Linking biogeochemistry and groundwater salinity at Clark's Floodplain, Bookpurnong, South Australia

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5.6.2 NANOTEM

5.6.3 EM31

ABSTRACT

Salinisation of the Murray River and adjacent floodplains is an ongoing problem in southeast Australia, affecting human populations and the environment. Until now, monitoring rising salinity typically requires access to bores or geophysical data that can be expensive to obtain and require specialised knowledge to interpret. Emphasis over the past 50 years has been placed on developing biogeochemistry as a mineral exploration tool. The potential of biogeochemistry as an environmental monitoring tool, specifically its innovative application in salinity detection, is explored in this study as well as proposing a multi-disciplinary index for assessing the risk of floodplain areas prone to salinisation. A biogeochemical sampling program using *Eucalyptus camaldulensis* (river red gum) and *Eucalyptus largiflorens* (black box) was designed for the study area at Clark's Floodplain, near Loxton, South Australia. Results of the survey were then compared with three geophysical surveys, groundwater analyses, and a regolith-landform map to assess how well the survey acted as a proxy for groundwater quality and salinity. Key factors contributing to salinity were also identified. Statistical and spatial analysis of Na, Mo, Cu, Mn, Fe, U, Au, Cd, Ca, P, Mg, Ti, K, and S biogeochemical data was also conducted. From the biogeochemical survey, it is evident that Na, K, and Mo show strong correlation with conductivity variations in the upper 9 m of sediment, which corresponds with the location of saline groundwater in the area and are suitable pathfinder elements for groundwater salinity. The proposed assessment index uses a scale of 1 to 14 to express risk from factors including flooding frequency, depth to the water table, and Na, K, and Mo concentrations in vegetation. The study supports the potential for plant biogeochemistry to be used as a viable tool for groundwater monitoring and salinity risk assessment but works best as part of an integrated, multi-disciplinary approach, incorporating regolith-landform mapping and, where available, geophysical and water chemistry data. The study also demonstrates potential for further research in areas where contaminated groundwater and groundwater salinity are environmental management issues. Future research will ideally focus on temporal studies that are beyond the scope of this study, as well as different landscape settings and groundwater chemistry and the application of biogeochemistry to monitoring acid sulphate regolith.

Keywords: Biogeochemistry, salinity, river red gum, black box, groundwater, Murray River, Bookpurnong

1. INTRODUCTION

1.1 Project aims

The aims of this project are to: i) assess the potential of using plant biogeochemistry to express groundwater quality and salinity hazards within the Murray Basin of southeastern Australia and, ii) subsequently propose an index to quantify the salinity risk of floodplains along the Murray River. The aims have been achieved by correlating major and trace element expression in tree leaves to data from three geophysical surveys and groundwater salinity data from the study area. The result is an understanding of how groundwater chemistry can be expressed in plants, specifically *Eucalyptus camaldulensis* (river red gum) and *Eucalyptus largiflorens* (black box) leaves. It establishes a link between hydrogeochemistry and biogeochemistry – linking water users with water contents, in a quantifiable and accessible technique. The premise for employing biogeochemistry for groundwater monitoring was proposed by Hulme and Hill (2003) in their study of river red gums as a biogeochemical sampling medium in mineral exploration and environmental chemistry research.

1.2 Background

1.2.1 BIOGEOCHEMISTRY

Biogeochemistry was first developed as a mineral exploration tool in the early 1950s (Warren 1984) in response to a growing need for alternative mineral exploration methods that were cheaper and more time efficient. Initially soils, stream sediments, and water were used as sampling media but access to suitable samples was not always possible. Trees and other vegetation forms, such as moss and lichen, were later adopted as exploration media. In more recent research, other biota have been used in biogeochemical surveys, including termitaria (Petts *et al.* 2009), meat ants (Jennings *et al.* 2007), and kangaroo droppings (Hill 2004; McMahon & Hill 2007). Biogeochemistry was initially used in exploration for Cu and Zn, which are known essential elements utilised by plants for metabolic processes. Over the following decade more elements were found to be absorbed and expressed by plants (Warren 1984). In Australia, biogeochemistry is particularly useful as a mineral exploration

tool for areas covered by transported regolith and where there is sparse outcrop to sample (Hill 2003; Hulme *et al.* 2006; Petts *et al.* 2009; Reid *et al.* 2009; Reid & Hill 2010).

From early in its development, biogeochemistry was used in environmental studies, in addition to mineral exploration. Studies in the early 1960s demonstrated that Pb content in vegetation was partly due to pollution generated by the addition of tetraethyl lead to petrol. Subsequent research led to the publication of a UK paper that proved tetraethyl lead was an environmental hazard (Everett et al. 1967 *in* Warren 1984), leading to its removal from petrol (Warren 1984).

Plants require certain nutrients to grow and it is the absorption of these elements that make biogeochemistry an effective analytical tool. Root tips are weakly charged and slightly acidic, leading to the exchange of H^+ for elements like Cu, Zn, and Ni as well as other metals, at the colloidal interface. Alternatively, plants gain nutrients via passive integration through simple diffusion. Elements are then sequestered in various plant organs depending on their biochemical role (Hulme & Hill 2003). For example, K is a macronutrient used in pH buffering and osmoregulation, also in carbohydrate and protein synthesis. Magnesium is also used in protein synthesis, as well as enzyme activation and pH regulation. Calcium plays a role in membrane stability and cell division while iron is used in photosynthesis and chlorophyll production (Leonard & Field 2004).

Plants can reveal the geochemistry of an area in one or a combination of two ways: i) amalgamation; or ii) penetration. Amalgamation includes the collection of stream sediment chemistry and hydrogeochemistry of shallow aquifers from within transported regolith, whereas penetration involves direct contact with underlying bedrock. The mechanism a particular plant employs mostly depends on the kind of root system it has, such as spreading lateral roots or deep sinker roots (Hulme & Hill 2005).

1.2.2 GROUNDWATER HYDROGEOCHEMISTRY

Groundwater hydrogeochemistry has been used previously in mineral exploration (e.g. Caritat and Kirste 2004); this project will take the approach one step further. As groundwater interacts with buried substrates, major and trace elements as well as isotopic chemistry may be transferred to the water and this chemical signature transported through the subsurface. The water may be intersected by a bore from which samples can be taken. The groundwater geochemical footprint of underlying substrates is likely to be broader than that of soil or transported regolith (Caritat & Kirste 2004).

1.3 Significance

The Murray River has a number of problems affecting its health (Jolly 1996) (Jolly *et al.* 1993) mostly due to poor management of the water resource without regard to the complexity of the landscape and hydrogeochemical system. The significance of this project is measured in the short term, medium term, and long term. In the short term, this project offers a new way of determining river and tree health before the effects become irreparable. It also further defines the uses and limitations of biogeochemistry. In the medium term, this analytical method will form the basis of an environmentally and culturally sensitive, inexpensive way of testing groundwater quality in rural and remote areas without the need for drilling or bore access. In the long term, there is potential scope for monitoring other hazards, such as acid-sulphate regolith (Rogers 2005), where acidic groundwater can mobilise harmful metals and trace elements, in addition to groundwater quality and contamination monitoring.

2. STUDY AREA

2.1 Location and climate

 The study area is at Clark's Floodplain, Bookpurnong, approximately 10 km north of Loxton, South Australia, downstream of Lock 4 **(Figure 1)**. The climate is arid to semi-arid. **Table 1** summarises rainfall and evaporation statistics for the area.

 The hydrogeology, vegetation, and climate of Clark's Floodplain is typical of the lower reaches of the Murray River, with a single meandering channel over flat terrain incising alluvial deposits (Doble *et al.* 2006). In such floodplain settings, regular inundation is an important process to leach accumulated solutes from the soil. Since the beginning of river regulation in the early 20th century, however, medium to large scale floods (60-100 GL/day) have decreased by a factor of three (Ohlmeyer 1991).

2.2 Previous studies

 Prior research on areas related to this study includes spatial data, hydrogeological processes, and background information on the study area and similar regions in the Murray Basin. The aims of this project are innovative and as such there is no previous research on the specific application of this technique; however groundwater has been used previously in the search for concealed mineral deposits (Gray 2001; Caritat & Kirste 2004, 2005; Caritat *et al.* 2006) and also to a limited extent in detecting environmental issues such as acid sulphate regolith (Rogers 2005).

 There has been a large amount of work conducted at Clark's Floodplain (Doble *et al.* 2006; Berens *et al.* 2009a; Berens *et al.* 2009b; White *et al.* 2009) and also around the Chowilla Anabranch system, a floodplain approximately 200km^2 in size, 80 km upstream. At Clark's Floodplain, studies by the Department of Water, Land and Biodiversity Conservation (DWLBC) have developed and tested techniques to reduce root zone salinity for vegetation. These reports include the compilation of substantial geophysical data and remote imagery. Studies have also been undertaken testing several geophysical methods to define and monitor salinity in both river and floodplain sediments (Fitterman & Stewart 1986; Reid & Howlett 2001; Barrett *et al.* 2002; Telfer *et al.* 2005; Fitzpatrick *et al.* 2006; Munday *et al.* 2006). The Chowilla anabranch system is the second largest contributor of salt to the lower

reaches of the Murray River and possesses similar hydrogeology and landscape setting to Clark's Floodplain (Jolly *et al.* 1993; Thoms & Walker 1993; Mensforth *et al.* 1994; Jolly 1996; Akeroyd *et al.* 1998; Slavich *et al.* 1999b; Lamontagne *et al.* 2005; Overton *et al.* 2006; Jolly & Rassam 2009). The area has been used to model spatial relationships between vegetation health and saline groundwater discharge (eg Doble *et al.* 2006) as well as work investigating the impact of altered flow regimes on semi-arid/arid floodplains (eg Jolly *et al.* 1993). The studies at Chowilla, although 80 km from Bookpurnong, are useful for background information; both floodplains have similar climate, hydrogeology, vegetation, and excessive salinity.

In addition to physical information on the floodplains, some previous work involves modelling of floodplain processes and classification of land types. Models have been developed at Chowilla to simulate vegetation health in response to modified flow regimes and generate spatial predictions for floodplain salinisation (Slavich *et al.* 1999a; Slavich *et al.* 1999b). Classification schemes for soil types have also been created to assess risks and management options for agricultural land in South Australia (Maschmedt 2002; PIRSA Soil and Land Information Group 2002). These studies provide a basis for the proposed salinity risk index in this study. The previous work on the Murray River system, particularly at Clark's Floodplain, provides an ideal background dataset on which to draw conclusions on the accuracy of biogeochemistry as a proxy for groundwater salinity in the area.

2.3 Geology and hydrogeology

The study area is within the Murray Basin, a Cainozoic sedimentary basin that includes laterally extensive and undeformed carbonate and clastic sedimentary rocks (Lukasik & James 1998). The basin contains three major aquifers; from oldest to youngest:

i) the Renmark Group,

ii) the Murray Group, and

iii) the Pliocene Sands.

The Renmark Group is the most extensive. It is a confined aquifer of alluvial sediments, deposited 30-50 Ma (Brown & Stephenson 1991). Overlying the Renmark Group, the Murray Group is a fossiliferous limestone aquifer, deposited in the last marine transgression in the

Oligocene. The Murray Group aquifer, which underlies the western side of the Murray Basin including Clark's Floodplain, is extensively developed for irrigation and agricultural water use. Its salinity increases moving west from the Mallee region in Victoria to the Riverland in South Australia, where salinity is in excess of 30,000 EC (Thompson & Barnett 2009). The Pliocene Sands aquifer is the youngest at 2-6 Ma and includes the Loxton-Parilla Sands marine sequence and only occurs upstream of Overland Corner, South Australia (Brown & Stephenson 1991; Thompson & Barnett 2009). Groundwater in this aquifer in the Bookpurnong region can exceed 130,000 EC (Thompson & Barnett 2009).

 Figure 2 is a schematic cross-section of the geology and hydrogeology at Clark's Floodplain, typical of floodplains in the lower reaches of the Murray River. Over the floodplain, the Coonambidgal Clay forms the surface layer and is comprised of narrow alluvial deposits from recently abandoned ancestral channels and the modern Murray River (Doble *et al.* 2004; Lewis *et al.* 2008). The sequence acts as a partially confining layer above the Monoman Sands, typical of the eastern regions of the Lower Murray (Jolly 1996; Doble *et al.* 2004, 2006). The Monoman Formation, deposited from the late Pleistocene, is a fine to coarse unconsolidated alluvial sand, up to 30m thick in some areas. Beneath the Monoman Formation are the Bookpurnong Beds and Loxton-Parilla Sands, deposited in the Miocene during the last marine transgression (Stephenson 1986). The Murray Group limestone aquifer is confined by the Bookpurnong Beds and the Winnambool Formation (Jolly *et al.* 1993). The Murray River incises the Coonambidgal and Monoman Formations. Further to the northeast of the floodplain, away from the river channel, cliffs expose the lithologies underlying the highland areas; from oldest to youngest these are:

 i) the Loxton-Parilla Sands,

 ii) Blanchetown Clay, and

iii) the Woorinen Formation.

The late Miocene Loxton-Parilla Sands is a poorly indurated yellow-brown quartz sand of variable grain size, deposited as a regressive marine facies. It is referred to as the Loxton-Parilla Sands due to the lack of distinctive boundary between the two sands (Geoscience Australia 2009). The Blanchetown Clay, deposited in the Pleistocene, varies from silty to sandy clay and suggests a high-energy, shallow freshwater lake with fluvio-lacustrine influence. The formation has low permeability which has formed a groundwater mound of fresh irrigation-derived groundwater (Geoscience Australia 2009; Viezzoli *et al.* 2009). The

Woorinen Formation is a perched aquifer, deposited from the mid-Pleistocene to the Holocene. It is comprised of unconsolidated red-brown medium to fine silty sand, with broad E-W trending longitudinal dunefields, developed after the drying of the former Lake Bungunnia (Lawrence & Upchurch 1982; Zhisheng *et al.* 1986; Geoscience Australia 2009).

2.4 Vegetation

The initial biogeochemistry survey design only used *Eucalyptus camaldulensis,* however, there were parts of the survey length where *E. camaldulensis* were absent or those present were of such poor health it was not possible to sample the leaves. **Figure 3** shows the location and distribution of vegetation samples. To ensure an even distribution of sample points, *Eucalyptus largiflorens* leaves were sampled when there was no *E. camaldulensis* suitable to sample. There were also some sites where the two species were sampled from adjacent trees to enable at least some species comparison of results. This section provides a brief explanation of the similarities and differences between these two species, with particular emphasis on their water use and salt tolerance.

The lower Murray River floodplains are dominated by *Eucalyptus largiflorens* (black box), *Eucalyptus camaldulensis* (river red gum), and *Muehlenbeckia florulenta* (lignum), with *E. largiflorens* comprising approximately 30% and *E. camaldulensis* making up approximately 20% of the vegetated floodplain areas (Holland *et al.* 2006). Salvich, Walker et al. (1999b) found *E. largiflorens* populations tend to develop in areas of floodplain at higher elevation than stands of *E. camaldulensis* with a supply of shallow groundwater; *E. camaldulensis* tends to grow along large alluvial channel systems (Hulme & Hill 2005) and at lower elevations on the floodplains. Field observations at the study site show the distribution of the *Eucalyptus* populations in the study area is consistent with these studies. *E. largiflorens* have been shown to be opportunistic in their water use as the species will access both groundwater and low salinity surface water when available. They will tend to use lower salinity water when available when growing over highly saline (>40 dS/m) groundwater to prevent physiological drought (Holland *et al.* 2006). Both vegetation types tend to establish root systems where groundwater is available in the subsurface (Lintern *et al.* 1997).

2.5 Landscape evolution

As a part of this study, a landscape evolution model has been developed from the interpretations of landforms from remotely sensed imagery and previous studies on the palaeogeography and development of the Murray Basin. This section provides an overview of the evolution of the Murray Basin, dating back to the Pliocene, and how modern changes to the river contribute to salinity.

Prior to forming the contemporary meandering river channel, the Murray River was dammed by the uplift of the Pinnaroo Block in the mid- to late-Pliocene and formed Lake Bungunnia which extended across most of the western Murray Basin (Firman 1971; Stephenson 1986; Zhisheng *et al.* 1986). The age of this megalake is not fully constrained but has been placed between 3.2-0.7 Ma (Stephenson 1986; Zhisheng *et al.* 1986). The lake contained freshwater and led to the deposition of clastic lacustrine sediments. Further ancestral salt lake and channel systems have since incised the Lake Bungunnia basin (Zhisheng *et al.* 1986).

Lake Bungunnia is thought to have had significant fluctuations in size, both depth and area, with layers of clays and sands observed in the sediments. Clays, however, are more abundant, which indicate slow deposition in a deeper, lower energy environment. Zhisheng and Bowler (1986) put the beginning of the Lake Bungunnia sedimentation at about 3.2 Ma, followed by about 1.5 Ma of alternating wet and dry conditions. The megalake was divided into smaller lakes that emptied in the mid-Pleistocene (Bowler 1980 in Stephenson 1986; Stephenson 1986). It is a subject of ongoing debate whether the lake dried up because of increasing aridity or the development of an outlet channel through the tectonic barrier, however the most likely cause is the Murray River breaking through the Pinnaroo Block, draining the lake in the late Pleistocene (Stephenson 1986). The contemporary and prior landforms, including dunes and salt lakes overlying the former Lake Bungunnia, formed in the last 400-500 ka (Zhisheng *et al.* 1986).

Tectonic activity and subsidence has been relatively low in the Murray Basin so eustatic fluctuations have been the most significant influence on sedimentation in the area (Brown & Stephenson 1986). The last marine transgression into the Murray Basin during the Miocene deposited deep-water clays (Bookpurnong Beds) and marginal marine sands (Loxton-Parilla Sands) (Stephenson 1986). It is thought that the contemporary Murray River channel has remained in a similar position to its ancestral channel since the mid-Pliocene (Twidale *et al.*

1978). Prior to this the river probably emptied into the ocean via a more southerly path in the Late Eocene (Stephenson 1986).

The modern Murray River channel is a 'suspended load channel' with low bed gradients, low sinuosity, low energy, and 'highly cohesive bank materials' (Thoms & Walker 1993). The introduction of locks and weirs from the early 20th century has resulted in a decrease in sediment supply to the lower reaches of the Murray River of about 1.05×10^6 tonnes/year (Thoms & Walker 1993). A study of pools behind Locks 2 and 3, downstream from Bookpurnong, has revealed variable responses in channel morphology in the last century. Features such as channel slope and areas of degradation and aggradation have experienced changes but the channel has low energy and bank materials tend to be cohesive so significant changes in morphology in response to regulation have not had time to develop (Thoms & Walker 1993). Groundwater levels in many floodplain areas along the Murray River in South Australia have risen permanently in response to river regulation. At Bookpurnong, and similar Murray River floodplains, the groundwater has moved higher in the soil profile, reaching the Coonambidgal Formation, a formation with high potential for capillary rise of water and salts. This increased potential for capillary rise draws more saline water to the surface where it evaporates and leads to further salinisation of the floodplain (Thompson & Barnett 2009).

2.6 Salinity and acidity problems

Salinisation of floodplain soils occurs when changes in river flow regime disturb the natural 'balance' of salt movement (Jolly 1996). The balance involves: i) salt moving up the soil profile via capillary action and evapotranspiration, and ii) leaching of salt down the soil profile during flood events. When the 'salt balance' is modified, often due to changes in water flow, net accumulation of salt near the surface occurs as it moves up in the soil profile and is not removed by flooding. Increased salinity in floodplain soils is the most common result of altered flow regimes (Jolly 1996).

The salinity problem along the River Murray is a naturally occurring situation that has been exacerbated and magnified by anthropogenic activities and poor management of the natural water resource (Jolly 1996). Anthropogenic influences, such as clearing native vegetation for agriculture and diverting water for irrigation, have unbalanced the natural hydrological system (Herczeg *et al.* 2001). Groundwater salinity underlying the study area is in excess of

30,000 mg/L and recharge from the adjacent Bookpurnong irrigation district is approximately 5,000 mg/L. This comparatively fresh water has formed a groundwater mound in the upland areas of the floodplain that drives saline groundwater into the river **(Figure 2)** (Munday *et al.* 2006).

Approximately 1.5 million tons of salt is introduced to the Murray-Darling system through rainfall each year (Herczeg *et al.* 2001). Stable isotopic data have shown the current salt load has developed through the introduction of marine and continentally derived salt, rather than remnant sea water residing in the formations. This, combined with high evapotranspiration potential, low topographic relief, and poor drainage has resulted in the concentration of solutes in aquifers; such processes are typical of an arid to semi-arid climate (Herczeg *et al.* 2001).

The Chowilla anabranch system contributes approximately 140 tonnes of salt per day to the Murray River (Jolly 1996). River regulation has resulted in more water from the River Murray moving through the anabranch system, intersecting saline groundwater, thereby increasing the salt load in the Murray (Jolly 1996). During flood events, up to 1800 tonnes of salt per day, in groundwater, can flow through the creeks of the anabranch and end up in the Murray. The increased rate in salt input to the Murray River from the anabranch system may last for up to two years after flooding (National Environmental Consultancy 1988). Jolly *et al.* (1993) describe how river regulation has directly resulted in the salinisation of the floodplains at Chowilla by increasing the water table height, thereby increasing the discharge of saline groundwater and movement of salt vertically in the soil profile. In addition, regulation of flow means there is less flooding of the area leading to less salt being leached and transported away from the surface.

Soils and soil water of semi-arid floodplains are often high in salt due to climatic conditions, and evapotranspiration can cause salt to move up out of the groundwater into the soil (Jolly 1996). This salt at the surface rather than in the root zone means riparian vegetation can survive. Highly saline water in the soil profile is not readily available for vegetation use, however, as the osmostic potential is too low so vegetation dies from physiological drought (Jolly 1996). Ion toxicity can occur in species that are not tolerant of high salt level and cannot control the amount of salt taken up through the root system (Jolly 1996).

Acid sulphate regolith is another environmental problem of concern in the study area. Pyrite is contained in the Lower Loxton Sands, which can form sulphuric materials if

disturbed and exposed to air, leading to acid sulphate soils and mobilisation of metals into groundwater and the river (Fitzpatrick *et al.* 2009). Fitzpatrick and Shand (2008) define saline soils as soils with excessive soluble chloride or sulphate salts. In Australia, chloride salts are the dominant cause of salinisation however in areas such as Bookpurnong, sulphates at the surface of soils can also contribute to salinity. Of more concern with regard to sulphates, however, is the potential for them to contribute to the development of acid sulphate regolith.

3. METHODOLOGY

To meet the project aims of: i) assessing the viability of biogeochemistry as a tool for monitoring groundwater quality and, ii) proposing an index to quantify the salinity risk of floodplains along the Murray River, a biogeochemical sampling program was designed (3.1) and compared with geophysical data (3.2) and a regolith-landform map of the area (3.3). This section describes the methods used to compile the dataset and analyses conducted on the data to achieve the aims of the study.

3.1 Vegetation sampling

Vegetation samples were collected along a seven kilometre line on the floodplain, adjacent to the Murray River. Trees for sampling were as close to the river channel as possible and range from on the banks of the channel to 150 m away from it. In addition to the main line of sampling, a transect corresponding to a series of Department of Water, Land and Biodiversity Conservation (DWLBC) study sites was also sampled. This transect corresponds with transect three from site B in the study of the effects of pumping saline groundwater out of the floodplains on vegetation health (Berens *et al.* 2009b) and is arranged normal to the channel margin. The sample program was designed to include one *E. camaldulensis* every 100 m along the river, however, areas of sparse vegetation required the substitution of *E. largiflorens* for *E. camaldulensis* in some areas. This distance also increased in some areas due to the lack of appropriate sampling material. Both *E. camaldulensis* and *E. largiflorens* match criteria for ideal sample species set out by Hill (2002a): both species can be identified easily in the field, they are the dominant species in the study area and they are widespread, both in the study area and through the lower reaches of the Murray River (Jolly *et al.* 1993; Hill & Hill 2003). Vegetation sampling was conducted in one day in April 2010. Between 200-300 g of leaves were taken from around the canopy of the tree at head height and placed in unbleached paper bags labelled with the sample number. GPS coordinates were recorded for each tree, using GDA 94 datum. Leaves sampled were mature where possible and poor tree or leaf condition was noted. All jewellery was removed prior to sampling and powder-free latex gloves were worn to reduce contamination, particularly from Na in sweat.

Sample bags were left open to air dry in a low-dust and low-contaminant environment for 48 hours to prevent decomposition and further dried in a low-temperature oven, at 60°C for

24 hours in open bags. Twigs, fruit and other debris were removed on bleached butcher's paper while wearing powder-free latex gloves before leaves were ground to a fine powdery consistency using a rotating stainless steel blade spice mill (Breville™ Coffee 'n' Spice mill). Prior to each sample being milled, the grinder was pre-contaminated with a small amount of sample. Following each sample the mill was cleaned with laboratory-grade ethanol and paper towel, based on the preparation method used by Reid and Hill (2010) and Hill (2002a). Ground leaf samples were poured into small plastic snap-lock bags and labelled with sample numbers.

Samples were analysed by inductively coupled plasma-mass spectrometry (ICP-MS) at ACME Laboratories, Vancouver, Canada. This technique can analyse for multiple elements, is low-cost, and has suitably low element detection limits (Dunn 2007). Advantages of ICP-MS analysis over other techniques like inductively coupled plasma-atomic emission spectrometry (ICP-AES or ICP-ES) include low detection limits and less spectral interference; when spectral interference does occur it is simple to correct for (Dunn 2007). ICP-MS also has a variety of uses in other areas of geochemistry so results are more comparable with other sample media (Jenner *et al.* 1990). There are other methods available for biogeochemical analysis; however, these have some major disadvantages compared to ICP-MS. For example, X-Ray fluorescence (XRF) does not offer low multi-element detection limits; instrumental neutron activation analysis (INAA) is prone to technical problems, variable detection limits when some elements have high concentrations and no longer commercially available; atomic absorption spectrometry (AAS) is prone to more errors and is a more labour intensive single-element technique. Hence, ICP-MS was deemed the most appropriate analytical tool for this study.

3.2 Geophysical surveys

The extent of correlation between the biogeochemistry and the data from three geophysical surveys is a comparison upon which the assessment of how well biogeochemistry picks up groundwater quality is largely based. This is largely because these surveys are considered to provide a successful expression of groundwater salinity in the area. The geophysical surveys are at the small, medium, and large scale. First is an EM31 conductivity survey, organised by the DWLBC. The second survey is an in-stream electromagnetic survey, NanoTEM, the result of collaboration between the DWLBC and the University of Adelaide (Michael Hatch,

University of Adelaide, pers comm. 2010), and the third is an airborne electromagnetic survey from the RESOLVE frequency domain helicopter EM system as part of the CSIRO Earth Science and Engineering Application of Airborne Geophysics in the Riverland, South Australia (Project CNRM054127).

The small scale EM31 survey was conducted in November 2007. The survey comprised the Geonics EM31 frequency domain EM system carried about one metre above the ground surface. The instrument is made up of a coplanar receiver and transmitter, 3.66 m apart (Reid & Howlett 2001; Barrett *et al.* 2002). It has a penetration depth of 2-6 m and variations in salinity are the greatest contributor to changes in sediment conductivity picked up by the EM31 survey (Tan *et al.* 2009). The EM31 system and similar instrumentation has been applied in detecting and delineating saline environments previously to provide a geophysical method for monitoring salinity and floodplain processes (Sheets *et al.* 1994; Reid & Howlett 2001; Barrett *et al.* 2002; Munday *et al.* 2006).

The medium scale time-domain (or transient) electromagnetic (NanoTEM) system collects data using an apparatus towed behind a boat, collecting data every 5-8 m, to a depth of approximately 20 m beneath the river bed. The apparatus includes receiving and transmitting antennae mounted on a floating PVC frame. The data are time stamped and synchronised with a GPS logger to locate sample points and river depths (Munday *et al.* 2006). Data is then inverted using STEMINV software (MacInnes & Raymond 2001). Changes in the conductivity of sediments shown by the in-stream data are then used to infer characteristics of groundwater and soil, for example salinity (Berens *et al.* 2009b), beneath and directly adjacent to the river. Peaks in conductivity can suggest regions where there is an influx of saline groundwater to the river (Thompson & Barnett 2009).

The large-scale airborne electromagnetic (AEM) data used in this study were collected using the RESOLVE system which is useful for mapping conductivity near the surface (40-50 m) at high resolution. Data were collected using the six-frequency Fugro RESOLVE frequency domain helicopter EM system and then inverted using the holistic inversion algorithm of Brodie and Sambridge (2006) (Munday *et al.* 2006). Like the in-stream data, variations in conductivity in the AEM data are use to infer changes in conductivity of groundwater and sediments beneath the floodplains (Berens *et al.* 2009b).

3.3 Regolith-Landform Map

Regolith-landform mapping is a useful way to represent regolith materials, geomorphology, and landscape processes. It incorporates major and minor regolith cover, vegetation, and landform attributes into a form that can be tailored to a specific end use. There is little in the way of universally accepted guidelines for producing regolith-landform maps however the Geoscience Australia Regolith Landform Unit (RLU) approach developed by (Pain *et al.* 2007) outlines criteria for regolith-landform unit classification that has been adopted in other studies within Australia (eg Hill 2002b). Regolith-landform units are based on regolith materials and their associated landforms, employing a code system:

$$ACah_1$$

Upper case – regolith material

Lower case – Landform

Subscript – Numbers to differentiate similar units

Assigning RLUs can be subjective in some cases and depends on the scale and intended purpose of the map, and the experience and mapping approach of the individual creating the map. Detailed RLU descriptions, however, comprised of observations rather than interpretations will ensure discrepancies are kept to a minimum (Hill 2002b).

Some maps of the Murray Basin have been produced but prior maps have focused on the geomorphology of the river and landforms. Kotsonis *et al.* (1999) mapped the geomorphology of the Hattah Lakes region of the Murray River. A similar approach has been taken with the map in this project but with more emphasis on regolith materials and processes affecting the landscape. Units in the map of this study area are also grouped together into similar time periods to show the evolution of the area. Butler (1973) undertook extensive mapping of the Riverine Plain in Victoria and NSW with a focus on geomorphic features, divided into aeolian and alluvial processes. Like Kotsonis *et al.* (1999) and the map in this study, the map shows the geomorphic evolution of the region. These mapping studies were undertaken prior to the development of regolith-landform mapping techniques (Hill 2002b), but have similar aims, bringing together landscape processes, transported regolith cover, vegetation patterns, and geomorphic evolution of an area. In South Australia there have been extensive studies to map soil types and their distribution in agricultural regions but they do not incorporate landscape processes or other regolith

features (Maschmedt 2002; PIRSA Soil and Land Information Group 2002). These publications provide a classification system of soils in SA agricultural regions for landusers to assess productivity potential and management requirements. The reports and map sheets also provide information on hazards such as weed infestations, extent of water repellent soils and land prone to erosion. The classification system is based on soil and landscape attributes but are very large scale and only useful as a preliminary analysis of risk factors.

The regolith-landform map for the study area is at a scale of 1:15,000. This scale is best suited to delineating local variations in sampling media and substrate (Hill 2002b). Major regolith materials and landform features were visible on remotely sensed imagery such as LANDSAT, obtained from the DWLBC; this image made up the base image for the regolith-landform map. Regolith-landform attributes were interpreted and annotated onto the base map while field surveying validated interpretations derived from remotely sensed data. Some larger scale features, such as point-bars from the ancestral Murray River channel, are prominent in the satellite imagery, but are not readily observable at ground level. This demonstrates the importance of combining remotely sensed imagery interpretations with field observations to define subtle yet significant heterogeneity in regolith materials and landforms (Brown & Hill 2004). Regolith-Landform Unit (RLU) descriptions were compiled through field observations and descriptions from the previous DWLBC Living Murray reports of the area. The initial stage for producing the map was identifying RLUs from remotely sensed imagery which then enabled the identification of sites suitable for further field investigation. Observations made during field surveying included major and minor regolith materials, vegetation, position within the landscape, and how cover and landforms change over the study area. An advantage of regolith-landform maps over geological maps is they can be constructed to suit intended uses and outcomes, for example in planning a drilling program or in environmental management (Hill 2002b).

3.4 Index of salinity risk

The generalised index of floodplain salinity risk proposed in this project is based on the approach of Slavich *et al.* (1999a; 1999b). Key factors contributing to floodplain salinisation have been identified in this study, and from previous work, and are combined to produce a static numerical model.

3.5 Groundwater analyses

Groundwater analyses used in this project are from the data published by DWLBC as a part of the Bookpurnong Living Murray Pilot Project (2009/21) (Berens *et al.* 2009b). Testing involved using a YSI XLM600 multi-parameter downhole profiler for vertical logging of changes in groundwater salinity. Measurements were repeated over several years to show temporal changes in salinity. The groundwater profiling in the DWLBC study was used to assess the development of a fresh water lens beneath the floodplain in response to saline groundwater being pumped out of the ground (Berens *et al.* 2009b). The groundwater analyses in the study area are used here to qualitatively verify whether the geophysical data accurately represent variations in salinity. Berens, *et al*. (2009b) show the correlation between groundwater salinity monitoring results and the NanoTEM and EM31 geophysical surveys. The results are consistent with the depth of measurement of the two techniques beneath the surface and were used to delineate and track the development of a freshwater lens under the floodplain in response to artificial inundation. The EM31 and NanoTEM methods were successful in tracing the freshwater lens. The AEM survey does not have sufficient spatial resolution to show such small scale features, however, regional trends in the AEM survey correspond with general trends in the NanoTEM and EM31 data. Thus, the geophysical surveys used in this study to represent changes in groundwater and soil salinity are assumed to be accurate.

3.6 Quality assurance and quality control

Quality assurance and quality control measures were performed at three stages of data collection. During sampling, all jewellery was removed, gloves were worn, and vegetation was sampled from around the canopy of the tree to increase the homogeneity of samples. Leaves collected were of a similar age to minimise differences in element distribution due to age (Dunn 2007). During sample preparation, blind duplicate samples were created from one in ten samples by shaking the powder to ensure homogeneity and pouring one half of the sample into a new bag with a new sample number. This process is to confirm the analytical integrity of the results. Sample preparation was done in-house rather than by the laboratory so quality assurance could be readily tracked and monitored. For analysis by the laboratory, pulp duplicates and standards V14 and V16 (mountain hemlock) were used for in-house quality assurance to calculate analytical bias. Errors are 95% confidence limits from

duplicate samples and from laboratory standards and pulp duplicate samples. **Table 2** presents summary statistics calculated from the analytical results.

3.7 Statistical analysis

Spatial association maps of the concentration of each element and each species were created using ArcGIS 9.2 software. Concentration cut-offs for each element were determined automatically in ArcGIS using the geometrical interval classification function. This classification gives each class the same number of values and creates consistent changes between classes. It is particularly useful for continuous datasets or data that are not normally distributed (ESRI 2007). **Appendix 1** shows a comparison of natural breaks (Jenks) classification and geometrical interval classification methods. Split population normal probability plots were generated using ioGAS 4.2 software to determine if the two tree species possessed different elemental associations. Dendrograms were created using Statistica 9 software to establish clusters of elements with similar or contrasting behaviour. Hierarchical clustering was used to create the dendrograms, where progressively similar observations are joined to form clusters. Pearson's correlation distance was used because Euclidean distance gives equal weight to each variable which can create skewed distances. Ward's method was used, which is generally accepted as an efficient method in dendrogram calculation, however, it can tend to create small clusters (STATSOFT 2009).Dendrograms were generated for the results of both species combined as well as the individual species. *E. largiflorens*, however, makes up fewer than 20% of the total samples and has a low influence on the clustering of elements. With such a low number of sample points, the clusters calculated for *E. largiflorens* are not as reliable as those for *E. camaldulensis*.

3.7.1 VERIFICATION OF DATA

Aluminium, Zr, La, Ce, and Y were used to verify the behaviour of the dataset and reveal any contamination of samples. Aluminium and Zr concentrations are low, indicating contamination by dust or clays were minimal (Dunn 2007). Striping of Al and Zr data in normal probability plots shows that concentrations are close to detection limits, again suggesting contamination levels are low (Steven Hill, University of Adelaide, pers. comm. 2010). Lanthanum, Ce and Y are all rare earth elements and have similar geochemical characteristics (Kabata-Pendias & Pendias 2001) and thus would be expected to be closely associated relative to one another. The dendrograms of elements analysed show these rare

earth elements are closely linked, confirming their similar geochemical characteristics. Following analysis of these five elements, the trends in the remaining data are assumed to be relatively free of detrital contamination and significant sampling errors. **Figures 4 and 5** show spatial association map for Al and Zr, respectively. **Figure 6** shows a dendrogram cluster analysis of 39 elements. Fourteen elements were removed as the data had no variance and could not be included in cluster analysis. The red boxes indicate the association of Zr, Al, and La, Ce, and Y. **Figures 7a and 7b** are normal probability plots of Al and Zr, respectively.

3.8 Elements for Analysis

The ICP-MS analysis conducted returned results for a suite of 53 major and trace elements. It is not practical or necessary to subject all variables to statistical analysis. Elements with no values greater than the analytical detection limit and with fewer than 15% of values above analytical detection limit were removed. For novel research like this, where there are few expectations about which elements will prove useful, care is needed to ensure data that are potentially significant are not discarded. Values below analytical detection limits were changed to half the detection limit for statistical analyses to average out unknown values. A table with all analysed elements, detection limits, units, precision, and reason for inclusion or exclusion from final data analysis is presented in **Appendix 3.**

4. RESULTS

Previous studies on the application of biogeochemistry for mineral exploration (Warren 1984; Ashton & Riese 1989; Hill 2003; Hill & Hill 2003; Hulme & Hill 2003; Hulme *et al.* 2006; Dunn 2007; Reid & Hill 2010) have a predetermined set of some elements that are typically significant in further analysis. In this study, however, there are no such preconceptions. It was not known if the distribution of Na or any other element would be a reliable indicator of salinity in groundwater. This section attempts to summarise the results of the biogeochemical and geophysical surveys and regolith-landform map while justifying the selection of certain elements for more in-depth statistical analysis.

4.1 Comparability of *E. camaldulensis* and *E. largiflorens*

Eucalyptus largiflorens samples were substituted in some areas of the biogeochemical survey when *E. camaldulensis* samples were not available. In order to test the spatial bias of the Na concentration in vegetation and determine if Na levels are comparable between the two species, the Na concentration of adjacent *E. camaldulensis* and *E. largiflorens* were plotted against each other **(Figure 8)**. Only six pairs of adjacent trees were analysed in the survey area. Compared to the total sample size of 83 trees, the population sample for assessing spatial bias is very small, but it allows for a general comparison. The data show a group of points with a positive correlation and one outlier. The outlier was removed from the analysis as the anomalous Na value may be a result of a particular tree accessing especially saline water in what is a very heterogeneous system. The remaining points show a slightly positive correlation between the Na concentrations of *E. camaldulensis* and *E. largiflorens* in similar locations.

4.2 Salinity-related biogeochemistry

Calcium, Co, K, Mo, Ni, and Sr show some similar behaviour to Na in a visual comparison of spatial association maps **(Figures 9-15)**. This group of elements possess similar distribution trends to those of Na. There also appears to be an antagonistic relationship, evident in spatial association plots, between Cu and Na **(Figure 16)**. High Cu concentrations occur where low concentrations of Na are located and vice-versa. **Figures 17a and 17b** show

dendrograms for the 17 target elements in *E. camaldulensis* and *E. largiflorens*, respectively. The cluster analyses show that Na is closest linked to Mo, K, and Cu in *E. camaldulensis* and Mo and Co in *E. largiflorens*.

Probability plots show similar behaviour between Na, K, and Mo, with a visible break in slope at particular concentrations: 0.45% for Na and 0.78% for K. For Mo there is a difference between species; the threshold concentration is 0.08 ppm in *E. camaldulensis* and 0.05 ppm in *E. largiflorens.*

4.3 Other element biogeochemistry

Dendrograms of element associations were also generated, for both species combined, and also separating the two species **(Figure 18)**. Table 3 summarises important element associations in the dendrograms. The results of both species combined is biased, however, as *E. largiflorens* comprises fewer than 20% of the total samples. Some of the trends such as the association of Na and K, P and Ti, and Sr, Ca, and Mg, however, are comparable between the three cluster analyses.

Split population normal probability plots show how different elements tend to favour one species or the other, except for S and Mg which have the same behaviour between both species. **Figures 19-25** show split probability plots for some important elements as an indication of differences in behaviour between species. Plots of other elements are presented in **Appendix 4**. In addition to most elements being preferentially absorbed by one species or the other, most elements also have a break in the slope of the probability plot at a 'threshold concentration'. At this point the slope in most elements increases, with the exception of K. The threshold concentration is different for each of the species, except for Na and K. **Table 4** summarises element behaviour based on normal probability plots and the threshold concentrations for each element.

Nickel and Cd are clustered in the dendrograms of both species but when the species are separated for cluster analysis this relationship breaks down:

- Nickel tends to favour Co in *E. camaldulensis* (linkage distance = 0.4)

- Nickel tends to favour Cd in *E. largiflorens* (linkage distance = 0.6)

Iron is close to detection limit in the probability plots, with striped data. It also has variable associations evident in cluster analysis. In *E. camaldulensis* Fe is associated with U and S, whereas in *E. largiflorens* it is linked with Ni and Cd. Iron has a tendency to be associated with Na in vegetation (Dunn 2007) however there appears to be no such relationship in this set of analyses.

Some gold concentration values in the samples are relatively high (Reid *et al.* 2009; Reid & Hill 2010) for an area not covering known mineralisation, up to 1.5 ppb **(Figure 27)**.Uranium, however, showed very few values above background concentrations (0.01 ppm) **(Figure 28)**. Uranium and S are closely linked in the cluster analysis of both species. Titanium and P have very similar distribution patterns in spatial association maps and are closely linked in both species in the dendrograms. Titanium and P are both expressed more by *E. camaldulensis*, visible in the normal probability plots.

4.4 Regolith-landform map

The regolith-landform map **Appendix 5** shows variations in surface cover as well as slight changes in elevation which will influence where water will flow during inundation. Changes in elevation on a floodplain setting will have a significant impact on the distribution and extent of inundation during flood events and subsequently vegetation growth (Jolly 1996). This section describes the regolith- landform units defined in the study area and features from field observations and the geophysical surveys. Three broad classifications of regolith-landform units are outlined:

- Alluvial landforms
- Aeolian landforms
- Transported regolith

4.4.1 ALLUVIAL LANDFORMS

Some of the alluvial landform units have been grouped together because they were formed during a similar time period. This grouping is shown by brackets in the regolith-landform unit legend. The Aed units, comprised of narrow lenticular channels perpendicular to the Murray River that overprint other alluvial landforms and are thus youngest. This unit is shallow and has water content that fluctuates seasonally. They are often associated with *Eucalyptus camaldulensis* (river red gum) populations along the banks.

The modern Murry River has formed three distinct units – $Acah_1$, $ACah_2$, $ACah_3$. The channel itself, $ACah_1$, is a moderately sinuous meandering channel with low energy, low slope and permanent water that incises marginal marine sediments. Adjacent to the river are recent sandy point bar deposits ($ACah_2$). These are comprised of fine to medium grained light grey-brown sands and silts with sparse *E. camaldulensis* and forbs. The ancient path of the Murray River can be traced through the migrating alluvial point bar deposits ($ACah_3$). This unit is characterised by fine to medium grained light coloured sands with large scale banding of dense *E. camaldulensis*, *Eucalyptus largiflorens* (black box), and *Acacia salicina* (river cooba) corresponding with subsequent point bar deposits.

The prior path of the Murray River can be seen in parts of the $ACah_4$ unit which has been overprinted in parts by $ACah_3$ and recent deposition of transported regolith. This unit is characterised by fine grained sand and silt deposits and, similar to $ACah_3$, large-scale banding of sediments and vegetation. Vegetation in this unit, however, includes moderately dense *E. largiflorens* and dense *Muehlenbeckia florulenta* (lignum). This unit tends to be higher in elevation than alluvial landforms adjacent to the river.

Sandy sediments ($ACah_5$) deposited by ancient alluvial channels have been mostly overprinted by later alluvial landform units but appear in some areas. The deposits are distinguished by dense *E. largiflorens, E. camaldulensis, A. salicina* and slightly darker sediments than surrounding units.

Low-lying floodplain units (Aaf_1, Aaf_2) with dense *M. florulenta* and poorly consolidated light grey sand with salt crusted on the surface are distinguished on their elevation – Aaf_1 is lower than Aaf_2 – leading to slight differences in vegetation distribution. These floodplain units are separated from the alluvial swamp unit (Aaw) by low relief levees (Aea). The levees are characterised by grey silt and sparse *E. largiflorens* with dense *A. salicina* growth. The levees border a very low-lying swamp comprised of an abandoned alluvial channel with permanent water now disconnected from the main river channel. The swamp unit has poorly consolidated light grey silts with minor mudcracks and salt crusted on the surface.

4.4.2 AEOLIAN LANDFORMS

Common throughout the Murray Basin are sandy dunefields, characterised by large-scale (hundreds of metres) longitudinal dunes. In the study area and surrounding irrigation district, much of these dunefields are covered by citrus plantations ($ISps_1$). Some areas are still exposed ($ISps_2$) and are eroded in some areas by minor alluvial channels. The ISu and

ISud units of transported regolith have been overprinted in many areas by more recent alluvial landforms. The areas still present, however, are distinguished on the prominence of large-scale Aeolian landforms – the ISud unit has broadly linear dunes visible on remote imagery whereas the ISu unit does not. Both units are covered by moderately *E. camaldulensis, E. largiflorens,* and *A. salicina* woodlands.

4.4.3 TRANSPORTED REGOLITH

As previously mentioned, there is very little change in elevation over the floodplain except for a narrow unit (Teu) with steep slopes characterised by sparse vegetation, exposing the weathered sequences of the Woorinen, Blanchetown, and Loxton-Parilla formations.

Over the floodplain, elevation does not vary by more than about 2 m until the break in slope in the Teu regolith unit, where the elevation rises 20-25 m. Levees (Adl regolith unit) cause the further build up of salt on low-lying areas, reducing drainage and allowing water to stagnate and evaporate. Field observations revealed how *E. largiflorens* communities tend to be established on higher areas, whereas *E. camaldulensis* tends to grow in areas subject to permanent or regular water, for example, the lenticular channels radiating away from the Murray River (Aed unit). These channels also show as areas of very high conductivity on the EM31 survey. The AEM survey shows zones of high conductivity in the east of the floodplain where regions of elevated conductivity continue into the river. Zones of high conductivity in the AEM survey in the centre of the floodplain correspond with low-lying RLUs, for example Adl and Aaf units, where water does not readily drain away.

4.5 Groundwater analyses

The groundwater analyses, along with the geophysical surveys, allow for further interpretation of salinity patterns and movement. They how quickly salinity levels change vertically whereas the geophysical data is better suited to show rapid lateral changes in conductivity. The time series salinity measurements also show how quickly the salt content of groundwater responds to fresh water influx. Groundwater monitoring of transect three shows low conductivity (salinity), below 1000 EC, in the top 3 m of the groundwater profile adjacent to the river quickly reaching more than 50,000 EC with depth. Ninety metres away from the river, the groundwater profile is more saline, with conductivities in excess of 50,000 EC. Correlation analysis by the DWLBC between groundwater analyses and

geophysics in the area (Berens *et al.* 2009b) show that the EM31 and NanoTEM methods accurately represent lateral and vertical changes in conductivity in the subsurface.

4.6 Geophysical surveys

4.6.1 AEM

Figures 29 and 30 present the results of the AEM survey at two depths (4.20 – 6.62 m and 6.62 – 9.30 m, respectively) overlying a LANDSAT image of the study area.

The AEM survey shows regional trends in conductivity variations. The areas of highest conductivity lie in the centre and towards the rear of the floodplain and are generally higher at lower depths. A feature of interest, particularly in the deeper conductivity data, is a region in the eastern side of the floodplain. Here the high conductivity continues into the river instead of being cut-off at the river margins, as is observable in other areas of the floodplain.

4.6.2 NANOTEM

Figures 31 and 32 present the results of the NanoTEM survey. Figure 31 shows the inverted data and Figure 32 shows the inverted data with a low-pass filter applied to smooth out changes in conductivity.

The in-stream NanoTEM data shows variations in conductivity in river sediments over hundreds of metres. The raw data were plotted in ArcGIS as XY point data. Conductivity ranges were determined using the natural breaks (Jenks) classification. A five-, eleven-, and twenty one-cell moving average, or low pass, filter was applied to values to smooth out heterogeneities. Only the original data values and five-cell filter are shown here as the higher order filters significantly displaced and over-simplified changes in conductivity. **Appendix 6** shows the results of the eleven- and twenty-one-cell filters. Generally, peaks in conductivity occur where the meanders of the river cut into the floodplain, when the channel is closest to regions of high conductivity inland; lows occur when the river is furthest away from the centre of the floodplain.

4.6.3 EM31

Figure 33 shows the results of the EM31 survey overlying a LANDSAT image of the area. An inset shows the position of the survey in the study area.

The EM31 survey shows small-scale variations in soil and water conductivity across tens of metres, adjacent to the river and to a depth of 4-6 m (Berens *et al.* 2009b). Features of interest include strips of high conductivity radiating away from the channel margins and the patchiness of conductivity at the smaller scale when compared to the regional data. Variations in conductivity in the EM31 survey data appear to line up closely with highs and lows of conductivity in the regional AEM survey, at 2.0-4.2 m depth. The AEM survey at 2.00 – 4.20 m depth is presented in **Appendix 7**.

4.7 Comparison of biogeochemistry, regolith-landform map and geophysics

4.7.1 BIOGEOCHEMISTRY, EM31 AND REGOLITH-LANDFORM MAP RELATIONSHIPS

Both the EM31 data and biogeochemistry data have large variations in magnitude over short distances, not visible in the larger NanoTEM and AEM surveys. The EM31data shows strips of high conductivity material perpendicular to the Murray River which correspond with the Aed regolith-landform unit. **Figure 34** presents the regolith-landform map compared to the EM31 survey.

4.7.2 EM31 AND NANOTEM CONDUCTIVITY VS ELEMENT CONCENTRATION (CLASSIFIED APPROACH)

To graphically represent the degree of correlation between the geophysical surveys and the biogeochemical survey, a plot of conductivity against Na concentration was generated; **Appendix 8** presents the classification map used to plot Na concentration against conductivity.

The plot essentially 'grids' the data and does not show any obvious trends **(Figures 35a, 35b & 36a, 36b)**. This has been attributed to artefacts derived from the classification of data. In plotting classified data against each other, artefacts and anomalies created by the classification method are magnified resulting in little or no observable correlation between data. Although natural breaks classification and geometrical interval are useful classification methods for the data, they do not completely represent the distribution of the data (ESRI

2007). Further, matching discrete sample points to particular regions on conductivity was done by matching the centre of each data point to the most dominant conductivity classification in that area for the EM31 survey; a straight-line method was used for the NanoTEM survey. This way of allocating sample points to a specific area of land does not account for the complexity of the hydrogeological system and how the vegetation interacts with the subsurface.

4.7.3 NANOTEM CONDUCTIVITY VS ELEMENT CONCENTRATION (DOWNSTREAM DISTANCE APPROACH)

Another test for spatial bias was plotting Na concentration and conductivity from the NanoTEM survey against downstream distance **(Figure 37)**. Element concentrations are plotted as points because the data are from discrete sample points, whereas the geophysical data are plotted as a continuous data series. This curve is inserted over the concentration data as a curve of comparison, showing the relative variation in conductivity. The plot shows association between the NanoTEM (instream) conductivity variations and the behaviour of Na, Mo, Cd, Mn, Ni, Ca, and Zn **(Figures 38-43)**. Molybdenum and Cd follow the general trends of the conductivity curve with corresponding peaks. Sodium has some distinct peaks corresponding with conductivity peaks but has a poor signal-to-noise ratio. Nickel, Zn, and Mn also demonstrate some similarities to conductivity but tend to have signatures with very poor signal-to-noise ratios. In addition, these elements appear to have peaks in concentration between 4000-5000 m, where conductivity is low. There is only a marginal association with Co, Cu, Fe, P, S, and Ti. Both Co and Cu show some trends correlating with conductivity but the relationship is tenuous; these elements also have outliers that can mask important features. **Appendix 9** presents conductivity vs concentration plots of elements not presented in the figures.

4.7.4 BIOGEOCHEMISTRY, REGOLITH-LANDFORM MAP, AND AEM RELATIONSHIPS

The scale of the AEM survey is generally too broad to reliably compare the results with the biogeochemical data. The regolith-landform map and AEM survey are similar in scale, however, and thus visually comparable. **Figures 44 and 45** present a comparison of the regolith-landform map and both depths of the AEM survey. The large area of high conductivity in the AEM survey extending out from the floodplain in the eastern area of the

floodplain corresponds with the $ACah_4$ unit. Likewise, much of the high conductivity areas in the AEM survey correspond with the $ACah_4$ unit as well as the floodplain units.

5. DISCUSSION

There are several assumptions made in the analysis of the data. First, it is assumed that changes in conductivity in geophysical data are directly proportional to changes in the salinity of soil and groundwater. Second, it is assumed that most of the salt in the floodplain is NaCl. Chlorine was not measured in the biogeochemical survey because halogens are difficult to detect using ICP-MS due to spectroscopic interferences (Wolf 2005). Its analysis could prove to be an interesting extension of this research. The biogeochemical signatures of La, Ce, and Y – rare earth elements – are very similar, as expected (Dunn 2007). Further, concentrations of Al and Zr are low indicating low dust contamination. It is thus assumed the data from other elements is a true reflection of the concentration of elements absorbed by the vegetation with minimal spurious results. Elements comprising the chemical signature of vegetation in this study area may have come from the groundwater, transported regolith materials (Reid & Hill 2010) or the influx of solutes during flood events. It is assumed that groundwater is the main water source for vegetation in the study area.

5.1 Comparison between species

The geobotanical distribution of the two *Eucalyptus* species shows how important landscape setting is in influencing vegetation and groundwater movement. Results suggest both *E. largiflorens* and *E. camaldulensis* are useful as environmental monitoring sample media. Field observations show that *E. largiflorens* tends to grow on more elevated areas than *E. camaldulensis*. Due to this difference in landscape setting, it is more likely that differences in the biogeochemical signature between the species is more closely related to the pattern of salinity in the landscape rather than differences in salt tolerance or expression of the two species. In addition, the low sample population of *E. largiflorens* (less than 20% of samples) makes it difficult to draw conclusions about the activity of this species.

Split probability plots, however, show distinct differences in element concentrations between species. Although not normally distributed, the change in slope of the data shows a shift in distribution of elements. The change in slope in most of the probability curves is thought to correspond with a shift in element-vegetation interaction in response to high salinity or other groundwater conditions, hence the term 'threshold concentration'. Only Na and K have approximately the same threshold concentration values (0.45% and 0.78%,

respectively) however at 0.78% the slope of K flattens out. This is probably due to Na blocking further uptake of K (Dunn 2007). The values of Na, Mo, and K above the threshold concentrations represent the concentration at which absorption patterns of elements in vegetation changes, potentially in response the high salinity levels. These concentrations are used as threshold concentrations in the proposed salinity index. High values of Mo also correspond with the higher concentration of Na and K in spatial association plots. Sodium, K, and Mo are expressed more strongly by *E. largiflorens*; however, the distribution of *E. largiflorens* is strongly spatially dependent, as shown in the regolith-landform map. The preference of Na, Mo, and K for *E. largiflorens* is thus probably driven by salinity distribution so that the differences observed between species are thus due to the location of highly saline areas rather than a particular species absorbing more Na, K, or Mo **(Figures 9, 12 & 13).**

The data from the test of spatial bias demonstrate that an equivalent relationship between the *E. largiflorens* and *E. camaldulensis* concentrations is approximate. A 1:1 line has been added to the plot as a reference for a perfect equivalent relationship. The relationship here is not perfect due to differences between the setting of individual trees and that adjacent trees are up to 100 m away from each other rather than exactly the same location. Generally it suggests the two species are comparable but *E. camaldulensis* tends to pick up slightly more Na than *E. largiflorens*, again suggesting the trend of *E. largiflorens* absorbing more Na, Mo, and K is spatially driven.

5.2 Salinity related biogeochemistry

There are few elements that consistently show patterns proportional to salinity changes in the landscape. Sodium, K, and Mo have been identified as elements that work best as pathfinder elements for salinity in a biogeochemical survey. The variable behaviour of major and trace elements, particularly metals, makes it difficult to draw conclusions about the usefulness of some elements in detecting and monitoring salinity. A stronger influence than Na on the mobilisation of these metals is pH. Such elements may thus be useful in monitoring the movement of harmful metals through groundwater and acid sulphate regolith (ASR).

 To detect salinity problems, the most useful elements were, as expected, Na, also K, and surprisingly, Mo. Although K and Na often behave similarly, for example substituting for each

other in mineral structures, their different biochemical roles mean their biogeochemical signatures do not necessarily correlate. Potassium is, however, linked to Na and Mo in the dendrograms and possesses a similar trend in concentration variation to that of Mo in the spatial association maps thus making it indicative of excess salinity in groundwater. The role of Mo is potentially due to a physiological response by plants to high salinity involving nitrogen fixation or other reaction catalysed by Mo (Marston 1952; Nicholas *et al.* 1954). Unlike Na, Mo shows fewer significant changes in concentration over small distances and its distribution and movement in groundwater and soil may be influenced less by changes in landforms and regolith. Molybdenum is highly mobile in soils and is not significantly influenced by changes in pH its indication of salinity is not influenced by changes in pH like the signature of Na. Patterns of Na distribution in the biogeochemical results may be influenced by a physiological response of vegetation to high concentrations of Na rather than a direct reflection of soil concentrations.

 Iron and Na are often associated with vegetation (Kabata-Pendias & Pendias 2001) but neither spatial plots or dendrograms show any significant link between these two elements. This could be due to high Na concentrations in the area masking any relationship with Fe. Sulphur does not correlate significantly with Na, Mo, or K in the biogeochemistry or with conductivity levels in the geophysical surveys suggesting sulphur compounds are not significant contributors to the salt load in this system. The concentration of Cd, Mn, Ni, Ca, and Zn corresponds with conductivity variations; however these elements only show marginal relationships with Na and Mo in spatial association maps and are thus not completely reliable as salinity pathfinder elements.

5.3 Other element biogeochemistry

There are several anomalous gold values detected, however, given the poor accuracy of measuring gold, significant seasonal variations in concentrations in vegetation, as well as the tendency for gold to form 'phyto-nuggets' in leaves, the area would have to be re-sampled to see if the gold anomalies are repeatable (Ashton & Riese 1989; Reid *et al.* 2009; Reid & Hill 2010). Titanium anomalies can be indicative of sample contamination from dust (Dunn 2007) but at Clark's Floodplain peaks could be from large heavy mineral deposits in the Loxton-Parilla Sands (Lukasik & James 1998). It is unclear why Ti and P are so closely linked in both species however P may be contained in irrigation recharge, which forms the

groundwater mound above the Loxton-Parilla Sands (Thompson & Barnett 2009), combining with Ti in the heavy minerals.

There are a number of elements that are mobilised and made available for plant uptake in low pH conditions, including Cu, Mn, Fe, Sr, and Al, and to a lesser extent, Cd, Co, and Zn. These elements could be combined to form a suite of pathfinder elements for acidic subsurface conditions. Copper, for example, is generally quite soluble but becomes even more soluble in low pH conditions (Kabata-Pendias & Pendias 2001) making Cu a good indicator of low pH. Likewise, Fe, Mn, Sr, and Al are readily available for plant absorption in low pH conditions (Kabata-Pendias & Pendias 2001; Dunn 2007). Cadmium is most mobile between pH 4.5-5.5 while Zn is less soluble in acidic conditions than Cd. A detailed biogeochemical survey and pH analysis would be able to establish whether the relationship between the solubility of Cd and Zn and pH is directly reflected in the vegetation, again providing potential pathfinder elements for ASR. Aluminium and Zn, however, tend to be indicators of airborne dust contamination of vegetation samples and thus in biogeochemistry could have misleading values.

Uranium is unique in its chemical behaviour. Unlike many other metals, it is immobilised by low pH soils and chemically reduced conditions (Dunn 2007)and when compared with species that are highly mobile in acidic and chemically reduced soils, it may be a useful indicator of redox controlled acidic soils. Uranium concentrations expressed in vegetation in the study area, however, were very low. This suggests that the low pH of the soils has made U unavailable for vegetation uptake or U is not present. It is difficult to assess the usefulness of these species for monitoring ASR without extensive pH and further vegetation sampling; however, it appears to be a promising area for further research.

5.4 Regolith-landform map

The regolith-landform map reveals the morphological evolution of the Murray River and Clark's Floodplain. The river overprints ancient aeolian landforms. It is useful in delineating medium scale trends in the landscape and how it influences the results of the geophysical and biogeochemical data.

5.5 Groundwater analyses

The agreement between prior analyses (Berens *et al.* 2009b) and the geophysical and biogeochemical data demonstrates the usefulness of a multi-disciplinary approach to understanding a complex, heterogeneous system like Clark's Floodplain. The groundwater analyses also show that the geophysics is accurate in its representation of subsurface conductivity and that these variations are proportional to salinity variations thereby showing that the conductivity is proportional to salinity.

5.6 Correlation between biogeochemistry, regolith-landform map and geophysics

Studies integrating regolith-landform mapping with biogeochemistry surveys and other datasets have demonstrated the usefulness of such an integrated and multidisciplinary approach to delineate the influence of regolith and landform features on the residence and movement of chemical elements through the landscape (Hill 2002b; Brown & Hill 2004). Regolith-landform maps and biogeochemistry surveys are well suited to accompany one another for data interpretation and compilation, and can reveal relationships that would otherwise be missed by a purely quantitative analysis. In this analysis comparisons have been made between biogeochemical data and geophysical data at three scales – large, medium, and small.

5.6.1 AEM

The AEM shows regional trends in conductivity relating to variations in groundwater salinity at different depths. The areas of highest conductivity for both depths are located in the middle and towards the rear of the floodplains. The most rapid changes in conductivity over distance occur at the western meander and on the eastern margin of the study area. Conductivity also slightly increases with depth in the top 9 m in this area. In analysis of results, the regolith-landform map has been compared with the AEM survey data to show potential links between landforms and salinity **(Figure 44)**. The highest areas of conductivity correspond with the ACah$_4$ RLU and also the floodplain units suggesting these units contain highly saline groundwater. Studies integrating regolith-landform mapping with biogeochemistry surveys and other datasets have demonstrated the usefulness of such a multidisciplinary approach to delineate the influence of regolith and landform features on

the residence and movement of chemical elements through the landscape (Brown & Hill 2004). Regolith-landform maps and biogeochemistry surveys are well suited to supplement one another for data interpretation and compilation and can reveal relationships that would otherwise be missed by a purely quantitative analysis.

5.6.2 NanoTEM

The NanoTEM data shows that the areas with the highest salinity levels occur in association with the channel meanders. This is consistent with floodplain processes where the channel cuts into the floodplain, shortening the flow path of the groundwater resulting in discharge of saline groundwater (Doble *et al.* 2004). It is also consistent with the AEM survey; however, conductivity appears higher at the margins than in the AEM image. This may be due to the NanoTEM showing the gain of saline groundwater through the base of the river and immediately adjacent to the banks which AEM cannot show. Areas of the floodplain with high conductivity correspond with regions of high in-stream conductivity (Munday *et al.* 2006). Gaining sections of the river in the NanoTEM and AEM data correspond with the trend of peaks in Na and Mo.

From the plot of Na concentration and NanoTEM (instream) conductivity against downstream distance, Na shows a very erratic distribution when compared with the signature of Mo, which is much more subdued. This is partly due to Mo having a number of values close to the analytical detection limit. Both elements correspond well with peaks in conductivity of the in-river data, however, the pattern of Mo contains less "noise" (small-scale, irregular variability) compared to Na, and thus may be a more appropriate measure of high salinity. This plot is a particularly useful measure of the correlation between conductivity and biogeochemistry due to the strong spatial dependence of both salinity distribution and other elements. The biogeochemical data do not fit the geophysical data perfectly due to the differences between discrete and continuous datasets. The spatial resolution of both surveys has contributed to discrepancies between the datasets. In spite of this, however, it does reveal relationships otherwise not visible.

5.6.3 EM31

The EM31 survey data is particularly good at showing the small-scale variations in conductivity that the NanoTEM and AEM surveys cannot. In the study area, salinity has been interpreted as being the main contributor to conductivity changes (Berens *et al.* 2009b). Samples containing high Na levels do not appear to closely follow the patterns of

conductivity in the EM31 survey, however, the survey was collected two and a half years before vegetation samples were collected and so the position of high conductivity and high salinity may have shifted over time. Given, however, that the highest regions of conductivity in the survey correspond with lenticular channels in the floodplain, perpendicular to the river, it is unlikely that these zones of high salinity would have shifted significantly in the time between the survey data being collected and vegetation samples being taken. The EM31 survey does show, however, that conductivity levels can change significantly over short distances. This is not expressed in the larger-scale conductivity data and may show why some samples, although close together, show large variations in Na, K, and Mo concentrations.

There are some discrepancies between conductivity levels in the three geophysical datasets and subsequently in comparison with the biogeochemical data. These differences are probably caused by large differences in resolution of the geophysical surveys. Discrepancies may also be from differences in substrate, for example river sediments compared with floodplain sediments. Differences also exist in the magnitude of values between the methods, and this may be from the differences in spatial coverage of each of the surveys (Fitzpatrick *et al.* 2006). To minimise this, a continuous scale of low-high conductivity is used thus showing the relative changes in conductivity in the data.

5.7 Quantifying risk

This section integrates results of the biogeochemical survey, regolith-landform observations, and previous work on floodplain salinity to propose an index of salinity risk, termed the Floodplain Salinity Risk Index (FSR Index). It outlines previous models and the proposed index based on models by Slavich *et al.* (1999a; 1999b) that simulate movement of salt through the soil profile. The approach also draws on elements of the classification system of soil types developed by PIRSA in agricultural regions of South Australia (Maschmedt 2002; PIRSA Soil and Land Information Group 2002).

The WAVES model (Slavich *et al.* 1999b) is a dynamic simulation that functions under transient conditions with daily fluctuations in groundwater level, also incorporating changes in climate, water use by vegetation, as well as flood frequency and duration. The model is used in simulating plant growth and health with changing water table levels and flooding frequencies, assessing the effectiveness of altered flow regimes on floodplains. WAVES is a

detailed model but it is limited by its complexity. Calibration of growth-related parameters is required for different vegetation types and can lead to error.

A simplified version of the WAVES model is the WINDS model (Slavich *et al.* 1999a). It is static and does not take changing groundwater levels into account. The model is calculated using groundwater discharge rates, soil salinity, and soil water availability. It is limited, however, by not accounting for fluctuating groundwater levels during flood events. To model changes in groundwater levels in response to flooding however, would be prohibitively complex for the index in this study. Both WINDS and the FSR index assume that groundwater is the only source of water for the trees and all three models can be incorporated into a GIS for ease of presentation and assessing management options. The index proposed in this study places less emphasis on vegetation health with the aim of identifying areas of risk before vegetation health begins to decline.

Salinisation of floodplain soils and groundwater is caused by capillary rise and accumulation of salts from groundwater due to high water tables and low flooding frequency. The index proposed reflects the impact of these factors on the salinity levels of floodplain groundwater and soils. It uses five 'key factors' to quantify the risk of salinisation to a particular region:

1. Frequency of medium to large scale floods (>60 GL/day)

2. Depth to the water table

3. Concentration of Na in vegetation

4. Concentration of K in vegetation

5. Concentration of Mo in vegetation

The FSR index uses the scaling criteria outlined in **Table 5**.

The approach is a simplified model of what is a complex and heterogeneous natural system, given the temporal and spatial limitations of this study; it is intended to be applicable throughout the Murray Basin, be readily applied and understood by parties with little specialist knowledge of hydrogeology or chemistry, and to be adaptable for use in conjunction with other risk indices. The FSR index assumes:

• Flooding of the area leaches solutes from the soil/surface

• There is a threshold concentration of Na, K, and Mo that vegetation will tolerate

- Groundwater level does not fluctuate significantly over the unit being assessed

- Floodplain being assessed is a homogenous system where soil properties are generally uniform with depth

The FSR Index has generalised implications for floodplain management and is intended to be used as a preliminary assessment to prioritise management and further investigations. The index demonstrates the importance of a multi-disciplinary approach to salinity detection and risk assessment.

This set of risk factors is a simple way to determine if a particular area is at risk of excessive salinisation. Given the temporal and spatial limits of this study, this approach incorporates five key factors that indicate excessive salinity. Characteristics of a particular area to also consider include landscapes with low topographic relief and areas with high sediment conductivity. The lag between elevated Na, K, and Mo levels in vegetation and a visual decline in tree health is not known. It is possible that concentrations will increase to a certain level before the salt tolerance threshold is reached. Only Na, K, and Mo are used in the index for two reasons. First, it is simpler than trying to incorporate five or ten elements and second, the correlation with other elements is less certain at this stage and needs to be refined further.

The index proposed here is limited in its applications as it is a static model. A dynamic model is not possible to develop within the temporal limitations of this project. In addition such a model would be too complex to be applied by those without specialised understanding of such processes.

5.8 Approach for further research

Given the success of this project as a proof of concept exploration of the uses of biogeochemistry, a three-fold approach to further research is proposed. The approach includes:

1. Temporal study

This would define the time lag between a change in groundwater chemistry and the subsequent chemical expression in vegetation to further refine biogeochemistry as an on-going environmental monitoring technique.

2. Calibration study

 This study would use vegetation not under severe stress from influences such as drought or high salinity, to define element interactions and distinguish the physiological response of vegetation to environmental hazards from water chemistry.

3. Other hazards

 This study would apply biogeochemistry to assess other groundwater hazards, such as ASR and contaminated groundwater.

6. CONCLUSION

 This study has shown that biogeochemistry is a viable option for monitoring of groundwater quality, particularly salinity, but also it requires further research and refinement of the technique. Specifically it demonstrated that Na, K, and Mo are indicators of high salinity in groundwater in *Eucalyptus camaldulensis* and *Eucalyptus largiflorens* and other elements have potential as indicators of acid sulphate regolith. In addition, the study also defined a salinity risk index for floodplain salinisation based on key factors identified from previous studies and the results of the biogeochemistry survey. The study is limited, however, by the short length of time of the research with studies to further refine the technique required.

 The study area and project demonstrates the complex relationship between vegetation, individual vegetation species, hydrogeology, chemistry, and landforms of an area and how this affects salinity and groundwater quality and interpretations of monitoring data. The project further demonstrates the applications of biogeochemistry, not just in mineral exploration, but also in environmental management.

7. ACKNOWLEDGEMENTS

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9. FIGURE CAPTIONS

Figure 1: Location of the study area at Clark's Floodplain, Bookpurnong, South Australia (Source: Murray-Darling Basin Authority).

Figure 2: Schematic of the geology and hydrogeology of the study area (Modified from Thompson and Barnett 2009).

Figure 3: Biogeochemistry sample locations, showing the distribution of *Eucalyptus camaldulensis* (river red gum) and *Eucalyptus largiflorens* (black box).

Figure 4: Spatial association map of Al.

Figure 5: Spatial association map of Zr.

Figure 6: Dendrogram for all analysed elements. Elements with no variance (14 out of 53 elements) were removed from the cluster analysis. The red box shows the clustering of the rare earth elements and Zr and Al.

Figure 7a: Normal probability plot of Al.

Figure 7b: Normal probability plot of Zr.

Figure 8: Plot of the sodium concentration of adjacent *Eucalyptus camaldulensis* and *Eucalyptus largiflorens* trees. The orange line is a 1:1 reference line for a perfect correlation. The blue ellipse highlights the general trend of the data.

Figure 9: Spatial association map of Na distribution in vegetation. Concentration cut-offs were defined using the geometrical interval classification method.

Figure 10: Spatial association map of Ca distribution in vegetation. Concentration cut-offs were defined using the geometrical interval classification method.

Figure 11: Spatial association map of Co distribution in vegetation. Concentration cut-offs were defined using the geometrical interval classification method.

Figure 12: Spatial association map of K distribution in vegetation. Concentration cut-offs were defined using the geometrical interval classification method.

Figure 13: Spatial association map of Mo distribution in vegetation. Concentration cut-offs were defined using the geometrical interval classification method.

Figure 14: Spatial association map of Ni distribution in vegetation. Concentration cut-offs were defined using the geometrical interval classification method.

Figure15: Spatial association map of Sr distribution in vegetation. Concentration cut-offs were defined using the geometrical interval classification method.

Figure 16: Spatial association map of Cu distribution in vegetation. Concentration cut-offs were defined using the geometrical interval classification method.

Figure 17a: Dendrogram of element clustering in *E. camaldulensis.* Analysis used Ward's method and Pearson's correlation linkage distance. Values below detection limit were set to half detection limit.

Figure 17b: Dendrogram of element clustering in *E. largiflorens*. Analysis used Ward's method and Pearson's correlation linkage distance. Values below detection limit were set to half detection limit.

Figure 18: Dendrogram of element clustering in for both species combined. Analysis used Ward's method and Pearson's correlation linkage distance. Values below detection limit were set to half detection limit.

Figure 19: Split population normal probability plot of Ca. Values below detection limit were changed to half the detection limit.

Figure 20: Split population normal probability plot of Co. Values below detection limit were changed to half the detection limit.

Figure 21: Split population normal probability plot of Cu. Values below detection limit were changed to half the detection limit.

Figure 22: Split population normal probability plot of Mo. Values below detection limit were changed to half the detection limit.

Figure 23: Split population normal probability plot of Ni. Values below detection limit were changed to half the detection limit.

Figure 24: Split population normal probability plot of Sr. Values below detection limit were changed to half the detection limit.

Figure 25: Split population normal probability plot of K. Values below detection limit were changed to half the detection limit.

Figure 26: Split population normal probability plot of Na. Values below detection limit were changed to half the detection limit.

Figure 27: Spatial association map of Au distribution in vegetation. Concentration cut-offs were defined using the geometrical interval classification method.

Figure 28: Spatial association map of U distribution in vegetation. Concentration cut-offs were defined using the geometrical interval classification method.

Figure 29: RESOLVE AEM geophysical survey, 4.20-6.62 m depth.

Figure 30: RESOLVE AEM geophysical survey, 6.62-9.30 m depth.

Figure 31: NanoTEM instream conductivity survey results. Inverted data.

10. FIGURES

Figure 1

Figure 2

Figure 6

Dendrogram for 39 Variables
E. camaldulensis and *E. largiflorens*
Ward's method
1-Pearson r
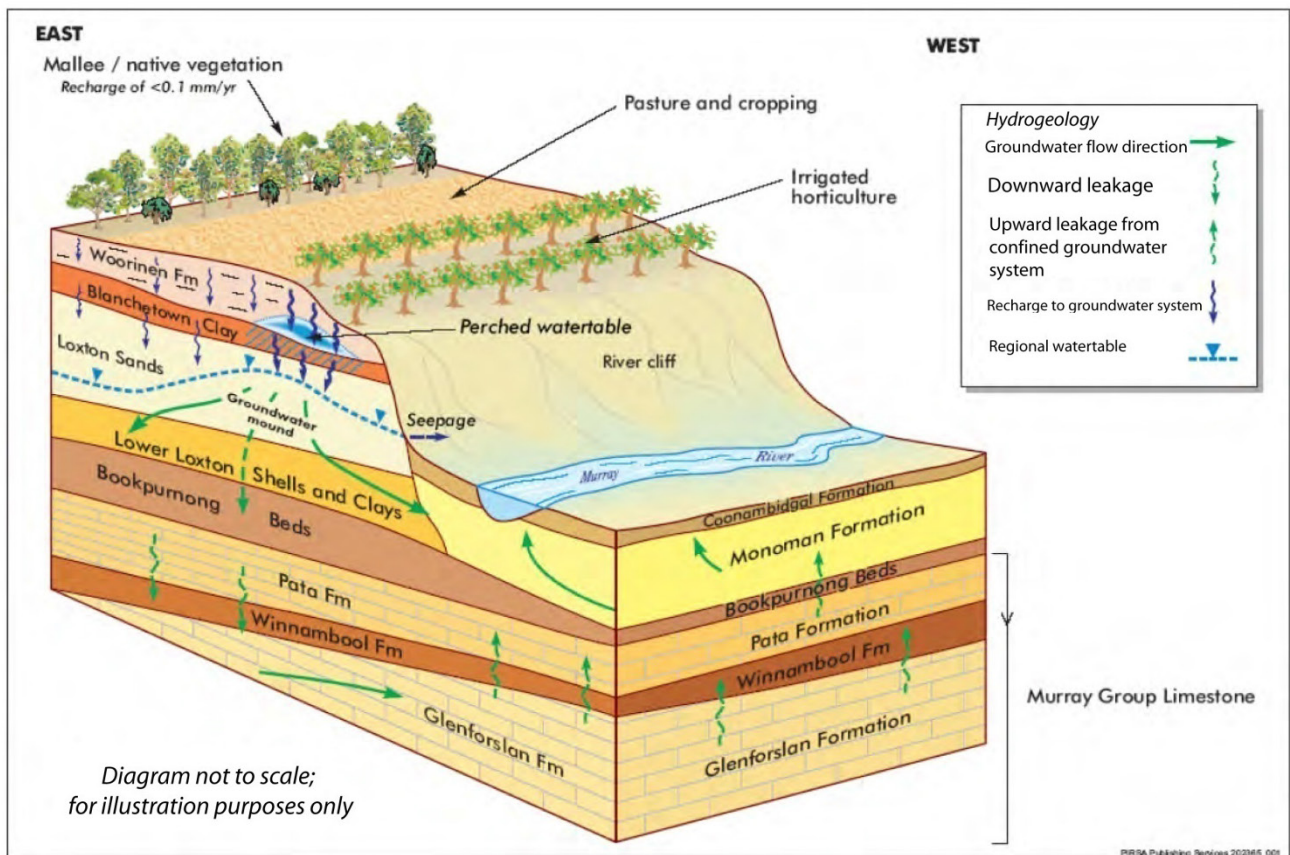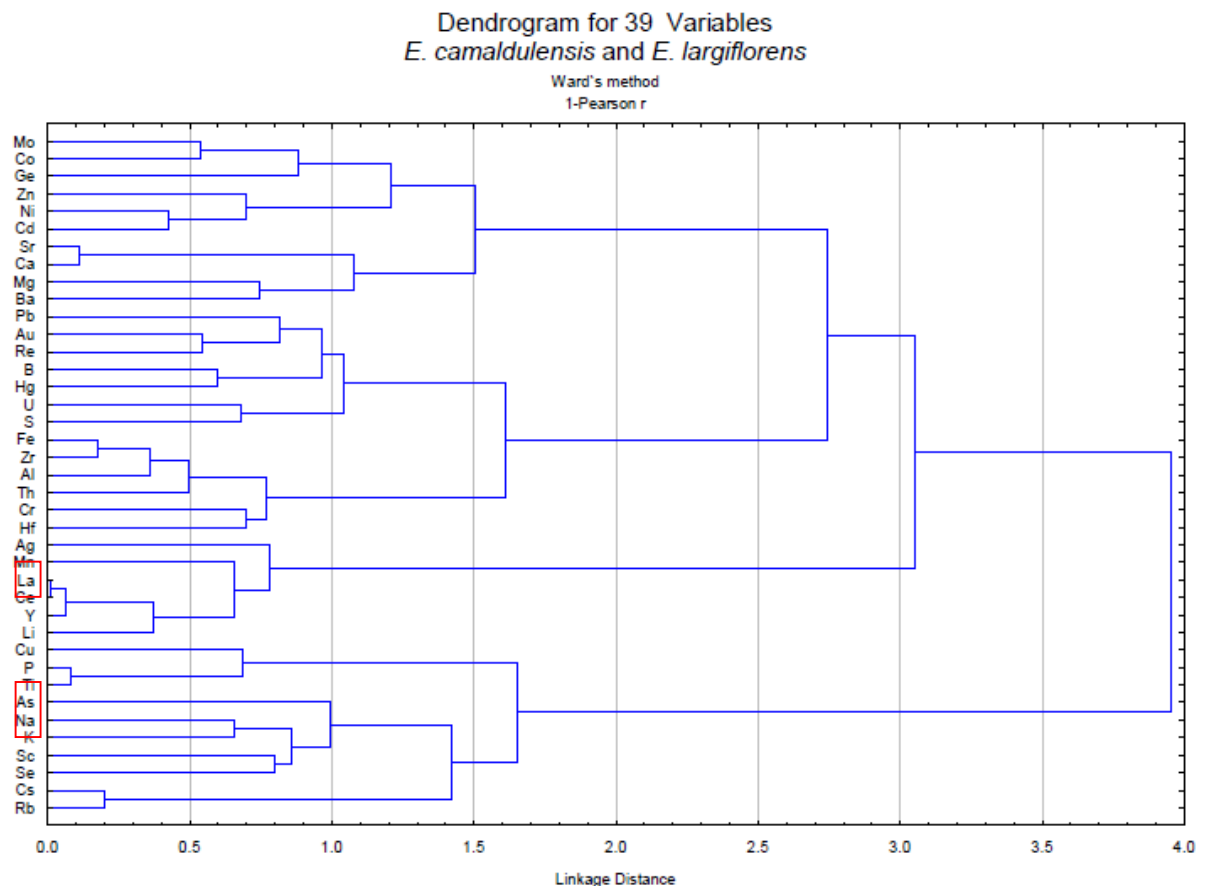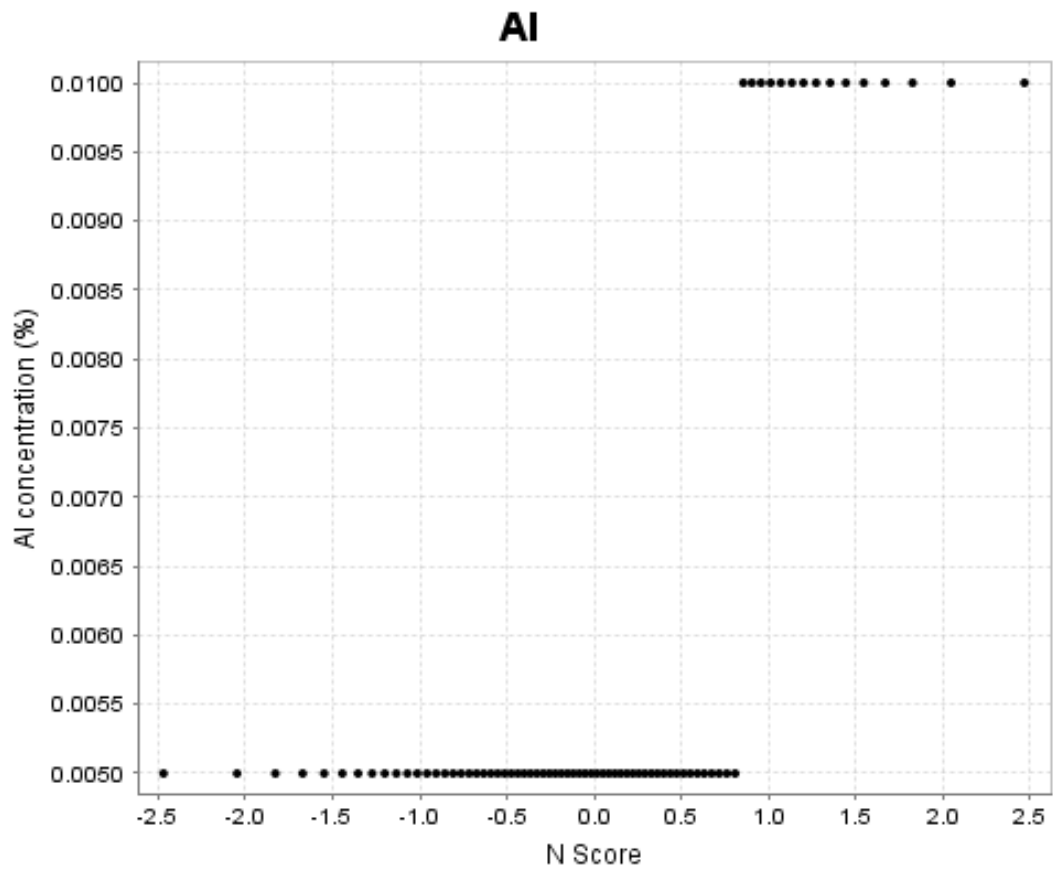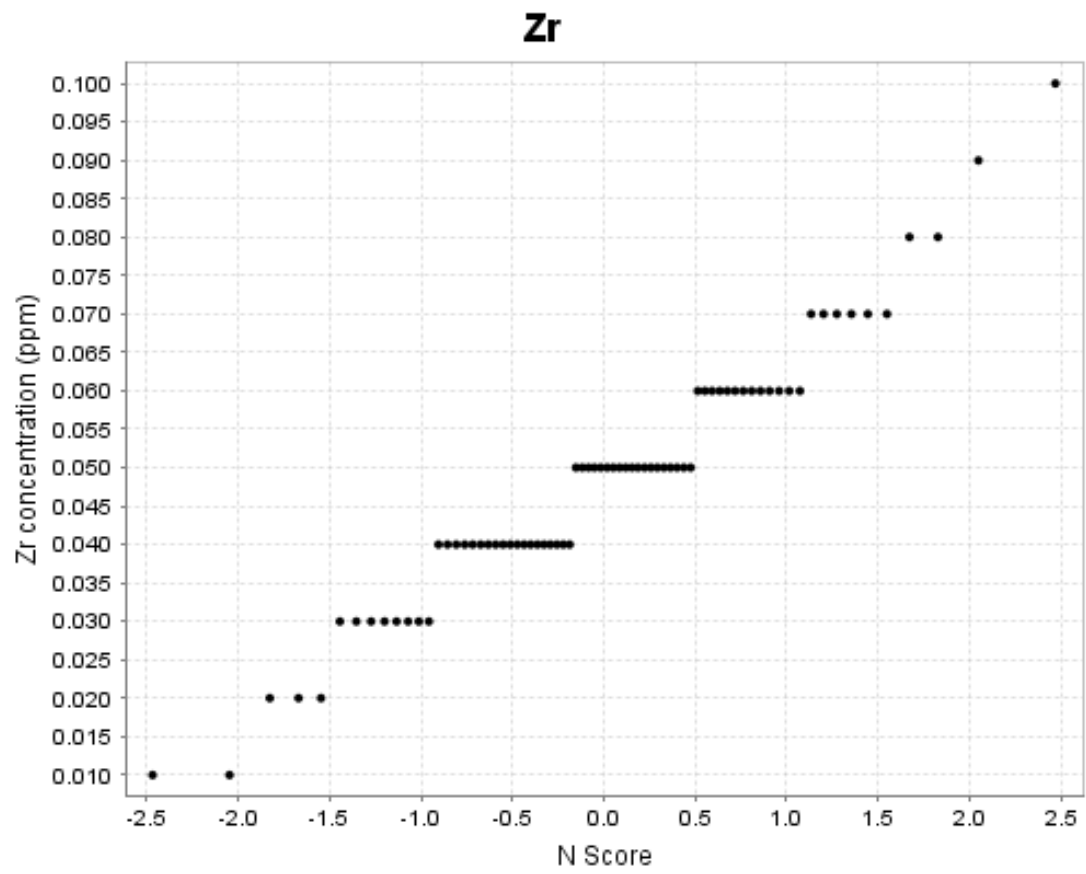
Figure 7a

Figure 7b

Figure 8
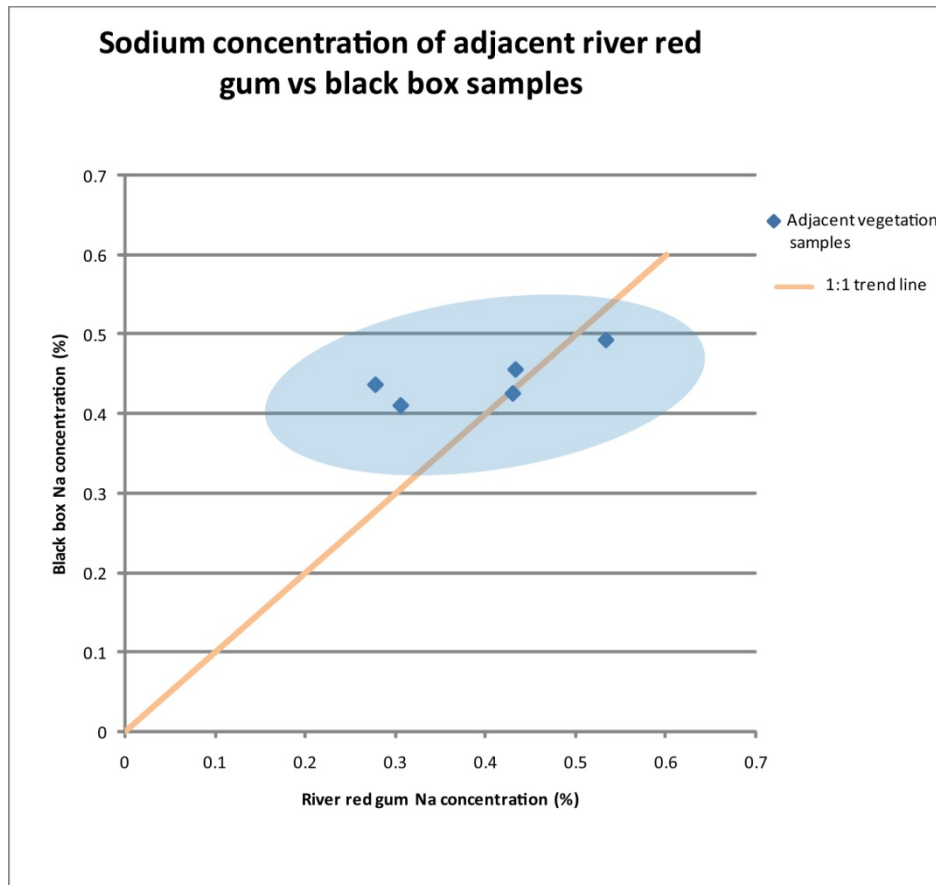
Figure 3

Location of biogeochemistry survey vegetation samples
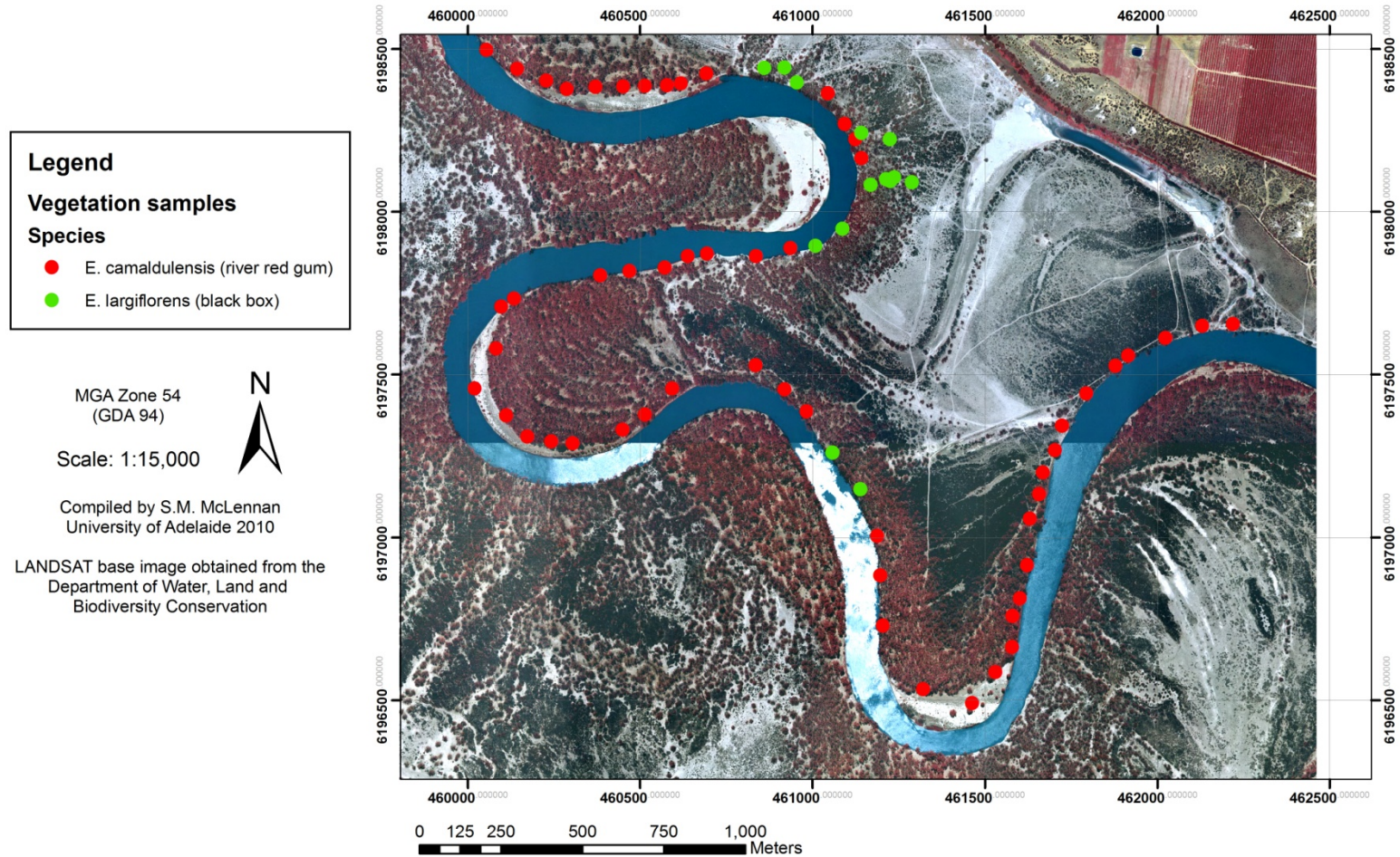
Figure 4

Spatial Association Map of Biogeochemical Element Distribution
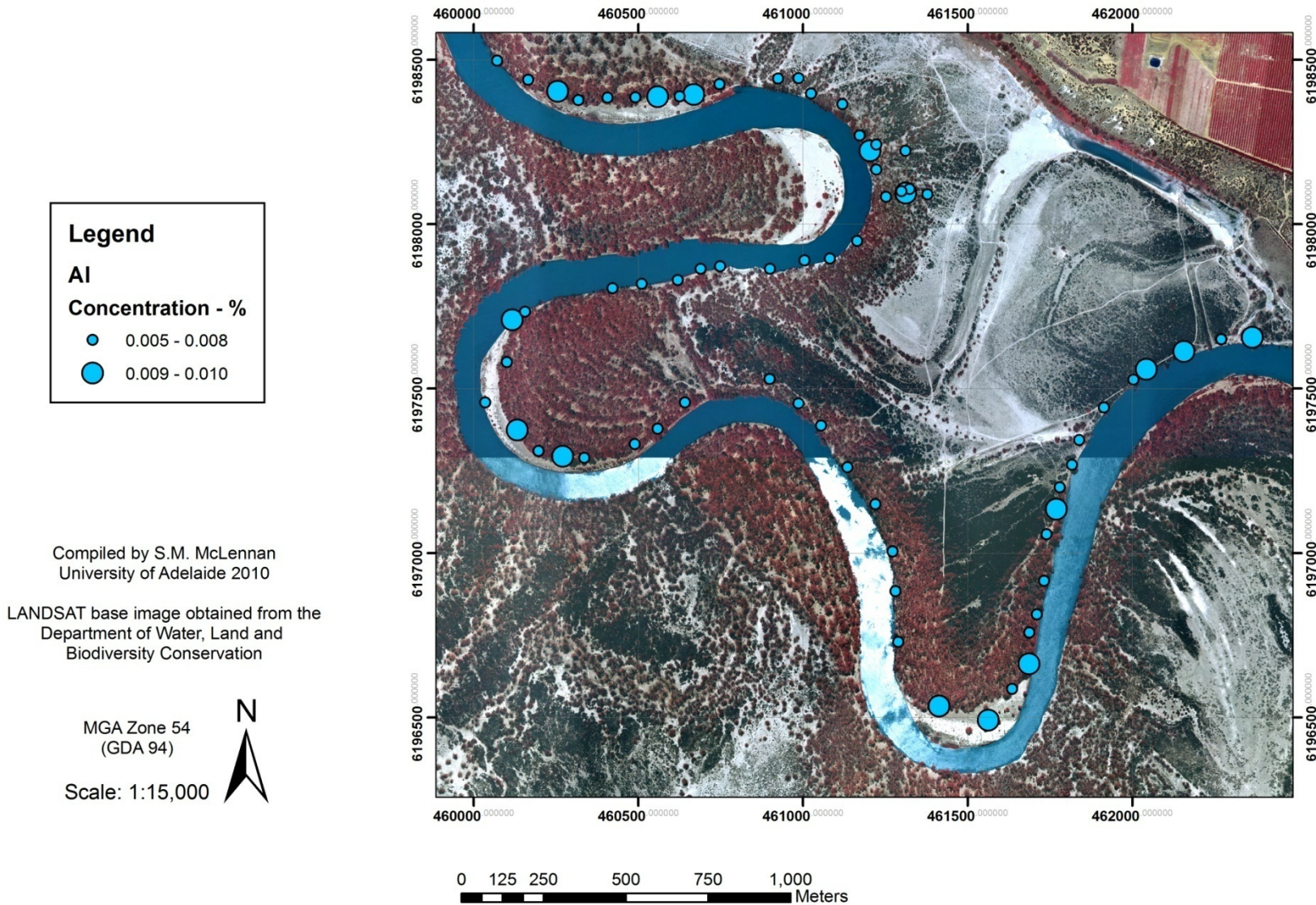
Figure 5

Spatial Association Map of Biogeochemical Element Distribution

Legend

Zr

Concentration - ppm

- 0.010 - 0.025
- 0.026 - 0.041
- 0.042 - 0.059
- 0.060 - 0.079
- 0.080 - 0.100

Compiled by S.M. McLennan
University of Adelaide 2010

LANDSAT base image obtained from the
Department of Water, Land and
Biodiversity Conservation

MGA Zone 54
(GDA 94)

N

Scale: 1:15,000

0   125 250   500   750   1,000
Meters

Figure 9

Spatial Assocation Map of Biogeochemical Element Distribution

Legend

Na

Concentration - %

0.130 - 0.223
0.224 - 0.286
0.287 - 0.379
0.380 - 0.519
0.520 - 0.729

MGA Zone 54
(GDA 94)

N

Scale: 1:15,000

Compiled by S.M. McLennan
University of Adelaide 2010

LANDSAT base image obtained from the
Department of Water, Land and
Biodiversity Conservation
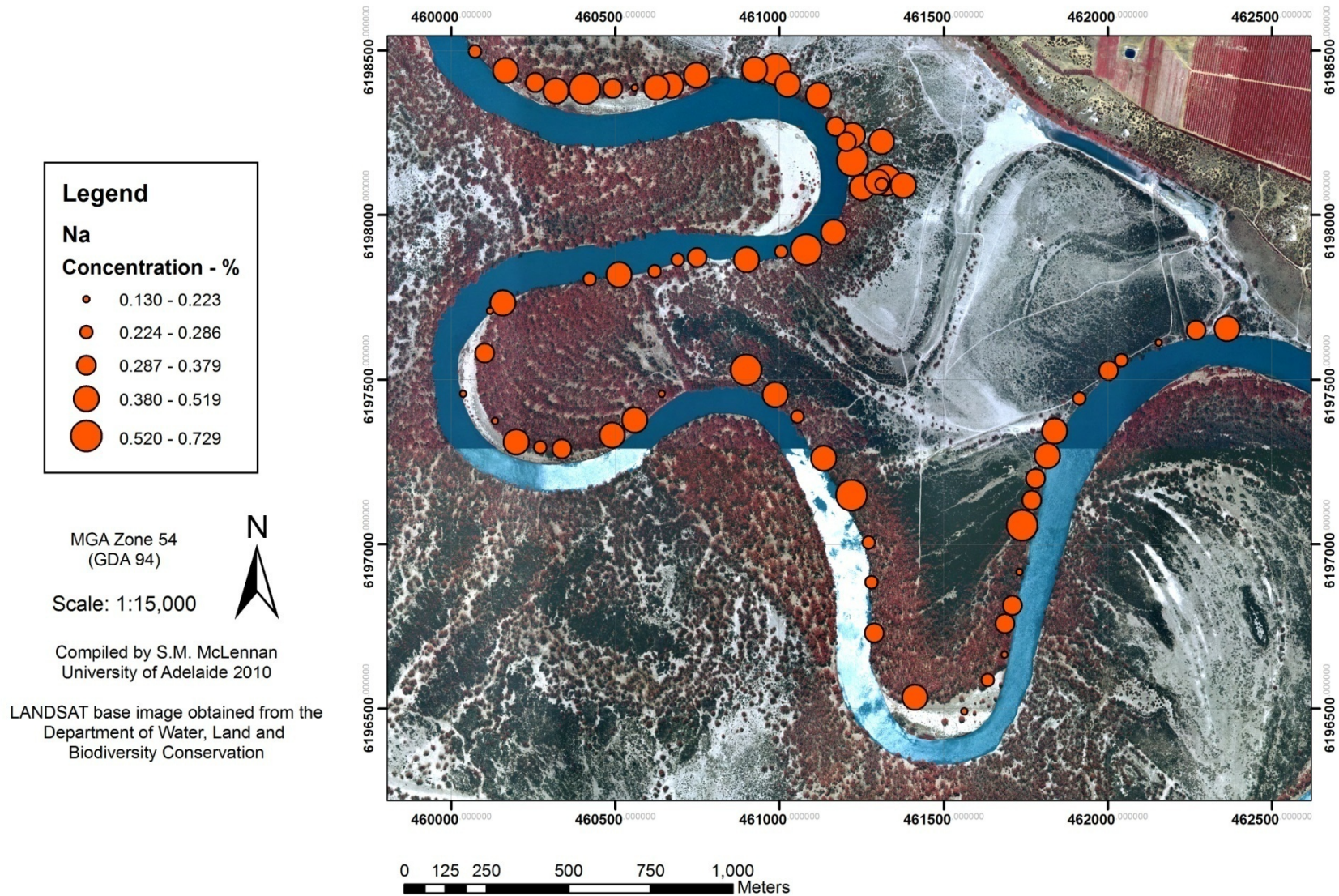
Figure 10

Spatial Assocation Map of Biogeochemical Element Distribution
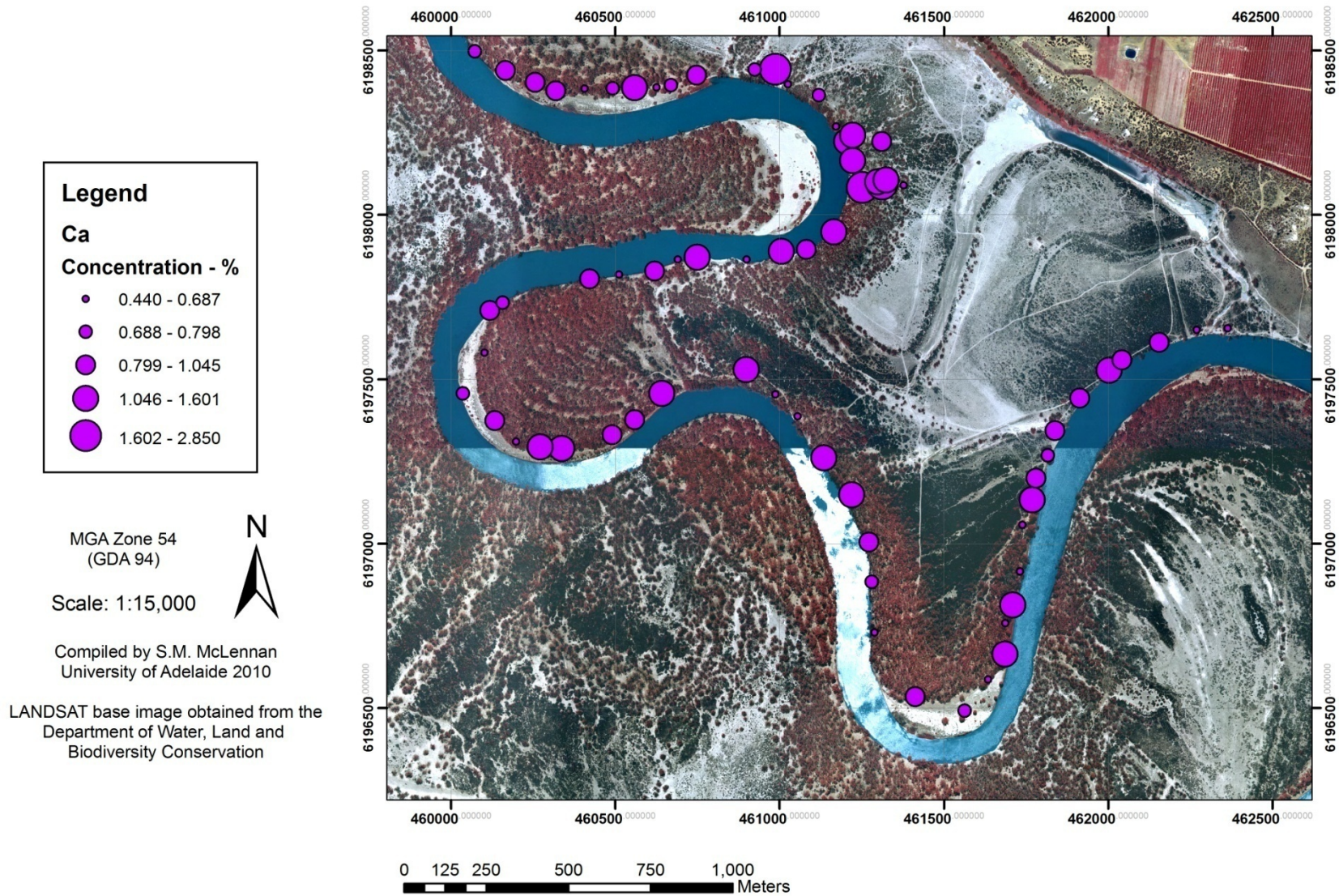
Figure 11

Spatial Assocation Map of Biogeochemical Element Distribution
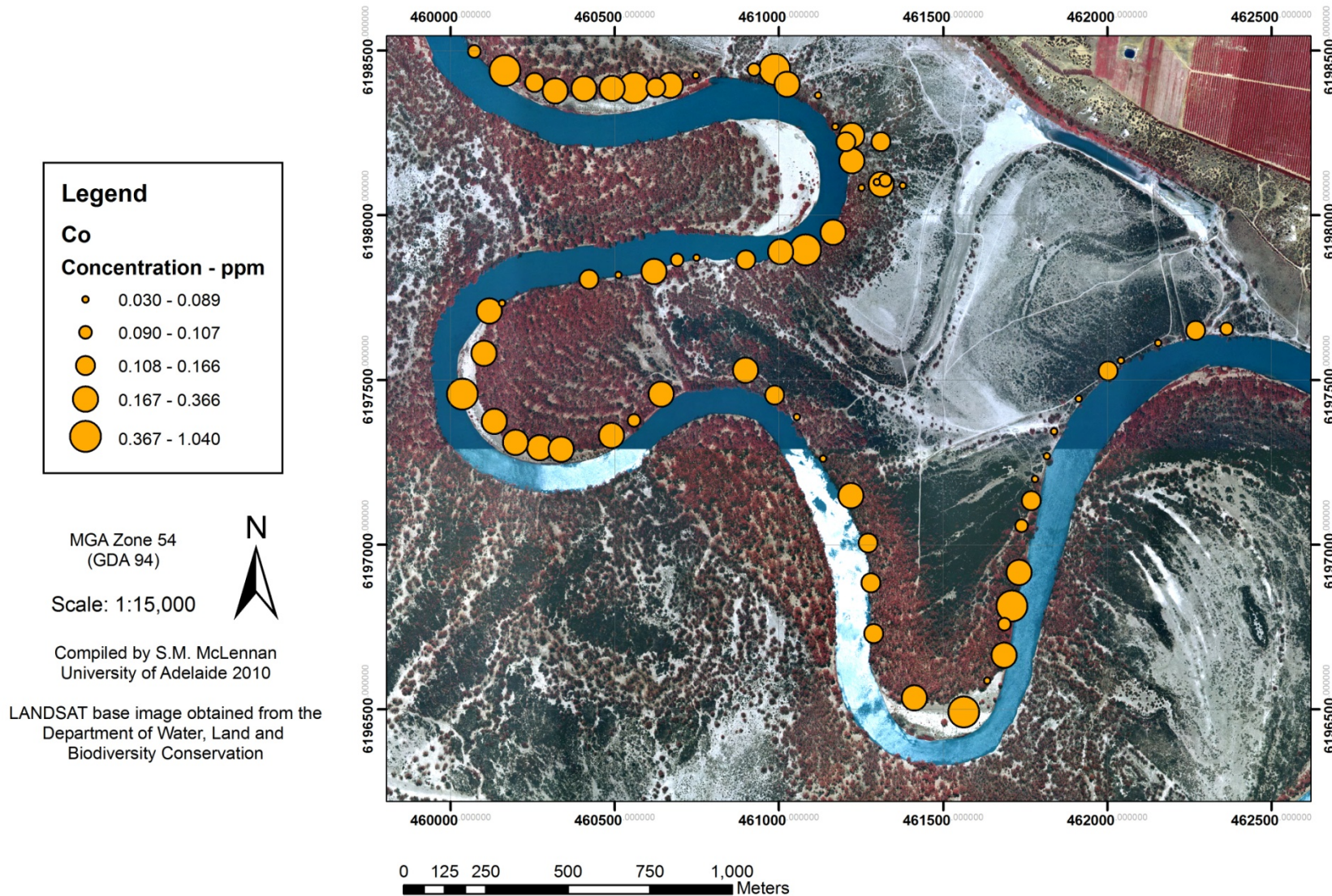
Figure 12

Spatial Assocation Map of Biogeochemical Element Distribution

Figure 13

Spatial Assocation Map of Biogeochemical Element Distribution

Legend

Mo

Concentration - ppm

- 0.005 - 0.020
- 0.021 - 0.023
- 0.024 - 0.038
- 0.039 - 0.100
- 0.101 - 0.360

MGA Zone 54
(GDA 94)

N

Scale: 1:15,000

Compiled by S.M. McLennan
University of Adelaide 2010
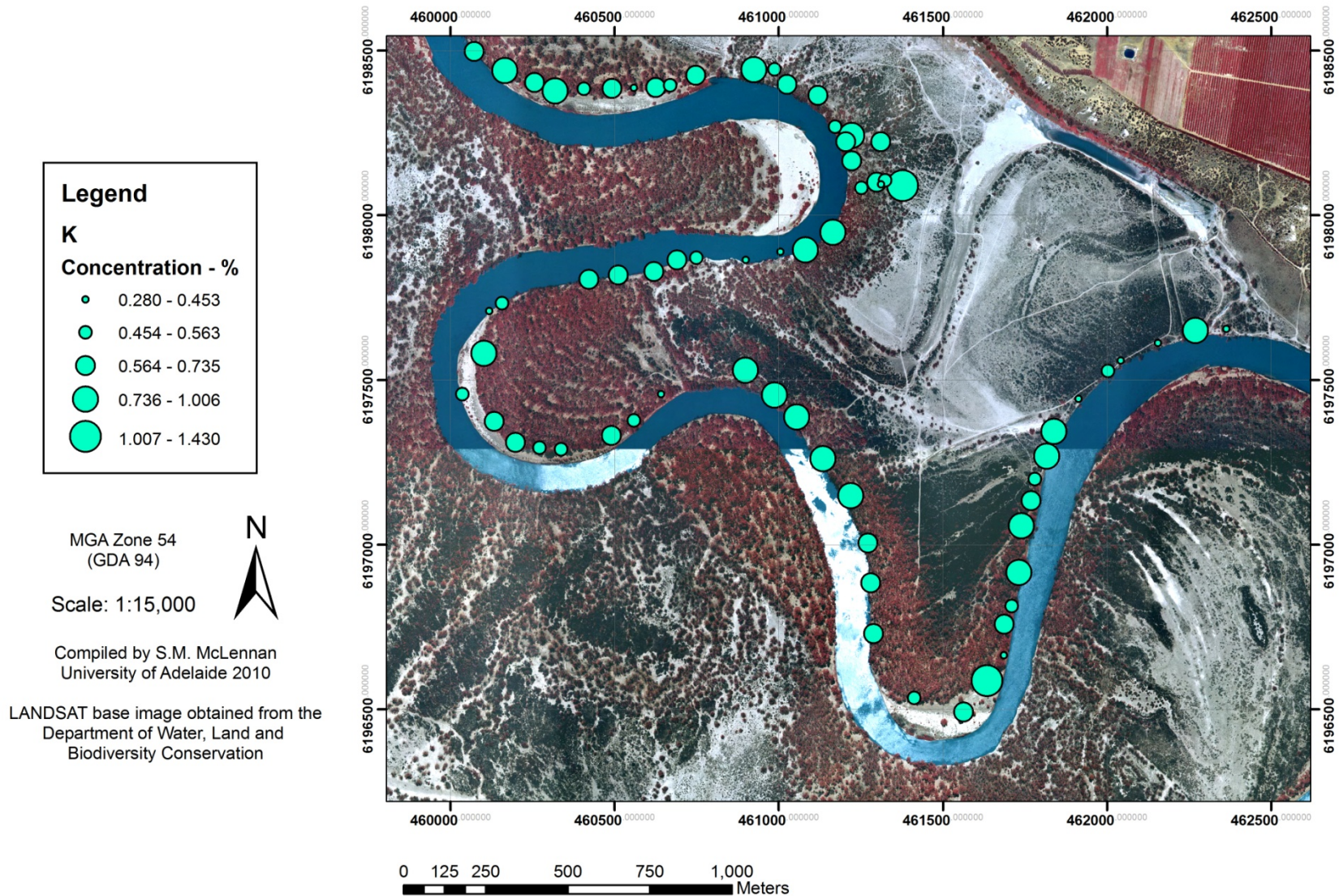
LANDSAT base image obtained from the
Department of Water, Land and
Biodiversity Conservation
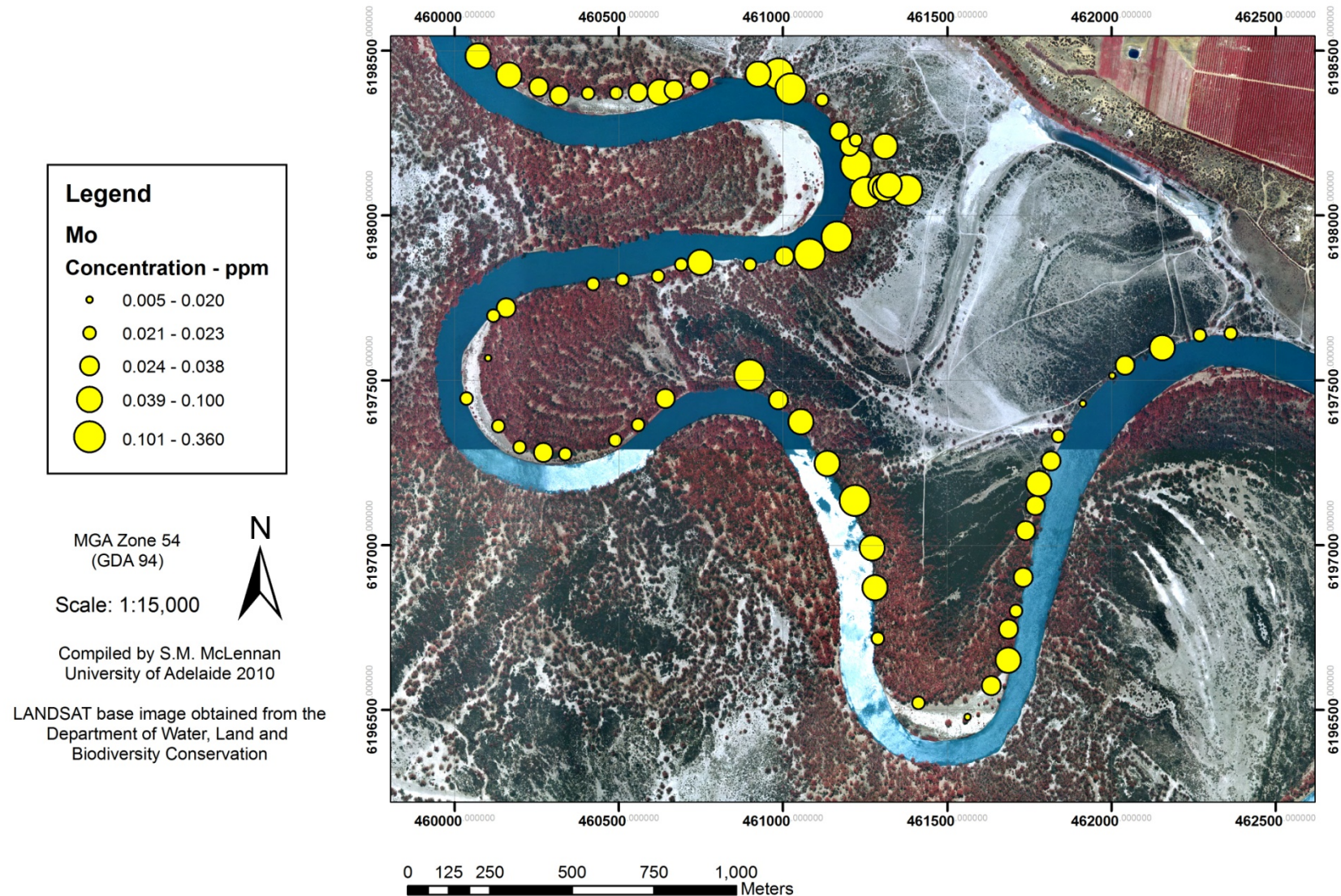
Figure 14

Spatial Assocation Map of Biogeochemical Element Distribution
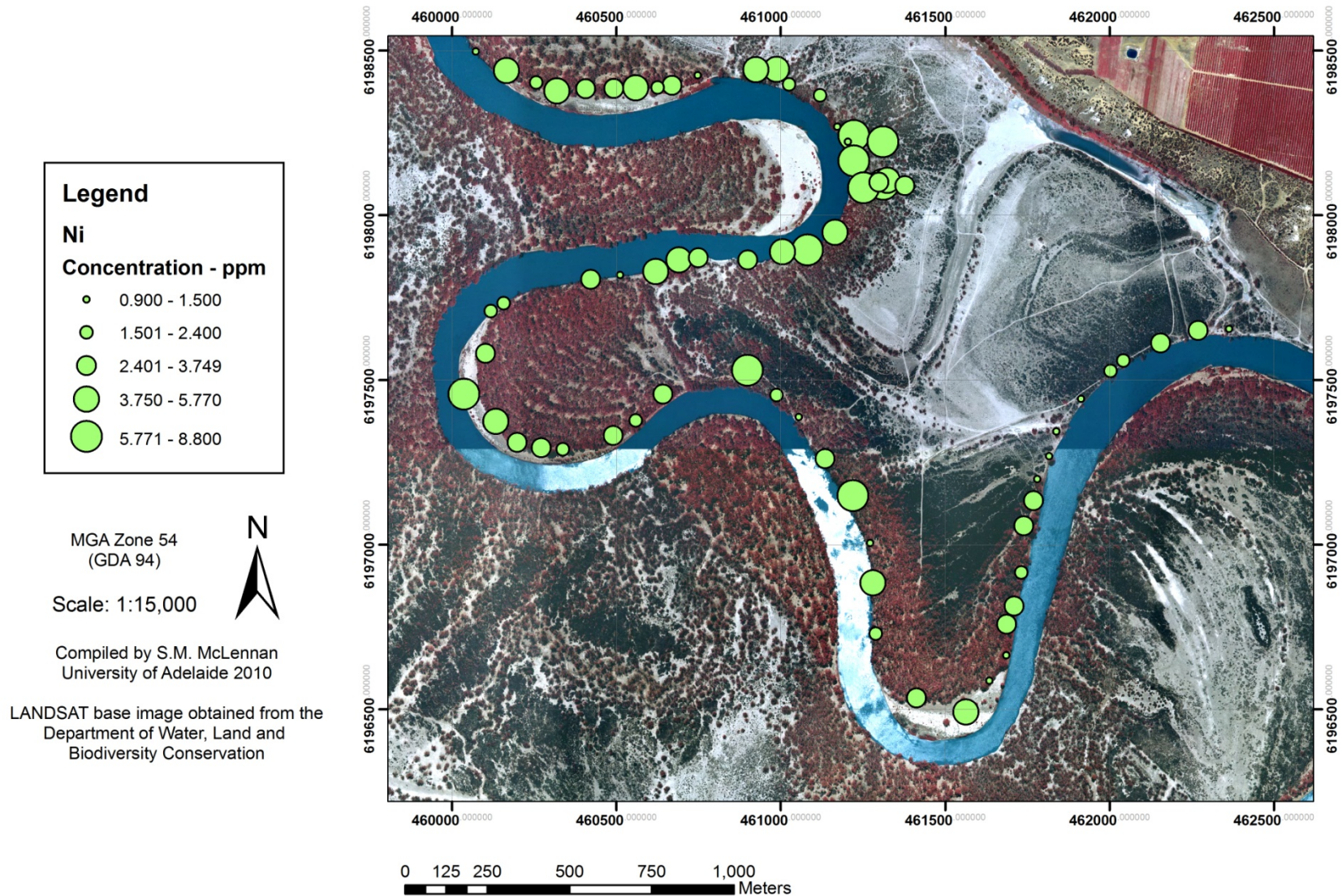
Figure 15

Spatial Assocation Map of Biogeochemical Element Distribution
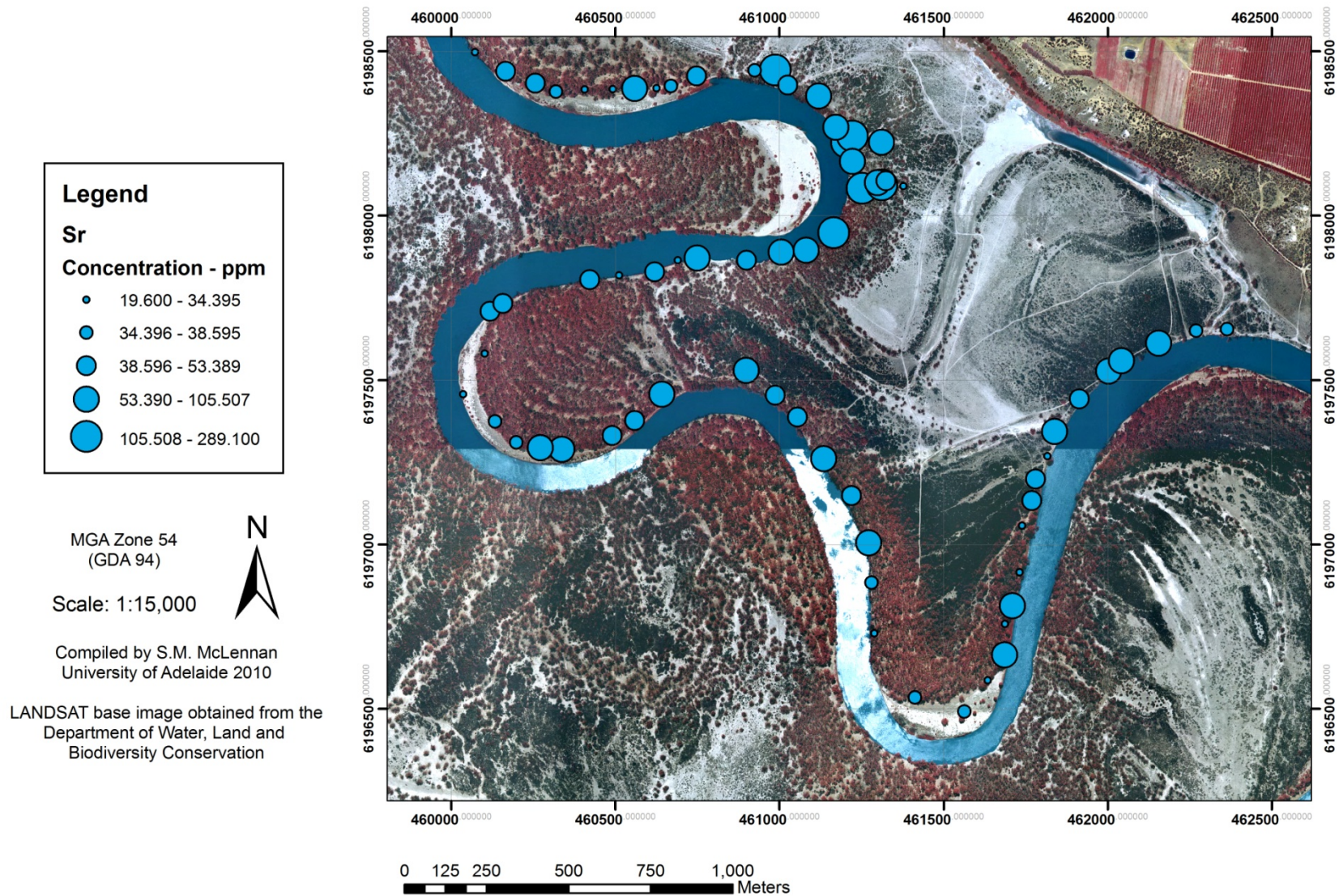
Figure 16

Spatial Assocation Map of Biogeochemical Element Distribution

Figure 17a

Dendrogram for 17 Variables
E. camaldulensis
Ward's method
1-Pearson r

Figure 17b

Dendrogram for 17 Variables
E. largiflorens
Ward's method
1-Pearson r

Figure 18

Dendrogram for 17 Variables
E. camaldulensis and *E. largiflorens*
Ward`s method
1-Pearson r
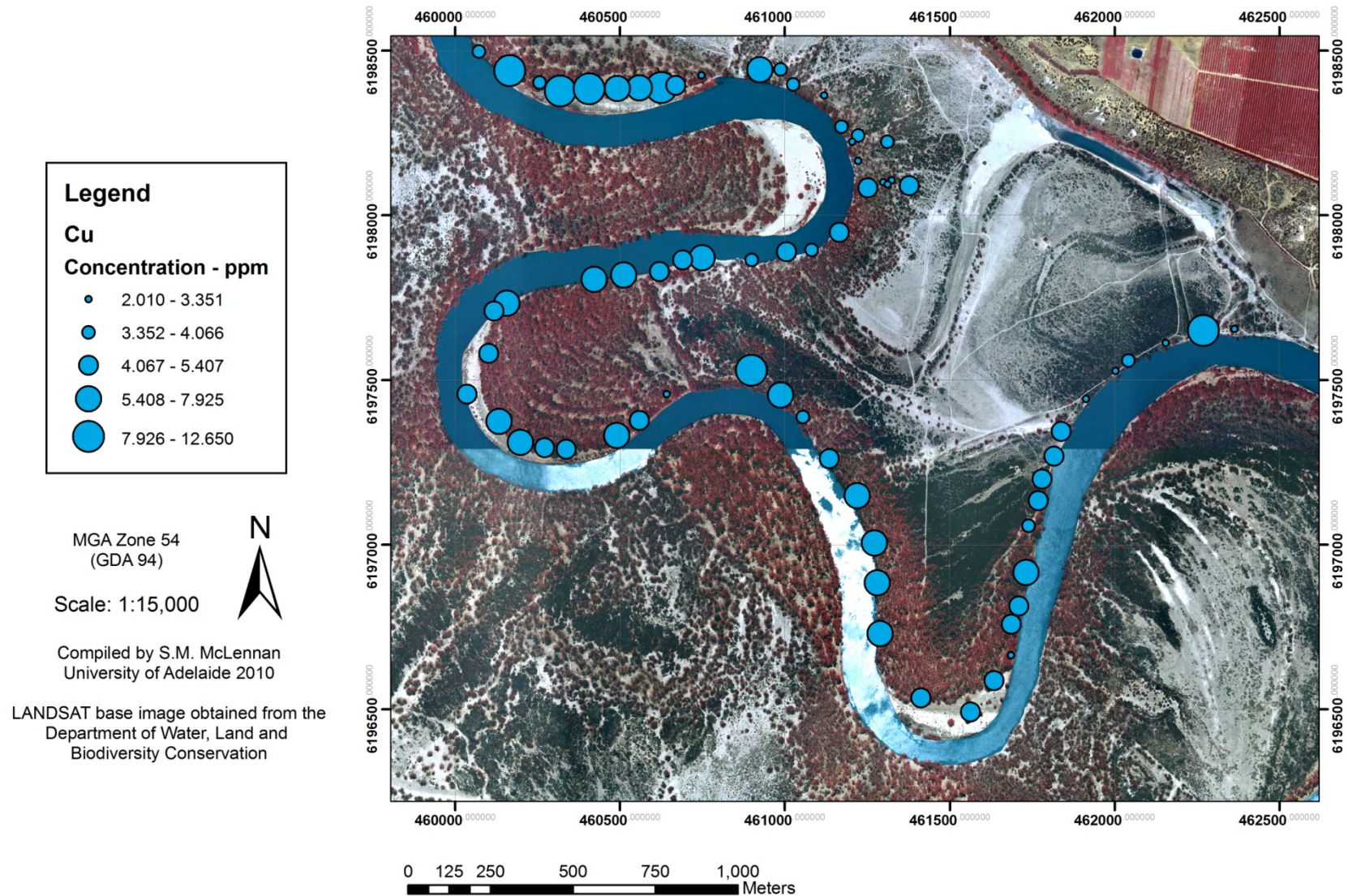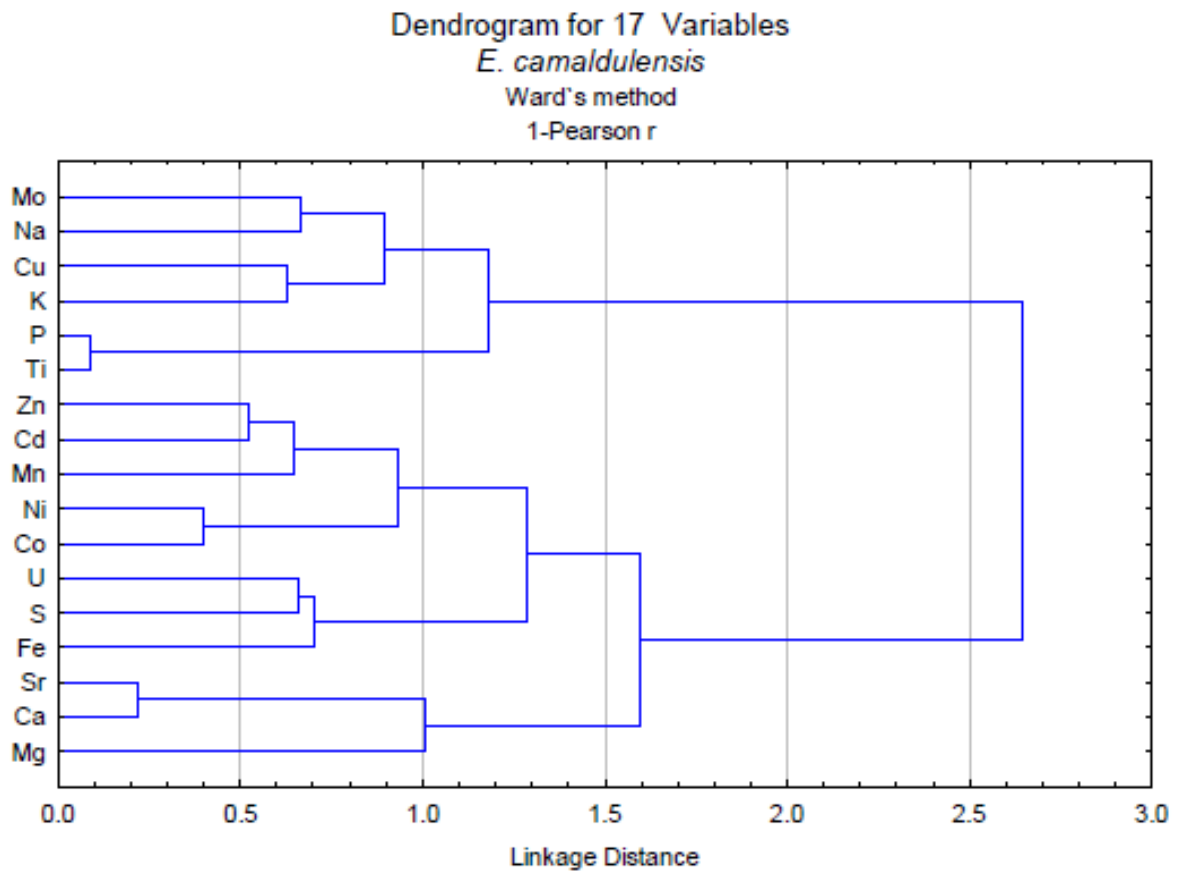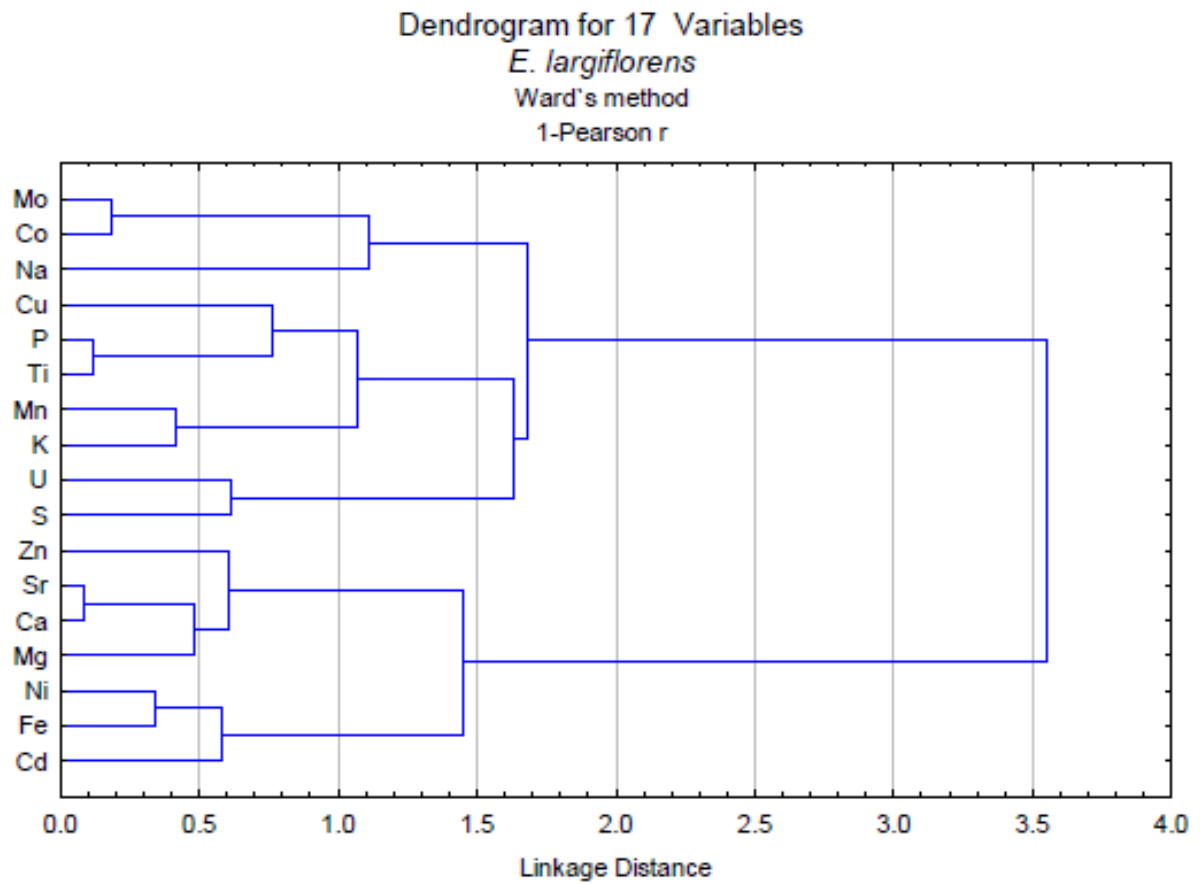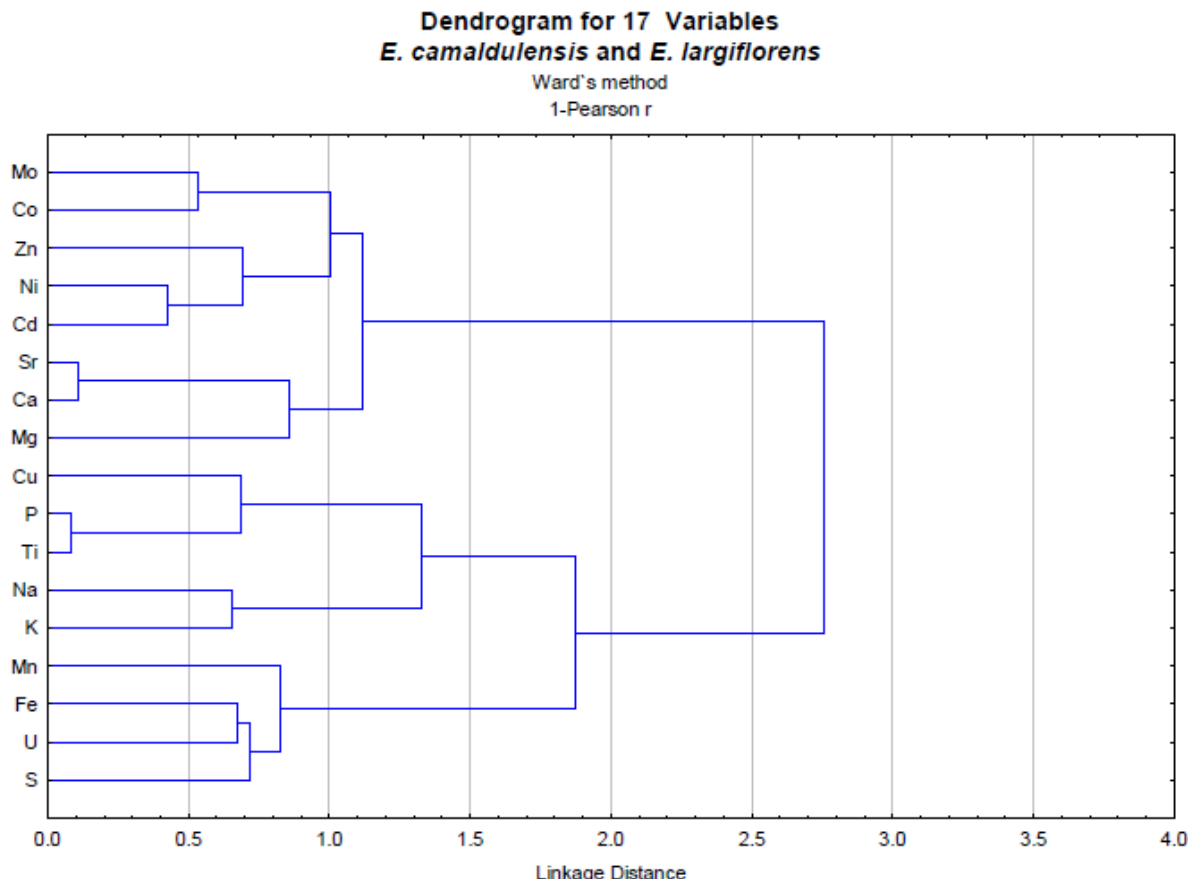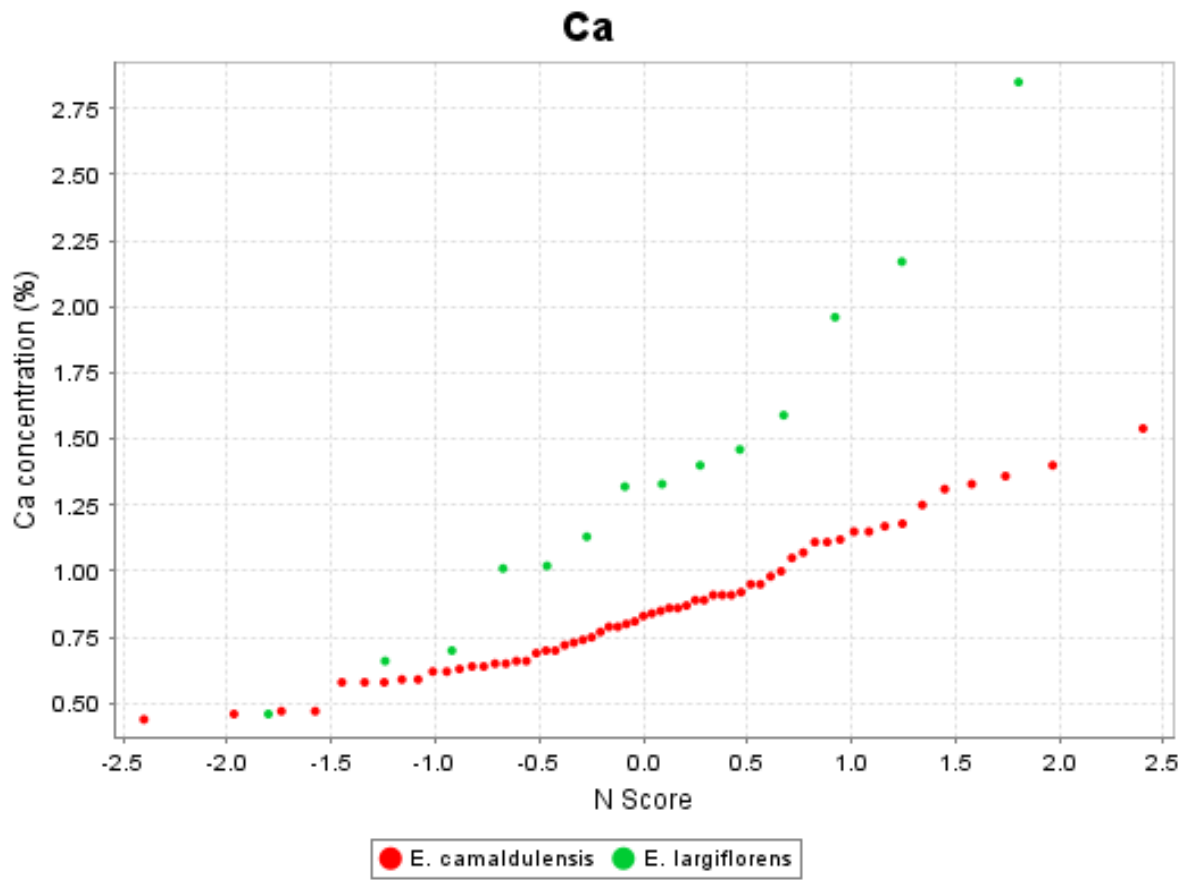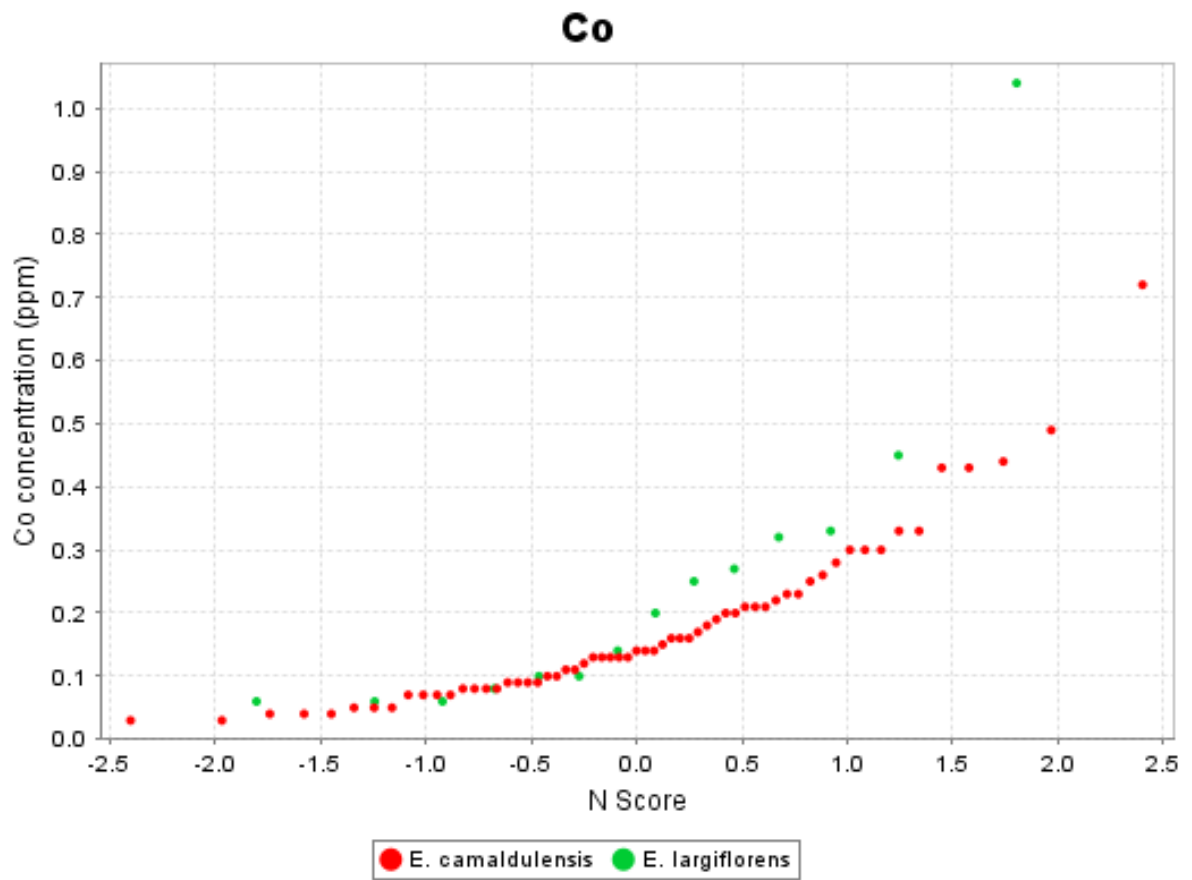
Figure 19

Figure 20

Figure 21
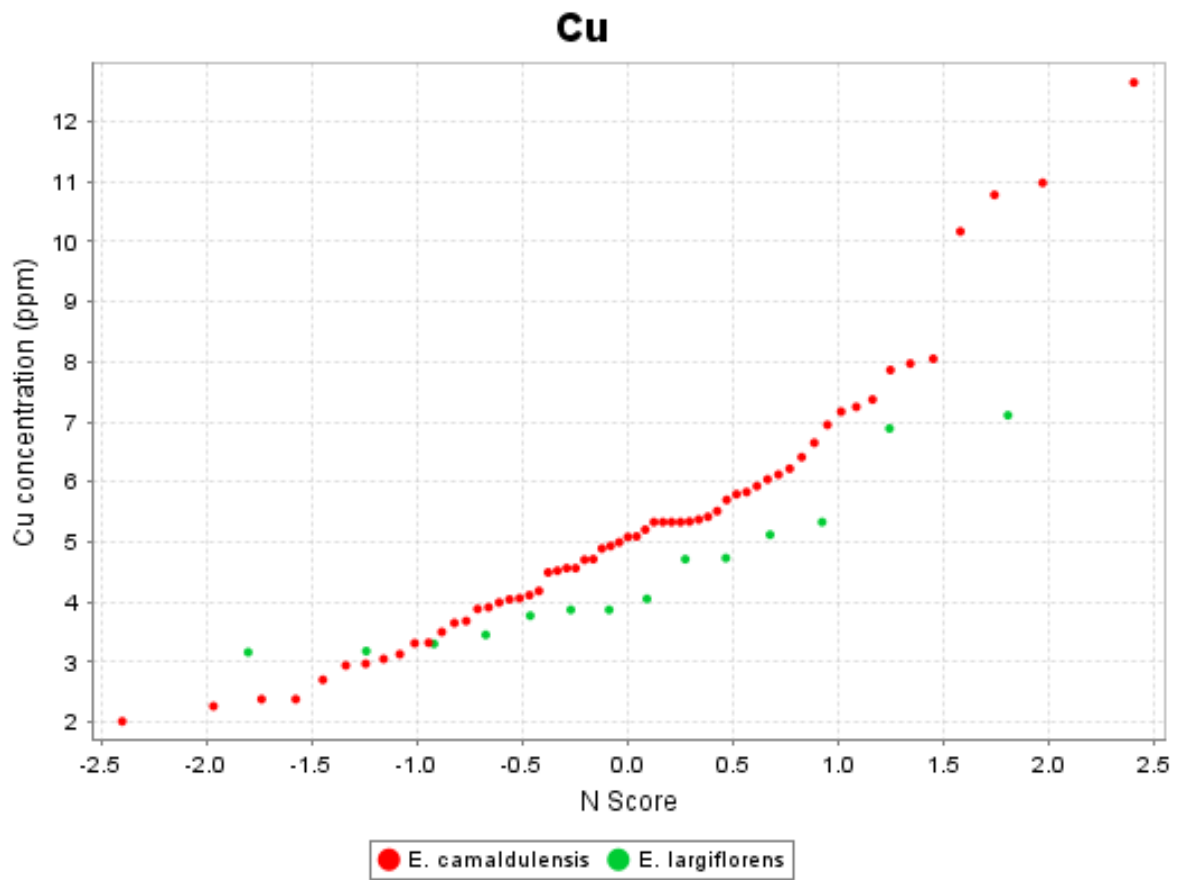
Figure 22
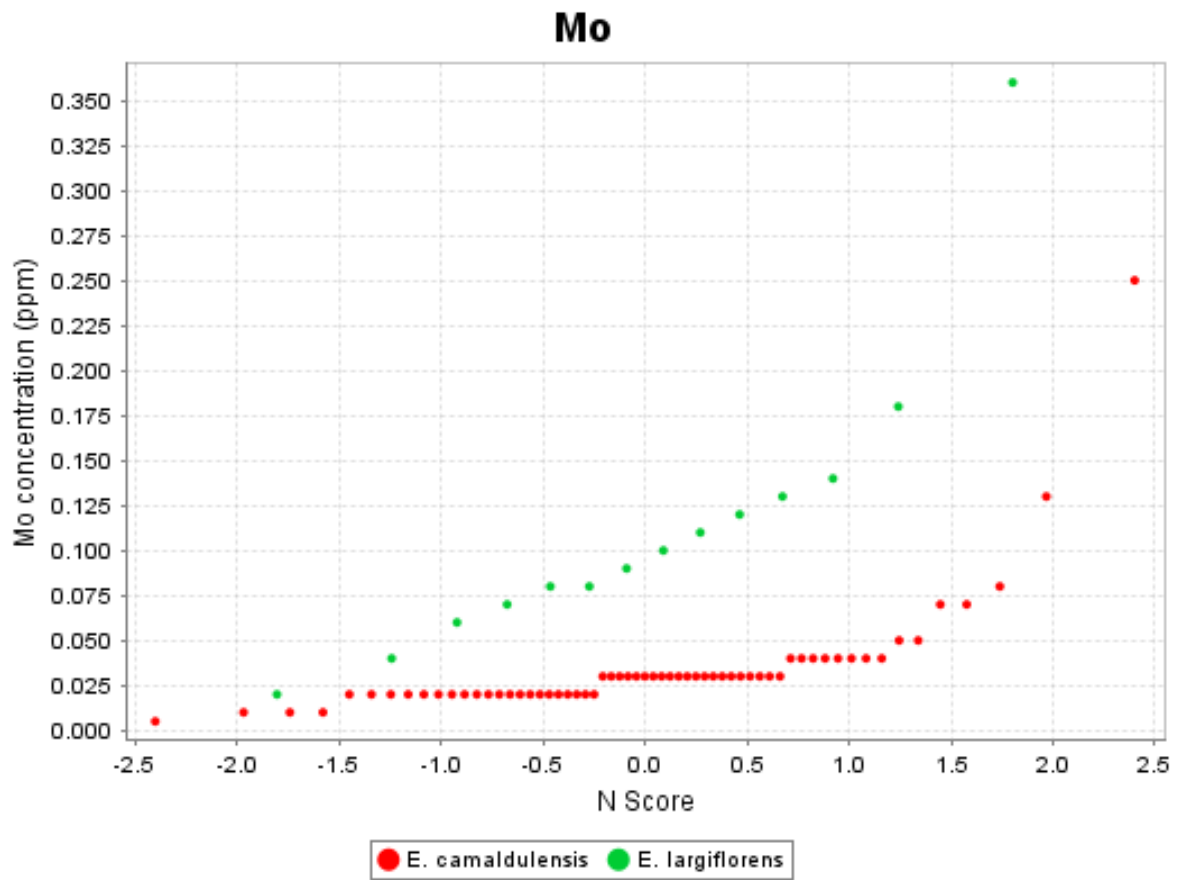
Figure 23
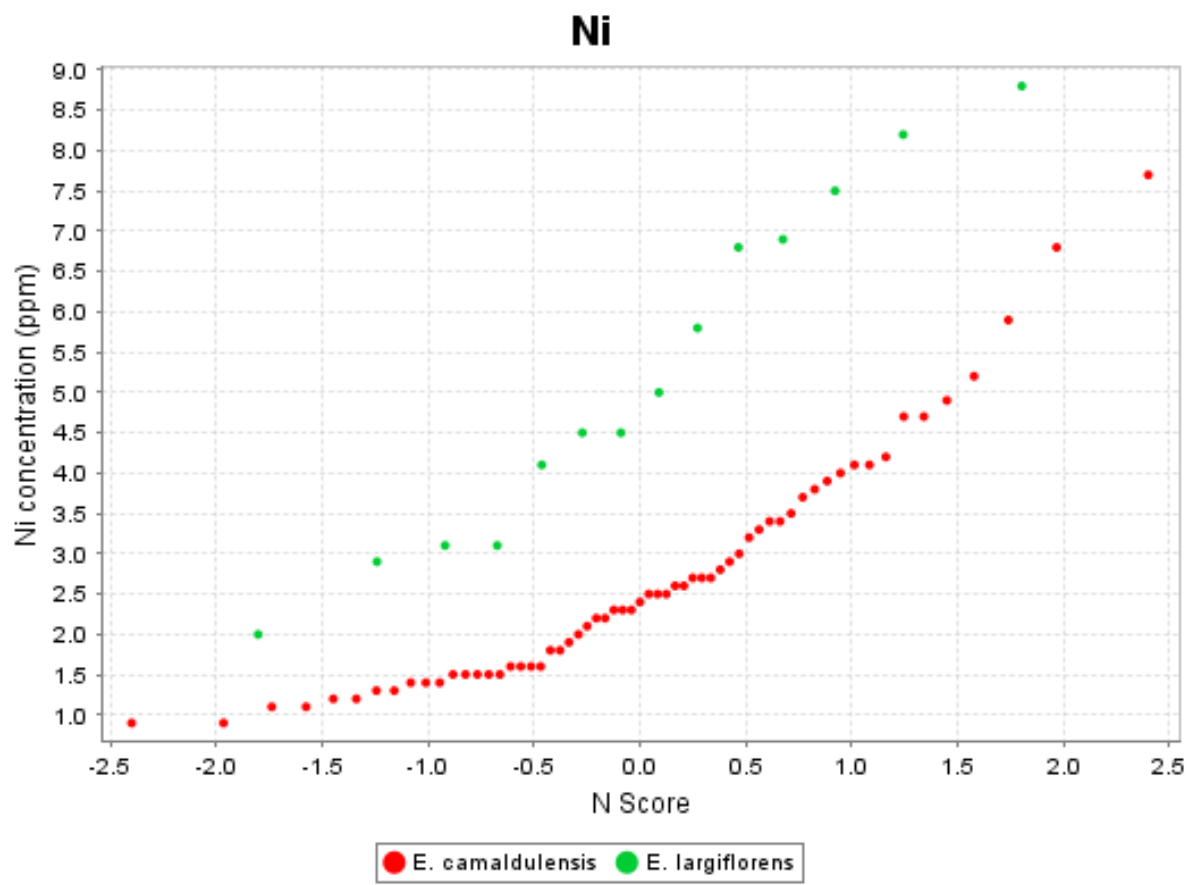
Figure 24
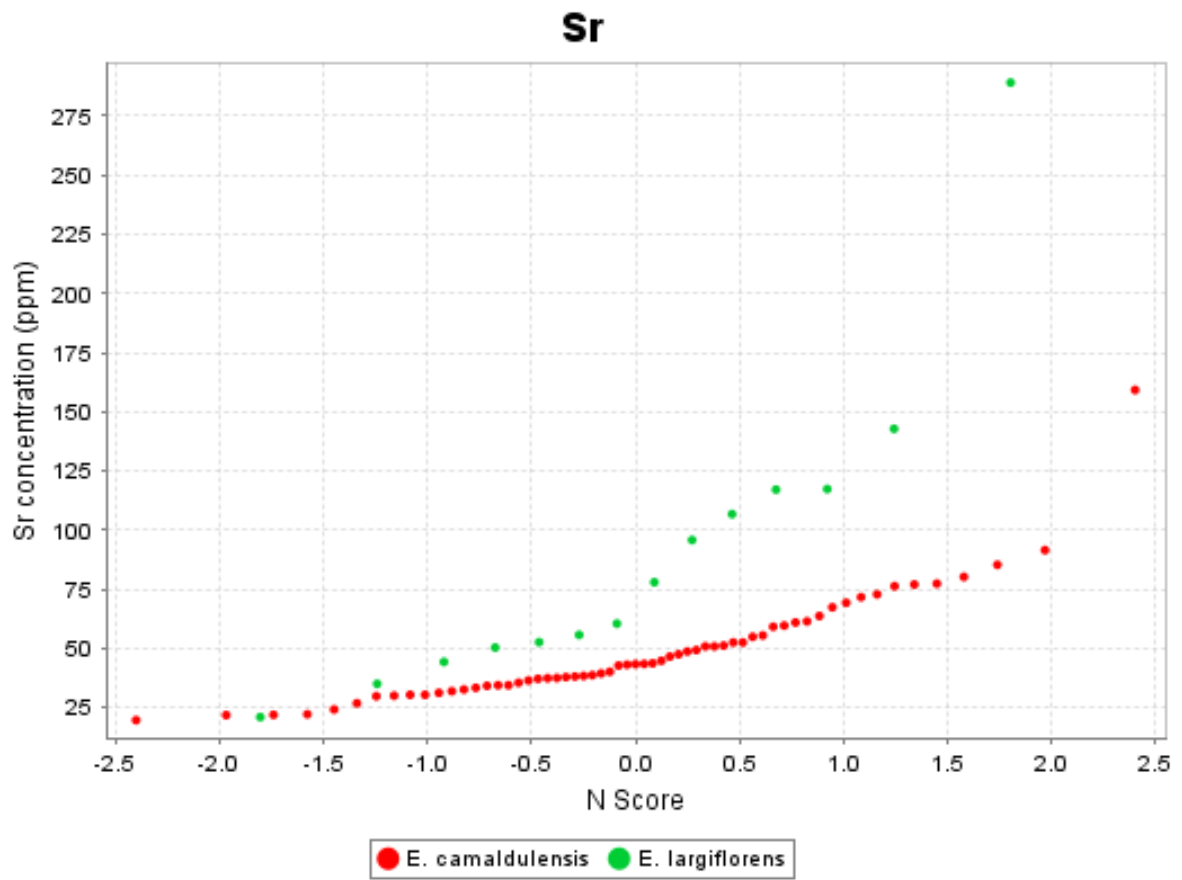
Figure 25
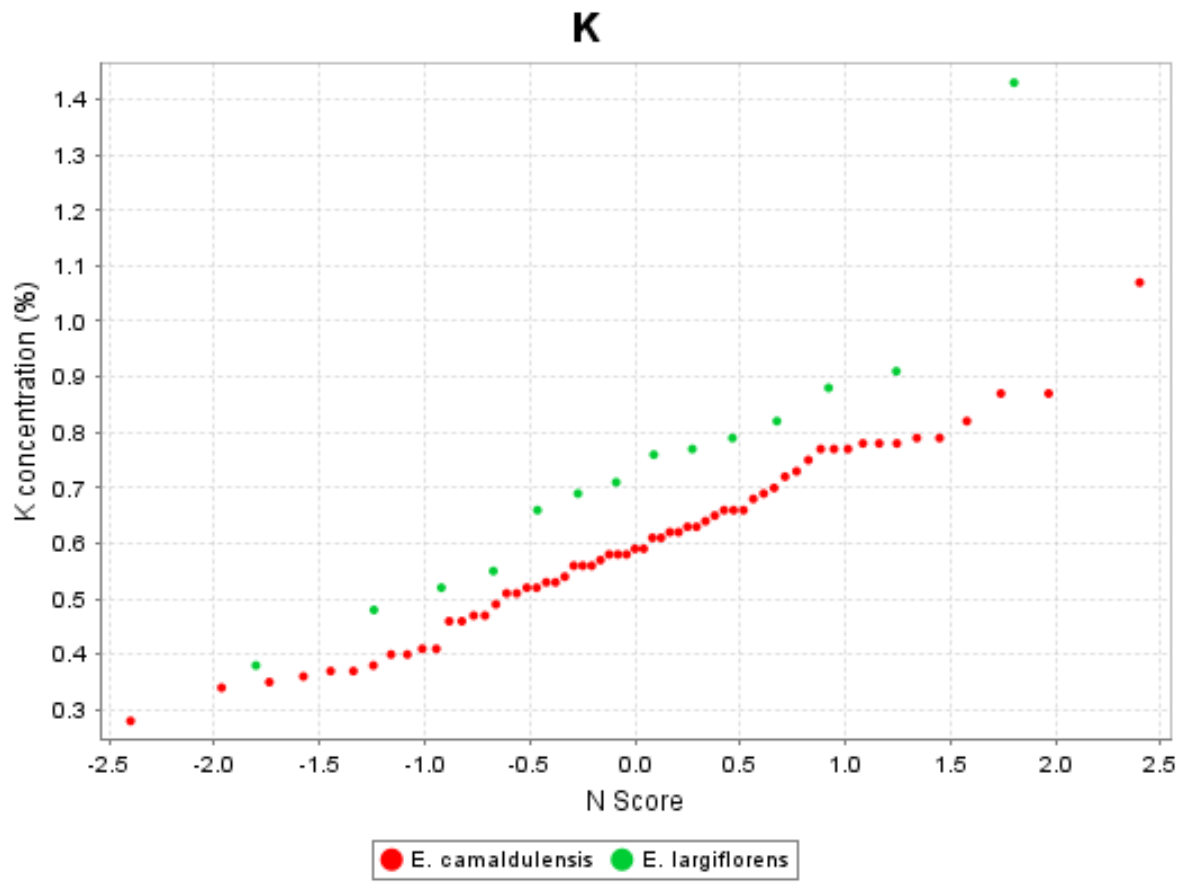
Figure 26
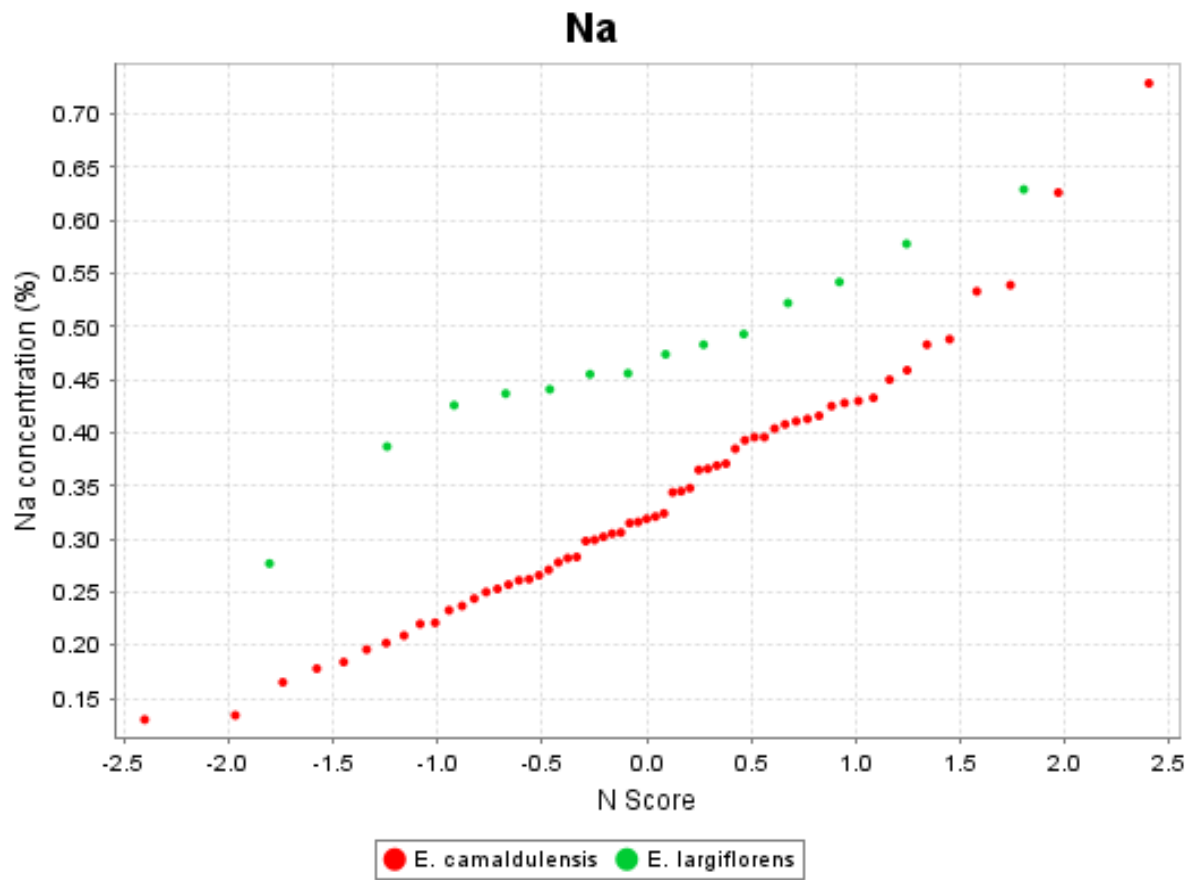
Figure 27

Spatial Assocation Map of Biogeochemical Element Distribution

Legend

Au

Concentration - ppb

- ○ 0.100 - 0.194
- ○ 0.195 - 0.225
- ○ 0.226 - 0.319
- ○ 0.320 - 0.608
- ○ 0.609 - 1.500

MGA Zone 54
(GDA 94)

N

Scale: 1:15,000

Compiled by S.M. McLennan
University of Adelaide 2010

LANDSAT base image obtained from the
Department of Water, Land and
Biodiversity Conservation

0   125   250   500   750   1,000
Meters
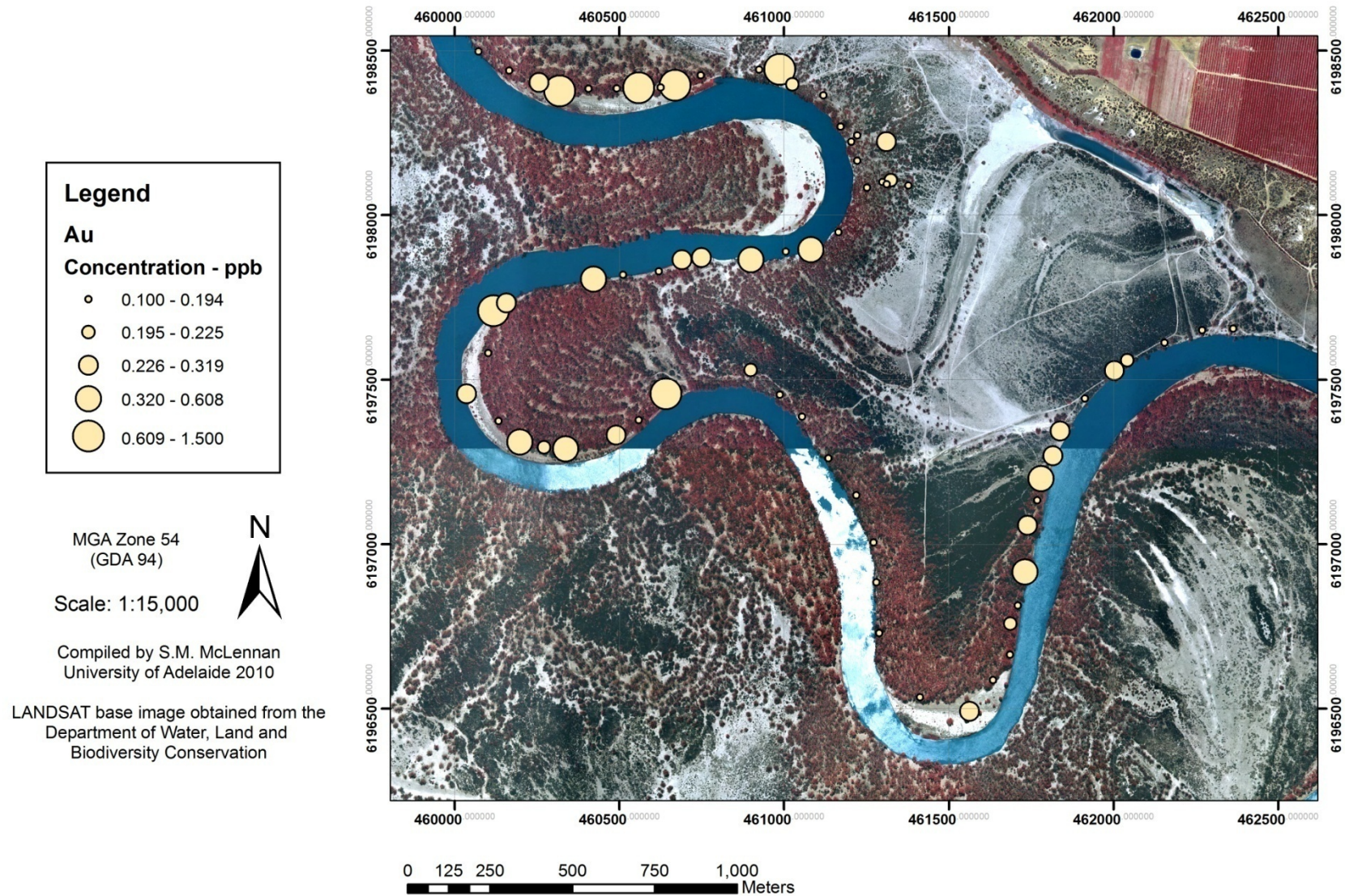
Figure 28

Spatial Assocation Map of Biogeochemical Element Distribution
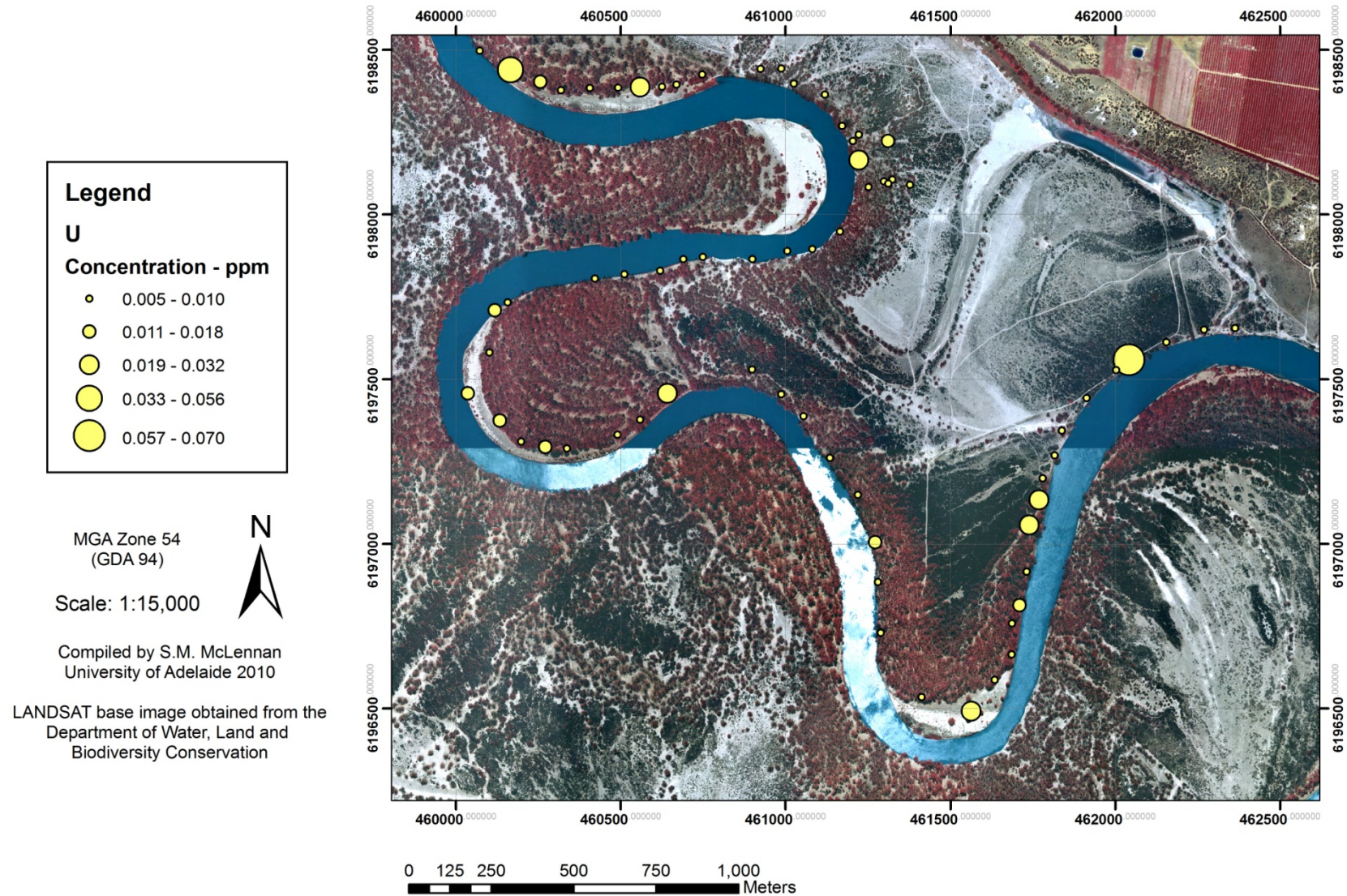
Figure 29

RESOLVE Airborne Electromagnetic Survey, 4.20 - 6.62 m depth
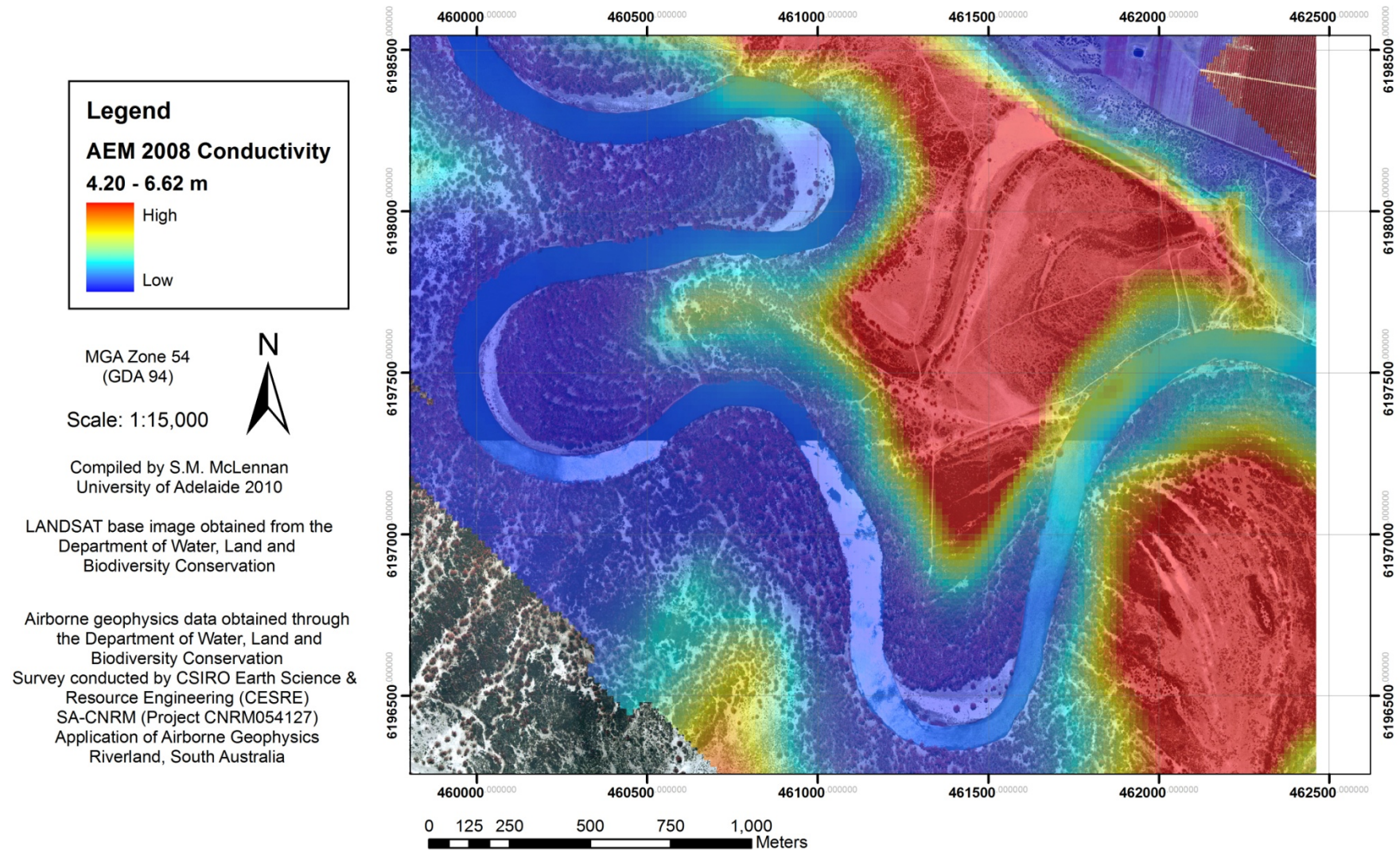
Figure 30

RESOLVE Airborne Electromagnetic Survey, 6.60 - 9.30 m depth

Figure 31

Instream NanoTEM Survey
(No filter)

Legend

Instream NanoTEM
Conductivity

- Very low
- Low
- Moderate
- High
- Very high

Inverted data, no filter

MGA Zone 54
(GDA 94)

N

Scale: 1:15,000

Compiled by S.M. McLennan
University of Adelaide 2010

LANDSAT base image obtained from the
Department of Water, Land and
Biodiversity Conservation

Instream NanoTEM data obtained from
Michael Hatch, University of Adelaide, Australia

Figure 32

Instream NanoTEM Survey
(5 cell low pass filter)

Figure 33

EM31 conductivity survey

MGA Zone 54
(GDA 94)

Scale: 1:6,000

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University of Adelaide 2010

LANDSAT base image obtained from the
Department of Water, Land and
Biodiversity Conservation

EM31 conductivity data obtained from the
Department of Water, Land and
Biodiversity Conservation

Legend

**EM31
Conductivity**

High

Low
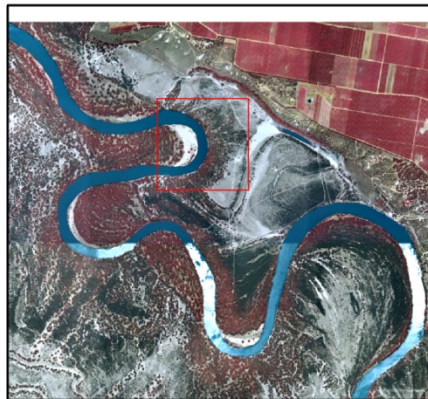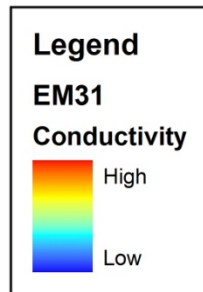
Red square shows location
of EM31 survey extent
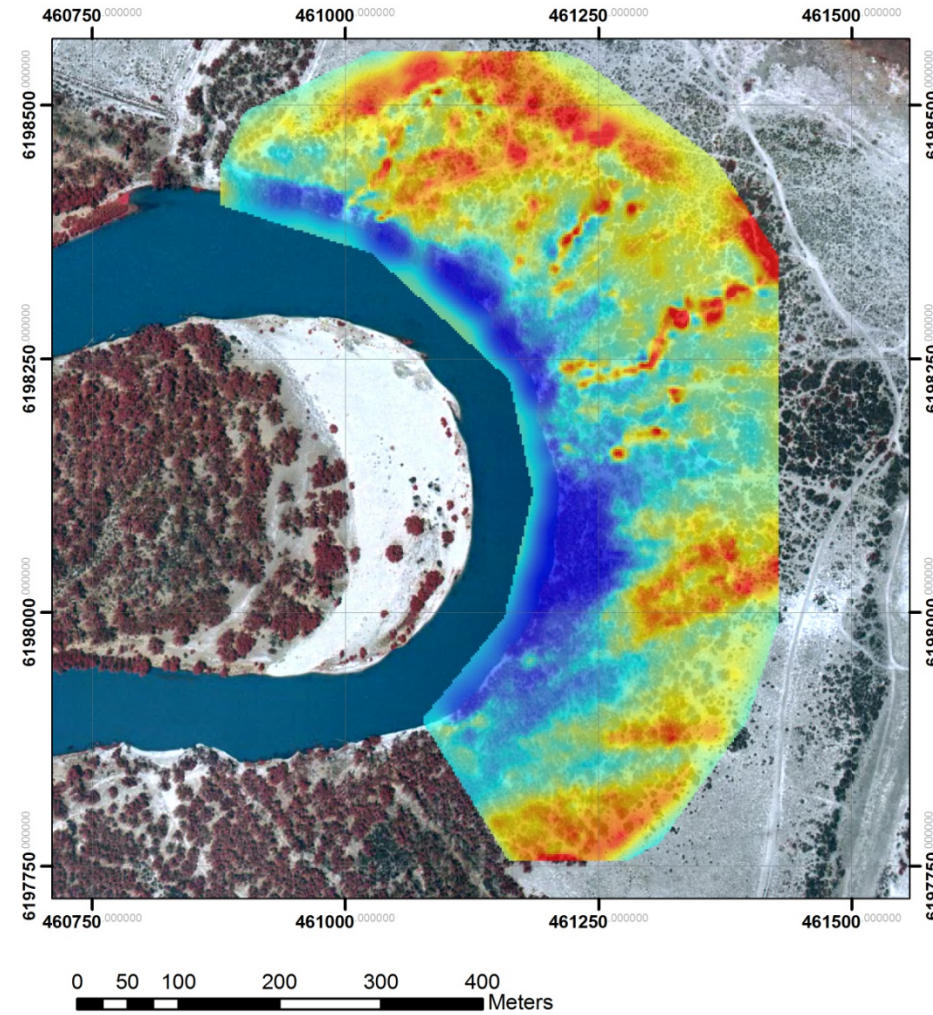
Regolith landform map and EM31 survey

Figure 34

0 50 100   200   300   400
Meters

N

Scale: 1:7,500

MGA Zone 54
(GDA 94)

Mapped and compiled by S.M. McLennan
University of Adelaide 2010

LANDSAT base image obtained from the
Department of Water, Land and
Biodiversity Conservation

EM31 conductivity data obtained from
the Department of Water, Land and
Biodiversity Conservation

Legend

**EM31
Conductivity**

High

Low
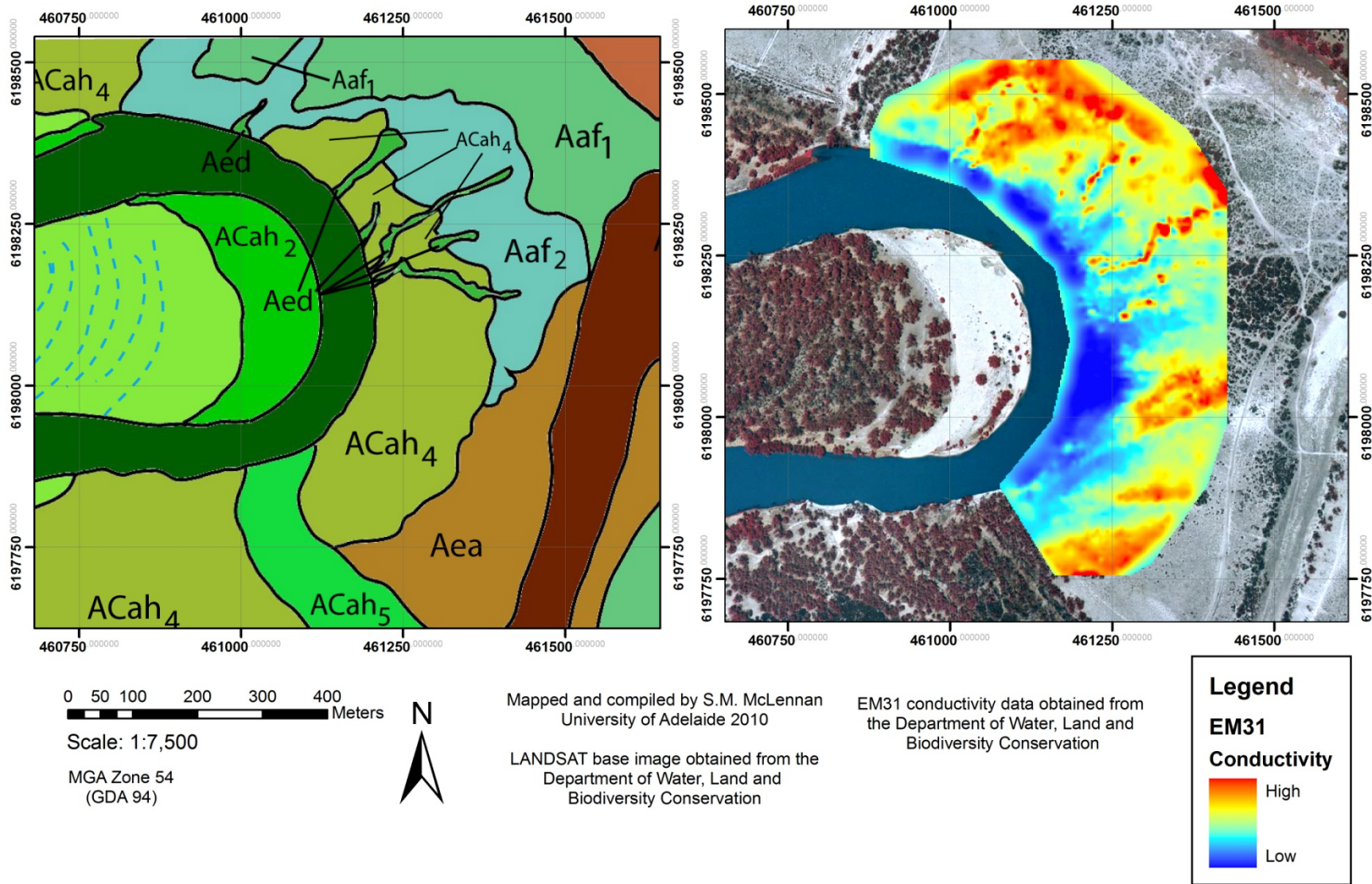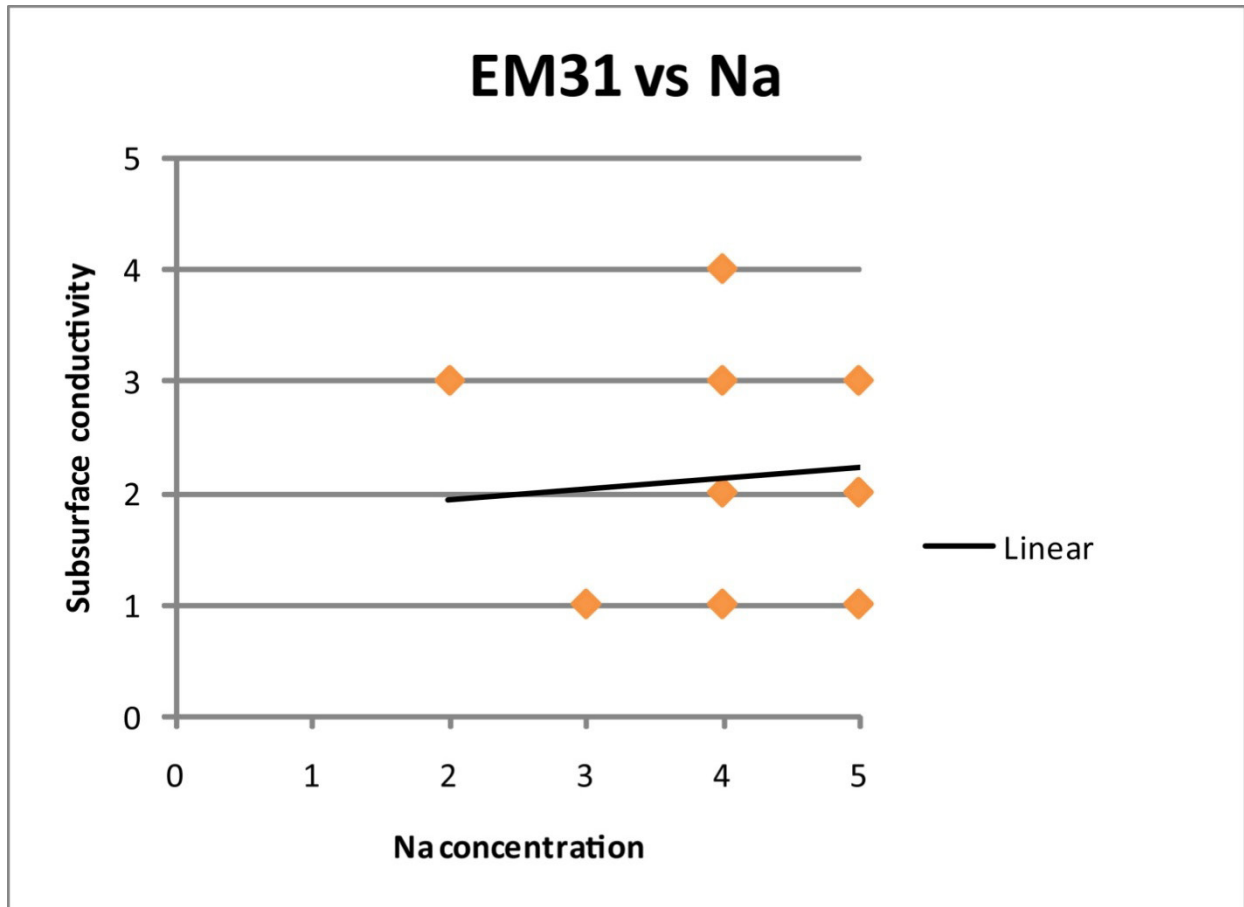
Figure 35a
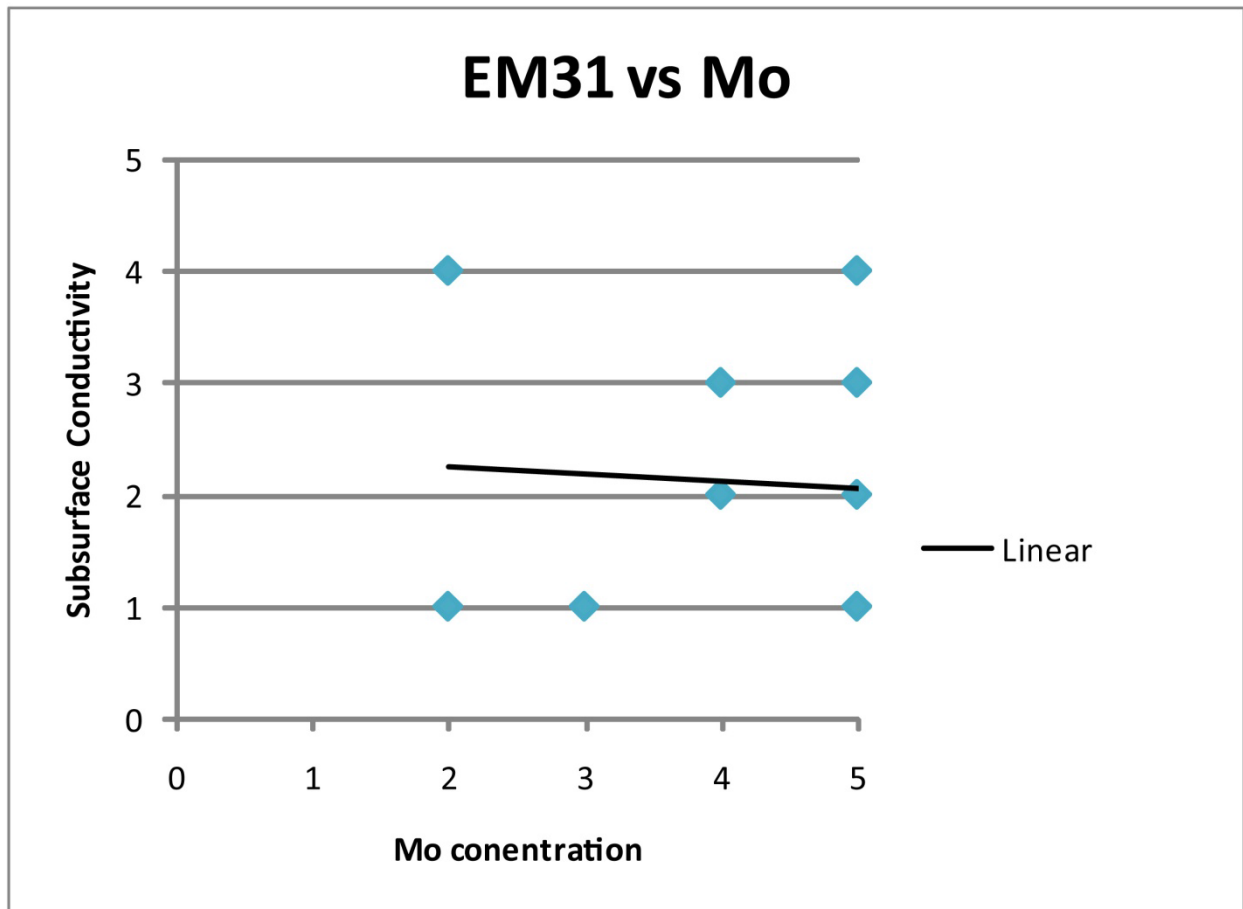
Figure 35b

Figure 36a
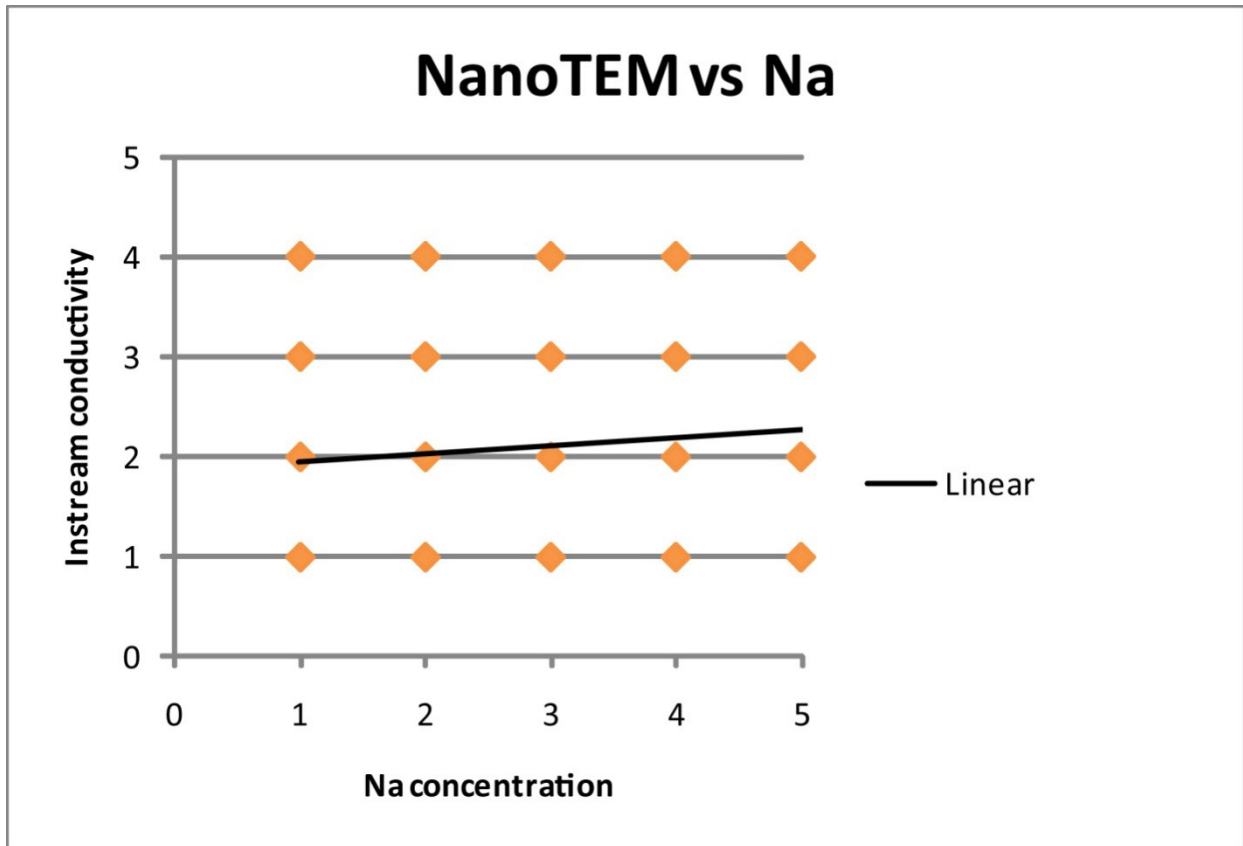
Figure 36b

Figure 37

Figure 38

Mo concentration and instream conductivity vs downstream distance

Figure 39

Cd concentration and instream conductivity vs downstream distance

Figure 40

Figure 41

Ni concentration and instream conductivity vs downstream distance

Figure 42

Ca concentration and instream conductivity vs downstream distance

Figure 43

Zinc concentration and instream conductivity vs downstream distance
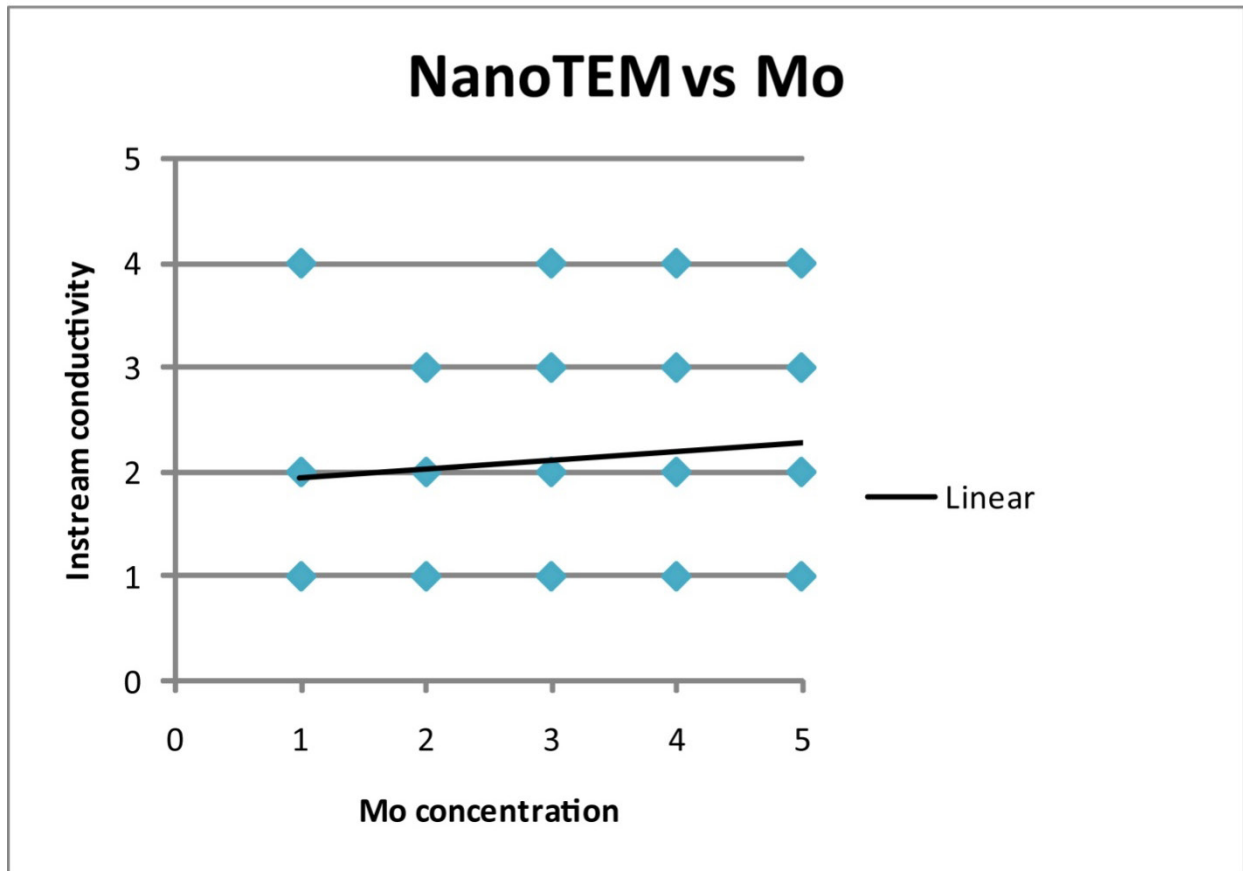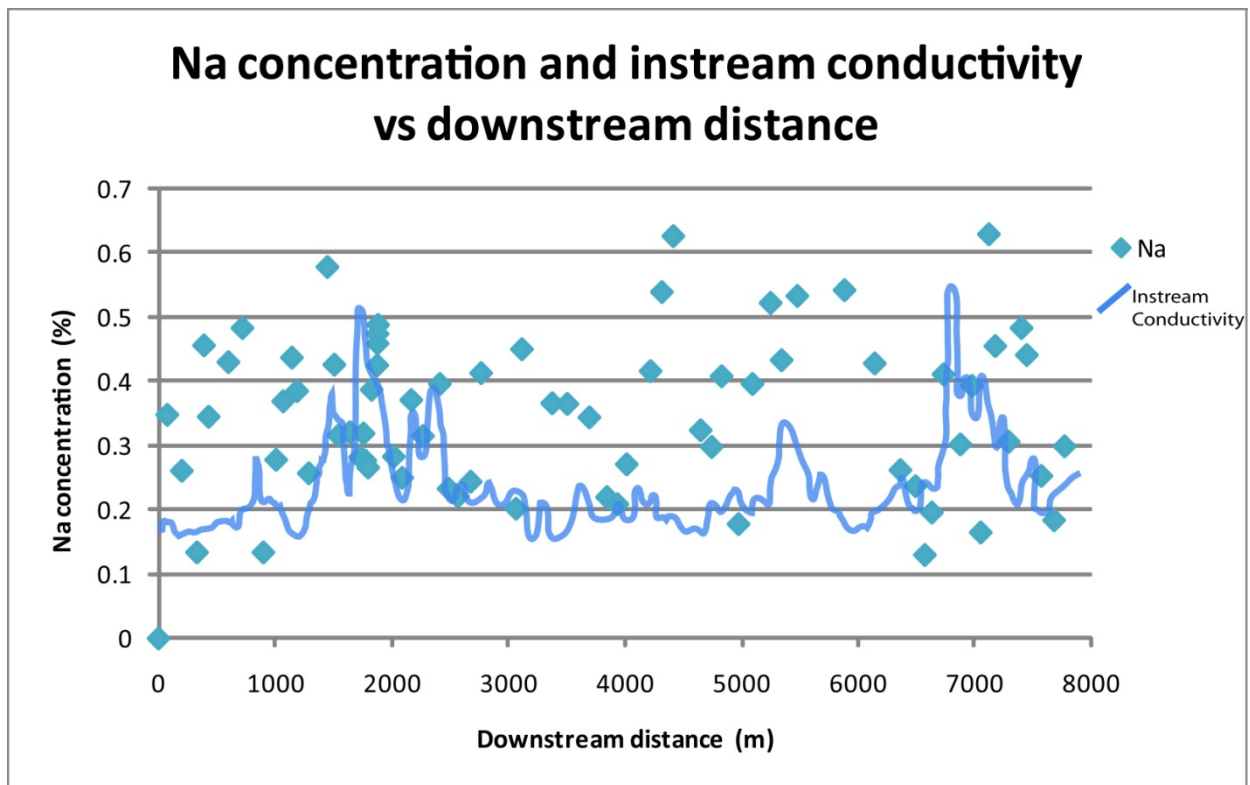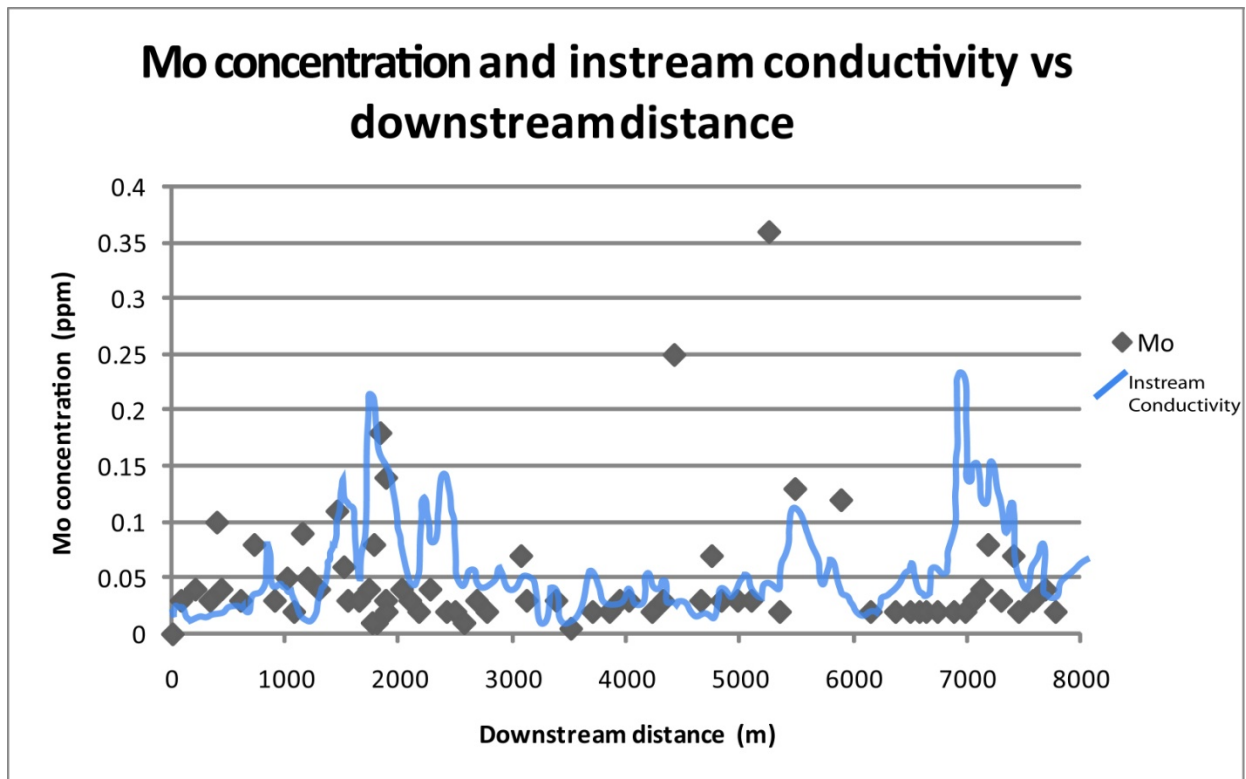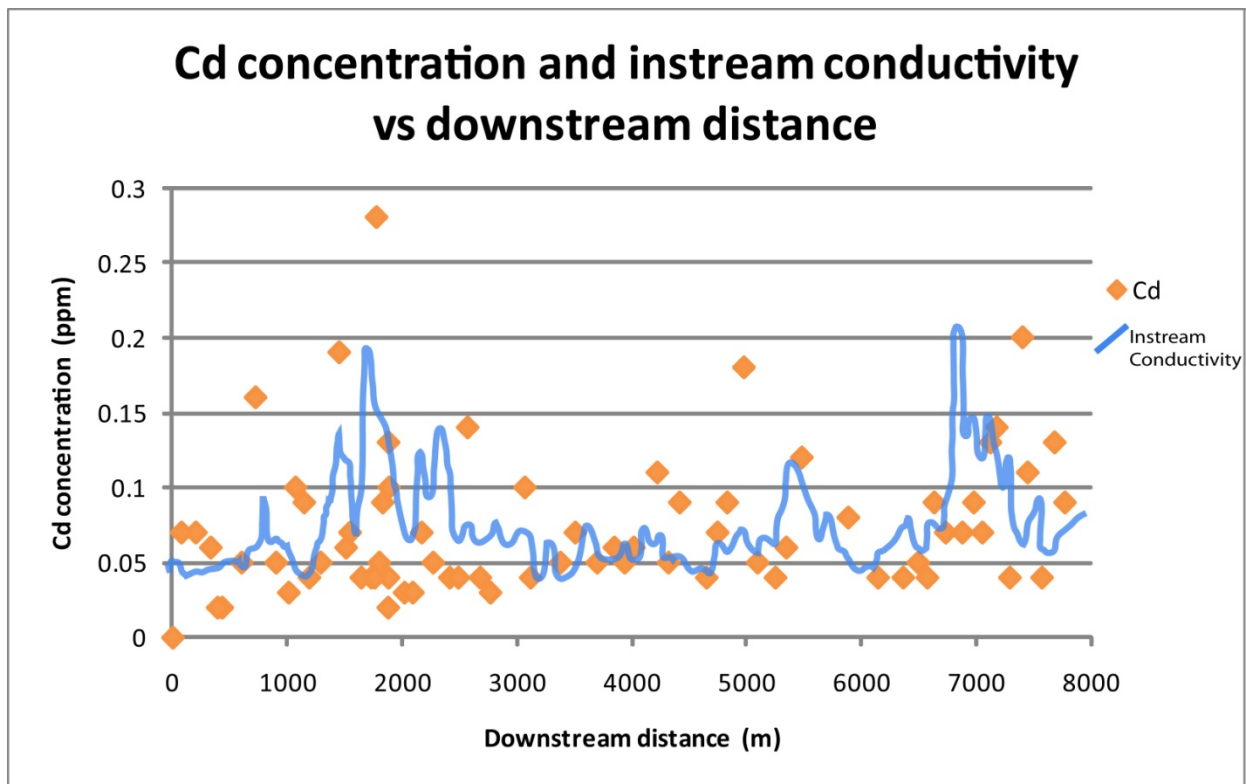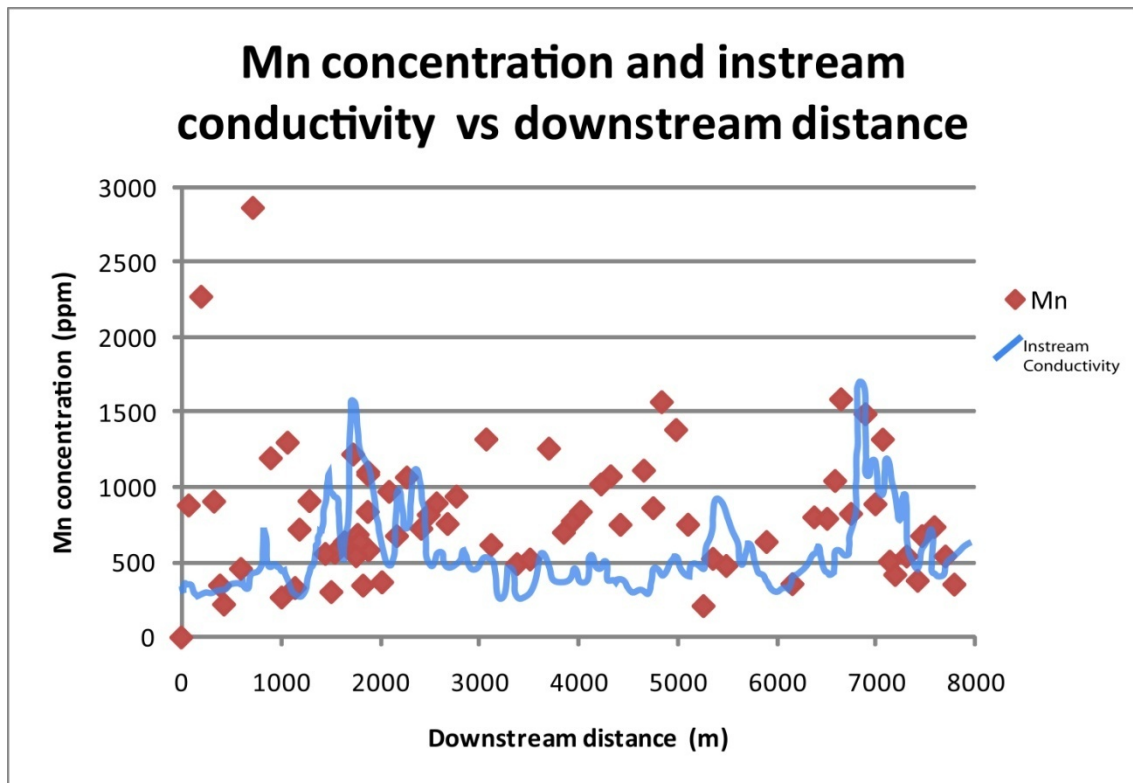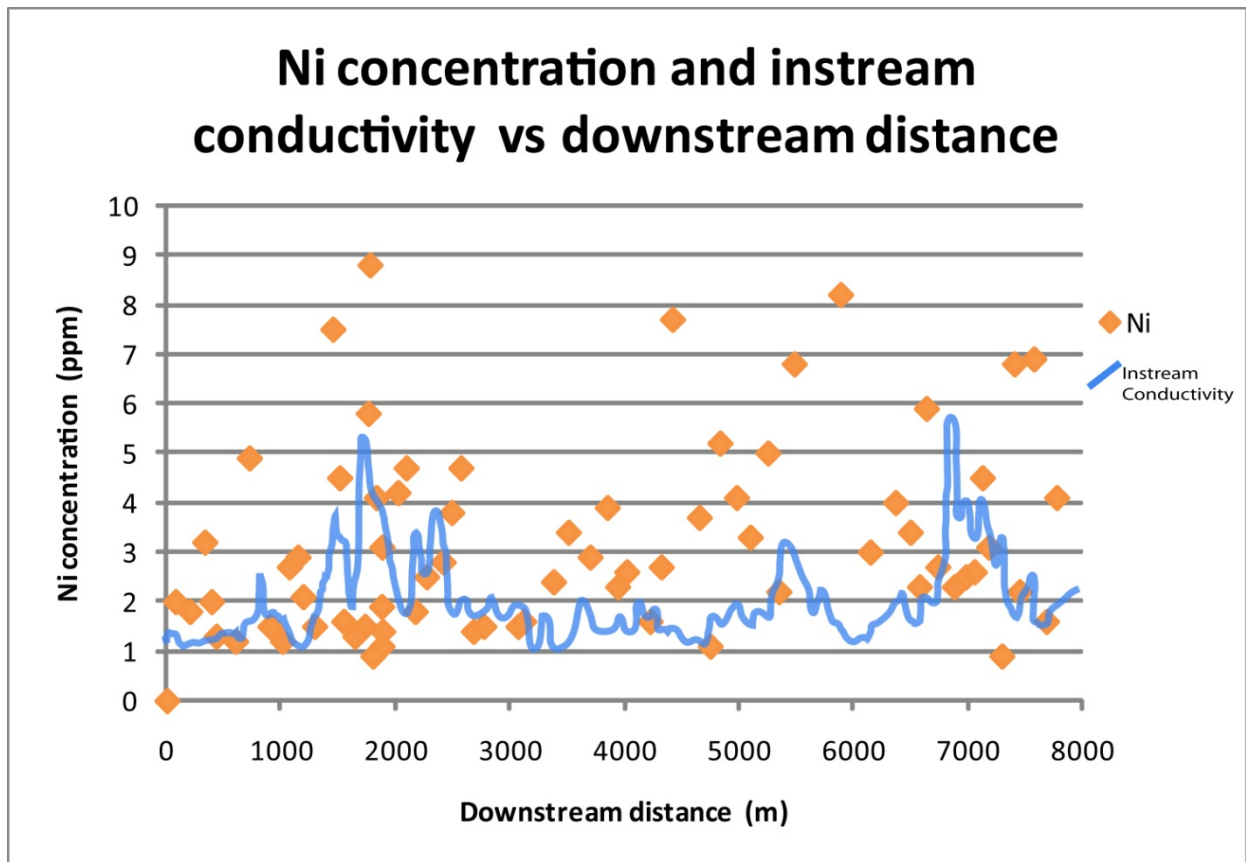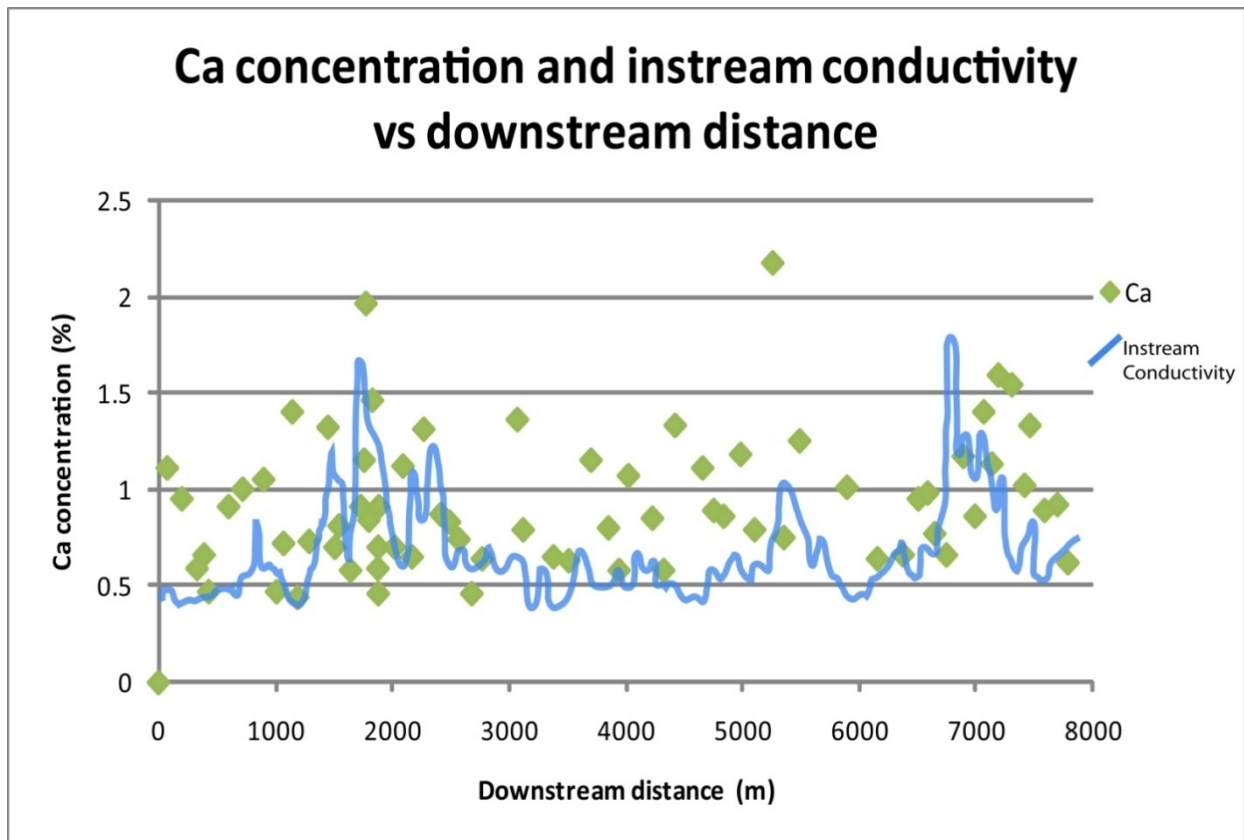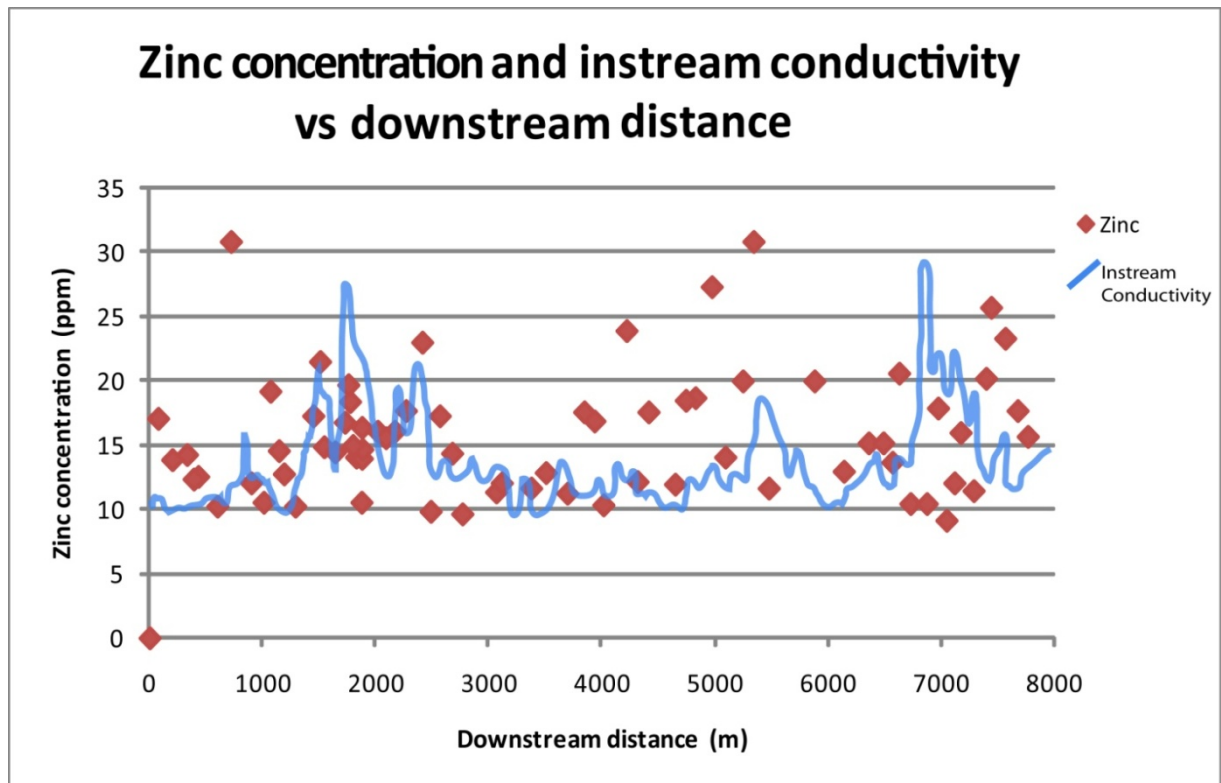
Figure 44

Regolith landform map and AEM survey (4.20-6.62 m)
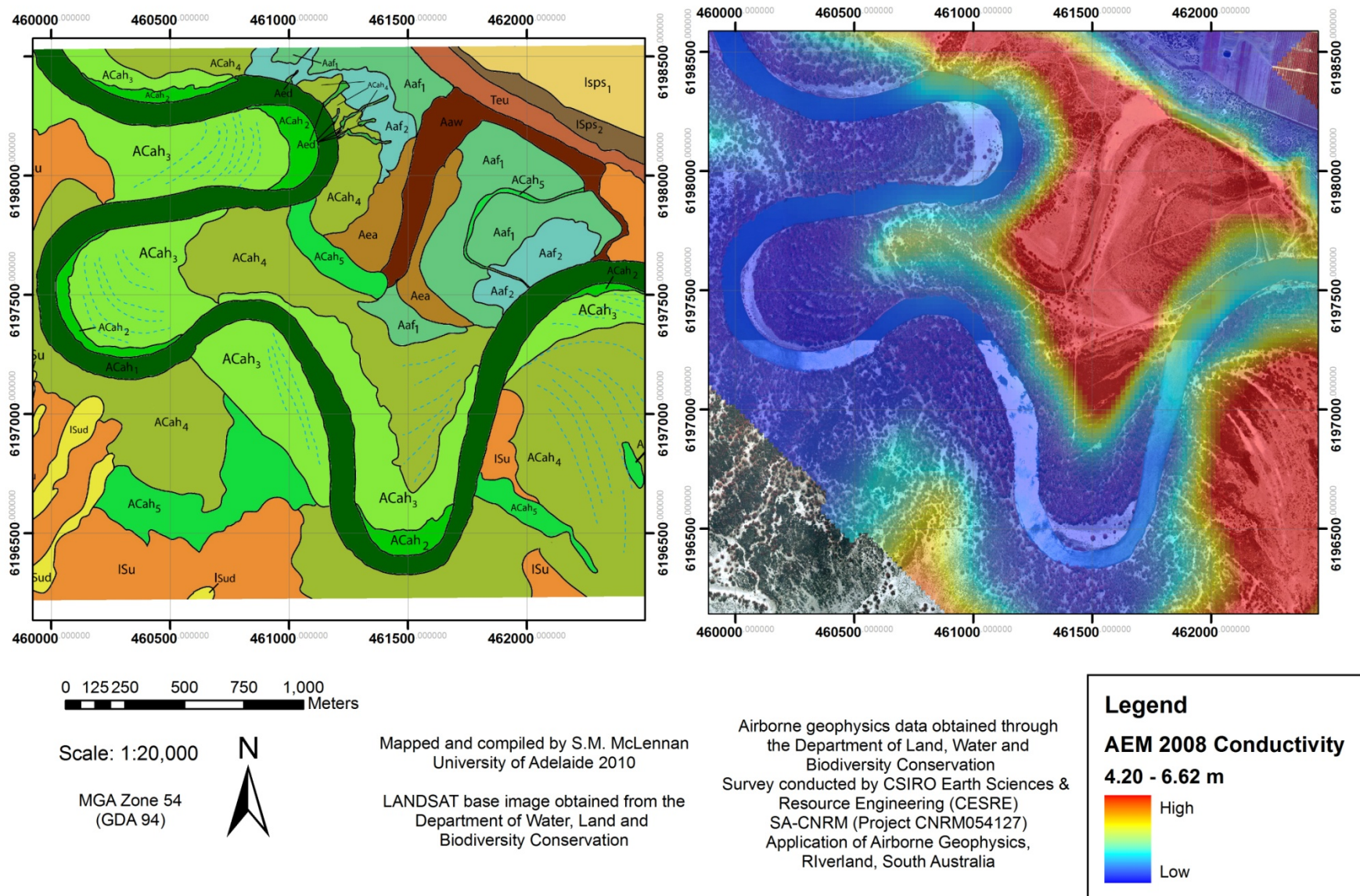
Figure 45

Regolith landform map and AEM survey (6.62-9.30 m)
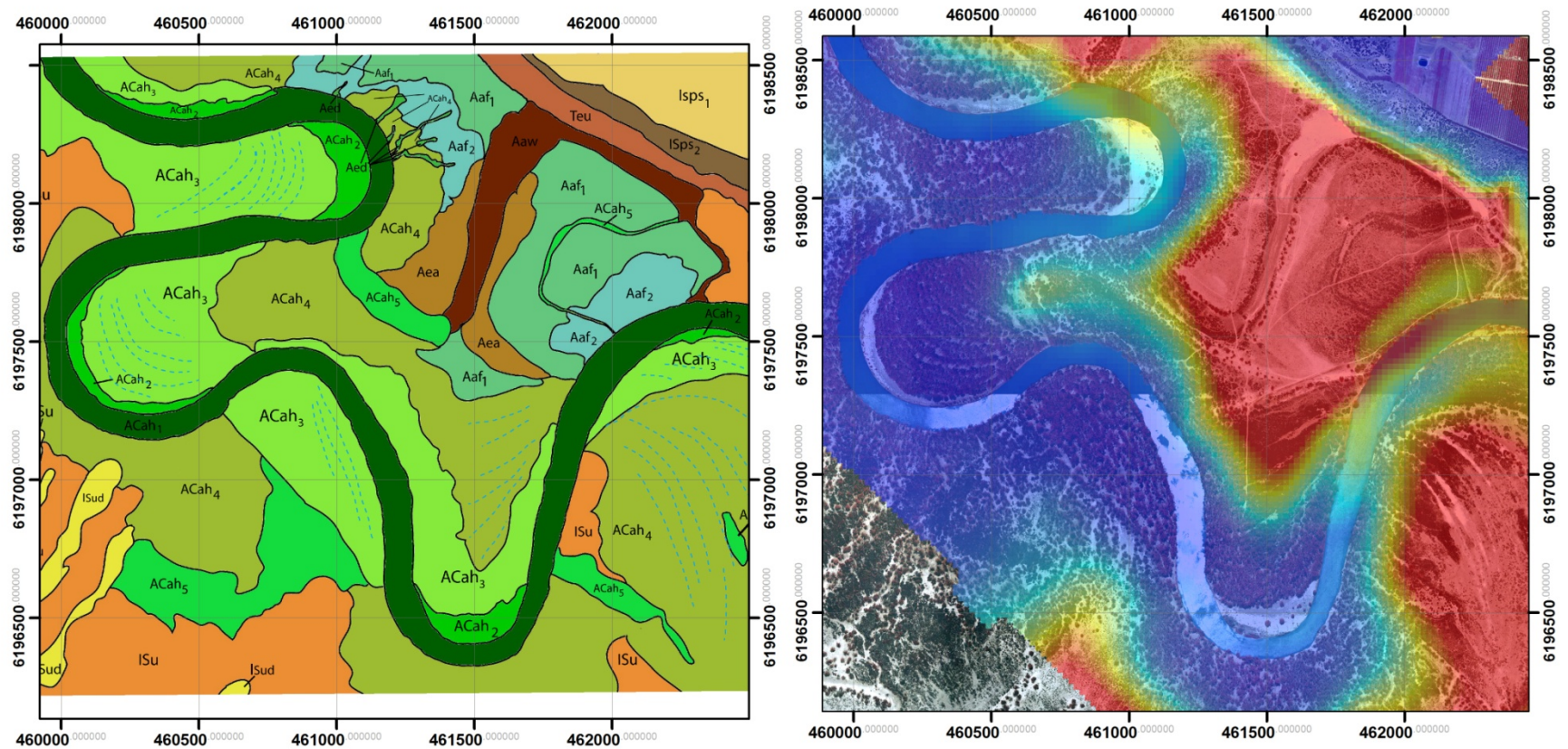
Scale: 1:20,000

MGA Zone 54
(GDA 94)

N

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University of Adelaide 2010

LANDSAT base image obtained from the
Department of Water, Land and
Biodiversity Conservation

Airborne geophysics data obtained through
the Department of Land, Water and
Biodiversity Conservation
Survey conducted by CSIRO Earth Sciences &
Resource Engineering (CESRE)
SA-CNRM (Project CNRM054127)
Application of Airborne Geophysics,
RIverland, South Australia

Legend

AEM 2008 Conductivity

6.62 - 9.30 m

High

Low
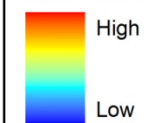
11. Tables

Table 1: Summary climate statistics for Bookpurnong Irrigation District (Source: Bureau of Meteorology)

Rainfall, April 2010	17.4mm
Evaporation, April 2010	119.1mm
Mean low temp, April 2010	11.5°C
Mean high temp, April 2010	24.7°C
Mean rainfall (from 1984 to 2010)	262.1mm
Mean monthly evap. (Aug '09 to Aug '10)	162.3mm per month

Table 2: Summary statistics for biogeochemistry results. Duplicate errors are calculated from blind sample duplicates. Standard errors are calculated from laboratory standards and blanks.

Element	Detection limit	Minimum	Maximum	Duplicate error	Standard error
Cu	0.01ppm	2.01	12.65	±0.13	±0.32
Mn	1ppm	209	2857	±163	±27
Fe	0.001%	0.002	0.014	N/A	±0.03
U	0.01ppm	BDL	0.07	N/A	N/A
Au	0.2ppb	BDL	1.5	N/A	±0.12
Cd	0.01ppm	0.02	0.28	±0.01	±0.01
Ca	0.01%	0.44	2.85	±0.04	±0.01
P	0.001%	0.069	0.263	±0.01	±0.003
La	0.01ppm	0.02	0.59	±0.02	±0.004
Mg	0.001%	0.152	0.509	±0.01	±0.01
Ba	0.1ppm	1	33.1	±1	±0.10
Ti	1ppm	3	11	±0.3	±0.6
Al	0.01%	BDL	0.01	N/A	N/A
Na	0.001%	0.13	0.729	±0.01	±0.004
K	0.01%	0.28	1.43	±0.02	±0.01
S	0.01%	0.06	0.23	±0.01	±0.02

Zr	0.01ppm	DL	0.1	±0.01	±0.01
Y	0.001ppm	0.011	0.513	±0.21	±0.003
Ce	0.01ppm	0.03	1.35	±0.05	±0.01
Mo	0.01ppm	BDL	0.36	±0.003	±0.12

Table 3: Key element associations derived from the dendrogram cluster analysis.

Species	Element cluster
E. camaldulensis	Mo, Na, Cu, K
	P, Ti
	Sr, Ca, Mg, Ba
	Ni, Co
E. largiflorens	Mo, Na, Co
	Mn, K
	P, Ti
	Sr, Ca, Mg
Both (combined results)	Mo, Co
	Na, K
	P, Ti
	Sr, Ca
	Ni, Cd

Table 4: Element behaviour based on split population normal probability plots.

Element	Species with higher concentration	Threshold concentration	
		E. camaldulensis	*E. largiflorens*
Cu	E. camaldulensis	5.20 ppm	3.90 ppm
Mn	E. camaldulensis	900.00 ppm	500.00 ppm
Fe	E. camaldulensis	n/a	n/a
Zr	E. camaldulensis	n/a	n/a
Ti	E. camaldulensis	n/a	n/a
Ba	E. camaldulensis	7.50 ppm	2.60 ppm
P	E. camaldulensis	0.14%	0.13%
Zn	E. largiflorens	17.50 ppm	20.00 ppm
Ni	E. largiflorens	3.00 ppm	1.50 ppm
Sr	E. largiflorens	40.00 ppm	60.00 ppm
Cd	E. largiflorens	0.10 ppm	0.13 ppm
Ca	E. largiflorens	0.90%	1.00%
K	E. largiflorens	0.78%	0.78%
Na	E. largiflorens	0.44%	0.45%
Mo	E. largiflorens	0.08 ppm	0.05 ppm
Co	Minimal distinction	n/a	n/a
S	Minimal distinction	n/a	n/a
Mg	Minimal distinction	0.31%	2.75%
Al	n/a	n/a	n/a

Table 5: Assessment criteria and scaling for Floodplain Salinity Index (FSR Index).

Key factor	Scale	Score
Frequency of medium to large scale floods (>60 GL/day)	< 3 years	1
	< 5 years	2
	5-10 years	3
	>10 years	4
Depth to the water table	>10 m	1
	5-10 m	2
	<5 m	3
	<3 m	4
Concentration of Na in vegetation (*E. camaldulensis*)	<0.45%	0
	>0.45%	2
Concentration of K in vegetation (*E. camaldulensis*)	<0.78%	0
	>0.78%	2
Concentration of Mo in vegetation (*E. camaldulensis*)	<0.05 ppm	0
	>0.05 ppm	2

12. APPENDICES

APPENDIX 1

NATURAL BREAKS (JENKS) CLASSIFICATION SPATIAL ASSOCIATION MAP

GEOMETRICAL INTERVAL CLASSIFICATION SPATIAL ASSOCIATION MAP

APPENDIX 1

NATURAL BREAKS (JENKS) CLASSIFICATION SPATIAL ASSOCIATION MAP

Spatial association map of Na concentration: Natural Breaks (Jenks) classification
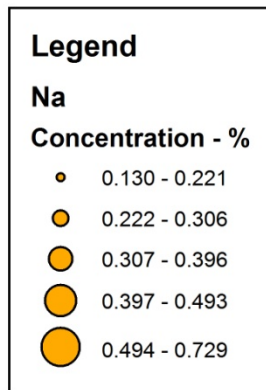
Legend

Na

Concentration - %

- o 0.130 - 0.221
- o 0.222 - 0.306
- O 0.307 - 0.396
- O 0.397 - 0.493
- O 0.494 - 0.729

Compiled by S.M. McLennan
University of Adelaide 2010

LANDSAT base image obtained from the
Department of Water, Land and
Biodiversity Conservation

MGA Zone 54
(GDA 94)

N

Scale: 1:15,000

0   125 250   500   750   1,000
Meters
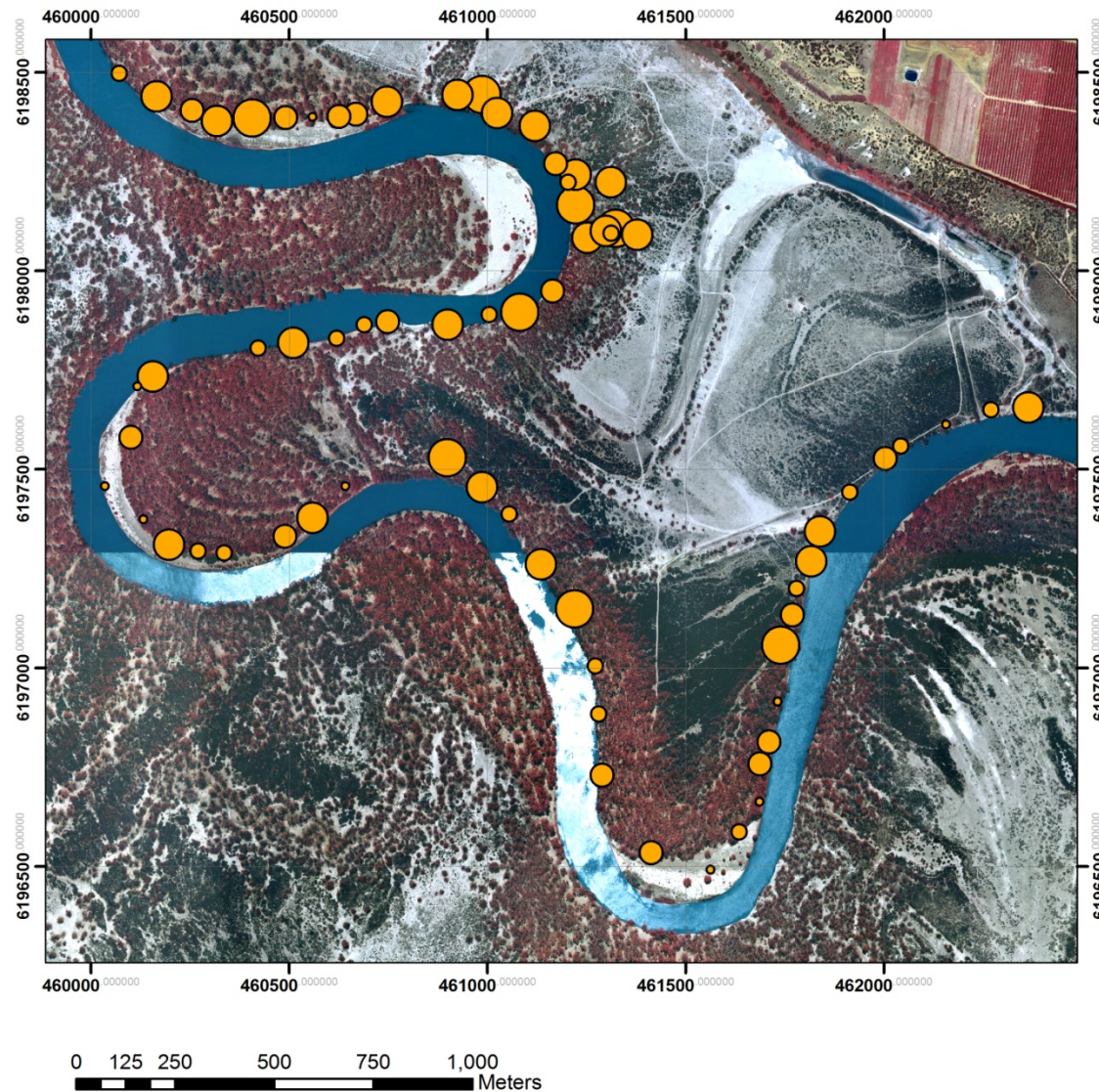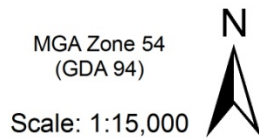
Spatial association map of Na concentration: Geometrical interval classification
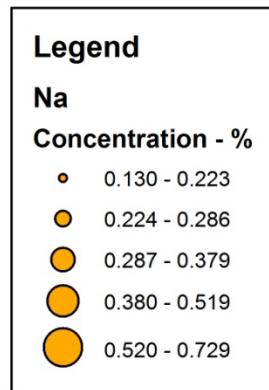
Legend

Na

Concentration - %

- 0.130 - 0.223
- 0.224 - 0.286
- 0.287 - 0.379
- 0.380 - 0.519
- 0.520 - 0.729

Compiled by S.M. McLennan
University of Adelaide 2010

LANDSAT base image obtained from the
Department of Water, Land and
Biodiversity Conservation

MGA Zone 54
(GDA 94)

N

Scale: 1:15,000

0   125   250   500   750   1,000
Meters
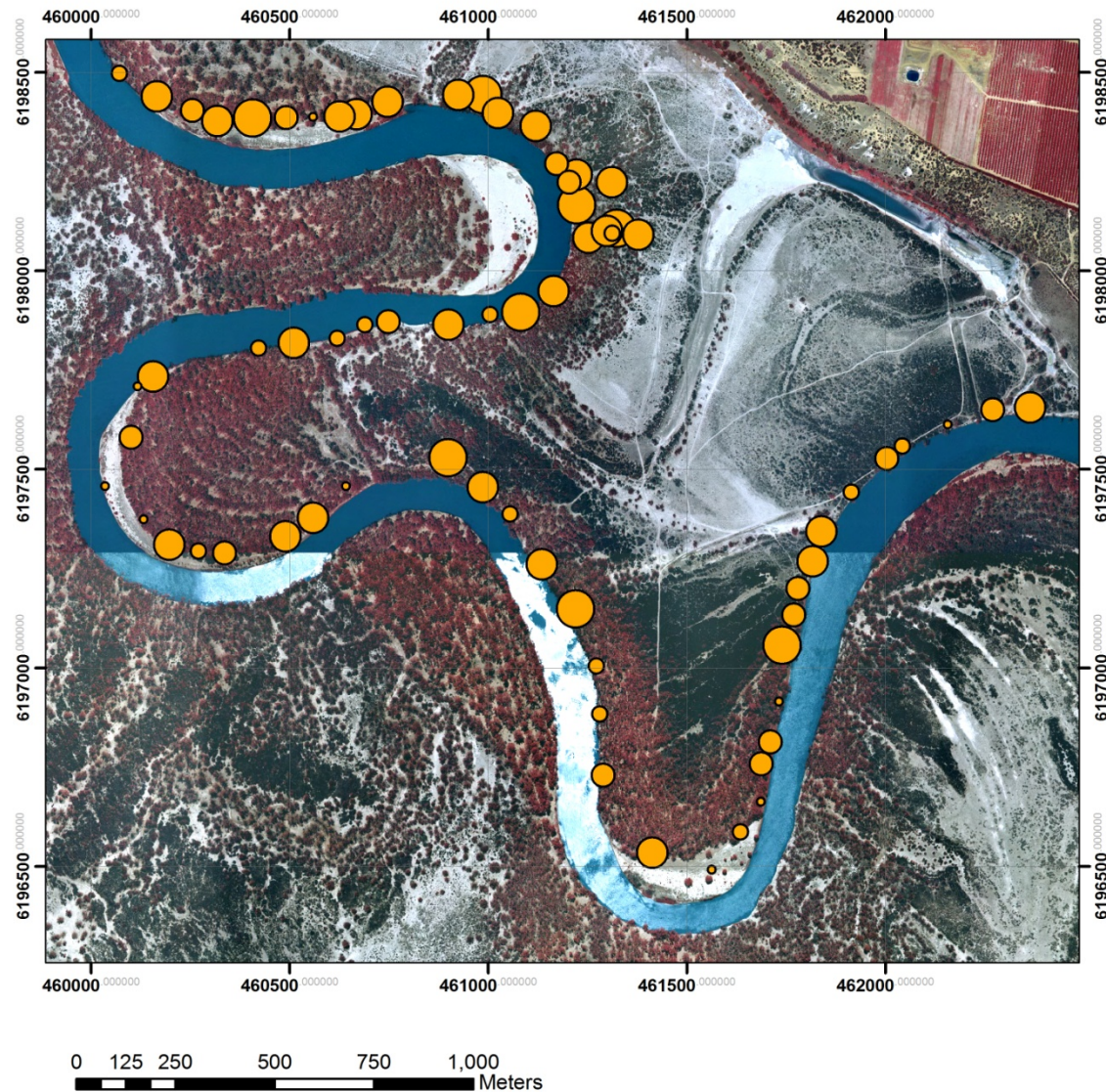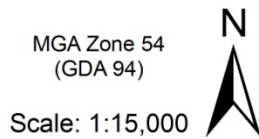
APPENDIX 2

BIOGEOCHEMISTRY ASSAY RESULTS

|				Element	Mo	Cu	Pb	Zn	Ag	Ni	Co	Mn	Fe	As	U
				Unit	ppm	ppm	ppm	ppm	ppb	ppm	ppm	ppm	%	ppm	ppm
				DL	0.01	0.01	0.01	0.1	2	0.1	0.01	1	0.001	0.1	0.01
Sample #	GDA E	GDA N	Species												
BOOK 001	459884	6198880	E. camaldulensis		0.04	3.31	0.07	13.8	<2	1.8	0.04	2266	0.005	0.2	<0.01
BOOK 002	459987	6198683	E. camaldulensis		0.03	5.33	0.03	17.0	<2	2.0	0.14	878	0.004	<0.1	<0.01
BOOK 003	459940	6198828	E. camaldulensis		0.03	4.04	0.09	12.0	<2	1.5	0.13	1192	0.006	0.5	<0.01
BOOK 004	460407	6198371	E. camaldulensis		0.02	10.98	0.07	14.2	2	3.2	0.19	904	0.006	<0.1	<0.01
BOOK 005	460073	6198606	E. camaldulensis		0.04	6.12	0.02	12.5	<2	1.3	0.14	219	0.004	<0.1	<0.01
BOOK 006	460072	6198484	E. camaldulensis		0.04	3.68	0.08	10.2	<2	1.5	0.10	907	0.007	0.2	<0.01
BOOK 007	460747	6198412	E. camaldulensis		0.03	3.13	0.05	10.2	<2	1.2	0.05	456	0.005	0.1	<0.01
BOOK 008	460166	6198426	E. camaldulensis		0.08	10.17	0.06	30.7	3	4.9	0.43	2857	0.009	0.1	0.05
BOOK 009	460256	6198390	E. camaldulensis		0.03	4.06	0.08	14.8	<2	1.6	0.15	563	0.012	0.2	0.01
BOOK 010	461025	6198384	E. largiflorens		0.10	3.87	0.03	12.3	<2	2.0	0.32	346	0.006	<0.1	<0.01
BOOK 012	460319	6198364	E. camaldulensis		0.03	12.65	0.09	18.6	<2	5.2	0.33	1565	0.005	<0.1	<0.01
BOOK 013	461055	6197374	E. camaldulensis		0.05	3.99	0.09	10.5	<2	1.2	0.07	266	0.002	<0.1	<0.01
BOOK 014	460492	6198372	E. camaldulensis		0.02	5.51	0.03	19.1	2	2.7	0.20	1296	0.003	<0.1	<0.01
BOOK 015	460559	6198374	E. camaldulensis		0.03	7.37	0.13	27.2	<2	4.1	0.43	1380	0.011	<0.1	0.02
BOOK 016	461135	6197247	E. largiflorens		0.09	5.12	0.03	14.5	<2	2.9	0.06	329	0.004	<0.1	<0.01
BOOK 017	460626	6198375	E. camaldulensis		0.05	7.97	0.07	12.7	<2	2.1	0.13	717	0.006	<0.1	<0.01
BOOK 018	460669	6198381	E. camaldulensis		0.03	5.33	0.07	14.0	<2	3.3	0.23	750	0.009	<0.1	<0.01
BOOK 019	461220	6197135	E. largiflorens		0.11	7.11	0.06	17.2	3	7.5	0.25	556	0.009	<0.1	<0.01
BOOK 020	460925	6198429	E. largiflorens		0.06	6.89	0.04	21.4	3	4.5	0.10	302	0.005	<0.1	<0.01
BOOK 021	460987	6198430	E. largiflorens		0.36	4.05	0.13	19.9	4	5.0	1.04	209	0.006	<0.1	<0.01
BOOK 022	461272	6196991	E. camaldulensis		0.04	6.95	0.02	16.7	<2	1.5	0.12	1217	0.005	0.2	0.01
BOOK 023	461172	6198256	E. camaldulensis		0.03	3.91	0.04	14.4	<2	1.3	0.07	633	0.007	0.8	<0.01
BOOK 024	461120	6198351	E. camaldulensis		0.02	2.97	0.03	30.7	<2	2.2	0.08	523	0.005	<0.1	<0.01
BOOK 025	461281	6196870	E. camaldulensis		0.04	7.25	0.04	16.0	<2	4.2	0.13	367	0.007	0.2	<0.01
BOOK 026	461165	6197935	E. largiflorens		0.18	4.73	0.07	14.0	<2	4.1	0.33	345	0.006	<0.1	<0.01
BOOK 027	461223	6198152	E. camaldulensis		0.13	3.32	0.07	11.6	<2	6.8	0.30	476	0.006	<0.1	0.02
BOOK 028	461289	6196716	E. camaldulensis		0.02	5.83	0.15	16.0	<2	1.8	0.13	674	0.008	<0.1	<0.01
BOOK 029	461005	6197876	E. camaldulensis		0.03	5.34	0.09	15.5	<2	4.7	0.23	969	0.008	0.3	<0.01
BOOK 030	461082	6197882	E. largiflorens		0.12	3.87	0.05	19.9	5	8.2	0.45	635	0.005	0.2	<0.01

			Element	Au	Th	Sr	Cd	Sb	Bi	V	Ca	P	La	Cr	Mg
			Unit	ppb	ppm	ppm	ppm	ppm	ppm	ppm	%	%	ppm	ppm	%
			DL	0.2	0.01	0.5	0.01	0.02	0.02	2	0.01	0.001	0.01	0.1	0.001
Sample #	GDA E	GDA N	Species												
BOOK 001	459884	6198880	E. camaldulensis	<0.2	<0.01	40.1	0.07	<0.02	<0.02	<2	0.95	0.131	0.08	0.9	0.273
BOOK 002	459987	6198683	E. camaldulensis	<0.2	<0.01	52.4	0.07	<0.02	<0.02	<2	1.11	0.152	0.07	0.9	0.348
BOOK 003	459940	6198828	E. camaldulensis	<0.2	<0.01	50.8	0.05	<0.02	<0.02	<2	1.05	0.115	0.08	1.1	0.282
BOOK 004	460407	6198371	E. camaldulensis	<0.2	<0.01	21.9	0.06	<0.02	<0.02	<2	0.59	0.263	0.22	1.1	0.192
BOOK 005	460073	6198606	E. camaldulensis	<0.2	<0.01	22.1	0.02	<0.02	<0.02	<2	0.47	0.143	0.03	1.3	0.175
BOOK 006	460072	6198484	E. camaldulensis	<0.2	<0.01	29.7	0.05	<0.02	<0.02	<2	0.73	0.165	0.09	1.1	0.198
BOOK 007	460747	6198412	E. camaldulensis	<0.2	<0.01	49.2	0.05	<0.02	<0.02	<2	0.91	0.102	0.04	1.1	0.154
BOOK 008	460166	6198426	E. camaldulensis	<0.2	<0.01	42.7	0.16	<0.02	<0.02	<2	1.00	0.245	0.59	0.9	0.282
BOOK 009	460256	6198390	E. camaldulensis	0.3	0.01	44.7	0.07	<0.02	<0.02	<2	0.81	0.256	0.11	1.5	0.214
BOOK 010	461025	6198384	E. largiflorens	0.2	<0.01	44.2	0.02	<0.02	<0.02	<2	0.66	0.108	0.13	1.1	0.279
BOOK 012	460319	6198364	E. camaldulensis	0.8	<0.01	34.4	0.09	<0.02	<0.02	<2	0.86	0.189	0.28	1.0	0.234
BOOK 013	461055	6197374	E. camaldulensis	<0.2	<0.01	43.4	0.03	<0.02	<0.02	<2	0.47	0.121	0.02	1.2	0.182
BOOK 014	460492	6198372	E. camaldulensis	<0.2	<0.01	31.2	0.10	<0.02	<0.02	<2	0.72	0.139	0.23	1.0	0.223
BOOK 015	460559	6198374	E. camaldulensis	1.5	<0.01	59.1	0.18	<0.02	<0.02	<2	1.18	0.124	0.52	1.2	0.254
BOOK 016	461135	6197247	E. largiflorens	<0.2	<0.01	77.9	0.09	<0.02	<0.02	<2	1.40	0.127	0.05	1.0	0.237
BOOK 017	460626	6198375	E. camaldulensis	<0.2	<0.01	21.8	0.04	<0.02	<0.02	<2	0.44	0.198	0.14	1.4	0.175
BOOK 018	460669	6198381	E. camaldulensis	1.2	<0.01	34.4	0.05	<0.02	<0.02	<2	0.79	0.190	0.22	1.2	0.242
BOOK 019	461220	6197135	E. largiflorens	<0.2	<0.01	52.6	0.19	<0.02	<0.02	<2	1.32	0.149	0.07	1.1	0.220
BOOK 020	460925	6198429	E. largiflorens	<0.2	<0.01	34.9	0.06	<0.02	<0.02	<2	0.70	0.116	0.03	1.1	0.258
BOOK 021	460987	6198430	E. largiflorens	1	0.01	117.3	0.04	<0.02	<0.02	<2	2.17	0.167	0.30	1.2	0.424
BOOK 022	461272	6196991	E. camaldulensis	<0.2	<0.01	60.9	0.04	<0.02	<0.02	<2	0.91	0.179	0.15	1.1	0.217
BOOK 023	461172	6198256	E. camaldulensis	<0.2	<0.01	63.6	0.04	<0.02	<0.02	<2	0.58	0.140	0.06	1.1	0.379
BOOK 024	461120	6198351	E. camaldulensis	<0.2	<0.01	71.6	0.06	<0.02	<0.02	<2	0.75	0.130	0.06	0.9	0.224
BOOK 025	461281	6196870	E. camaldulensis	<0.2	<0.01	38.3	0.03	<0.02	<0.02	<2	0.70	0.242	0.10	1.3	0.357
BOOK 026	461165	6197935	E. largiflorens	<0.2	<0.01	117.1	0.09	<0.02	<0.02	<2	1.46	0.112	0.06	1.0	0.221
BOOK 027	461223	6198152	E. camaldulensis	<0.2	<0.01	80.2	0.12	<0.02	<0.02	<2	1.25	0.127	0.11	1.0	0.219
BOOK 028	461289	6196716	E. camaldulensis	<0.2	<0.01	29.9	0.07	<0.02	<0.02	<2	0.65	0.221	0.10	1.0	0.427
BOOK 029	461005	6197876	E. camaldulensis	<0.2	<0.01	85.3	0.03	<0.02	<0.02	<2	1.12	0.126	0.17	1.1	0.289
BOOK 030	461082	6197882	E. largiflorens	0.4	<0.01	60.4	0.08	<0.02	<0.02	<2	1.01	0.104	0.08	1.1	0.276

			Element	Ba	Ti	B	Al	Na	K	W	Sc	Tl	S	Hg	Se
			Unit	ppm	ppm	ppm	%	%	%	ppm	ppm	ppm	%	ppb	ppm
			DL	0.1	1	1	0.01	0.001	0.01	0.1	0.1	0.02	0.01	1	0.1
Sample #	GDA E	GDA N	Species												
BOOK 001	459884	6198880	E. camaldulensis	29.6	5	27	<0.01	0.261	0.56	<0.1	<0.1	<0.02	0.13	13	0.3
BOOK 002	459987	6198683	E. camaldulensis	4.9	6	25	<0.01	0.348	0.47	<0.1	0.2	<0.02	0.15	11	0.3
BOOK 003	459940	6198828	E. camaldulensis	12.9	5	31	<0.01	0.134	0.38	<0.1	0.1	<0.02	0.17	20	0.3
BOOK 004	460407	6198371	E. camaldulensis	2.9	9	26	<0.01	0.729	0.47	<0.1	0.2	<0.02	0.14	23	0.2
BOOK 005	460073	6198606	E. camaldulensis	2.3	5	19	<0.01	0.345	0.77	<0.1	0.2	<0.02	0.13	11	0.2
BOOK 006	460072	6198484	E. camaldulensis	13.1	7	28	<0.01	0.257	0.64	<0.1	0.2	<0.02	0.12	15	0.2
BOOK 007	460747	6198412	E. camaldulensis	9.8	4	15	<0.01	0.430	0.59	<0.1	0.2	<0.02	0.12	11	0.2
BOOK 008	460166	6198426	E. camaldulensis	13.5	8	31	<0.01	0.483	0.77	<0.1	0.1	<0.02	0.23	19	0.3
BOOK 009	460256	6198390	E. camaldulensis	14.7	11	38	0.01	0.316	0.73	<0.1	0.2	<0.02	0.14	26	0.3
BOOK 010	461025	6198384	E. largiflorens	2.2	4	32	<0.01	0.456	0.69	<0.1	0.2	<0.02	0.15	9	0.3
BOOK 012	460319	6198364	E. camaldulensis	5.4	7	19	<0.01	0.408	0.87	<0.1	0.2	<0.02	0.12	16	0.3
BOOK 013	461055	6197374	E. camaldulensis	5.0	4	13	<0.01	0.278	0.77	<0.1	0.2	<0.02	0.13	3	0.3
BOOK 014	460492	6198372	E. camaldulensis	10.4	5	25	<0.01	0.369	0.58	<0.1	0.1	<0.02	0.16	14	0.2
BOOK 015	460559	6198374	E. camaldulensis	19.2	6	34	0.01	0.178	0.40	<0.1	0.1	<0.02	0.18	27	0.2
BOOK 016	461135	6197247	E. largiflorens	5.8	5	41	<0.01	0.437	0.77	<0.1	0.1	<0.02	0.19	21	0.3
BOOK 017	460626	6198375	E. camaldulensis	3.7	7	23	<0.01	0.385	0.70	<0.1	0.2	<0.02	0.17	12	0.2
BOOK 018	460669	6198381	E. camaldulensis	6.9	7	47	0.01	0.396	0.56	<0.1	0.1	<0.02	0.20	27	0.2
BOOK 019	461220	6197135	E. largiflorens	4.6	6	25	<0.01	0.578	0.88	<0.1	0.2	<0.02	0.12	18	0.4
BOOK 020	460925	6198429	E. largiflorens	1.0	4	27	<0.01	0.426	0.76	<0.1	0.2	<0.02	0.10	11	0.3
BOOK 021	460987	6198430	E. largiflorens	1.6	7	38	<0.01	0.522	0.55	<0.1	0.2	<0.02	0.14	14	0.4
BOOK 022	461272	6196991	E. camaldulensis	16.9	6	22	<0.01	0.282	0.68	<0.1	0.2	<0.02	0.16	17	0.2
BOOK 023	461172	6198256	E. camaldulensis	20.8	5	32	<0.01	0.321	0.54	<0.1	0.1	<0.02	0.14	13	0.1
BOOK 024	461120	6198351	E. camaldulensis	3.5	5	45	<0.01	0.433	0.62	<0.1	0.1	<0.02	0.15	18	0.3
BOOK 025	461281	6196870	E. camaldulensis	11.4	9	30	<0.01	0.283	0.61	<0.1	<0.1	<0.02	0.13	14	0.1
BOOK 026	461165	6197935	E. largiflorens	3.7	5	34	<0.01	0.387	0.91	<0.1	0.1	<0.02	0.13	18	0.2
BOOK 027	461223	6198152	E. camaldulensis	6.5	5	67	<0.01	0.533	0.63	<0.1	0.2	<0.02	0.12	18	0.1
BOOK 028	461289	6196716	E. camaldulensis	2.7	8	19	<0.01	0.371	0.59	<0.1	0.2	<0.02	0.13	15	0.3
BOOK 029	461005	6197876	E. camaldulensis	24.3	5	42	<0.01	0.250	0.41	<0.1	0.1	<0.02	0.06	17	0.1
BOOK 030	461082	6197882	E. largiflorens	2.6	4	56	<0.01	0.542	0.79	<0.1	0.2	<0.02	0.11	13	0.3

Element			Te	Ga	Cs	Ge	Hf	Nb	Rb	Sn	Ta	Zr	Y
Unit			ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
DL			0.02	0.1	0.005	0.01	0.001	0.01	0.1	0.02	0.001	0.01	0.001
Sample #	GDA E	GDA N	Species										
BOOK 001	459884	6198880	E. camaldulensis	<0.02	<0.1	0.011	<0.01	0.001	<0.01	2.1	<0.02	<0.001	0.04	0.101
BOOK 002	459987	6198683	E. camaldulensis	<0.02	<0.1	0.009	0.01	<0.001	<0.01	2.8	<0.02	<0.001	0.02	0.049
BOOK 003	459940	6198828	E. camaldulensis	<0.02	<0.1	0.008	<0.01	<0.001	<0.01	1.5	0.04	<0.001	0.05	0.068
BOOK 004	460407	6198371	E. camaldulensis	<0.02	<0.1	0.005	0.02	0.001	<0.01	1.7	<0.02	<0.001	0.04	0.178
BOOK 005	460073	6198606	E. camaldulensis	<0.02	<0.1	0.015	0.02	<0.001	<0.01	6.6	<0.02	<0.001	0.05	0.024
BOOK 006	460072	6198484	E. camaldulensis	<0.02	<0.1	0.025	0.02	<0.001	<0.01	7.6	0.02	<0.001	0.06	0.070
BOOK 007	460747	6198412	E. camaldulensis	<0.02	<0.1	<0.005	<0.01	0.001	<0.01	1.8	<0.02	<0.001	0.04	0.027
BOOK 008	460166	6198426	E. camaldulensis	<0.02	<0.1	0.009	0.01	0.002	<0.01	5.2	<0.02	<0.001	0.04	0.513
BOOK 009	460256	6198390	E. camaldulensis	<0.02	<0.1	0.012	<0.01	0.003	<0.01	2.9	<0.02	<0.001	0.08	0.104
BOOK 010	461025	6198384	E. largiflorens	<0.02	<0.1	0.006	0.01	0.002	<0.01	0.7	<0.02	<0.001	0.04	0.067
BOOK 012	460319	6198364	E. camaldulensis	<0.02	<0.1	0.009	0.02	0.001	<0.01	4.8	<0.02	<0.001	0.03	0.188
BOOK 013	461055	6197374	E. camaldulensis	<0.02	<0.1	0.012	<0.01	<0.001	<0.01	3.4	<0.02	<0.001	0.01	0.018
BOOK 014	460492	6198372	E. camaldulensis	<0.02	<0.1	0.006	<0.01	<0.001	<0.01	3.2	<0.02	<0.001	0.03	0.159
BOOK 015	460559	6198374	E. camaldulensis	0.02	<0.1	0.011	<0.01	0.001	<0.01	1.3	<0.02	<0.001	0.07	0.429
BOOK 016	461135	6197247	E. largiflorens	<0.02	<0.1	0.009	0.03	0.001	<0.01	2.8	<0.02	<0.001	0.05	0.025
BOOK 017	460626	6198375	E. camaldulensis	<0.02	<0.1	0.010	<0.01	0.003	<0.01	2.0	<0.02	<0.001	0.05	0.121
BOOK 018	460669	6198381	E. camaldulensis	<0.02	<0.1	0.008	<0.01	0.002	<0.01	1.3	<0.02	<0.001	0.06	0.209
BOOK 019	461220	6197135	E. largiflorens	<0.02	<0.1	0.031	0.01	<0.001	<0.01	9.5	<0.02	<0.001	0.05	0.048
BOOK 020	460925	6198429	E. largiflorens	<0.02	<0.1	<0.005	0.01	<0.001	<0.01	0.5	<0.02	<0.001	0.02	0.023
BOOK 021	460987	6198430	E. largiflorens	0.03	<0.1	0.007	0.02	0.001	<0.01	0.5	<0.02	<0.001	0.05	0.156
BOOK 022	461272	6196991	E. camaldulensis	<0.02	<0.1	0.020	<0.01	0.001	<0.01	6.7	<0.02	<0.001	0.04	0.095
BOOK 023	461172	6198256	E. camaldulensis	<0.02	<0.1	0.008	0.02	0.003	<0.01	1.3	<0.02	<0.001	0.04	0.037
BOOK 024	461120	6198351	E. camaldulensis	<0.02	<0.1	<0.005	0.02	0.001	<0.01	0.5	<0.02	<0.001	0.04	0.038
BOOK 025	461281	6196870	E. camaldulensis	<0.02	<0.1	0.009	0.03	0.002	<0.01	2.5	<0.02	<0.001	0.04	0.064
BOOK 026	461165	6197935	E. largiflorens	<0.02	<0.1	0.008	<0.01	0.002	<0.01	2.0	<0.02	<0.001	0.06	0.039
BOOK 027	461223	6198152	E. camaldulensis	0.02	<0.1	0.005	0.02	0.001	<0.01	0.5	<0.02	<0.001	0.04	0.067
BOOK 028	461289	6196716	E. camaldulensis	<0.02	<0.1	0.006	0.01	0.001	<0.01	1.3	0.17	<0.001	0.04	0.073
BOOK 029	461005	6197876	E. camaldulensis	<0.02	<0.1	0.007	<0.01	0.003	<0.01	0.7	<0.02	<0.001	0.05	0.160
BOOK 030	461082	6197882	E. largiflorens	<0.02	<0.1	<0.005	<0.01	0.002	<0.01	0.9	<0.02	<0.001	0.04	0.045

			Element	Ce	In	Re	Be	Li	Pd	Pt
			Unit	ppm	ppm	ppb	ppm	ppm	ppb	ppb
			DL	0.01	0.02	1	0.1	0.01	2	1
Sample #	GDA E	GDA N	Species							
BOOK 001	459884	6198880	E. camaldulensis	0.17	<0.02	<1	<0.1	1.28	<2	<1
BOOK 002	459987	6198683	E. camaldulensis	0.10	<0.02	1	<0.1	2.22	<2	<1
BOOK 003	459940	6198828	E. camaldulensis	0.18	<0.02	<1	<0.1	2.59	<2	<1
BOOK 004	460407	6198371	E. camaldulensis	0.39	<0.02	<1	<0.1	4.21	<2	<1
BOOK 005	460073	6198606	E. camaldulensis	0.08	<0.02	<1	<0.1	0.33	<2	<1
BOOK 006	460072	6198484	E. camaldulensis	0.17	<0.02	<1	<0.1	2.22	<2	<1
BOOK 007	460747	6198412	E. camaldulensis	0.09	<0.02	<1	<0.1	0.44	<2	<1
BOOK 008	460166	6198426	E. camaldulensis	1.35	<0.02	<1	<0.1	4.51	<2	<1
BOOK 009	460256	6198390	E. camaldulensis	0.25	<0.02	1	<0.1	3.31	<2	<1
BOOK 010	461025	6198384	E. largiflorens	0.23	<0.02	<1	<0.1	1.26	<2	<1
BOOK 012	460319	6198364	E. camaldulensis	0.52	<0.02	1	<0.1	3.05	<2	<1
BOOK 013	461055	6197374	E. camaldulensis	0.03	<0.02	<1	<0.1	0.73	<2	<1
BOOK 014	460492	6198372	E. camaldulensis	0.43	<0.02	1	<0.1	4.64	<2	<1
BOOK 015	460559	6198374	E. camaldulensis	1.01	<0.02	2	0.1	9.47	<2	<1
BOOK 016	461135	6197247	E. largiflorens	0.07	<0.02	<1	<0.1	1.68	<2	<1
BOOK 017	460626	6198375	E. camaldulensis	0.26	<0.02	<1	<0.1	3.13	<2	<1
BOOK 018	460669	6198381	E. camaldulensis	0.45	<0.02	2	<0.1	5.13	<2	<1
BOOK 019	461220	6197135	E. largiflorens	0.14	<0.02	1	<0.1	1.28	<2	<1
BOOK 020	460925	6198429	E. largiflorens	0.05	<0.02	<1	<0.1	0.61	<2	<1
BOOK 021	460987	6198430	E. largiflorens	0.59	<0.02	<1	<0.1	1.53	<2	<1
BOOK 022	461272	6196991	E. camaldulensis	0.27	<0.02	<1	<0.1	2.25	<2	<1
BOOK 023	461172	6198256	E. camaldulensis	0.10	<0.02	<1	<0.1	1.37	<2	<1
BOOK 024	461120	6198351	E. camaldulensis	0.09	<0.02	<1	<0.1	2.22	<2	<1
BOOK 025	461281	6196870	E. camaldulensis	0.18	<0.02	2	<0.1	2.58	<2	<1
BOOK 026	461165	6197935	E. largiflorens	0.11	<0.02	<1	<0.1	0.77	<2	<1
BOOK 027	461223	6198152	E. camaldulensis	0.18	<0.02	<1	<0.1	2.17	<2	<1
BOOK 028	461289	6196716	E. camaldulensis	0.18	<0.02	1	<0.1	2.36	<2	<1
BOOK 029	461005	6197876	E. camaldulensis	0.32	<0.02	1	<0.1	4.04	<2	<1
BOOK 030	461082	6197882	E. largiflorens	0.13	<0.02	<1	<0.1	1.39	<2	<1

			Element	Mo	Cu	Pb	Zn	Ag	Ni	Co	Mn	Fe	As	U
			Unit	ppm	ppm	ppm	ppm	ppb	ppm	ppm	ppm	%	ppm	ppm
			DL	0.01	0.01	0.01	0.1	2	0.1	0.01	1	0.001	0.1	0.01
Sample #	GDA E	GDA N	Species											
BOOK 031	461413	6196521	E. camaldulensis	0.02	5.33	0.05	22.9	<2	2.8	0.28	723	0.009	<0.1	<0.01
BOOK 032	460749	6197858	E. camaldulensis	0.04	6.65	0.02	17.6	<2	2.5	0.08	1064	0.003	0.8	<0.01
BOOK 033	460900	6197851	E. camaldulensis	0.02	3.65	0.03	12.9	2	3.0	0.11	355	0.004	0.3	<0.01
BOOK 034	461563	6196478	E. camaldulensis	0.01	4.52	0.34	17.2	2	4.7	0.44	892	0.011	0.7	0.02
BOOK 035	460620	6197816	E. camaldulensis	0.02	4.56	0.02	9.8	<2	3.8	0.21	815	0.011	0.5	<0.01
BOOK 036	460690	6197851	E. camaldulensis	0.02	5.08	0.03	15.1	<2	4.0	0.10	799	0.011	0.7	<0.01
BOOK 037	461635	6196573	E. camaldulensis	0.03	4.70	0.04	14.3	3	1.4	0.05	755	0.005	<0.1	<0.01
BOOK 038	460511	6197805	E. camaldulensis	0.02	6.22	<0.01	9.6	<2	1.5	0.03	937	0.004	<0.1	<0.01
BOOK 039	460422	6197792	E. camaldulensis	0.02	6.04	0.03	15.1	<2	3.4	0.16	789	0.007	0.3	<0.01
BOOK 040	461686	6196650	E. camaldulensis	0.07	2.01	0.06	11.3	<2	1.5	0.18	1317	0.012	0.9	<0.01
BOOK 041	460157	6197720	E. camaldulensis	0.03	6.41	<0.01	12.0	<2	1.6	0.08	615	0.004	0.3	<0.01
BOOK 042	460118	6197696	E. camaldulensis	0.02	5.33	0.03	13.6	<2	2.3	0.20	1041	0.011	0.3	0.01
BOOK 043	461687	6196745	E. camaldulensis	0.03	5.09	0.01	11.6	<2	2.4	0.09	488	0.006	0.2	<0.01
BOOK 044	460102	6197567	E. camaldulensis	<0.01	5.37	0.02	12.8	<2	3.4	0.26	519	0.006	0.2	<0.01
BOOK 045	460036	6197444	E. camaldulensis	0.02	4.11	0.03	20.5	16	5.9	0.49	1584	0.005	0.3	0.01
BOOK 046	461710	6196800	E. camaldulensis	0.02	4.89	0.06	11.2	<2	2.9	0.72	1256	0.008	0.3	0.01
BOOK 047	460133	6197361	E. camaldulensis	0.02	5.42	0.03	17.5	<2	3.9	0.30	697	0.011	0.1	0.01
BOOK 048	460198	6197297	E. camaldulensis	0.02	5.93	0.06	10.4	<2	2.7	0.17	822	0.009	0.4	<0.01
BOOK 049	461732	6196902	E. camaldulensis	0.03	7.86	0.02	16.8	<2	2.3	0.21	773	0.012	0.5	<0.01
BOOK 050	460271	6197281	E. camaldulensis	0.03	5.20	0.02	10.3	<2	2.6	0.22	835	0.012	0.4	0.01
BOOK 051	460337	6197276	E. camaldulensis	0.02	4.93	0.02	10.4	5	2.3	0.21	1485	0.007	0.3	<0.01
BOOK 052	461740	6197044	E. camaldulensis	0.03	3.50	0.01	12.1	<2	2.7	0.09	1072	0.007	0.3	0.02
BOOK 053	460559	6197364	E. camaldulensis	0.02	4.49	<0.01	23.8	<2	1.6	0.09	1018	0.009	0.3	<0.01
BOOK 054	460490	6197318	E. camaldulensis	0.02	5.70	<0.01	17.8	<2	2.5	0.33	886	0.006	0.2	<0.01
BOOK 055	461769	6197120	E. camaldulensis	0.03	4.56	0.04	11.9	<2	3.7	0.16	1110	0.009	0.5	0.02
BOOK 056	460899	6197516	E. camaldulensis	0.25	8.05	0.01	17.5	<2	7.7	0.25	749	0.008	<0.1	<0.01
BOOK 057	460642	6197444	E. camaldulensis	0.03	2.94	0.2	9.1	<2	2.6	0.30	1316	0.006	0.3	0.02
BOOK 058	461780	6197186	E. camaldulensis	0.07	4.18	0.02	18.4	<2	1.1	0.03	860	0.007	0.5	<0.01
BOOK 059	460987	6197441	E. camaldulensis	0.03	5.79	0.01	10.5	<2	1.9	0.11	835	0.004	<0.1	<0.01

			Element	Au	Th	Sr	Cd	Sb	Bi	V	Ca	P	La	Cr	Mg
			Unit	ppb	ppm	ppm	ppm	ppm	ppm	ppm	%	%	ppm	ppm	%
			DL	0.2	0.01	0.5	0.01	0.02	0.02	2	0.01	0.001	0.01	0.1	0.001
Sample #	GDA E	GDA N	Species												
BOOK 031	461413	6196521	E. camaldulensis	0.3	<0.01	91.5	0.05	<0.2	<0.01	37.1	0.04	<0.02	<0.02	<2	0.870
BOOK 032	460749	6197858	E. camaldulensis	0.6	<0.01	50.8	0.04	<0.02	<0.02	<2	1.31	0.197	0.05	1.0	0.430
BOOK 033	460900	6197851	E. camaldulensis	0.3	<0.01	36.4	0.14	<0.02	<0.02	<2	0.64	0.138	0.05	1.2	0.352
BOOK 034	461563	6196478	E. camaldulensis	<0.2	<0.01	43.3	0.04	0.02	<0.02	<2	0.74	0.151	0.24	1.2	0.226
BOOK 035	460620	6197816	E. camaldulensis	0.3	<0.01	33.3	0.04	<0.02	<0.02	<2	0.83	0.195	0.21	1.0	0.237
BOOK 036	460690	6197851	E. camaldulensis	<0.2	<0.01	19.6	0.04	<0.02	<0.02	<2	0.66	0.178	0.14	1.0	0.303
BOOK 037	461635	6196573	E. camaldulensis	<0.2	<0.01	31.9	0.03	<0.02	<0.02	<2	0.46	0.133	0.10	1.1	0.160
BOOK 038	460511	6197805	E. camaldulensis	0.4	<0.01	43.7	0.05	<0.02	<0.02	<2	0.64	0.134	0.04	1.1	0.254
BOOK 039	460422	6197792	E. camaldulensis	<0.2	0.01	76.3	0.10	<0.02	<0.02	<2	0.95	0.118	0.15	1.0	0.233
BOOK 040	461686	6196650	E. camaldulensis	0.3	<0.01	43	0.04	<0.02	<0.02	<2	1.36	0.097	0.10	1.2	0.390
BOOK 041	460157	6197720	E. camaldulensis	0.7	0.01	46.5	0.04	<0.02	<0.02	<2	0.79	0.205	0.12	1.1	0.328
BOOK 042	460118	6197696	E. camaldulensis	0.2	<0.01	34.1	0.05	<0.02	<0.02	<2	0.98	0.135	0.08	1.1	0.326
BOOK 043	461687	6196745	E. camaldulensis	<0.2	<0.01	26.7	0.07	<0.02	<0.02	<2	0.65	0.126	0.13	1.2	0.190
BOOK 044	460102	6197567	E. camaldulensis	0.3	<0.01	32.6	0.09	<0.02	<0.02	<2	0.63	0.205	0.18	1.1	0.260
BOOK 045	460036	6197444	E. camaldulensis	<0.2	<0.01	61.4	0.05	<0.02	<0.02	<2	0.77	0.121	0.58	0.8	0.205
BOOK 046	461710	6196800	E. camaldulensis	<0.2	0.01	35.4	0.06	<0.02	<0.02	<2	1.15	0.167	0.15	1.0	0.405
BOOK 047	460133	6197361	E. camaldulensis	0.5	<0.01	37.8	0.07	<0.02	<0.02	<2	0.80	0.120	0.17	1.3	0.262
BOOK 048	460198	6197297	E. camaldulensis	0.4	<0.01	24.1	0.05	<0.02	<0.02	<2	0.66	0.170	0.14	1.3	0.277
BOOK 049	461732	6196902	E. camaldulensis	0.2	0.01	54.8	0.06	<0.02	<0.02	<2	0.58	0.125	0.15	1.1	0.300
BOOK 050	460271	6197281	E. camaldulensis	0.6	<0.01	59.6	0.07	<0.02	<0.02	<2	1.07	0.140	0.15	1.1	0.270
BOOK 051	460337	6197276	E. camaldulensis	0.3	<0.01	30.3	0.05	<0.02	<0.02	<2	1.17	0.101	0.20	1.0	0.152
BOOK 052	461740	6197044	E. camaldulensis	<0.2	<0.01	47.5	0.11	<0.02	<0.02	<2	0.58	0.165	0.16	1.1	0.166
BOOK 053	460559	6197364	E. camaldulensis	0.3	<0.01	39.3	0.09	<0.02	<0.02	<2	0.85	0.131	0.11	1.1	0.509
BOOK 054	460490	6197318	E. camaldulensis	<0.2	<0.01	52.5	0.04	<0.02	<0.02	<2	0.86	0.157	0.12	1.1	0.208
BOOK 055	461769	6197120	E. camaldulensis	0.2	0.01	67.3	0.09	<0.02	<0.02	<2	1.11	0.220	0.12	1.1	0.250
BOOK 056	460899	6197516	E. camaldulensis	1	<0.01	72.8	0.07	<0.02	<0.02	<2	1.33	0.165	0.07	1.0	0.282
BOOK 057	460642	6197444	E. camaldulensis	0.4	<0.01	48.6	0.07	<0.02	<0.02	<2	1.40	0.231	0.09	1.0	0.263
BOOK 058	461780	6197186	E. camaldulensis	<0.2	<0.01	38.7	0.02	<0.02	<0.02	<2	0.89	0.181	0.06	1.0	0.290
BOOK 059	460987	6197441	E. camaldulensis	0.2	<0.01	50.3	0.13	<0.02	<0.02	<2	0.59	0.170	0.12	1.0	0.261

			Element	Ba	Ti	B	Al	Na	K	W	Sc	Tl	S	Hg	Se
			Unit	ppm	ppm	ppm	%	%	%	ppm	ppm	ppm	%	ppb	ppm
			DL	0.1	1	1	0.01	0.001	0.01	0.1	0.1	0.02	0.01	1	0.1
Sample #	GDA E	GDA N	Species												
BOOK 031	461413	6196521	E. camaldulensis	0.1	0.15	1.20	0.24	10.10	5	28	0.01	0.396	0.46	<0.1	0.2
BOOK 032	460749	6197858	E. camaldulensis	33.1	7	20	<0.01	0.315	0.53	<0.1	0.1	<0.02	0.12	14	0.3
BOOK 033	460900	6197851	E. camaldulensis	15.8	5	33	<0.01	0.428	0.40	<0.1	0.1	<0.02	0.09	13	0.2
BOOK 034	461563	6196478	E. camaldulensis	16.5	6	51	0.01	0.221	0.63	<0.1	0.1	<0.02	0.15	22	0.1
BOOK 035	460620	6197816	E. camaldulensis	17.3	7	22	<0.01	0.233	0.69	<0.1	0.1	<0.02	0.13	29	0.3
BOOK 036	460690	6197851	E. camaldulensis	13.5	7	39	<0.01	0.262	0.57	<0.1	<0.1	<0.02	0.11	32	0.2
BOOK 037	461635	6196573	E. camaldulensis	5.8	5	20	<0.01	0.244	1.07	<0.1	0.2	<0.02	0.16	9	0.3
BOOK 038	460511	6197805	E. camaldulensis	26.3	5	22	<0.01	0.413	0.62	<0.1	0.2	<0.02	0.11	15	0.3
BOOK 039	460422	6197792	E. camaldulensis	24.5	5	33	<0.01	0.237	0.66	<0.1	0.2	<0.02	0.12	28	0.2
BOOK 040	461686	6196650	E. camaldulensis	11.2	4	39	0.01	0.202	0.36	<0.1	<0.1	<0.02	0.17	28	0.3
BOOK 041	460157	6197720	E. camaldulensis	11.6	7	24	<0.01	0.450	0.51	<0.1	0.3	<0.02	0.16	11	0.4
BOOK 042	460118	6197696	E. camaldulensis	10.2	6	33	0.01	0.130	0.28	<0.1	0.2	<0.02	0.17	20	0.3
BOOK 043	461687	6196745	E. camaldulensis	7.8	5	29	<0.01	0.366	0.66	<0.1	0.1	<0.02	0.11	17	0.2
BOOK 044	460102	6197567	E. camaldulensis	3.5	7	29	<0.01	0.365	0.87	<0.1	0.2	<0.02	0.16	18	0.2
BOOK 045	460036	6197444	E. camaldulensis	14.5	4	39	<0.01	0.196	0.56	<0.1	<0.1	<0.02	0.10	13	0.3
BOOK 046	461710	6196800	E. camaldulensis	12.1	6	39	<0.01	0.344	0.49	<0.1	0.2	<0.02	0.11	19	0.2
BOOK 047	460133	6197361	E. camaldulensis	14.8	5	32	0.01	0.220	0.58	<0.1	<0.1	<0.02	0.17	25	0.3
BOOK 048	460198	6197297	E. camaldulensis	9.5	6	38	<0.01	0.411	0.72	<0.1	0.2	<0.02	0.14	18	0.2
BOOK 049	461732	6196902	E. camaldulensis	15.5	5	23	<0.01	0.209	0.78	<0.1	0.2	<0.02	0.12	19	0.2
BOOK 050	460271	6197281	E. camaldulensis	13.9	6	41	0.01	0.271	0.53	<0.1	0.2	<0.02	0.19	22	0.3
BOOK 051	460337	6197276	E. camaldulensis	5.2	4	45	<0.01	0.302	0.51	<0.1	0.2	<0.02	0.13	19	0.2
BOOK 052	461740	6197044	E. camaldulensis	5.8	7	21	<0.01	0.539	0.82	<0.1	0.2	<0.02	0.13	22	0.3
BOOK 053	460559	6197364	E. camaldulensis	20.2	6	33	<0.01	0.416	0.46	<0.1	0.2	<0.02	0.12	19	0.3
BOOK 054	460490	6197318	E. camaldulensis	7.1	6	28	<0.01	0.393	0.66	<0.1	0.2	<0.02	0.14	14	0.3
BOOK 055	461769	6197120	E. camaldulensis	17.4	9	68	0.01	0.324	0.58	<0.1	0.1	<0.02	0.15	27	0.3
BOOK 056	460899	6197516	E. camaldulensis	7.8	7	26	<0.01	0.626	0.78	<0.1	0.1	<0.02	0.11	21	0.3
BOOK 057	460642	6197444	E. camaldulensis	7.3	8	41	<0.01	0.165	0.34	<0.1	0.1	<0.02	0.17	36	0.2
BOOK 058	461780	6197186	E. camaldulensis	18.2	7	26	<0.01	0.298	0.52	<0.1	0.1	<0.02	0.14	14	0.2
BOOK 059	460987	6197441	E. camaldulensis	4.0	6	33	<0.01	0.425	0.78	<0.1	0.2	<0.02	0.13	11	0.2

			Element	Te	Ga	Cs	Ge	Hf	Nb	Rb	Sn	Ta	Zr	Y
			Unit	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
			DL	0.02	0.1	0.005	0.01	0.001	0.01	0.1	0.02	0.001	0.01	0.001
Sample #	GDA E	GDA N	Species											
BOOK 031	461413	6196521	E. camaldulensis	<0.02	0.13	22	0.2	<0.02	<0.1	0.011	<0.01	0.002	<0.01	2.0
BOOK 032	460749	6197858	E. camaldulensis	<0.02	<0.1	0.006	<0.01	0.004	<0.01	2.2	<0.02	<0.001	0.03	0.031
BOOK 033	460900	6197851	E. camaldulensis	<0.02	<0.1	<0.005	<0.01	<0.001	<0.01	0.5	<0.02	<0.001	0.04	0.052
BOOK 034	461563	6196478	E. camaldulensis	<0.02	<0.1	0.017	<0.01	0.001	<0.01	3.6	<0.02	<0.001	0.05	0.276
BOOK 035	460620	6197816	E. camaldulensis	<0.02	<0.1	0.010	0.01	0.003	<0.01	3.6	<0.02	<0.001	0.05	0.250
BOOK 036	460690	6197851	E. camaldulensis	<0.02	<0.1	0.009	<0.01	0.002	<0.01	2.3	<0.02	<0.001	0.06	0.144
BOOK 037	461635	6196573	E. camaldulensis	<0.02	<0.1	0.015	<0.01	0.002	<0.01	8.7	<0.02	<0.001	0.05	0.079
BOOK 038	460511	6197805	E. camaldulensis	<0.02	<0.1	0.011	<0.01	<0.001	<0.01	5.5	<0.02	<0.001	0.03	0.043
BOOK 039	460422	6197792	E. camaldulensis	<0.02	<0.1	0.009	<0.01	0.003	<0.01	3.2	<0.02	<0.001	0.05	0.113
BOOK 040	461686	6196650	E. camaldulensis	<0.02	<0.1	0.012	<0.01	0.002	<0.01	1.1	<0.02	<0.001	0.07	0.062
BOOK 041	460157	6197720	E. camaldulensis	<0.02	<0.1	0.006	<0.01	<0.001	<0.01	2.8	<0.02	<0.001	0.02	0.098
BOOK 042	460118	6197696	E. camaldulensis	<0.02	<0.1	0.009	<0.01	<0.001	<0.01	1.7	<0.02	<0.001	0.07	0.106
BOOK 043	461687	6196745	E. camaldulensis	0.02	<0.1	0.027	<0.01	<0.001	<0.01	7.4	<0.02	<0.001	0.04	0.116
BOOK 044	460102	6197567	E. camaldulensis	<0.02	<0.1	0.006	<0.01	0.002	<0.01	1.8	<0.02	<0.001	0.03	0.155
BOOK 045	460036	6197444	E. camaldulensis	<0.02	<0.1	0.011	<0.01	<0.001	<0.01	3.7	<0.02	<0.001	0.04	0.460
BOOK 046	461710	6196800	E. camaldulensis	<0.02	<0.1	0.009	0.02	0.003	<0.01	4.4	<0.02	<0.001	0.05	0.243
BOOK 047	460133	6197361	E. camaldulensis	<0.02	<0.1	0.017	0.01	0.005	<0.01	3.7	<0.02	<0.001	0.07	0.154
BOOK 048	460198	6197297	E. camaldulensis	<0.02	<0.1	0.009	<0.01	0.003	<0.01	2.1	<0.02	<0.001	0.06	0.131
BOOK 049	461732	6196902	E. camaldulensis	<0.02	<0.1	0.015	<0.01	<0.001	<0.01	6.8	<0.02	<0.001	0.06	0.102
BOOK 050	460271	6197281	E. camaldulensis	<0.02	<0.1	0.012	<0.01	<0.001	<0.01	1.8	<0.02	<0.001	0.06	0.120
BOOK 051	460337	6197276	E. camaldulensis	<0.02	<0.1	<0.005	<0.01	0.002	<0.01	1.6	<0.02	<0.001	0.04	0.184
BOOK 052	461740	6197044	E. camaldulensis	<0.02	<0.1	0.034	<0.01	0.002	<0.01	14.3	<0.02	<0.001	0.05	0.145
BOOK 053	460559	6197364	E. camaldulensis	<0.02	<0.1	0.007	<0.01	<0.001	<0.01	1.3	<0.02	<0.001	0.05	0.086
BOOK 054	460490	6197318	E. camaldulensis	<0.02	<0.1	0.007	<0.01	<0.001	<0.01	2.0	<0.02	<0.001	0.04	0.097
BOOK 055	461769	6197120	E. camaldulensis	<0.02	<0.1	0.012	<0.01	0.002	<0.01	6.9	<0.02	<0.001	0.07	0.182
BOOK 056	460899	6197516	E. camaldulensis	<0.02	<0.1	0.025	<0.01	0.002	<0.01	8.3	<0.02	<0.001	0.06	0.046
BOOK 057	460642	6197444	E. camaldulensis	0.03	<0.1	0.005	<0.01	<0.001	<0.01	1.4	<0.02	<0.001	0.04	0.146
BOOK 058	461780	6197186	E. camaldulensis	<0.02	<0.1	0.017	<0.01	<0.001	<0.01	6.1	<0.02	<0.001	0.04	0.038
BOOK 059	460987	6197441	E. camaldulensis	<0.02	<0.1	0.006	<0.01	<0.001	<0.01	3.9	<0.02	<0.001	0.03	0.070

			Element	Ce	In	Re	Be	Li	Pd	Pt
			Unit	ppm	ppm	ppb	ppm	ppm	ppb	ppb
			DL	0.01	0.02	1	0.1	0.01	2	1
Sample #	GDA E	GDA N	Species							
BOOK 031	461413	6196521	E. camaldulensis	<0.02	<0.001	0.06	0.129	0.28	<0.02	<1
BOOK 032	460749	6197858	E. camaldulensis	0.09	<0.02	<1	<0.1	1.02	<2	<1
BOOK 033	460900	6197851	E. camaldulensis	0.11	<0.02	<1	<0.1	2.01	<2	<1
BOOK 034	461563	6196478	E. camaldulensis	0.52	<0.02	1	0.1	10.27	<2	<1
BOOK 035	460620	6197816	E. camaldulensis	0.41	<0.02	2	<0.1	4.12	<2	<1
BOOK 036	460690	6197851	E. camaldulensis	0.29	<0.02	<1	<0.1	3.98	<2	<1
BOOK 037	461635	6196573	E. camaldulensis	0.18	<0.02	<1	<0.1	1.48	<2	<1
BOOK 038	460511	6197805	E. camaldulensis	0.08	<0.02	<1	<0.1	1.37	<2	<1
BOOK 039	460422	6197792	E. camaldulensis	0.26	<0.02	<1	<0.1	3.13	<2	<1
BOOK 040	461686	6196650	E. camaldulensis	0.18	<0.02	<1	<0.1	2.92	<2	<1
BOOK 041	460157	6197720	E. camaldulensis	0.25	<0.02	<1	<0.1	1.53	<2	<1
BOOK 042	460118	6197696	E. camaldulensis	0.19	<0.02	<1	<0.1	3.60	<2	<1
BOOK 043	461687	6196745	E. camaldulensis	0.25	<0.02	<1	<0.1	2.73	<2	<1
BOOK 044	460102	6197567	E. camaldulensis	0.31	<0.02	<1	0.1	3.20	<2	<1
BOOK 045	460036	6197444	E. camaldulensis	1.12	<0.02	<1	0.1	9.85	<2	<1
BOOK 046	461710	6196800	E. camaldulensis	0.35	<0.02	<1	<0.1	3.38	<2	<1
BOOK 047	460133	6197361	E. camaldulensis	0.35	<0.02	2	<0.1	5.42	<2	<1
BOOK 048	460198	6197297	E. camaldulensis	0.29	<0.02	2	<0.1	5.62	<2	<1
BOOK 049	461732	6196902	E. camaldulensis	0.27	<0.02	1	<0.1	2.17	<2	<1
BOOK 050	460271	6197281	E. camaldulensis	0.27	<0.02	3	<0.1	4.66	<2	<1
BOOK 051	460337	6197276	E. camaldulensis	0.42	<0.02	3	<0.1	5.03	<2	<1
BOOK 052	461740	6197044	E. camaldulensis	0.33	<0.02	<1	<0.1	2.53	<2	<1
BOOK 053	460559	6197364	E. camaldulensis	0.17	<0.02	1	<0.1	3.57	<2	<1
BOOK 054	460490	6197318	E. camaldulensis	0.21	<0.02	1	<0.1	3.18	<2	<1
BOOK 055	461769	6197120	E. camaldulensis	0.32	<0.02	<1	<0.1	5.21	<2	<1
BOOK 056	460899	6197516	E. camaldulensis	0.12	<0.02	<1	<0.1	1.19	<2	<1
BOOK 057	460642	6197444	E. camaldulensis	0.21	<0.02	4	<0.1	4.56	<2	<1
BOOK 058	461780	6197186	E. camaldulensis	0.12	<0.02	<1	<0.1	1.40	<2	<1
BOOK 059	460987	6197441	E. camaldulensis	0.19	<0.02	<1	<0.1	1.50	<2	<1

			Element	Mo	Cu	Pb	Zn	Ag	Ni	Co	Mn	Fe	As	U
			Unit	ppm	ppm	ppm	ppm	ppb	ppm	ppm	ppm	%	ppm	ppm
			DL	0.01	0.01	0.01	0.1	2	0.1	0.01	1	0.001	0.1	0.01
Sample #	GDA E	GDA N	Species											
BOOK 060	461324	6198093	E. largiflorens	0.04	3.18	0.01	12.0	<2	4.5	0.10	505	0.005	<0.1	<0.01
BOOK 061	461817	6197255	E. camaldulensis	0.03	4.71	0.05	16.3	<2	1.1	0.04	1099	0.007	1.5	<0.01
BOOK 062	461378	6198077	E. largiflorens	0.14	5.33	<0.01	13.9	<2	3.1	0.06	1082	0.003	<0.1	<0.01
BOOK 063	461299	6198087	E. largiflorens	0.08	3.30	<0.01	15.9	<2	3.1	0.08	416	0.004	<0.1	<0.01
BOOK 064	461839	6197330	E. camaldulensis	0.02	4.99	0.11	14.6	<2	1.4	0.05	580	0.007	0.2	<0.01
BOOK 065	461312	6198081	E. largiflorens	0.08	3.16	0.09	18.3	<2	8.8	0.20	683	0.008	0.1	<0.01
BOOK 066	461204	6198210	E. camaldulensis	0.03	2.38	0.1	11.4	<2	0.9	0.14	539	0.011	0.1	<0.01
BOOK 067	461914	6197429	E. camaldulensis	0.01	2.38	0.1	14.9	<2	0.9	0.04	637	0.006	0.1	<0.01
BOOK 068	461252	6198070	E. largiflorens	0.13	4.71	0.09	28.2	<2	6.8	0.06	377	0.006	<0.1	<0.01
BOOK 069	461311	6198210	E. largiflorens	0.07	3.77	0.08	20.1	<2	5.8	0.14	541	0.007	<0.1	0.01
BOOK 070	462003	6197514	E. camaldulensis	0.01	3.05	0.08	19.6	<2	2.2	0.16	674	0.007	0.1	<0.01
BOOK 071	461223	6198229	E. largiflorens	0.02	3.45	0.06	25.6	<2	6.9	0.27	734	0.007	<0.1	<0.01
BOOK 073	462042	6197545	E. camaldulensis	0.03	3.88	0.1	23.2	<2	1.6	0.08	539	0.013	0.4	0.07
BOOK 075	461281	6196870	E. camaldulensis	0.04	7.17	0.06	14.9	<2	4.1	0.07	352	0.009	<0.1	<0.01
BOOK 076	462156	6197599	E. camaldulensis	0.04	2.26	0.08	17.6	<2	2.5	0.07	910	0.014	0.5	<0.01
BOOK 079	462270	6197637	E. camaldulensis	0.02	10.78	0.06	15.6	4	3.5	0.13	897	0.009	0.1	<0.01
BOOK 082	462364	6197642	E. camaldulensis	0.02	2.70	0.05	11.1	<2	1.4	0.09	689	0.01	0.8	<0.01

Sample #	GDA E	GDA N	Species	Au	Th	Sr	Cd	Sb	Bi	V	Ca	P	La	Cr	Mg
BOOK 059	460987	6197441	E. camaldulensis	0.2	<0.01	50.3	0.13	<0.02	<0.02	<2	0.59	0.170	0.12	1.0	0.261
Element				Au	Th	Sr	Cd	Sb	Bi	V	Ca	P	La	Cr	Mg
Unit				ppb	ppm	ppm	ppm	ppm	ppm	ppm	%	%	ppm	ppm	%
DL				0.2	0.01	0.5	0.01	0.02	0.02	2	0.01	0.001	0.01	0.1	0.001
BOOK 060	461324	6198093	E. largiflorens	0.3	<0.01	30.3	0.04	<0.02	<0.02	<2	1.13	0.081	0.11	1.1	0.278
BOOK 061	461817	6197255	E. camaldulensis	<0.2	<0.01	20.9	0.13	<0.02	<0.02	<2	0.70	0.162	0.08	1.0	0.167
BOOK 062	461378	6198077	E. largiflorens	<0.2	<0.01	95.7	0.14	<0.02	<0.02	<2	0.46	0.186	0.06	0.9	0.158
BOOK 063	461299	6198087	E. largiflorens	0.3	<0.01	69.2	0.10	<0.02	<0.02	<2	1.59	0.069	0.06	1.1	0.231
BOOK 064	461839	6197330	E. camaldulensis	<0.2	<0.01	142.7	0.28	<0.02	<0.02	<2	0.91	0.246	0.08	1.1	0.233
BOOK 065	461312	6198081	E. largiflorens	<0.2	0.01	159.2	0.04	<0.02	<0.02	<2	1.96	0.099	0.19	1.0	0.500
BOOK 066	461204	6198210	E. camaldulensis	<0.2	<0.01	51.1	0.05	<0.02	<0.02	<2	1.54	0.110	0.07	1.3	0.152
BOOK 067	461914	6197429	E. camaldulensis	<0.2	<0.01	289.1	0.07	<0.02	<0.02	<2	0.84	0.084	0.07	1.0	0.322
BOOK 068	461252	6198070	E. largiflorens	0.3	<0.01	55.7	0.20	<0.02	<0.02	<2	2.85	0.079	0.08	1.1	0.374
BOOK 069	461311	6198210	E. largiflorens	0.3	<0.01	77.3	0.04	<0.02	<0.02	<2	1.02	0.097	0.12	1.2	0.270
BOOK 070	462003	6197514	E. camaldulensis	<0.2	<0.01	106.7	0.11	<0.02	<0.02	<2	1.15	0.101	0.17	1.2	0.300
BOOK 071	461223	6198229	E. largiflorens	0.2	0.01	55.4	0.04	<0.02	<0.02	<2	1.33	0.121	0.33	1.0	0.257
BOOK 073	462042	6197545	E. camaldulensis	0.2	<0.01	37.3	0.02	<0.02	<0.02	<2	0.89	0.130	0.15	1.3	0.330
BOOK 075	461281	6196870	E. camaldulensis	<0.2	0.01	77	0.13	<0.02	<0.02	<2	0.69	0.237	0.12	1.3	0.338
BOOK 076	462156	6197599	E. camaldulensis	<0.2	<0.01	37.5	0.09	<0.02	<0.02	<2	0.92	0.101	0.13	1.2	0.463
BOOK 079	462270	6197637	E. camaldulensis	<0.2	<0.01	38	0.07	0.02	<0.02	<2	0.62	0.199	0.25	1.4	0.235
BOOK 082	462364	6197642	E. camaldulensis	<0.2	<0.01	38	0.07	<0.02	<0.02	<2	0.62	0.093	0.16	1.2	0.306

			Element	Ba	Ti	B	Al	Na	K	W	Sc	Tl	S	Hg	Se
			Unit	ppm	ppm	ppm	%	%	%	ppm	ppm	ppm	%	ppb	ppm
			DL	0.1	1	1	0.01	0.001	0.01	0.1	0.1	0.02	0.01	1	0.1
Sample #	GDA E	GDA N	Species												
BOOK 060	461324	6198093	E. largiflorens	1.9	4	28	<0.01	0.629	0.52	<0.1	0.2	<0.02	0.12	13	0.3
BOOK 061	461817	6197255	E. camaldulensis	14.0	6	20	<0.01	0.459	0.79	<0.1	0.2	<0.02	0.18	10	0.3
BOOK 062	461378	6198077	E. largiflorens	1.7	6	7	<0.01	0.474	1.43	0.1	<0.1	<0.02	0.17	3	0.3
BOOK 063	461299	6198087	E. largiflorens	4.5	3	26	<0.01	0.455	0.66	<0.1	0.1	<0.02	0.09	16	0.2
BOOK 064	461839	6197330	E. camaldulensis	14.1	9	27	<0.01	0.488	0.75	<0.1	0.2	<0.02	0.14	19	<0.1
BOOK 065	461312	6198081	E. largiflorens	4.3	5	31	0.01	0.277	0.38	<0.1	<0.1	<0.02	0.13	27	<0.1
BOOK 066	461204	6198210	E. camaldulensis	18.3	5	51	0.01	0.306	0.65	<0.1	<0.1	<0.02	0.19	17	0.1
BOOK 067	461914	6197429	E. camaldulensis	19.0	4	12	<0.01	0.266	0.35	<0.1	0.1	<0.02	0.13	8	<0.1
BOOK 068	461252	6198070	E. largiflorens	26.6	4	39	<0.01	0.493	0.48	<0.1	0.1	<0.02	0.17	14	0.2
BOOK 069	461311	6198210	E. largiflorens	4.2	4	70	<0.01	0.483	0.71	<0.1	0.1	<0.02	0.18	16	<0.1
BOOK 070	462003	6197514	E. camaldulensis	6.6	5	51	<0.01	0.319	0.52	<0.1	0.1	<0.02	0.17	13	<0.1
BOOK 071	461223	6198229	E. largiflorens	4.7	5	93	<0.01	0.441	0.82	<0.1	0.2	<0.02	0.15	27	0.2
BOOK 073	462042	6197545	E. camaldulensis	9.7	7	29	0.01	0.253	0.37	<0.1	0.2	<0.02	0.17	21	0.1
BOOK 075	461281	6196870	E. camaldulensis	10.5	9	34	<0.01	0.305	0.61	<0.1	0.2	<0.02	0.17	14	0.2
BOOK 076	462156	6197599	E. camaldulensis	16.4	6	67	0.01	0.184	0.41	<0.1	0.2	<0.02	0.15	19	0.1
BOOK 079	462270	6197637	E. camaldulensis	3.1	8	45	<0.01	0.299	0.79	<0.1	0.2	<0.02	0.19	16	0.1
BOOK 082	462364	6197642	E. camaldulensis	11.4	5	38	0.01	0.404	0.37	<0.1	0.2	<0.02	0.16	13	<0.1

			Element	Te	Ga	Cs	Ge	Hf	Nb	Rb	Sn	Ta	Zr	Y
			Unit	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
			DL	0.02	0.1	0.005	0.01	0.001	0.01	0.1	0.02	0.001	0.01	0.001
Sample #	GDA E	GDA N	Species											
BOOK 060	461324	6198093	E. largiflorens	<0.02	<0.1	<0.005	<0.01	0.001	<0.01	0.5	<0.02	<0.001	0.03	0.055
BOOK 061	461817	6197255	E. camaldulensis	<0.02	<0.1	0.011	<0.01	0.001	<0.01	5.9	<0.02	<0.001	0.05	0.054
BOOK 062	461378	6198077	E. largiflorens	<0.02	<0.1	<0.005	<0.01	<0.001	<0.01	5.4	<0.02	<0.001	0.01	0.011
BOOK 063	461299	6198087	E. largiflorens	<0.02	<0.1	<0.005	<0.01	<0.001	<0.01	0.7	<0.02	<0.001	0.03	0.033
BOOK 064	461839	6197330	E. camaldulensis	<0.02	<0.1	0.007	<0.01	0.001	<0.01	1.4	<0.02	<0.001	0.06	0.058
BOOK 065	461312	6198081	E. largiflorens	<0.02	<0.1	0.009	<0.01	0.003	<0.01	0.5	<0.02	<0.001	0.07	0.105
BOOK 066	461204	6198210	E. camaldulensis	<0.02	<0.1	0.012	<0.01	0.004	<0.01	0.6	<0.02	<0.001	0.08	0.047
BOOK 067	461914	6197429	E. camaldulensis	<0.02	<0.1	0.005	<0.01	0.002	<0.01	0.9	<0.02	<0.001	0.05	0.065
BOOK 068	461252	6198070	E. largiflorens	<0.02	<0.1	0.007	<0.01	0.002	<0.01	1.0	<0.02	<0.001	0.05	0.038
BOOK 069	461311	6198210	E. largiflorens	<0.02	<0.1	0.005	<0.01	0.002	<0.01	0.6	<0.02	<0.001	0.06	0.067
BOOK 070	462003	6197514	E. camaldulensis	<0.02	<0.1	0.008	<0.01	0.002	<0.01	1.0	0.02	<0.001	0.06	0.163
BOOK 071	461223	6198229	E. largiflorens	<0.02	<0.1	0.007	<0.01	0.001	<0.01	0.4	<0.02	<0.001	0.05	0.195
BOOK 073	462042	6197545	E. camaldulensis	<0.02	<0.1	0.011	<0.01	0.003	<0.01	0.8	<0.02	<0.001	0.09	0.174
BOOK 075	461281	6196870	E. camaldulensis	<0.02	<0.1	0.009	<0.01	0.001	<0.01	2.8	<0.02	<0.001	0.07	0.077
BOOK 076	462156	6197599	E. camaldulensis	0.02	<0.1	0.012	<0.01	0.004	<0.01	0.8	<0.02	<0.001	0.10	0.087
BOOK 079	462270	6197637	E. camaldulensis	<0.02	<0.1	0.007	<0.01	0.001	<0.01	1.7	<0.02	<0.001	0.05	0.178
BOOK 082	462364	6197642	E. camaldulensis	<0.02	<0.1	0.010	<0.01	0.002	<0.01	0.9	<0.02	<0.001	0.06	0.103

Sample #	GDA E	GDA N	Species	Ce	In	Re	Be	Li	Pd	Pt
			Element	Ce	In	Re	Be	Li	Pd	Pt
			Unit	ppm	ppm	ppb	ppm	ppm	ppb	ppb
			DL	0.01	0.02	1	0.1	0.01	2	1
BOOK 060	461324	6198093	E. largiflorens	0.17	<0.02	<1	<0.1	1.36	<2	<1
BOOK 061	461817	6197255	E. camaldulensis	0.14	<0.02	<1	<0.1	1.28	<2	<1
BOOK 062	461378	6198077	E. largiflorens	0.09	<0.02	<1	<0.1	0.21	<2	<1
BOOK 063	461299	6198087	E. largiflorens	0.10	<0.02	<1	<0.1	1.41	<2	<1
BOOK 064	461839	6197330	E. camaldulensis	0.15	<0.02	1	<0.1	2.90	<2	<1
BOOK 065	461312	6198081	E. largiflorens	0.30	<0.02	<1	<0.1	1.76	<2	<1
BOOK 066	461204	6198210	E. camaldulensis	0.15	<0.02	<1	<0.1	2.64	<2	<1
BOOK 067	461914	6197429	E. camaldulensis	0.15	<0.02	<1	<0.1	0.76	<2	<1
BOOK 068	461252	6198070	E. largiflorens	0.13	<0.02	<1	<0.1	1.98	<2	<1
BOOK 069	461311	6198210	E. largiflorens	0.21	<0.02	<1	<0.1	1.58	<2	<1
BOOK 070	462003	6197514	E. camaldulensis	0.31	<0.02	1	<0.1	3.66	<2	<1
BOOK 071	461223	6198229	E. largiflorens	0.58	<0.02	<1	<0.1	4.01	<2	<1
BOOK 073	462042	6197545	E. camaldulensis	0.33	<0.02	2	<0.1	3.24	<2	<1
BOOK 075	461281	6196870	E. camaldulensis	0.21	<0.02	2	<0.1	2.65	<2	<1
BOOK 076	462156	6197599	E. camaldulensis	0.25	<0.02	<1	<0.1	2.73	<2	<1
BOOK 079	462270	6197637	E. camaldulensis	0.48	<0.02	<1	<0.1	3.18	<2	<1
BOOK 082	462364	6197642	E. camaldulensis	0.29	<0.02	<1	<0.1	1.89	<2	<1

APPENDIX 3

TABLE OF ELEMENTS INCLUDED AND EXCLUDED FROM IN-DEPTH ANALYSIS

| Element	DL	Precision	Why
Cu	0.01ppm	Excellent	Released into solution in acidic conditions
Mn	1ppm	Good	Readily absorbed by plants in acidic conditions Increasing solubility with increasing acidity
Fe	0.001%	Excellent	Mobilised by acid, reducing conditions
Au	0.2ppb	Dubious	This dataset has interesting values but their reliability is questionable and may not be reproducible
Sr	0.5ppm	Excellent	Correlates with Ba and Ca on carbonate lithologies
Cd	0.01ppm	Excellent	Generally correlates with S Found in phosphate fertilisers – link in the study area?
Ca	0.01%	Excellent	Indicative of carbonate substrates
P	0.001%	Excellent	Linked closely with Cu and Ti in this dataset
La	0.01ppm	Good	LREE – correlates with other REE, verifying dataset
Mg	0.001%	Excellent	Essential to plant function
Ba	0.1ppm	Very good	Often associated with carbonate Accessible to plants in acidic soils
Ti	1ppm	Very good	Used as an indicator for contamination
Al	0.01%	Dubious near DL	Used as an indicator for contamination
Na	0.001%	Moderately good	Main element of interest Levels well in excess of DL, thereby increasing precision
K	0.01%	Excellent	Appears associated with Na Reliable results
S	0.01%	Fair below 0.2%	Dubious results in this dataset – few results above 0.2%
Zr	0.01ppm	Very good	Used as an indicator of contamination
Y	0.001ppm	Excellent	REE

|			
Ce	0.01ppm	Excellent above DL	REE
Mo	0.01ppm	Very good	Closely linked to Na in tree analysis Potential indicator of acidity
U	0.01ppm	Very good	May indicate oxidising or reducing conditions but very few values above background concentrations
Co	0.01ppm	Good	May be contributing to conductivity
Sc	0.1ppm	Fair to poor	Levels close to DL, with poor precision
Pb	0.01ppm	Very good	No correlated with many other elements in this dataset
Zn	0.1ppm	Excellent	Not relevant to this study Can be an indicator of plant health
Ag	2ppb	Very good to excellent	Element not of interest Not correlated with any elements
Ni	0.1ppm	Very good	Element not of interest Not indicative of salinity or acidity
As	0.1ppm	Poor precision in plant concentrations	Values close to DL Pathfinder element for mineralisation but not for salinity or acidity
Th	0.01ppm	Good	Few values above DL
Sb	0.02ppm	Fair to poor precision in plant concentrations	Few values above DL
Bi	0.02ppm	Fair to good	No values above DL
V	2ppm	Fair	No values above DL
Cr	0.1ppm	Good	Element not of interest
W	0.1ppm	Fair to poor	No values above DL
Tl	0.02ppm	Excellent for values >0.05ppm	No values above DL
Hg	1ppb	Good	Element not of interest

|			
Se	0.1ppm	Fair to poor	Values close to DL (<0.1-0.4ppm)
Te	0.02ppm	Fair to poor	Few values above DL
Ga	0.1ppm	Fair	No values above DL
Cs	0.005ppm	Good	Element not of interest
Ge	0.01ppm	Poor	Values below or close to DL
Hf	0.001ppm	Fair to poor	Values below or close to DL (<0.001-0.004ppm)
Nb	0.01ppm	Poor	No values above DL
Rb	0.1ppm	Excellent	Element not of interest
Sn	0.02ppm	Fair to poor	Few values above DL
Ta	0.001ppm	Poor	No values above DL
In	0.02ppm	Fair to poor	No values above DL
Re	1ppb	Excellent	Few values above DL
Be	0.1ppm	Good	Few values above DL
Li	0.01ppm	Fair	Element not of interest
Pd	2ppb	Fair	No values above DL
Pt	1ppb	Fair	No values above DL

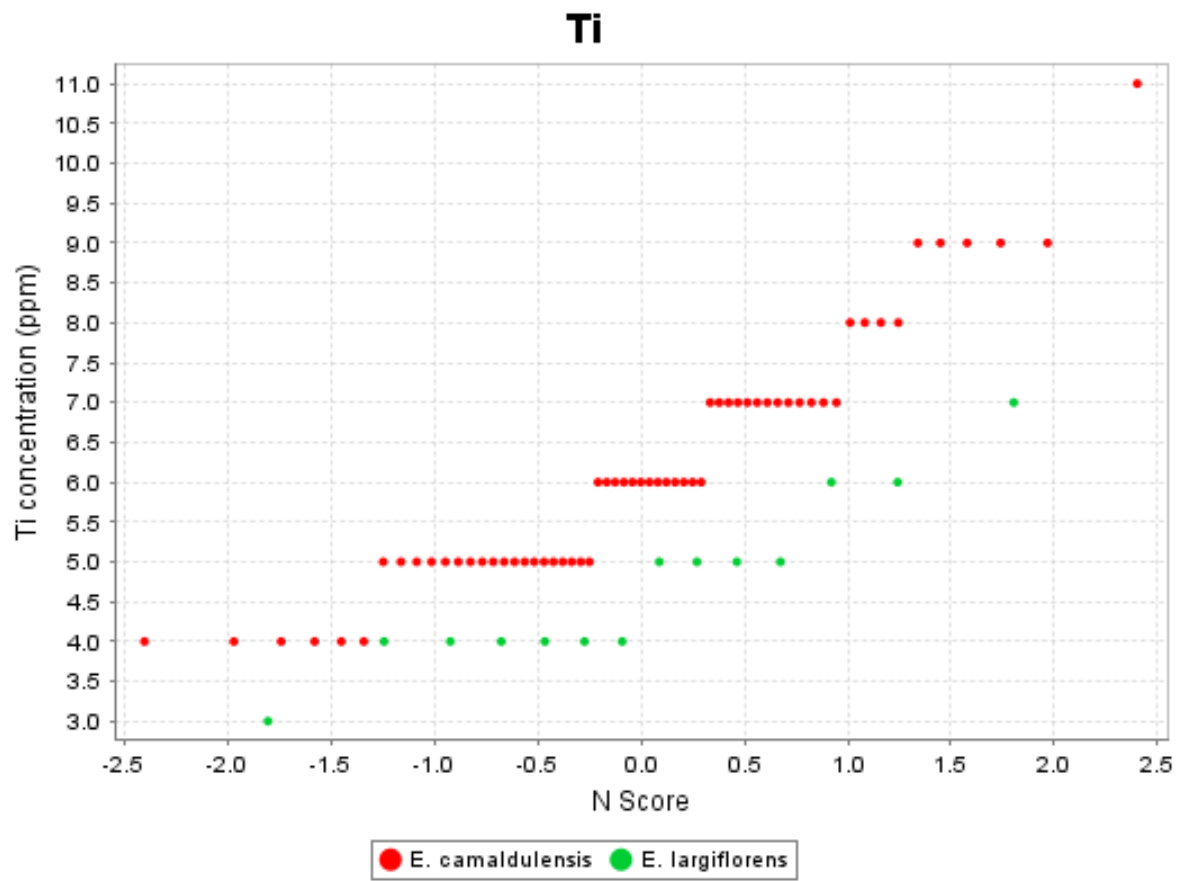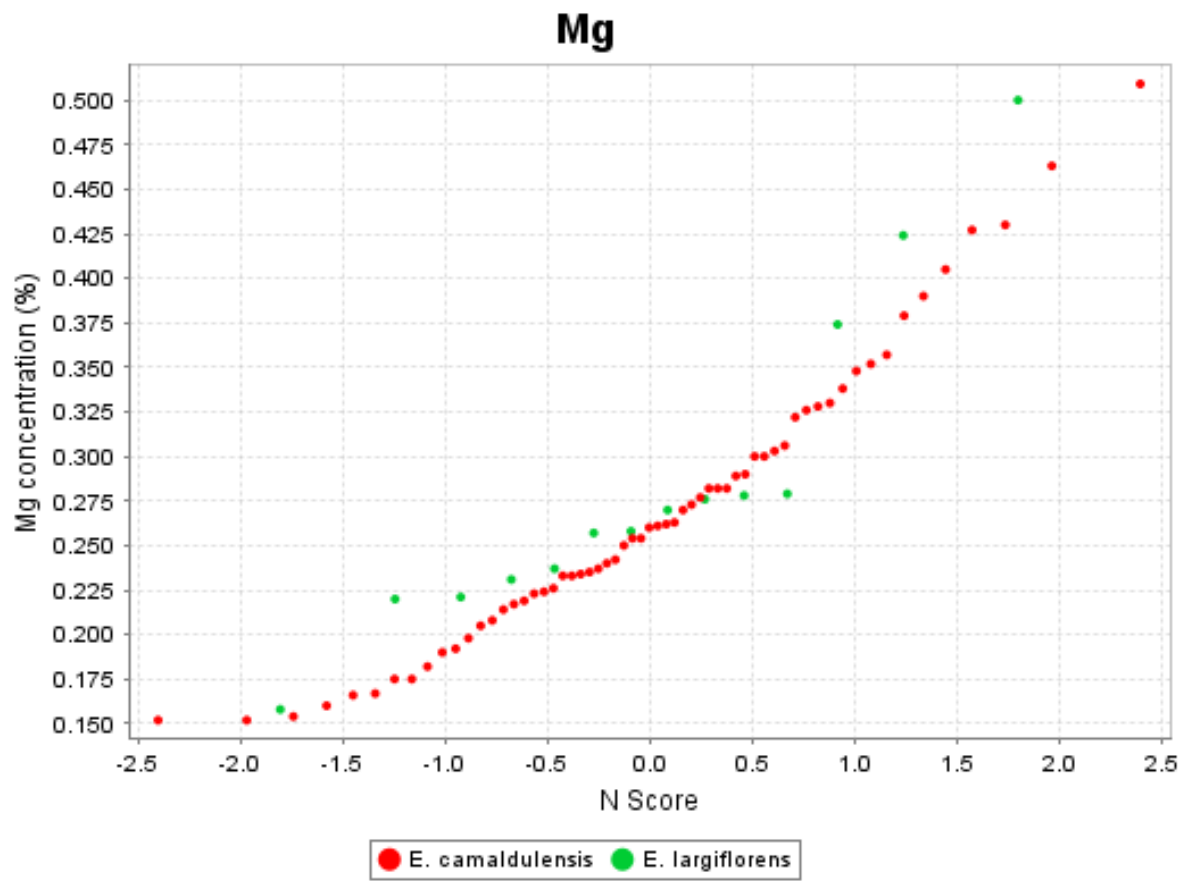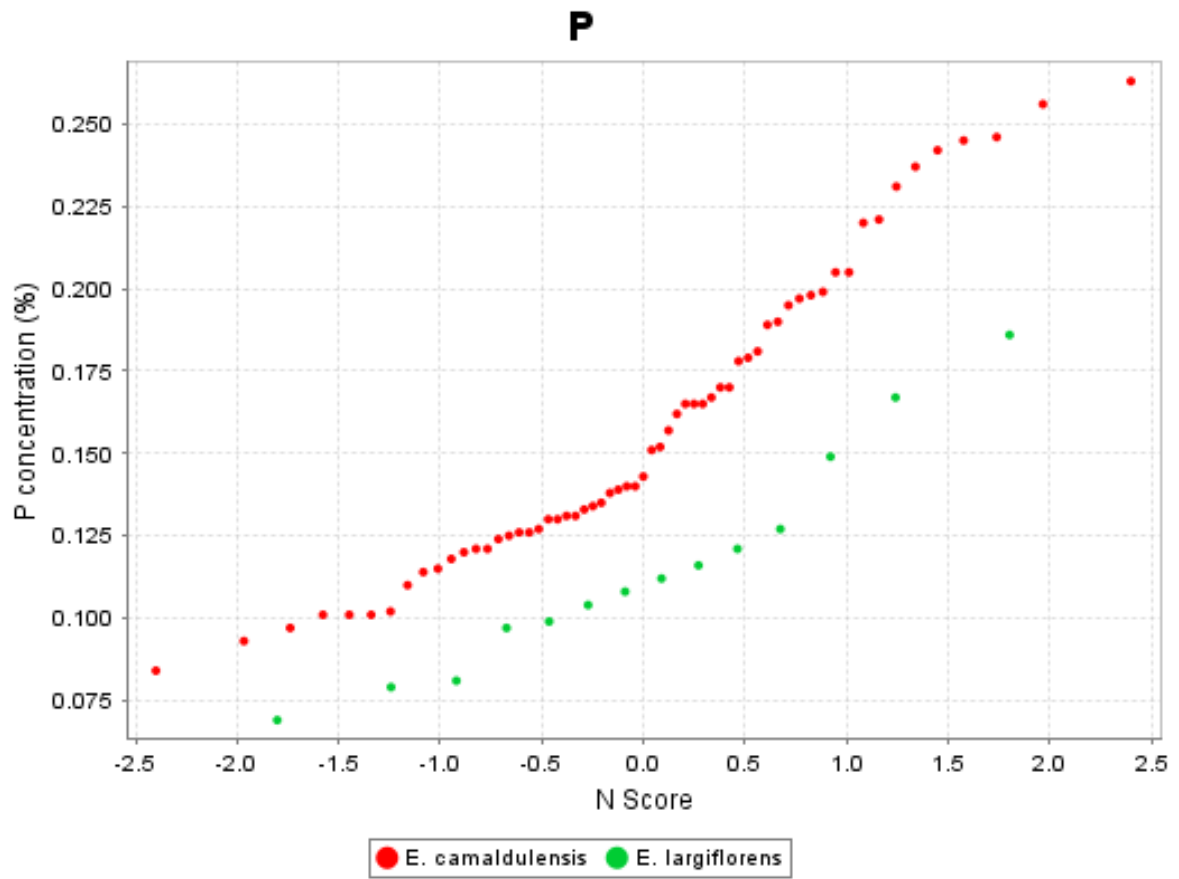## APPENDIX 4

SPLIT POPULATION NORMAL PROBABILITY PLOTS

Mn
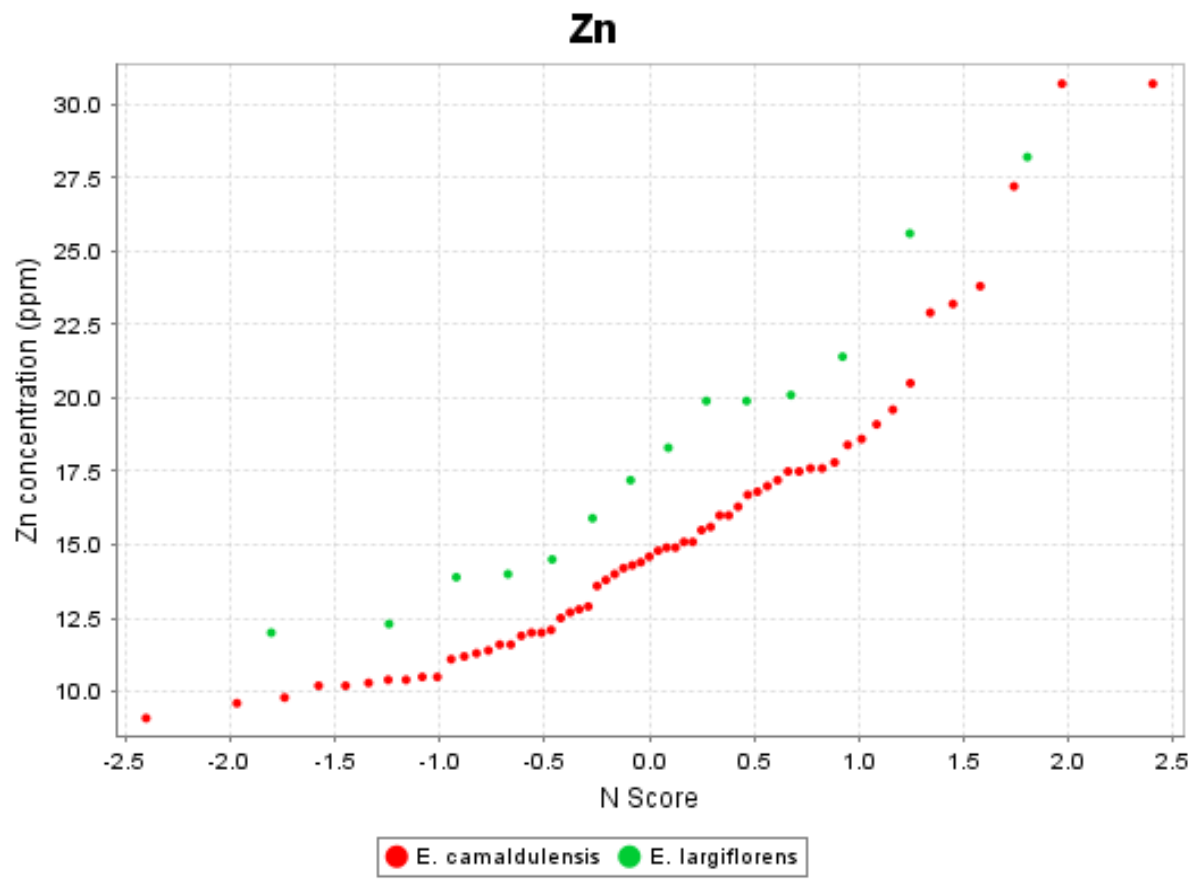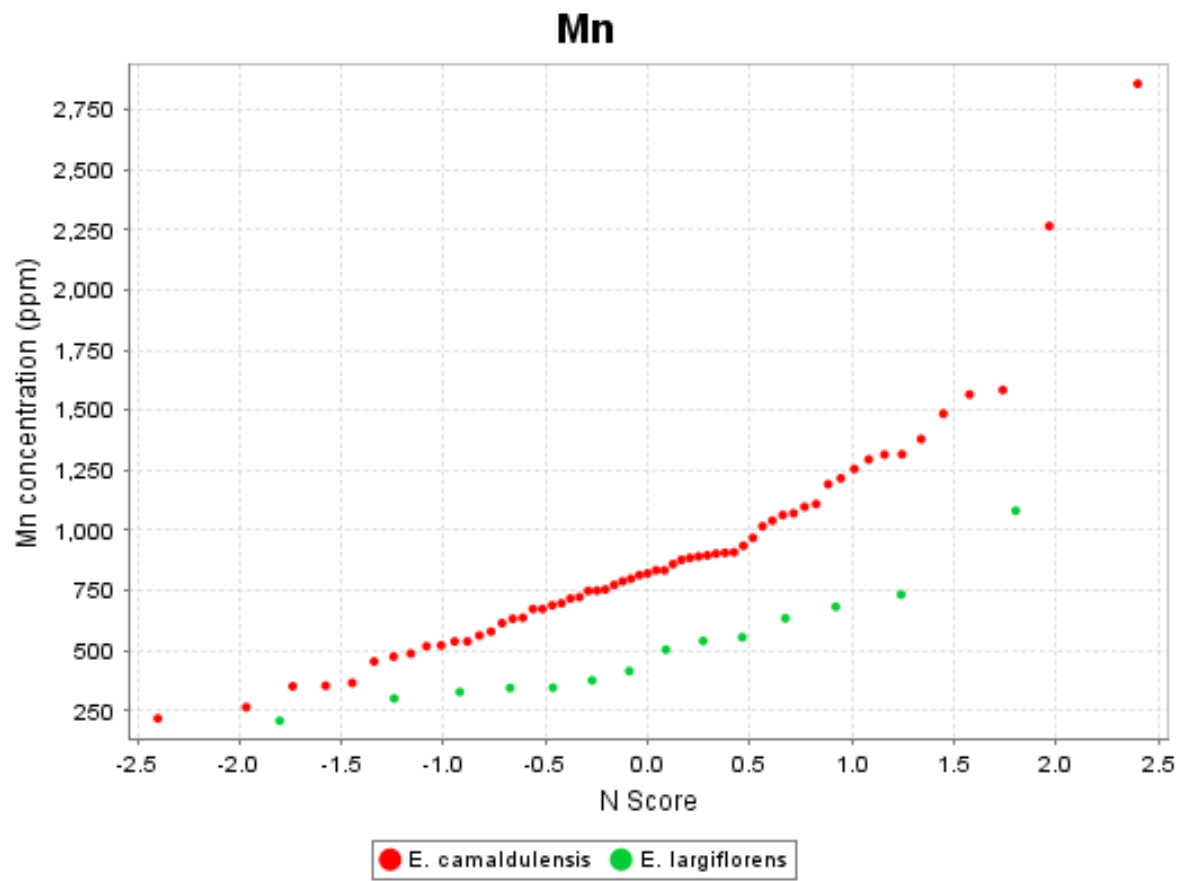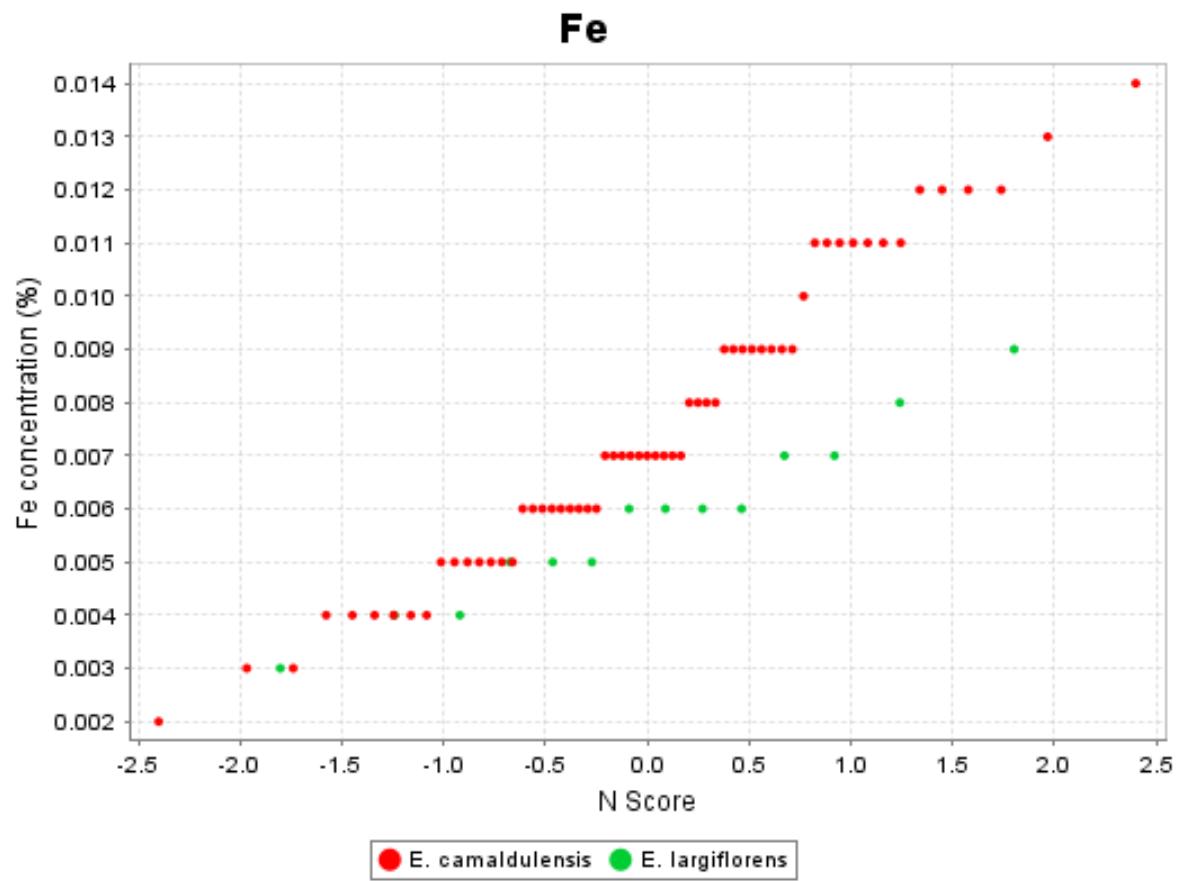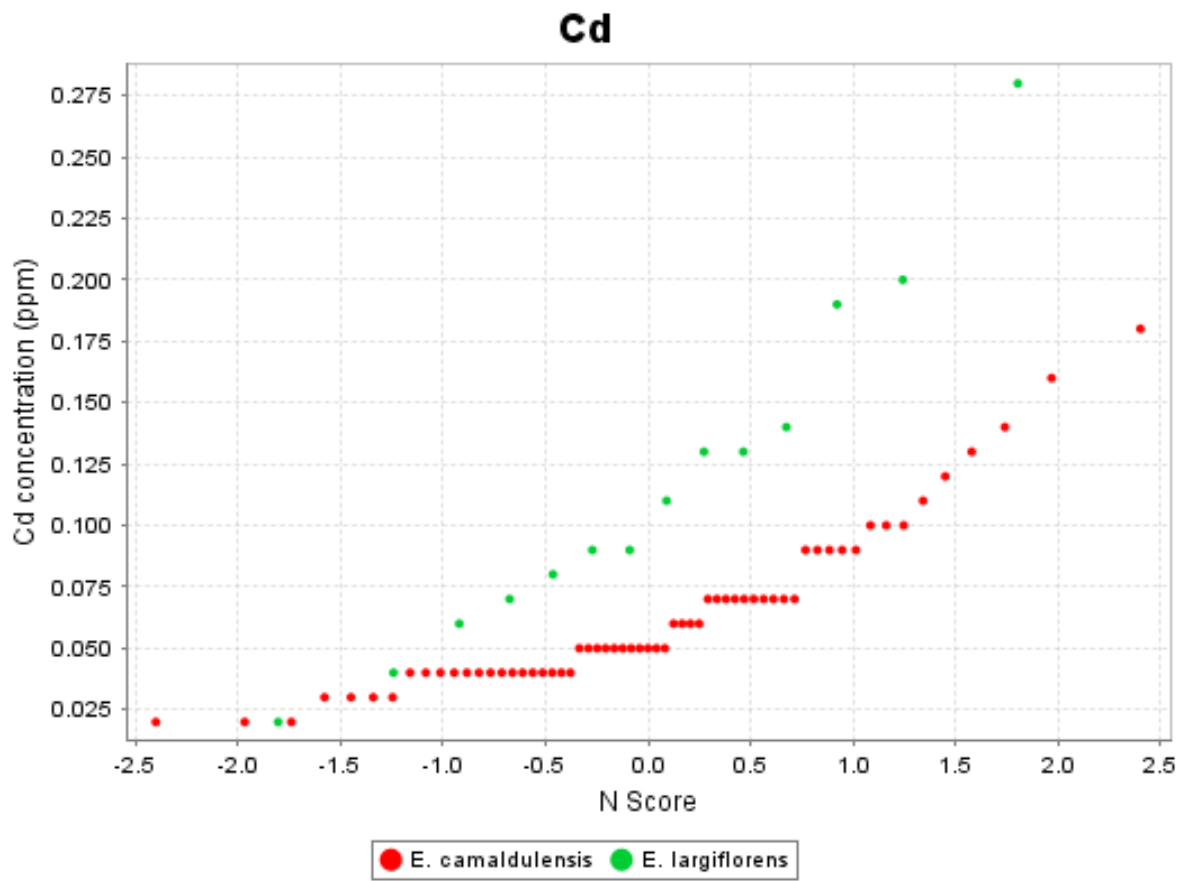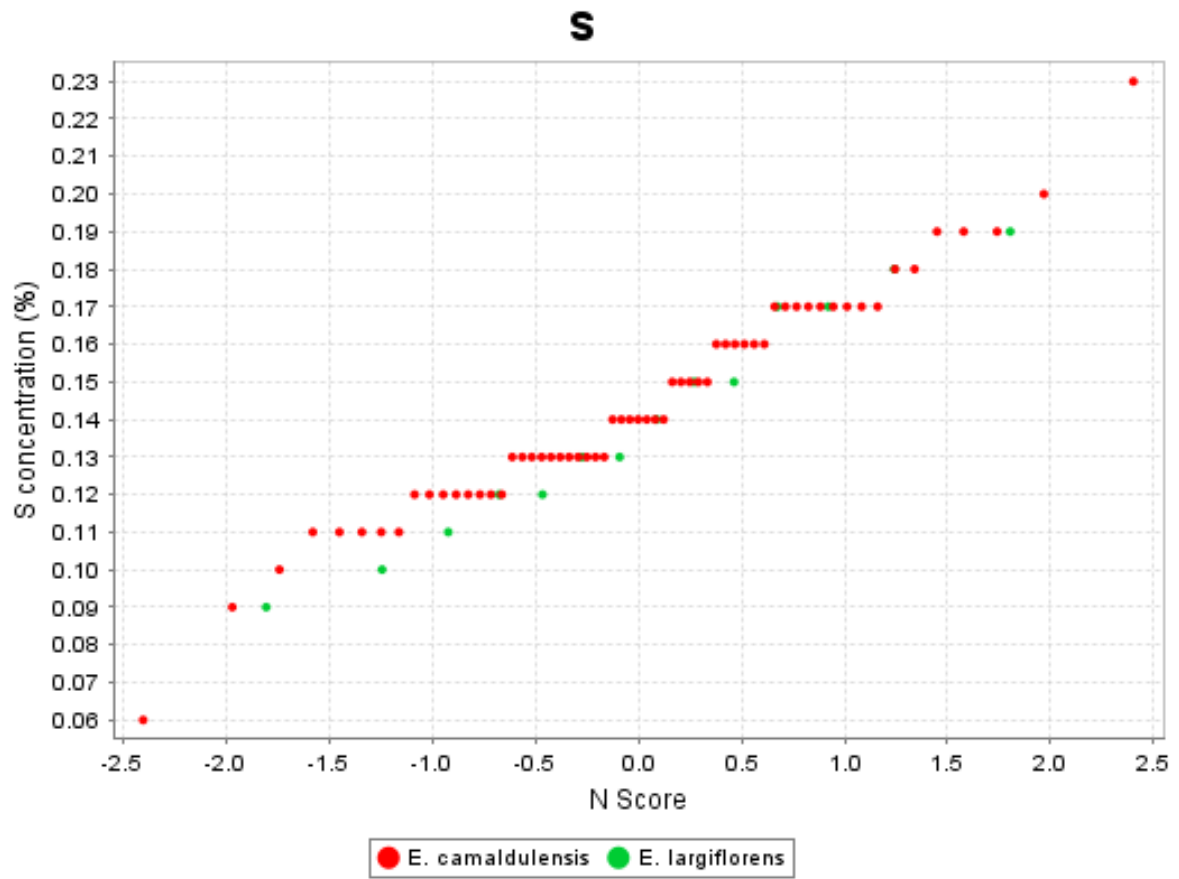
APPENDIX 5

REGOLITH-LANDFORM MAP

REGOLITH-LANDFORM UNIT DESCRIPTIONS

APPENDIX 5