

The extent and potential area of salt-affected land in Western Australia estimated using remote sensing and digital terrain models

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Abstract: A number of ways of mapping, monitoring and predicting salt-affected land have been used, all of which have strengths and weaknesses. In WA, methods that have been used include ABS surveys, extrapolating from detailed catchment mapping, groundwater levels coupled with soil-landform maps (NLWRA methodology) and satellite remote sensing and digital terrain models (“Land Monitor” – this paper). The ABS method may underestimate the extent of salinity whereas catchment mapping and the NLWRA method overestimates its extent and hazard. The Land Monitor method estimates that about 960,000 hectares were affected by secondary salinity in 1996 and this area had increased by about 14,000 ha per annum since 1989. The area with a salinity hazard (ie may develop salinity in future depending upon controlling factors) is estimated to be up to 5.4 million hectares of total land (between 2.8 and 4.4 million hectares of agricultural land). The results indicate that there may be more time to develop innovative plant and engineering solutions than was previously thought. The Land Monitor method has advantages in that it shows where salinity is within catchments and hazard areas are identified more accurately than in any other method. In addition, the method allows confidence limits to be placed on the estimates.

Keywords: Salinity extent, salinity prediction, remote sensing, satellite, digital terrain model.

1. INTRODUCTION

The current and predicted future extent of salinity is useful to help decide how much resources agencies and landowners should commit to saving assets that may be at risk, and when they should commit these resources. Some landholders have stated that they would have taken the problem more seriously had they known what affect it may have on their land and water assets. However salinity is often insidious with small changes occurring each year as saline groundwater is slowly drawn into the root zone of plants with larger changes occurring after wet years. Likewise, government needs to know which public assets may be at risk as there is usually a long lead time before vegetative solutions can lower groundwater levels and engineering solutions need to be budgeted well in advance.

Ferdowsian *et al.* [1996] reviewed the methods that had been used in Western Australia to estimate the extent of salinity and its likely long term impact at equilibrium. Since that time two other methods have been further developed – the National Land and Water Resource Audit (NLWRA) method and Land Monitor. This paper briefly reviews each method before providing the first consolidated results from the Land Monitor method.

2. REVIEW OF PREVIOUS METHODS

2.1 Australian Bureau of Statistics (ABS)

Four surveys were carried out of West Australian farmers in the 1974 – 1993 period asking whether land that had been previously productive had become saline (a definition of secondary salinity). When plotted, these data show a straight line increase with 529,000 ha (or 3.1% of cleared land)

being reported in 1993. Ferdowsian *et al.* [1996] reported discrepancies between ABS shire average data and detailed mapping of major catchments and concluded that the ABS statistics may be reporting bare saline land but not areas marginally affected. As farmers' recollections of what was previously productive decrease, the surveys have less validity.

A further ABS survey was undertaken in 2002 as part of a major analysis of salinity and management actions at the start of the National Action Plan. In Western Australia the survey initially identified that the estimated total land affected by salinity was 1,240,643 hectares, comprising 835,695 hectares of land within NAP regions and a further 404,948 hectares of land outside NAP regions. A recent revision of the boundaries indicated that salinity in the NAP regions was 932,695 ha and that outside is 307,947 ha (C. Poulton, ABS, July 2004). Of the 1.2M ha, farmers reported that about a half was unable to be used. The doubling in reported salinity between 1993 and 2002 partly reflects the question that was asked. It is therefore possible that the new figure includes some primary salinity (ie land that was saline before clearing for agriculture), raised awareness and increased saline area.

2.2 Mapping of catchments using air photographs and/or geophysics

A number of exercises have mapped salt-affected land for shires [eg Nulsen 1981], sub-regions, soil survey areas and part or complete catchments. These are reviewed in Ferdowsian *et al.* [1996] and not repeated here. However they did show that when salinity was measured objectively and comprehensively (for the given area) estimates were usually 2 to 6 times that reported in the earlier ABS surveys.

Using all data sources, a group of regionally-based hydrogeologists [Ferdowsian *et al.* 1996] came up with an estimate of current and projected salinity for Western Australia which was the basis for planning used in the Salinity Action Plan [1996] and the Salinity Strategy [2000]. These show that the area thought to be salt affected to some extent (> 50% crop and pasture yield reduction) in 1994 was about 1.8M hectares (9.4% of cleared land) and that this would expand to 3.3M ha in 2010/2020 (depending on seasonal conditions) before stabilising at 6.1M ha or 31.8% of cleared agricultural land.

2.3 NLWRA Method

The audit was established to determine the extent of salinity in Australia on a nationally-consistent basis. This required a data set that all states would be able to use, rather than using methods that may be more accurate but unachievable in some states.

All states had soil landform maps and some had reasonable bore networks showing the depth of groundwater in different soil-landscape positions [NLWRA 2001]. This method was therefore used to estimate the current saline risk (areas with groundwaters within 2 metres of the surface or within 2-5 metres and rising) and longer term hazard (groundwater levels likely to be within 2 or 2-5 metres and rising within 50 years).

The NLWRA method has the advantage that it includes risks when groundwater levels were still below the surface and not affecting vegetation and reflectances. It is also based on available data sets such as soil landform maps of 1:250,000 scale. However there are also several disadvantages:

- Few soil-landforms had many bores and even fewer had long records to determine trends
- It was assumed that the bores were distributed evenly throughout the landform but in reality they are concentrated low in the landscape
- The salinity of the groundwater was not taken into account so areas with high but fresh or brackish watertables were considered at risk.
- Risk at 2050 is often assumed to be equilibrium extent when in fact some catchments may not equilibrate until 2200 at current rates of rise.

Using this methodology it was estimated that about 3.54M ha of agricultural land in WA was currently at risk of being saline and this areas was estimated to double to 6.5M ha (33%) by 2050. An additional 1.8M ha of perennial vegetation was also considered to be at risk by 2050.

3. THE LAND MONITOR PROJECT

Land Monitor was a multi-agency project to produce information products for the south-west of Western Australia. The project:

- Produced highly accurate digital elevation models (DEMs) (with accuracy of the order of 1-2 metres in elevation);

- Mapped and monitored changes in the area of salt-affected land from 1988;
- Predicted areas at risk of future salinisation (henceforth referred to as hazard maps);
- Monitored changes in reflectance for forest and perennial/woody vegetation, and areas of revegetation from 1988;
- Distributed the information to the end-users and the community; and
- Established a baseline for on-going monitoring.

3.1 Methods

The Land Monitor method uses; (i) Long-term sequences of Landsat TM and MSS satellite data to provide observations relating to land use and condition (ii) accurate DEM data to place the observations in a landscape context; and (iii) ground data provided by experts for analysis and validation.

The methods were progressively developed and refined as are outlined in numerous papers, some examples are; Campbell and Kiiveri [1988], Furby *et al.* [1995], Caccetta [1997], Campbell *et al.* [2000].

The south-west agricultural region of Western Australia is covered by approximately 16 Landsat scenes or 24 million hectares. A sequence of two to three images in successive years were processed, along with DEM-derived data, to provide a mapping of salt-affected land of acceptable standard (Furby *et al.* 1995). For monitoring, at least six spring images were processed. Morphological landform information derived from DEMs provide strong prior evidence to which parts of the terrain are likely to be/become saline and which parts are not [Caccetta, 1997]. This information was used in conjunction with observations from satellite imagery. Areas of consistently low productivity (AOCLP) were assessed by field staff to identify those areas for which the low productivity was caused by salinity.

For salinity mapping and monitoring, the DEM was partitioned into the set of classes {hilltops, ridges and upper slopes, upper valleys, lower valleys, broad valleys}, which were used in conjunction with land covers classes derived from satellite imagery to specify classifier parameter values. Certain combinations of land cover and landform classes are more likely to be saline than others. The

information obtained from the field was used to refine the initial maps until an agreed acceptable standard was obtained, at which point a formal accuracy assessment was performed. Salinity hazard used ground data and DEM derived variables to predict the location of channel heads of flow paths which were likely to go saline (as defined by the ground truth). The flow paths were truncated at the channel heads and then morphologically grown to include all adjacent areas within a given height tolerance. The maximum extent of these areas defined the extent of salinity hazard. Within the areas of salinity hazard, each pixel is given a label identifying its height above the flow path which identified it as being a hazard. This serves as a secondary measure of the level of risk. Where possible, the accuracy of the hazard map was determined by calculating the accuracy of the map as compared to ground data not used in training the classifier.

4 RESULTS AND MAPPING ACCURACIES

The results are described in a series of reports which may be accessed at:

<http://www.landmonitor.wa.gov.au/reports/index.html>

4.1 Comments on mapping accuracies

The reports contain mapping accuracies summarised as tables, an example of which is provided in Table 1 [Caccetta *et al.*, 2000] for mapping and monitoring and Table 2 [Dunne *et al.*, 2001] for prediction.

Table 1a, b gives an overall accuracy of 95%, with errors of omission and commission being present. For each region a description of the major sources of error were noted, as in this case: Generally, errors of commission include sites such as degraded bush in low lying areas, eroded catchments and new dams not included in the dam mask. Errors of omission included underestimates of the extent of hillside seeps, and saline sites which supported productive plant growth.

Table 1a: Site counts (pixels) obtained from field validation (example only)

		Image map label		
		Non saline	Saline	Total
Ground Label	Non saline	98	1	99
	Saline	6	26	32
	Total	104	27	131

Table 1b: Percent accuracy of mapped classes (* errors of commission, ** errors of omission).

		Image map label	
		Non saline	Saline
Ground label	Non saline	94	4*
	Saline	6**	96
Total (%)		100	100

Table 1c: Percentage of ground classes actually mapped (* errors of omission; ** errors of commission).

		Image map label		
		Non saline	Saline	Total (%)
Ground label	Non saline	99	1**	100
	Saline	19*	81	100

Table 2 shows an overall hazard accuracy of 91%, with the mapping overestimating the extent of areas giving total area at risk as 23% of the validation area as opposed to 19% calculated directly from the validation data.

Table 2a: Image Class Label versus Validation Data (pixel counts).

		Image map label		
		At Risk	Not At Risk	Total
Ground label	At Risk	133,121	19,920	153,041
	Not At Risk	55,723	608,257	663,980
	Total	188,844	628,177	817,021

Table 2b: Percent accuracy of mapped classes (* errors of commission, ** errors of omission).

		Image map label	
		At Risk	Not At Risk
Ground Label	At Risk	97	23**
	Not At Risk	3*	77
Total (%)		100	100

Table 2c: Percentage of ground classes actually mapped (* errors of commission, ** errors of omission).

		Image map label		
		At Risk	Not At Risk	Total (%)
Ground label	At Risk	87	13**	100
	Not At Risk	8*	92	100

4.2 Regional Statistics

The maps provide spatially explicit information on historical changes in the extent of secondary salinity and estimates of future extent on a 25m pixel basis. These results are useful at local scale.

The results may be aggregated over units of interest, for example over shires, catchments areas or soil-landforms. Table 3 summarises historical changes and likely equilibrium extent of secondary salinity aggregated over a selected number of shires. Primary saline areas have been removed through a “water mask”. 1996 salinity is the area of consistent low productivity land which could be attributed to salinity in this year. This totalled 957,581 ha or 2.9% of shire land and 5.1 % of agricultural land. In 1989, the areas was 859,306 ha or 2.6% of shire land 4.6 % of agricultural land). This represents an annual increase of about 100,000 ha over the seven year period, or 14,000 ha per annum.

Seventeen shires recorded an increase of more than 0.5 % between 1989 and 1996: Nungarin (3.40 %), Moora (1.46 %), Tambellup (0.92 %), Kulin (0.90 %), Wagin (0.85 %), Woodanilling (0.83 %), Gnowangerup (0.80 %), Kent (0.78 %), Katanning (0.77%), Broomehill (0.75 %), Wongan-Ballidu (0.70 %), West Arthur (0.69 %), Lake Grace (0.68 %), Dumbleyung (0.67 %), Boddington (0.61 %), Jerramungup (0.56 %) and Narrogin (0.55 %).

Two-thirds of these shires are in the 400 – 600 mm rainfall zone which has rainfall sufficient to raise levels and moderate salt stores. Those shires in the < 400 mm rainfall with rapid increases probably experienced high summer rainfalls that can rapidly expand saline areas.

One shire (Nungarin) had a salinity hazard in excess of 40% (Table 3). This area is unlikely to fully eventuate but does indicate that the landforms in the shire appear susceptible to salinity more than many others. Thirteen other shires (not included in table 3) had a salinity hazard of between 30 and 40% - Cunderdin, Dowerin, Goomalling, Kellerberrin, Koorda, Morawa, Mukinbudin, Quairading, Tambellup, Tammin, Trayning, Woodanilling and Wyalkatchem. Almost all of these shires are characterised by low relief and poor flushing of salt. They also mainly have low rainfalls and the time for full expression of their salinity extent will be more than 50 years.

Areas of current salinity and salinity hazard were also determined during a re-evaluation of the raw LM data (Table 4). SIF (2003) provided a slightly different estimate of salinity extent and hazard based on modified classes (using between 0.5 and

2.0 m average height above valley floors), by regional hydrogeologists in areas where the technique was known to be less accurate (especially

the internally drained and deep sedimentary areas, eg South Coast). Their estimates suggest a range of 2.8 to 4.4 M ha at equilibrium (> 2100).

Table 3 Examples of salinity statistics for selected Shires (ha)

Shire	Shire area (Ha)	1996 salinity (Ha)	Percentage of shire with salinity in 1996	1989 Salinity (Ha)	Percentage of shire with salinity in 1989	Change between 1989 salinity and 1996 salinity	Salinity Hazard (ha)	Hazard as a Percentage of Shire
Boddington	191,761	2,361	1.2%	1,195	0.6%	0.61%	12,767	6.7%
Broomehill	117,251	4,786	4.1%	3,902	3.3%	0.75%	21,395	18.2%
Dumbleyung	253,993	15,206	6.0%	13,505	5.3%	0.67%	54,169	21.3%
Gnowangerup	426,640	14,009	3.3%	10,578	2.5%	0.80%	89,850	21.1%
Jerramungup	651,858	15,494	2.4%	11,820	1.8%	0.56%	125,571	19.3%
Katanning	151,791	11,072	7.3%	9,911	6.5%	0.77%	39,306	25.9%
Kent	562,415	30,683	5.5%	26,275	4.7%	0.78%	138,454	24.6%
Kulin	471,217	22,364	4.7%	18,138	3.8%	0.90%	84,794	18.0%
Lake Grace	1,038,210	79,613	7.7%	72,578	7.0%	0.68%	273,648	26.4%
Moora	376,296	28,868	7.7%	23,371	6.2%	1.46%	81,158	21.6%
Narrogin	161,723	7,996	4.9%	7,107	4.4%	0.55%	45,613	28.2%
Nungarin	116,236	12,913	11.1%	8,956	7.7%	3.40%	50,012	43.0%
Tambellup	143,634	12,325	8.6%	11,001	7.7%	0.92%	49,286	34.3%
Wagin	194,463	12,919	6.6%	11,261	5.8%	0.85%	56,488	29.0%
West Arthur	283,085	8,317	2.9%	6,353	2.2%	0.69%	72,640	25.7%
Wongan-Ballidu	336,712	36,595	10.9%	34,240	10.2%	0.70%	94,822	28.1%
Woodanilling	112,882	6,256	5.5%	5,322	4.7%	0.83%	36,217	32.1%
TOTALS	32,596,370	957,581	2.9%	859,306	2.6%	0.30%	5,464,834	16.8%

Table 4: A Statewide summary of the agriculture based Salinity Investment Framework analyses (SIF 2003). * Defined by subtraction of total shire area and area of hazard.

Asset Class		Current Salinity (1996)	Hazard Area (<2.0 m class)
SW Total area	26,511,000 ha		
Agricultural land	18,790,000 ha		
Shires agricultural land	ha (%)	1,047,000 (5.6%)	5,428,000 (29%)
Agricultural land	ha	821,000 (4.4%)	4,408,000 (23%)
Public Land	ha	226,000*	1,020,000*
Towns	ha	4000	20,800
Highways	km	1100	520
Local roads	km	2400	14,900
Main roads	km	140	670
Unclass. roads	km	1450	8100
Railways	Total km	210	1050
Soil Zones	ha	992,000	5,139,000
Soil Systems	Ha	992,000	4,794,000
Hydro Zones	ha	992,000	5,139,000
CALM Estate	Ha	196,500	764,000
Plantations	ha	0	40
Private vegetation	ha	390	8900

5 DISCUSSION

The estimates of the extent of salinity on agricultural land of about 860,000 ha in 1989 and 960,000 ha in 1996 are the best available. This is similar to that by farmers observations of 933,000 ha (2002). The Land Monitor method is known to underestimate saline areas in high rainfall areas and overestimate some paddocks in the drier areas with consistently low productivity (for reasons other than salinity). The change in saline areas is also subject to some error as indicated by some shires reporting a net decrease in saline land, almost certainly an error. Estimating what may be the final extent of salinity is more difficult because areas that may be at risk may not ever become saline due to mitigating factors (eg a drying climate, evaporative loss from adjacent saline areas stopping the rise in water levels, hydrogeology, soil types etc). The areas shown to have a salinity hazard (2 m class) are almost certainly overestimates of the final area (better reflected by

0.5 m class) that will be affected if land use stays approximately the same as today.

Even taking these factors into account, it is evident that the Land Monitor estimates are likely to be much more accurate and spatially correct than all other previous estimates. Despite the shortcomings of the Land Monitor method, there is a requirement that another round of estimates be produced because it is eight years since the past estimates and this included several wet summers where salinity was reported to have spread rapidly in the north eastern wheatbelt. The fact that the areas currently affected by salinity and its hazard, are slightly more than half that estimated by Ferdowsian et al. [1996] indicates a difference in methodology (salinity definition) and that the rate of spread of salinity is slower than previously perceived. It is therefore logical to conclude that there may be more time to develop biological and/or engineering solutions to the problem that first thought.

6 CONCLUSIONS

The Land Monitor method has estimated that the area currently affected by salinity in Western Australia is about 1 million ha and the annual rate of increases is about 14,000 ha. The area that has a salinity hazard has been mapped as about 5.4 M ha, most of this on cleared agricultural (81%) land but including some very important areas of remnant vegetation, water resources and built infrastructure. Further refinements and updates of Land Monitor methodology and area estimates are warranted as it is eight years since the last estimate and saline areas may have increased by a further 100,000 ha or 0.3% in this time.

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8 REFERENCES

Caccetta, P. A., Remote Sensing, GIS and Bayesian Knowledge-based Methods for

Monitoring Land Condition, PhD Curtin University, 1997.

Caccetta, P.A., Wallace, J.F., Beetson, B. and Crossley, N., Mapping salinity in the Perth Landsat TM scene (112-082), CMIS Report Number 2000/203, 2000.

Campbell N.A., R., George, T., Hatton, D., McFarlane, D., Pannell, M., Van Bueren, Caccetta P.A. Clarke C., Evans F., R. Ferdowsian and G., Hodgson 'Using Natural Resource Inventory Data to Improve the Management of Dryland Salinity in the Great Southern, Western Australia', Final Report to the National Land and Water Resources Audit, Implementation Project No 2, 2000.

Campbell, N. A. and H. T. Kiiveri, Spectral temporal indices for discrimination. *Applied Statistics*, 37, 51-62, 1988.

Dunne, R., Caccetta, P.A. and B. Beetson, Prediction of Areas of Shallow Water Table and Salinity Risk: The Newdegate Landsat TM Scene (110/03) and Surrounding Areas, CMIS reports number 01/110, 2001.

Ferdowsian, R., George, R., Lewis, F., McFarlane, D., Short, R., and R. Speed, The extent of dryland salinity in Western Australia. Proceedings of the 4th National Conference and Workshop on the Productive Use and Rehabilitation of Saline Lands, Albany, WA, pp. 89-97. 1996.

Furby, S. L. and N. A. Campbell, Calibrating images from different dates to 'like value' digital counts. *Remote Sensing of Environment*, 177-2, 186-196, 2001.

Furby, S.L. Wallace, J.F., Caccetta, P. and G.A. Wheaton, Detecting and Monitoring Salt-Affected Land, Report to LWRDC, 1995.

Government of Western Australia. Salinity Action Plan, 1996.

Government of Western Australia. Salinity Strategy, 2000.

NLWRA Australian Dryland Salinity Assessment, Extent impacts processes monitoring and management options, Land and Water Australia, Canberra, pp129, 2002.

Nulsen, R.A. Salt-affected land in the Shire of Wongan-Ballidu, Western Australia, *Australian Journal of Soil Research*, 19:87-91, 1981.

SIF Salinity Investment Framework Interim Report - Phase 1. Department of Environment SLUI 32, 2003.