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Avon Catchment Council

Report for Protection of Transport Assets IWM 004

Detailed Risk Assessment - Priority Regional Roads Part 1

June 2007

INFRASTRUCTURE | MINING & INDUSTRY | DEFENCE | PROPERTY & BUILDINGS | ENVIRONMENT

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1. Introduction

GHD were engaged by the Avon Catchment Council to deliver the *Protection of Transport Assets* (IWM004), project component of the 2005 -- 2008 Investment Plans.

The methodology for delivering the *Protection of Transport Assets* project included a detailed salinity risk assessment of priority roads within the Avon River Basin (ARB).

Priority roads were previously identified in the inventory of transport assets (GHD 2006). Approximately 7,200 km of regionally significant roads were identified through discussions with Main Roads WA (MRWA) and Local Government Authorities (LGAs). Project implementation will include 2,000 km of electromagnetic survey (EM38 & EM31) of regionally significant roads during each year of the current three-year investment period, ensuring that the majority of key roads will have been surveyed by 2008.

This document (Part 1) includes assessment of the first 2,000 km of electromagnetic survey of regional priority roads within the Avon River Basin. The remaining 5,200 km (of the total 7,200 km) of survey will be presented in Parts 2 and 3 of the detailed risk assessment.

The detailed risk assessment of priority roads is considered a key component to delivering a range of management action targets, including:

- *L1 MAT 2.1 The risk of high water tables and flooding for transport infrastructure is known within each local government area by 2009;*
- *L1 – MAT 3.3 Methods of Road Risk Assessment are evaluated by 2005;*
- *L1 MAT 4.1 Priority roads for preservative action are identified through regional transport policy development processes by 2007;*
- *L1 MAT 8.1 Monitoring of road assets at risk is initiated and arranged by 2006.*

The detailed risk assessment is central to a range of outcomes within the project. Identification of roads at greatest risk of waterlogging and salinity is critical in effective planning of investment in road maintenance.

The detailed risk assessment undertaken provides a quantitative assessment of roads at risk of salinity and waterlogging. It therefore provides a mechanism for understanding the spatial distribution of threats and provides a mechanism by which the rate of change of this threat can be quantified.

In undertaking the analysis presented in this report, the results of the electromagnetic survey undertaken were compared to results from alternative methods of risk assessment, including Land Monitor data and aerial photograph interpretation. The purpose of the assessment was to determine whether investment into electromagnetic surveys can be justified in light of alternative methods of assessment.

Ultimately, the detailed risk assessment provides a quantitative mechanism that could be central to the identification of priority roads for preservative action at a regional scale.

2. Background

2.1 Detailed Risk Assessment – EM Survey

The geophysical survey undertaken comprised EM38 (horizontal and vertical dipole) and EM31 electromagnetics (EM). The survey was conducted over 2,140 km of priority regional roads throughout the ARB.

The electromagnetic devices were fitted to a vehicle with a specially designed trailer to accommodate the electromagnetic devices. Streaming of data from the electromagnetic devices was recorded on large capacity data loggers, with readings taken at intervals of approximately 100 mm. Positioning was recorded using differential GPS.

The survey was undertaken by Geoforce Ltd (based in Malaga, Western Australia), under contract to GHD. Geoforce provided GHD with raw data output from the differential GPS and electromagnetic devices. GHD undertook the analysis of geophysical data presented in this report.

2.2 Evaluation of Alternative Methods

In undertaking the analysis, GHD compared the results of the electromagnetic survey with alternative methods for assessment of roads at risk of salinity, including:

- *Aerial Photography* – A visual assessment of digitally rectified aerial photograph mosaic was undertaken for roads subjected to the electromagnetic survey of 2006. The purpose of the aerial photograph interpretation was a first order assessment of the accuracy of the electromagnetic survey, and to determine patterns in salinity and development associated with transport assets.
- *Land Monitor*. Land Monitor is an estimation of the distribution of salinity within the region developed through spectral analysis of multi-temporal satellite imagery, undertaken by CSIRO. Land Monitor uses satellite images from consecutive years to estimate the area of low vegetation cover (consistently low producing land). Ground truthing of the dataset has been undertaken to remove the majority of the areas that are associated with landscape features, including deep sands, roads etc. The assessment undertaken to date includes scenes from 1987 – 1992 and 1995 – 1998. Land Monitor also includes salinity hazard mapping, defined as the area between zero and 2 m above natural drainage lines.

Salinity predicted by the Land Monitor was overlaid with regional priority roads, to enable the development of a transport inventory for the region (GHD 2006). The result was a dataset that included roads currently impacted by salinity, and roads that are within the salinity hazard area, as predicted by Land Monitor.

2.3 Development of a Monitoring Methodology

A component of the Protection of Transport Assets Project (IWM 004) includes the development of a monitoring methodology for transport assets at risk of salinity within the Avon River Basin.

The development of a monitoring methodology for the impact of salinity and waterlogging on transport assets within the region is beyond the scope of this report. However, the electromagnetic survey undertaken provides a baseline for assessing the rate of change of salinity associated with regionally significant transport assets. The specific advantage that electromagnetic survey has over alternative methods for monitoring is the quantitative nature of the assessment. Effective monitoring requires the adoption of quantitative assessment tools, particularly where high-value assets are at risk.

2.4 Identification of Priorities for Preservative Action

The identification of priority roads for preservative action is undertaken by the Regional Road Board under the guidance of Main Roads, and in consultation with Local Government Authorities.

A range of different criteria are used in determining investment priorities for preservative action, including road priority status, urgency with which preservative action needs to be undertaken, and distribution of funds within the region. It is considered that the results of the electromagnetic survey undertaken will provide additional information, which will form a basis for determining priorities for investment. As the electromagnetic data provides an indication of roads at risk of salinity, the survey provides a means for more effective strategic planning.

3. Electromagnetic Survey

3.1 Background

Electromagnetic devices, including the EM38 and EM31 used in the survey generate a small electrical current within the soil and the measure the strength of the secondary electromagnetic field generated within the soil profile to determine soil profile conductivity. In doing so, the electromagnetic device measures the electro conductivity of the soil itself.

Electromagnetic devices are widely used to map terrain conductivity. They are well suited to assessing soil salinity as they respond to more conductive (including saline) soils and, furthermore, do not require electrical contact with the ground.

The exploration depth of these devices is determined by the spacing between the transmitter and receiver coils, but typically measure from a depth of approximately 1m to several tens of meters. Their chief advantage is that large areas can be surveyed quickly (McNeill, 1992).

The bulk electrical conductivity of the in situ soil is largely a function of the electrical conductivity of the soil water, which is directly proportional to the soil salinity. However, the in situ conductivity is also a function of the degree of saturation of the soil (which controls the continuity of the current paths), the porosity of the soil, the temperature of the soil and finally the clay content of the soil (since clays with high ion-exchange capacity such as smectite can supply additional ions to enhance electrical conductivity). Wet, clayey soils with a high salt content will generate a stronger electromagnetic field, whereas sandy, dry soils with a low salt content will generate a weaker electromagnetic field. (University of Sydney, 2007)

Due to the various factors other than soil salinity, which affect the bulk soil conductivity, soil samples are often taken at larger intervals as a means of calibration, particularly where a relatively sensitive analysis of soil salinity is required.

Electromagnetic survey (EM 38) is often used to map the soil moisture content, and generally presents a high correlation with soil moisture, particularly in sandy soils, up to a moisture content of approximately 40%. Electromagnetic surveys can also be influenced by lateritic soils, which are sensitive to electromagnetics, due to their relatively high iron content. (Hu et. al. 2005)

Soil temperature can influence electroconductivity, however, its influence is usually minor and a high conductivity is generally indicative of more saline soils.

The electromagnetic survey was undertaken to identify areas where regionally significant roads intersected waterlogged and saline, lower landscape soils. The survey was undertaken during October 2006, when water tables are typically near their seasonal peak within the wheatbelt. Typically, saline valley floors have a high moisture content at this time of year, meaning variability in the electromagnetic survey in response to soil moisture is reduced.

As the purpose of the electromagnetic survey was to identify areas of very high to extreme salinity, the soil salt content is likely to be the overriding factor influencing the electroconductivity of the soil. This is because groundwater within the survey area is typically hypersaline (ie. More saline than seawater), resulting in a very high salt content within the soil profile, where water tables are near to the natural surface.

A detailed soil sampling of the sample area was considered unnecessary. Soil sampling is generally undertaken where small variations in soil conductivity, and soil salinity are required for determining the suitability of the soil for growing various crops. The electromagnetic survey undertaken in October 2006 yielded very large variations in electro conductivity of the soil profile. In identifying roads at risk of salinity, identification of very high to extremely high electroconductivity readings was required. These areas are typically waterlogged and saline.

Variations in soil electroconductivity associated with parameters such as clay and moisture content, porosity and temperature, are considered to be relatively minor compared with those associated with the variation of groundwater salinity within the plan area.

3.2 Survey Details

Both EM38 and EM31 electromagnetic devices were used in the survey undertaken. The EM38 was used in both the horizontal and vertical dipole positions, to provide different depth penetration within the soil profile.

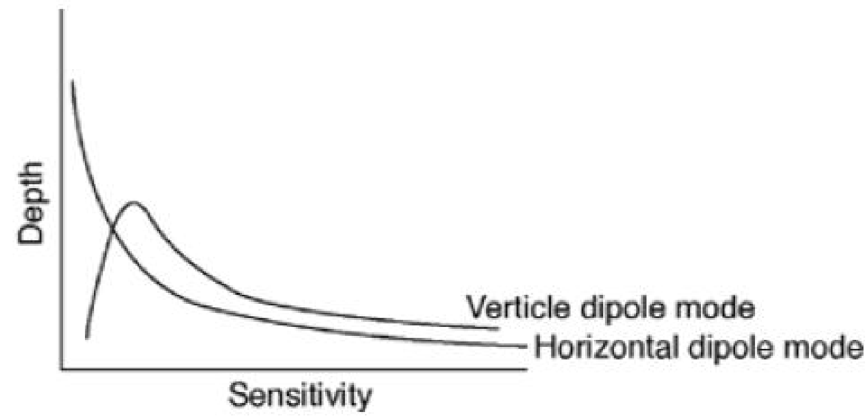
The signal from each of these devices penetrates to various depths, as indicated in Table 3-1 below.

Table 3-1 Typical Depths of Penetration of Electromagnetic Devices (Source: Stratascan [Online] http://www.stratascan.co.uk/pdf/eng-em31.pdf)

Electromagnetic Device	Dipole orientation	Typical depths of analysis (metres)
EM38	Horizontal	0.75
EM38	Vertical	1.5
EM31	Vertical	5.0

Table 3-1 indicates that the focus the EM38 is directed to a different depth depending on its orientation. In the vertical mode, the EM38 has a low sensitivity to near surface resistance, providing a deeper focal point for the electromagnetic field generated. In the horizontal dipole of operation, the device is most sensitive to material at the surface and sensitivity declines with increased depth (refer Table 3-1).

Figure 3-1 Variation of Instrument Sensitivity with Depth for Horizontal and Vertical Orientation (Source: Stratascan [Online] http://www.stratascan.co.uk/pdf/eng-em31.pdf)



Both the EM38 and EM31 electromagnetic devices were used to provide a more robust assessment of salinity within the soil profile. EM38(H) values indicate salt accumulation near the soil surface. High EM38(V) values indicate significant salt accumulation within the upper soil profile at a depth where capillary rise is likely to result in salt accumulation near to the natural surface. High EM31 values may indicate groundwater saturation within the top 5 m of soil profile, or the existence of a perched water table, potentially indicating a risk of salinity development sometime in the future.

Table 3-2 describes how EM values can be used to provide a general classification of salinity. However, DAFWA include the disclaimer: *"EM readings are useful to compare within and between similar sites, but use EM readings with caution unless they are calibrated against soil salinities (ECe for preference) and other influencing factors*" (*Salinity Measures, Uses and Classes*, Nov 2006). This issue is discussed in Section 3.1, suffice to say that given the nature of the investigation, salinity and moisture are considered to be the key drivers influencing soil conductivity within the survey conducted in October 2006.

Table 3-2 Salinity Classes for Plants Using Various Techniques (Source: Department of Agriculture and Food WA)

	EM38 (H) (mS/m)	ECe (mS/m)	EC 1:5 (w/v) loam (mS/m)	ECgw (mS/m)	Tolerance
	Soil	Soil	Soil	Water	
Not saline	< 50	< 200	< 20	< 500	Sub clover, field peas, medic etc.
Slightly saline	50 -100	200 – 400	20 – 40	500 – 1,000	Strawberry clover, phalaris, 2-row barley
Moderately saline	100 -150	400 - 800	40 – 80	1,000 – 2,000	Tall fescue, broombush, tall wheat grass
Very saline	150 - 200	800 – 1,600	80 - 160	2,000 – 3,000	Acacia saligna / Eucalyptus spathulata
Extremely saline	>200	> 1,600	> 160	> 3,000	Salt bush / blue bush

(Department of Agriculture and Food WA)

Typically EM values of interest within the survey undertaken are in the range of greater than 150 mS/m (Table 3-2). These are typically highly saline areas supporting blue bush or associated with bare salt.

4. Methodology

This section documents the methodology used in undertaking analysis of the electromagnetic data collected.

4.1 Aerial Photograph Interpretation

Aerial photography interpretation was undertaken as a first order assessment of the results of the electromagnetic survey and Land Monitor dataset. Aerial photograph interpretation was also used to assess trends in salinity development associated with transport assets.

A sub-set of the area of the electromagnetic survey was selected for aerial photograph interpretation, ensuring a relatively even distribution across the plan area. Approximately 80 sites where transport assets intersected natural drainage lines, and where the electromagnetic survey and/or Land Monitor dataset indicated salinity were selected for analysis.

Aerial photograph interpretation was undertaken using digitally rectified aerial photograph mosaic, supplied by the Department of Land Information. Sites were viewed at a scale of 1:10,000 or less.

A visual assessment of the accuracy of the Land Monitor dataset compared with the salinity apparent on the digital aerial photograph was also undertaken, for the purpose of assessing the accuracy of the Land Monitor data.

4.2 EM Data Manipulation

Geoforce provided GHD with raw electromagnetic data (Comma Separated Value [CSV] format). The EM survey was collected at intervals of between 10 – 100 mm, resulting in approximately 72,000 data points. GHD filtered the data to reduce the file size such that consecutive points were approximately 10 linear metres apart.

In some cases, Geoforce collected EM38 and EM31 data in separate trips, due to equipment failure. Where this was the case, the EM38 and EM31 datasets were merged so that each data point had both EM38 and EM31 values associated with it. Merging of data was conducted using ArcMap. Datasets were spatially joined to the nearest available data point, typically less than a few metres away.

The result of this data manipulation was the development of an EM Survey shape file (point). The EM point was then spatially joined with the Land Monitor shape file, using ArcMap, to enable spatial comparison of the two datasets. Following the above manipulation, each data point had the following associated attributes:

- *Easting*
- *Northing*
- *EM. 38 (H)*
- *EM 31 (H)*
- *EM 31 (V)*
- *Land Monitor connectivity (1987-1992; 1995-1998; no connection)*

The EM Survey dataset was divided into arbitrary geographic zones to make it more manageable. Zones included:

- *Eastern,*
- *Northern,*
- *Southern and*
- *Central.*

The development of zones was influenced in part by the EM data being received in 'blocks'. Figure 4-1 presents the geographical division of the electromagnetic data. Some EM data has been excluded from the north eastern area of the region due to the limited coverage of the Land Monitor dataset.

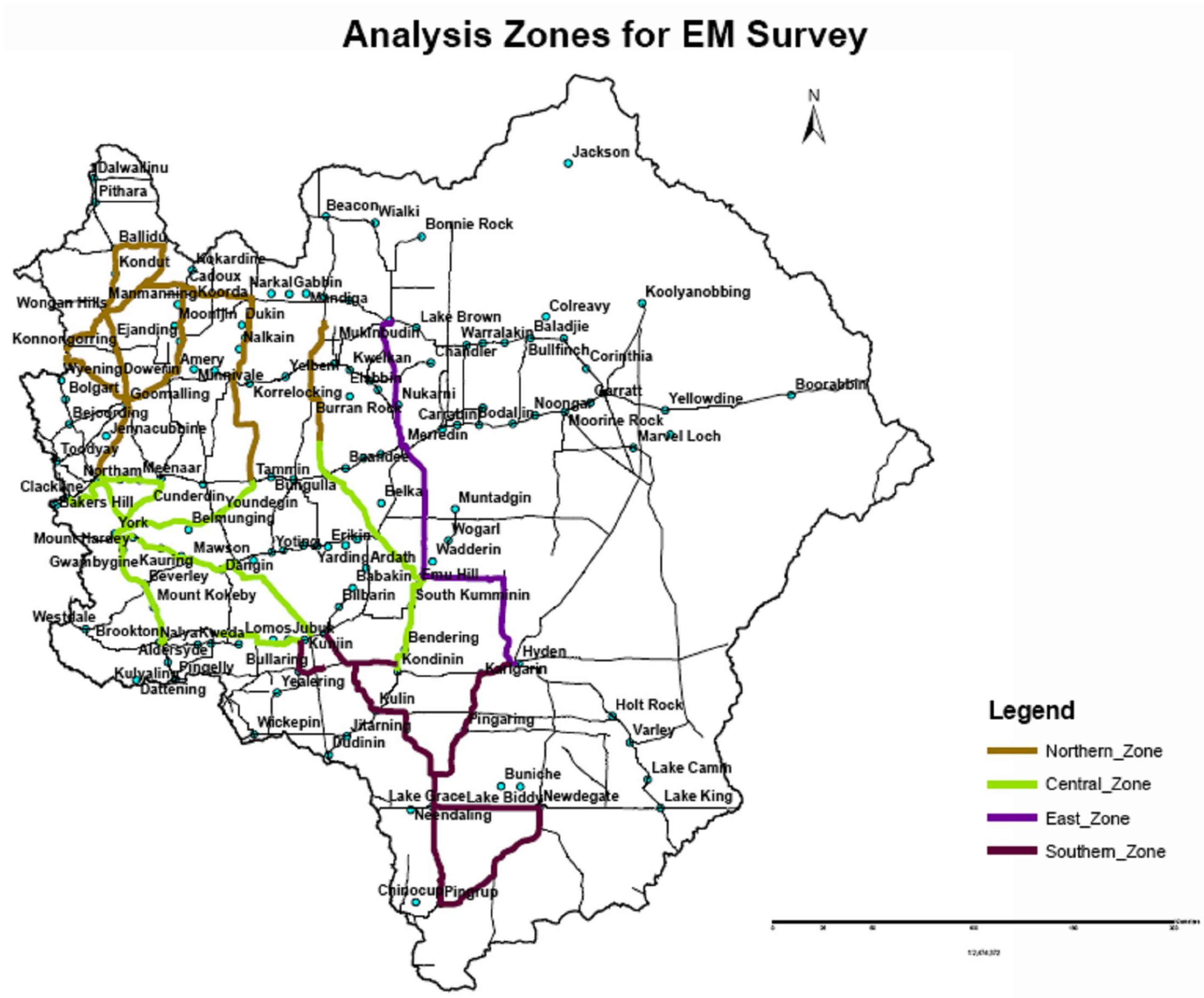


Figure 4-1 Geographical Division of EM Survey

4.3 Comparative Analysis

In theory, both the Land Monitor dataset and the EM Survey data sets can be used to estimate the location and extent of transport assets currently impacted or at risk of salinity.

A key outcome of the analysis undertaken was to compare the relative merits of each, in terms of accuracy, capacity, cost etc.

In undertaking the comparative analysis the Land Monitor dataset was compared to each of the three variable of the EM Survey dataset (i.e EM38H, EM38V and EM31V). This comparison included an analysis of the spatial distribution of salinity as predicted by Land Monitor when compared to the EM Survey dataset.

Saline sites identified by Land Monitor for each geographic location were analysed to determine how many of these sites also possessed EM Survey values of 100 (moderately -- highly saline) or greater and 150 or greater (highly saline). The intent was to develop an insight into the efficacy of Land Monitor in recognising saline sites. In other words, if Land Monitor is to be considered an effective assessment tool, it should be expected, at the very least, to be able to detect highly saline sites.

The reverse analysis was also conducted. Sites with EM Survey values over 100 and 150 were assessed to determine the proportion that fell within saline Land Monitor areas. Results of the analysis are presented in Section 5.4 of this report.

4.4 EM Maps (LGA)

A series of A3 maps of the EM Survey dataset was developed, providing an assessment of roads at risk of salinity at a LGA scale.

The series of EM Survey - LGA scale maps include:

- Near-surface conductivity (EM38 H). Predictor of roads at immediate risk of saline damage to either the sub-base, or the bitumen.
- Conductivity of road base (EM38 V). Predictor of roads at imminent risk to the development of salinity.
- Subsoil conductivity (EM31 V). Predictor of salt within the soil profile at a depth of around five metres, highlights areas that may be at risk of future saline damage. In such locations, remedial measures could potentially be implemented that will mitigate the ensuing saline influence.

5. Results

5.1 Limitations

In considering the assessment presented, a number of caveats must be acknowledged that may influence the reliability of both the EM survey and Land Monitor data set used.

Inference of salinity from EM survey data is not a precise science. Section 3 discusses a range of variables that potentially influence the soil electro-conductivity, including soil texture, water content and temperature. However, it is considered that at the higher end of the conductivity scale, salinity becomes the overriding contributor to electro-conductivity. In terms of the analysis undertaken here, it is this higher end of the electro-conductivity scale that is of interest.

Data from different parts of the ARB may possess different properties, so direct comparisons between the electromagnetic survey data collected in one part of the region with survey data collected in another part of the region is not necessarily recommended.

Areas recognised as lakes from the satellite imagery are not included in the Land Monitor salinity dataset. Lakes are intentionally made distinct from saline areas because otherwise a false representation of the total area of saline land would be obtained. Consequently the analysis undertaken does not identify roads that traverse areas designated as lakes, as saline sites, although they may indeed be located in highly saline areas.

5.2 Aerial Photograph Interpretation

Presenting the results for the aerial photograph interpretation poses difficulties.

Aerial photograph interpretation is by its nature a qualitative assessment of salinity. Identification of saline areas from a photograph is largely a subjective process. Whilst salt scalds are relatively easily to detect, regions that are mildly saline are often difficult to identify and different people are likely to classify saline sites in different ways. A degree of experience is required to accurately identify saline sites from aerial photographs, and consistency of a visual survey may be difficult to achieve, particularly if a number of people are involved in the analysis.

A visual assessment of aerial photographs does not provide numerical data that can be used in the analysis of the extent and location of salinity. Land Monitor provides the advantage of salinity assessment at different historical times (approx. 1990 and 1996). The EM Survey data provides an indication of the severity of salinity at a particular site, and can be repeated over time to provide an indication of the temporal development of salinity at any given survey site.

The visual assessment of the correlation between Land Monitor data, EM data, and aerial photographs conducted as part of this study suggested the following:

- It appears that Land Monitor data does provide a reasonable approximation of the areas affected by salinity. An analysis undertaken within the Yenyening catchment comparing Land Monitor with accurate aerial salinity mapping, indicated that Land Monitor was approximately 80% accurate but tended to underestimate the extent of salinity (GHD 2006). An assessment undertaken by CSIRO also indicates that Land Monitor predicts land impacted by salinity and 80% accuracy (Cacetta et. al. 2005).
- All highly saline sites (presence of bare salt) identified during the aerial photograph interpretation returned extremely saline readings from the EM Survey undertaken.
- A comparison of sites potentially at risk of developing salinity was not possible as identifying risk areas through aerial photograph interpretation only is ultimately very difficult. However, aerial photograph assessment of areas identified by the EM Survey generally appeared to be in areas of salinity hazard.
- In a high percentage of sites where aerial photograph interpretation was undertaken, the presence of the road appeared to exacerbate the development of salinity upstream of the road itself. In other words, on 80% - 90% of occasions the road appeared to be exacerbating the expression of salinity, probably acting as a barrier to groundwater movement downslope.

In summary, aerial photograph interpretation is a useful tool in assessing salinity risk to transport assets when used in conjunction with other assessment tools, and in particular an electromagnetic survey. The effectiveness of aerial photograph interpretation on its own is limited by its interpretive nature and lack of quantitative assessment.

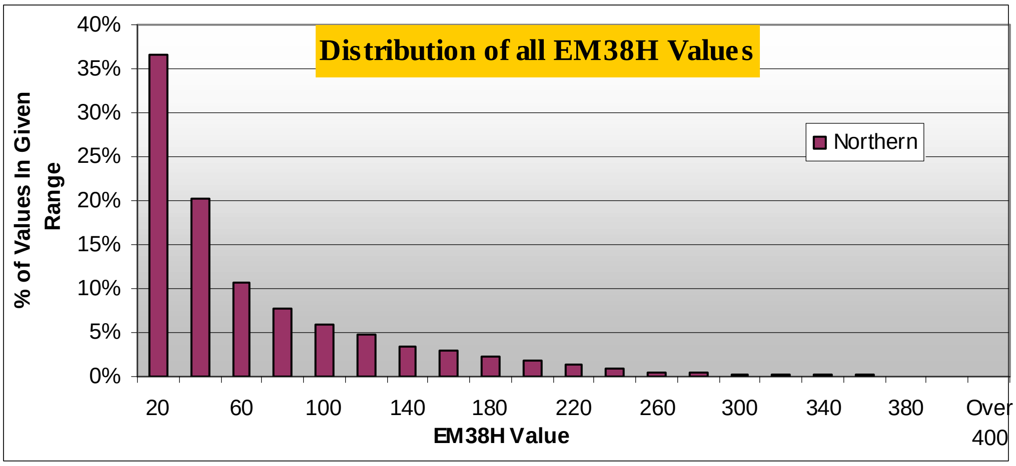
5.3 Distribution Analysis EM Survey

The overall distribution of EM values suggests that the majority of regionally significant roads surveyed are not saline (EM38 H < 100). Figure 5-1 indicates that approximately 35% of the northern zone has EM38H values below 20, and approximately 80% of EM Survey data for the northern zone exhibit EM38 H values of below 100 (moderately saline).

Figure 5-1 also indicates that the EM Survey data collected is strongly skewed to the left, with an apparent exponential decrease in the number of EM Survey points with increasing EM38 H values.

Charts representing the range of EM Survey data from each zone are presented in Appendix A.

Figure 5-1 Distribution of EM Survey Points (EM38 H) - Northern Zone



The Department of Agriculture and Food WA suggests that in 1994, around 9% of the southwest agricultural region was impacted by salinity and that by 2020; approximately 20% of the region could be "*at risk of a high watertable*" (George & Short, 2006).

The shallow near surface EM Survey (EM38 H) values predict a level of salinity consistent with existing knowledge.

5.4 Analytical Comparison (Land Monitor Data and EM Survey)

A comparison of Land Monitor data with the EM Survey undertaken is offered.

Figure 5-2 presents the distribution of EM38 H values for the northern zone, that fall within areas described as saline by Land Monitor. The majority (80%) of recorded points in the EM Survey that fall within the saline are as described by Land Monitor.

Figure 5-2 Distribution of EM Survey Points (EM38 H) within Saline Areas as Predicted by Land Monitor (northern zone only)

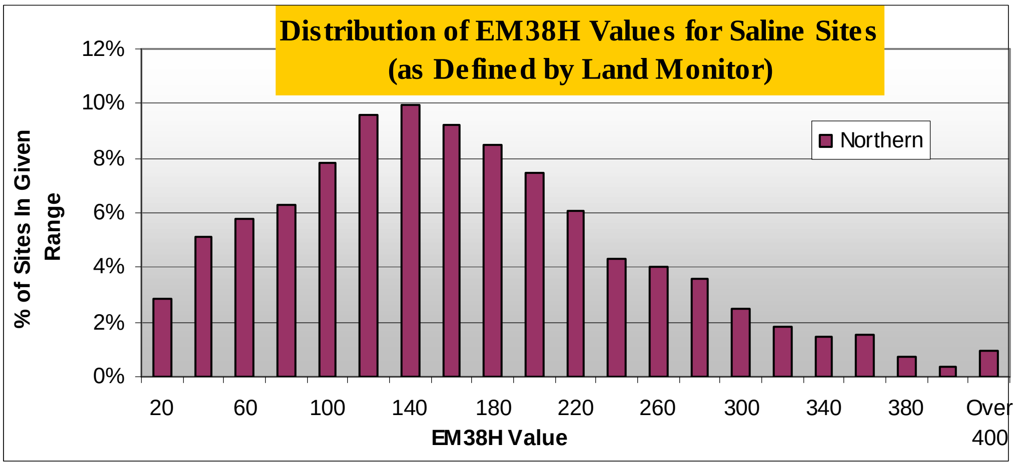


Figure 5-3 The Percentage of Values for Certain EM38H Ranges that Fall Within the Area Designated as Saline by Land Monitor

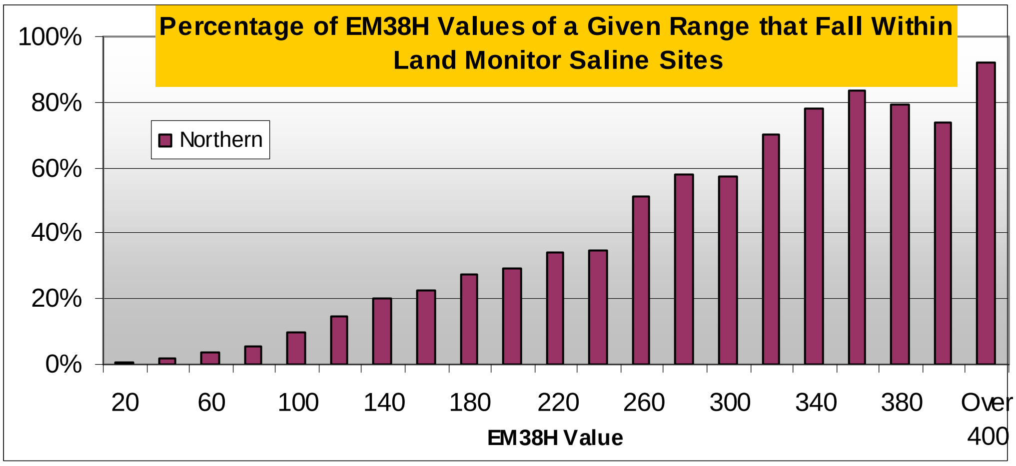


Figure 5-2 indicates that within Land Monitor saline sites, EM38H values between 100 and 200 are most prevalent. The relatively small percentage of very high EM values is in response to the relatively small area of extremely saline land in the surveyed area.

Figure 5-3 appears to indicate that Land Monitor becomes more accurate at predicting salinity as the severity of salinity increases. Land Monitor appears to be most accurate in predicting areas impacted by salinity where EM38 H values are greater than 250 mS/m. The analysis undertaken indicates that Land Monitor is generally effective in identifying areas of extreme salinity, however it is less reliable in identifying areas of mildly -- moderately saline areas.

The EM38H data presented in Figure 5-1, Figure 5-2 and Figure 5-3 is largely representative of the other analysis data, presented in Appendix A. Anomalies evident within some of the data reflect the level of noise in both the Land Monitor and EM Survey datasets.

Table 5-1 indicates that approximately 27% of EM Survey points (EM 38 H) of value greater than 100 mS/m, and only approximately 21% of all EM Survey points (EM 31 V), fall within the saline area as predicted by Land Monitor. This provides further evidence that Land Monitor has limited value in identifying mildly -- moderately saline land, and land at risk of becoming saline.

Table 5-1 Proportion of EM Survey Points that Fall Within Saline Areas as predicted by Land Monitor (Northern Zone)

	> 100 mS/m	> 150 mS/m
EM38 (H)	27%	35%
EM38 (V)	25%	36%
EM31 (V)	21 %	25%

Table 5-2 indicates that land described as saline by Land Monitor, is typically saline. More than 70% of the EM Survey points contained within the area identified as saline by Land Monitor, are > 100 mS/m (moderately saline).

Table 5-2 Proportion of Saline Land (as predicted by Land Monitor) with an EM Survey Value of greater than 100 mS/m and 150 mS/m (Northern Zone)

	> 100 mS/m	> 150 mS/m
EM38 (H)	77%	55%
EM38 (V)	72%	48%
EM31 (V)	84%	66%

The analysis undertaken tends to support the following conclusions:

1. There is a reasonable correlation between Land Monitor and EM data for extremely saline sites.
2. Land Monitor is not particularly effective in identifying areas of mildly –- moderately saline land or land at risk of becoming saline.
3. Land Monitor is a relatively effective tool when applied at a regional scale, and whilst it underestimates the area of salinity, it appears to display a relatively high accuracy for areas that are described as saline.
4. Aerial photograph interpretation, whilst not a reliable tool for identifying all sites at risk of becoming saline, is particularly useful in adding value to other datasets, including Land Monitor and EM survey data.

6. Conclusions

6.1 Aerial Photograph Interpretation

Aerial photograph interpretation is a useful tool in identifying transport assets at risk of salinity, however it is typically a relatively laborious exercise, particularly when considering the scale of the ARB, and it requires a relatively high degree of skill in interpretation. Aerial photograph interpretation is most useful when undertaken in conjunction with a range of other datasets, including a digital terrain model and a quantitative assessment of salinity risk.

The key constraints associated with aerial photograph interpretation include:

- It is a subjective exercise and relies on the skill and experience of the operator.
- It does not yield a numerical output that can be readily compared to other time series data.
- It is labour-intensive.

Due to these constraints, it would be difficult to maintain consistency in the assessment of aerial photographs over a large area or even a moderate time frame. In addition, aerial photograph interpretation includes the potential for errors in identification, including omissions of saline areas.

It is possible to digitise salinity from aerial photographs to develop a time series change in salinity, however this is likely to be very labour-intensive and is unlikely to identify areas of mild -- moderately saline land. As a result, aerial photograph interpretation is unlikely to provide the most effective means of identifying transport assets at risk of salinity.

The major advantage of aerial photograph interpretation is in developing insight into the interaction between salinity and transport assets. For example, aerial photography can be used to identify whether a road is creating a structural barrier that contributes to the development of salinity.

6.2 Analysis of Land Monitor Data

Land Monitor is an effective tool for identifying regional trends in salinity distribution and development. Analysis undertaken within this project indicates that Land Monitor is generally effective in identifying areas of high -- extreme salinity, however is much less effective in identifying areas of mild -- moderate salinity. This is not surprising given that Land Monitor identifies areas of consistently low producing land. Mild -- moderately saline land may fluctuate in its productive potential as a result of seasonal variations, and therefore, it is less likely to be identified.

Land Monitor contains no effective salinity risk assessment tool. Although salinity hazard mapping has been undertaken, it is not particularly useful in identifying areas at actual risk of developing salinity.

The value of Land Monitor could be increased significantly by an additional run, to expand the sequence 1997 – 1992 and 1995 – 1998. An additional Land Monitor coverage for the period 2002 – 2006 would provide additional capacity for identifying regional trends in salinity development.

In summary, Land Monitor is considered to be an effective regional assessment tool. However, its relatively poor capacity to identify mild -- moderately saline soils, and the absence of an effective risk assessment tool, limit its capacity to be used as an effective tool for detailed evaluation of transport assets at risk of salinity.

6.3 Analysis of EM Data

Prediction of soil salinity through electromagnetic survey is not an exact science. A range of factors, in addition to salinity, can impact the electromagnetic conductivity of the soil profile, particularly at relatively low soil salinity. Typically, ground truthing, via soil sampling, is undertaken as a means of calibrating the results of the electromagnetic survey.

One of the key advantages of undertaking electromagnetic surveys to identify roads at risk of salinity is the relatively low cost and ease of undertaking the assessment. Undertaking effective ground truthing (soil sampling) over the 2,140 km of the survey would simply not be possible, given the relative sample density that would be required.

The primary purpose for undertaking electromagnetic survey is to identify waterlogged highly saline soils. As a result calibration requirements normally associated with electromagnetic surveys appear less critical in this case.

The EM Survey undertaken appears very effective in identifying highly saline sites. The effectiveness of the EM Survey in identifying areas at risk of further salinity development is less clear. However, unlike aerial photography and Land Monitor, the EM Survey provides a quantitative assessment of salinity, and offers the potential for the development of a consistent temporal comparison of data.

The EM Survey also provides a reasonably cost-effective means of collecting salinity data at a relatively fine scale, not supported by the other methods investigated.

7. Recommendations

The analysis undertaken indicates that the results from the EM Survey are superior when compared with outcomes from analysis of Land Monitor data and aerial photograph interpretation. However, Land Monitor and aerial photograph interpretation contribute to a greater appreciation of the extent of salinity and should be used in conjunction with the data provided by an EM survey. As a result it is considered that analysis of a range of datasets provides the most effective means of determining roads at risk of salinity within the region.

The EM survey conducted in 2006 cost approximately $22,000 and covered a distance of 2,140 km. Over a period of three years, the majority of the regionally significant roads within the Avon River Basin could effectively be surveyed.

If the survey were to be repeated every five years, then an understanding of trends in salinity development associated with regionally significant transport assets could be developed. Assuming today's cost of the survey, then an investment of approximately $65,000 over five years would be required. This roughly equates to the cost of replacing one significant road crossing, of which there are literally hundreds within the Avon River Basin.

The following recommendations are offered:

1. *An electromagnetic survey of the significant roads in the Avon River basin is conducted on a 5-year cycle.*
2. *Land Monitor data and aerial photography are used to support the EM survey.*
3. *The results of the EM survey are provided to LGAs and the Regional Road Board to assist in the development of strategic planning for regionally significant roads at risk of salinity impacts.*

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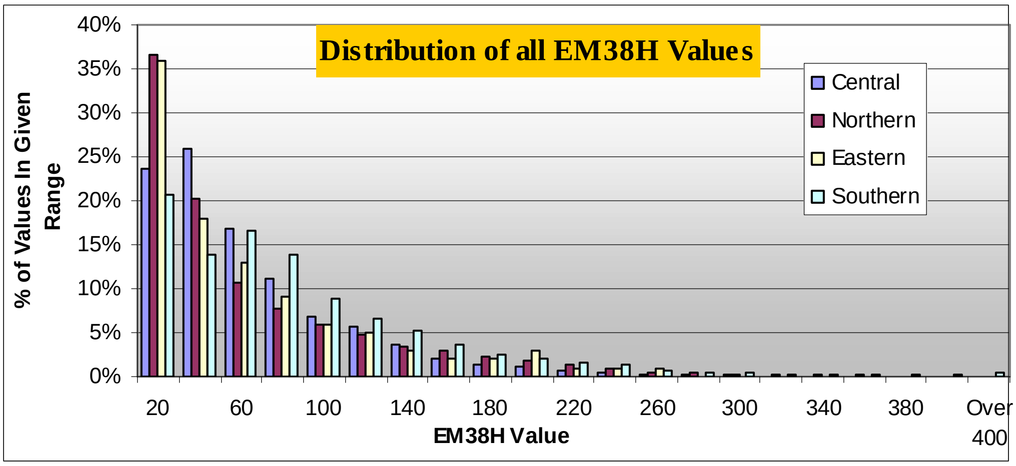
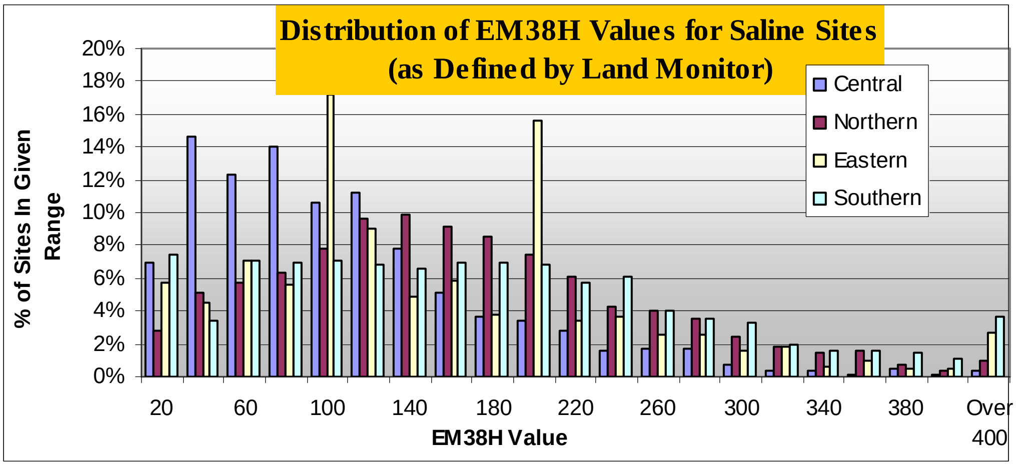
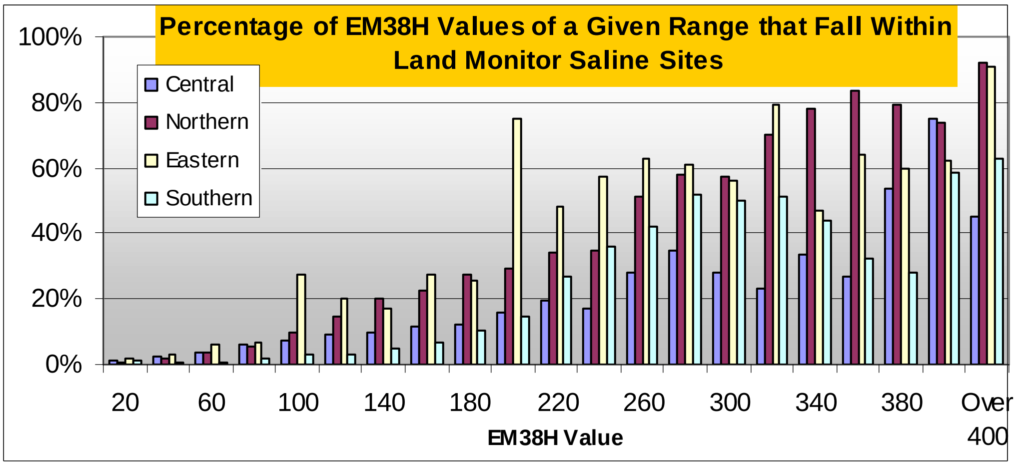
http://www.usyd.edu.au/su/agric/ACSS/sphysic/physics.html

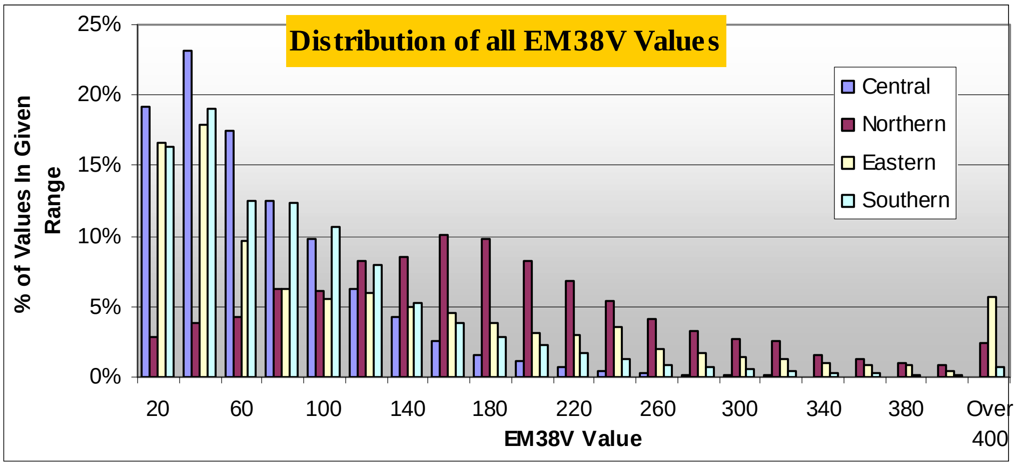
Appendix A

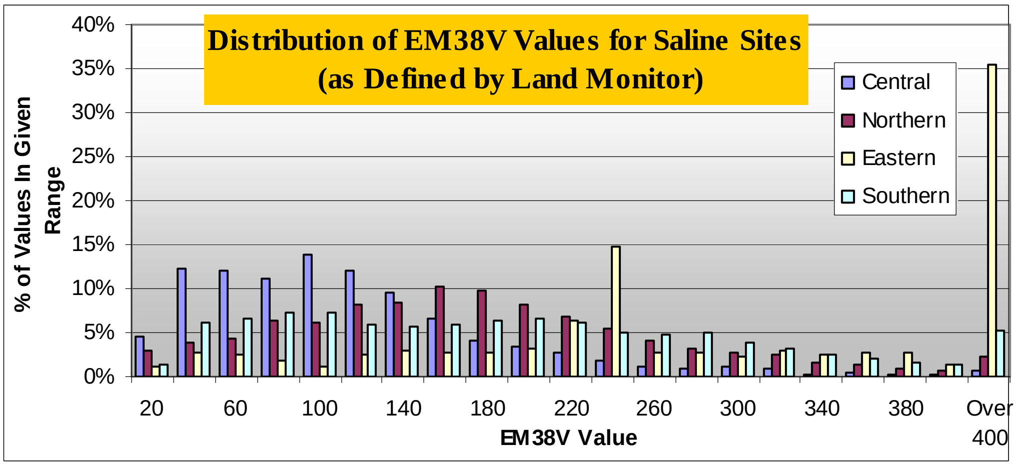
Charts Providing Analysis of EM Data

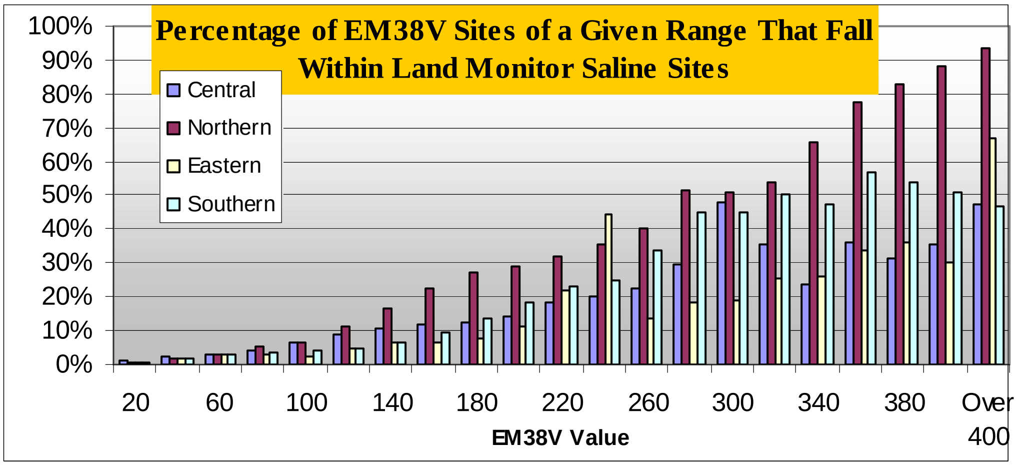

Distribution of all EM38H Values
% of Values In Given Range
40%
35%
30%
25%
20%
15%
10%
5%
0%
Central
Northern
Eastern
Southern
20
60
100
140
180
220
260
300
340
380
Over 400
EM38H Value

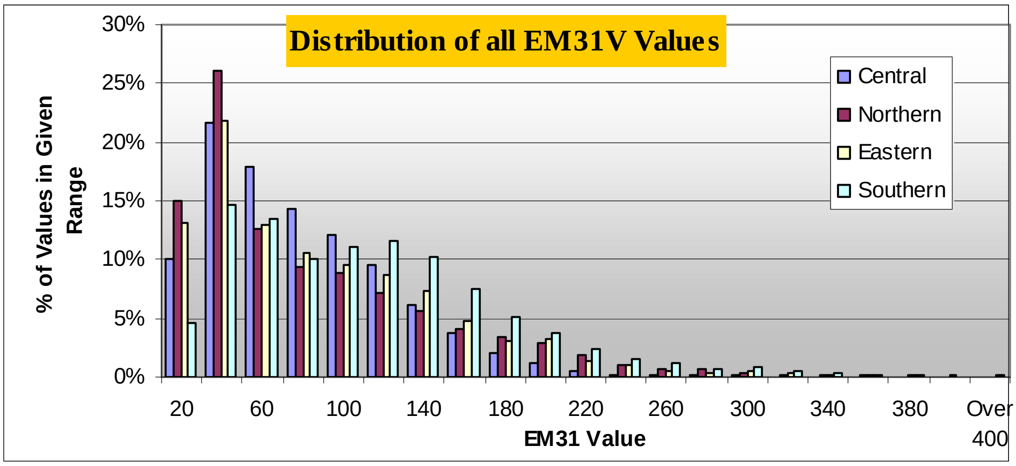

Distribution of EM38H Values for Saline Sites (as Defined by Land Monitor)
% of Sites In Given Range
20%
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
Central
Northern
Eastern
Southern
20
60
100
140
180
220
260
300
340
380
Over 400
EM38H Value

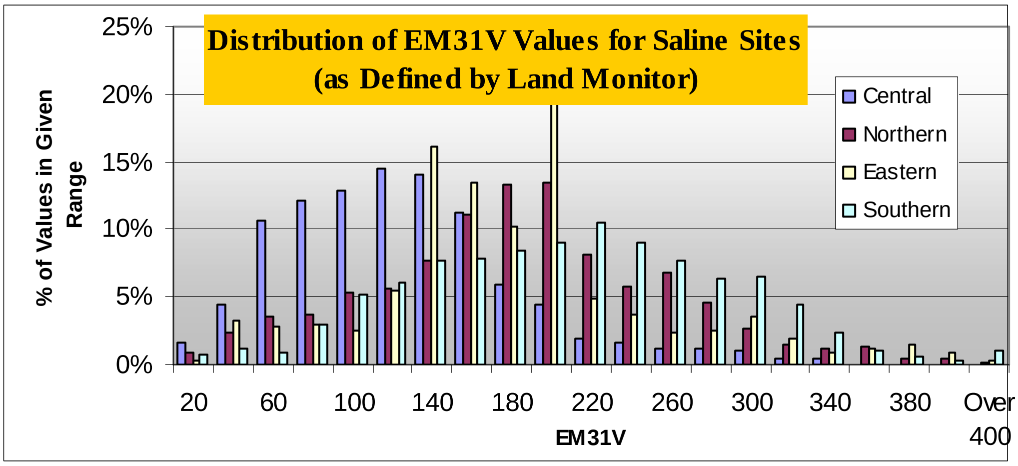

Percentage of EM38H Values of a Given Range that Fall Within Land Monitor Saline Sites
100%
80%
60%
40%
20%
0%
Central
Northern
Eastern
Southern
20
60
100
140
180
220
260
300
340
380
Over 400
EM38H Value

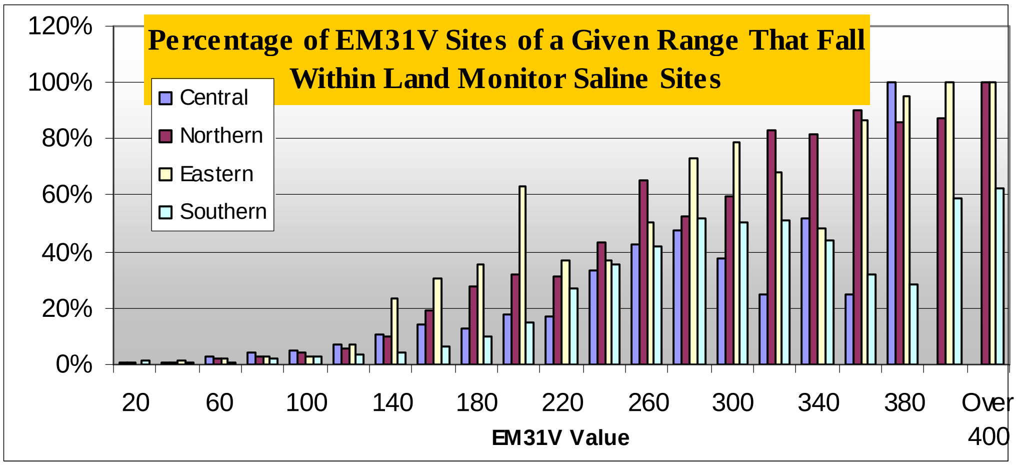

Distribution of all EM38V Values
% of Values In Given Range
EM38V Value
Central
Northern
Eastern
Southern
25%
20%
15%
10%
5%
0%
20
60
100
140
180
220
260
300
340
380
Over 400


Distribution of EM38V Values for Saline Sites (as Defined by Land Monitor)
% of Values In Given Range
EM38V Value
Central
Northern
Eastern
Southern
40%
35%
30%
25%
20%
15%
10%
5%
0%
20
60
100
140
180
220
260
300
340
380
Over 400


Percentage of EM38V Sites of a Given Range That Fall Within Land Monitor Saline Sites
EM38V Value
Central
Northern
Eastern
Southern
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
20
60
100
140
180
220
260
300
340
380
Over 400


Distribution of all EM31V Values
% of Values in Given Range
30%
25%
20%
15%
10%
5%
0%
Central
Northern
Eastern
Southern
20
60
100
140
180
220
260
300
340
380
Over 400
EM31 Value


Distribution of EM31V Values for Saline Sites (as Defined by Land Monitor)
% of Values in Given Range
25%
20%
15%
10%
5%
0%
Central
Northern
Eastern
Southern
20
60
100
140
180
220
260
300
340
380
Over 400
EM31V


Percentage of EM31V Sites of a Given Range That Fall Within Land Monitor Saline Sites
120%
100%
80%
60%
40%
20%
0%
Central
Northern
Eastern
Southern
20
60
100
140
180
220
260
300
340
380
Over 400
EM31V Value

Appendix B

Comparison Tables of Land Monitor Saline Sites to EM Data

CENTRAL DATA

Total Number of Saline Sites According to Land Monitor	2909		
Number of EM38V Values over 150 that correspond to Land Monitor Saline Sites	611	Number of EM38V Values over 100 that corespond to Land Monitor Saline Sites	1346
Total Number of EM38V Values over 150	3613	Total Number of EM38V Values over 100	11088
Percentage of EM38V Values over 150 that are co-incident with Land Monitor Saline Sites	17%	Percentage of EM38V Values over 100 that are co-incident with Land Monitor Saline Sites	12%
Percentage of sites designated as saline by Land Monitor that have an EM38V Value over 150	21%	Percentage of sites designated as saline by Land Monitor that have an EM38V Value over 100	46%

Number of EM38H Values over 150 that corespond to Land Monitor Saline Sites	569	Number of EM38H Values over 100 that corespond to Land Monitor Saline Sites	1204
Total Number of EM38H Values over 150	3317	Total Number of EM38H Values over 100	9849
Percentage of EM38H Values over 150 that are co-incident with Land Monitor Saline Sites	17%	Percentage of EM38H Values over 100 that are co-incident with Land Monitor Saline Sites	12%
Percentage of sites designated as saline by Land Monitor that have an EM38H Value over 150	20%	Percentage of sites designated as saline by Land Monitor that have an EM38H Value over 100	41%

Number of EM31V Values over 150 that corespond to Land Monitor Saline Sites	676	Number of EM31V Values over 100 that corespond to Land Monitor Saline Sites	1696
Total Number of EM31V Values over 150	3857	Total Number of EM31V Values over 100	14840
Percentage of EM31V Values over 150 that are co-incident with Land Monitor Saline Sites	18%	Percentage of EM31V Values over 100 that are co-incident with Land Monitor Saline Sites	11%
Percentage of sites designated as saline by Land Monitor that have an EM31V Value over 150	23%	Percentage of sites designated as saline by Land Monitor that have an EM31V Value over 100	58%

Eastern Data

Total Number of Saline Sites According to Land Monitor	2727		
Number of EM38 values over 150	2180.000	Number of EM38 values over 100	4486.000
Number of EM38 Values over 150 that correspond with Land Monitor Saline Areas	1178	Number of EM38 Values over 100 that correspond with Land Monitor Saline Areas	1634
Percentage of EM38 Values over 150 that correspond with Land Monitor Saline Areas	54%	Percentage of EM38 Values over 100 that correspond with Land Monitor Saline Areas	36%
Percentage of Land Monitor Saline Areas that correspond with EM38 Values over 150	43%	Percentage of Land Monitor Saline Areas that correspond with EM38 Values over 100	60%

Number of EM38V values over 150	2558.000	Number of EM38V values over 100	4486.000
Number of EM38V Values over 150 that correspond with Land Monitor Saline Areas	1296	Number of EM38V Values over 100 that correspond with Land Monitor Saline Areas	2082
Percentage of EM38V Values over 150 that correspond with Land Monitor Saline Areas	51%	Percentage of EM38V Values over 100 that correspond with Land Monitor Saline Areas	46%
Percentage of Land Monitor Saline Areas that correspond with EM38V Values over 150	48%	Percentage of Land Monitor Saline Areas that correspond with EM38V Values over 100	76%

Number of EM31V values over 150	3379.000	Number of EM31V values over 100	8126.000
Number of EM31V Values over 150 that correspond with Land Monitor Saline Areas	1618	Number of EM31V Values over 100 that correspond with Land Monitor Saline Areas	2407
Percentage of EM31V Values over 150 that correspond with Land Monitor Saline Areas	48%	Percentage of EM31V Values over 100 that correspond with Land Monitor Saline Areas	30%
Percentage of Land Monitor Saline Areas that correspond with EM31V Values over 150	59%	Percentage of Land Monitor Saline Areas that correspond with EM31V Values over 100	88%

NORTHERN DATA

Total Number of Saline Sites According to Land Monitor	3653		
Number of EM38V Values over 150 that corespond to Land Monitor Saline Sites	1996	Number of EM38V Values over 100 that corespond to Land Monitor Saline Sites	2803
Total Number of EM38V Values over 150	5692	Total Number of EM38V Values over 100	11185
Percentage of EM38V Values over 150 that are co-incident with Land Monitor Saline Sites	35%	Percentage of EM38V Values over 100 that are co-incident with Land Monitor Saline Sites	25%
Percentage of sites designated as saline by Land Monitor that have an EM38V Value over 150	55%	Percentage of sites designated as saline by Land Monitor that have an EM38V Value over 100	77%

Number of EM38H Values over 150 that corespond to Land Monitor Saline Sites	1761	Number of EM38H Values over 100 that corespond to Land Monitor Saline Sites	2634
Total Number of EM38H Values over 150	4853	Total Number of EM38H Values over 100	9861
Percentage of EM38H Values over 150 that are co-incident with Land Monitor Saline Sites	36%	Percentage of EM38H Values over 100 that are co-incident with Land Monitor Saline Sites	27%
Percentage of sites designated as saline by Land Monitor that have an EM38H Value over 150	48%	Percentage of sites designated as saline by Land Monitor that have an EM38H Value over 100	72%

Number of EM31V Values over 150 that corespond to Land Monitor Saline Sites	2400	Number of EM31V Values over 100 that corespond to Land Monitor Saline Sites	3071
Total Number of EM31V Values over 150	6818	Total Number of EM31V Values over 100	14468
Percentage of EM31V Values over 150 that are co-incident with Land Monitor Saline Sites	35%	Percentage of EM31V Values over 100 that are co-incident with Land Monitor Saline Sites	21%
Percentage of sites designated as saline by Land Monitor that have an EM31V Value over 150	66%	Percentage of sites designated as saline by Land Monitor that have an EM31V Value over 100	84%

SOUTHERN DATA

Total Number of Saline Sites According to Land Monitor	**2717**		
Number of EM38V Values over 150 that correspond to Land Monitor Saline Sites	1547	Number of EM38V Values over 100 that corespond to Land Monitor Saline Sites	1939
Total Number of EM38V Values over 150	6120	Total Number of EM38V Values over 100	12845
Percentage of EM38V Values over 150 that are co-incident with Land Monitor Saline Sites	25%	Percentage of EM38V Values over 100 that are co-incident with Land Monitor Saline Sites	15%
Percentage of sites designated as saline by Land Monitor that have an EM38V Value over 150	57%	Percentage of sites designated as saline by Land Monitor that have an EM38V Value over 100	71%

Number of EM38H Values over 150 that corespond to Land Monitor Saline Sites	1385	Number of EM38H Values over 100 that corespond to Land Monitor Saline Sites	1850
Total Number of EM38H Values over 150	5374	Total Number of EM38H Values over 100	11536
Percentage of EM38H Values over 150 that are co-incident with Land Monitor Saline Sites	26%	Percentage of EM38H Values over 100 that are co-incident with Land Monitor Saline Sites	16%
Percentage of sites designated as saline by Land Monitor that have an EM38H Value over 150	51%	Percentage of sites designated as saline by Land Monitor that have an EM38H Value over 100	68%

Number of EM31V Values over 150 that corespond to Land Monitor Saline Sites	1919	Number of EM31V Values over 100 that corespond to Land Monitor Saline Sites	2416
Total Number of EM31V Values over 150	8918	Total Number of EM31V Values over 100	20382
Percentage of EM31V Values over 150 that are co-incident with Land Monitor Saline Sites	22%	Percentage of EM31V Values over 100 that are co-incident with Land Monitor Saline Sites	12%
Percentage of sites designated as saline by Land Monitor that have an EM31V Value over 150	71%	Percentage of sites designated as saline by Land Monitor that have an EM31V Value over 100	89%

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