# THE LAND MONITOR PROJECT

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## Abstract

The Land Monitor Project is providing information over the southwest agricultural region of WA. It is assembling and processing sequences of Landsat TM data, a new high-resolution digital elevation model (DEM) and other spatial data to provide monitoring information on the area of salt-affected land, and on changes in the area and status of perennial vegetation over the period 1988-2000. Land Monitor is a multi-agency project of the Western Australian Salinity Action Plan supported by the Natural Heritage Trust. The Project will also providing estimates of areas at risk from secondary or future salinisation, based on the historical salinity maps and a set of landform variables derived from the high resolution DEM.

Sequences of calibrated Landsat Thematic Mapper satellite images integrated with landform information derived from height data, ground truthing and other existing mapped data are used as the basis for monitoring changes in salinity and woody vegetation. Procedures for accurate registration and calibration were developed by CSIRO Mathematical and Information Sciences (CMIS), as were the data integration procedures for salinity mapping and prediction. For the DEM, heights are derived on a 10m grid from stereo aerial photography flown at 1:40,000 scale, using soft-copy automatic terrain extraction (image correlation) techniques.

Land Monitor products include: high resolution DEMs; calibrated sequences of Landsat imgery; present and historical salinity maps; predicted salinity maps; maps of change in vegetation status and spectral/temporal statistics. These products are available in a range of formats and scales, from paddock to catchment and shire scales to suit customer needs.

### 1 Introduction

Since settlement by Europeans, the south-west of Western Australia has been extensively cleared for agriculture. The replacement of native perennial vegetation with annual pastures and crops has altered the hydrological balance. Ground waters are generally rising across the region with consequent increases in dryland and stream salinity.

The WA State of Environment Report (1998) identified land salinisation, salinisation of inland waters, and maintenance of biodiversity as the three highest priority environmental issues in Western Australia. However, at that time, the state of knowledge of the extent and changes in dryland salinity was poor. Government agencies and landholders have grossly underestimated the extent of salt-affected land in the agricultural areas of Western Australia (Ferdowsian et al, 1996). The effect of salinity on the extent and condition of native vegetation in the south-west had not been accurately assessed. The WA Salinity Action Plan is a coordinated attempt to address the issue. It was released in 1996 and stated that over 70% of Australia's dryland salinity could be found in WA. It estimated that about 1.8 million ha in WA were already salt-affected, and that this area could double in the next 15 to 25 years and then double again before reaching equilibrium.

At the same time, a LWRRDC-funded research project CDM1 'Detecting and Monitoring Land Changes in Land Condition through time using Remotely Sensed Data' had been carried out by CSIRO Mathematical and Information Sciences (CMIS) in Perth. The project demonstrated that sequences of Landsat TM data could be used for mapping and monitoring salt affected land and changes in perennial vegetation in WA's agricultural regions. Associated research developed and demonstrated a method for prediction of the future extent of saline land using TM data, high-resolution digital elevation models (DEMs), and expert ground knowledge.

The Land Monitor project is a three-year (1998-2000) operational project built on these results which is assembling and processing data over the agricultural region. The project partners include Agriculture WA, CSIRO, Department of Land Administration, Water and Rivers Commission, Department of Environmental Protection, Department of Conservation and Land Management, and Main Roads WA. The project is supported by the WA Salinity Action Plan and by the Natural Heritage Trust.

## 2 Project Aims

Land Monitor is committed to produce information products for land management covering the south-west of Western Australia. The project aims to:

- Produce highly accurate Digital Elevation Models (DEMs) (with accuracy of the order of 1-2 metres in elevation);
- Map and monitor changes in the area of salt affected land from 1988;
- Predict areas at risk of future salinisation;
- Monitor changes in the forest and perennial / woody vegetation, and areas of revegetation from 1988;
- Distribute the information to the end-users and the community; and
- Establish a baseline for on-going monitoring.

To achieve this, the Project is assembling and consistently processing basic data sets (DEMs and sequences of TM data) over the entire agricultural region. The base and processed data and products are distributed to partner agencies, and made available for wider use.

### 3 The Project area

The south-west agricultural region of Western Australia is covered by approximately 16 Landsat scenes; it covers 24 million hectares.

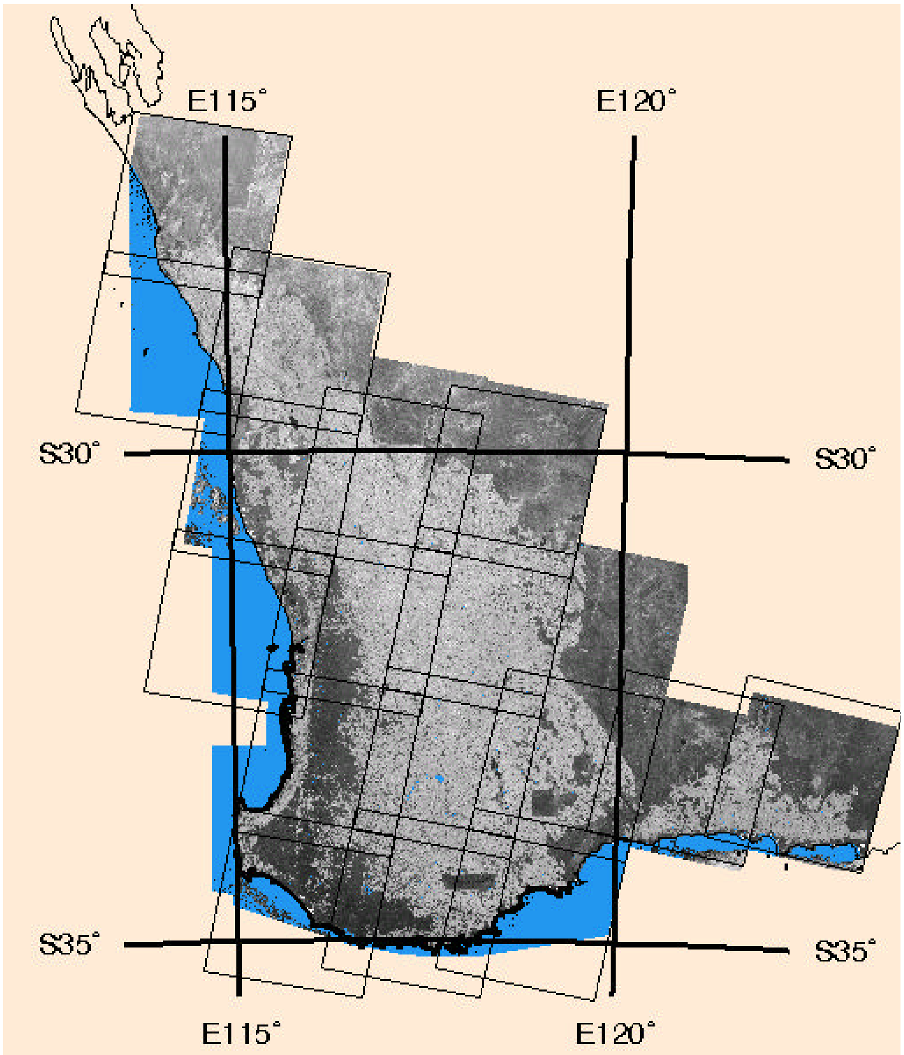


Figure 1 : The south-west Agricultural region of Western Australia, the extent of the Land Monitor Project. Overlay shows coverage of standard Landsat scenes.

### 4 Data and pre-processing

#### *4.1 Ground data*

Ground data for salinity classification, and for accuracy assessment of the map product, are collected by Agency representatives and catchment groups throughout the study area. Training data are provided in the form of areas marked on aerial photographs, farm plans, maps and images. A manual for the collection of ground data is provided to each person collecting ground data (Furby et al 1998). Ground training data for the salinity prediction are provided by expert hydrologists.

### *4.2 Landsat TM imagery*

For each scene area, sequences of spring and summer data are acquired from the period 1988-2000. Spring Landsat TM images are optimal for detection of salt-affected land since crops and pastures in the region are then at maximum growth and maximum spectral contrast with the lower productivity areas of salt-affected land (Wheaton *et al* 1992). Earlier research had shown that a sequence of two to three images in successive years are required to be processed, along with DEM-derived data, to provide an acceptably accurate mapping of salt-affected land (Furby *et al.* 1995). For monitoring, at least six spring images are processed (section 5).

For monitoring perennial vegetation (forests and remnant vegetation) summer Landsat TM images have been shown to be most useful. Summer images are acquired at least every two years, so a typical scene will have a sequence of seven images spanning the period 1988-2000.

To enable multi-temporal analyses of Landsat TM data, it is essential that the images are accurately registered, so that each pixel in the multi-temporal sequence represents the same ground location. Considerable effort was invested to produce an accurate base mosaic of the region. This involved the use of tie points on scene overlaps, and the use of an accurate GPS-derived road centreline database provided by Main Roads WA. The scenes in the base mosaics for summer and spring were cross-calibrated using the robust regression method described below to provide a consistent radiometric base across the region. Cross-correlation feature matching techniques are used to improve the speed and accuracy of co-registration of the images in each sequence to the base.

Image calibration is required to enable comparisons of the digital data from different dates and multi-temporal analysis of the data. Calibration to 'like-values' (Furby *et al.*, 1997) relies on the selection of ground targets which are spectrally invariant through time (such as deep water, bare sands and gravel pits). Sets of such targets have been found for each image in the region. Robust regression techniques, in particular the S-estimation technique described by Rousseeuw and Leroy (1984), are used to produce the calibrated images, so that targets that show spectral changes through time (eg. shifting patterns of sand and shadow in bare sand targets) are down-weighted in the regression analysis.

The satellite images are co-registered to AMG coordinates at 25m pixel and calibrated to 'like-values'. A small subregion of the calibrated imagery for August 1989 and September 1990 is shown in Figure 2.

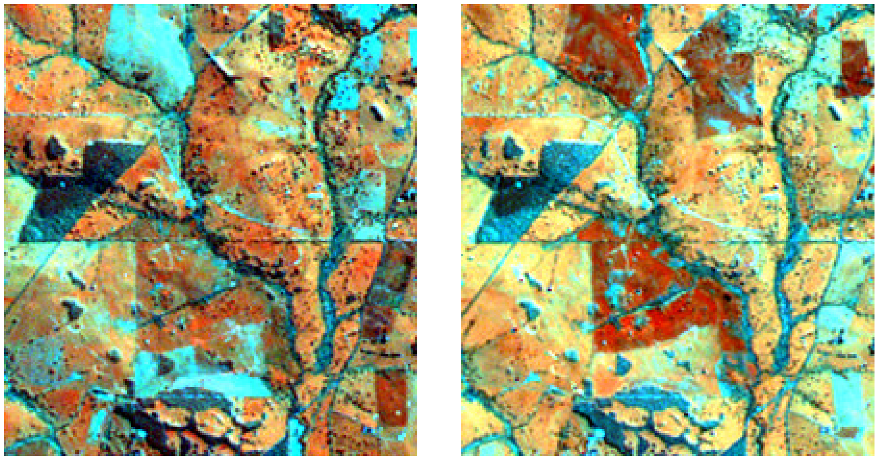

Figure 2  Calibrated (i) 1989 and (ii)1990 Landsat TM images with bands 4, 5, 7 in red, green and blue.

### *4.3 Digital elevation models and derived data*

The new land monitor DEMs are being produced from 1:40000 aerial photography  soft-copy automated photogrammetric techniques.  New photography and processing are being carried out by private sector companies, while DOLA is responsible for contracts and quality control. The DEMs are produced on 10m grid with specifications of height accuracy of +/- 1m.  This is a dramatic improvement over the existing contour data, which were inadequate in most areas for the mapping and prediction processes.

For the mapping and prediction, the raw DEMs are processed to produce derived variables which relate to the risk of salinity. In particular, per-pixel watershed parameters are derived from models which simulate flow of water across the landscape. The models are commonly referred to as water accumulation models (O'Callaghan and Mark; 1984; Jensen and Domingue, 1988; Quinn *et al.*, 1991 and Schultz, 1994). Derived variables include 'upslope area' and 'upslope cleared area'. Jensen and Domingue (1988) defined water accumulation models by assigning each cell a value equal to the number of cells that flow to it; this definition produces estimates of upslope area, and is the definition used here. The *multiple-direction* water accumulation model described by Quinn *et al.* (1991) is combined with a method for identifying and labelling flat areas (Caccetta, 1997).  Since water accumulation is low on the top of hills and increases as water flows into the valleys and drainage systems, the accumulation maps are used as a continuous measure of landform. Individual landform classes (such as hilltops, upper slopes, lower slopes, foothills and valleys) can be derived by simply stratifying the water accumulation maps in an appropriate manner. Figure 3 shows the water accumulation map corresponding to the area shown in Figure 2. A range of other derived variables are produced for the prediction process (Caccetta 1999).

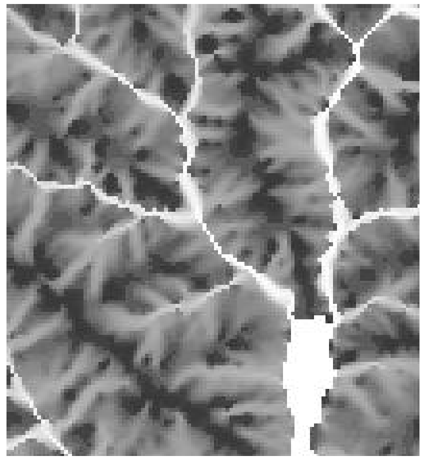

Figure 3 Water accumulation map derived from a DEM - increasing values are shown from black to white.

## 5 Mapping and monitoring salinity

A standard methodology is being used for Land Monitor salinity mapping and monitoring. The process requires supervised classification of a sequence of images, which are then combined with landform variables in a data integration procedure. The steps are outlined below.

1. (Basic data processing) Co-register & calibrate the images to common map and radiometric bases respectively. Assemble and digitise ground training data. Process DEM to provide landform classes.

2. 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 are processed separately.

3. Apply discriminant analysis procedures for each image (canonical variate analyses (CVA)) (Campbell and Atchley, 1981), to the training data to examine the separation of ground cover types in the TM spectral data, to define sensible spectral groupings of ground cover types, especially saline and marginally saline areas.

4. Apply enhanced maximum likelihood classification to each image date. This produces for each pixel not a hard class label, but a set of probabilities of membership of each of the major cover classes on each date for each pixel in the images.

5. Combine the cover class probabilities from each date with DEM-derived landform position in the landscape (hilltops & ridges, slopes, upper valley, lower valleys,broad valleys) to calculate the probability of each pixel being salt-affected, and to produce final maps for each date. A conditional probability network (CPN) is used for these calculations (Lauritzen & Spiegelhalter 1988). CPNs, also called Bayesian networks and causal probabilistic networks, provide a framework for describing probabilistic relationships between a number of different variables. A CPN is a graphical model that describes the joint probability distribution for a

number of variables via conditional independence assumptions and local probability distributions. In salinity processing, the CPN graph structure is designed to account for the temporal links between ground states (e.g. saline land is likely to remain saline), and the links between landform and the probability of salinity (e.g. salinity is more likely to occur in low-lying areas than hilltops). An EM algorithm (Dempster *et al* 1977) is used to estimate the parameterise of the model.

6. Post-processing masking is applied to remove obvious errors of commission in the final salinity maps, such as roads, firebreaks and dry dams.

7. Interim maps are produced for field evaluation and error checking. This provides a new set of ground information, and the processing is repeated to produce a final classification of salinity over the period. The map is then subjected to a formal accuracy assessment within sub-areas across the image.

Final salinity mapping and change products are produced on CD with a report which includes the accuracy assessments. Standard maps are produced for each scene which include accuracy assessment areas and figures. A summary table is included of the mapped saline area in hectares (historical and change) for each Local Government Area.

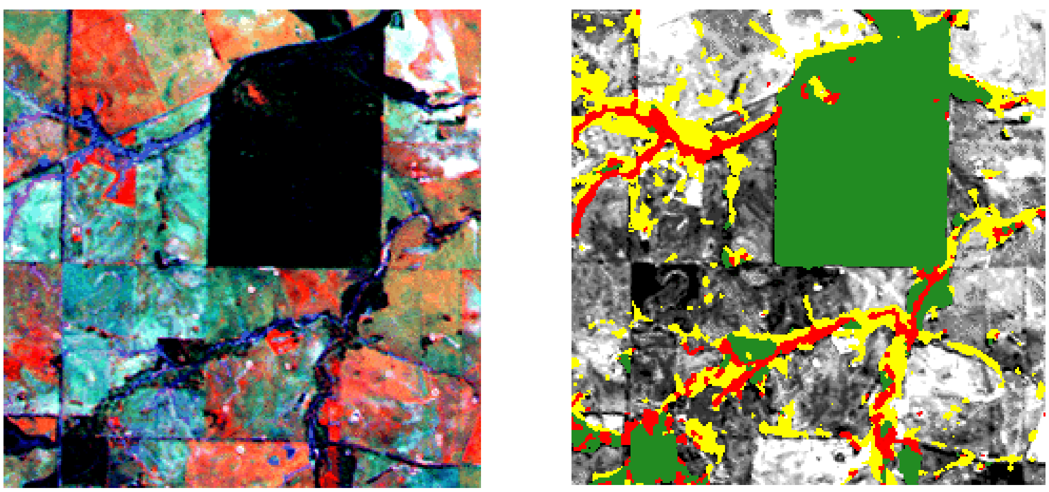

Figure 5 Example of salinity map at farm scale (i) Landsat TM image and (ii) corresponding salinity map - areas mapped as salt-affected (red and yellow) have been mapped as being in poor condition for more than one growing season.

## 5 Salinity Prediction

The salinity predictions are not processed-based, but use an ‘expert system’ decision tree classifier to determine rules which match input spatial data to training data (salinity predictions) provided by hydrologists expert in the region. Input data include landcover maps derived from Landsat TM, and a series of DEM-derived landform variables which may be associated with salinity risk; examples are landform position, height-above streamline, and relative height in a subcatchment. The resulting maps are assessed in the field. The procedures and output are described in (Evans *et al* 1995) and the DEM-processing in (Caccetta 1999). Where adequate training data have been provided, high accuracies have been obtained (Evans et al), and it is at present the best operational procedure for salinity prediction which can be applied over broad regions in this environment (Hatton *et al* 2000). Only limited areas have been processed to date. The collection of quality ground data is the most difficult part of this process.

## 6 Monitoring vegetation

Two types of vegetation change products are produced from the sequences of summer imagery. Maps of the extent of perennial / woody vegetation cover and its change through time provide a history of clearing and regeneration, and have tracked the dramatic growth in forest plantations in the high rainfall areas.

Land Monitor is also producing information of more subtle changes in vegetation over time. The issue of remnant vegetation decline from multiple causes is a significant one across the region for conservation, water balance and other reasons. Spectral indices can discriminate differences in density within vegetation types, and temporal summaries can be used to identify areas which are stable, declining or improving over time (Wallace et al 1997, Furby et al 1998).

For example, Figure 6 shows a cover change map for the Stirling Range national Park produced using seven dates of Landsat imagery between 1988 and 1998. In this map, colours represent the calculated linear and quadratic trends. Blue areas have shown in a linear increase in cover density over the seven years. These areas correspond to recovery of ground burnt bushfires that occurred in 1988. The red areas have decreased in condition during the ten-year period. Green and yellow areas have shown a negative quadratic change in cover index, which corresponds to disturbance and different rates of recovery. These differences may have important implications for habitat and fire management. Furby and Wallace (1997) describe an example of the use of the vegetation and salinity monitoring products in addressing integrated land management issues in the Fitzgerald Biosphere region of WA.

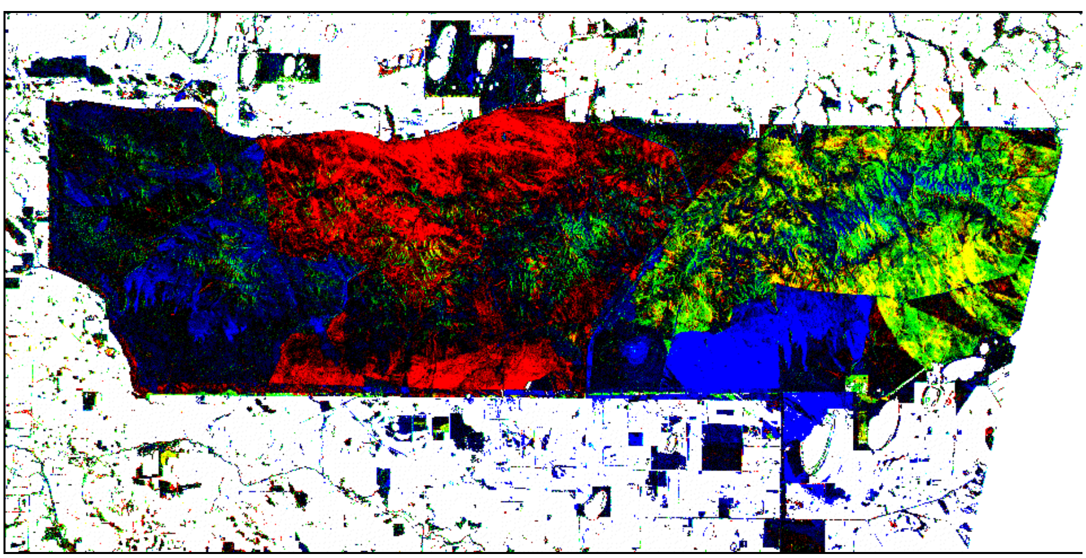

Figure 6. Cover change map (linear & quadratic trends) for the Stirling Range National Park, 1988 - 1998

### 7 Distribution of Data and Products

Products from Land Monitor are made widely available to landcare groups, land managers, participating agencies and the WALIS community. They are provided in either analog / printed or digital form.

While standard products are produced and provided to Agencies, there is a demand for a range of customised products for different users. Printed products can be produced at a scale to suit individual needs, from paddock, farm, catchment, shire or regional scales. Landsat TM data can be printed as large as 1:50000 scale and at any customised smaller scale and integrated with various datasets from other agencies. Digital products can be packaged in an 'easy-to-use' CD-ROM product with free image viewing software which allows integration with other geocoded data, in various data formats such as BIL, ERMapper, Arc View and TIF.

The Land Monitor Website www.landmonitor.wa.gov.au contains information on the project as a whole and a set of product samples. It also maintains an up-to-date record in map form of the progress of the Project in assembling base data sets and products. It is hoped that a number of products will be directly down-loadable via the website.

### 8 Conclusion

The Land Monitor project is providing the State with a series of base datasets and a range of information products for the south-west agricultural area of Western Australia. It is applying innovative technologies to address information gaps which are relevant across a range of resource management issues. Land Monitor is a significant example of collaboration across agencies. The datasets and products will be used at a range of scales and for many purposes. It is expected that these datasets will form a basis for on-going monitoring programs.

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