Application of Ground-based Geophysical Surveys to Planning Remediation of Land Subject to Dryland Salinity at Kamarooka – Northern Victoria

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Executive Summary

Geophysical surveys are commonly used to identify and map areas of salt affected land. They are also useful in identifying variations in soils across saline land and within the catchments of saline land. As such they are regarded as a valuable tool in planning the rehabilitation of degraded saline land.

Geophysical surveys were completed at Kamarooka during 2005 and 2006 with the aim of delineating various classes of soil salinity. The work was undertaken to support the rationale for works aimed at mitigating severely salt affected land. The surveys identified target areas for a range of plant species with varying salt tolerance. These included a spectrum that ranged from native eucalypts and salt tolerant acacias through to various species of saltbush (halophytes).

In addition to the salinity mapping radiometric surveys identified variations in soils throughout the project area. By measuring minute changes in mineral radiation the survey was able to delineate soils formed on the undulating weathered bedrock from the transported alluvial soils formed on the Riverine Plains.

A range of Electromagnetic techniques were used to map salinity. The simplest and most effective technique proved to be the use of the standard EM-38 instrument used in horizontal dipole mode. The various classes of saline land important in considering the deployment of plant species were easily identified with this technology.

The radiometric survey readily identified the various soil types across the project site, and proved useful in further considering landscape/groundwater interactions and processes.

Both the salinity and soil mapping techniques proved extremely valuable and the experience in their application to re-vegetation has been valuable. The techniques can be best described as an essential part of the planning process in considering the re-vegetation of saline land.

Introduction

Geophysical surveys provide the opportunity to map many of the physical and chemical properties of soils and landscapes through the application of remote sensing technologies. A machine passing over the land can sense and measure the salinity of the soil and small changes in mineral composition. The results when considered together with other site information afford a valuable tool for targeting specific vegetative options and species in attempts to rehabilitate land degraded by salinity.

Geophysical surveys were completed at Kamarooka during 2005 and 2006. The surveys focussed on the need to (a) understand the various classes of saline land throughout the 40 ha Project Area, and (b) to examine the application of radiometric imagery in considering local variance in soil and landform distribution.

The information derived from the geophysical surveys was used to assist in establishing a rationale for dividing up the site for the various treatments being used to rehabilitate and manage the salt affected land.

The EM-38 is an instrument that is able to detect surface soil and subsoil salinity to a depth of about 1.5 metres. In contrast the EM-31 instrument shows where salts have accumulated deeper in the soil are located. It can measure to depths as great as five metres. The EM-38, thus, is useful for measuring shallow soil salinity whilst the EM-31 is more useful in revealing soil-landscape processes associated with deeper salt storage and mobilisation.

Combined EM-38, EM-31, soil survey patterns and topographic (Digital Elevation Model) information form the basis for developing and constructing improved whole-of-landscape process models with three-dimensional architecture and water flow systems (not readily apparent from previous two-dimensional toposequence models).

The techniques

The Northern United Forestry Group contracted PIRVIC (Primary Industries Research Victoria) staff from Bendigo to complete the geophysical surveys. PIRVIC performed the work with a quad bike fitted with the appropriate instrumentation and computers.

Electromagnetic induction

Electromagnetic induction (EMI) surveys involve measuring the apparent electrical conductance of the soil. Since this is proportional to soil salt content EMI measurements taken throughout salt prone lands allow mapping of the extent of saline land.

The technology involves generating a primary electromagnetic field from a transmitting coil that creates eddy currents within the soil. These eddy currents promote a weaker secondary electromagnetic field and the intensity and timing of this secondary field relative to the primary field is a measure of soil conductance and salinity.

The EM-38 instrument comprises transmitter and receiver coils separated by a distance of one meter. This small instrument can be set up so that the coils are arranged either horizontally or vertically. It is generally thought that the depth of penetration is a little deeper in the vertical mode. In either mode, however, the apparent electrical conductivity readings (salinity) established during the survey generally apply over a depth of less than one metre.

The EM-31 instrument uses the same technology as the EM-38 in horizontal dipole mode, but a distance of three metres separates the coils. This allows for a deeper penetration of (perhaps) two to three metres.

The PIRVIC survey unit included three electromagnetic induction instruments. These were (a) an EM-38 instrument arranged in horizontal dipole mode, (b) an EM-38 instrument arranged in vertical dipole mode, and (c) an EM-31 in horizontal dipole mode.

The survey was completed by towing the instruments on a sled to avoid the immediate influence of the metal in the quad bike. It was programmed to automatically record readings at set travel distances. Readings from each site were automatically located through the deployment of a GPS (Global Positioning System) and downloaded to an on-bike computer (Figure 1). The operator drove a series of transects across the site to complete the survey.

Radiometric Survey

In addition to the EMI survey for salinity a radiometric survey was also completed to investigate potential variation in soil mineralogy throughout the site. Radiometric studies are also known as gamma ray spectrometry surveys - they measure small amounts of naturally occurring gamma radiation emitted from certain minerals as a result of their radioactive decay.

Radiometric surveys typically measure the energy emitted from potassium (K), thorium (Th) and uranium (U) decay. They establish the abundance and distribution of the minerals that comprise these elements in the soil. The technique is, thus, a surrogate method of establishing variation in soil mineralogy. Since water largely absorbs gamma radiation and other elements, the radiation response is usually confined to the upper 30 centimetres (cm) of soil.

Radiometric surveys can be quite useful for detecting variations in mineralogy that can be attributed to the genesis of the soil. This in turn may support greater insight into soil hydrology. For example, a radiometric survey may establish variations in sand or rock content that may point to the presence or absence of zones of preferential groundwater recharge.

Results of the geophysical surveys

EM-38 horizontal dipole

The results from the geophysical surveys are presented as image maps in the figures below. Figure 1 depicts the relative distribution of the most saline land throughout the 40 ha of the study area.

The results from the EM-38 survey (horizontal dipole) are presented in Figure 1. PIRVIC did not supply a map legend, however, there is an obvious correlation between the darker areas and the known surface expression of salinity. The boundary afforded by the four most intense colours coincides with the most severely saline land comprising severe salinity on exposed subsoils. In this region large areas of soil have also become severely degraded as a consequence of salinity-induced wind erosion.

The occurrence of salinity depicted by the EM-38 survey correlates with the known incidence of salinity along the subtle break of slope that exists at the juncture of the undulating weathered bedrock hills and the adjacent Riverine Plains. The northeast/southwest orientation of the high salinity zone depicted in the survey image perfectly matches this zone of high salinity groundwater discharge.

The softer colours in the northwest and southeast of the project region correlate with regions in which the watertable is slightly deeper and there is a lesser salt concentration in the surface soils. The difference in watertable depth, however, is only of the order of 0.5 to 1 metre; hence the analyses and the image depict a near surface response to salinity.

**Figure 1 Image showing variation in soil salinity.
EM-38 (horizontal dipole) survey**

As a general guide the NUFG determined the areas most suitable for tree planting coincided with the less saline land depicted by the two least intense coloured zones in the map presented in Figure 1. The most saline lands depicted by the four most intense coloured regions in the image were deemed to be more suited to the establishments of highly salt tolerant vegetation, and in particular Old Man Saltbush (*Atriplex numularia*).

EM-38 Vertical dipole

Figure 2 presents the results of the EM-38 survey completed in vertical dipole mode. It should be noted that PIRVIC have supplied this image using a different colour range, hence the colours are not directly comparable with those in Figure 1. Despite this compatibility, however, there is a good correlation between the two techniques. The zones of saline land depicted by both techniques are comparable and point to the same land use choices. The area of saline land indicated by the vertical dipole technique suggests it may be recording salt stored a little deeper in the soil. Given the lack of additional data afforded by the vertical dipole technique the indication is that the simpler horizontal dipole techniques will most likely suffice in future salinity surveys.

Figure 2 Image showing variation in soil salinity.
EM-38 (vertical dipole) survey.

Em-31 Survey

Figure 3 depicts the results of the EM-31 survey, which are in broad agreement with the results from the EM-38 analyses. The additional depth afforded by the wider coil separation appears to have not provided additional detail. This is most likely because the entire project area has a very shallow watertable and very saline groundwater that typically in the range of 25 000 to 40 000 microsiemens per centimetre (uS/cm). High salinity groundwater most probably establishes a fixed depth of EMI penetration. The EM-31 results also appear to have been distorted along the eastern boundary as a result of the survey coming within the immediate proximity of the boundary fence.

Again it would seem from the results that the simpler EM-38 survey is all that is required to ascertain the location of high surface salinity compared with soils of a lesser salinity more suited to tree planting.

Figure 3 Image showing variation in soil salinity.
EM-38 (vertical dipole) survey.

Results of radiometric survey

Potassium survey

Figure 4 depicts the results from gamma radiation spectrometry. They appear to correlate well with knowledge of the regional geology and geomorphology known from recent investigations (drilling). The pale green and white colours seen along the eastern and southeastern margins of the image most likely coincides either with soils derived from weathered bedrock or colluvium derived from weathered bedrock. The more intense blue colours appearing in the west are likely to reflect the presence of transported alluvium, associated with the Myers Creek floodplain and the Riverine Plains sediments.

The correlation with salinity is most interesting because the apparent bedrock/plains boundary suggested by the imagery fits hydrogeological rationale almost perfectly. That is, the zone of acute groundwater discharge and associated salinity is seen to occur along the break of slope afforded by the bedrock-plains interface apparent in the image.

The radiometric imagery featuring potassium appears to have some application in locating variations in soils and landforms that are otherwise not immediately apparent at the land surface.

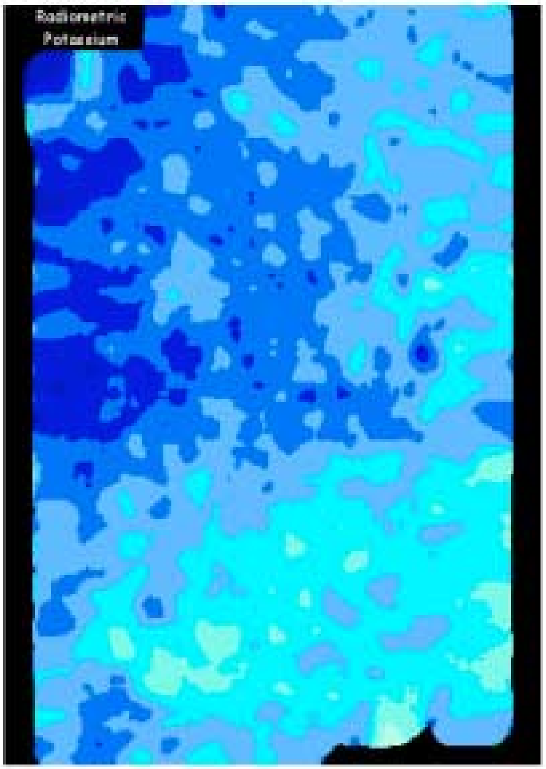

Figure 4 Image showing variation in radiometric Potassium.

Thorium survey

Figure 5 depicts the results of the Thorium survey. The response from Thorium is also consistent with the concept of transported alluvium occurring in the west and, perhaps, weathered bedrock occurring in the southeast of the project area.

The more intense response from the transported soils suggests that there is a higher proportion of coarser grained sediments with a higher proportion of 'naturally occurring' radioactive minerals. Again this is consistent with sandy sediments being deposited in times of flood in the floodplain of the Myers Creek.

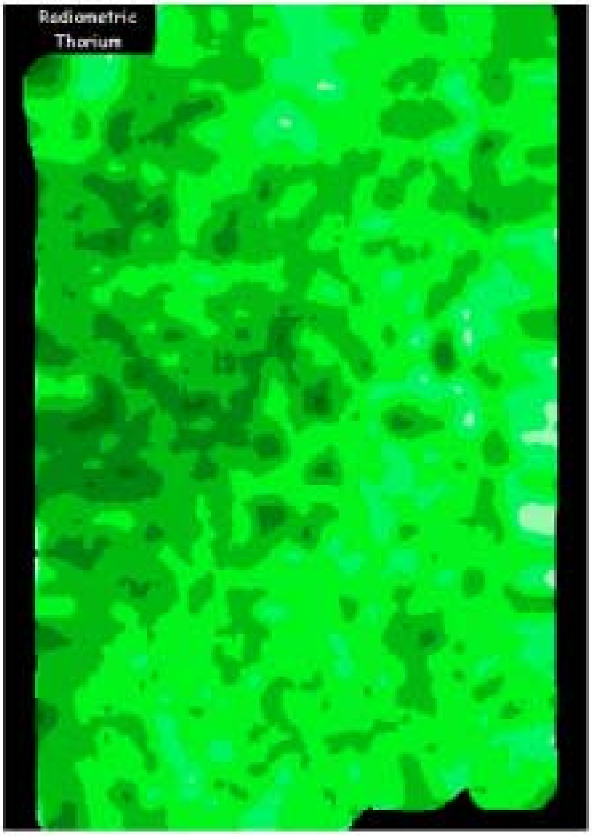

Figure 5 Image showing variation in radiometric Thorium.

Uranium survey

Figure 6 shows the results of the uranium survey. The image is once again broad agreement with the results of the Potassium survey, and consistent with the Thorium survey.

The radiometric imagery is affording consistent results that demonstrate differences in origin between the soils in the western region of the project area and the eastern/southeastern regions. As discussed above this is most likely attributable to transported alluvial sediments and weathered bedrock respectively.

Figure 6 Image showing variation in radiometric Uranium.

Total radiometric count

Figure 7 depicts the results for the total radiometric count. This clearly demonstrates the differences between soils located in the southeast compared with the soils in the northwest of the project area. Indeed the image presents very compelling evidence for a weathered bedrock origin and a transported alluvium origin for the latter.

The image presenting the total count data is particularly interesting as there is no surface expression of the bedrock in the region other than a very subtle rise in elevation present in the southeast corner of the site.

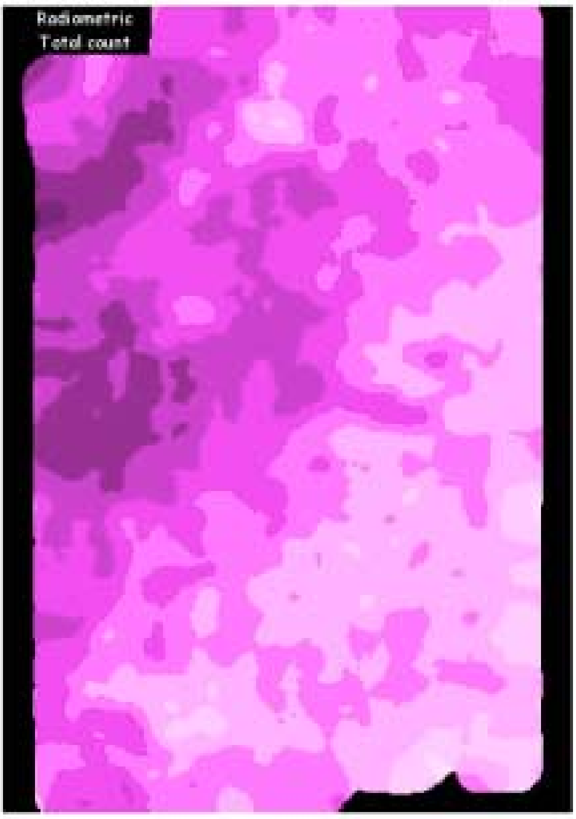

Figure 7 Image showing variation in the total radiometric count.

Phase 2 – Eastern Extension of Project Area

During 2005 the NUFG began to plan an expansion of the project beyond the original 40 hectares of salt prone land. A decision was taken to establish trees in a paddock to the immediate east of the original treatments and in the first instance to establish another native tree plantation in this area.

The Department of Primary Industries was, once again, contracted by the NUFG to complete a geophysical survey of this land using the same techniques they had deployed in the original project area.

The results of this second survey are set out and discussed below.

EM-38 horizontal dipole survey

The image presented in Figure 8 clearly indicates the distribution of saline land throughout the region of the extended project (Stage2). The region depicted within the image lies to the immediate east of the original project site. The analyses are entirely consistent with Stage 1 assessment in that the EM-38 survey shows a very clear delineation of saline soils that correlates extremely well with the known distribution of salt affected land.

The results of the EM-38 survey demonstrate, once again, a very strong correlation between the land affected by salinity and the plains/bedrock interface. This phenomenon is entirely consistent with the original conceptual hydrogeological model for Kamarooka published by Dyson and Jenkin (1983).

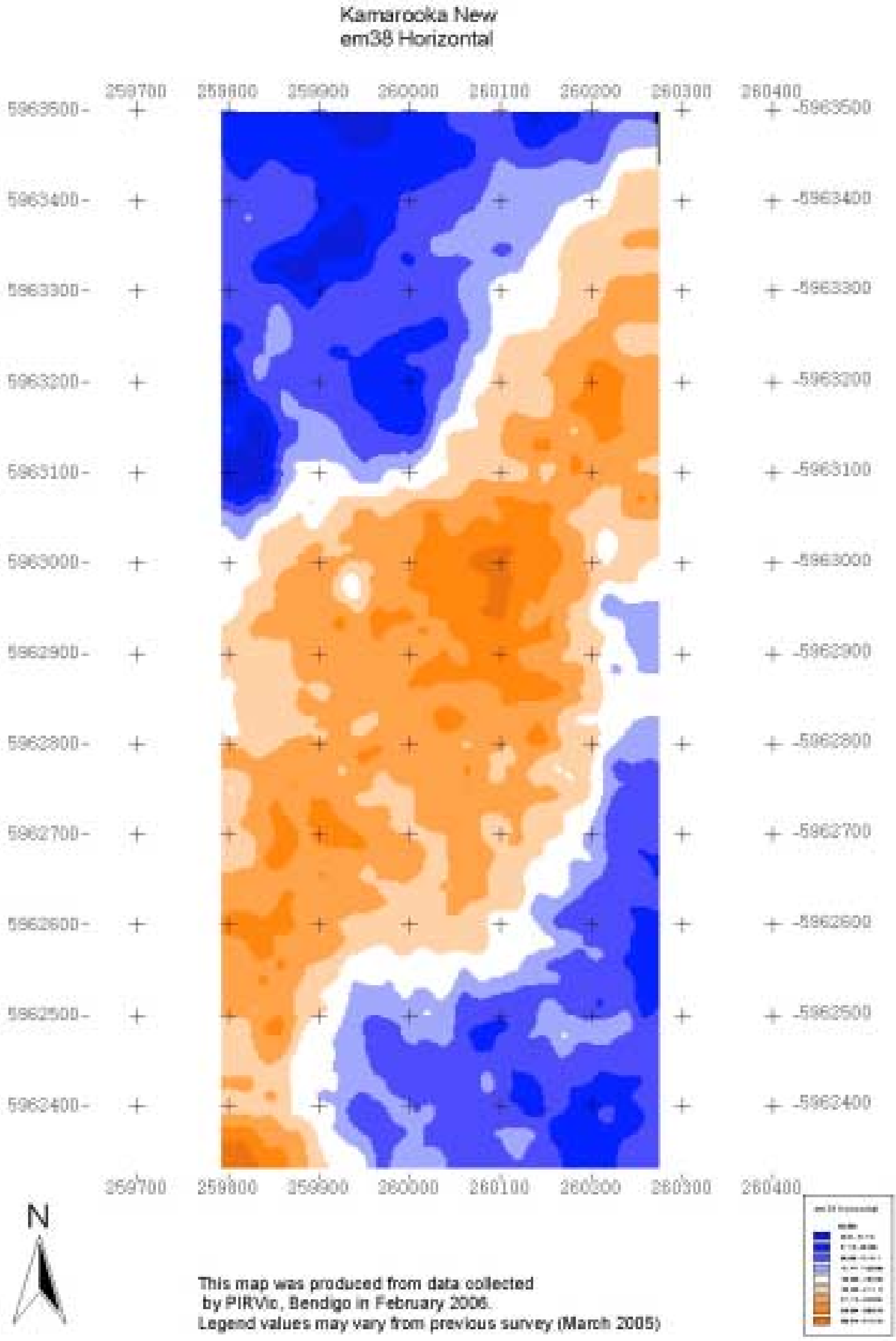

Figure 8 Image showing apparent electrical conductivity (salinity) - Kamarooka Stage 2 planting using EM-38 in horizontal dipole mode.

EM-38 vertical dipole

The EM-38 vertical dipole survey conforms with the horizontal dipole survey, and adds little additional detail. Consistent with the stage one results it indicates that EM-38 in horizontal mode is quite sufficient to map salinity in the high salinity salt prone lands of Kamarooka.

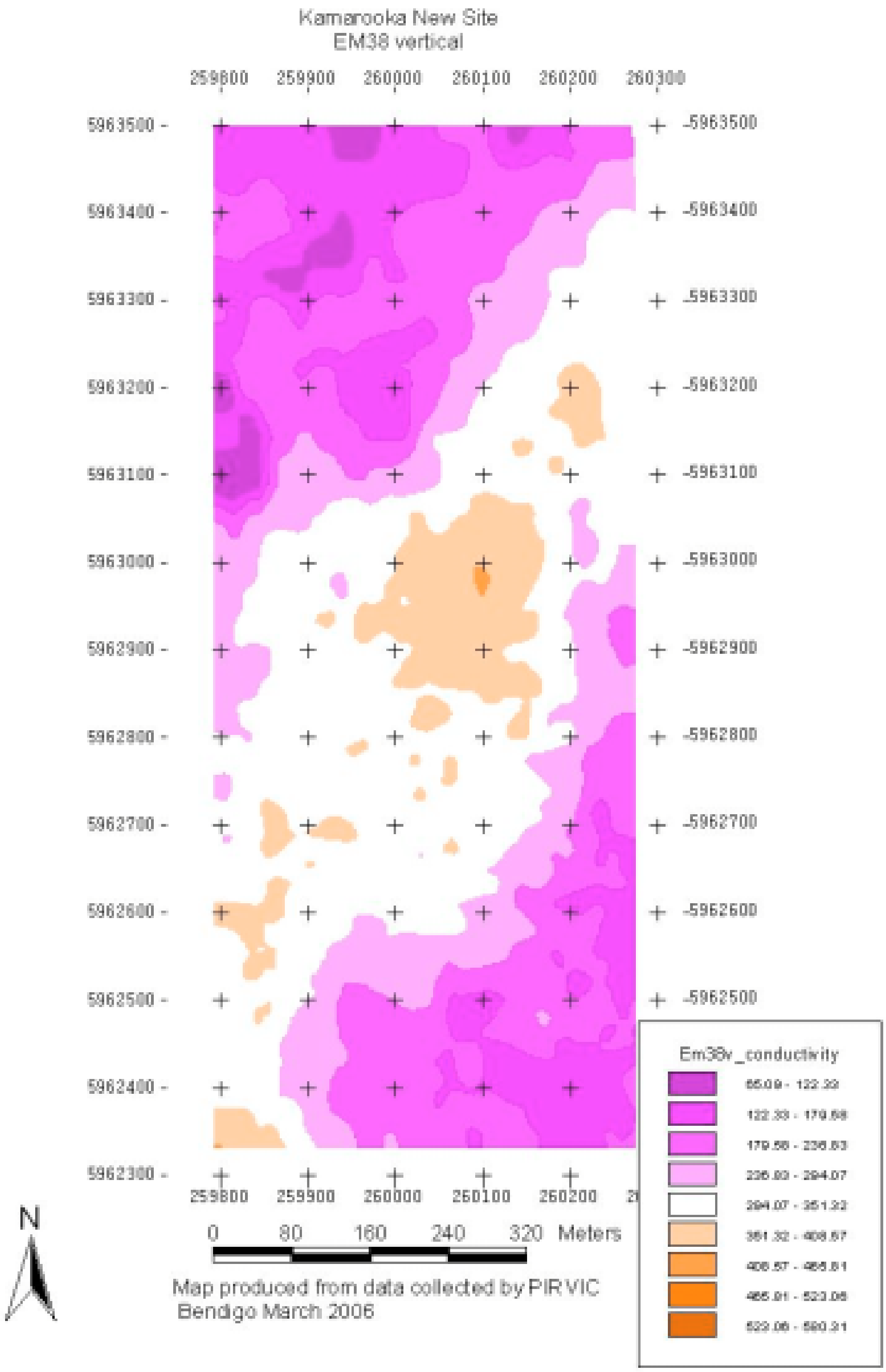

Figure 9 Image showing apparent electrical conductivity (salinity) - Kamarooka Stage 2 planting using EM-38 in vertical dipole mode.

EM-31 Survey

Figure 10 shows the EM31 results for the Kamarooka Stage 2 planting. The EM-31 results are very similar to those attained using the EM-38 technology. The results are, however, somewhat different in the northeast corner of the study area. In this region there appears to be a low conductivity region that is not apparent in EM-38 surveys.

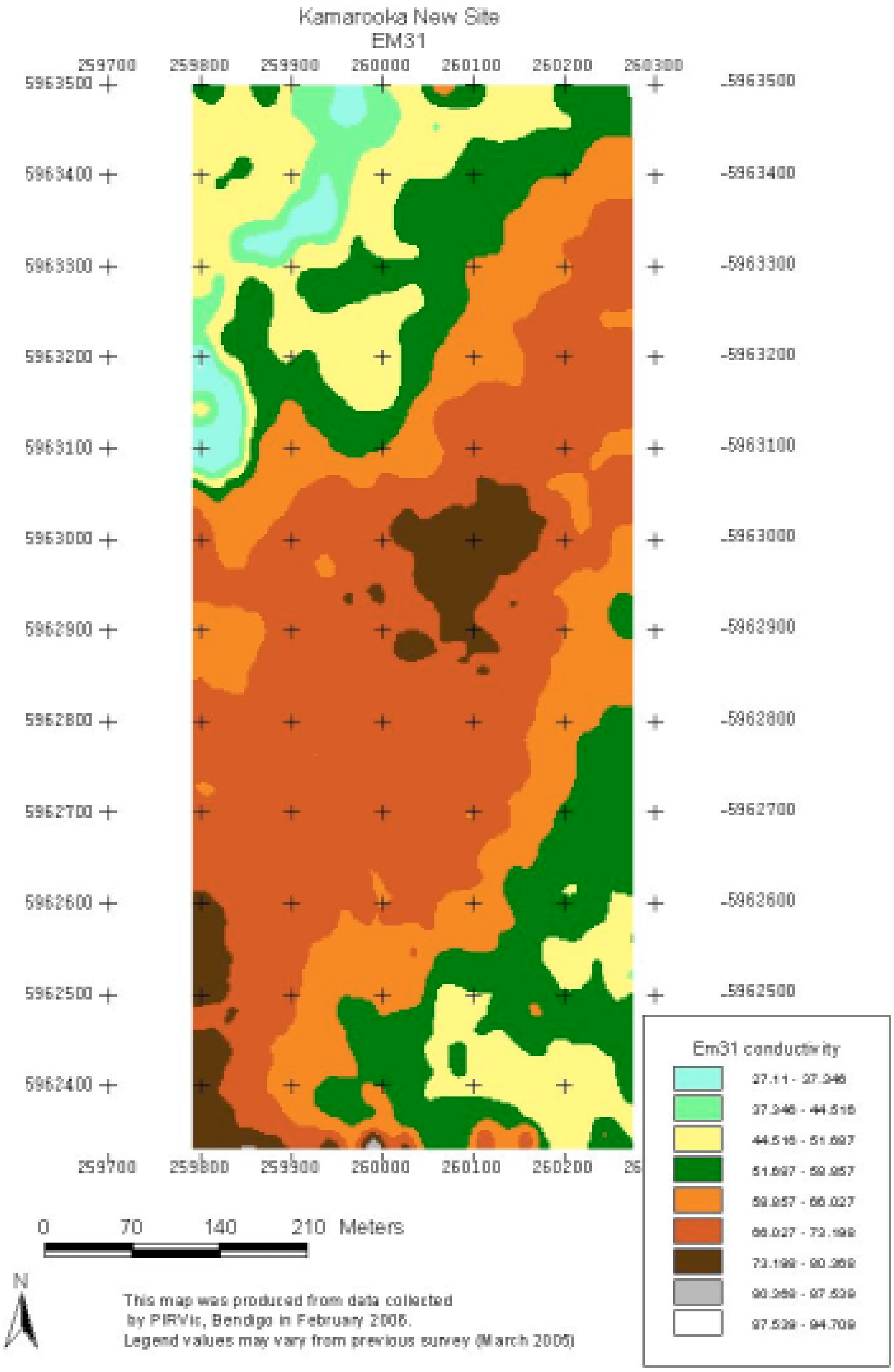

Figure 10 Image showing apparent electrical conductivity (salinity) - Kamarooka Stage 2 planting using EM-31.

As discussed above the wider coil separation used by the EM-31 array affords some potential for greater depth penetration, and this is possibly the reason for some variance with the EM-38 results in the northeastern sector. Recent drilling in this area confirms the presence of low permeability bedrock close to the land surface. It seems probably that this material is reasonably dense and has a lower water-content and a lower salt store than the surrounding weathered rock/sediment. This less permeable weathered rock may also form a barrier to groundwater flow and assist in constraining salinity a relatively narrow band along the immediate bedrock plains interface.

Radiometric survey of the expanded project area

Radiometric data consistent with the phase one survey was also collected for the expanded region (Stage 2). The results and discussion follow.

Radiometric Potassium

Figure 11 presents the results for radiometric Potassium for the Stage 2 planting. The lower levels recorded throughout the southeast and central regions of the survey correlate well with soils derived from weathered bedrock or colluvium (hill-slope sediment) derived from weathered bedrock. Higher levels occurring in the north appear indicate alluvial sediments deposited in a sallow southwest/northeast trending depression. This depression is also evident in the results from the Stage 1 survey. It occurs along the break of slope in the immediate region of the saline land.

There appears to be a good correlation between the depression and much of the area of land affected by salinity. Whilst the existence of this feature was known from the earlier geophysical survey this second survey emphasises its significance. The geomorphic origin of this newly discovered somewhat curious feature remains largely unknown at this stage.

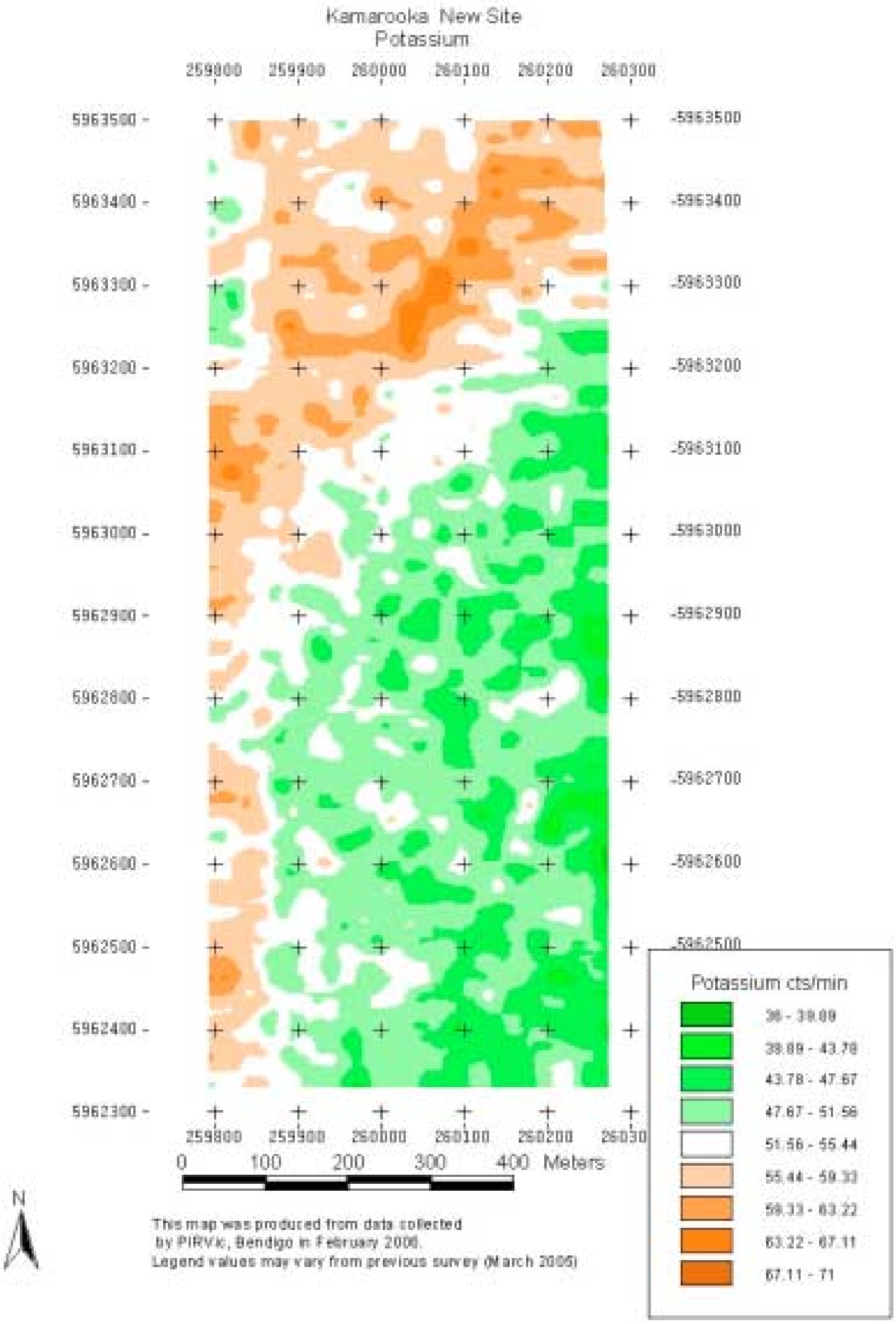

Figure 11 Radiometric potassium image - Kamarooka Stage 2 planting.

Radiometric Thorium

Figure 12 presents the thorium image for the Stage 2 planting. The results are broadly consistent with those from the potassium survey although the latter affords greater detail in correlation with the surface morphology.

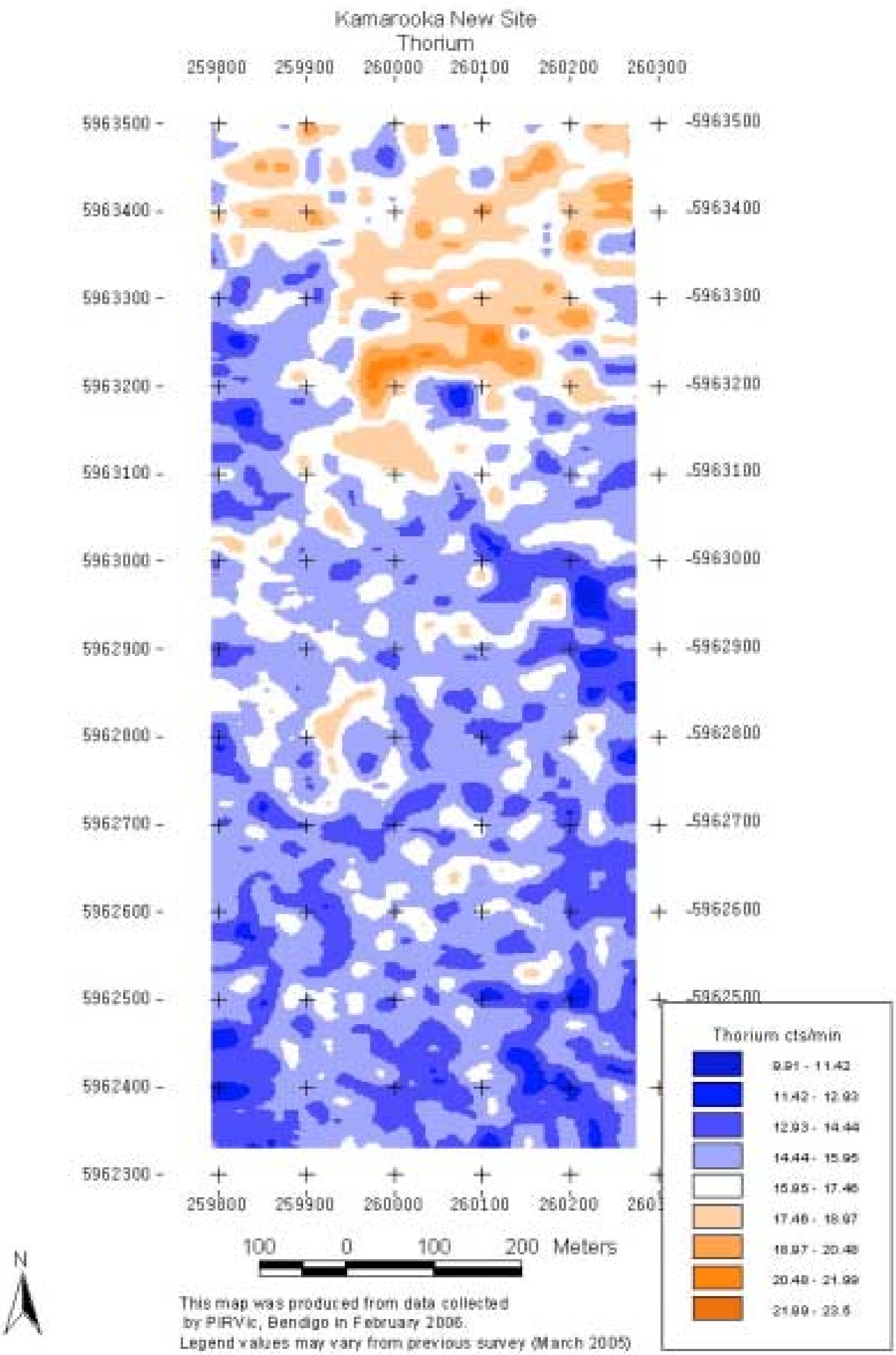

Figure 12 Radiometric thorium image - Kamarooka Stage 2 planting.

Radiometric Uranium

Figure 13 depicts the results from the radiometric Uranium survey. Once again the results are broadly consistent with soils of a weathered bedrock/colluvium origin in the southeast and central regions and alluvial origins in the northern regions.

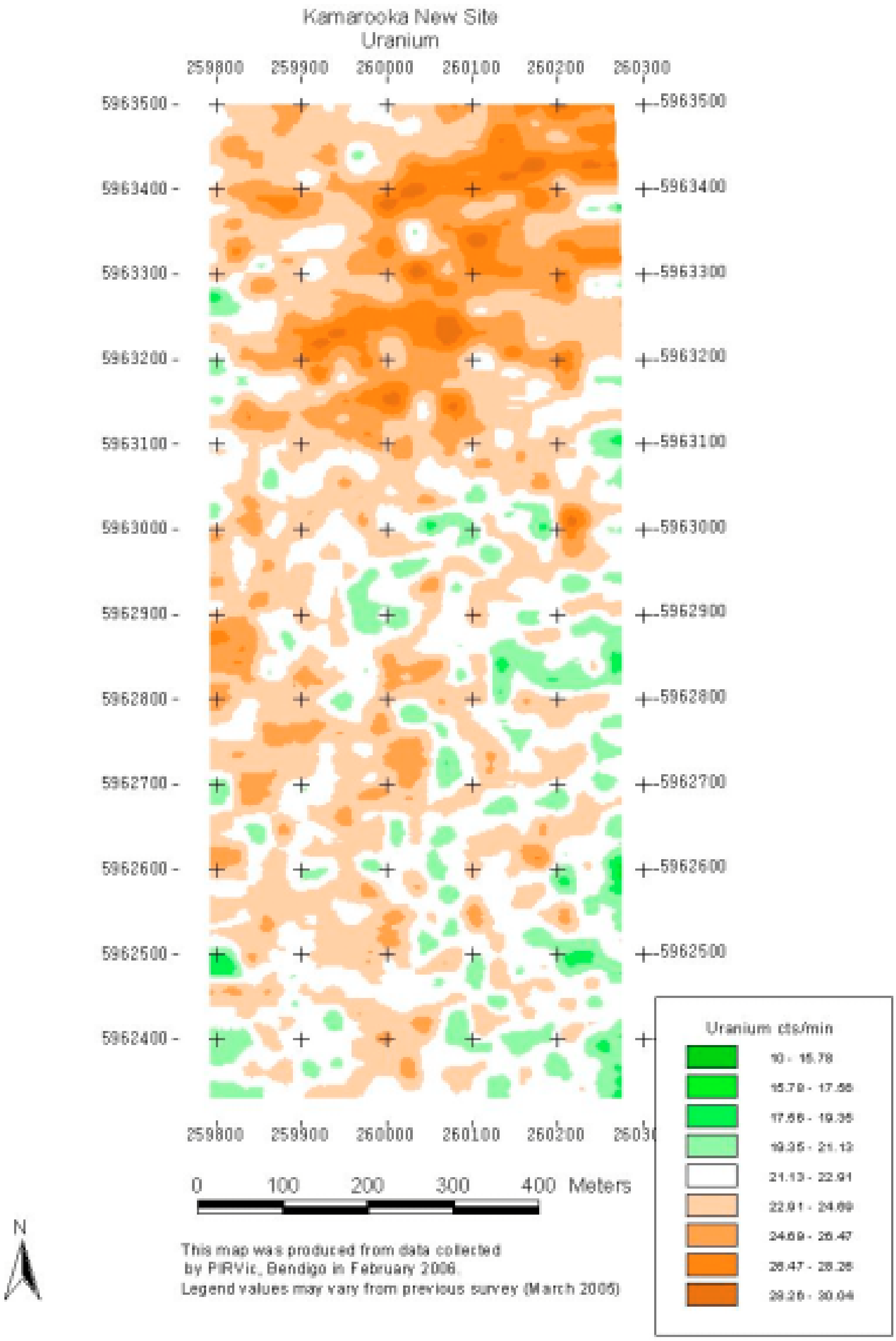

Figure 13 Radiometric Uranium image - Kamarooka Stage 2 planting.

Radiometric total count

Figure 14 presents the total radiometric count for the region of the Kamarooka Stage 2 planting. This image appears to summarise the results from the other radiometric results. The weathered bedrock/colluvium is readily apparent, found on the mid- to lower slope regions of the southeast and central regions. Equally greater radiometric activity associated with the presence of alluvial sediments is evident from more elevated counts recorded in the northern parts of the region.

Once again the presence of a southwest/northeast trending feature believed to be a broad shallow depression is evident and consistent with the results from the potassium data.

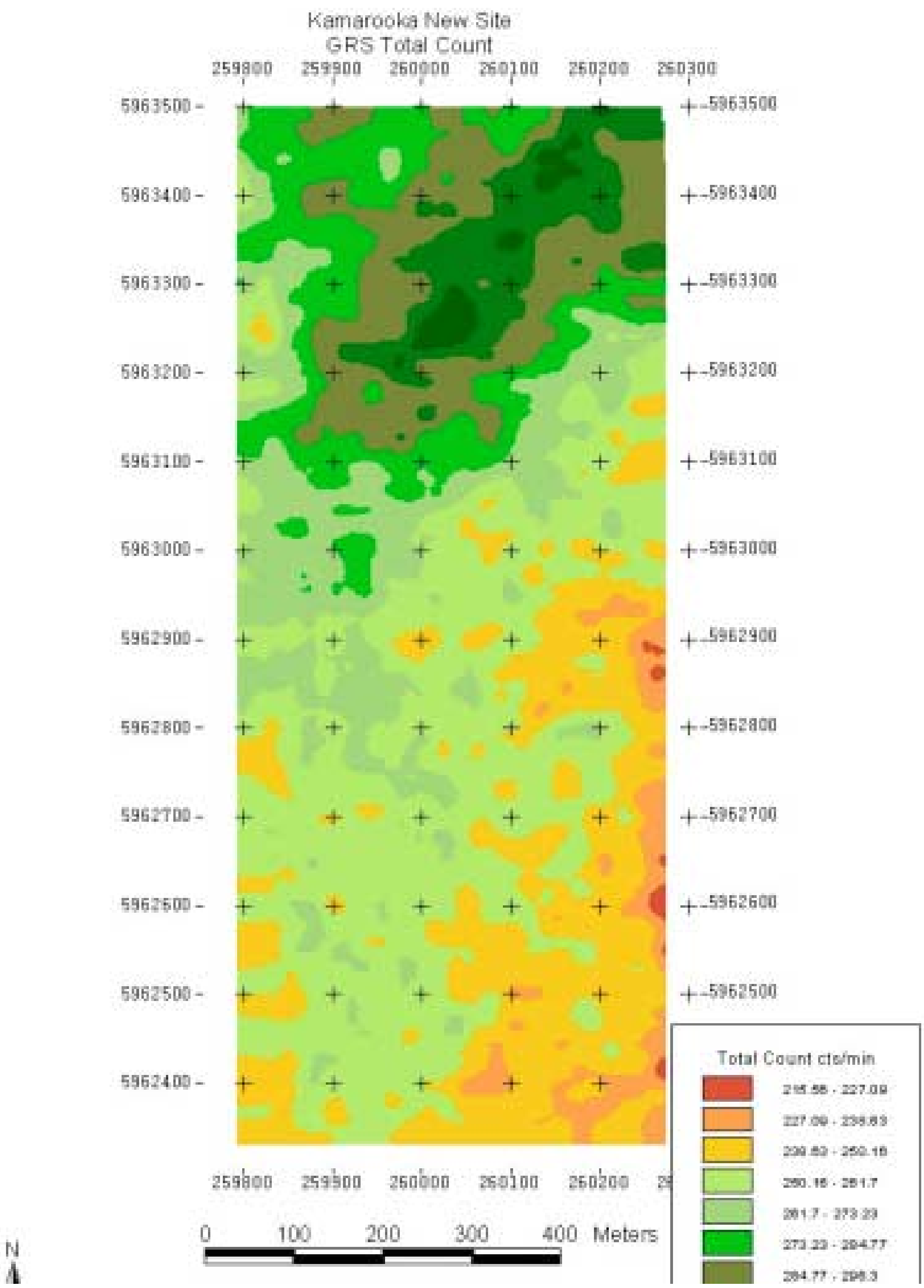

Figure 14 - Image showing variation in the total radiometric count - Kamarooka Stage 2 planting.

General conclusions from the Kamarooka Stage 2 planting area results

The results from the Stage 2 survey are consistent with those from the Stage 1 survey in that they clearly demonstrate EM-38 surveys are sufficient to map the incidence of soil salinity in the Kamarooka region. When considered in the context of other biophysical information including depths to watertable, soil analyses, and soil surveys the knowledge acquired affords a robust framework for the design of salinity treatments.

The results from the radiometric survey provide ancillary information pointing to the mineralogical composition of the soils of the region. This information is very useful in that it affords greater understanding of the geomorphic origins of various parts of the landscape, and this knowledge informs a greater understanding spatial distribution and hydrological properties of the soils.

When the information acquired from the EMI survey is brought together with that derived from the radiometric survey the results are both consistent with the existing well-established knowledge of salinity, but also add a level of greater detail to that understanding.

The collective results unequivocally demonstrate that saline groundwater discharge occurs along the break of slope that coincides with the interface between the weathered bedrock uplands of the immediate surface water catchment and the alluvium of the adjacent Riverine Plains. This is entirely consistent with the established science of salinity in the region that recognises hydraulic connectivity between the fractured rock aquifer of the catchment and the zone of saline groundwater discharge. The geophysical surveys confirm saline groundwater discharge in the region is coincident with the zone of reduced hydraulic gradient in the region of the bedrock/plains interface.

At very local scales the geophysical results indicate site-specific variations in the manifestation of salinity. These are both interesting from a hydrogeological perspective, and very relevant in terms of the design of salinity management strategies.

Perhaps one of the most interesting aspects of the EMI/geophysical surveys in the Stage 2 region of the project is the lack of complete spatial coincidence between the EMI surveys and the radiometric surveys. At first glance the results from the two surveys appear highly correlated. A more detailed inspection, however, reveals salinity manifestation indicated by the EMI surveys is somewhat offset from the radiometric surveys. This is not unexpected because the two surveys are measuring entirely different aspects of the land. The stark correlation, albeit offset, between the two data sets, however, suggests salinity is intimately related to the distribution of the soil/landforms. Soil salinity as measured by the EMI surveys occurs immediately south of, and is bounded, by the sediments of the plains. The surveys, thus, point to saline groundwater discharge occurring within the weathered bedrock immediately south of the of plains/bedrock interface. This is consistent with an immediate reduction in the transmissive capacity of the fractured rock aquifer as it gives way to the fins grained clay rich sediments of the plains and localised zones intense and deep weathering within the bedrock.

The geophysical data together with the results of recent drilling suggest a somewhat complex relationship between the manifestation of salinity in the immediate region of Stage 2 of the project. An outlier of shallow weathered bedrock is known to occur occurs at or very near the land surface in this region and may form a localised barrier to groundwater flow. This region of salinity/groundwater discharge is also coincident with the shallow depression discussed above (see section on potassium radiometrics). It would appear that there is a geological or geomorphic structure in this region that impedes groundwater flow and confines salinity to relatively narrow zone in the immediate region of the break of slope.

It is also tempting to believe that the broad depression occurring in the region of the saline land may be the residual manifestation of deflation (wind erosion) effected by previous historical salinity episodes, but further investigation may cause this rather speculative assertion to give way to more anthropogenic explanations. Nevertheless the existence of the feature is of some scientific interest.

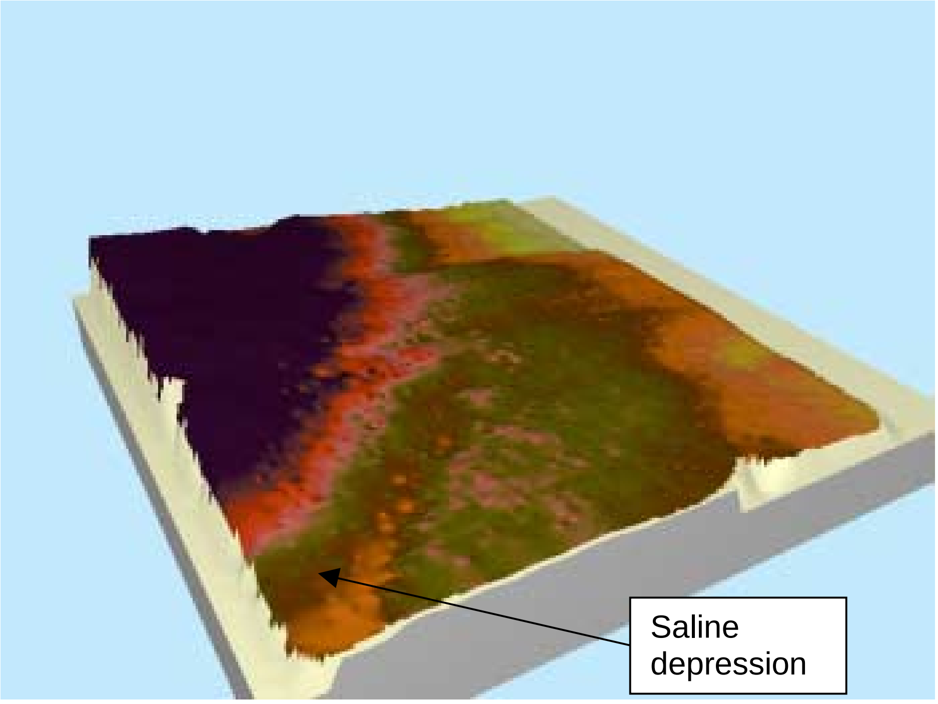

Figure 15 High-resolution 3D topographic image illustrating the depression partially coincident with saline land

General conclusions relevant to both geophysical surveys

The geophysical surveys of saline land at Kamarooka have been very successful in both defining various classes of land affected by dryland salinity and providing local insight into soils and landscape processes. There is a very high correlation between land that is obviously degraded by salinity and the results from the EMI surveys. As discussed in the sections dealing with the EMI results the EM-38 surveys alone proved entirely sufficient to deliver assessments adequate for considering the spatial design of local salinity management strategies.

It is important to appreciate that the geophysical assessments at Kamarooka are made in the context of a much large body of knowledge of soils and groundwater systems. They assist by mapping boundaries and affording an improved rationale for considering the spatial location of various treatments consistent with their salinity tolerance. The surveys were designed and implemented exclusively for these purposes. They were purely investigative, that is they were not established to provide benchmarks for future assessments of the changes in salinity status. Other NUFG monitoring provides for these objectives.

The merit of geophysical surveys in support of local investigations aimed at designing revegetation/remediation strategies for land subject to dryland salinity is strongly endorsed following application of the technology on the Kamarooka site by the Northern United Forestry Group. The technique proved very useful in extrapolating the results from watertable surveys, geological and geomorphic surveys, soil salinity analyses, and from simple observational assessments.

References:

Jenkin, J.J.& Dyson. P.R (1983) Groundwater and Soil Salinisation Near Bendigo, Victoria. In Collected Case Studies in Engineering Geology, Engineering Geology, Hydrogeology, Environmental Geology. Eds. Knight, J., Minty E., and Smith B. Geological Society of Australia.