geophysical solutions

Report

to

THE DEPARTMENT OF CONSERVATION AND LAND MANAGEMENT
NARROGIN DISTRICT HEADQUARTERS

on

ELECTROMAGNETIC GROUND SURVEY OF TOOLIBIN LAKE

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CA257_3

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Summary

In November 2003, Geoforce performed a ground electromagnetic (EM) survey for the Department of Conservation and Land Management (CALM) on Lake Toolibin Nature Reserve, approximately 250km south-east of Perth. The work was conducted as part of an on-going assessment of the effect that saline surface water and hypersaline groundwater are having on Lake Toolibin Nature Reserve and the effect groundwater pumping and engineering works are having on salinity.

A GEONICS EM31 and a GEONICS EM38 were used to collect the conductivity data. EM data were collected concurrently and position data taken with a standard Global Positioning System (GPS), giving accuracies of +/- 3 metres. As per contract RFQ 407 10/03, parallel lines were conducted at 50m spacing, taking measurements every second while on the quad-bike and spot readings every 20m whilst on foot.

Several processing filters were applied to the data in order to analyse the effect of the groundwater pumping. These filters were applied to the data in order to extract the following information:

- To compare the data with similar data collected in 1998
- To determine areas in which there may be concentration of salinity near the surface from capillary rise
- To perform a statistical correlation between the ECa values from the EM31 and EM38 with the distance from the operational pumps
- To create an ECe dataset of the area from the EM38 ECa data.

The data analysis and processing yielded the following conclusions:

- There has been a reduction of the ground conductivity across some areas of the lakebed. Further investigations would be required to determine whether or not these areas of decrease are forming from the pumping of groundwater from the lake
- Concentration of salt close to the surface, possibly due to capillary rise, is mostly restricted to the open to lightly forested areas in the southern half of the lakebed. There is little evidence of this in the open areas in the northern half of the lakebed
- There was little to no correlation between ECa values and distance from operational pumps. From the depth of operation of the pumps, it is possible that the localised effects are at a depth greater than that imaged by the EM31. It is possible that at the depth of investigation of the EM31 and EM38, the effect of the groundwater pumping has dispersed over a larger area. This would account for the fact that the ground conductivity has decreased across most of the site but does not correlate well with the distance from operational pumps.

From the data collections and subsequent analysis, several recommendations can be made for future studies:

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- All future data is stored with processing notes, accompanying reports, etc. The lack of this information with the 1998 ECa data made quantitative processing and interpretation impossible.
- Regular EM31 and EM38 surveys could be used to investigate seasonal variations in the ground conductivity, from both groundwater pumping and rainfall.
- Radiometrics data could be collected concurrently with the EM data to provide soil maps of the lakebed.
- A more comprehensive soil sampling program would provide much better information regarding the vertical and lateral changes in salt concentrations across the lakebed. For the extremely hard terrain encountered, we would recommend using an auger mounted on a Dingo or the back of a 4WD
- Information of the ground conductivity with depth could be obtained through logging existing boreholes with gamma and conductivity probes. This can give information on changes in clay, water and salinity content with depth.
- Use of the resistivity method to obtain information on both the vertical and lateral variations in the ground conductivity under the lakebed. The typical depth on investigation of the resistivity method ranges from metres to hundreds of metres, depending on the distance at which the electrodes are spaced. Resistivity would be a useful tool for investigating the lateral effects the groundwater pumping close to the pumps at depth greater than the 4m investigated by the EM31.

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1 Introduction

OBJECTIVE
The main objective of the project was to

Determine the conductivity of the upper and lower root zones, spatial correlation with treatments (pumping) and temporal changes since 1998.

MAJOR TASKS

1. Conduct an EM31 & EM38 ground survey across the floor of Toolibin Lake.

2. Sample soil moisture content & soil EC at 10 sites (at least) across the floor of the lake to a depth of 1-2m (0.25 – 0.5m increments). This data will be used to calibrate the EM38 data.

3. Interpolate EM31 and EM38 data to create 10m gridded data sets

4. Analyse the gridded data sets:
    a. Statistical correlation between ECa values and distance from pumps (the Department will supply pump location data);
    b. Comparison between 1998 and 2003 data – finding areas of greatest change;&
    c. Use a ratio of EM38 to EM31 ECa values to highlight possible areas of salt accumulation due to capillary rise.

5. Calibrate and convert ECa measurements to ECe values and create 10m grids of ECe (EM31 & EM38).

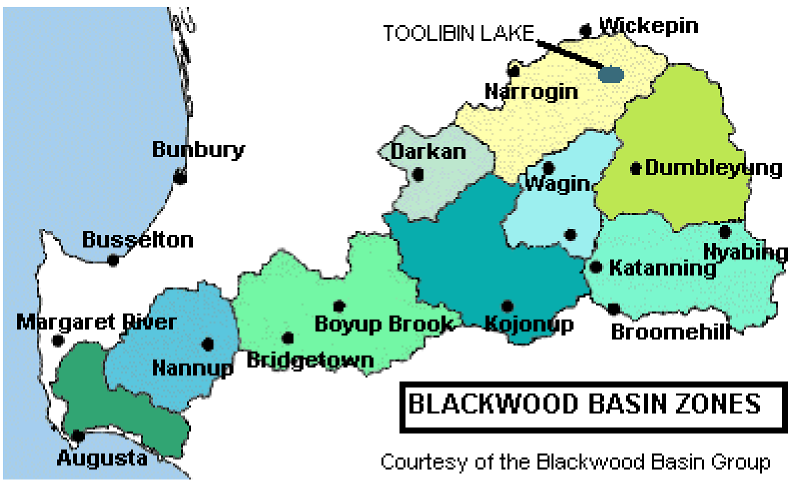

Figure 1.1 – Location of Lake Toolibin

2 Background[2]

2.1 Lake Toolibin Recovery Catchment

Toolibin Lake is located at the headwaters of the Blackwood River. It is a seasonal wetland and lies east of Narrogin in the Western Australian wheatbelt. The lake is situated in the Toolibin Lake Nature Reserve which is managed by the Department of Conservation and Land Management. Annual rainfall in the catchment is 400 mm, with Class-A pan evaporation of 1900 mm. Approximately 95% of the Toolibin catchment (47,000 ha) has been cleared of deep-rooted perennial native vegetation within the last 100 years.

Toolibin Lake is recognized as a conservation area of international significance. Dryland salinity has already claimed 8% of the Toolibin Lake Catchment and severely threatens the conservation values of Toolibin Lake.

The lake is one of six natural diversity recovery catchments in Western Australia. The protection of natural values is a key community goal for all six natural diversity recovery catchments. These catchments are also an important vehicle for testing and developing generic technologies for tackling salinity.

2.2 Existing recovery actions

In an effort to lower the groundwater table, 8 production bores were established near the western edge of the Lake in May 1997. This production field produces up to 230 kilolitres per day and has resulted in drawdown of groundwater close to all pumps.

Computer modelling[3] suggested that three production bores extracting water from a palaeochannel located along the eastern side of the lake would significantly improve the protection of the lake floor vegetation and other conservation values. A new bore field based on these investigations was commissioned in July 2001 and is currently producing approximately 500 kilolitres per day. The location of all production bores is annotated in Figure 2.1.

The objective of groundwater pumping at Toolibin Lake is to lower the groundwater table to at least 1.5m to prevent the salinisation of the vegetation root zone[4].

Monthly groundwater monitoring of 40 bores located across Toolibin Lake is primarily the method used to judge the success of this recovery action. Currently, groundwater levels in all Toolibin Lake bores, except one, are deeper than 2m. Analysis suggests that the lowered groundwater levels are in response to both below average rainfall and groundwater pumping.

Another, more subjective, measure of success of this recovery action is the continued health or recovery of lake bed vegetation. Regular vegetation monitoring (since 1977) of permanently marked plots suggests that the health of the lake bed vegetation is generally in decline[5]. However, significant and continued seedling

[2] Excerpt from Wyland, J, 2003
[3] SKM, 2000
[4] Recovery Team & Technical Advisory Group, 1994
[5] ECU, 2002

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recruitment is occurring around an area (P9) where experimental pumping began in the early 1990's.

Electromagnetic surveys are a practical and objective method of measuring soil salinity. An electromagnetic survey was used to measure the salinity of the lake floor in May 1998. The survey showed a circular pattern of reduced salinity around P9. It is hypothesised that groundwater pumping at P9 has lowered soil salinities which has in turn provided favourable conditions for seedling survival.

The western pumps have now been extracting water for 6 years and the eastern pumps for over 2 years. A similar, circular pattern of reduced salinity might be expected around these pumps if rainfall has been sufficient to flush salts from the top metre of soil.

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3 Data acquisition and processing

3.1 Data acquisition

In November 2003, Geoforce performed a ground electromagnetic (EM) survey for the Department of Conservation and Land Management (CALM) on Toolibin Lake Nature Reserve. EM data from the lakebed was primarily collected using a quad-bike mounted system. See Figure 3.1 for a photograph of the acquisition system.

Figure 3.1 – Photograph of the ground conductivity acquisition system

A GEONICS EM31 and a GEONICS EM38 were used to collect the conductivity data. These instruments use a transmitting coil to produce a 'primary' EM field. This transmitted current induces eddy currents in the ground. The size of these eddy currents varies with ground conductivity. The eddy currents create EM fields of their own. These 'secondary' EM fields induce a current in a second receiving coil, which is amplified, corrected for the transmitted current and transmitted to a data logger on the surface[6]. The EM31 is mounted on fibreglass poles on the side of the quad-bike and the EM38 dragged in a fibreglass sled behind the quad-bike, as indicated in Figure 3.1.

The EM38 returns average conductivity values from approximately the top 0.5m of the ground while the larger EM31 returns average values from approximately the top 4m.

GPS data were collected concurrently with the EM data . A standard Global Positioning System (GPS) was used, giving accuracies of +/- 3 metres. As per contract RFQ 407 10/03, parallel lines were conducted at 50m spacing, taking measurements every second while on the quad-bike and spot readings every 20m whilst on foot. In some areas, the vegetation was found to be too dense even for

[6] Telford, Geldard, Sheriff and Keys (1976)

accurate surveying on foot and hence no data was collected. The location of these areas is shown in Figure 3.2, along with the areas covered by the quad-bike and areas traversed on foot. The scale of the survey and spacing of the lines meant that the +/-0.1m accuracy of a differential GPS (DGPS) was not required.

3.2 Data processing

3.2.1 2003 ECa data processing

The ECa data obtained from the EM31 and EM38 were stored in an ASCII file in the field and imported into ChrisDBF V14, a software package designed to manipulate databases and create grids of point data. Processing consisted of:

- Applying a time parallax correction on the EM31 data, to correct for time lag, and a distance parallax on the EM38 data, to correct for the distance the instrument was located behind the GPS antenna
- A simple, 3-point, non-linear to remove spikes associated with metallic features
- The data were gridded with a 10m mesh size and a 60m scan distance.

The data resulting from these two processing steps is shown in Appendix 1. It was found that large portions of this data, particularly towards the middle of the lake, contained high frequency fluctuations in the conductivity recorded by both the EM31 and the EM38. These fluctuations are due to numerous depressions in the ground averaging 1.5. wide and 0.5m deep. Owing to the overall flat character of the lakebed, these small depressions brought the instruments closer to the saline water table, causing an increase in ECa averaging 200mS/m at the bottom of the depression compared to the ECa on higher ground. As the scale of the survey was for a larger-scale indication of the effect of the pumping, these smaller features were filtered out of the data using a grid filter with a block size of 5. The outputs from the grid filtering have been provided as the final datasets for the EM31 (Figure 3.3) and EM38 (Figure 3.4).

3.2.2 1998 ECa data processing

We were unable to obtain any information pertaining to processing that had been applied to the 1998 data that was collected by Tesla 10. The character of the data (e.g. presence of high-frequency variations, etc) suggested that the data had been subjected to spike removal and parallax corrections, but no larger-scale smoothing filters had been used. The 1998 data covered the open areas in and around the lakebed. The 2003 data was confined to the lakebed but almost the entire lakebed was covered, including most of the heavily forested areas.

The location of the data relative to the 2003 data we collected revealed that the 1998 data was located on the AGD84 grid, as opposed to the current GDA94 grid or the more universal WGS84 grid. We converted the 1998 positions to WGS84 by both converting several positions across the lakebed into WGS84 by means of an online calculator and by manually checking this conversion with geographic features on the lake boundary present in both the 1998 and the 2003 data. The conversion applied to the 1998 data was to add 165 to the Easting coordinates and to add 93 to the Northing coordinates.

The 1998 data was gridded under the same conditions as the 2003 data (10m mesh size, 60m scan distance) and a grid filter of block size 5 was also applied to maintain a similar character between the 1998 and the 2003 data. The result of the gridding is shown in Figure 3.5 for the EM31 and Figure 3.6 for the EM38.

3.2.3 Comparison of 1998 and 2003 data

Initially, the grid-to-grid correlation function was utilised in ChrisDBF to obtain an idea of the areas of greatest change between the 1998 and the 2003 data. Unfortunately, due to the large difference between the areas covered by the 1998 and the 2003 surveys, the correlation function did not yield a great deal of useful information. A grid subtraction and a grid mask were then applied. This analysis demonstrated that there are several large areas of the lakebed that have seen a reduction in the ground conductivity but, as has been stated previously, this data it not considered to be accurate nor precise due to the lack of information regarding the 1998 data. For clarity, results have not been presented in this report but are contained on the accompanying CD.

A qualitative analysis of the two datasets was performed by overlaying the datasets in GIS software and looking for areas where the character of the data had changed, e.g. areas where the 1998 data was fairly uniform in amplitude that correspond to areas in the 2003 data with marked increases and/or decreases present. Areas of greatest change were located from this visual analysis and are shown in Figure 3.7.

Insufficient information about the processing and referencing of 1998 data limited the comparison of the two datasets to a qualitative analysis. Any quantitative comparisons between the two datasets could not be considered reliable because of the lack of information about the 1998 dataset.

3.2.4 Ratio of EM31 to EM38 ECa values

The ratio of the EM31 to the EM38 ECa values was once created by using a grid-to-grid arithmetic function in ChrisDBF. The final gridded data sets (shown in figures 3. and 3.4) were used, with the EM38 data being divided by the EM31. This approach means that the areas where the EM38 data were relatively higher than the EM31 data are highest in value (i.e. plot as red) and areas in which the EM31 was higher than the EM38 are lower in value (i.e. plot as blue). The result of this ratio is plotted in Figure 3.8. The ratio emphasises areas where the salinity is being concentrated near the surface due to capillary rise. Highs (red) indicate where the EM38 ECa values were relatively higher than the EM31 and the lows (blue) where the EM38 are relatively lower than the EM31 values.

3.2.5 Statistical correlation between ECa values and distance from pumps

In order to obtain a measure of the effect of the groundwater pumping on the salinity levels with distance from the pumps, the ECa values from both the EM31 and the EM38 were compared with the distance from the operational pumps using a multiple regression approach.

Initially, regression was done for the EM31 and EM38 ECa data for each borehole and the results were then combined to obtain the multiple regression result. The

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distance from the pump was used as the independent data and the ECa values as the dependent data. Pump 12 has never been operational and Pump 8 had not been used for 3 years at the time of this report (December 2003). Hence, neither of these pumps were used in the regression analysis. The results from the individual boreholes are provided in Appendix 2 and the combined results are given in figures 3.9 and 3.10. The regressions do not highlight any pervasive change in ground conductivity with distance from the pumps.

3.2.6 EM38 ECa to ECe conversion

The final step of data processing was to use the ECe data from the soil sample analysis to calibrate the ECa data from the EM38 to provide a map of ECe across the survey area.

It was planned that samples were to be taken at 0.25m intervals down to 1m at 10 locations across the lakebed. Initially, a hand-auger was used to collect the samples but it was found that the hardness of the clay under the topsoil was much higher than expected. A petrol-driven, 2 man post-hole digger was then employed in order to obtain the samples. Even utilising this, it was found that the clay present was too viscous as the clutch of the post-hole digger was burnt out by the end of the 6th hole. This caused a decrease in the number of samples taken and as such has imposed the following limitations on the ECe data obtained and the subsequent conversion of the EM38 ECa data:

1) Only one auger hole was made at each location. This means that lateral variations could not be averaged out across several samples and as such small-scale interpretation of the ECe values may not be reliable
2) While the location of the soil samples did cover most of the range of ECa values recorded by the EM38, there was no duplication of samples from similar ECa values, especially at the higher and lower ends of the spectrum. As such, number and range of ECe values obtained were sufficient to convert the EM38 ECa data to ECe but not sufficient to rigorously test the accuracy of this conversion

The location of the auger holes are annotated in Figure 3.12.

The ECe values from the soil sample analysis were plotted alongside the EM38 ECa values from corresponding locations. The result of this is shown in Figure 3.11. The ECe values used for the conversion calculated are the average of readings from the first 0.5m of the auger holes. This corresponds to the 0.5m depth of investigation of the EM38 when used in the horizontal mode as in the case of this survey.

The linear regression trendline through the data points has a moderately high correlation (R^2 = 0.8612). However, the ECa data points below 400mS/m show the limitation of the precision and accuracy of this conversion as mentioned previously.

The trendline formula was applied to all of the initially processed ECa data from the EM38 (i.e. parallax correction and non-linear filter applied) and the resulting dataset from the formula gridded with the 10m mesh size and 60m scan distance standard across all grids created from this survey. The final ECe grid is shown in Figure 3.13.

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4 Discussion of results

4.1 Comparison of 1998 and 2003 data

From the EM31 and EM38 data presented in figures 3.3 and 3.4, it appears that there has been a decrease in soil conductivity in the top 5m of the soil profile in some areas across the lake bed. This is more prominent towards the western side of the lake, where there is a definite decrease in soil conductivity in the vicinity of pumps 1, 2, 3, 4, 9, 7 and 14. There is little change in conductivity around most of the other operational pumps and there is a definite area of increased conductivity directly to the south of Pump 13. More detailed investigations would be required to determine whether or not the decreased areas of conductivity are resulting from groundwater pumping or some other cause

As stated previously, there was no quantitative information on the processing and referencing of the 1998 data. This means that we can not be certain of the accuracy of the 1998 datasets and use of the numerical differences between the 1998 and the 2003 datasets should be used with caution.

The areas of greatest change between the 1998 and the 2003 data are often not located directly over an operational pump but are generally confined to within 200 to 300m of an operational pump. It is interesting to note that the areas of greatest change are all in areas that are either completely open or are only lightly forested; it is unfortunate that there was no ground conductivity data collected in the more heavily forested areas to see the effects of the pumps in areas of denser vegetation.

4.2 Areas of suspected capillary rise

From Figure 3.8, the ratio of EM31 to EM38 ECa values, it appears that most of the areas in which there is possible salt accumulation due to capillary rise are located in the southern half of the lakebed. A comparison of this data with an aerial photograph of the site indicates that these areas coincide with areas of little to no established trees south of 6357300. It is interesting that this increase in ground conductivity near the surface does not occur in the open area surrounding Pump 11.

It would be interesting to investigate whether or not this lack of supposed capillary rise in the vicinity of borehole 11 is due to the pumping and if so, what the effect making pumps 8 and 12 operational would be on the large area of suspected capillary rise to the south would be. It would be important to fully characterise the soil stratigraphy and hydrology around all 3 boreholes prior to conducting any investigations of this nature.

4.3 Data regression analysis

There was little indication in the regression analysis to indicate any large-scale correlation between the ground conductivity and distance from pumps. The plots of the individual pump distances (see Appendix 2) show that there may be some correlation within the first 200m, but often this is offset by some data points providing a decrease in ground conductivity with an increase in distance from the pumps.

A look at the location of the operational pumps in figures 3.3 and 3.4 concur with this. Several pumps (e.g. Pump 7 and Pump 3) show a decrease in ground conductivity in

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the immediate vicinity of some operational pumps but even these more pronounced features to not extend more than 200m from the pump.

It is clear from the comparison of the 1998 and the 2003 data that the groundwater pumping is having an impact on the ground conductivity levels across the lakebed but there is little to no correlation between changes in ground conductivity and distance from pumps with the data obtained in 2003. As the depth of the operational pumps are at least 10m deeper than the 4m depth of investigation of the EM31, it is possible that at greater depths there would be a much better correlation between the decrease in ground conductivity with the depth from operational pumps.

4.4 Soil sample analysis

As mentioned in Section 3.2.6, the limited number of soil samples taken has had a detrimental effect on quantity of the ECa to ECe conversion. Even if the full 10 samples were taken, it is likely that locating each of these at different sites would still not provide enough data points for an accurate conversion. We recommend that at least 2 to 3 auger holes be made at each location so that the ECe readings can be averaged for each location prior to creating a conversion formula top improve accuracy and precision. If only being used to convert the EM38 ECa values to ECe, the holes need only be augered to a depth of 0.75m.

Despite the limitations of the soil analysis data, a couple of interesting results can be seen. One of these is the significant increase in the ECe of the soil samples below a depth of 0.75m for 4 of the 6 auger holes. The other interesting result is in both of the auger holes placed in the open areas with little to no vegetation (auger holes 5 and 6) there is a much higher ECe value in the top 0.5 for hole 5 and the top 0.25m for hole 6. Hole 5 is located within a zone of higher concentration of salt near the surface (see Figure 3.8) whereas hole 6 is located in an area of lower ground conductivity and the concentration of salt appears to be at a lower depth.

A more in depth investigation of the depth at which the salt is primarily stored across various areas of the lakebed would be a useful approach to determine the reason for the differences between the depth of high salt concentration seen in the 6 auger holes from this survey. Once again, we recommend that 2 to 3 auger holes be made at each location to obtain better accuracy and precision with the results. It would be advisable to auger to depths of 2 to 3 metres in order to ascertain the depth of highest concentration and samples to this depth could be qualitatively interpreted with the deeper ECa values from the EM31.

5 Recommendations for future studies

Given the scope of the existing recovery actions, there is also a wide scope for future studies, both geophysical and non-geophysical. For the purposes of this report, we 7shall focus on the geophysical possibilities for future studies. We have provided a qualitative discussion of the various methods available; more detailed information and examples are available upon request.

5.1 Surface soil and salinity mapping

Comparison of the EM31 and EM38 data collected in 1998 and 2003 indicates that in some areas the groundwater pumping is having a significant effect on the salinity, at least within the first few metres. However, the short to medium term effect of the groundwater pumping is relatively unknown. From a management point of view, the most important time for another salinity survey would be after Toolibin Lake has had some form of flushing event, such as after it has filled. Further investigation, using the EM31, EM38 and soil sampling, could be used to determine seasonal variation if surveys are conducted on a 3 or 6-monthly basis.

More detailed investigations could include the use of radiometrics in conjunction with the EM31 and EM38 data. The radiometrics unit measures the Uranium, Potassium and Thorium counts and from this, statistical analysis can yield soil maps of the site surveyed. The main problem with this approach is that the radiometrics unit can only feasibly be mounted on a quad-bike and would not cope with many of the rougher areas traversed in the 2003 survey. We estimate that radiometrics data could be obtained for approximately 50% of the lakebed.

5.2 Resistivity

Resistivity would be a useful tool for investigating the effect of the groundwater pumping close to the pumps at depth greater than the 4m investigated by the EM31. As the resistivity method maps changes in electrical properties, features such as fresh/saline water boundaries, changes in clay and salinity content and changes in moisture content can all be imaged with this method. Resistivity can even be used on a large scale to map such features as depth to bedrock.

Resistivity is a method that obtains information about the geo-electrical structure of the subsurface. The method consists of hammering in a series of electrodes into the ground and measuring the voltage between various combinations of electrodes while inputting an electrical current between various electrodes. The method can be extremely time consuming but Geoforce recently purchased a new resistivity unit that can measure up to 10 readings at one time, greatly reducing the data collection time required.

The typical depth on investigation of the resistivity method ranges from metres to hundreds of metres, depending on the distance at which the electrodes are spaced. We have successfully used the resistivity approach to delineate groundwater tables, clay layers, leakage from waste dumps and numerous other situations. More information regarding the geology of Lake Toolibin would be required prior to us recommending the use of the resistivity system.

5.3 Soil sample analysis

While the soil sampling undertaken as a part of this survey did yield useful information, a more comprehensive sampling program would provide much better information regarding the vertical and lateral changes in salt concentrations across the lakebed in combination with the EM31 and EM38 ECe data. As mentioned in Section 4.4, multiple samples would need to be taken at each location to provide better accuracy and precision and to a greater depth if depth variations are to be investigated.

For the extremely hard terrain encountered, we would recommend using an auger mounted on a Dingo or the back of a 4WD to provide sufficient power to auger properly and to depths sufficient enough to obtain information on the depth variation of salinity concentrations.

5.4 Borehole logging

One approach is to obtain information on changes in soil type and salinity with depth is to conduct EM and gamma-ray activity logs of the monitoring boreholes. The use of an EM39 instrument to do this provides information on conductivity and gamma activity with depth and can subsequently be interpreted to yield quantitative changes in clay content and salinity levels. This is done by using changes in the gamma-ray activity to gauge the change in clay levels and the changes in conductivity, with no corresponding changes in gamma-ray activity, to estimate changes in salinity.

This approach is rapid to deploy, with it possible to log up to 20 boreholes per day. The minimum diameter of the borehole to allow access is 40mm, though ideally boreholes would be greater than 50mm in diameter. The method only works in open or PVC-cased holes. Metallic casing causes too much interference with the EM data. Gamma-ray activity can be collected in holes with metallic casing but in this situation would not yield much useful information without the complimentary use of EM data.

6 Qualification and disclaimer

The interpretations contained in this report are based on the training and experience of the author and information passed on to him during the course of the investigation. As with all geophysical data, multiple interpretations are possible. The client is advised to consider information from all available sources prior to making a decision on how to proceed.

Tristan Campbell
(Geophysicist)

7 References

ECU Edith Cowan University 2002. **Vegetation Monitoring of Toolibin Lake and Surrounding Reserves, 2002.** Report prepared for the Department of Conservation and Land Management, Western Australia

SKM Sinclaire, Knight & Mertz 2000. **Lake Toolibin Numerical Groundwater Model** Report prepared for the Department of Conservation and Land Management, Western Australia.

Telford, WM., Geldart, LP., Sheriff, RE., Keys, DA., 1976, Applied Geophysics, Press Syndicate of the University of Cambridge, Melbourne.

Tesla 10 Pty Ltd, 1998: Suit of EM31 and EM38 data collected from the environs of Lake Toolibin.

Toolibin Lake Recovery Team & Technical Advisory Group 1994. **Toolibin Lake Recovery Plan**. Report prepared for the Department of Conservation and Land Management and the National Parks and Nature Conservation Authority.

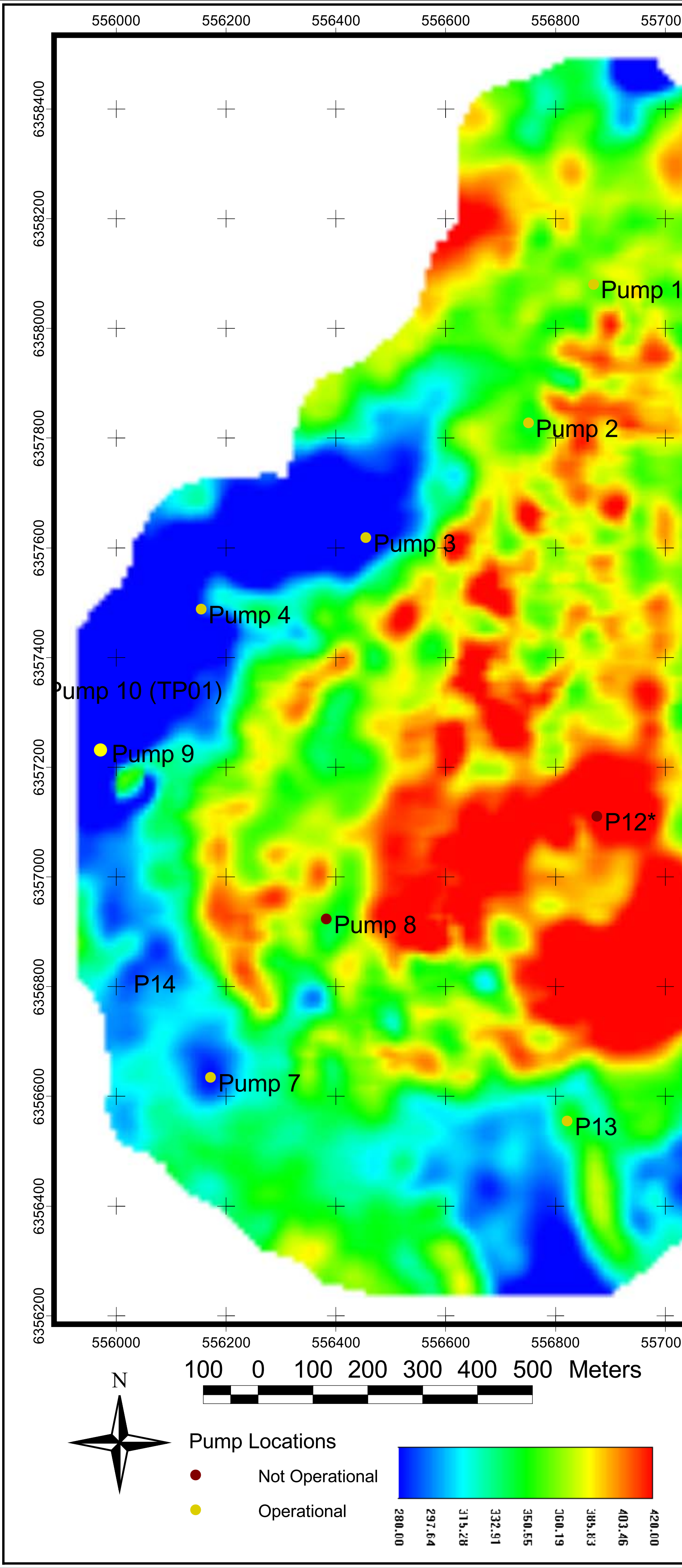
Wyland, J, 2003. EEI Project Proposal: Assessing the effectiveness of groundwater pumping to lower soil salinities at Toolibin Lake

ELECTROMAGNETIC GROUND SURVEY OF LAKE TOOLIBIN

Figure 2.1 - Aerial photograph of Lake Toolibin Reserve with pump locations overlain

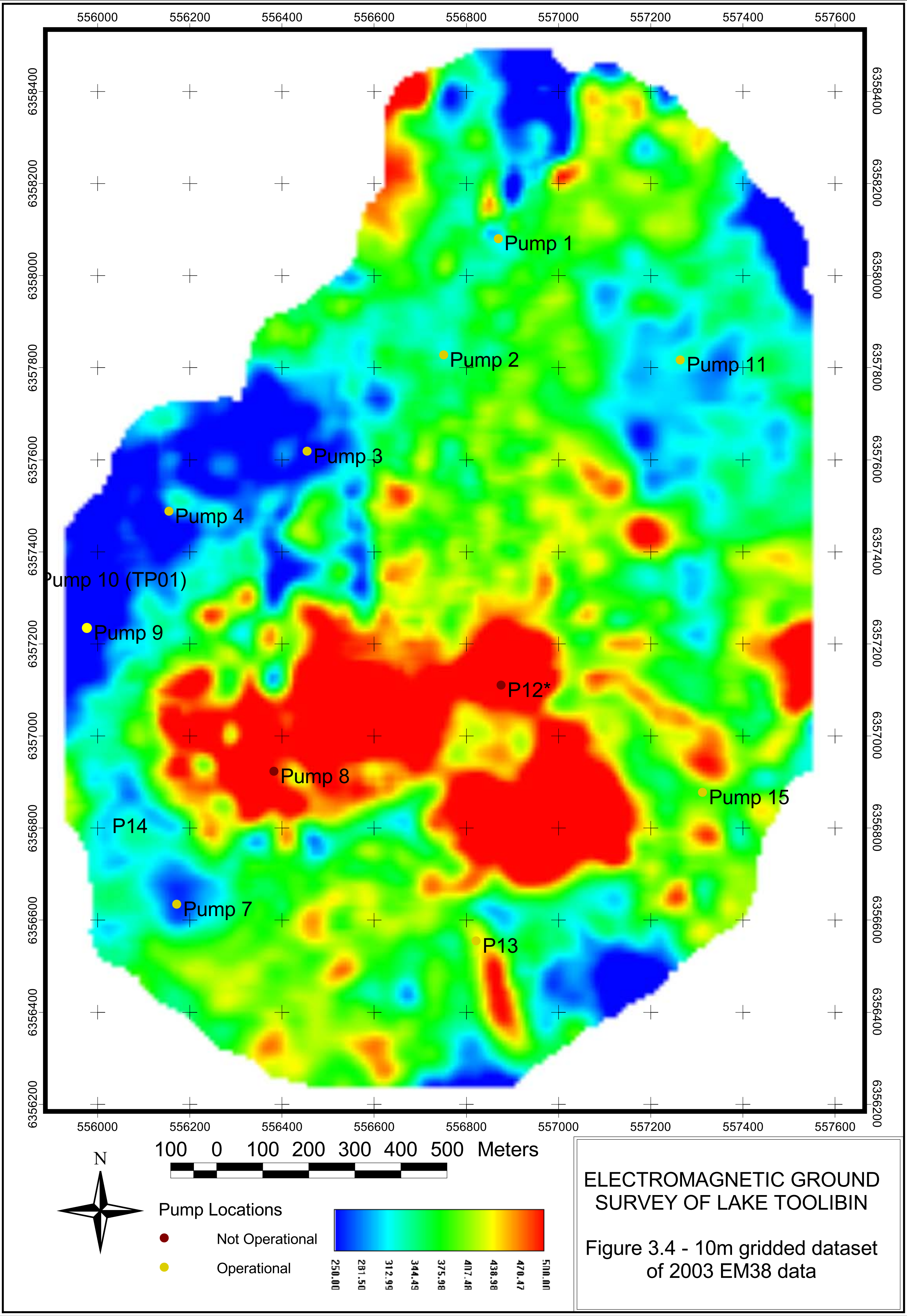
ELECTROMAGNETIC GROUND SURVEY OF LAKE TOOLIBIN

Figure 3.2 - Aerial photograph of Lake Toolibin Reserve with survey areas overlain



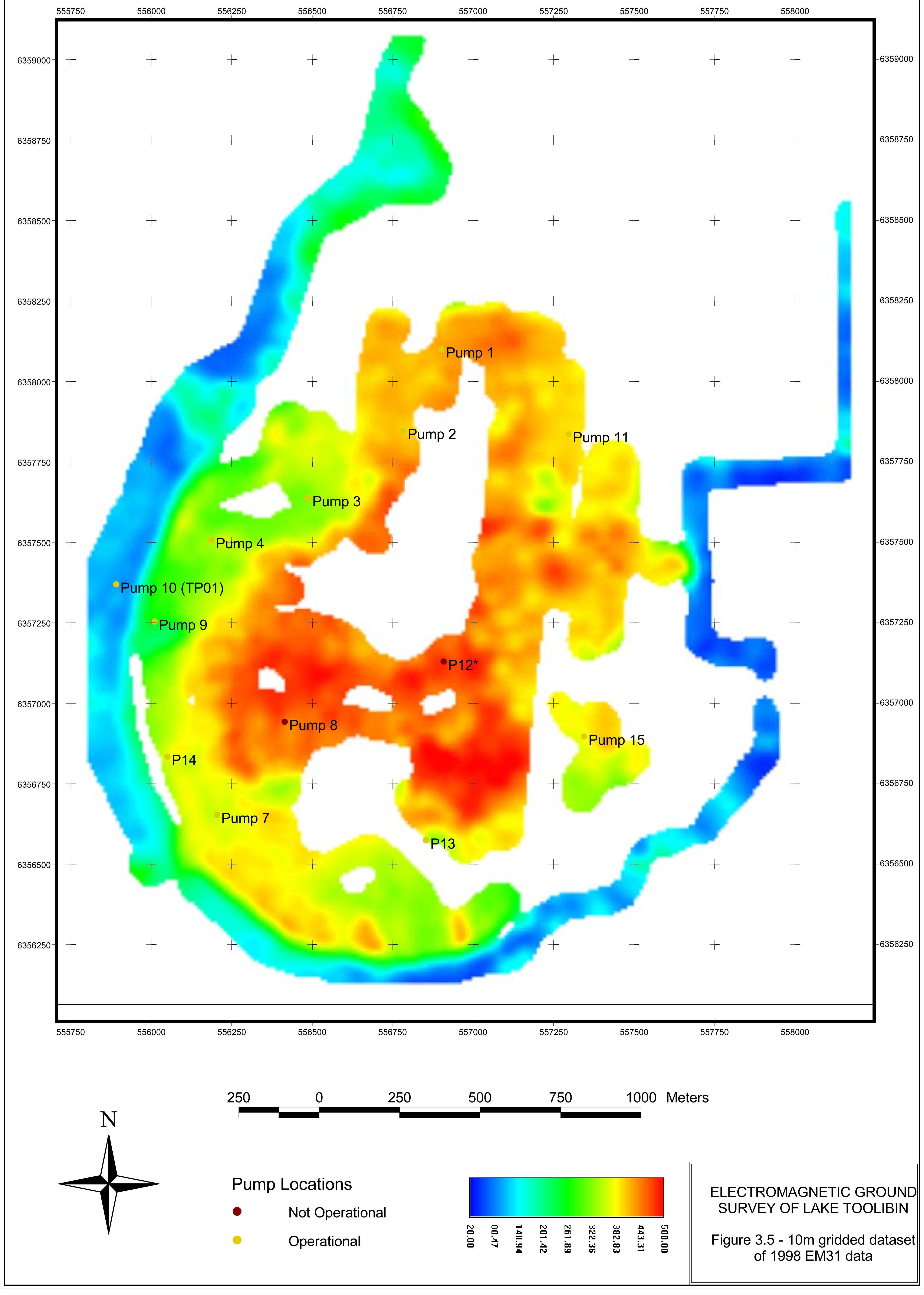
ELECTROMAGNETIC GROUND SURVEY OF LAKE TOOLIBIN

Figure 3.3 - 10m gridded dataset of 2003 EM31 data



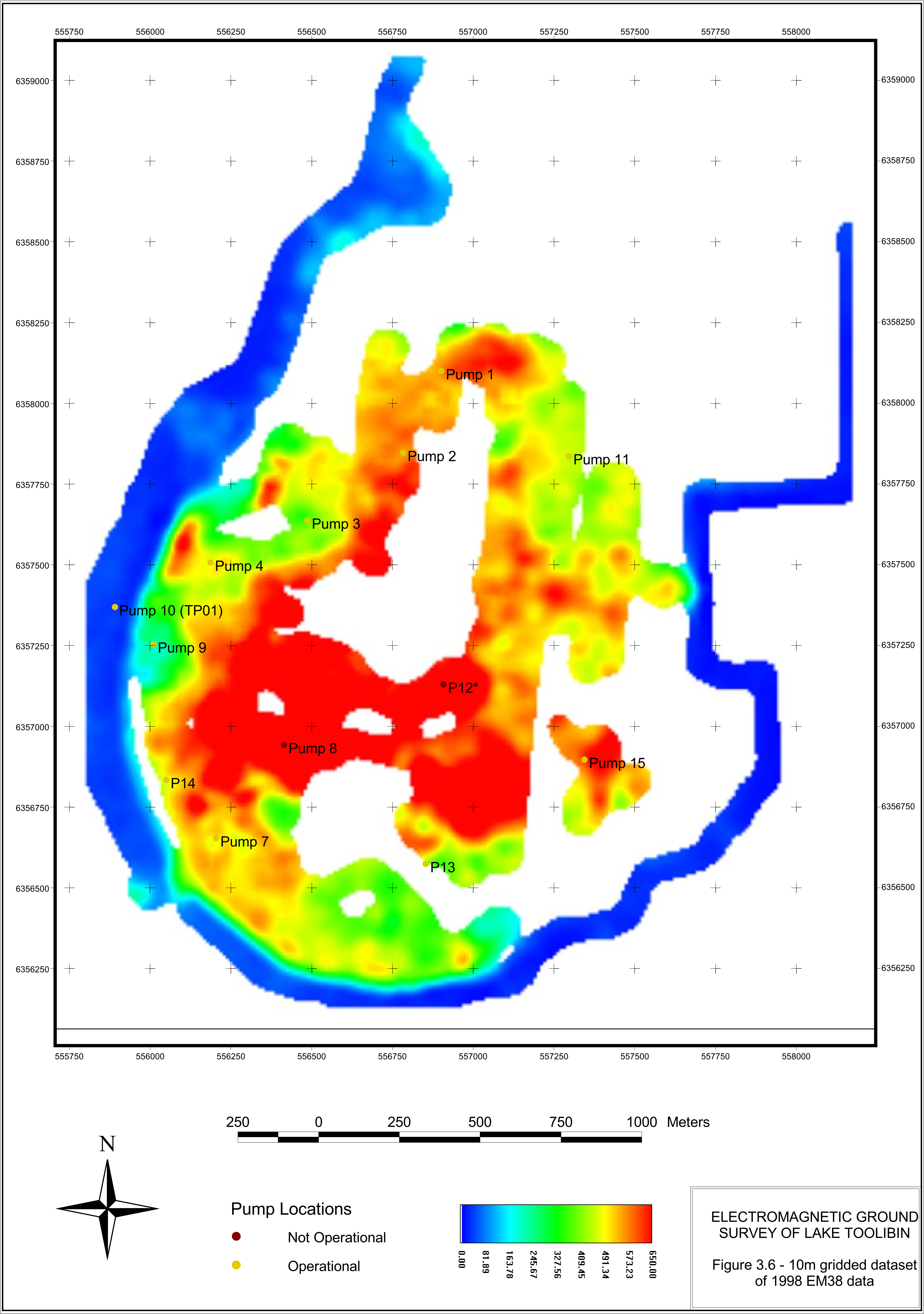
ELECTROMAGNETIC GROUND SURVEY OF LAKE TOOLIBIN

Figure 3.4 - 10m gridded dataset of 2003 EM38 data



ELECTROMAGNETIC GROUND SURVEY OF LAKE TOOLIBIN

Figure 3.5 - 10m gridded dataset of 1998 EM31 data

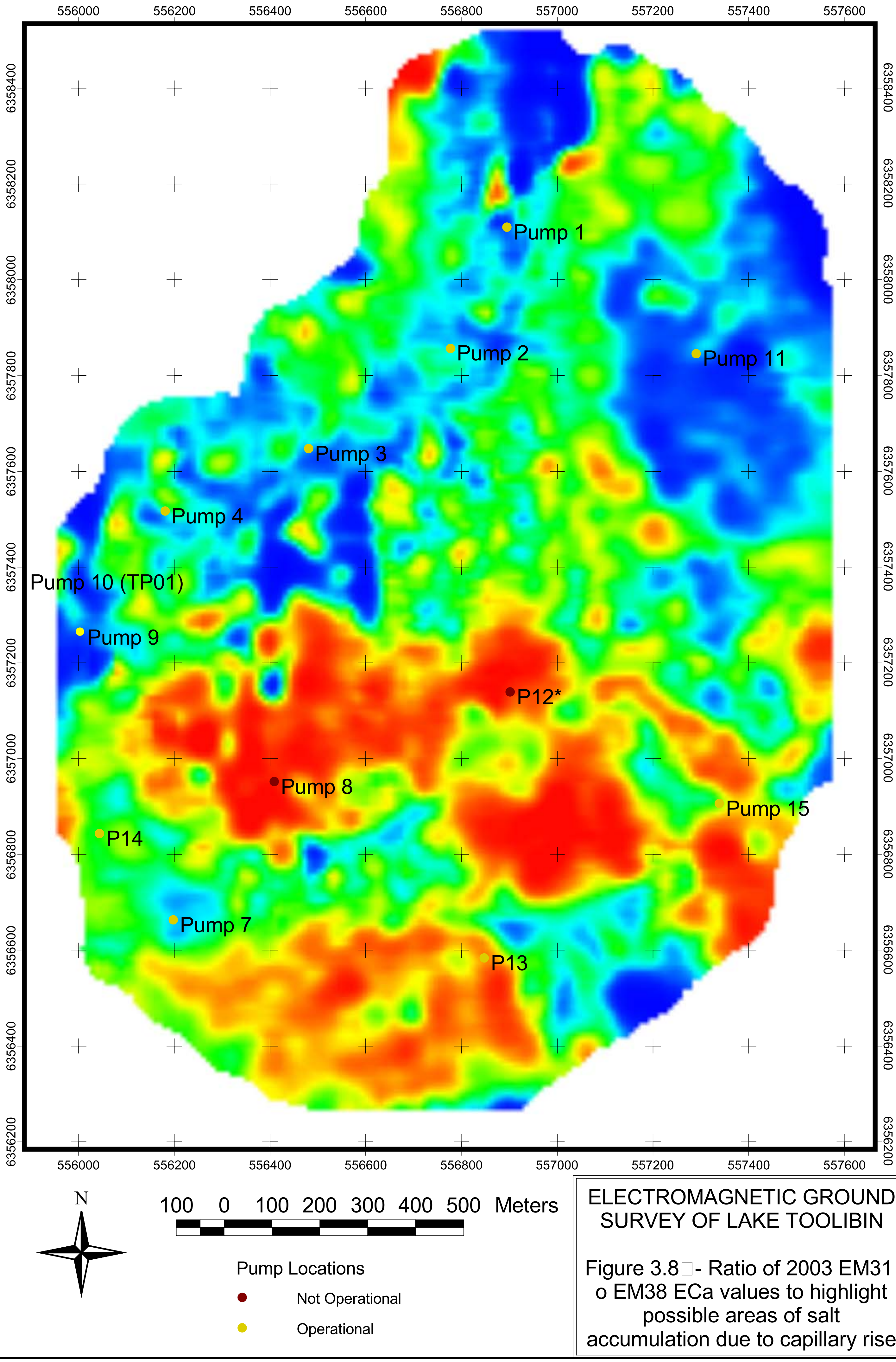


ELECTROMAGNETIC GROUND SURVEY OF LAKE TOOLIBIN

Figure 3.6 - 10m gridded dataset of 1998 EM38 data

ELECTROMAGNETIC GROUND SURVEY OF LAKE TOOLIBIN

Figure 3.7 - Comparison of 1998 and 2003 EM31 and EM38 data



ELECTROMAGNETIC GROUND SURVEY OF LAKE TOOLIBIN

Figure 3.8 - Ratio of 2003 EM31 o EM38 ECa values to highlight possible areas of salt accumulation due to capillary rise

Figure 3.9 - Multiple regression analysis of the EM31 ECa data with distance from pumps

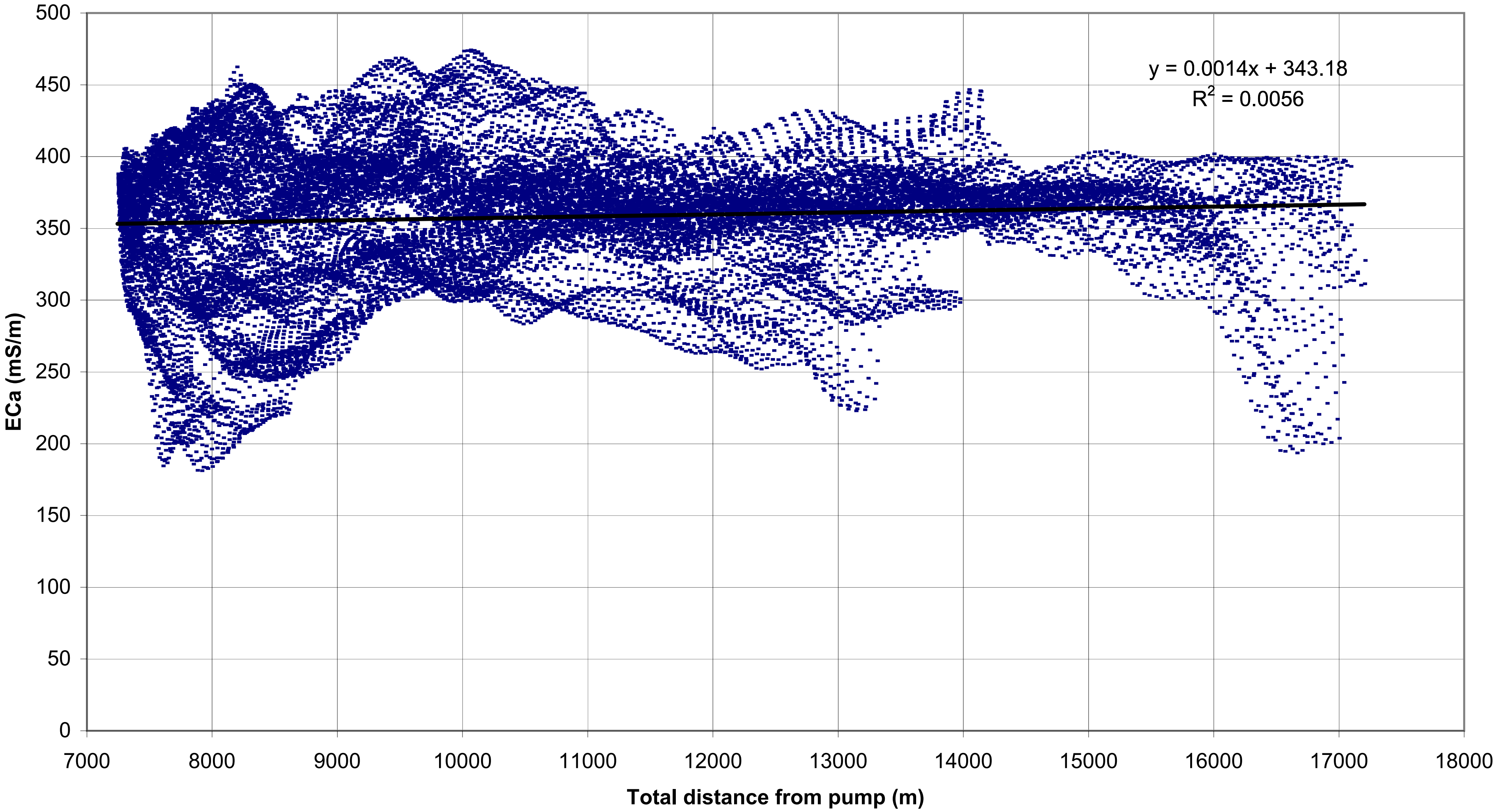


Figure 3.10 - Multiple regression analysis of the EM38 ECa data with distance from pumps

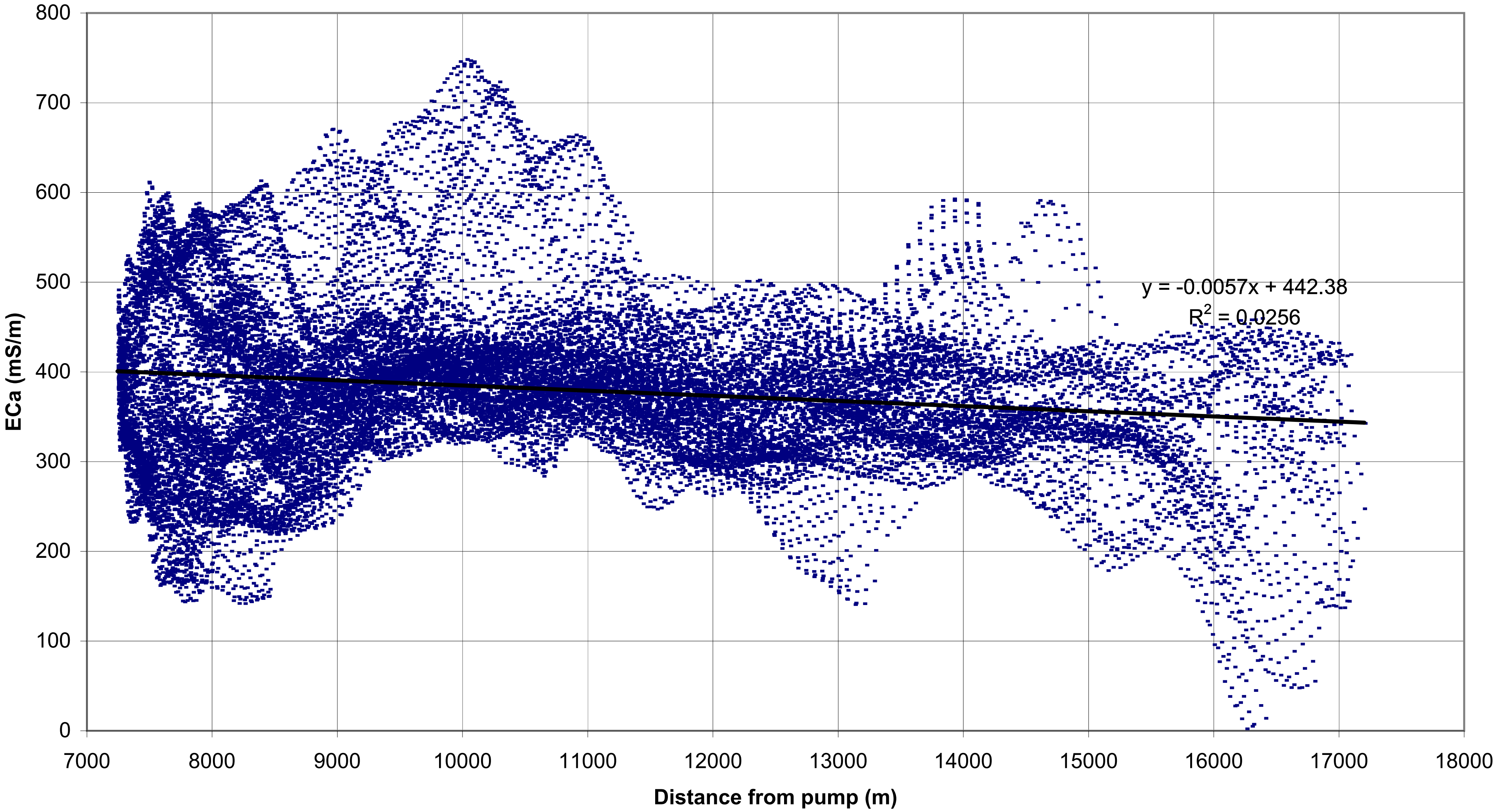
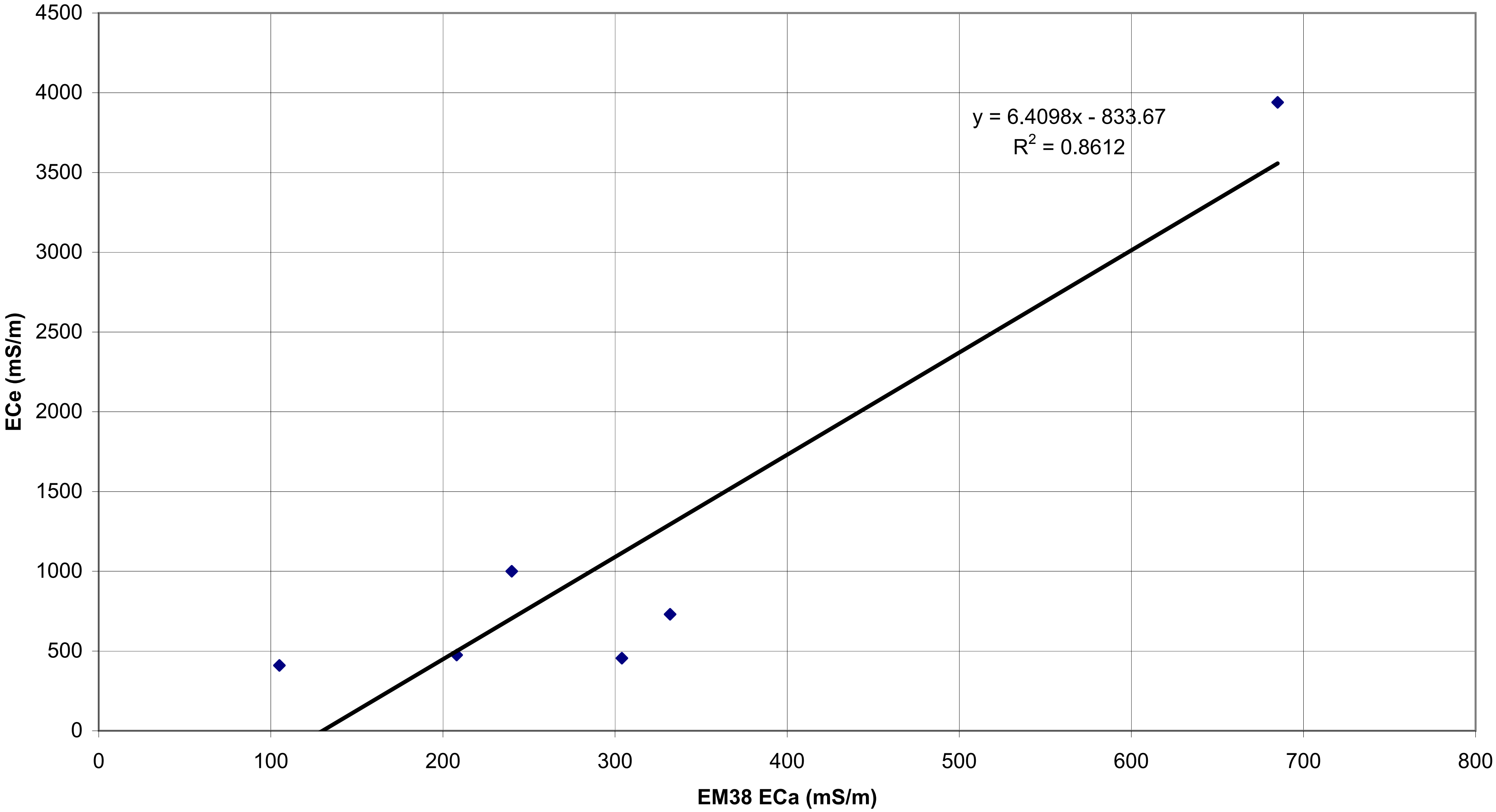
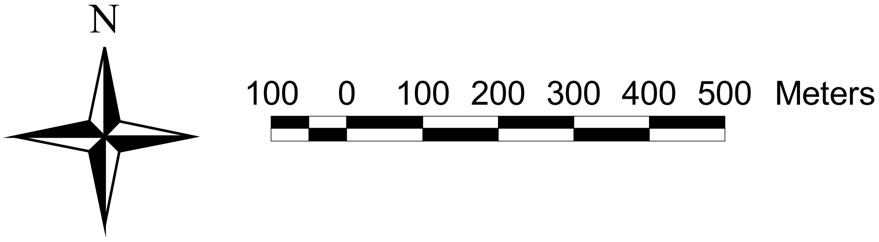


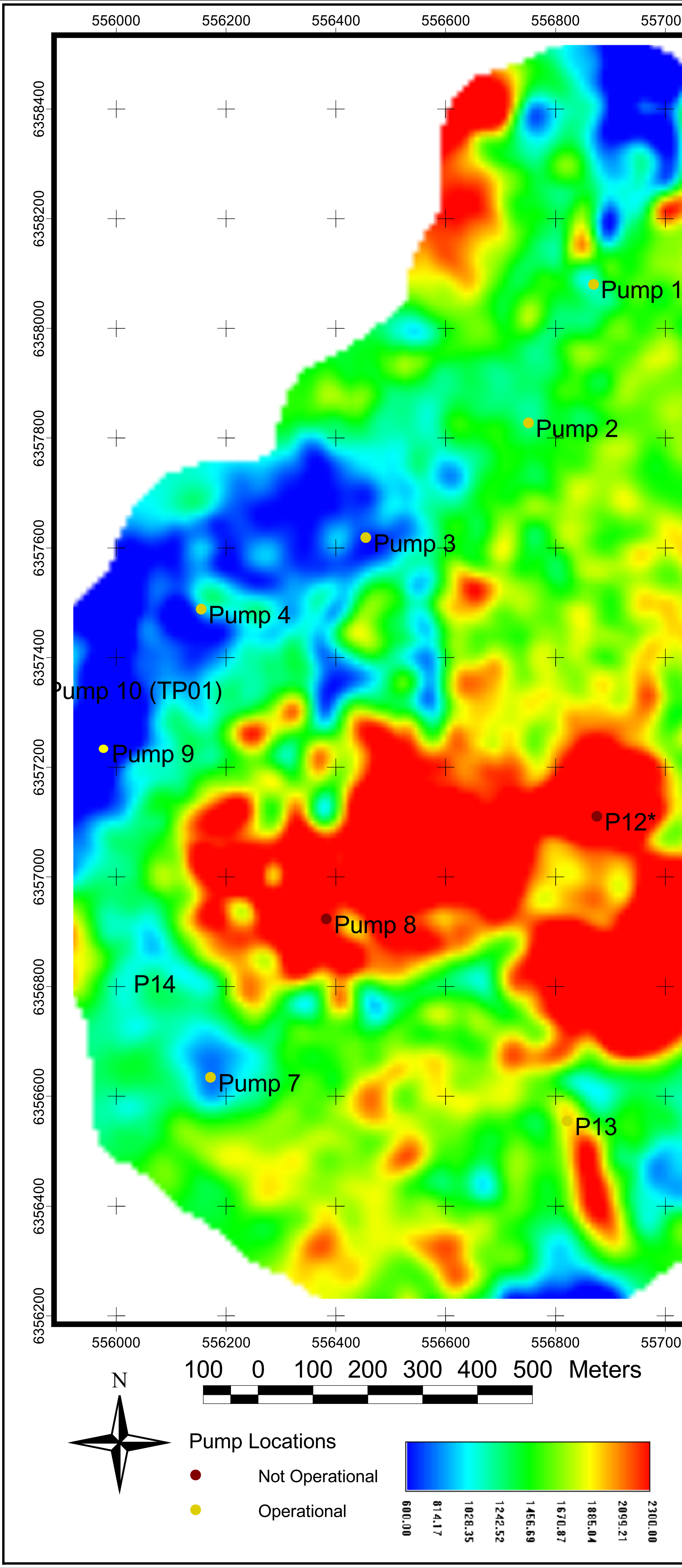
Figure 3.11 - ECa to ECe conversion graph





ELECTROMAGNETIC GROUND SURVEY OF LAKE TOOLIBIN

Figure 3.12 - Aerial photograph of Lake Toolibin Reserve with auger hole locations overlain

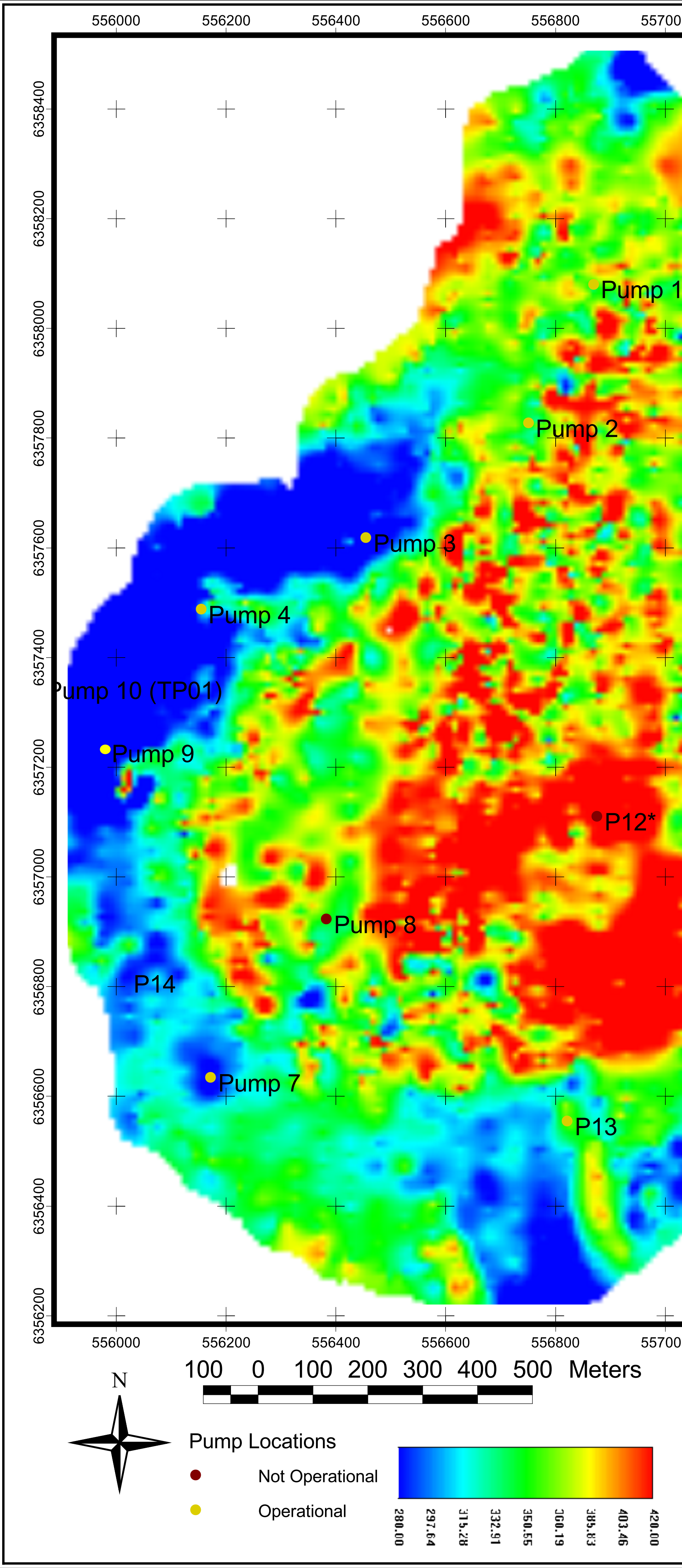


ELECTROMAGNETIC GROUND SURVEY OF LAKE TOOLIBIN

Figure 3.13 - 10m gridded dataset of ECe values from 2003 EM38 and soil sample analysis

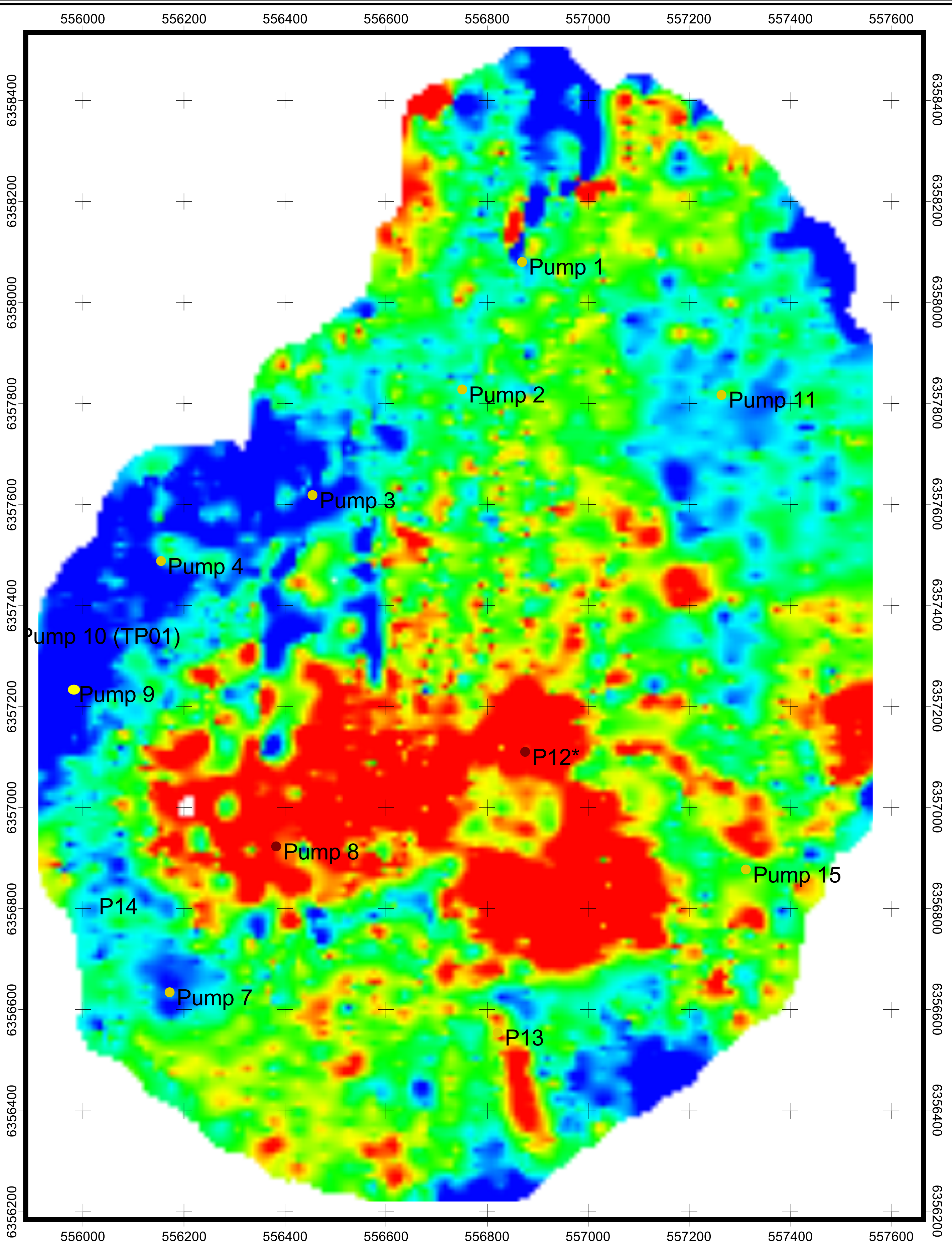
Appendix 1

10m gridded dataset of unsmoothed EM31 and EM38 ECe data



ELECTROMAGNETIC GROUND SURVEY OF LAKE TOOLIBIN

Figure A1.1 - Initial processed EM381 2003 data



ELECTROMAGNETIC GROUND SURVEY OF LAKE TOOLIBIN

Figure A1.2 - Initial processed EM38, 2003 data

Appendix 2

Table of soil sample analysis results

Hole	Label	Depth (M)	ECe mS/m
1	A	0 - 0.25	310
	B	0.25 - 0.50	510
	C	0.50 - 0.75	880
	D	0.75 - 1.00	860
2	A	0 - 0.25	260
	B	0.25 - 0.50	690
	C	0.50 - 0.75	1260
	D	0.75 - 1.00	1540
3	A	0 - 0.25	590
	B	0.25 - 0.50	870
	C	0.50 - 0.75	920
	D	0.75 - 1.00	1110
4	A	0 - 0.25	1010
	B	0.25 - 0.50	990
	C	0.50 - 0.75	990
	D	0.75 - 1.00	2590
5	A	0 - 0.25	3840
	B	0.25 - 0.50	4040
	C	0.50 - 0.75	430
6	A	0 - 0.25	720
	B	0.25 - 0.50	190

Table A4.1 Field notes and soil sample analysis results from auger holes