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Method for field assessment of dryland salinity in Victoria using GPS technology

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Summary

This report describes in detail the current field method employed to identify, assess and map the extents of dryland salinity in Victoria.

Salinity has long been recognised as a feature of the Victorian landscape. Where hydrological balances have or had been maintained by retention of deep-rooted vegetation and natural water flow into sinks such as salt lakes continued unchanged, the distribution of salt in the landscape did not change significantly; apart from seasonal ebbs and flows. However, a significant increase in soil salinity levels (thought to result from changes in land use following European settlement), became evident in the 1940s. By the 1950s soil salinity was acknowledged as a major environmental problem that had significant impacts upon both natural and built assets. Through the 1970s and 1980s above average rainfall led to a significant rise in groundwater levels and an increase in the extent of salt affected soil.

In order to manage an environmental threat such as soil salinity, it is necessary to understand the extent and severity of the problem, and then provide ongoing feedback to intervention programs by monitoring change over time. Early efforts to identify the size of the problem and combat it were piecemeal and fragmented and it was not until the late 1980s that a nationally coordinated approach led to the development of a set of criteria for identifying and assessing dryland soil salinity in Victoria. A Victorian field guide (Spotting Soil Salinity) was also produced to assist in mapping the extent of the problem and since the late 1980s almost all soil salinity mapping in Victoria has used both these standards and the field guide. The mapping standards were formally documented in 1996 (Allen 1996).

Changes in community values and technology have altered the way salinity is viewed and the way it is mapped since the field mapping method was last documented in 1996. Both land managers and the broader community have come to take a broader view of salinity, and as well as viewing salinity as a threat to agricultural productivity and built infrastructure, the value of naturally saline areas for the unique ecosystems they support is now recognised. The advent of Global Positioning System (GPS) technology has revolutionised the way field data can be mapped. GPS technology is now commonly used for a variety of applications, and provides an integral tool for further dryland salinity mapping projects in Victoria. In addition, there have been advances in the way sites are attributed to take better advantage of the GIS environment in which the data is stored.

Field data collected using the method described in this report is added to the soil salinity layer in the Corporate Spatial Data Library (CSDL). This dataset forms the primary source for almost all dryland salinity monitoring and reporting in Victoria. As such it represents a valuable public resource as land salinity has been accepted as one of the Matters for Targets indicators within the National Framework for Natural Resource Management Standards. Additionally, the extent and severity of land salinity has been listed by the Victorian government as one of the Victorian Catchment indicators. Its status will be reported in a statewide Catchment Condition Report in 2007 and a State of Environment Report for Victoria and a second National Land and Water Audit are both due in 2008.

Contents

Figures

Tables

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1 Introduction

Dryland salinity is a major soil and water problem in Victoria and refers to the build-up of salt in the soil and groundwater in non-irrigated areas. Early mapping targeted secondary (human induced) salinity, but over time a number of primary (natural) sites have been mapped as their environmental value was recognised. To date, over 260 000 ha of land has been mapped and this estimate includes both primary and secondary salinity located across non-irrigated areas of Victoria and impacts upon both natural and built assets. Victorian government estimates put the direct cost of salinity in irrigated and dryland areas at $50 million annually and the Victorian Auditor General calculated that $1.8 billion of private and public funds had been spent on salinity management over the period 1990-2001 (Auditor General Victoria 2001).

In order to manage an environmental threat such as soil salinity, it is first necessary to understand the extent and severity of the problem, and then provide ongoing feedback to intervention programs by monitoring change over time. In addition, the Victorian government is committed to a number of salinity monitoring requirements, particularly in the Murray Darling Basin, where end of valley targets (for salt-loads) have been set for northern catchments. Land salinity has been accepted as one of the Matters for Targets indicators within the National Framework for Natural Resource Management Standards. The extent and severity of land salinity has been listed by the Victorian government as one of the Victorian Catchment indicators. Its status will be reported in a statewide Catchment Condition Report in 2007. A State of Environment Report for Victoria and a second National Land and Water Audit are both due in 2008 (Clark 2006).

To provide feedback to landholders, land managers and federal and state government funding bodies, all dryland salinity mapping conducted across Victoria was compiled onto a single database in the early 1990s. This database records the extent of all recorded salt affected sites in Victoria at a scale of 1:25 000 (Allan 1994). A number of other attributes, including severity, have been recorded at many of the sites. This database is currently held on the Corporate Spatial Data Library (CSDL) in a Geographic Information System (GIS) environment and is managed by the Department of Primary Industries (DPI) for the Department of Sustainability and Environment (DSE). It forms the primary source for almost all dryland salinity monitoring and reporting in Victoria (Figure 1). The extent and severity of soil salinity in irrigated areas has primarily been mapped via ground-based electromagnetic (EM38) surveys[1] rather than using the method described in this report which is based on an assessment of vegetation and other physical indicators . This information is held on a separate database.

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[1] The EM38 surveys were conducted as part of a whole farm planning exercise for farmers in the irrigation district where the high value of the land and the farming enterprises justified the extra time and cost.

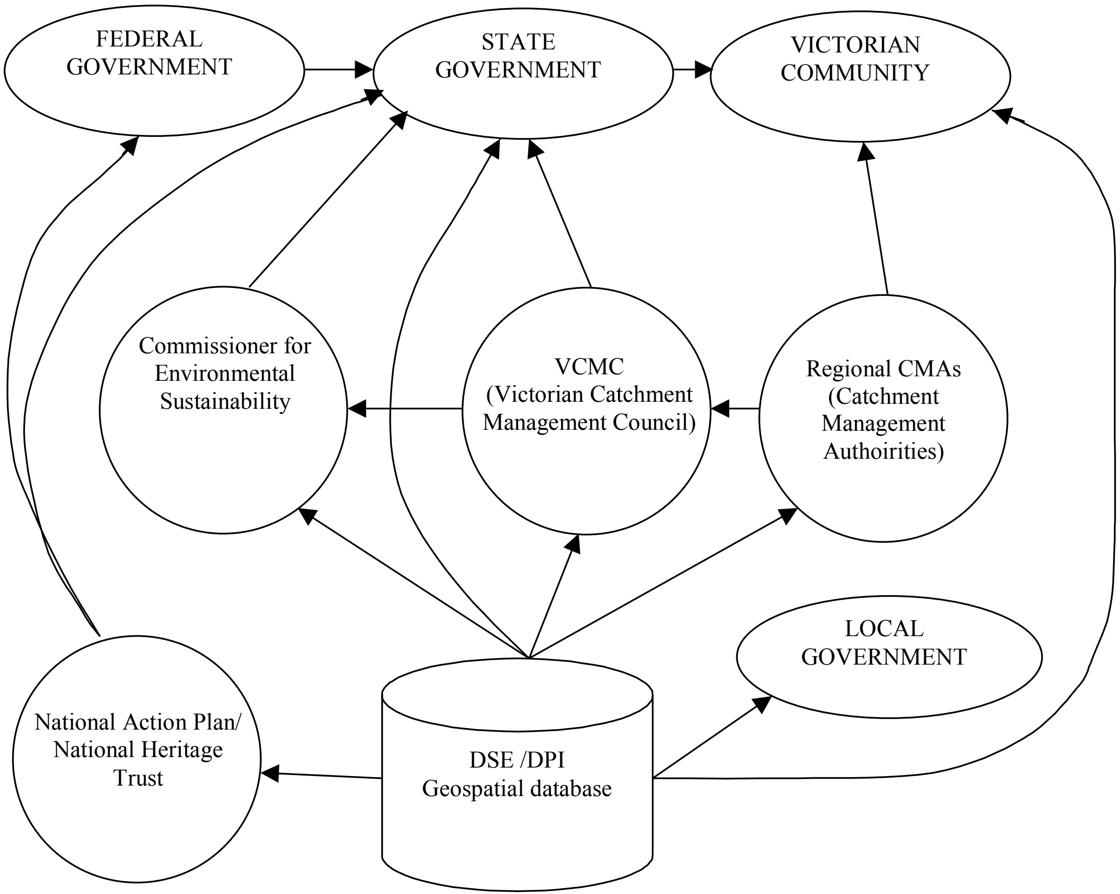

Figure 1 Schematic drawing showing how the DSE/DPI geospatial database is the primary source for all reporting on dryland salinity

This report details the current field method employed to identify and assess dryland salinity in Victoria. It represents an updated version of the method documented by Allan (1996) and is heavily based on that text. There are a number of significant differences between the current method and that described by Allan (1996), primarily in the attributes recorded for each site and the technology and method used to map the spatial extents of the saline areas. However, much of the original approach remains and to save frequent repetition, the 1996 report is not always cited. Nevertheless the authors would like to acknowledge a debt to previous contributors and their documentation.

1.1 History of dryland salinity assessment

Salinity has long been recognised as a feature of the Victorian landscape. Robertson (1898) referred to the appearance of saline springs on the Dundas Tablelands in Western Victoria in 1853 shortly after European settlement of the district commenced. While hydrological balances were maintained by retention of deep-rooted vegetation and natural water flow into sinks such as salt lakes continued unchanged, the distribution of salt in the landscape was unlikely to change significantly over long periods-apart from seasonal ebbs and flows. However, a significant increase in soil salinity levels (thought to result from changes in land use following European settlement), became evident in the 1940s. The 1950s saw dryland salinity acknowledged as a major environmental problem in Victoria and government agencies began to assess the size of the problem and monitor its progress. Cope(1958), estimated that over 5000 ha of land was affected by dryland salinity. Through the 1970s and 1980s above average rainfall led to a significant rise in groundwater levels and an increase in the extent of salt affected soil. By the late 1970s, the Soil Conservation Authority (1978) estimated that 85 000 ha was affected by dryland salinity.

In the early 1900s it was recognised that certain plants were useful indicators for identifying both saline and alkaline soils. A body of research based on the interaction between vegetation and the chemical and physical characteristics of soil was developed in the USA (United States Salinity Laboratory Staff 1954). The first salinity surveys in Victoria were confined to specific regions and assessment criteria varied from region to region. Over time it was recognised that a piecemeal or uncoordinated approach to identifying the extent and severity of soil salinity would not be in the best interests of the community. As a consequence, a project was funded under the National Soil Conservation Project to develop a standard method for identifying, assessing and recording dryland salinity in Victoria (Matters 1987). Following this initiative, a statewide project was established in 1989 to compile all existing data on secondary discharge sites and to coordinate the collection of further data by Department of Conservation and Natural Resource (CNR) regional staff (Allan 1994). In addition, a strategy involving a network of monitoring sites was designed to identify how soil salinity changed over time. This work is continued through the Salinity Discharge Monitoring and Salinity GIS Project funded by the Department of Sustainability and Environment (DSE) and undertaken by the Department of Primary Industries (DPI), Bendigo (Clark 2005).

Much of the field data was collected in the late 1980s and early 1990s and a database of dryland salinity in Victoria was created which recorded every mapped discharge site in the state (Allan 1994). With the advent of Geographic Information Systems (GIS), the soil salinity database was loaded onto the CSDL in the early 1990s. This database has been maintained on the CSDL since that time by DPI on behalf of DSE. The last coordinated, regional mapping programs were completed in North East Victoria in 1998 and the Glenelg Hopkins region in 1999. The extent of soil salinity in the Mallee has only recently been mapped using a combination of spatial modelling based on ortho-rectified airphotos from autumn 2003, Ecological Vegetation Condition (EVC) mapping, a digital elevation model (DEM) and limited ground truthing. This survey identified areas of moderate to extreme levels of soil salinity typically characterized by halophytic plant communities. It was not able to identify slightly saline areas or areas where salinity is transient (Grinter and Mock 2007).

Mapping since the late 1990s has been *ad hoc* and limited in extent, although some small areas are being remapped to monitor change over time, notably in the North East and Corangamite CMA catchments. Almost a decade of below average rainfall has seen a general fall in watertables across Victoria and many saline areas shrank in size, although it is becoming clear that there may not always be a direct correlation between a change in the depth to watertable and change in the extent and severity of soil salinity at a site.

Allan (1994) identified two types of dryland salinity, primary and secondary. Both of which are mapped using the same salinity severity class criteria:

- Primary (or natural) salinity, which existed long before European settlement and is held to be the result of natural environmental processes.
- Secondary (or induced) salinity, which has occurred since European settlement and is considered to be the result of changes in land and water management practices.

When the salinity monitoring project commenced, the focus was on identifying secondary saline sites as they were considered as areas of productivity loss that were more amenable to reclamation. At such sites efforts were frequently made to rehabilitate the site or at least stop it degrading further and regain some productivity for the landholder. With productivity as the focus, it appeared there was little to be gained from investing in salinity treatments in areas that were saline prior to European settlement (Allen 2006) and primary sites tended to be ignored. However, in recent years the community’s understanding of salinity has become more sophisticated and primary saline sites have been recognised as natural assets from a biodiversity perspective and the salinity program aims to identify primary saline sites to support their management and preservation.

2 Primary salinity

Natural or primary salinity existed for thousands of years in many parts of Victoria before European settlement and is considered to be a natural feature of the landscape. Many saline areas were permanently or seasonally inundated, or frequently became waterlogged. Over geological time periods, patterns of waterlogging, inundation and the salinity of soil, ground and surface waters has changed with climate (Allen 2006). Secondary salinity (as distinct from primary salinity), by definition is a direct consequence of post-European settlement activity.

Primary salinity sites tend to be populated by a highly diverse and stable community of salt-tolerant vegetation where the vegetation community, climate and the environmental conditions at the site have achieved a state of equilibrium over many years. There may be relatively small seasonal fluctuations in the vegetation community as some species are either favoured or disadvantaged by short-term climatic variation (Matters 1987) or where annual species may dominate in years when conditions are most favourable. Longer-term change in climate may cause some species to disappear or enable other species to colonise a site (Allen 2006). The total area of primary salinity in Victoria is estimated to be 250 000 ha (Allan 1994) and includes semi-permanent and permanent wetlands on the coast and inland as well as dryland areas such as salt flats and drainage lines. A significant number of these sites have not been included in the soil salinity database as its focus was primarily on secondary salinity.

A classification of primary salinity may be as follows:

Salt marshes and saline swamps (coastal and inland)

Salt marshes are not restricted to the coast and may well occur inland. Typical examples are tidal flats or periodically inundated depressions inland. Salt marshes tend to be treeless and dominated by grasses.

Saline swamps are similar to salt marshes, but tend to be dominated by trees e.g. mangrove or tea tree. Not many inland saline swamps remain.

Although salt marshes are a distinct class of primary salinity from salt swamps, they tend to occur in similar parts of the landscape.

Approximately 100 000 ha of coastal salt marshes and swamps exist in Victoria, with major occurrences at Discovery Bay (western Victoria), Westernport Bay, Andersons Inlet, north of Wilsons Promontory, and along the Gippsland Lakes (Corrick pers.comm.[2]). To date, salt marshes and swamps within the tidal influence of the sea have generally not been included in soil salinity surveys and as a consequence are not represented in the soil salinity layer on the CSDL. This may change as local government authorities come under increased pressure to allow residential development closer to the coast.

Salt lakes

Salt lakes may be distinguished from salt flats and salt pans as they have permanent or near permanent water under 'natural' conditions and as a consequence only support vegetation around the edges. Typical examples are Lake Corangamite or Lake Albacutya, although alteration to water flows has changed their primary status to some extent.

Salt flats (including playa) and salt pans

Salt pans and flats are saline areas of low relief generally associated with arid or desert environments—pans are notably hard and flats are dry lake beds or adjacent to large water bodies. Playas are a special form of salt flat that are alkaline in nature and tend to be of uncertain surface strength and often overlie soft mud. Salt flats and salt pans are commonly found in the north-western Victoria.

Natural salt springs, seepages and drainage lines

These arise where natural upwelling or drainage of saline water occurs. Examples of this type of primary salinity can be found in south-western Victoria around Dundas and Linton.

Identifying primary salinity in the field

Primary salinity must be distinguished from secondary salinity in the field because secondary dryland salinity is regarded as a land degradation problem while naturally saline ecosystems are considered natural assets. However, in practice it can be difficult to distinguish between primary and secondary salinity in the field. Adding to the complexity is that primary sites may also have a secondary salinity component if changes in land management and land use lead to an increase in salinity severity at the site, an expansion of the original site, or both.

Allen (2006) developed a field-based method based on composition of the vegetation community for discriminating between primary and secondary saline sites. The method is based on the premise that long established sites contain species that are adapted to saline environments that may have a relatively limited ability to disperse and colonise new sites. The following criteria result from this premise:

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[2] AH Corrick (Arthur Rylah Institute, NRE) January 1991

- A site is likely to be a primary site if it has a high diversity of native salt tolerant species that have low capacities for dispersing and colonising newly salinised sites. This criterion may not hold true where a secondary saline site adjoins a primary site from which otherwise poor colonisers may more readily disperse.
- A site with few species considered to be poor colonisers, may be a secondary site or it may be a highly disturbed primary saline site. In some instances, the grazing of primary sites may lead to the introduction of volunteer salt-tolerant species and other weeds, making the distinction between primary and secondary salinity difficult.

Primary salinity tends to occur at certain positions in the landscape as a result of interaction between surface water, groundwater and the landscape. Some region specific examples of the links between primary salinity, landscape and process are:

- The presence of clay lunettes, typically on the eastern side of lakes or depressions—is also an indicator of natural salinity in the north-west and west of the state. Clay lunettes are formed down-wind of a saline lake that periodically dries out. High levels of soil salinity impact on the soil structure of the exposed lake bed leaving it prone to wind erosion. Deposition of the lake bed sediment forms the distinctive crescent-shaped lunettes over time (e.g. Lake Tyrell). However, sand lunettes may also be formed adjacent to freshwater lakes by wave and wind action at times of high water level (Allen 2006).
- Primary salinity may form within water bodies found at the terminal end of a surface water and/or groundwater drainage system within basalt terrain in southern Victoria. Over time salts may accumulate as a result of evaporation. An example of this process is Lake Corangamite.
- Natural wetlands and depressions that act as windows to naturally saline groundwater bodies. An example of this is the salt lakes within the Douglass Depression in the Wimmera (Swane et al 2001).

3 Secondary salinity

Secondary salinity is characterized by sites that have become affected by increasing levels of soil salinity since European settlement due to the impacts of changing land management practices and land use. Originally, mapping was restricted to secondary soil salinity in non-irrigated agricultural areas, however as community attitudes to salinity matured, the environmental value of primary sites was recognized and a number of primary salinity sites were also mapped. Over 260 000 ha of land has been identified and mapped as saline, including natural dryland salt flats and wetlands inland and some of the saline wetlands along the coast. These areas are recorded on the soil salinity layer held on the CSDL.

Across Victoria approximately 25 000 ha of the mapped area has been positively identified as purely secondary salinity. Over 8000 ha of the mapped dryland salinity was positively identified as primary salinity, almost 12000 was considered to be a combination of primary and secondary salinity, while around 217 000 ha of land mapped as saline has not been identified as either primary or secondary salinity. It is not possible to state conclusively how much of the state is affected by secondary salinity, but if we accept Allan's estimate (Allan 1994) of 15 000 ha of secondary salinity in the Mallee as reasonable, the mapped area affected by secondary dryland soil salinity in Victoria could range from 40 000 ha to as much as 160 000 ha.

By implication, secondary salinity occurs at disturbed sites (created either by direct destruction of vegetation or loss of vegetation and topsoil caused by increased soil salinity levels) which may not yet have achieved a state of equilibrium between the vegetation community, climate and other environmental features of the site. The vegetation community at such sites may see an initial influx of species capable of dealing with the changing environment. The composition of the vegetation community may stabilize if the site attains some degree of equilibrium, but is open to change if this new found equilibrium is disrupted (Brown[3] pers. comm.).

Secondary dryland saline sites may be populated by both native and non-native plant species with differing tolerance of salinity from many plant groups e.g. grasses, legumes, native forbs and

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[3] Austin Brown (Statewide Leader, Pedology and Soil Physics, Future Farming Sytems Division, DPI) June 2007

herbs (Matters 1987). One characteristic common to most species at a secondary site is the ability to adapt to change and/or an ability to colonise disturbed areas. Species with this characteristic are known as ruderal plants, and they tend to be efficient seed producers and have relatively short life cycles and are. Fewer salt-tolerant native species have these characteristics than introduced species, and as a consequence vegetation communities at secondary saline sites are usually dominated by introduced species (Allen 2006). There are some exceptions to these principles. For example, in the Victorian Mallee, members of the *Halosarcia* and *Sarcocornia* species are not short lived or known as particularly efficient seeders and are often the only vegetation apart from annuals to colonise secondary saline sites (Brown[4] pers.comm.).

3.1 Drivers of secondary salinity

Several causal mechanisms, all linked to changed land management practices and land use since European settlement, have been identified and are believed to lead to increased levels of secondary dryland salinity:

Increased groundwater recharge

The clearing of deep-rooted perennial native vegetation and its replacement with shallow-rooted low water-using annual plants common in pasture and cropping enterprises generates increased accessions to groundwater leading to raised groundwater levels and increased groundwater discharge (Cook et al 2001, Cope 1958, Jenkin 1981, Rowan 1971). Some examples of secondary dryland salinity resulting from increased accession to watertables and the geophysical features that control this expression of salinity within the landscape are:

- The presence of aquitards (clay units) within sand dunes that cause perched saline watertables; typical example Victorian Mallee (Rowan 1971).
- Where weak points in aquitards of regional groundwater systems allow for upward groundwater flow and discharge at the soil surface; typical example along the Riverine Plains of Victoria (Macumber 1978).
- Groundwater discharge occurring at the break-of-slope caused by a change in hydraulic gradient; typical example Palaeozoic sediments, central Victoria (Jenkin 1981).
- Increased base flow to streams, which leads to an increase in stream saltloads. Typical examples include Collie River basin Western Australia (Peck and Williamson 1987) and Moorabool River, Victoria (Evans 2006).

Altered surface and sub surface environments

While increased recharge following European settlement is considered the most common cause of secondary salinity, there exist examples where dryland salinity has been attributed to other processes, such as:

- Transient salinity. This type of salinity is not related to shallow watertables. Transient salinity occurs in cropping and pasture areas overlaying sodic subsoils, and results from a combination of reduced leaching associated with sodic clays, low rainfall in dryland areas, transpiration by vegetation and high evaporation in summer. More than 60% of the 20 million ha of cropping soil in Australia has the potential to be affected by transient salinity as opposed to about 16% likely to be affected by salinity resulting from shallow watertables (Rengasamy 2002).
- Alteration of shallow regolith flow systems and accumulation of salt caused by post clearing and geomorphological processes, such as landslide and debris flows. Typical examples include the Heytsbury region of Victoria (MacEwan et al 1996) and the southern Tablelands of NSW (Acworth et al 1997).
- The removal/disturbance of vegetation communities in primary groundwater discharge zones, which leads to increased evaporation and alterations in soil chemistry resulting in increased salinity levels in soil and groundwater and decreased soil pH (Fawcett 2004; Dahlhaus and Cox 2005).
- Salinity in and around wetlands and watercourses caused by disruption of the existing local salt and water budget; typical example Lake Wallace, Edenhope (Fawcett and Huggins 2004, Vinall 2000).

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[4] Austin Brown, (Statewide Leader, Pedology and Soil Physics, Future Farming Sytems Division, DPI), June 2007

- Alteration of watercourses and shallow regolith groundwater systems due to 19th century mining activities, typical examples around the Ballarat goldfields (Dahlhaus and Cox 2005).

4 Major indicators of dryland salinity

This methodology for dryland salinity assessment is based on a visual appraisal of locations as salinity affects the soil and vegetation at salinised sites. These effects frequently produce or initiate changes in the environment that form the distinctive characteristics common to salt-affected landscapes that are readily observed in the field. The major visual indicators of salinity are: vegetation species and community, surface moisture, bare soil, soil surface condition, salt accumulation and organic matter stains. The position in the landscape where these indications occur is contextually valuable and can significantly inform site evaluation.

Excess salt levels in the soil can produce two major effects to visually alter a site:

1. Plant growth may be inhibited as a result of increased osmotic pressure of the soil solution making it difficult for plants to absorb water from the soil. At low to moderate salt concentrations, plants are able to manage the osmotic balance between the soil and their root system by accumulating internal salts. This process maintains an osmotic gradient that enables water influx to continue. However there is a penalty, for under such conditions energy used to accumulate solutes is no longer available for plant growth. As salinity increases, individual plants may be affected to a greater degree. Typical symptoms are: severe leaf tip burning, disturbance of cell membrane function, internal solute balances and even death (Matters 1987). Less commonly, toxic effects due to excessive accumulation of ions may directly affect the surface membranes of plant roots or tissues, or the uptake or metabolism of essential nutrients (United States Salinity Laboratory staff 1954).
2. Increased percentages of exchangeable sodium on the soil cation exchange process leading to a deterioration in the soil structure (Cope 1958). Loss of structure can lead to hard-set surfaces which decrease water infiltration, increase runoff and overland salt movement, decrease seed germination and emergence and increase the potential for surface soil erosion. In addition, poor subsurface soil structure will reduce both internal drainage during wet conditions and moisture holding capacity during dry conditions (significant factors contributing to transient salinity unrelated to shallow watertable processes). Reduced subsoil stability can lead to tunnel and gully erosion and increase the connectivity of saline groundwater to surface streams and rivers.

4.1 Vegetative indicators

Dryland salinity assessment based on an assessment of the vegetation community largely relies on observation of ground and under-storey species of plants. As most salt-tolerant species will also grow in non-saline soil, it is variation in the composition of the plant community compared to the surrounding area rather than the presence of one or two salt-tolerant species that is the key to identifying a salt-affected site. When traversing a site from non-saline to saline soil, the number of salt-tolerant plants will tend to increase and the number of salt-sensitive plants will tend to decrease. Sites should only be classified as saline if there is a significant change in the plant community from a mix of both salt-tolerant and salt-sensitive species to one dominated by salt-tolerant species that cannot be plausibly explained by some other management or environmental factor. The presence of a vegetation community dominated by salt-tolerant species and with decreased numbers or total absence of salt-sensitive species in conjunction with any of the physical signs (presence of groundwater, bare soil, deteriorating soil surface structure, salt or organic stains or the position in the landscape where saline soil is commonly found) is a good indication of salinity without the need to take soil samples.

Plant response to salt

Excessive levels of soil salinity can effect vegetation in several ways:

1. Increased concentration of salts in the soil water may increase the osmotic gradient between plant and soil by reducing a plant’s ability to take up the moisture required to balance moisture loss via the leaf canopy. The total concentration of solute particles rather than their chemical nature is responsible for this effect. In such cases the plant tends to dehydrate and in severe cases die. A common symptom of plants affected in this manner is a cupping or rolling of the leaves, however water deficient plants in non-saline soil may show similar symptoms (United States Salinity Laboratory Staff, 1954).

2. In saline soils the presence of excessive concentrations of ions such as chloride, sulfate, bicarbonate, sodium, calcium, magnesium and less frequently potassium and nitrate may lead to injury such as firing of the leaf margins, chlorotic and necrotic areas on the foliage or simply depressed plant growth. These symptoms may be partly caused by a reduced ability to metabolise essential nutrients, although it is not always possible to clearly distinguish the mechanisms related to specific ions (United States Salinity Laboratory Staff, 1954).

At the upper end of a plant's salinity tolerance range morphological changes such as stunting, thickening of the leaf surface, reduction of leaf hairiness, semi-succulence in leaves and reddening of the plant may occur. These are common stress responses and may be brought on by any one of a number of environmental factors such as soil moisture deficit, poor cultivation practices, water logging, spray drift, root disease and insect attack as well as increasing soil and water salinity levels. Stress symptoms can be useful in the field to show that a plant may be at the upper end of its tolerance range and therefore helpful when assessing severity levels. However, it is important to remember that rising salinity levels are only one of a number of possible stress factors and field observation combined with knowledge of the likely management and environmental processes influencing a site should be considered when looking at stress response. Stress response alone is not sufficient grounds to classify an area as saline as many other processes can evoke a similar response.

Not all of the relationships between plant and soil are fully understood and although it is generally acknowledged that while increasing salt concentrations in the soil profile generally have a negative effect on plant growth, vegetation sometimes shows little effect from increased salinity levels or moisture stress. Vegetation response to salinity may vary with climate and soil type and there are examples in both the Corangamite (Allan 1994) and Glenelg Hopkins regions where laboratory measurement of levels of soil salinity were higher than expected given the vegetation present and the general physical conditions at the site. It is not known exactly why this occurs, but it is presumably a function of the variation of the soil water conditions within the root zone and atmospheric conditions (particularly those conditions that affect evaporation) that allow species to establish and grow more successfully than predicted. At times of the year when surface salinity is leached by rainfall, seed often has a much better opportunity to establish and develop salt tolerant mechanisms before salt levels increase again with evaporation. In some regions the climatic factors may combine to reduce the osmotic pressure gradient between soil and leaf thereby limiting water utilisation and loss.

Regional differences in vegetation response to salinity need to be known and understood to produce accurate maps of soil salinity. To do this adequately, it will be necessary to collect and analyse soil samples and correlate them with the vegetation community and condition for different regions. It is hoped that regional salinity field guides will be developed for all of Victoria.

Salt-tolerant species

Salt-tolerant species have physiological mechanisms that allow them to cope with high salinity levels and grow in saline environments, each species having a specific range of tolerable soil salinity in a particular climatic zone. In saline areas, this capability gives these plants a competitive advantage over salt-sensitive species, and as soil salinity levels increase, species with a higher tolerance tend to replace less tolerant species. However, these physiological mechanisms have a downside, as less energy is available for plant growth because much energy is used in accumulating solutes to maintain the osmotic gradient. They cannot be switched on and off and in non-saline environments, halophytic plants are at a competitive disadvantage to more vigorous, glycophytic species, which do not employ such mechanisms.

Appendix 1 lists some of the salt-tolerant species found in Victoria, but it is by no means a comprehensive list of all Victorian salt-tolerant plants. Some species are rated in terms of their ability to tolerate soil salinity and others are only listed as tolerant.

Salt-sensitive species

Salt-sensitive species do not have the physiological mechanisms that allow them to cope with the effects of increased soil salinity levels and suffer reductions in yield/ growth when salinity levels increase beyond a tolerable threshold. The United States Department of Agriculture (USDA) accepted 2 dSm^{-1} as a threshold above which yields of sensitive crops may be restricted (United States Salinity Laboratory Staff 1954).

An important indicator of salinity is a noticeable reduction in the number of salt-sensitive species from a suspected discharge site compared to the adjacent non-saline area. This is a useful indicator, but taken on its own could be misleading and it should always be examined in conjunction with an assessment of change in the distribution of salt-tolerant species.

Morphologic changes in salt-sensitive species may result from increased soil salinity. Matters (Matters 1987) states that such changes may take the form of decreased germination rate, slow growth rate, incomplete life cycle (e.g. plants do not flower), diminished abundance, depressed health (commonly apparent by characteristic yellowing and stunting of crop or pasture species), greater susceptibility to disease and decreased seed viability. These changes may also result from water-logging, nutrient deficiency or other limiting environmental factors, and there should be a thorough examination of the surrounding area to determine if the changes are limited to a particular location and if there is a corresponding increase in salt-tolerant species. In the absence of any other indicators, it is not good practice to classify such a site as saline based solely on morphological change.

Appendix 2 lists some of the known salt-sensitive species found in Victoria, but it is by no means a comprehensive list of all Victorian salt-sensitive plants.

Tree health

Dieback or death of trees may be due to salinity, though other factors such as drought, flooding, insect attack, damage by stock or wildlife, soil compaction, cultivation or other forms of disturbance must be exhaustively ruled out before salinity is attributed as the cause.

Limitations on assessment using vegetative indicators

Given that the main assessment criterion is identification of vegetation, it is essential that field assessment be restricted to the time of year when the critical vegetation is present and can be easily and reliably identified. This is usually around flowering time in late spring through to early summer but will vary depending on the species, region and season. Failure to observe this restriction may reduce the accuracy of the field assessment.

As an example, subterranean clover (*Trifolium. subterraneum*) is a salt-sensitive pasture species common across much of Victoria. It is an annual, highly palatable and frequently not visible after mid-summer. Sea barley grass (*Hordeum marinum*), like subterannean clover has an annual life cycle, however it is generally not palatable to stock or native wildlife and frequently persists in an identifiable form after setting seed for most, if not all the year. Sea barley grass is found across much of Victoria, but its concentration is generally higher in saline sites. It is not uncommon to find subterannean clover thriving in areas around but not in discharge sites. These same areas may also carry a relatively small population of sea barley grass, which increases within the saline area. An assessment in autumn, based solely on the area of sea barley grass may over-classify the salt affected area by mapping all of the sea barley grass cover as saline. A more accurate assessment at such a site would take place in late spring or early summer when both species are easily identified and the areas where subterannean clover dominated would be assessed as non-saline.

Field assessment should not be based on the presence or absence of a single species, but should take into account the whole plant community present at a site and the non-saline areas adjacent and the physical characteristics of the whole site and surrounding area.

If assessment is taking place in years of below average rainfall, there may be very little plant germination or growth and flowering may be brought forward or limited. This is likely to reduce the window of opportunity to conduct vegetation-based assessments. In years of severe water shortage and high temperatures, some annual species may not germinate at all and increased grazing pressure from stock and wildlife brought on by the general shortage of feed may further shorten any window of opportunity. In extreme years the option exists to delay the assessment until favourable climatic conditions return. To state the obvious; if the indicator species are not present then a vegetation-based assessment is not feasible at that time.

Changes in land management and ground cover may also reduce the usefulness of this vegetation-based assessment. This is covered in more detail in the section titled ‘masking’.

This field assessment method relies on a visual assessment of vegetation communities and other physical indicators by individual officers in the field. This involves subjective judgement and will vary from individual to individual. One of the aims of publishing this methodology is to set out clear guidelines that will assist field officers to make judgements consistent with other field officers. To further reduce the subjective nature of the field assessment, it is recommended that:

- All staff members are trained in using the method prior to commencing field work. Training is currently funded by the Statewide Salinity Monitoring Program.
- The number of staff working on a mapping project is kept to a minimum i.e. It is better to have two people working for two weeks each than four staff working for one week each.
- All staff working on a mapping project should spend the first day or two mapping sites together. This will assist them to bring their assessments into alignment and will produce a more consistent assessment.

4.2 Physical indicators of salinity

Groundwater

Free water or dampness at the ground surface (particularly in summer) may be due to groundwater discharge. Recent rainfall events and waterlogging are other possible causes. Free water should be analysed for salt using a field electroconductivity (EC) meter. Any water registering above 0.5 dSm^{-1} in winter may reasonably be assumed to be discharging saline groundwater and therefore the site is deemed to be salt affected. See the section titled 'waterlogging'.

Bare soil

If soil salinity levels rise to critical levels, salt-sensitive vegetation may die. Salt-tolerant species may then establish, though this is dependent on the proximity of a suitable seed source, the amount of traffic, grazing and cultivation and susceptibility of the site to water and wind erosion. At extremely high levels of salinity no plant species can persist, bare soil is exposed and a damaging cycle commences, as bare soil is more prone to erosion by wind, water or traffic. Evaporation rates are likely to increase, as there is no barrier to water being drawn to the surface by capillary action leading to an accumulation of salt near the soil surface. This will accelerate the risk of erosion, as excess salt in a soil tends to break down soil structure. Stock frequently exacerbate baring as they like the cool and salty conditions found at a discharge site, often preferentially grazing the salt-affected vegetation and camping on these sites. The process of "baring" due to salinity usually begins in depressions, these being marginally but critically closer to the watertable.

Not all bare sites will be associated with salinity. It is important to thoroughly examine a site in the field to determine if salinity is the prime cause of bare soil or some other agent such as stock or human traffic, wind or water erosion or cultivation is the underlying cause. Often several processes will be occurring simultaneously at a site and there may be some evidence of soil salinity nearby. Areas around gates and dams are often bare because of traffic, water erosion may be the primary cause on some slopes and in gullies or stock may wallow in a depression that is wet but not salty.

Salt stain or crystals

Salt is sometimes observable (more so on bare soil) as minerals (evaporites) that form a white stain, or actual salt crystals (encrustation). This is one of the more definitive indications of salinity. The evaporite stain or encrustation may be tasted for confirmation.

Position in the landscape

Regional groundwater aquifer systems have flat or gently sloping watertables that extend under a number of surface water catchments. Due to the evapo-transpiration process, discharge generally occurs where the watertable reaches to within 2 m of the ground surface. However, this may vary depending on soil type and climate and topography. Discharge tends to appear at topographically low sites, i.e. on flats, drainage lines, lake margins, depressions and stream banks.

Local groundwater aquifer systems have watertables that generally follow surface topography. Perched watertables, caused by an aquifer overlying a confining (usually clay) layer, may discharge as seeps along slopes. Salinity may occur at the break-of-slope where a change in surface gradient leads to a corresponding decrease in hydraulic gradient and a consequent rise in groundwater. Local groundwater systems may overlie and interact with regional groundwater systems.

Soil blackening

Salt-affected soil that is also low in phosphorus and nitrogen can sometimes be recognised by a characteristic blackening due to the dispersion of dark coloured organic matter (Matters 1987).

4.3 Factors affecting recognition of dryland salinity

There a number of factors affecting the recognition of dryland salinity. Two types of recognition errors can be produced, omission and commission errors. Omission error results when an area is classed as non-saline when it is in fact saline. Commission error results when an area is classed as saline when it is non-saline. Some of the factors affecting recognition of dryland salinity may produce both types of error.

Masking

Site disturbance or modification such as cultivation, slashing or harvesting can conceal the presence of salinity at a site. This is termed 'masking', and to determine if this effect is in operation it may be necessary to take a soil sample for analysis or make a return visit to assess the site when a crop, pasture or other vegetation regime has developed. Masking generally increases the likelihood of omission errors and may dampen assessments of severity levels at a site.

Another form of masking occurs when the vegetation community within an area has been modified by external factors to favour saline tolerant species i.e. 'salinity treatments'. Treatment of discharge sites usually incorporates non-saline areas bordering the saline site. Planting the treated area with salt-tolerant species such as tall wheat grass, strawberry clover or *Puccinellia* may make it difficult to identify the extent of the saline area and its severity given the ability of these species to grow on both saline and non-saline soil. This form of masking favors commission error. At such sites the salt-tolerant vegetation often follows paddock boundaries. If the site has been treated for a long period and has had time for the vegetation to reflect the underlying soil salinity levels, the non-saline areas may contain a number of salt-sensitive species that have been able to out-compete the salt-tolerant species. The areas of higher soil salinity may be showing degradation and reduced plant cover, or invasion by species with a higher level of tolerance if a source of seed exists nearby. As a rule of thumb, unless there is invasion by species with higher tolerance or bare ground to indicate increasing soil salinity, or invasion by salt-sensitive species, the mapping officer can assume that the salinity must have been at least moderate (class 2 severity) for the landholder to have bothered treating the site. Although the mapped extent of the salt-tolerant vegetation may well reflect paddock boundaries, mapping the edge of the salt-tolerant vegetation will place the site on the data base for future monitoring and contribute to a greater understanding of the distribution of soil salinity across a catchment.

Another form of masking may arise during seasonal wet periods if salt-sensitive plants with a short life cycle can complete their growth and reproductive stages before salt levels in the soil rise again. These opportunistic species may mask the true level of salinity at the site by providing a good cover at a time of temporarily reduced salinity level. This is not an acquired tolerance to salinisation, but an adaptation. This confusion can be avoided to some extent by looking at the broader site and ignoring occasional occurrences of known salt–sensitive plants within an area generally considered to be saline on the basis of other indicators. This is particularly the case if the season has been wet or if the salt-sensitive species are growing on areas of favoured micro-relief (see leaching and microrelief section for more detail).

Waterlogging

Waterlogging is the ponding of surface or near-surface water due to a heavy clay layer in the soil profile or other physical barriers, such as roads or railways, causing inadequate drainage of a site. The water may be fresh or saline depending on its source and the paths it has travelled to the site where it remains impounded. If a body of water is impounded at a site for a period of time some will be lost to evaporation, causing the concentration of salt in the remaining ponded water and soil water to rise. Over many years this may cause a significant increase in soil and water salinity.

As part of the field assessment, it is critical to distinguish non-saline waterlogged sites from saline ones. This is achieved by examining the plants at the site, as well as by testing the water and possibly the soil.

Local increases in the number of plants tolerant of waterlogging and a decrease in the number of plants sensitive to waterlogging or a decline in their condition, indicate a likelihood of waterlogged conditions in the soil profile. Waterlogging usually occurs at low points in the landscape, but restrictions to free drainage of water can sometimes occur at relatively high points in the landscape. Classification of a waterlogged site as saline or non-saline will depend on the species present at the site. A range of plant species are tolerant of waterlogging. Within this group there are plants that are salt-sensitive and salt-tolerant. Included in salt-sensitive species are subterannean clover, Yorkshire fog, capeweed and hairy hawkbit are all tolerant of water-logging, as are salt-tolerant species such as bucks horn plantain, water buttons, annual beard grass and creeping brookweed. Plants adapted to waterlogging also include sedges and rushes, but within these two groups of water-loving plants are species that are also salt-tolerant or salt-sensitive. Some well known salt-tolerant plants such as spiny rush and strawberry clover do well in waterlogged conditions whether they are salty or fresh and it is essential that other species are included in the assessment. Refer to Appendices 1 and 2 for salt-sensitive and salt-tolerant sedges and rushes to further assist in the determination.

If surface water is present, its electrical conductivity (EC) should be measured as an aid to classification. However climatic events can influence EC measurement. Evaporation during summer can increase salt concentration in surface water even if the original source of this water was fresh (rain or flooding). Recent rainfall may dilute the salts of a normally saline body of surface water. Although the vegetation community should be regarded as the major indicator when classifying a site, if the measured EC is less than 0.5 dS/m, the site is less likely to be classed as saline.

If the visual assessment is inconclusive, it may be necessary for a soil sample to also be tested for salinity.

Leaching and micro-relief

Periods of high rainfall may temporarily reduce levels of salinity at or near the soil surface by leaching salts down the soil profile. This effect frequently occurs on small, slightly raised areas at the margins or even within salt affected areas (Figure 2). Within some saline areas, micro depressions may accumulate sufficient surface water to dilute soil salinity at and near the surface and allow tolerant and ephemeral species to germinate on the floor of the micro depressions (Figure 3).

If care is not taken, these temporary effects may result in assessments that underestimate the level of apparent salinity at the soil surface. Again, seasonal climate events, micro-relief and the broader site characteristics should be taken into consideration when classifying a site.

Figure 2 Leaching may allow vegetation to survive on small, slightly raised areas at the margins or even within salt affected areas

Figure 3 Within some saline areas, micro depressions may accumulate sufficient surface water to dilute soil salinity at and near the surface and allow tolerant and ephemeral species to germinate on the floor of the micro depressions.

5 Assessment methodology

As this method is based on visual assessment of the vegetation community, field surveys need to be conducted when indicator species are easily visible. Most of the indicator species are best identified when in flower and some of the annual species have relatively short life cycles. For most areas of Victoria this means that surveys are best conducted from late spring through to late summer, although this may vary depending on the season and the region. Prior to the field survey, several tasks ranging from identifying likely saline areas, contacting landholders and possibly hiring mapping staff must be completed and the aim is to be ready to commence the field survey as soon as conditions are optimal. Figure 4 gives an overview of the sequence of events that typically occur prior to and during a salinity field survey and conclude with the addition of the attributed spatial data to the soil salinity data base on the CSDL. Table 11 in Appendix 3 lists the tasks and suggested timing involved in preparing for and conducting a field survey through to the entry of data onto the GIS database. This should be used as a guide when planning a field survey. The following sections describe in some detail the actions required at each stage in the process of preparing for and conducting a salinity field survey through to the point where data is handed over for storage on the CSDL.

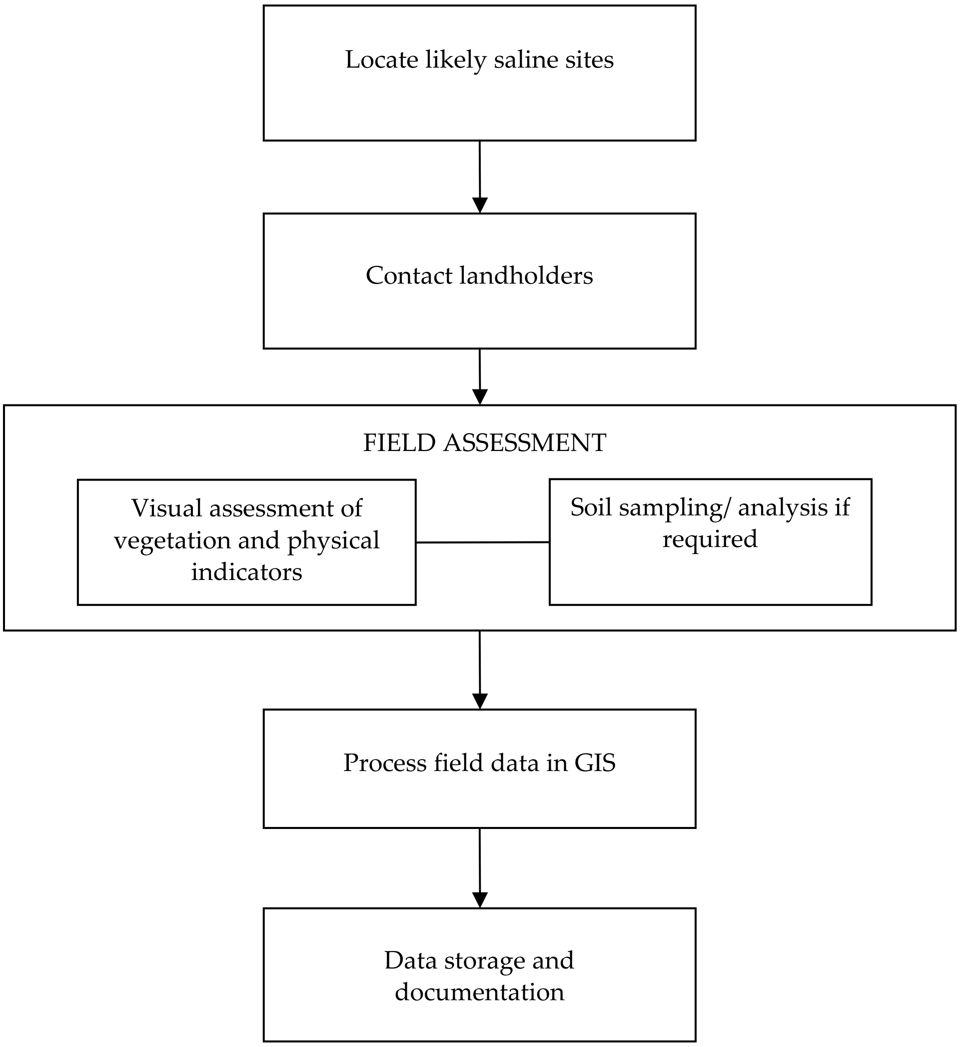

Figure 4 An overview of the sequence of events in a salinity field survey.

5.1 Locating sites affected by soil salinity

In areas that have been previously mapped, the soil salinity data held on the CSDL provides an excellent starting point. Prior to conducting any field survey, maps showing all previously recorded expressions of salinity should be produced and circulated to all relevant DPI, DSE and Catchment Management Authority officers, Landcare coordinators and landholders across the proposed study area to assist in identification of any new or previously unrecorded sites. When local experts are used to identify potential sites, it is better to over estimate and include all sites that may be affected (ie even by other processes such as waterlogging or stock traffic rather than only salinity). If there is a suspicion that a site may be saline it should be inspected in the field by the survey team to determine conclusively whether or not it is saline.

Potential saline areas may also be identified using airphotos to highlight areas where the ground cover type or lack of it may suggest the presence of soil salinity. Bare ground and salt crystals are usually obvious, and salt-tolerant plants sometimes appear as a different visual pattern to the surrounding pasture or crop. With the benefit of local knowledge and/or previous surveys recorded on the CSDL, airphoto interpretation (API) can provide an effective means of identifying previously unmapped sites. However, a salinity survey based entirely on API is discouraged, as practical experience has demonstrated that API alone will seriously underestimate the actual salinity. Field inspection is essential to obtain a true picture of the extent of the problem. When using API to identify possible saline sites, late summer or early autumn photos from a period when ground water levels were relatively high (such as the late 1980s or early 1990s) rather than a recent photo captured during drier years will tend to maximise the visual contrast between saline sites and adjacent non-saline areas. If a site was once saline it should be checked in the field to determine its current status. However, if airphotos are to be used to assist field mapping of the current extents of soil salinity, only current airphotos should be used.

Suspected saline areas may also be identified using a combination of conceptual hydrogeological models, depth to watertable maps, knowledge of vegetation types e.g. Ecological Vegetation Class (EVC) maps, digital elevation models (DEMs) and other landscape features. These factors can also be used to highlight areas that may be at future risk of salinisation.

5.2 Contacting landholders

Existing local knowledge is essential to the process of identifying and recording dryland salinity and it is important that landholders and extension officers be involved in the mapping process. While landholders may provide a valuable resource in terms of locating potential saline sites, it is essential that the rights of landholders be respected.

Privacy

The *Information Privacy Act* (Parliament of Victoria 2000) has made it more difficult to obtain landholder contact details and this can have a significant effect on ground based surveys. The Act restricts the publishing of names, personal details and photos of landholders and their land without permission. It also ensures that data collected from landholders must only be used for the purpose for which it was collected. Landcare networks often provide a good source for collecting information on new and previously unrecorded sites and gaining landholder permission for site access.

Biosecurity

In recent times concern over biosecurity has increased significantly and the heightened awareness of stock diseases such as Ovine Johne's Disease and Footrot have led to the development of certification schemes that have strict standards and protocols regarding cleaning of vehicles and footwear prior to entering and leaving properties (Millar 2006). Prior to visiting a site, it is essential that all landholders be contacted to gain permission for access and determine if there are any limitations to or conditions of access. It is essential that all conditions of entry set by landholders must be strictly observed and are seen to be observed.

5.3 Field mapping procedure

The field mapping procedure follows a logical sequence commencing with an initial inspection to determine if the site is salt affected, assessment of the severity of soil salinity at the site, delineation of the extent of the saline area, recording of attribute values and collection of soil samples if required. The following sections describe in some detail how to perform each of these steps.

Initial site inspection

Prior to mapping, the field officer should spend 5 to 10 minutes walking over the site (or at least a representative part of it) to identify salt-tolerant or salt-sensitive species and any other physical indicators that may assist them to determine the level of salinity at the site. As each known indicator species (either salt-tolerant or salt-sensitive) is identified they should be recorded in a field book along with their severity rating (by reference to the appropriate field guide on the VRO website (Victoria Resources Online 2007). Appendix 4 provides a sample field sheet that could be used for this purpose. It does not include species relevant for all areas of Victoria, but could be used as a template for developing region specific field sheets. Recording each indicator species is not mandatory, but experience shows it will assist the officer to determine if the site is saline, assess the level of soil salinity at the site and provide a useful record to clarify any future queries regarding the site assessment.

Field assessment of the vegetation community and other physical factors

Salt-tolerant species and physical factors can be used to assess the level of salinity (see Table 1 for criteria). This technique should be used wherever possible because plants are generally the best indicators of salinity levels experienced throughout the year and between seasons. In comparison, soil testing is time consuming, costly and less reliable. Matters (1987) classified a number of Victorian plant species as either salt-sensitive (glycophytic) or salt-tolerant (halophytic), based on previous knowledge (Cope 1958, Duff 1983, Moore 1984, White 1981) field observations and soil sampling. A list of salt-tolerant and salt-sensitive plants listed by Matters and other sources (Allan

1996; Allen 2006; Bridgewater et al. 1981, Cross et al. 2001, Matters and Bozon 1995, Rogers et al. 2005, Ross et al. 2003, Victoria Resources Online, 2007) are shown in Appendix 1 and 2 respectively. Salinity class is given where it is known for a species. However, salinity tolerance of individual species may vary from region to region depending on interactions between climate, soil and vegetation and it is often difficult to assign absolute EC_{se} values for salinity tolerance.

Soil salinity severity classes

Five classes of soil salinity have been applied (see Table 1). These classes are based on widely accepted standards developed by the United States Department of Agriculture (United States Salinity Laboratory Staff 1954), and are indicative of relative plant tolerances only.

The original field method developed by Matters (1987) and documented by Allan (1996) was also based on the standards developed by the USDA but only used four saline classes:

- non-saline (<2 dSm^{-1})
- low (2–4 dSm^{-1})
- medium (4–8 dSm^{-1})
- high (>8 dSm^{-1}).

This classification system was used for all Victorian surveys from the late 1980s until 2004. Development of a field mapping guide for north-western Victoria in 2004, where areas of extreme soil salinity levels tend to be more common than in central and southern Victoria, led to the reinstatement of the fifth class used in the original USDA system (United States Salinity Laboratory Staff 1954) . This five-class system, with its separation of 'high' into 8-16 dSm^{-1} and >16 dSm^{-1}, has only been used for field surveys conducted since 2004.

Salinity tolerance of vegetation

Salinity tolerance crosses a broad spectrum—from sensitive plants where growth is noticeably inhibited at EC_{se} values of 2 dSm^{-1}, to extremely salt tolerant species that are able to maintain growth within normal limits in soils where the EC_{se} values exceed 16 dSm^{-1}. There are few if any species that are true obligate halophytes (plants that have optimal growth at moderate to high salinity and are incapable of growth at low salinity). Almost all salt-tolerant species will grow better in non-saline soils but many seldom occur in large number as they are out-competed by salt-sensitive species in such environments. The energy required by the internal mechanisms used to deal with the effects of increased soil salinity means that salt-tolerant species often tend to be slower growing. However, because salt-tolerant plants have a competitive advantage over salt-sensitive plants in saline soils they become more dominant members of the vegetation community. As salinity levels rise, the species that are favoured by the changing environment will also change until the salinity levels and the vegetation community reaches equilibrium. Even sites that have reached a state of equilibrium may experience a regular seasonal fluctuation in soil salinity levels that allows some species with relatively short periods of growth and reproduction to complete their lifecycle over temporary short periods when salinity levels are reduced at a site. Longer term climatic change may lead to a drift in the dominant species at stable sites as the vegetation community adjusts to changing conditions (Allen 2006).

Vegetation condition versus vegetation community composition

The most reliable method for identifying soil salinity and assessing its severity is to examine the composition of the vegetation community at a site compared to the vegetation community at adjacent non-saline areas. Species growing at a site where soil salinity levels are at the upper end of their tolerance range may show a stress response, but there are a number of other factors that could induce a similar response i.e. drought, waterlogging, attack by stock, wildlife or insects, cultivation, compaction etc. Vegetation condition may help determine the severity level at a site or corroborate other more reliable evidence of salinity but should not be used as a conclusive indicator of salinity on its own. One feature of vegetation response that has been noted is how increased salinity levels affect the foliage colour of crop plants. Plants stunted because of low fertility are usually yellowish green, whereas those stunted due to excessive salinity levels are characteristically blue green. The bluish appearance is the result of an unusually heavy waxy coating on the surface of the leaves, and the darker colour to an increase in the chlorophyll content on a surface area or fresh-weight basis (United States Salinity Laboratory Staff 1954).

Table 1 Criteria for soil salinity classes

Soil salinity class	Typical symptoms
S0 (Non-saline)	**Non-saline, no effects on plant growth or yield**.
Soil salinity (EC_{se}) < 2 dSm^{-1}.	Salt-sensitive species present e.g. pasture grasses, subterannean clover, Yorkshire fog etc. No reduction in yield or vigour of pasture or crop species. Distribution of salt-sensitive native species unchanged.
S1 (Low)	**Some effect on sensitive plants**.
Soil salinity (EC_{se}) ranges from 2–4 dSm^{-1}.	Salt-tolerant species such as sea barley grass are often abundant. Salt-sensitive plants in general, show a reduction in number and vigour and salt-sensitive legumes (e.g. white and subterannean clover, soybeans, chick pea etc.) in particular are affected. At the upper end of the range, grasses and shrubs may be prominent in the plant community. There are no bare saline patches and salt stain/crystals are not evident on bare ground.
S2 (Moderate)	**Growth/ yield restrictions for many plants**.
Soil salinity (EC_{se}) ranges from 4–8 dSm^{-1}.	Salt-tolerant species begin to dominate the vegetation community and all salt-sensitive plants are markedly affected by soil salinity levels. At the upper end of the range, some slightly tolerant species disappear and are replaced by others with higher salt tolerance. Legumes are almost non-existent as the plant community is dominated by grasses, shrubs and broad leaf weeds. Small bare areas up to 1 m^2 may be present and salt stain/crystals may sometimes be visible on bare soil at the upper end of the range.
S3 (High)	**Only tolerant plants grow/yield satisfactorily at the low end of this range.**
Soil salinity (EC_{se}) ranges from 8–16 dSm^{-1}.	Salt-tolerant species like sea barley grass and buck’s-horn plantain may dominate large areas and only salt-tolerant plants remain unaffected. In low rainfall areas, it is unlikely that any improved species will be present and trees may be showing some effect i.e. dieback and stagginess. Large, bare saline areas may occur showing salt stains or crystals (on some soils a dark organic stain may be visible), or the top soil may be floury or puffy with some plants surviving on small pedestals and the B horizon may be exposed in some areas. At the upper end of the range, halophytic plants may dominate the plant community and some species (e.g. buck’s-horn plantain) may show a reddening of the leaves.
S4 (Extreme)	**Very few plants species grow/yield satisfactorily.**
Soil salinity (EC_{se}) is greater than 16 dSm^{-1}.	Only highly salt-tolerant plants survive and the community is typically dominated by 2 or 3 species. Moderately and highly salt-tolerant species may show a reddening of the leaves. At the upper end of the range, even highly salt-tolerant plants may be scattered and in poor condition. Trees will be dead or dying. Extensive bare saline areas occur with salt stains and or crystals evident (on some soils a dark organic stain may be visible). Top soil may be floury or puffy with some plants surviving on small pedestals and the B horizon may be exposed in some areas.

Physical indicators

Physical indicators such as area and condition of bare soil and presence of salt stain and crystals on the soil surface are useful for determining the severity of soil salinity. Slightly saline areas (S1) will never show bare soil, salt stain or salt crystals. Areas affected by moderate levels of soil salinity (S2) may show small patches of bare areas (< 1 m^2) and possibly salt stain or crystals as soil salinity approaches the upper end of the range (around 8 dSm^{-1}). As salinity levels rise to high and extreme levels, vegetation may die resulting in extensive areas of bare soil and surface soil structure is often dramatically changed. A floury or puffy appearance is usually a sign of high salinity levels and is often followed by a loss of topsoil exposing the B horizon and leaving the remaining vegetation growing on pedestals. This is common at highly and severely affected sites (Classes 3 and 4).

Other physical indicators such as the presence of saline ground water at the surface and blackened soil may corroborate an assessment of a site as saline but give little indication of the degree of severity.

Mapping the extent of the saline area

When the field officer has formed a mental picture of the likely range of the severity of soil salinity at the site, they should begin mapping the salt affected area. Field mapping of the site is generally carried out by walking the edge of the salt-affected area with a GPS and estimating the percentage of the salt-affected site that falls within each salinity class (S1, S2, S3 or S4). If possible, use a GPS that can be differentially corrected. Such instruments typically ensure a spatial accuracy of better than +/- 5 m at 95% confidence. Not all GPS instruments are capable of collecting data in a way that allows differential correction. Such instruments are known as autonomous or stand-alone instruments. Although accuracy will depend on individual instrument specifications, autonomous GPS instruments are less accurate than instruments that allow differential correction of positional data. Many autonomous GPS instruments commonly used for natural resource management have a spatial accuracy of >+/- 10 m at 95% confidence (Milner and Hale 2002).

When mapping the extent of the salt affected area, leave a temporary marker at the start point and commence walking the boundary with a GPS until you return to the start point. To provide sufficient positional data while limiting the amount of data collected, set the GPS to record a position every five or 10 m (At some large sites it may be possible to drive the boundary and the GPS setting should be adjusted accordingly). As you walk the boundary of the salt-affected area continue to assess the severity of the salt-affected area. When the boundary of the salt-affected area has been mapped with the GPS, estimate for the whole site what proportion each salinity class forms of the total area.

It may be that islands of non-saline soil do exist within larger salt-affected areas. If positively identified, these non-saline areas should be recorded, with some regard for the scale of mapping for the Victorian database. The mapping scale is 1:25 000, which equates to a resolution of +/- 12.5 m on the ground (Milner and Hale 2002). If a non-saline area within a saline area (or any other spatial feature of the site boundary) is less than 10 m to 15 m in diameter, it should be ignored in the field, as it will be insignificant when shown on the CSDL.

Using air photos as a map base

Prior to the advent of GPS technology, air photos were used as the base over which to map the extent of saline areas. Until the mid 1990s, air photos collected across Victoria were made available as a public resource. Since then air photos have been flown in an ad hoc manner, particularly in rural areas and often must be purchased. This limits the use of air photos as a map base for field mapping. If current air photos are available they may be used to identify possible saline areas and as a base for mapping in the field. Software such as ArcPad in conjunction with palm top computers or customised lap top computers with outdoor screens allow air photos to be used in the field in combination with GPS technology. If current air photos are available and appropriate software and hardware is accessible, their use should improve the data collection process. However, considerable skill is required to set up and use such a system.

Mapping scale and ground resolution

The standard scale adopted for recording data is 1:25 000. This scale is appropriate as many of the discharge sites on the corporate GIS database are less than 2 ha in area. This scale represents the best spatial resolution for all datasets currently held on the CSDL. It is sufficient to pick up virtually all sites and identify significant change over time and is broadly in line with the accuracy of the field method used to identify salinity. A mapping scale of 1:25 000 translates to an actual ground resolution of 12.5 m. In a practical sense, when mapping the boundary of a saline area there is little point in mapping small deviations or features less than 12.5 m in diameter. Anything smaller will not be evident in the GIS environment at 1:25 000 scale. Although it is possible in the GIS to zoom in to a higher resolution, such magnification is not valid, as it does not take into account the errors inherent in both identification and mapping.

Lines versus polygons; a question of scale

For linear saline features that are less than 12.5 m wide such as a drainage line or watercourse, only map the centre of the saline area with the GPS rather than mapping both sides of the feature. If the watercourse contains water (or is inaccessible for other reasons) at the time of mapping, map one boundary and use the offset function if your GPS has that capability. Otherwise, carefully note which boundary is mapped and estimate the distance to the centre-line of the feature. The centre-line may then be created in the office by offsetting from the field measurement in ArcView. Given that the scale of the GIS layer is 1:25 000 there is little point in recording a polygon for such features. All attributes for a linear feature should be recorded the same as for polygons.

Recording the site attributes

A site may consist of more than one polygon and the judgement as to where a site starts and finishes is somewhat arbitrary. A group of polygons may be given the same identification tag (the Dssite attribute) if all other attributes are the same for all that group of polygons. However if one polygon in a group is significantly different in terms of its severity ratings then it should be given a different Dssite tag. If visiting a previously mapped site, use the same site number (Dssite), but the site should be mapped only on what is observed in the field at the time of the survey. Previously recorded extents and severity should be ignored and not allowed to influence the current assessment.

Attributes may be recorded on the field sheet (Appendix 5 describes the attributes that should be recorded in the field at each site), or in a field notebook. At the completion of a day's fieldwork, attributes should be entered into a spreadsheet (use the *.xls format) using the headings and formats listed below. This is important, as it will allow attribute data to be attached to the correct polygons easily and accurately as the data is processed in the GIS.

If the GPS has a GIS capability, the attributes may be tagged directly against each polygon in the GPS and downloaded as an ESRI shapefile if possible. In this case, an attribute table should be set up using the field names and formats listed below. If the attributes are not logged directly into the GPS, each polygon should at least be tagged in the GPS with its unique site name/number as it is captured.

Other site details

The standard field sheet (Appendix 4) has a number of other fields that may be filled out. Apart from the attributes listed above, all other attributes are optional and recorded only for the information of the field staff. The main purpose of the field sheet is to help the field officer determine the level of salinity at each site and record the mandatory attributes.

Soil sampling and analysis

For experienced staff operating in familiar landscapes, vegetation and other visible indicators allow saline areas to be confidently identified and rated for severity level. Soil samples are not routinely used to identify and classify soil salinity, as they are costly to collect and process. However, in some instances, even experienced field staff resort to soil sampling and analysis to validate site classifications. For inexperienced staff or staff operating outside their normal region, selective soil sampling and analysis in the early stages of a field survey is useful to gain a good understanding of the nature of the soil properties and their relationship to local vegetative and physical symptoms of soil salinity.

Collecting soil samples to assess soil salinity

When collecting soil samples it should be remembered that salinity assessment is in relation to the effect of soil salinity levels on plant growth and soil sampling should aim to determine salinity levels in the active root zone. At saline sites, it is common to find a much higher accumulation of salt at the soil surface than in the active root zone. At high levels of salinity, this often occurs in the form of a white stain or crystals on the soil surface. Studies of root distribution and water uptake by plants have shown that the major root activity occurs in the less saline parts of the soil matrix. To correlate plant growth with salinity, any surface incrustations of salt should be excluded from the soil samples (United states Salinity Laboratory Staff 1954). Probably the best practice for all sites regardless of severity is to exclude the top 2 cm from soil samples so that the sample depth is actually 2–10 cm.

To assess the soil salinity at a site in the rooting zone of grasses and herbaceous plants the soil sampling procedure used at salt-affected sites is:

1. Delineate the area for which you wish to determine the severity. The area should be of a relatively uniform severity. If you wish to test more than one severity class at a site you should collect a set of samples to produce one combined sample for each class.
2. Within each uniform area, collect soil from a depth of 2–10 cm at 7–10 points. Combine the soil from all the points into one bag to make one sample representing the area and label appropriately. Calico sample bags are preferred as they allow the sample to breathe, are easy to label and will not easily rot. Samples should be kept dry to prevent any leaching of salts or cross-contamination of samples.

How should soil salinity be measured?

Soil testing provides a quantitative measure of the level of soil salinity. It is commonly measured by determining the electrical conductivity (EC) of a prepared soil-water solution. Various laboratory procedures have been developed to ensure that the laboratory measurements of EC correlate with actual plant growth/yield in situ (Shaw 1999). While it is recommended that saturation extract measurements (EC_{se}) be used in preference to measurement of the electrical conductivity of a 1:5 soil/water extract ($EC_{1:5}$), the latter is the more common standard method employed in Australia, due to convenience, time and cost (Shaw 1999). Interpretation of the $EC_{1:5}$ measurement is complicated by the very high dilution entailed, relative to natural field conditions. The 1:5 soil-water extract does not take into account the effect soil texture has on the moisture content and water availability (to plants) of the soil. The soil water content may affect the osmotic potential of the soil solution and consequently the availability of water within that soil matrix to vegetation.

In contrast, EC_{se} gives a more direct measure of the concentration of salt in the soil solution and its osmotic properties (United States Salinity Laboratory Staff 1954) and measurements can be directly compared to others from sites with different soil textures. However, EC_{se} itself is not a precise measure (there is no absolute saturation value) and is a tedious technique (Shaw 1999). Results from both methods are affected by:

- the solubility of the salts present (e.g. gypsum is only sparingly soluble compared to common salt)
- the presence of fine organic particulates
- clay held in suspension.

Conversions between EC_{se} and $EC_{1:5}$ are often employed which include chloride concentration and clay content. A general 'rule of thumb' conversion (Appendix 6) employs simple multiplying factors for texture groups to convert $EC_{1:5}$ to EC_{se} .

Determining the EC_{se} value

To determine the salinity level of soil samples, the samples should be sent to a laboratory accredited by the National Association of Testing Authorities (NATA) to perform EC analyses as soon as possible. Laboratories with NATA certification can be identified on the NATA website at <http://www.nata.asn.au/>.

If you wish to determine the EC_{se} value yourself, the procedure is as follows:

1. Analyse each sample using the standard test for EC of 1:5 soil/water extract (Appendix 7).
2. Determine the texture of each sample using the characteristics developed by Northcote (1984). See Appendix 8 for Northcote's soil texture classes.
3. Convert $EC_{1:5}$ values to estimates of EC_{se} values by applying the correction factor (see Appendix 6) appropriate for the texture of each sample using Equation 1.

$$EC_{se} \text{ (dSm-1)} = EC_{1:5} \text{ (dSm-1)} \times \text{multiplier factor} \qquad \text{(Equation 1)}$$

Interpreting soil analyses

Results of soil analyses should be compared with the classes in Table 1, and used with caution as a number of factors may affect both the measured conductivity value and their correlation with actual plant growth/yield. Environmental factors that should be considered when assessing EC measurements include:

- Salt levels in a soil profile can be sensitive to seasonal variation. In a dryland environment, soil salts are leached downwards through the soil profile when rainfall exceeds evapotranspiration. Conversely, soil salts are concentrated in the upper layers of the soil profile when evapotranspiration rates exceed rainfall (Rengasamy 2002).

- Soil salinity levels may change significantly over small distances and can be significantly affected by variation in micro-relief.
- Fertiliser and gypsum applications may increase the measured EC by increasing the concentration of soluble ions (other than chloride) in the soil. In reality, plant growth/yield may not be adversely affected as it is electrical conductivity of the soil rather than the salinity level that has risen.
- Climate may be the most significant influence on plant response to salinity (Shaw 1999). Soil analyses in the Corangamite region (Allan 1994) and the Glenelg Hopkins region (McCaskil et al 2006) have indicated that soil salinity levels were higher than expected given the vegetation present at the site. This suggests that strict application of the criteria in Table 1 may lead to an under estimation of soil salinity levels in parts of south-western Victoria.

5.4 Processing field data in the GIS

Spatial data should be downloaded from the GPS on a regular basis, if possible at least twice a week. The preferred download format is ArcView .shp files but this option is not available on all GPS instruments. Ultimately the data must be transferred to ArcView. Once in Arcview, some editing of the spatial data may be required to clean up any spikes in the GPS positional data. If salt affected areas were mapped as lines in the field they should be converted to closed polygons. All lines or polygons in the ArcView .shp files should at least be tagged with their site identification (if the GPS was capable of attaching attributes in the field then all attributes may be attached to the polygons), which is replicated in the Excel spreadsheet containing the attribute information.

5.5 Data storage and documentation

After all survey data has been processed, the ArcView .shp files and accompanying Excel spreadsheet (if the attributes were not attached directly to the .shp files) should be forwarded to DPI staff at Bendigo (managers of the soil salinity layer) so that the data can be included on the soil salinity layer in the CSDL.

Documenting the survey

It is recommended that all surveys should be documented in the form of a brief report and that report should be published. The report should at least document:

- the purpose of the survey
- who requested the survey
- who carried out the survey
- the survey method used to identify and map salinity
- the reference material used to assess salinity (which field guide)
- the type of GPS instrument and its accuracy specifications
- a hard copy summary of the attributes collected for each site
- any relevant land use/land management details recorded in the course of the survey
- full details of any soil samples and analyses collected in the course of the survey
- any other relevant details recorded that may have some bearing on the survey output and its future use.

Documentation of these details will allow future users of the data to make better use of it and increase confidence in any estimates of change in extent and severity over time. The report should be published to ensure that it can be located by users 10 or 20 or more years in the future. A copy of all reports documenting salinity surveys should be forwarded to DPI staff at Bendigo that currently manages the soil salinity layer for DSE.

Recording the survey extent

When a survey is finished, it is necessary to create a polygon in Arcview showing the extent of the total survey area. This is necessary because surveys have not been coordinated and sometimes there are overlaps or gaps between adjacent surveys. Comparison with previous and future surveys allows an estimate of how salinity has changed over time. This has become increasingly important and the ability to do this makes the survey data much more useful. Lack of information on the survey extents compromises the ability to monitor change over time at a landscape scale.

6 Other options for mapping soil salinity

Although the methodology described above is the standard way of visually assessing and mapping soil salinity in Victoria there are a number of other ways that soil salinity can be identified and/or mapped.

- Satellite borne multispectral data was used by CSIRO in Western Australia to map soil salinity across 18 million ha with reasonable accuracy. This method was trialled in the Wimmera region of Victoria and found to work with reasonable accuracy although results were affected by errors in the digital elevation model (DEM) that was used (Furby and Clark 2004). To provide estimates of soil salinity across whole regions at 1:25 000 scale it uses a time series of multi-spectral data across seasons to identify areas of consistently poor growth. In conjunction with the spectral data a high resolution DEM is used to identify parts that are more likely to be saline (based on position in the landscape). Due to the limited spectral resolution of multispectral data, this method is likely to be less reliable where saline areas maintain a good cover of salt-tolerant vegetation.
- Airborne hyperspectral data has been trialled in the Western District of Victoria and achieved an accuracy of around 85% for identifying saline and non-saline soil based on vegetation cover (Clark et al 2007). This method shows some promise but several problems remain to be overcome before it could be implemented as a cost effective option at a landscape scale.
- Satellite borne hyperspectral imagery has been used to discriminate saline soils from non-saline soils and distinguish perennial halophytic plants from other perennial vegetation (Dutkiewicz et al 2006). Satellite-borne sensors are more cost efficient than airborne sensors. However, this study found that a poor signal to noise ratio and reduced spatial resolution meant that the results were significantly poorer than achieved with airborne hyperspectral sensors.
- Ground-based electromagnetic (EM38) measurements have long been used to infer soil salinity by measuring apparent soil conductivity in the root zone of plants. The EM38 provides an objective, highly accurate (when sufficient calibration data is collected) and repeatable way of measuring and monitoring soil salinity. The downside is the cost of data collection and associated calibration, which makes it unsuitable for landscape scale mapping although it is well suited to mapping paddock scale sites. This technique is also of limited use in areas of low soil moisture and soils with naturally high magnetic fields. The latter may be caused by rocks rich in ferromagnesian minerals, ironstone deposits rich in magnetite and some mineral sands (Dahlhaus[5], pers.comm.).
- Airborne gamma ray spectrometry is based on the measurement of naturally occurring gamma radiation emitted from the top 30 to 40 cm of the soil profile. Signal to noise ratio is poor for many elements and analysis tends to concentrate on the three common radioactive elements; potassium, thorium and uranium which all have high signal to noise ratios. Gamma ray spectrometry cannot directly map soil salinity but can assist in mapping soil types and this may be used to assist with modelling the occurrence of soil salinity and perhaps salt store in the landscape (Spies and Woodgate 2005).
- Airborne electromagnetics has been tested in a number of areas around Australia. It has been found to be useful for identifying salt store at depth in the landscape and improving the understanding of processes likely to cause salinity. However, it is unable to make conductivity measurements of near surface layers in a way that could be used to map surface soil salinity.

7 Conclusions

The use of a field assessment based on the vegetation community and other physical factors, as described in this report, will ensure a consistent standard of mapping in Victoria. The method has been developed over many years and has been used successfully in most parts of Victoria.

The method has application to:

- completion of discharge mapping in Victoria
- remapping of selected areas for monitoring salinity

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[5] Peter Dahlhaus (Senior Lecturer in Geology, University of Ballarat) January 2007

- mapping projects in other parts of Australia.

Although various remote sensing methods developed for mapping soil salinity have been trialled, only the Land Monitor project (based on a time series of multispectral satellite imagery) has matured to operational status. This technique performed well in Western Australia and in a Victorian trial in conditions similar to those in Western Australia. However it is not proven (and experience suggests that it is unlikely) that multispectral satellite data is capable of mapping soil salinity in areas that achieve a persistent cover of salt-tolerant vegetation. Other methods such as airborne hyperspectral and ground-based EM38 surveys are capable of achieving the required accuracy in a variety of landscapes, but are either not currently cost-effective at the scale required or are limited by other factors (such as soil moisture). While research and development of alternative mapping methods should be continued, such as sensor networks; and as software and hardware technologies further mature, the vegetation-based field assessment of soil salinity is likely to play an important role in the practical monitoring of soil salinity for some time to come.

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Appendix 1 Salt tolerant plants

Below are a series of lists of some of the plant species associated with saline soils in Victoria. This is not an exhaustive list of species.

Life cycle data was derived from:

Allan (1994) where A = Annual, B = Biennial, P = Perennial

Scientific names were derived from:

Ross and Walsh (2003)

Common names were derived from:

Cross et al. (2001)

The Salinity Class estimates were derived from these references:

Allan (1994), salinity class = 1, 2, 3

Allen (2006), salinity class = brackish, saline, hypersaline

Matters and Bozon (1995), salinity class = 1, 2, 3

Rogers et al. (2006), salinity class = Sensitive, Moderately sensitive, Potential, Moderately tolerant, Tolerant

Victorian Resources Online (2007), salinity class = 1, 2, 3, 4 (The VRO estimates were placed in brackets)

Waterlogging tolerance was derived from:

Rogers et al. (2006), waterlogging tolerance = Potential, Moderately tolerant, Tolerant

Species were identified from the following references:

A = Allan (1994)

B = Allen (2006)

C = Bridgewater et al. (1981)

D = Matters and Bozon (1995)

E = Rogers et al. (2006)

F = Victorian Resources Online (2007)

Table 2 Salt-tolerant herbs

Life cycle	Scientific name	Common name	Salt class	Waterlogging tolerance	Reference
	Angianthus preissianus	Salt Angianthus	1-2	Not reported	A
	Apium annuum	Annual Celery	Brackish	Not reported	B
	Apium prostratum	Salt Celery	Brackish	Tolerant	B, E
	Aptenia cordifolia	Heart-Leaf Ice-plant	3	Not reported	A
	Sclerostegia arbuscula	Shrubby Glasswort	Tolerant	Tolerant	C., E
	Halosarcia pergranulata subsp. *pergranulata*	Grey Glasswort	Tolerant	Tolerant	C., E
	Aster subulatus	Aster-weed	Brackish	Not reported	B
	Brachyscome graminea	Grass daisy	Brackish	Not reported	B
	Carpobrotus aequilaterus	Angled Pigface	Tolerant	Tolerant	A, E
	Carpobrotus rossii	Karkalla	Not reported	Not reported	C
	Centaurium spicatum	Spike Centaury	1-2	Not reported	A
	Chenopodium glaucum	Glaucous Goosefoot	Brackish	Not reported	B
(A)	*Cotula bipinnata*	Ferny Cotula	(3-4)	Not reported	A, F
(A/P)	*Cotula coronopifolia*	Water Buttons	2, (2-3)	Not reported	A, F
	Cotula vulgaris var. australasica	Slender Cotula	Brackish	Not reported	B
(P)	*Disphyma crassifolium* ssp. *Clavellatum*	Rounded Noon-Flower	2-3, (2–4)	Not reported	A, F

Life cycle	Scientific name	Common name	Salt class	Waterlogging tolerance	Reference
	Einadia trigonos	Lax Goosefoot	Not reported	Not reported	A
	Hemichroa pentandra	Trailing Hemichroa		Tolerant	C.
	Hydrocotyle capillaris	Thread Pennywort	Tolerant	Tolerant	C., E
	Lawrencia glomerata	Clustered Lawrencia	Not reported	Not reported	A
	Lawrencia spicata	Salt Lawrencia	Brackish	Not reported	B
	Leptinella reptans	Creeping Cotula	Brackish	Not reported	B
	Limonium australe	Yellow Sea-lavender	Saline	Not reported	B
	Medicago minima	Little Medic	Not reported	Not reported	A
	Medicago polymorpha	Burr Medic	(0-2), Moderately Tolerant	Moderately Tolerant	E, F
	Melilotus albus	Bokhara Clover	(1-3), Moderately Tolerant	Potential	E, F
	Mesembryanthemum crystallinum	Common Ice-plant	2, (2-4)	Not reported	A, F
	Mesembryanthemum nodiflorum	Ice Plant	(2-4)	Not reported	F
	Mimulus repens	Creeping Monkey-flower	2, (0-2), Tolerant	Tolerant	A, E, F
(A)	*Myosurus minimus* var. *australis*	Mouse-tail	Not reported	Not reported	A
	Osteocarpum salsuginosum	Inland Bonefruit	3, Tolerant	Tolerant	A, E
(P)	*Plantago coronopus*	Buck's-Horn Plantain	0-3, Tolerant	Not reported	A, E
	Poa sallacustris	Salt-lake Tussock-grass	Brackish	Not reported	B
	Lobelia irrigua	Salt Pratia	Brackish	Not reported	B
	Ranunculus diminutus	Lesser River Buttercup	Brackish	Not reported	B
	Ruppia maritima	Sea Tassel	Not reported	Not reported	C.
	Salsola tragus	Prickly Saltwort	Not reported	Not reported	C
(P)	*Samolus repens*	Creeping Brookweed	2, Tolerant	Tolerant	A, E
	Sarcocornia blackiana	Thick-head Glasswort	Hypersaline, Tolerant	Tolerant	B, E
(P)	*Sarcocornia quinqueflora*	Beaded Glasswort	2-3, (3-4)	Not reported	A, B
	Sarcozona praecox	Sarcozona	Not reported	Not reported	A
	Selliera radicans	Shiny swamp-mat	1-2	Not reported	A
	Senecio pinnatifolius	Variable Groundsel	brackish	Not reported	B
(P)	*Spergularia marina*	Salt Sand-spurrey	Not reported	Not reported	A
	Spergularia media	Coast Sand-spurrey	1-2	Not reported	A
(A/B)	*Spergularia rubra*	Red Sand-spurrey	(2-4)	Not reported	A
(P)	*Suaeda australis*	Austral Seablite	2-3, (3-4)	Tolerant	A, E, F

Life cycle	Scientific name	Common name	Salt class	Waterlogging tolerance	Reference
	Trifolium arvense var. arvense	Hare's-foot Clover	Sensitive	Not reported	A, E, F
	Trifolium campestre	Hop Clover	Not reported	Not reported	A
(P)	*Trifolium fragiferum*	Strawberry Clover	1-2, (1-2), Moderately tolerant	Moderately tolerant	A, E, F
	Wilsonia backhousei	Narrow-leaf Wilsonia	Saline	Not reported	A, B
	Wilsonia humilis	Silky Wilsonia	Saline	Not reported	A, B
	Wilsonia rotundifolia	Round-leaf Wilsonia	2	Not reported	A
	Zygophyllum crenatum	Notched Twin-leaf	Not reported	Not reported	A
(A)	*Zygophyllum iodocarpum*	Violet Twin-leaf	Not reported	Not reported	A

Table 3 Salt-tolerant grasses

Life cycle	Scientific name	Common name	Salt class	Waterlogging tolerance	Source
	Aira caryophyllea	Silvery Hair Grass	Not reported	Not reported	A
	Lachnagrostis billardierei subsp. *billardierei*	Blown Grass			C.
(P)	*Austrodanthonia caespitosa*	Common Wallaby Grass	(0-2)	Not reported	F
(P)	*Austrodanthonia eriantha*	Wallaby Grass	1, Moderately tolerant	Not reported	A, E
	Austrostipa stipoides	Prickly Spear Grass	Not reported	Not reported	C
(P)	*Austrostipa tuckeri*	Tucker's Spear Grass	Tolerant	Not reported	A, E
(A)	*Briza maxima*	Large Quaking Grass	Not reported	Not reported	A
(A)	*Bromus rubens*	Red Brome	Not reported	Not reported	A
(P)	*Chloris gayana*	Rhodes Grass	Moderately tolerant	Not tolerant	A, E
(A/P)	*Chloris truncata*	Windmill Grass	1-2, (0-2), Tolerant	Not reported	A, E, F
(A)	*Hordeum marinum*	Sea Barley Grass	1-2, (2-4), Tolerant	Tolerant	A, E, F
(P)	*Cynodon dactylon*	Couch	1-2, (0-1), Moderately tolerant	Tolerant	A, E, F
(B/P)	*Leptochloa fusca* subsp. *fusca*	Brown Beetle Grass	Tolerant	Tolerant	A, E
(P)	*Distichlis dischtophylla*	Australian Salt Grass	2, (3-4), Tolerant	Tolerant	A, E, F
	Zoisia macrantha	Prickly Couch	Tolerant	Tolerant	C, E
	Enteropogon acicularis	Spider Grass	(0-2), Tolerant	Not reported	E, F
(P)	*Eragrostis australasica*	Cane Grass	Tolerant	Not reported	A, E
(P)	*Eragrostis setifolia*	Bristly Love Grass	Tolerant	Not reported	A, E
	Festuca arundinacea	Tall Fescue	Tolerant	Moderately tolerant	B, E
	Lachnagrostis filiformis	Common Blown Grass	Brackish, (0-2), Tolerant	Not reported	A, B, E, F
(A)	*Hainardia cylindrica*	Common Barb Grass	Not reported	Not reported	A, C
(A)	*Lolium rigidum*	Wimmera Rye Grass	1, (0-2), Brackish	Not reported	A, B, F
(P)	*Lophopyrum ponticum*	Tall Wheat Grass	1-2, (1-3), Brackish	Not reported	A, B, F
(A)	*Parapholis incurva*	Coast Barb Grass	2, (3-4), Brackish	Not reported	A, B, D, F
(A)	*Parapholis strigosa*	Slender Barb Grass	2	Not reported	A
	Phragmites australis	Common Reed	Brackish, Tolerant	Tolerant	B, E.
(A)	*Poa annua*	Annual Meadow Grass	Not reported	Not reported	A

Life	Scientific name	Common name	Salt class	Water logging ce	Source
(P)	*Poa bulbosa*	Bulbous Meadow Grass	Not reported	Not reported	A
(A)	*Polypogon monspeliensis*	Annual Beard-grass	2, (0-2)	Not reported	A, C., F
(A)	*Puccinellia stricta*	Australian rsh Grass	1-2, (3-4), nt	Tolerant	A, B, C, E
(P)	*Sporobolus caroli*	Yakka Grass	Tolerant	Not reported	A, E
	Sporobolus mitchellii	Rat-tail Couch	(0-2), nt	Tolerant	E, F
(P)	*Sporobolus virginicus*	Salt Couch	Tolerant	Tolerant	A, C, E
(P)	*Tripogon loliiformis*	Rye Beetle Grass	Not reported	Not reported	A
(A)	*Vulpia bromoides*	Squirrel-tail Fescue	Not reported	Not reported	A

Table 4 Salt-tolerant shrubs

Life cycle	Scientific name	Common name	Salt class	Waterlogging tolerance	Reference
	Atriplex cinerea	Coast Saltbush	Tolerant	Tolerant	C, E
	Atriplex prostrata	Hastate Orache	Tolerant	Tolerant	C, E
(P)	*Atriplex leptocarpa*	Slender-fruit Saltbush	(2-4), Tolerant	Not reported	A, E, F
	Atriplex lindleyi	Flat-top Saltbush	(2-4), Tolerant	Not reported	F, E
(P)	*Atriplex nummularia*	Old-man Saltbush	Tolerant	Tolerant	A, E
	Atriplex paludosa subsp. *paludosa*	Marsh Saltbush	Tolerant	Tolerant	C,
(A)	*Atriplex pseudocampanulata*	Mealy Saltbush	Not reported	Not reported	A
	Atriplex semibaccata	Berry Saltbush	1, (2-4), Tolerant	Not reported	D, E, F
	Atriplex suberecta	Sprawling Saltbush	(1-2)		F
(P)	*Atriplex vesicaria*	Bladder Saltbush	Tolerant	Tolerant	A, E
(P)	*Enchylaena tomentosa* var. *tomentosa*	Ruby Saltbush	2, (1-3), Tolerant	Not reported	E, D, F
	Frankenia pauciflora var. *gunnii*	Southern Sea-heath	Hypersaline	Not reported	B
	Galenia pubescens var. *pubescens*	Galenia	Brackish	Not reported	B
	Halosarcia halocnemoides subsp. *halocnemoides*	Grey Glasswort	Hypersaline, Tolerant	Tolerant	B, E
	Halosarcia pergranulata	Blackseed Glasswort	Hypersaline, 3, (3-4), Tolerant	Tolerant	B, D, F
	Maireana aphylla	Leafless Bluebush	Tolerant	Tolerant	A, E
	Maireana brevifolia	Short-leaf Bluebush	(0-2), Tolerant	Tolerant	A, E, F
	Maireana georgei	Slit-wing Bluebush	Tolerant	Tolerant	A, E
	Maireana humillima	Dwarf Bluebush	Not reported	Not reported	A
	Maireana oppositifolia	Heathy Bluebush	Tolerant	Tolerant	C, E
(P)	*Melaleuca ericifolia*	Swamp Paperbark	1-2	Not reported	A, D
(P)	*Melaleuca halmaturorum*	Salt Paperbark	(2-4)	Not reported	A, F
	Muehlenbeckia florulenta	Tangled Lignum	Brackish, (0-4)	Not reported	B, F
	Myoporum parvifolium	Creeping Myoporum	Brackish	Not reported	B
(P)	*Nitraria billardieri*	Nitre-bush	(1-4), Tolerant	Not reported	A, F
	Osteocarpum acropterum var. *deminutum*	Babbagia	Not reported	Not reported	A
	Osteocarpum salsuginosum	Inland Bonefruit	2, Tolerant	Tolerant	D, E
	Rhagodia candolleana	Seaberry Saltbush	Brackish, Tolerant	Not reported	B, C, E

Life cycle	Scientific name	Common name	Salt class	Waterlogging tolerance	Reference
	Rhagodia spinescens	Hedge Saltbush	(1-4)	Not reported	F
(P)	*Sclerochlamys brachyptera*	Short-wing Saltbush	Tolerant	Not reported	A, E
(P)	*Sclerolaena diacantha*	Grey Copperburr	Not reported	Not reported	A
(P)	*Sclerolaena divaricata*	Tangled Copperburr	Not reported	Not reported	A
	Sclerostegia arbuscula	Shrubby Glasswort	Hypersaline, Tolerant	Tolerant	B, E
	Sclerostegia tenuis	Slender Glasswort	Not reported	Not reported	A
	Tetragonia implexicoma	Bower Spinach	Brackish	Not reported	B

Table 5 Salt-tolerant trees

Life cycle	Scientific name	Common name	Salt class	Waterlogging tolerance	Reference
	Acacia stenophylla	Eumong	(0-4)	Not reported	F
	Eucalyptus largiflorens	Black Box	(0-4)	Not reported	F
	Melaleuca lanceolata	Moonah	Brackish, (1-3)	Not reported	B, F

Table 6 Salt-tolerant agricultural plants

Life cycle	Scientific name	Common name	Salt class	Water logging tolerance	Reference
	Hordeum vulgare	Barley (varieties)	(0-2)	Not reported	F
	Triticum aestivum	Wheat (varieties)	(0-2)	Not reported	F

Appendix 2 Some known salt sensitive species

Below are a series of lists of some of the plant species considered to be salt-sensitive in Victoria. This is not an exhaustive list of species.

Scientific names were derived from:

Ross and Walsh (2003)

Common names were derived from:

Cross *et al*. (2001)

The Salinity Class estimates were derived from these references:

Allan (1994), salinity class = 1,2,3

Victorian Resources Online (2007), salinity class = 1,2,3,4 (The VRO estimates were placed in brackets)

Species were identified from the following references:

A = Allan (1994)

F = Victorian Resources Online (2007)

Table 7 Salt-sensitive grasses

Life cycle	Scientific name (Taxonomic status)	Common name	Salt class	Waterlogging tolerance	Reference
	Anthoxanthum odoratum	Sweet Vernal Grass	Not reported	Not reported	A
	Briza minor	Lesser Quaking Grass	Not reported	Not reported	A
	Austrodanthonia carphoides	Short Wallaby Grass	Not reported	Not reported	A
	Deyeuxia sp.	Bent Grass	Not reported	Not reported	A
	Holcus lanatus	Yorkshire Fog	Not reported	Not reported	A
	Hordeum leporinum	Barley Grass	Not reported	Not reported	A
	Lolium perenne	Perennial Rye Grass	Not reported	Not reported	A
	Romulea rosea var. *australis*	Onion Grass	Not reported	Not reported	A
	Themeda triandra	Kangaroo Grass	Not reported	Not reported	A

Table 8 Salt-sensitive rushes

Life cycle	Scientific name (Taxonomic status)	Common name	Salt class	Waterlogging tolerance	Reference
	Juncus articulatus	Jointed Rush	Not reported	Not reported	A
	Juncus planifolius	Broad-Leaf Rush	Not reported	Not reported	A
	Juncus subsecundus	Finger Rush	Not reported	Not reported	A

Table 9 Salt-sensitive herbs

Life cycle	Scientific name (Taxonomic status)	Common name	Salt class	Waterlogging tolerance	Reference
	Arctotheca calendula	Capeweed	Not reported	Not reported	A
	Erodium sp.	Heron's-bill	Not reported	Not reported	A
	Leontodon taraxacoides subsp. *taraxacoides*	Hairy Hawkbit	Not reported	Not reported	A
	Spergularia diandra	Lesser Sand-spurrey	Not reported	Not reported	A
	Trifolium dubium	Suckling Clover	Not reported	Not reported	A
	Trifolium tomentosum var. *tomentosum*	Woolly Clover	Not reported	Not reported	A

Table 10 Salt-sensitive agricultural plants

Life cycle	Scientific name (Taxonomic status)	Common name	Salt class	Waterlogging tolerance	Reference
	Trifolium repens var. *repens*	White Clover	(0-1)	Not reported	F
	Trifolium subterraneum	Subterranean Clover	(0-1)	Not reported	F
	Brassica napus	Canola	(0-1)	Not reported	F
	Zea mays	Maize	(0-1)	Not reported	F
	Cicer arientinum	Chick Peas	(0-1)	Not reported	F

Appendix 3 The tasks involved in preparing for and conducting a salinity field survey and their likely timing

Table 11 shows a number of the tasks that are typically performed in preparation for a salinity field assessment and their likely timing. Not all tasks may be relevant for every survey. The aim of the preparation is to be ready to commence the survey at the optimum time for field identification of soil salinity based on assessment of the vegetation community.

Table 11 Tasks involved in a salinity field survey and their likely timing

ACTIVITY	TIMING
Produce maps of the salinity currently on the CSDL	Mid July
Identify and cost the image options for field mapping if current imagery is available	Early August
Purchase image data for field mapping	August
Circulate maps of currently mapped salinity to Landcare and other appropriate community groups for appraisal and comment (this provides a starting point for remapping program)	July-August
Develop contacts with local government, CMA, DPI, DSE, Landcare etc. to obtain lists of landholders that need to be contacted for land access	July-August
Finalise maps for field checking	August-Sept
Interview for the position and appoint a field mapping officer	July-August
Contact landholders to introduce project and obtain permission to enter property.	August-Sept.
Train mapping officer	Early October
Commence field mapping	Oct.-mid Dec.
Process field data each week as data is collected	Oct.-mid Dec.
Conclude field survey and complete processing and quality assurance of all data.	Late January
Forward spatial data and attributes to PIRVic, Bendigo for inclusion on CSDL	February

Appendix 4 Sample field mapping sheet

Landholder:________________________________

Address:____

Phone number:______________________________

Site number:________________________________

Field observer:________________________________

Evidence of salinity

Groundwater
Bare ground
Salt stain/crystals
Erosion
☐

Crop / Pasture Deterioration
Tree Deterioration
Tree Death
Vegetation (see table)
☐

Landuse:____

Treatment of discharge:

None
Yes

Describe:____
____

Other comments:

____
____
____
____

Commonly found Salt tolerant vegetation where the salt class is known

For the plants listed below; where the salt class is not in brackets it indicates a tolerance across Victoria. Where the salt class is enclosed in brackets the salt class is specific to North Western Victoria. Identification of some of these species may assist in determining whether or not a site is saline and the severity of soil salinity at that site.

Salt-tolerant herbs

Scientific name	Common name	Salt class	Waterlogging tolerance	Present
Suaeda australis	Austral Seablite	2-3, (3-4)	Tolerant	
Sarcocornia quinqueflora	Beaded Glasswort	2-3, (3-4)	Not reported	
Melilotus albus	Bokhara Clover	(1-3)	Potential	
Plantago coronopus	Buck's-Horn Plantain	3	Not reported	
Medicago polymorpha	Burr Medic	(2)	Moderately Tolerant	
Spergularia media	Coast Sand-spurrey	1-2	Not reported	
Mesembryanthemum crystallinum	Common Ice-plant	2, (2-4)	Not reported	
Samolus repens	Creeping Brookweed	2	Tolerant	
Mimulus repens	Creeping Monkey-flower	2, (2)	Tolerant	
Cotula bipinnata	Ferny Cotula	(3-4)	Not reported	
Aptenia cordifolia	Heart-Leaf Ice-plant	3	Not reported	
Mesembryanthemum nodiflorum	Ice Plant	(2-4)	Not reported	
Osteocarpum salsuginosum	Inland Bonefruit	3	Tolerant	
Spergularia rubra	Red Sand-spurrey	(2-4)	Not reported	
Disphyma crassifolium ssp. *Clavellatum*	Rounded Noon-Flower	2-3, (2–4)	Not reported	
Wilsonia rotundifolia	Round-leaf Wilsonia	2	Not reported	
Angianthus preissianus	Salt Angianthus	1-2	Not reported	
Selliera radicans	Shiny swamp-mat	1-2	Not reported	
Centaurium spicatum	Spike Centaury	1-2	Not reported	
Trifolium fragiferum	Strawberry Clover	1-2, (1-2),	Moderately tolerant	
Cotula coronopifolia	Water Buttons	2, (2-3)	Not reported	

Salt-tolerant grasses

Scientific name	Common name	Salt class	Waterlogging tolerance	Present
Polypogon monspeliensis	Annual Beard-grass	2, (0-2)	Not reported	
Distichlis dischtophylla	Australian Salt Grass	2, (3-4)	Tolerant	
Puccinellia stricta	Australian Saltmarsh Grass	1-2, (3-4)	Tolerant	
Parapholis incurva	Coast Barb Grass	2, (3-4)	Not reported	
Lachnagrostis filiformis	Common Blown Grass	(0-2)	Not reported	
Austrodanthonia caespitosa	Common Wallaby Grass	(0-2)	Not reported	
Cynodon dactylon	Couch	1-2, (0-1)	Tolerant	
Sporobolus mitchellii	Rat-tail Couch	(0-2)	Tolerant	

Scientific name	Common name	Salt class	Waterlogging tolerance	Present
Hordeum marinum	Sea Barley Grass	1-2, (2-4)	Tolerant	
Parapholis strigosa	Slender Barb Grass	2	Not reported	
Enteropogon acicularis	Spider Grass	(2)	Not reported	
Lophopyrum ponticum	Tall Wheat Grass	1-2, (1-3)	Not reported	
Austrodanthonia eriantha	Wallaby Grass	1	Not reported	
Lolium rigidum	Wimmera Rye Grass	1, (0-2)	Not reported	
Chloris truncata	Windmill Grass	1-2, (2)	Not reported	

Salt-tolerant shrubs

Scientific name	Common name	Salt class	Waterlogging tolerance	Present
Atriplex semibaccata	Berry Saltbush	1, (2-4)	Not reported	
Halosarcia pergranulata	Blackseed Glasswort	3, (3-4)	Tolerant	
Atriplex lindleyi	Flat-top Saltbush	(2-4)	Not reported	
Rhagodia spinescens	Hedge Saltbush	(1-4)	Not reported	
Osteocarpum salsuginosum	Inland Bonefruit	2	Tolerant	
Nitraria billardieri	Nitre-bush	(1-4)	Not reported	
Enchylaena tomentosa var. *tomentosa*	Ruby Saltbush	2, (1-3)	Not reported	
Melaleuca halmaturorum	Salt Paperbark	(2-4)	Not reported	
Maireana brevifolia	Short-leaf Bluebush	(2)	Tolerant	
Atriplex leptocarpa	Slender-fruit Saltbush	(2-4)	Not reported	
Atriplex suberecta	Sprawling Saltbush	(1-2)		
Melaleuca ericifolia	Swamp Paperbark	1-2	Not reported	
Muehlenbeckia florulenta	Tangled Lignum	(0-4)	Not reported	

Salt-tolerant trees

Scientific name	Common name	Salt class	Waterlogging tolerance	Present
Eucalyptus largiflorens	Black Box	(0-4)	Not reported	
Acacia stenophylla	Eumong	(0-4)	Not reported	
Melaleuca lanceolata	Moonah	(1-3)	Not reported	

Salt-tolerant agricultural plants

Scientific name	Common name	Salt class	Water logging tolerance	Present
Hordeum vulgare	Barley (varieties)	(0-2)	Not reported	
Triticum aestivum	Wheat (varieties)	(0-2)	Not reported	

Salt tolerant vegetation where the salt class is not known

The salt class has not been determined for the species listed below, although there may be an indication of their likely tolerance. Identification of some of these species may be useful for determining whether or not a site is classified as saline, but will be of limited assistance in determining the severity of soil salinity at that site.

Salt-tolerant herbs

Scientific name	Common name	Salt class	Waterlogging tolerance	Present
Carpobrotus aequilaterus	Angled Pigface	Tolerant	Tolerant	
Apium annuum	Annual Celery	Brackish	Not reported	
Aster subulatus	Aster-weed	Brackish	Not reported	
Leptinella reptans	Creeping Cotula	Brackish	Not reported	
Chenopodium glaucum	Glaucous Goosefoot	Brackish	Not reported	
Brachyscome graminea	Grass daisy	Brackish	Not reported	
Halosarcia pergranulata subsp. *pergranulata*	Grey Glasswort	Tolerant	Tolerant	
Ranunculus diminutus	Lesser River Buttercup	Brackish	Not reported	
Wilsonia backhousei	Narrow-leaf Wilsonia	Saline	Not reported	
Apium prostratum	Salt Celery	Brackish	Tolerant	
Lawrencia spicata	Salt Lawrencia	Brackish	Not reported	
Lobelia irrigua	Salt Pratia	Brackish	Not reported	
Poa sallacustris	Salt-lake Tussock-grass	Brackish	Not reported	
Sclerostegia arbuscula	Shrubby Glasswort	Tolerant	Tolerant	
Wilsonia humilis	Silky Wilsonia	Saline	Not reported	
Cotula vulgaris var. australasica	Slender Cotula	Brackish	Not reported	
Sarcocornia blackiana	Thick-head Glasswort	Hypersaline,	Tolerant	
Hydrocotyle capillaris	Thread Pennywort	Tolerant	Tolerant	
Senecio pinnatifolius	Variable Groundsel	Brackish	Not reported	
Limonium australe	Yellow Sea-lavender	Saline	Not reported	

Salt-tolerant grasses

Scientific name	Common name	Salt class	Waterlogging tolerance	Present
Eragrostis setifolia	Bristly Love Grass	Tolerant	Not reported	
Leptochloa fusca subsp. *fusca*	Brown Beetle Grass	Tolerant	Tolerant	
Eragrostis australasica	Cane Grass	Tolerant	Not reported	
Phragmites australis	Common Reed	Brackish, Tolerant	Tolerant	
Zoisia macrantha	Prickly Couch	Tolerant	Tolerant	
Chloris gayana	Rhodes Grass	Moderately tolerant	Not tolerant	
Sporobolus virginicus	Salt Couch	Tolerant	Tolerant	
Festuca arundinacea	Tall Fescue	Tolerant	Moderately tolerant	
Austrostipa tuckeri	Tucker’s Spear Grass	Tolerant	Not reported	
Sporobolus caroli	Yakka Grass	Tolerant	Not reported	

Salt-tolerant shrubs

Scientific name	Common name	Salt class	Waterlogging tolerance	Present
Atriplex cinerea	Coast Saltbush	Tolerant	Tolerant	
Atriplex prostrata	Hastate Orache	Tolerant	Tolerant	
Atriplex nummularia	Old-man Saltbush	Tolerant	Tolerant	
Atriplex paludosa subsp. *paludosa*	Marsh Saltbush	Tolerant	Tolerant	
Atriplex vesicaria	Bladder Saltbush	Tolerant	Tolerant	
Frankenia pauciflora var. *gunnii*	Southern Sea-heath	Hypersaline	Not reported	
Galenia pubescens var. *pubescens*	Galenia	Brackish	Not reported	
Halosarcia halocnemoides subsp. *halocnemoides*	Grey Glasswort	Hypersaline, Tolerant	Tolerant	
Maireana aphylla	Leafless Bluebush	Tolerant	Tolerant	
Maireana georgei	Slit-wing Bluebush	Tolerant	Tolerant	
Maireana oppositifolia	Heathy Bluebush	Tolerant	Tolerant	
Myoporum parvifolium	Creeping Myoporum	Brackish	Not reported	
Rhagodia candolleana	Seaberry Saltbush	Brackish, Tolerant	Not reported	
Sclerochlamys brachyptera	Short-wing Saltbush	Tolerant	Not reported	
Sclerostegia arbuscula	Shrubby Glasswort	Hypersaline, Tolerant	Tolerant	
Tetragonia implexicoma	Bower Spinach	Brackish	Not reported	

Salt-sensitive vegetation

Salt-sensitive grasses

Scientific name	Common name	Salt class	Waterlogging tolerance	Present
Hordeum leporinum	Barley Grass	Not reported	Not reported	
Deyeuxia sp.	Bent Grass	Not reported	Not reported	
Themeda triandra	Kangaroo Grass	Not reported	Not reported	
Briza minor	Lesser Quaking Grass	Not reported	Not reported	
Romulea rosea var. *australis*	Onion Grass	Not reported	Not reported	
Lolium perenne	Perennial Rye Grass	Not reported	Not reported	
Austrodanthonia carphoides	Short Wallaby Grass	Not reported	Not reported	
Anthoxanthum odoratum	Sweet Vernal Grass	Not reported	Not reported	
Holcus lanatus	Yorkshire Fog	Not reported	Not reported	

Salt-sensitive rushes

Scientific name	Common name	Salt class	Waterlogging tolerance	Present
Juncus planifolius	Broad-Leaf Rush	Not reported	Not reported	
Juncus subsecundus	Finger Rush	Not reported	Not reported	
Juncus articulatus	Jointed Rush	Not reported	Not reported	

Salt-sensitive herbs

Scientific name	Common name	Salt class	Waterlogging tolerance	Present
Arctotheca calendula	Capeweed	Not reported	Not reported	
Leontodon taraxacoides subsp. *taraxacoides*	Hairy Hawkbit	Not reported	Not reported	
Trifolium arvense var. arvense	Hare's-foot Clover	Sensitive	Not reported	
Erodium sp.	Heron's-bill	Not reported	Not reported	
Spergularia diandra	Lesser Sand-spurrey	Not reported	Not reported	
Trifolium dubium	Suckling Clover	Not reported	Not reported	
Trifolium tomentosum var. *tomentosum*	Woolly Clover	Not reported	Not reported	

Salt-sensitive agricultural plants

Scientific name	Common name	Salt class	Waterlogging tolerance	Present
Brassica napus	Canola	(0-1)	Not reported	
Cicer arientinum	Chick Peas	(0-1)	Not reported	
Zea mays	Maize	(0-1)	Not reported	
Trifolium subterraneum	Subterranean Clover	(0-1)	Not reported	
Trifolium repens var. *repens*	White Clover	(0-1)	Not reported	

SUMMARY OF GIS ATTRIBUTES FOR THE SITE

DSSITE: __________

SEVERITY RATING	Percentage of the site
SEV1	
SEV2	
SEV3	
SEV4	
SEV8	
TOTAL	100

ASSESSDATE: (mm/dd/yy) ___/___/___

DSTYPE:

N	(natural or primary salinity)
I	(induced or secondary salinity)
NI	(site is a combination of natural and induced salinity)

DSPROCESS:

D	(soil salinity derives from groundwater discharge)
W	(soil salinity derives from a process of waterlogging)
DW	(soil salinity derives from a combination of discharge and waterlogging processes)

DATACAPT	DESCRIPTION
1	Global Positioning System (GPS) - differentially corrected
2	GPS - uncorrected
3	Aerial Photo Interpretation allied with field work
4	API - no field work
5	Base Map used in conjunction with field work
6	Base Map with no field work
7	Remote Sensing in conjunction with field work
8	Remote Sensing - no field work
9	Derived Digital data - Spatial modelling using GIS data sets with some field work
10	Derived Digital data - Spatial modelling using GIS data sets with no field work

Appendix 5 Description of the site attributes

The following attributes must be recorded for each site:

Dssite

A unique name for each site comprised of a string of text or integers.

Each site should be assigned a unique name. This will allow other attributes to be attached to the correct polygon.

Sev1

Percentage of the whole site considered to have low salinity levels (Class 1 from **Error! Reference source not found.**). No more than 3 integer characters, with a value between 0 and 100.

Sev1 + Sev2 + Sev3+ Sev4+ Sev8 must equal 100.

Sev2

Percentage of the whole site considered to be moderately saline (Class 2 from **Error! Reference source not found.**). No more than 3 integer characters, with a value between 0 and 100.

Sev1 + Sev2 + Sev3+ Sev4+ Sev8 must equal 100.

Sev3

Percentage of the whole site considered to be highly saline (Class 3 from **Error! Reference source not found.**). No more than 3 integer characters, with a value between 0 and 100.

Sev1 + Sev2 + Sev3+ Sev4+ Sev8 must equal 100.

Sev4

Percentage of the whole site considered to be extremely saline (Class 4 from **Error! Reference source not found.**). No more than 3 integer characters, with a value between 0 and 100.

Sev1 + Sev2 + Sev3+ Sev4+ Sev8 must equal 100.

Sev8

Percentage of the whole site considered to be saline, but where the severity level cannot be classified. No more than 3 integer characters, with a value between 0 and 100.

Sev1 + Sev2 + Sev3+ Sev4+ Sev8 must equal 100.

This is also used for existing sites where the salinity class was not recorded at the time of survey. Allan (Allan 1994) said that salinity class had been recorded at only 57% of sites when the database was compiled in the early 1990s.

Sev9

A polygon forming a non saline island inside a larger salt affected area.

Assessdate

Record the date of the field assessment using six integers in the date format mm/dd/yy.

Dstype

Classification of the site as either primary or secondary salinity using one or two text characters (N, I, NI). Where:

N = natural or primary salinity, I = induced or secondary salinity and NI indicates sites where both primary and secondary salinity exists together.

Dsprocess

Characterisation of the groundwater process at the site as either discharge or waterlogging using one or two text characters (D, W, DW). Where:

D = a discharge related groundwater process, W = a waterlogging related groundwater process and DW indicates sites where both discharge and waterlogging processes occur together.

It may not be possible for field staff to record this attribute at the time of survey. It requires a good knowledge of the depth to groundwater and the dominant groundwater processes in the survey area. Consultation with a hydrogeologist familiar with the study area may be required.

Datacapt

This attribute describes the method used to map the soil salinity using a one-integer code. The codes and their definitions are listed in Table 12 . It gives an indication of the accuracy of the mapping for a site.

Table 12 Definition of the datacapt attribute values and their codes

Code	Method	Method description
1	GPS	Global Positioning System (GPS) - differentially corrected
2	GPS	GPS - uncorrected
3	API/FW	Aerial Photo Interpretation allied with field work
4	API	API - no field work
5	MAP/FW	Base Map used in conjunction with field work
6	MAP	Base Map with no field work
7	RS/FW	Remote Sensing in conjunction with field work
8	RS	Remote Sensing - no field work
9	DERDIG/FW	Derived Digital data - Spatial modelling using GIS data sets with some field work
10	DERDIG	Derived Digital data - Spatial modelling using GIS data sets with no field work

Appendix 6 Converting $EC_{1:5}$ values to EC_{se} values

To convert $EC_{1:5}$ values to estimates of EC_{se} values, apply the correction factor appropriate for the texture of each sample (see Table 13).

EC_{se} (dSm^{-1}) = $EC_{1:5}$ (dSm^{-1}) x conversion factor (Equation 1)

Table 13 Factors for converting $EC_{1:5}$ values (dSm^{-1}) for specific soil texture classes to estimates of EC_{se} values (dSm^{-1})

Soil texture	Multiplier factor
Loamy sand, clayey sand, sand	17
Sandy loam, fine sandy loam, light sandy clay loam	11
Loam, loam fine sandy, silt loam, sandy clay loam	10
Clay loam, silty clay loam, fine sandy clay loam, sandy clay, silty clay, light clay	9
Light medium clay	8
Medium clay	7
Heavy clay	6

Appendix 7 Methodology for standard $EC_{1:5}$ soil analysis

The $EC_{1:5}$ test offers a standard means of comparing the electric conductivity of various soil samples. $EC_{1:5}$ values cannot be directly related to the effect of soil salinity levels on plant growth.

The following methodology, taken from Rayment and Higginson (1992), describes standard practices for preparing and testing a solution produced from a subject soil sample.

Prepare a 1:5 soil-water suspension. For example, weigh 20.0 g air dry soil into a suitable bottle or jar and add 100 ml of de-ionised water. Mechanically shake at 25°C for one hour to dissolve soluble salts. Allow around 20–30 minutes for the soil to settle. Calibrate the conductivity cell and meter in accordance with manufacturer's instructions, and by using the potassium chloride reference solution at the temperature of the suspensions.

Dip the conductivity cell into the supernatant, moving it up and down slightly without disturbing the settled soil. Take the cell reading with the cell stationary when the system has stabilised. Rinse the cell with de-ionised water between samples and remove excess water. Complete EC measurements within three to four hours of obtaining the aqueous supernatant.

Report EC (dSm^{-1}) at 25°C on an air dry basis.

Appendix 8 Soil texture characteristics defined by Northcote (1984)

The soil texture characteristics defined by Northcote (1984) are used to identify the conversion factor required to convert $EC_{1:5}$ to EC_{se} values (Table 14).

Table 14 Soil texture characteristics defined by Northcote (1984)

Texture grade	Behaviour of moist bolus	Approx. clay content %
Sand (S)	Coherence nil to very slight; cannot be moulded; single sand grains adhere to fingers.	Always < 10 and commonly < 5
Loamy sand (LS)	Slight coherence; can be sheared between thumb and forefinger to give minimal ribbon of about 6 mm; discolours fingers with dark organic stain.	5–10
Clayey sand (CLS)	Slight coherence; sticky when wet; many sand grains stick to fingers; will form minimal ribbon 6–13 mm; discolours fingers with clay stain.	(some organic matter present)
Sandy loam (SL)	Bolus just coherent but very sandy to touch; will form ribbon of	5–10
Fine sandy loam	1.3–2.5 cm; dominant sand grains are of medium size* and are readily visible.	(little or no organic matter)
(FSL)	Bolus coherent; fine* sand can be felt and heard when manipulated; will form ribbon of	10–15
Light sandy clay loam	1.3–2.5 cm; sand grains are clearly evident under hand lens.	10–20
(SCL)	Bolus strongly coherent but sandy to touch; sand grains dominantly medium size* and easily visible; will form ribbon of about 2-5 cm.	15–20
Loam (L)	Bolus coherent and rather spongy; smooth feel when manipulated but with no obvious sandiness or “silkiness”; but may be somewhat greasy to the touch if much organic matter present; will form ribbon of about 2.5 cm.	about 25
Loam, fine sandy	Bolus coherent and slightly spongy; fine sand can be felt and heard when manipulated; will form a ribbon of about 2.5 cm.	about 25
(Lfsy)	Coherent bolus, very smooth to silky when manipulated; forms ribbons of about 2.5 cm.	about 25, and with silt 25% or more
Silt Loam (SiL)	Strongly coherent bolus sandy to touch; medium size sand grains visible in finer matrix; will form ribbon of 2.5–3.8 cm	20–30

Appendix 8 continued next page

Texture grade	Behaviour of moist bolus	Approx. clay content %
Fine sandy clay loam	Coherent bolus; fine sand can be felt and heard when manipulated; will form ribbon of 3.8–5 cm.	30–35
(FSCL)	Plastic bolus; fine to medium sands can be seen, felt or heard in clayey matrix; will form ribbons of	35–40
Sandy clay (SC)	5–7.5 cm.	35–40, and with silt 25% or more.
Silty clay (SiC)	Plastic bolus; smooth and silky to manipulate; will form ribbons of 5–7.5 cm.	35–40
Light clay (LC)	Plastic bolus; smooth to touch; slight resistance to shearing between thumb and forefinger; will form ribbons of 5–7.5 cm.	40–45
Light medium clay	Plastic bolus; smooth to touch, slightly greater resistance to ribboning shear than light clay; will form ribbon of about 7.5 cm.	45–55
(LMC)	Smooth plastic bolus, handles like plasticine and can be moulded into rods without fracture; has some resistance to ribboning shear; will form ribbon of 7.5 cm or more.	>50

NOTE: By definition sand grains in soils range from 2 mm to 0.2 mm diameter with an arbitrary separation of coarse and fine sand at 0.2 mm particle diameter.