 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.

Salinity maps were produced by the methodology listed above for the Western Australian catchments. Satellite images from consecutive seasons were readily available. Similar methodology was applied in both Victoria and South Australia; the exception was that images from consecutive seasons were not available.

In the Liverpool Plains catchment in New South Wales, landform information was not available. Single-date classifications were combined by means of simple rules applied in a GIS environment, rather than using a conditional probability network.

The post-processing performed on the salinity maps was designed to correct problems observed during the assessment phase of the project. In all catchments where road data were readily available, pixels along roads were masked. 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 the lack of vegetation cover.

In the Upper South East catchment, 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 in the Upper South East catchment 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. All areas east of this line that were labelled as salt-affected in the salinity map were relabelled as waterlogged.

### 3. The Study Areas

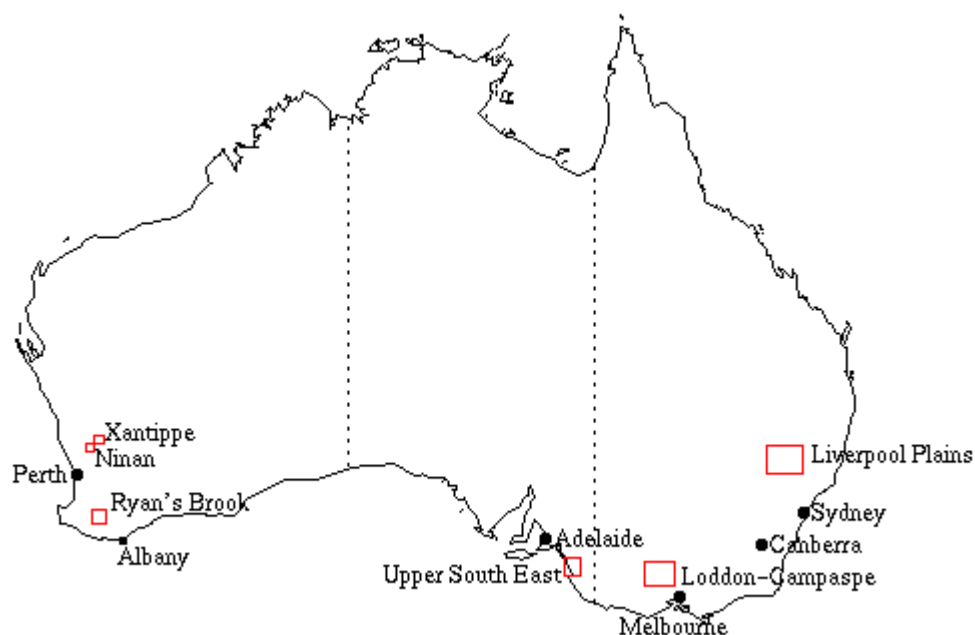


Figure 1: Location map showing the catchments.

#### 3.1 Upper South East catchment

The Upper South East catchment covers approximately 680,000 ha in the south-east of South Australia, approximately 250km south east of Adelaide.

A gently westwardly sloping basement of limestone is overlain with north-south trending remnant coastal dunes. In the northern part of the catchment, a jumbled dune system

exists. This is characterised by small flat areas between intersecting sandy dunes. In the southern part of the catchment, a well-defined dune system exists. This is characterised by large, low, flat areas separated by narrow dunes. Average annual rainfall is between 400 and 600mm.

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. Cropping is intensive on the eastern margin of the study area. Saltland agronomy has become extensive in recent times.

In the southern part of the catchment, the flat areas between the dunes act as 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.

### **3.2 Liverpool Plains catchment**

The Liverpool Plains covers an area of approximately 1.2 million hectares in the north-eastern part of New South Wales.

The plains contain an extensive area of extremely flat country, with 46% of the catchment having a 2% or less slope. The major land use on these flat areas is mixed summer and winter cropping, including periods of fallow. As a means to prevent erosion, strip cropping with strips of between 80 – 250 metres wide has been favoured. Areas with greater than 2% slope are primarily used for grazing of unimproved pastures.

Black earth soils predominate. They have a high flood hazard, localised seasonal waterlogging and an increasing salinity hazard. The average annual rainfall for the region is 600 to 690 mm increasing with elevation. There is a rainfall peak in summer due to summer storms.

### **3.3 Loddon and Campaspe catchments**

The Loddon and Campaspe catchments are part of the Murray Darling Basin and drain into the Victorian side of the Murray River. The region is centred on Bendigo in central Victoria. For the purpose of this project, the study area is the dryland salinity part of the catchments. The Campaspe catchment has an area of 443,100 hectares and the Loddon catchment covers 930,000 hectares, within a 120km by 230km region.

The southern parts of the catchments are “hill country”. This is characterised by high relief with well-dissected streamlines. The land use is predominantly improved pastures. Further north, the terrain becomes flatter and cropping is more prevalent. Agriculture in the area predominantly consists of wool, fat lamb and wheat production. Other crops include oats, barley, lupins, fieldpeas, chickpeas, canola and safflower. The average annual rainfall is between 400mm and 600mm in the southern part of the region and between 300 and 400mm further north.

The majority of salinity is occurring in the hill country. This is characterised by stream discharge and break-of-slope discharge. This is particularly evident as narrow linear areas associated with stream patterns. Salinity levels range from marginal areas

characterised by low-productivity cropping and increasing levels of indicative salt-tolerant plant species, such as sea barley grass and spiny rush, to severe areas dominated by bare, salt-encrusted ground with dead or dying trees.

### 3.4 Western Australian catchments

The Ninan and Xantippe catchments in Western Australia are in the northern wheatbelt, approximately 200km north-east of Perth. The major landuse in both catchments is a cropping (wheat) and pasture (sheep) rotation. Some lupins, barley and, increasingly, canola are also grown. The Ninan catchment has largely clay-based soils and an average annual rainfall of about 480mm. The Xantippe catchment has sandier soils and a lower annual rainfall of about 350mm.

The Ryan's Brook catchment is approximately 300km south-east of Perth. It is a sub-catchment of the Upper Blackwood catchment. Ryan's Brook catchment was used as a validation area for the Blackwood catchment salinity mapping and monitoring work. Historically the major landuse in the area has been grazing; however, with the falling wool prices, cropping is becoming more prevalent. The average annual rainfall is between 400 and 600mm.

## 4. Image, Ancillary and Ground Data

In all but the Ryan's Brook catchment, a sequence of Landsat TM images was obtained covering a single growing season. At the commencement of this project, using multiple images from a single growing season had been identified as the most promising approach for salinity mapping. Subsequent work in Western Australia (Furby et al, 1995) showed that having images from 2 or 3 consecutive seasons was the optimal way to discriminate between low productivity caused by long-term land condition problems, such as salinity, and low productivity caused by short-term management, such as overgrazing. Additional scenes were acquired for the Upper South East and Loddon-Campaspe catchments, but it was not possible to obtain images for seasons consecutive with the original images due to cloud cover.

Table 1 summarises the image data used to produce the salinity maps described here for each catchment.

**Table 1: Landsat TM Images Used for Each Catchment**

<b>Upper South East - SA</b>	<b>Loddon-Campaspe - VIC</b>	<b>Liverpool Plains - NSW</b>	<b>Ninan, Xantippe - WA</b>	<b>Ryan's Brook - WA</b>
24 Aug 1992 11 Oct 1992 24 Sep 1997	19 Aug 1992 22 Oct 1992 15 Oct 1995	29 Sep 1991 16 Nov 1991 18 Dec 1991 19 Jan 1992	29 Sep 1987 15 Sep 1988 Sep 1989 20 Aug 1990 23 Oct 1990 23 Aug 1991 26 Sept 1992 23 Aug 1993	Aug 1989 Sep 1990 Sep 1993 Aug 1994

Digital elevation data were acquired for all but the Liverpool Plains catchment. In the case of the Loddon and Campaspe catchments, digital elevation models (DEMs) were provided by CSIRO Land and Water on a 20m grid for the Axe Creek catchment and on a 100m grid for the whole study area. Contour data were supplied for the Upper South East (2m), Ninan and Xantippe (10m) and Ryan's Brook (10m) catchments. These data were gridded to form DEMs. Landform units, such as hilltops, slopes and valleys, were derived from the DEMs using water accumulation models. These procedures are described in Caccetta (1996).

Digital elevation data were not acquired for the Liverpool Plains catchment. The salinity mapping work had been completed in that catchment before the full value of landform information became apparent from work in Western Australia. However, since the cropped areas are all very flat, landform is likely to contribute little in such a region unless a very high resolution DEM is available.

Roads have been obtained digitally for the South Australian, Victorian and Western Australian catchments. Image pixels along these boundaries are spectrally mixed and have been labelled as saline in previous mapping exercises. Road data exist, but were not obtained for the other catchments.

Ground information has been provided for all catchments as a combination of annotated farm plans and satellite images annotated during field visits. In the Western Australian and Liverpool Plains catchments, some of the training data were reserved for validation of the salinity maps. In the Victorian and South Australian catchments, additional validation sites were acquired after the images had been processed.

## 5. Results and Discussion

Only a summary of the results of the salinity mapping in each catchment is presented here. Full details of the results can be found in the individual reports, listed in section 1 of this report.

Table 2 shows the accuracy assessment for the best salinity map produced for each region. Except for the Liverpool Plains catchment and the southern part of the Upper South East catchment, these assessments have been performed using independent ground data. The estimates for the other regions are estimates by the field officers involved.

**Table 2: Assessment of the Salinity Maps for Each Catchment Against Independent Ground Data**

Catchment	Salt-affected Land Detected	Non-saline Land labelled as Salt-affected
Upper South East (north)	75%	7%
**Upper South East (south)	> 90%	Too much
Loddon-Campaspe	55%	20%
** Liverpool Plains	~ 90%	6-10%
Ninan	88% (96% bare, 81% marg)	4%
Xantippe	70% (78% bare, 31% marg)	1%
Ryan's Brook	81%	7%

\*\*Estimates for these regions were provided by field officers

The salinity maps for the Western Australian catchments have been judged as adequate for use by catchment groups and field officers for making decisions on how to allocate resources and manage the land. Salt-affected areas that are not detected by the salinity mapping process are typically marginally saline areas supporting a good cover of salt-tolerant species or areas where productivity decline is as yet only small. Non-saline areas that are labelled as salt-affected are typically persistently bare areas such as roadside verges, dams and gravel pits and areas of persistently poor productivity caused by factors such as waterlogging and severe wind erosion.

The value of elevation data, in the form of landform units such as hilltop, slope and valley, 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.

In the rest of this section, the results for the catchments in the eastern states will be compared with those for the Western Australian catchments.

### **5.1 Upper South East Catchment**

The results for the northern part of this catchment are very similar to those in Western Australia. 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. The non-saline sites labelled as salt-affected include some "thin" bush sites as well as several sites in relatively poor condition due to causes other than salinity (primarily waterlogging). The salinity map is adequate for use in catchment planning.

In contrast to the northern part of the catchment, the southern part consists of large flat areas that are mostly marginally saline. 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. 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.

The major difference between the southern part of this catchment and the Western Australian catchments is the nature of the salinity process occurring. 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. Productivity is not affected until later in the growing cycle so salt-affected land is not necessarily associated with a loss of green vegetation cover, 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 in the satellite images.

## 5.2 Liverpool Plains Catchment

A final salinity map has not been produced for this region; however, a successful strategy for producing one has been identified. Factors affecting the salinity mapping process in the Liverpool Plains region that are not present in Western Australia are:

- the practice of strip cropping;
- crop stubble left on fallow strips; and
- variable crop sowing times and growth rates.

As a means to prevent erosion, strip cropping with strips of between 80 – 250 metres wide has been favoured. There are numerous “mixed” pixels that lie on the boundaries between the strips. Winter crop strips are usually adjacent to both summer crop and fallow strips, causing a mixture of crop and bare or treated soil in the edge pixels. These pixels are spectrally similar to salt-affected crop. Mixed pixels also occur in Western Australia at the edges of paddocks; however, since paddocks are much larger than the strips, the proportion of such pixels in the image is much lower.

Only 30–40% of the strips are cropped at any one time. Crop stubble is often left on the fallow strips as a means of erosion control. The strips are also usually treated to prevent weeds, which prevents the growth of volunteer plants. The spectral signature of fallow paddocks is very similar to the signature of salt scalds on the black earth soil types. At any single date, large areas of the catchment are left fallow.

This catchment differs from the others considered in this study in that there is both summer and winter cropping. Variable crop sowing times and growth rates within each growing season, particularly in summer, make it difficult to find single images when most of the cropped areas have good canopy cover.

The salinity mapping strategy adopted in this region is essentially the same as for the other regions; however, images are required for each “growing season” within the year and multiple images from within a single growing season are more valuable. Since more images are required, the cost of the salinity mapping process is greater than for areas with a single growing season per year.

## 5.3 Loddon and Campaspe Catchments

An adequate salinity map has not been produced for this region. The sites incorrectly labelled in this study area fall into the following categories:

- salt-affected areas supporting a cover of sea barley grass (a salt-tolerant species) are labelled as non-saline;
- waterlogged areas covered in spiny rush ( a water-tolerant species found on both waterlogged and salt-affected sites) are labelled as salt-affected; and
- persistently bare areas such as roadside verges, houses and shops and tracks through the forest are labelled as salt-affected.

Very few training sites of sea barley grass were provided. The sites that were provided were very similar spectrally to poor pasture areas and could not be separated using a single image date. A cover of sea barley grass is common on salt-affected sites in this region. Similar problems have been encountered in mapping salt-tolerant grasses in Western Australia, and the accuracy is generally lower for such areas than for more severely salt-affected sites.

Spiny rush is a species that is associated with wet land in the Loddon-Campaspe catchment area. It is a good indicator of persistent waterlogging, but is equally common on both saline and fresh areas. Spiny rush is not considered an indicator of salinity unless other salt-tolerant species are also present. Several training sites covered in spiny rush were provided as being salt-affected, leading to all occurrences of spiny rush being mapped as salt-affected. In situations where spiny rush is the dominant vegetation cover, it is not possible to discriminate between salt-affected and waterlogged land. Rush species are also an indicator of waterlogging in the Upper South East catchment in South Australia; however, the species that are common in that region are restricted to fresh water areas only.

The persistently bare sites that have been mapped as salt-affected are all man-made structures that can be expected to be consistently free of vegetation. Such structures are also usually mapped as salt-affected in Western Australia; however, there are fewer such structures in typical Western Australian rural areas. The persistently bare validation sites cannot be reliably separated from salt-affected land using the available image data. The only alternative is to manually identify such sites and mask them.

Better training data and images from at least three consecutive seasons may improve the salinity mapping accuracy. Better training data would include more examples of all the types of salinity present in the region, in particular, sea barley grass areas. Data from consecutive seasons would allow better discrimination between short-term management effects, such as poor pasture due to over-grazing, and long-term land condition effects, such as salinity and waterlogging. It is unlikely that the process will be able to adequately discriminate between waterlogged and saline areas on a consistent basis when spiny rush is the dominant vegetation cover.

Data from these catchments were also used to compare methods for combining the single-date classifications into a salinity map (landform data were not available at the time of the comparison). The study (Furby, 1997) showed that using CPNs to perform the data integration produced more accurate salinity maps (more salt-affected areas detected) with lower commission errors than the GIS-type approach of intersecting class labels. The value of the CPN approach comes from the fact that the probabilities of belonging to each land-use / condition class are the inputs to the model, rather than a single class label. 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, although hillside seeps are common in the region, this is only one cause of low productivity above the valley floors. When landform information is used, the probability of salinity in the higher regions will be low, but it is not zero. This allows a measure of certainty in the rules to be included in the calculations.

## 6. Conclusions

The salinity maps for the Western Australian catchments and for the northern part of the Upper South East catchment in South Australia are adequate for use by catchment groups and field officers for making decisions on how to allocate resources and manage the land. These salinity maps are formed from image data from two or three consecutive years (separate years in South Australia) and landform units - hilltops, slopes and valleys - derived from the digital elevation data.

In the Liverpool Plains catchment, a strategy has been developed that will lead to an adequate salinity map of the area. The approach requires at least five or six images over a two-year period to allow for both winter and summer cropping cycles. Since more satellite images are required, the mapping cost will be higher.

The salinity maps produced for the Loddon-Campaspe catchments and the southern part of the Upper South East catchment are not adequate.

The salinity mapping failed in the southern part of the Upper South East catchment due to the different salinity process operating there. Unlike the other catchments, salinity only affects plant growth during the latter part of the growing season. The system is fresh during the early growth stages during winter and becomes progressively saline by summer. This only affects plants at or near maturity and in the seed development phase.

Better training data and images from at least three consecutive seasons may improve the salinity mapping accuracy in the Loddon-Campaspe region. It is unlikely that the process will be able to adequately discriminate between waterlogged and saline areas on a consistent basis when spiny rush is the dominant vegetation cover.

In general, these salinity mapping studies have shown that image data from multiple consecutive growing seasons is required to discriminate between short-term causes of low productivity, such as over-grazing, and longer-term causes of low productivity, such as salinity. In areas such as Western Australia, where there is a single winter cropping season, images from, ideally, three consecutive years are required. In areas such as the Liverpool Plains catchment, where there is both winter and summer cropping, images from each cropping season are required over at least two years.

It was not possible to obtain such image sequences for some catchments in this study. Cloud cover can mean that it is not possible to obtain images in some years. Drought conditions or unusually wet seasons can also make images unsuitable for mapping land condition.

The value of elevation data, in the form of landform units such as hilltop, slope and valley, 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. This can greatly reduce the amount of non-saline land exhibiting low productivity labelled as salt-affected.

The methods used to combine the single-date classification with the landform information are also vital to successful salinity mapping. The value of the CPN approach comes from the fact that the probabilities of belonging to each land-use / condition class are the inputs to the model, rather than a single class label. This allows a measure of uncertainty in the class label to be included in the calculations. Secondly, the rules themselves are expressed in terms of probabilities, not hard yes-no rules. This allows a measure of certainty in the rules to be included in the calculations.

Active collaboration with skilled field officers is a vital ingredient in the salinity mapping process. Detailed ground data are required in small, representative parts of the region to be mapped. Examples of all the expressions of salinity in the region must be provided. Ongoing involvement of the field officer allows the identification of the factors affecting salinity in the region (and identification of appropriate ancillary data sets), assessment and refinement of preliminary maps and guidance on the appropriate rules and relationships that should be modelled by the CPN. Ground data processes are documented in Furby et al, 1997.

Skilled data analysts are the final essential ingredient in a successful salinity mapping process. Early attempts at salinity mapping in the Upper South East and Loddon-Campaspe catchments didn't reach satisfactory conclusions because the data analysts did not have the resource-base of a group of active image analysts to call on after an initial training phase. This was compounded by a lack of ground data support.

In summary, the ingredients of a successful salinity mapping process have been found to be:

- satellite images from consecutive growing seasons;
- digital elevation data;
- good, representative ground data;
- active collaboration with field officers in the area being mapped;
- appropriate data integration methods; and
- skilled data analysts.

With these ingredients in place, salinity can be mapped in regions where it causes a decrease in productivity at the time(s) of maximum green vegetation cover and is one of the more common causes of productivity decline.

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