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Salinity Investigation at Second Ponds Creek

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Consultancy report for
ROUSE HILL INFRASTRUCTURE PTY LTD

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Executive Summary

❖ **Extent of salinity and associated problems**

- Topsoils are generally only saline in the immediate vicinity of Second Ponds Creek.
- Subsoils in the creek and immediately adjacent (approx. 20 m on either side) and up into the tributaries are highly saline (i.e. EC_{se} > 16 dS/m) and due to saline groundwater. Subsoils from 20 to 150 m from the creek are moderately saline (i.e. EC_{se} 4 to 8 dS/m) due to leaching of salts in rainfall and natural weathering processes and salt accumulation around the rootzone of past vegetation.
- The volume and quantity of discharge into the creeklines will vary depending on seasonal groundwater fluctuations (seasonal recharge) and runoff. When groundwater levels are high the areal extent of the salinity problem will be greatest. Salts are being concentrated due to evaporation of surface water and groundwaters.
- Some very acid layers were present in some subsoils.
- The weathered shale layer could present problems for buildings and infrastructure
- Surface waterlogging (much of this water is fresh) is more extensive (approximately 60% of the area) than salinity. The waterlogging is caused by a sodic clay B horizon, which has low permeability.
- Sulfidic materials were observed in the vicinity of the creek. The extent of their presence is not known.
- Sodic soils (with high exchangeable sodium) are the dominant soils in the area (approximately 80%). All subsoils within 150 m of the creek are sodic (ESP > 15%). These soils are highly dispersive when in contact with low salinity water (e.g. rainwater) and some of these soils also have pronounced shrink-swell characteristics.

❖ **Management of salinity for urban development**

- Engineering options must particularly take into consideration the highly saline soil conditions in close proximity to the creekline and the tributaries (i.e. the development of housing in these areas must be carefully managed, taking into account the cause of the soil conditions).

- To reduce the potential impact of the housing development on site salinity, and manage waterlogging, we agree with the recommendations that all drainage lines have full-length subsoils drains.
- To minimise the risk of salinity impacts on dwellings, we agree with the recommendation they have suspended floors to minimise site earthworks. The water and salinity management approach suggested by Patterson and Britton does take into account CSIRO’s concerns with the potential for the residential development to be affected by saline soils near the creek. They have proposed engineering solutions to resolve these issues including a minimum 300 mm embankment (for the road and proposed houses adjacent to the creek) above the active water level. However ours concerns are as follows: i) the 300 mm is dependant on the nature of the material used to construct the embankment i.e. minimise capillary rise from saline groundwater, ii) the chemistry of the material embankment must be tested (i.e. minimise use of adjacent and underlying sodic material because it is unstable and requires amelioration with gypsum.
- The least risk option for the trunk drainage strategy is to install dry dams not wet dams to minimize the convective transport of salt. Engineering solutions proposed may minimise the risk of damage to infrastructure from salinity if inline, wet dams are installed. However, there is a higher risk of saline waters causing problems with infrastructure when comparing inline, wet dams with dry dams. We do acknowledge that there may be some “wetland” design that doesn’t exacerbate the salinity problem, which also allows clean up of sediment and nutrients. Wet basins would have to be lined to minimise leakage. However, the on-line water quality components should be deleted from Second Ponds Creek if alternative strategies are available to ensure pollutant target exports are achieved.
- The proposed engineering solutions for the sewerage installations (e.g. gravel infill) or chemical ameliorants (gypsum) will overcome problems associated with highly saline, sodic soils. Based on the mineralogy of the clays near Second Ponds Creek, where sewerage installations are proposed (Appendix 2,

Table 5), the sewerage pipe support design provided by Sydney Water Corporation will be suffice. We assume the “select fill” in accordance with WSA-02, Part 4 Section 13 has non-swell characteristics, is non sodic and therefore does not need the addition of gypsum.

- In general, any underground installations (e.g. sewer pipes and cables) in the vicinity of sodic soils with shrink-swell characteristics would be at risk of tunnel-type erosion (e.g piping) and possibly of mechanical damage due to shrink-swell processes. Sulfidic materials could produce corrosive sulfuric acid if exposed to the atmosphere and hence has implications for foundations and pipe installations in close proximity to the creek Thus, bulk earthworks should be minimised, a single sewer carrier is preferred over two shallower carriers and materials such as glass reinforced plastic piping be used where possible. Any concrete must be reinforced.
- To minimise erosion of Second Ponds Creek (as the soils are highly sodic), we agree with the recommendation for energy dissipation and drop structures along the creekline. A riparian corridor of salt and waterlogging tolerant species should be planted along the creekline.
- Streetscaping should include native, salt tolerant vegetation and residents encouraged to plant native species to minimise garden watering.
- After 25 years of using recycled water, between 2 and 15 T/ha of additional salt will accumulate in the soils, which at the time of the investigation had salt stores of up to 140 T/ha (to 2 m). The rate of salt accumulation would be lower if lateral drainage is included in the calculations.

❖ **Further work**

- Housing estates, although containing a high proportion of sealed surface area, attract high inputs of irrigation water for lawns and gardens. Over a period of time (up to a few decades) this almost invariably results in groundwater mounds developing beneath the estate and will place pressure on the creekline. At the site one could expect salt, already stored in the profile, to be leached towards Second Pond Creek and increased groundwater discharge into (and adjacent to) the creek would also be expected. Therefore, consideration should be given, in the planning phase, for installing a network of piezometers to provide that information in the future.

- The sodium, magnesium, chloride and sulfate content within the shale should be determined because these elements contribute strongly to sources of salinity, sodicity and acidity.
- To determine if the source of salinity in and near the creek is saline groundwater discharge, water levels and EC should be measured in the piezometers installed by Douglas Partners Pty Ltd.

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Introduction

An investigation into urban salinity in the Second Ponds Creek area was undertaken by CSIRO Land and Water at the request of Rouse Hill Infrastructure Pty Ltd to address the following key questions:

- Is there a salt problem (saline and sodic soils and/or saline water) in the Second Ponds Creek Catchment Area?
- What is the extent of the salt problem in the Second Ponds Creek Area?
- What is the cause of the salt problem, if any?
- Comment on the proposed trunk drainage schemes and any potential impacts on the salt problem, if any.
- If a salt problem exits, will it translate into an urban salinity problem as a consequence of the planned urban development?
- What are some of the general measures that can be adopted to minimise urban salinity?

Approach used

- Scoping of project (1st April 2002)
- Undertake field work April (April 2002)
- Samples analysed and interpreted (April 2002)
- Complete draft report and submit to Rouse Hill (8 May 2002)
- Presentation of findings to committee comprising representatives from Rouse Hill Infrastructure Pty Ltd, Soil Water Corporation, Landcom, Douglas Partners Pty Ltd, Gutteridge, Haskins and Davey Pty Ltd and Patterson Britton and Partners (15 May 2002)
- Response to specific questions and modified infrastructure proposal by clients (late June 2002)
- Final report submitted taking into consideration comments and modifications (11 July 2002)

Previous data

History of the site with respect to salinity

The site was cleared in the mid 1800s for grazing. Aerial photography from 1947 shows that approximately 5 ha along Second Ponds Creek was salt affected (Austin 1983). The area affected decreased around 1970 to 1 ha, possibly due to earthworks to control surface water (the contour banks in Figure 1; Austin 1983). Its current extent, possibly enhanced by uncontrolled grazing, can be seen in Figure 1.

The historical information, along with general knowledge of the effects of land clearance for agriculture on the hydrology of catchments, suggests that groundwaters would have risen to their present levels in the late 1800s or early 1900s (certainly prior to 1947) due to increased recharge. Changes in the area of the saline scalds over the years could be due to either changed management (e.g. the installation of contour banks to divert surface water, Figure 1) or periods of lower than average annual rainfall resulting in reduced groundwater recharge and thus periods of lower watertables and leaching of salt from the upper soil profile. Uncontrolled grazing near the creek over many years would probably have contributed to the erosion that has taken place along the creek.

Lithology

A study of soils across the site by Douglas Partners Pty Ltd and Sydney Environmental and Soil Laboratory (2001) suggest the A horizon is acidic to highly acidic ($pH_{1:5}$ <5.5) with low salinity (<0.4 dS/m; deci-Siemens per metre) and the B horizon is highly acidic (3.8 to 5.1) with elevated salinity (>1 dS/m). The depth at which bedrock has been encountered along the creekline (see bore locations in Figure 1) varies from just over 3 m (BH6) to more than 6 m (BH2) and its salinity is lower than the B horizon (Douglas Partners Pty Ltd 2001). It was thought that the salinity is derived from the bedrock from which the soils are derived and the saline soils result in elevated salinity levels in groundwater as it flows through these soils (Douglas Partners Pty Ltd 2001). It was also thought that salinity levels of water in Second Ponds Creek is elevated (see below) due to the flow of this groundwater into the creek and subsequent further concentration due to evaporation of water trapped in ponds (Douglas Partners Pty Ltd 2001).

Model EM31 Electromagnetic Conductivity Meter (EM31) readings integrate salinity over about 4 m depth. EM31 readings throughout the area suggest that soil salinity generally increases to the west from Cattai Creek (3 km east of Second Ponds Creek) toward Second Ponds Creek, with highest apparent electrical conductivity (ECa) values measured between Windsor Road and Second Ponds Creek. Some of the highest ECa readings were measured over the study site (as high as 1.8 dS/m) but similar values were measured in other areas, possibly including land with housing and infrastructure (see Map 3.2; Australian Water Technologies 2000).

Surface water and groundwater

Surface water within the Second Ponds Creek area is usually fresh (Austin 1983). Throughflow water (lateral flow above the B horizon) was moderately saline, increasing with lower elevation (Austin 1983). The water in Second Ponds Creek has been shown to vary between 0.8 and 63 dS/m within short periods (Austin 1983).

Groundwater levels in piezometers installed near the creek suggest the watertable was just over 1 m below the surface level in the lowest parts of the site. Groundwater salinity throughout the area was around 19 dS/m (Austin 1983). Groundwater salinity at the site has been measured by Douglas Partners Pty Ltd and Sydney Environmental and Soil Laboratory (2001) to be between 5.6 dS/m (BH1, Fig.1) and 11.5 dS/m (BH7, Fig.1). It has been measured by Douglas Partners Pty Ltd (2002) to be as high as 17.7 dS/m, which is consistent with the other studies.

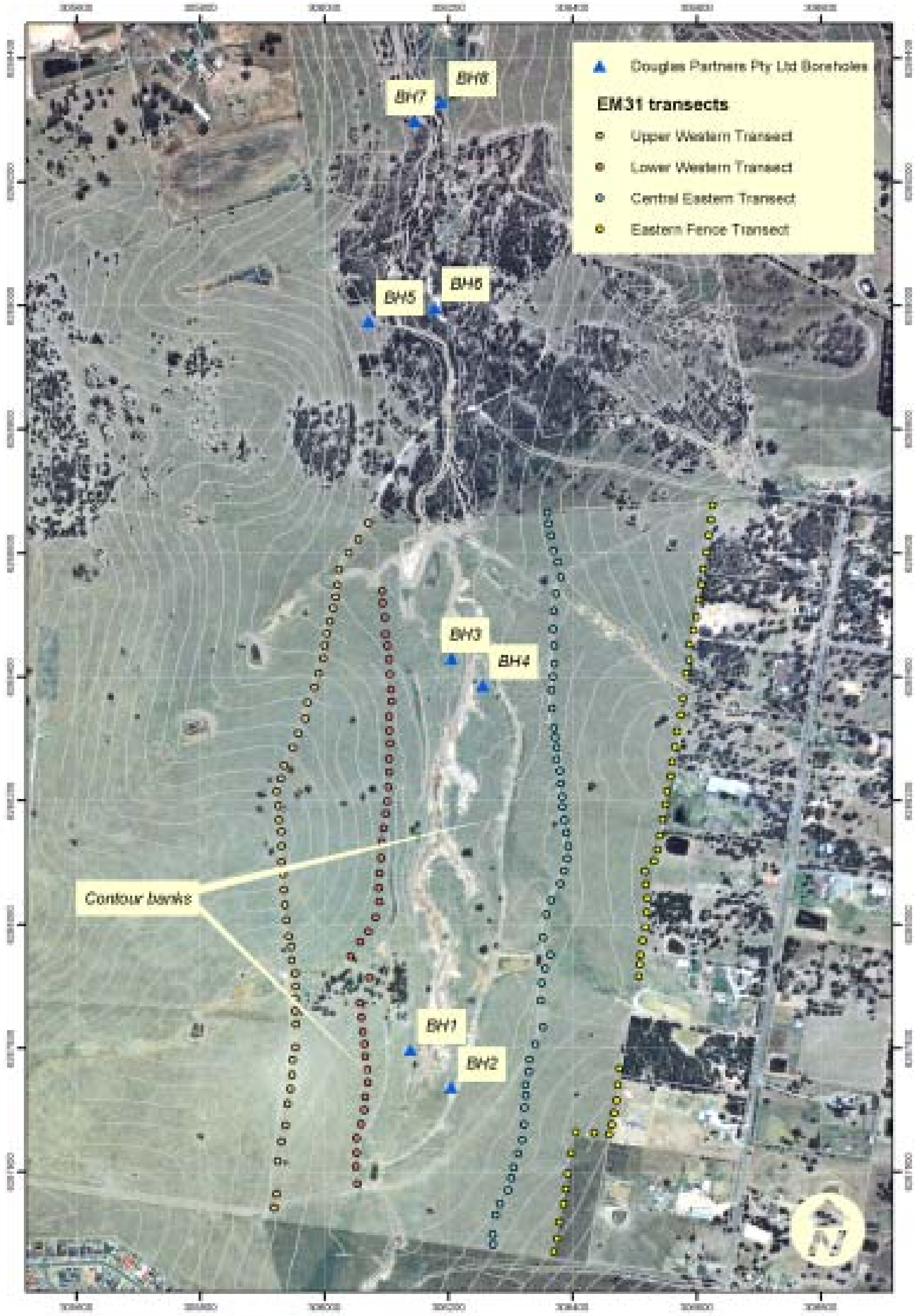

Figure 1. Site, bore locations (Douglas Partners Pty Ltd) and EM transects.

Methods

General

A survey of the area was conducted using electromagnetics (EM31), and describing and sampling the soil down to 3 m or less in seven pits was used to determine the extent of salinity across the site. This information combined with the data from other reports helped answer the key questions about urban salinity and its potential impacts on the site. A limiting factor in the interpretation was the lack of piezometric data across the site, which would confirm the variation in depth to saline groundwater across the site, the seasonal fluctuations in groundwater levels and changed in pressure within the aquifers.

Electromagnetic (EM31) survey

A model EM31 electromagnetic induction conductivity meter was used to measure the apparent electrical conductivity (ECa, see Glossary in Appendix 3) of the soil profile to an approximate depth of 5 m. The EM values (deciSiemens/metre – dS/m) were then related to the Total Soluble Salt (TSS) in the soil pit profiles.

The EM31 instrument was mounted on a 4-wheel drive vehicle, together with a GPS instrument for determining the map coordinates of each EM31 reading. Sample sites were also superimposed onto an air-photograph, using field notes, to determine locations. The vehicle mounted EM31 readings were corrected for any interference caused by their proximity to the vehicle by re-measuring about 30 sites (that had been marked with lime) in the absence of the vehicle.

Soil sampling and chemical analyses

Seven soil pits were dug across the area. Soil pits were photographed, described according to McDonald *et al*. (1990) and classified according to Isbell (1996). $EC_{1:5}$, $pH_{1:5}$, pH (in $CaCl_2$), major and total exchangeable cations, cation exchange capacity (CEC), and exchangeable sodium percentages (ESP) were measured on each soil horizon using standard techniques (Rayment and Higginson 1992). EC_{se} was estimated from $EC_{1:5}$ and soil texture to identify the salinity hazard and its affect on plants (Cass *et al*. 1996). On selected samples major cations, chloride, sulfate, EC and sodium adsorption ratio - SAR) were measured on the saturation extract (Rayment and Higginson 1992). A glossary of terms is provided in Appendix 3.

Results

Electromagnetic (EM31) survey

All EM transects were run upslope of the old contour banks (the old earthworks adjacent to the creek, Figure 1) due to very wet conditions closer to the creek but even so, gullies, tributaries of Second Ponds Creek and swampy conditions prevented readings being obtained in some areas. Figure 2, Figure 3, Figure 4, and Figure 5 show the apparent electrical conductivity (ECa) traces, in a south to north direction, for the upper western, lower western, central eastern and eastern fence transects. The distance units are arbitrary values obtained from an airphoto. Various features (gullies, dams, trees) that are useful in locating positions on the airphoto are shown in the Figures.

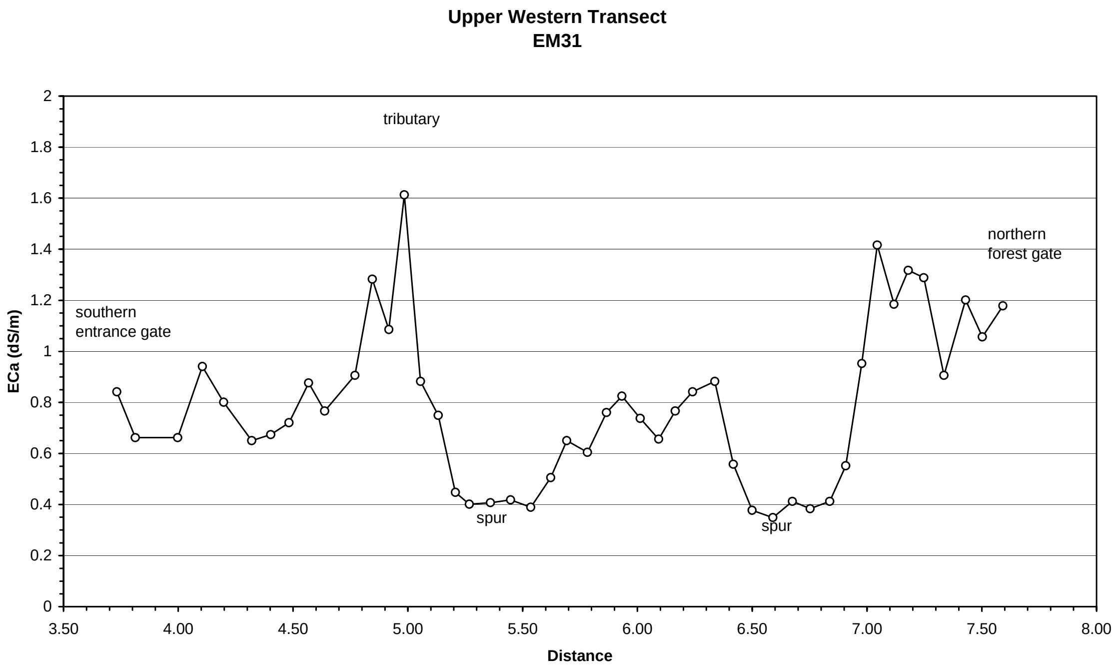

Figure 2. Apparent electrical conductivity (ECa) along the upper western transect (<1.2 is non saline to moderately saline soils, 1.2-1.6 dS/m are saline soils, 1.6-2.0 dS/m are very saline and >2.0 dS/m are highly saline).

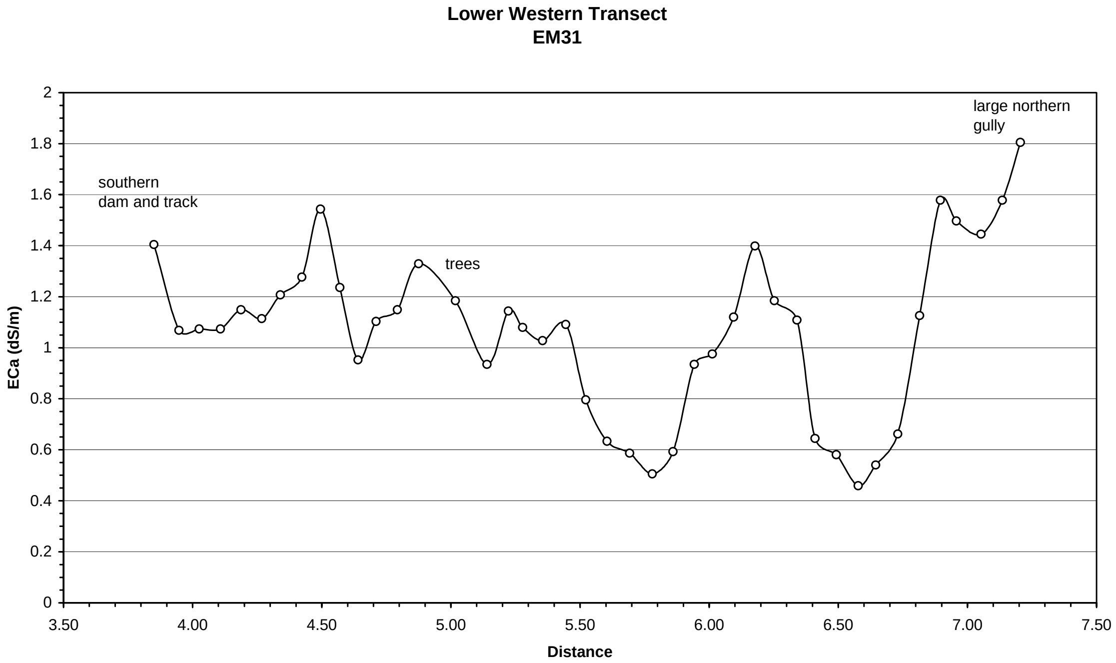

Figure 3. Apparent electrical conductivity along the lower western transect (<1.2 is non saline to moderately saline soils, 1.2-1.6 dS/m are saline soils, 1.6-2.0 dS/m are very saline and >2.0 dS/m are highly saline).

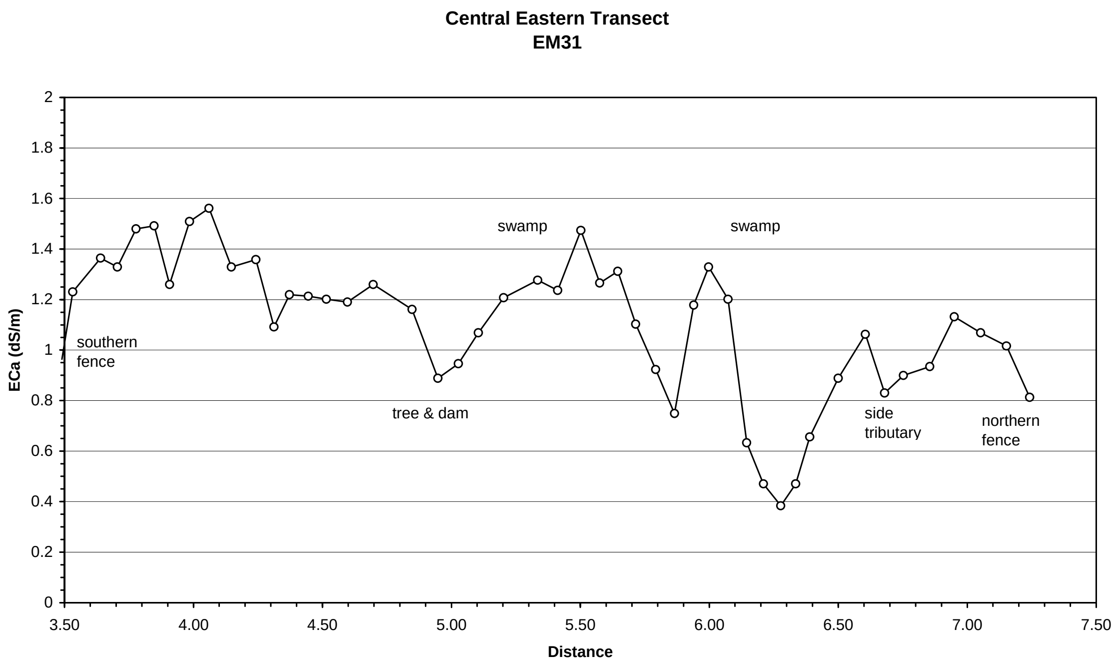

Figure 4. Apparent electrical conductivity along the central eastern transect (<1.2 is non saline to moderately saline soils, 1.2-1.6 dS/m are saline soils, 1.6-2.0 dS/m are very saline and >2.0 dS/m are highly saline).

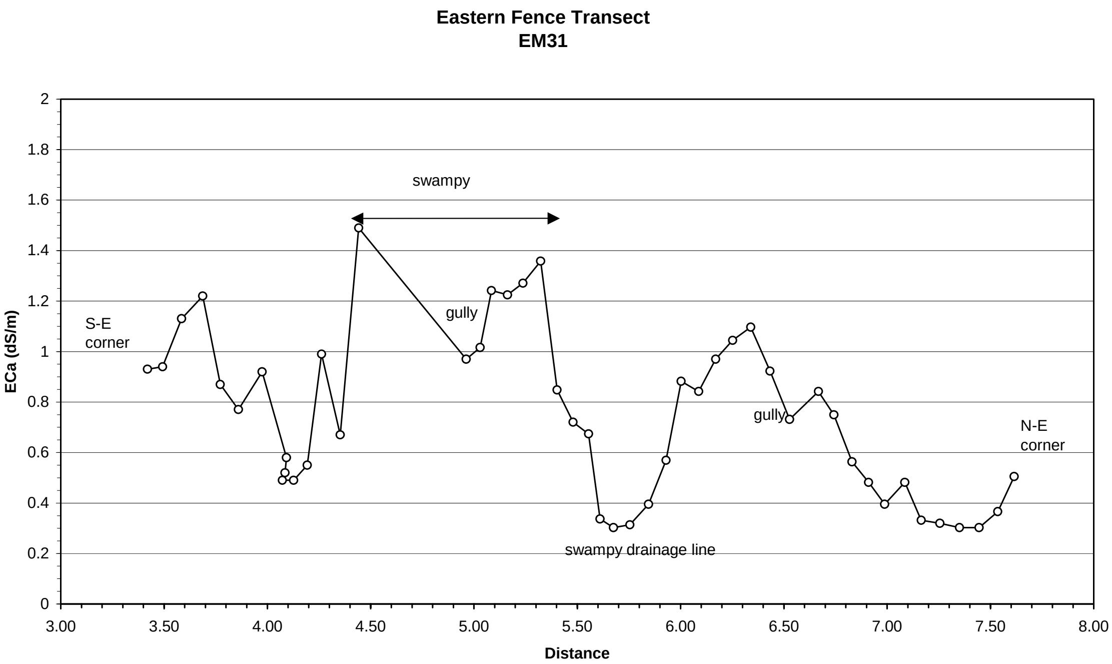

Figure 5. Apparent electrical conductivity along the eastern fence transect (<1.2 is non saline to moderately saline soils, 1.2-1.6 dS/m are saline soils, 1.6-2.0 dS/m are very saline and >2.0 dS/m are highly saline).

The main features shown in these figures are a series of high and low ECa values. The ‘highs’ correspond with areas of salt storage or accumulation; whilst the large ‘lows’ appear to be associated with areas where the shale bedrock is closer to the surface. The latter correspond with the upland sections (away from the creek) as well as side tributaries that stretch down towards Second Pond Creek. The bedrock is clearly illustrated in for example, soil pit NRH3 (see Appendix 1) where the shale is within 1 m of the soil surface. Smaller ‘lows’ are probably associated with layers of coarse colluvial material washed from the surrounding uplands.

In terms of the ECa values, previous experience would indicate that EM31 readings of >1.2 dS/m are saline and values above 1.6 dS/m are very saline, with respect to plant growth. Figure 2-Figure 5 inferred that the lower in the landscape, the greater the proportion of each transect that is saline. Very swampy conditions prevented surveys below the contour banks (Figure 1) but readings taken within the creek bed had ECa values of about 2.0 dS/m (i.e. highly saline soils).

When the data is plotted as a map of iso-electrical conductivity (Figure 6) a clearer picture of salt accumulation in the lower parts of the landscape is obtained. To the eastern side of Second Pond Creek the salinity hazard is dominant in the south-eastern sector whilst the creek line itself is highly saline. The low conductivity ridges are pronounced in the western sector with higher values in the tributaries. This map, although exploratory in nature, is reasonably cohesive, given the minimal sampling carried out.

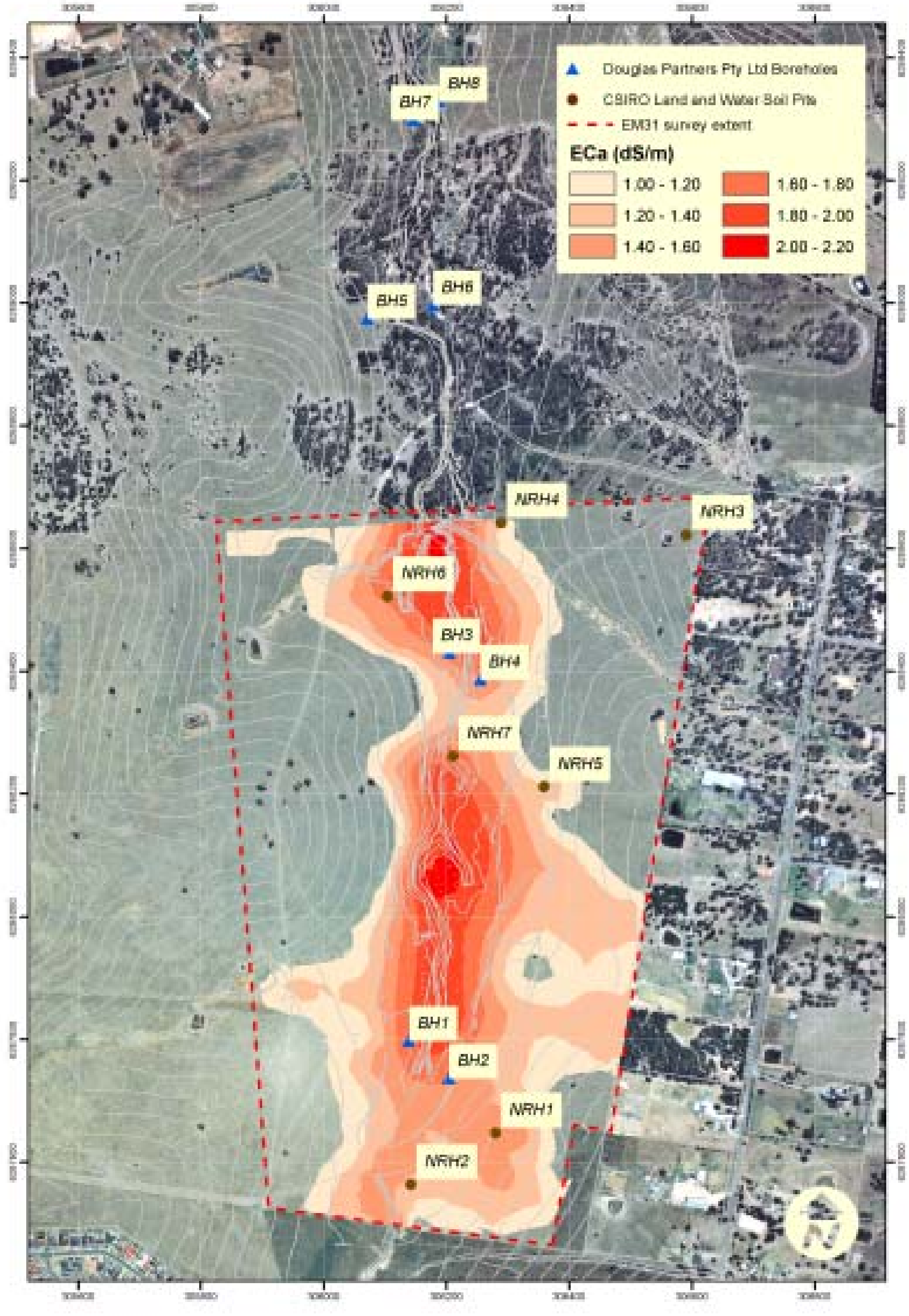

Figure 6. EM31 map of salinity and boundary of the EM31 survey.

A considerable area was very wet and swampy at the time of the investigation. This is a result of the relatively low slope gradients on the eastern side of the creek, barriers to water flow created by the contour banks (Figure 1), and the very heavy Paspalum grass (*Paspalum dilatatum*) surface cover. All of these factors exacerbate the evaporative concentration of atmospheric salt deposited in the area. This would amount to about 200 kg salt/ ha/ annum. Depending on the vertical infiltration rates into the soil the salt is either leached further down the profile or washed across the surface into Second Pond Creek. The presence of surface water does not in itself indicate a surface accumulation of salts although it does add to the evaporative concentration process.

Although it has been stated that ECa values of >1.6 dS/m are likely to be harmful to plant growth there is no evidence that the Paspalum grass is unduly affected in this area. This is in accord with the general observation that given warm, wet conditions, and soils with a high clay content, pasture plants are able to withstand higher salt concentrations in the root zone. Further, as described below, the surface soils where most of the paspalum roots are located, generally have quite low salt contents. This shows that the ECa reading is an integration of salinity over depth and does not describe salinity of each soil horizon. Thus $EC_{1:5}$ and EC_{se} (see data below) are done on all horizons from soils collected from the soil pits.

Soil sampling and chemical analyses

Soil morphology

Figure 7 shows the sites of soil pits excavated by back-hoe. Photographs of these soil pits and their descriptions are in Appendix 1. This information was used to construct a cross-section of the soils through the area (Figure 8), which shows how the different soil horizons, with varying soil matrix and mottle colours, are linked.

Red soils over shale are found on the upper parts of the hillslope with waterlogged yellow and grey soils over ferricrete along the creekline. The loamy, brownish grey and brown A and pale grey E horizons (see Legend in Figure 8) are underlain by less permeable clayey B horizons over the whole site, which restrict the vertical movement of water causing throughflow (fresh water flow on top of the clays). This process causes waterlogging on the lower parts of the site. Surface waterlogging is more extensive (approximately 60% of the area) than salinity (discussed below) and would be a problem if drainage isn’t installed throughout the area. It will be largely reduced when the contour banks (Figure 1) are removed and the proposed drainage system installed.

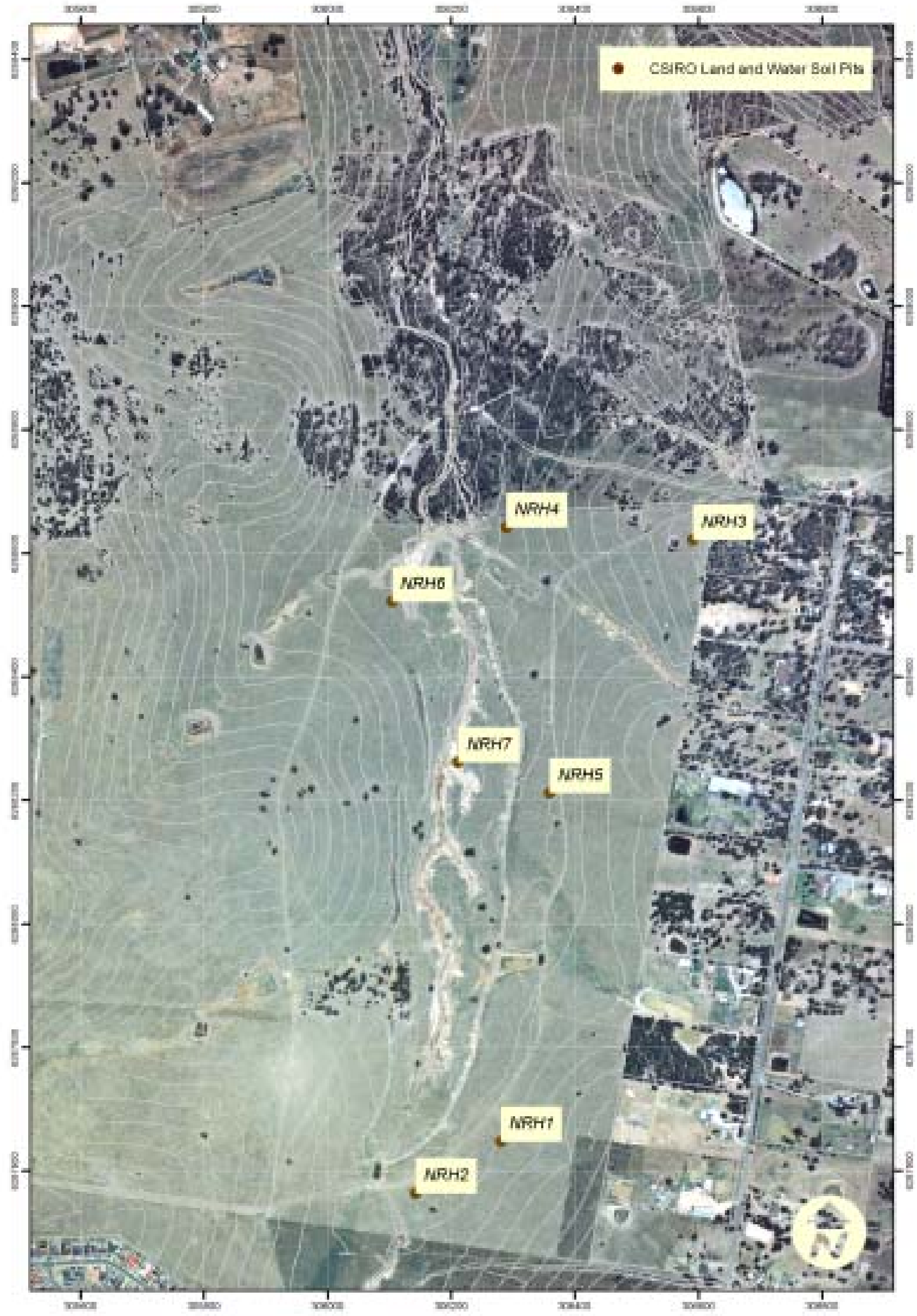

Figure 7. Location of CSIRO soil pits.

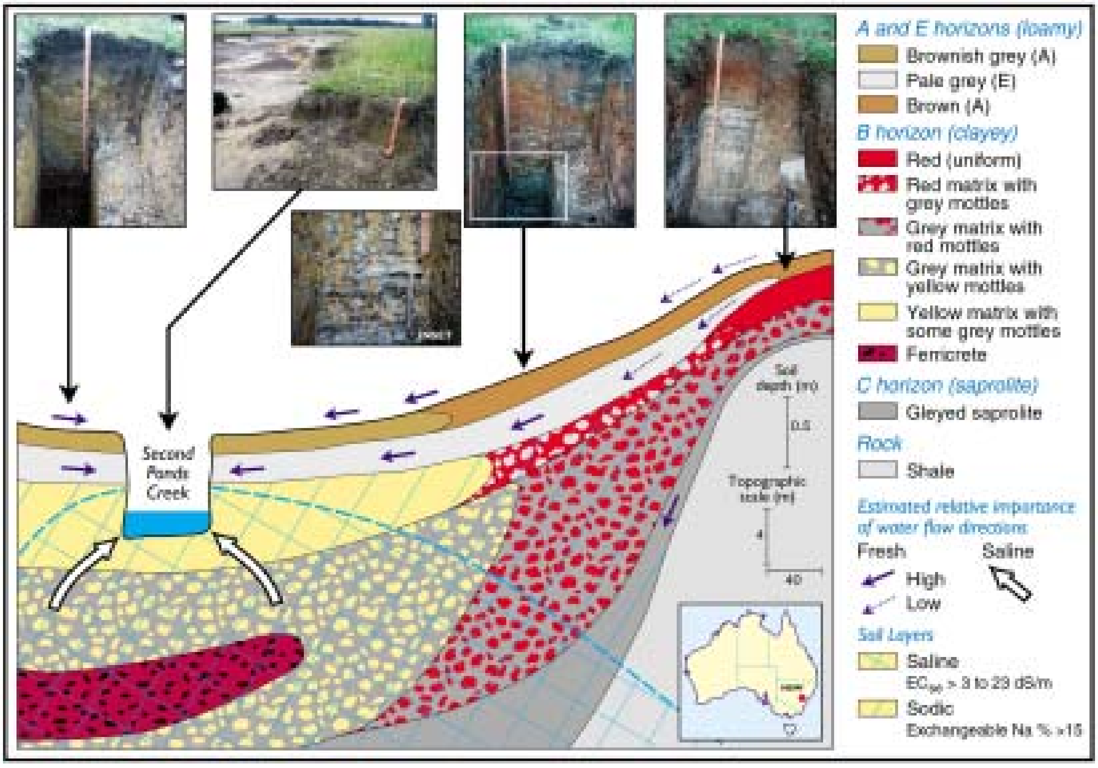

Figure 8. Cross section showing distribution of soil horizons and saline and sodic conditions (from a theoretical transect through soil pits 3, 4, 7 and 6).

Soil and water salinity

Salinity (electrical conductivity i.e. $EC_{1:5}$, EC_{se} calculated from clay content, and EC_{se} from saturation extract), particle size, mineralogy and bulk density data are in Table 1 to Table 5 in Appendix 2 as well as plots of the soil salinity ($EC_{1:5}$) data that was used to calibrate the EM31 to a depth of approximately 3 m. The distribution of soils with low (EC_{se} < 3) and moderate to high salinity (EC_{se} > 3 to 23 dS/m) is shown in Figure 8. Topsoils are generally only saline in the immediate vicinity of Second Ponds Creek. Subsoils in the creek, and immediately adjacent (approximately 20 m), are highly saline. All subsoils within 150 m of the creek are moderately saline. The source of salinity in and near the creek is saline groundwater discharge (although a series of nested piezometers across the site would be required to confirm this). The volume and quality of groundwater discharge into the creeklines will vary depending on seasonal groundwater fluctuations (seasonal groundwater recharge). When groundwater levels are high the areal extent of the salinity problem will be greatest. Salts in and near the creek are being concentrated due to evaporation of surface water and groundwaters.

In Table 1 (Appendix 2) $EC_{1:5}$ has been converted to EC_{se}. EC_{se} values of 4-8 dS/m are regarded as 'moderately' salinity and >8-16 dS/m as 'very' saline and >16 dS/m as 'highly' saline. Generally the upper 25 to 50 cm of soil has a very low soluble salt content, but this increases rapidly with depth. Site 7, in the scalded creek bed, was the only profile that showed highly saline values (see Appendix 2). This profile also showed a very hard, low permeability, ferruginous layer, at a depth of about 50 cm, containing a very high salt concentration.

The surface and subsoils horizons at soil pit site NRH3 have very low salt contents (low EC_{se} and exchangeable sodium percentage) but the weathered shale in this profile has very high exchangeable sodium (and low pH, as discussed below).

The numbers shown on the salinity profile plots in Appendix 2 represent the Total Soluble Salt stored in the profile to a depth of 3 m. They provide a means of converting the EM31 values (dS/m) into a comparative measure of salt concentration. Figure 9 indicates that about 90 percent of the variation in ECa values can be explained by the total soluble salt content, hence the EM readings can be taken as a very good prediction of the salt within the soil profiles. The difference between EC_{se} and ECa is discussed in the Glossary (Appendix 3).

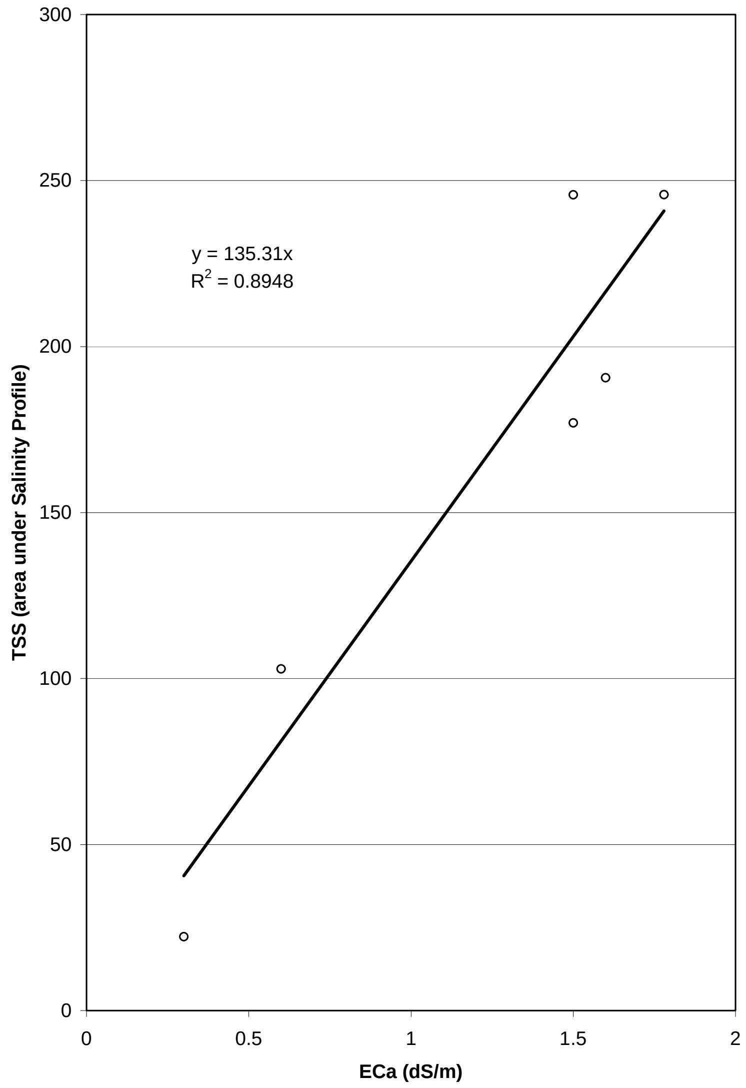

Figure 9. Total soluble salts (dS/m) vs EM31 readings.

Soil salinity in a forested area

Immediately to the north of soil pit NRH4 is an area of (largely regrowth) Grey Box (*Eucalyptus moluccana*) and Swamp Oak (*Casuarina glauca*) forest (Gunninah Environmental Consultants 2002). A foot traverse with the EM31 instrument was carried out (Figure 10) to determine the background salinity within the area. The approximate location of the traverse is shown as a series of white dots in Figure 10, although a number of survey markers were encountered that could be used later to tie that in to exact AMG coordinates.

Figure 10. Location of EM survey points in the forested area.

The frequency distribution of EM readings obtained are provided in Figure 11 which shows a high proportion of moderate salinity values (ECa <1.2 dS/m). About 16% of values exceeded 1.40 dS/m with a value of 1.72 dS/m being measured in the creek itself. The forest shows no signs of an adverse impact of the existing salt concentrations but this is not surprising as Grey Box is known to be moderately tolerant of salinity, and waterlogging whereas Swamp Oak is very highly tolerant (Dunn and Neales 1993, Sun and Dickinson 1995, Bell 1999). The damage to the Second Ponds Creek bed environment is probably due to past land use activities. In particular, stock can have a major impact on creek bank stability and the development of scalded areas due to overgrazing.

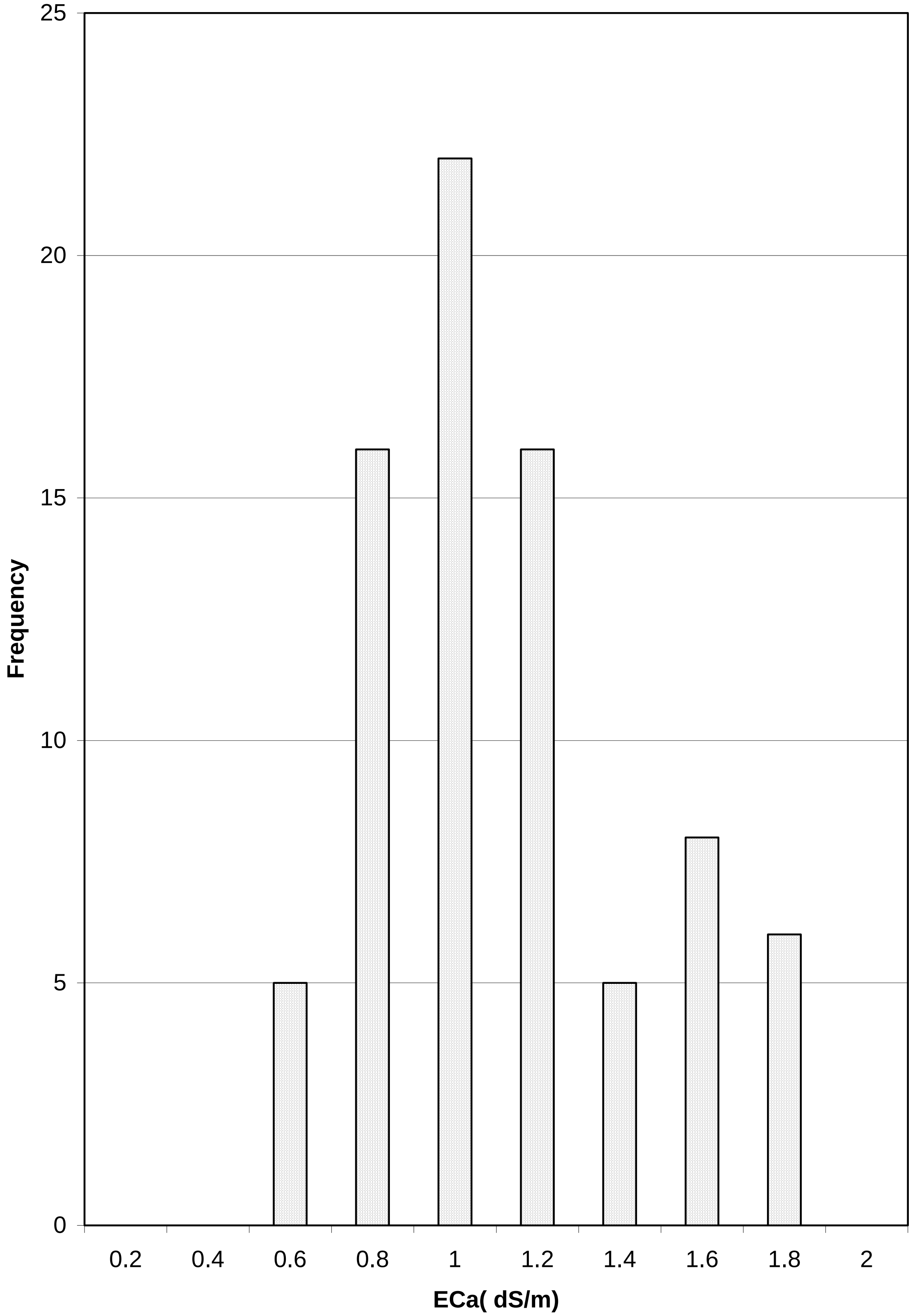

Figure 11. Frequency distribution of salinity in forested area.

Soil sodicity

Sodic soils are easily dispersive because they generally have a high exchangeable sodium percentage (ESP> 15%). ESP data is presented in Table 2 (Appendix 2). Sodic soils are dominant in the area (approximately 80%; Figure 8). The highest ESP values were present in soils in the creekline (Table 2, Appendix 2). Other than the creekline, high ESP only occurred in subsoil horizons, including saprolite.

Sodic soils are highly dispersive when in contact with low salinity water (e.g. rainwater) and some of these soils also have pronounced shrink-swell characteristics. Any underground installations (e.g. pipelines and cables) in the vicinity of sodic soils with shrink-swell characteristics would be at risk of tunnel-type erosion (e.g piping) and possibly of mechanical damage due to shrink-swell processes. Chemical ameliorants must be used with engineering solutions to overcome these problems.

Ca/Mg ratios in profile NRH3 were very low.

Soil acidity

The loamy A and E horizons are acidic to highly acidic (pH_{CaCl_2} <5.5) and pH often increases with depth through the B horizon (which is consistent with the report by Douglas Partners Pty Ltd and Sydney Environmental and Soil Laboratory 2001). However, in the weathered shale profile, NRH3, the trend is reversed (pH_{CaCl_2} decreasing from 3.9 to 3.7).

The weathered shale has low pH values and this could indicate the occurrence of sulfide in the weathered shale, which could affect housing infrastructure. In addition, the high exchangeable sodium percentages (ESP 11 and 19%; Appendix 2) indicate the potential for the shale to readily disperse and transport sulfur to lower in the landscape.

Sulfidic materials are present in the vicinity of the creek (possibly originating from the shale). Such material could produce corrosive sulfuric acid if exposed to the atmosphere and hence engineering techniques are required to prevent problems with foundations and pipe installations in close proximity to the creek. The low concentrations of the sulfides in the creek do not warrant strict handling procedures during construction (as would be required for acid sulfate soils). More analyses (pyrite content and geochemical analyses) need to be done to confirm the occurrence of pyrite in these materials.

Discussion

General

The purpose of this study included an assessment of the potential for a future problem with urban salinity once housing development has been completed. Figure 12 shows the location of the current extent of salinity with proposed infrastructure. The most likely 'salinity-type' problems that would be encountered in the future are those due to:

- the existing salt stored in the landscape;
- the type of salts present;
- the probability of a rising groundwater table; and
- the type of water related infrastructure proposed:
  - sewer carrier,
  - water mains,
  - trunk drainage;
- the use of recycled water in the catchment.

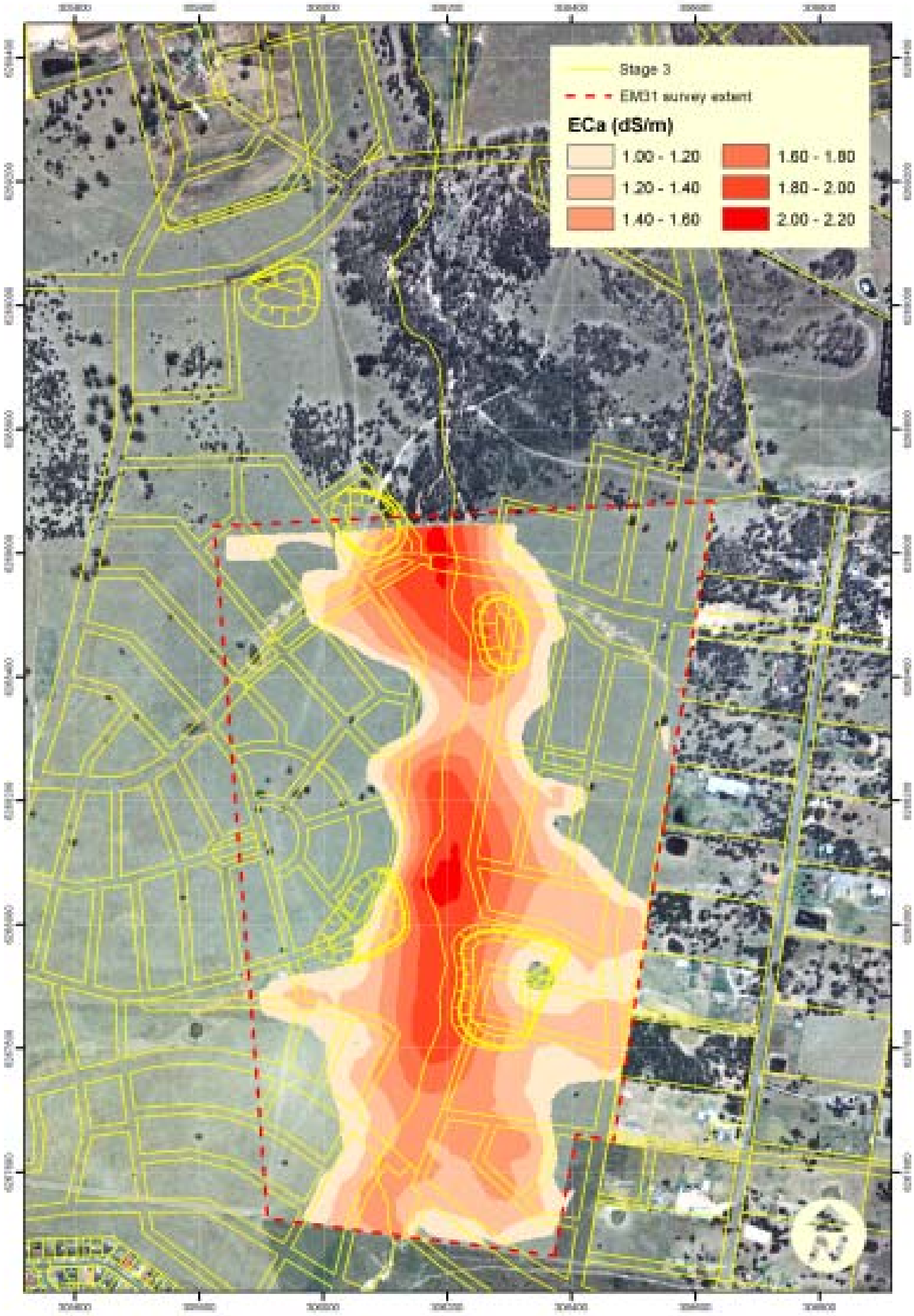

Figure 12. Map of salinity in relation to proposed urban infrastructure.

Salt in the soil

The shale is acidic and contains weatherable minerals that can release salt especially with drains and infrastructures being proposed within the shale. What we don't know is how much and how rapidly this is released. It would be advisable to verify this observation by doing further analysis on these samples and those already collected by others although it is noted that the Douglas Partners Pty Ltd and Sydney Environmental and Soil Laboratory (2001) makes a similar observation. Another possible source of parent material samples would be from the cores taken during piezometer installation, if in fact they were drilled into the bedrock.

Soluble salts (due to accumulation of salts from rainfall, weathering of minerals, evapotranspiration, etc) are largely stored in the heavy textured clay materials encountered below depths of about 50 cm (Figure 8). Their concentration generally increases with depth (within that material) and with lower positions in the landscape. Even the upper 50 cm of soil in the immediate vicinity of Second Pond Creek has moderate salt concentrations. In relative terms, the greatest soil salinity hazard is located below the existing contour banks (Figure 1) and in the south and south-eastern sectors and is due to saline groundwaters coming into contact with the soils. This is based on extrapolation from EM31 and recurring toposequence trend (Figure 8) from visual soil-landscape observations and the soil pit data.

Sydney Water has advised that that the maximum dissolved salts in recycled water brought into the area will be about 500 mg/L. Approximately 4200 houses in the area will be using about 100 KL/lot per year. The amount of salt this will add to the soil over time has to be based on many assumptions, as the required data needed to do the calculation are not available. These assumptions include all vertical drainage (none lateral), all excess water above deep drainage is evapotranspired and the leaching fraction is low. After 25 years, between 2 and 15 T/ha of additional salt will accumulate in the soils, which at the time of the investigation had salt stores of 15 to 140 T/ha (based on the amount of salt present to 2m depth in the soil pits). If there is lateral drainage as well (which there will be in these soils) then the rate of salt accumulation would be lower than calculated.

Type of salts

Very acid, very alkaline, or sodic (high exchangeable sodium) soils all present problems for buildings and infrastructure. In particular, low pH of the underlying shales, which come close to the surface (0.8 m) in the upper part of the catchment, must be considered if infrastructure is placed through them. Values of pH<4.0 (in 1:5 $CaCl_2$ extract) in Pit NRH3 suggest that sulfide materials may be present. Such material could produce corrosive sulfuric acid if exposed to the atmosphere and hence has implications for foundation and pipe installations.

A high proportion of exchangeable sodium, resulting in sodic soils, is present in all subsoils in the area. Highly sodic soils are evidenced by the columnar structure of subsoils exposed in the creek and considerable areas of ‘scalded’ soils adjacent to the tributaries. Sodic soils are generally very dispersive in nature when impacted by low salinity water and they have pronounced shrink-swell characteristics. Erosion of the creek (Soil profile 7, Appendix 1) and tributaries (Figure 13) has been exacerbated in the past by stocking practices and once gullies are initiated they can be difficult to rehabilitate. Because of sodicity, underground installation (such as the sewer, pipelines and cables) will be at risk of tunnel-type erosion (e.g. piping) and possibly of mechanical damage due to shrink-swell processes. Chemical ameliorants (gypsum) must be used with engineering solutions to overcome these problems.

Figure 13. Erosion of Second Pond Creek tributary.

Rising groundwater

Housing estates, although containing a high proportion of sealed surface area, attract high inputs of irrigation water for lawns and gardens. Over a period of time (up to a few decades) this almost invariably results in groundwater mounds developing beneath the estate and places pressure on the main drainage line. In the site one could expect salt, already stored in the profile, to be leached towards Second Pond Creek and increased groundwater discharge into (and adjacent to) the creek would also be expected. The proposed residential developments that are located in the area identified as being saline should be carefully managed, taking into account the soil conditions and their cause as described in Patterson and Britton and Partners Ltd report (provided 17th June 2002, after receipt of CSIRO's draft report which included quantitative salinity data).

At the present time a series of piezometers has been installed along the creek. These will be useful for detecting increased groundwater pressures over the development phase but they will provide little information on the general groundwater surface and its dynamics. Consideration should be given, in the planning phase, for installing a network of piezometers to provide that information in the future. Communities and service providers are more likely to react to real-time trend data than to computer-generated models.

Conclusions

- A map showing the areal extent of salinity (to about 3 m depth) has been produced for a key part of the site. A colour cross-sectional diagram has also been constructed to show the various saline and sodic soil horizons and water flow pathways. Extrapolation from the soil pit data and the EM survey suggest that highly saline soils (i.e. EC_{se} > 16 dS/m) are confined to either side of Second Ponds Creek and up into the tributaries as depicted in the salinity map (Figure 12) and cross-section (Figure 8). Urban infrastructure in these areas should take into consideration the highly saline soil conditions (i.e. the development of housing in these areas must be carefully managed, taking into account the cause of the soil conditions). There is a strong relationship between decreasing elevation and increasing salinity.
- Topsoils are generally only saline in the immediate vicinity of Second Ponds Creek. Subsoils in the creek and immediately adjacent (approx. 20 m) are highly saline (i.e. EC_{se} > 16 dS/m) and due to saline groundwater (see next point). All subsoils within 150 m of the creek are sodic (exchangeable sodium percentage, ESP > 15%) and moderately saline (i.e. EC_{se} 4 to 8 dS/m) due to leaching of salts in rainfall and natural weathering processes and salt accumulation around the rootzone of past vegetation.
- The source of salinity in and near the creek is saline groundwater discharge (a series of nested piezometers needs to be installed and water levels and EC measured). The volume and quantity of groundwater discharge into the creeklines will vary depending on seasonal groundwater fluctuations (seasonal groundwater recharge). When groundwater levels are high the areal extent of the salinity problem will be greatest. Salts are being concentrated due to evaporation of surface water and groundwaters.

- Surface waterlogging (much of this water is fresh) is more extensive (approximately 60% of the area) than salinity. The waterlogging is caused by a sodic clay B horizon, which has low permeability. It is critical that this water is managed (through drainage) so as not to damage infrastructure (e.g. salt damp).
- Sulfidic materials were observed in the vicinity of the creek. The extent of their presence is not known, but it should be kept in mind that such material could produce corrosive sulfuric acid if exposed to the atmosphere and hence has implications for foundations and pipe installations in close proximity to the creek.
- Sodic soils (easily dispersive with high exchangeable sodium) are the dominant soils in the area (approximately 80%). The highest values of exchangeable sodium were present in subsoils in the creekline. These soils are highly dispersive when in contact with low salinity water (e.g. rainwater) and some of these soils also have pronounced shrink-swell characteristics. In general, any underground installations (e.g. sewer pipes and cables) in the vicinity of sodic soils with shrink-swell characteristics would be at risk of tunnel-type erosion (e.g piping) and possibly of mechanical damage due to shrink-swell processes. The proposed engineering solutions to overcome these problems (e.g. gravel infill) or chemical ameliorants (gypsum) will overcome these problems. Based on the mineralogy of the clays near Second Ponds Creek where sewerage installations are proposed (Appendix 2, Table 5), the sewerage pipe support design provided by Sydney Water Corporation will be suffice. We assume the "select fill" in accordance with WSA-02, Part 4 Section 13 has non-swell characteristics, is non sodic and therefore does not need the addition of gypsum.
- Some very acid layers were present in the subsoils. The weathered shale layer could present problems for buildings and infrastructure.
- The least risk option is to install dry dams not wet dams to minimize the convective transport of salt. Engineering solutions proposed may minimise the risk of damage to infrastructure from salinity if inline, wet dams are installed. However, there is a higher risk of saline waters causing problems with infrastructure when comparing inline, wet dams with dry dams. We do

acknowledge that there may be some “wetland” design that doesn’t exacerbate the salinity problem (which also allows clean up of sediment and nutrients). We recommend you seek specialised advice on the specific design and modelling of an urban wetland for this area.

- Housing estates, although containing a high proportion of sealed surface area, attract high inputs of irrigation water for lawns and gardens. Over a period of time (up to a few decades) this almost invariably results in groundwater mounds developing beneath the estate and places pressure on the creekline. At the site one could expect salt, already stored in the profile, to be leached towards Second Pond Creek and increased groundwater discharge into (and adjacent to) the creek would also be expected. Therefore, consideration should be given, in the planning phase, for installing a network of piezometers to provide that information in the future.
- The water and salinity management approach suggested by Patterson and Britton does take into account CSIRO’s concerns with the potential for the residential development to be affected by saline soils near the creek. They have proposed engineering solutions to resolve these issues including a minimum 300 mm embankment (for the road and proposed houses adjacent to the creek) above the active water level. However, our concerns are as follows: 1) the 300 mm is dependant on the nature of the material used to construct the embankment i.e. minimise capillary rise from saline groundwater, 2) the chemistry of the material embankment must be tested (i.e. minimise use of adjacent and underlying sodic material because it is unstable and requires amelioration with gypsum.

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Appendix 1: Summary descriptions and photographs of soil profiles from soil pits

Soil Pit NRH1

Soil classification (Isbell 1996):
Mottled-Mesonatric, Eutrophic **Red Sodosol**; thick, slightly-gravelly, loamy, clayey, deep. Confidence level 1.

Sample No	Depth (cm): horizon; description
NRH 1.1	0-5: Ap11; Uniform coloured dark grey sandy loam.
NRH 1.2	5-10: Ap12; Uniform coloured dark grey sandy loam.
NRH 1.3	10-40: A2 (E); Mottled light grey sand.
NRH 1.4	40-60: Bt1; Red matrix with grey mottles, medium to heavy clay with 10% quartz and ironstone gravel.
NRH 1.5	60-90: Bt2; As above with no gravel.
NRH 1.6	90-110: Bt3; As above with no gravel.
NRH 1.7	170-270: Bt4/C1; Red matrix with grey mottles, medium clay and strongly weathered shale.
NRH 1.8	270+: C2; Weakly weathered shale.

Soil Pit NRH2

<table>
<tr>
<td>
Soil classification (Isbell 1996):
Mottled-Mesonatric, Eutrophic; Brown Sodosol; thick, slightly-gravelly, loamy, clayey, deep. Confidence level 1.

Sample No — Depth (cm): horizon; description

NRH 2.1 — 0-5: Ap11; Uniform coloured dark grey sandy loam with reddish-brown iron stained roots.
NRH 2.2 — 5-10: Ap12; Uniform coloured dark grey sandy loam with some reddish-brown iron stained roots.
NRH 2.3 — 10-25: A2 (E); Light grey matrix with 10% yellow-brown mottles; sandy loam.
NRH 2.4 — 25-40: Bt1; Yellow-brown matrix with grey 10% mottles, medium clay.
NRH 2.5 — 40-80: Bt2; Yellow-brown matrix with 20% grey and red mottles, and black (manganese) segregations, medium clay.
NRH 2.6 — 80-170: Bt2; Yellow-grey matrix with 20% grey and red mottles, and black (manganese) segregations, medium clay.
NRH 2.7 — 170-250: Bt3; Reddish-brown matrix with black (manganese) and ferricrete segregations, medium clay.
NRH 2.8 — 250+: As above.
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Soil Pit NRH3

Soil classification (Isbell 1996):
Eutrophic, Sodic, **Red Kurosol**; Medium, slightly- gravelly, loamy, clayey, moderate. Confidence level 1.

Sample No	Depth (cm): horizon; description
NRH 3.1	0-5: Ap11; Uniform coloured dark brown sandy loam.
NRH 3.2	5-10: Ap12; Uniform coloured brown sandy loam.
NRH 3.4	10-20: A2 (E); Uniform coloured brown sandy loam.
NRH 3.5	20-30: Bt1; Uniform coloured brown light clay.
NRH 3.6	30-50: Bt2; Uniform red medium to heavy clay.
NRH 3.7	50-70: Bt3; Red matrix with yellow and grey mottles; medium clay.
NRH 3.8	70-100: C1; Grey brown weathered shale.
NRH 3.9	100-200: R; Grey brown hard shale.

Soil Pit NRH4

Soil classification (Isbell 1996):
Mottled-Mesonatric, Eutrophic, **Yellow Sodosol**; Medium, slightly-gravelly, loamy, clayey, deep. Confidence level 1.

Sample No	Depth (cm): horizon; description
NRH 4.1	0-5: Ap11; Uniform coloured dark grey sandy loam with reddish-brown iron stained roots.
NRH 4.2	5-15: A2 (E); Uniform coloured dark grey sandy loam with reddish-brown iron stained roots.
NRH 4.3	16-60: Bt1; Yellow-brown matrix with grey 20% mottles, medium clay.
NRH 4.4	60-140: Bt2; As above but with grey 30% mottles, medium clay.
NRH 4.5	140-150: Bt3; Yellow-brown matrix with bright orange and grey mottles with manganese segregations and some saprolite.
NRH 4.6	150-200: Bt3g; As above but with increasing amounts of weathered shale.
NRH 4.7	200-300: Bt4g; As above
NRH 4.8	300+ Bt5/C1; As above but with increasing amounts of weathered shale and hard shale.

Soil Pit NRH5

Soil classification (Isbell 1996):
Mottled-Mesonatric, Eutrophic, **Brown Sodosol**; thick, slightly-gravelly, loamy, clayey, deep. Confidence level 1.

Sample No	Depth (cm): horizon; description
NRH 5.1	0-5: Ap11; Uniform coloured dark grey sandy loam with reddish-brown iron stained roots.
NRH 5.2	5-15: Ap12; Uniform coloured dark grey sandy loam with some reddish-brown iron stained roots.
NRH 5.3	15-40: A2 (E); Light grey matrix with 20% yellow-brown mottles; sandy loam.
NRH 5.4	40-95: Bt2; Yellow-brown matrix with 20% grey and red mottles, and black (manganese) segregations, heavy clay.
NRH 5.5	95-150: Bt3; Reddish-brown matrix with grey mottles and black (manganese) and ferricrete segregations, medium clay.
NRH 5.6	150-200: Bt4g; Grey matrix with red and black (manganese-rich) mottles.
NRH 5.7	200-280: Bt5/C1; As above but with increasing amount of saprolite.

Soil Pit NRH6

Soil classification (Isbell 1996):
Mottled-Mesonatric, Ferric, **Brown Sodosol**; thick, slightly-gravelly, loamy, clayey, deep. Confidence level 1.

Sample No	Depth (cm): horizon; description
NRH 6.1	0-5: Ap11; Uniform coloured dark grey sandy loam with reddish-brown iron stained roots.
NRH 6.2	5-10: Ap12; Uniform coloured dark grey sandy loam with reddish-brown iron stained roots.
NRH 6.3	10-25: A2 (E); Uniform coloured dark grey sandy loam with black organic patches.
NRH 6.4	25-40: Bt1; Yellow-brown matrix with grey 20% mottles, light clay.
NRH 6.5	40-80: Bt2; Yellow-brown matrix with grey 20% mottles, medium clay.
NRH 6.6	80-170: Bt3 Yellow-brown matrix with grey 30% mottles, medium clay.
NRH 6.7	170-270: B4; Ferricrete - red matrix with grey mottles with high amounts of medium clay fillings and organic matter.
NRH 6.8	300+: B5; As above

Soil Pit NRH7

Soil classification (Isbell 1996): Mottled-Mesonatric, Ferric, **Yellow Sodosol**; Medium, gravelly, loamy, clayey, moderate. Confidence level 1.	

Sample No	Depth (cm): horizon; description
NRH 7.1	0-8: Ap11; Uniform coloured dark grey sandy loam with reddish-brown iron stained roots.
NRH 7.2	8-20: A2 (E); Uniform coloured dark grey sandy loam with reddish-brown iron stained roots.
NRH 7.3	20-30: Btn1; Yellow-brown matrix with grey 20% mottles, medium clay (columnar structures).
NRH 7.4	30-50: Btn2; As above but less columnar structures.
NRH 7.5	50-60: Bt3; Yellow-brown matrix with grey mottles and black manganese segregations and 10% saprolite.
NRH 7.6	60-80 As above - but with increasing amounts of ferricrete with red matrix and grey mottles and manganese-rich segregations.

Appendix 2: Soil chemistry and physics

Table 1. Electrical conductivity, salinity hazard, potential impacts of salinity on plants and pH of soil samples

Sample	Depth cm	$EC_{1:5}$ dS/m	EC_{se}[1] dS/m	Salinity hazard	Effect on plants	$pH_{1:5}$ (soil:water)	pH (0.01M CaCl2)
NRH 1.1	0-5	0.11	1.12	Non saline	Negligible	5.9	4.9
NRH 1.2	5-10	0.07	0.71	Non saline	Negligible	6.2	5.0
NRH 1.3	10-40	0.03	0.37	Non saline	Negligible	6.9	5.5
NRH 1.4	40-60	0.32	1.82	Non saline	Negligible	5.6	4.5
NRH 1.5	60-90	0.49	3.23	Slightly saline	Sensitive plants affected	5.2	4.2
NRH 1.6	90-110	0.83	4.73	Moderately saline	Many plants affected	4.7	4.0
NRH 1.7	170-270	0.64	4.22	Moderately saline	Many plants affected	6.2	5.3
NRH 1.8	270+	0.98	6.47	Moderately saline	Many plants affected	8.3	7.5
NRH 2.1	0-5	0.07	0.71	Non saline	Negligible	5.8	4.8
NRH 2.2	5-10	0.05	0.51	Non saline	Negligible	6.3	4.9
NRH 2.3	10-25	0.05	0.51	Non saline	Negligible	7.0	5.5
NRH 2.4	25-40	0.13	0.86	Non saline	Negligible	7.5	6.2
NRH 2.5	40-80	0.33	2.54	Slightly saline	Sensitive plants affected	6.9	6.0
NRH 2.6	80-170	0.76	5.85	Moderately saline	Many plants affected	5.9	5.4
NRH 2.7	170-250	0.74	5.70	Moderately saline	Many plants affected	6.5	5.9
NRH 2.8	250+	0.93	6.14	Moderately saline	Many plants affected	6.4	5.9
NRH 3.1	0-5	0.06	0.53	Non saline	Negligible	5.4	4.6
NRH 3.2	5-10	0.03	0.26	Non saline	Negligible	5.8	4.7
NRH 3.4	10-20	0.03	0.26	Non saline	Negligible	6.1	4.8
NRH 3.5	20-30	0.03	0.23	Non saline	Negligible	5.7	4.3
NRH 3.6	30-50	0.05	0.29	Non saline	Negligible	5.3	3.9
NRH 3.7	50-70	0.05	0.29	Non saline	Negligible	5.5	3.9
NRH 3.8	70-100	0.04	0.26	Non saline	Negligible	5.5	3.7
NRH 3.9	100-200	0.09	0.59	Non saline	Negligible	5.4	3.7
NRH 4.1	0-5	0.09	0.92	Non saline	Negligible	6.0	5.0
NRH 4.2	5-15	0.06	0.61	Non saline	Negligible	6.0	4.9
NRH 4.3	16-60	0.49	2.79	Slightly saline	Sensitive plants affected	6.7	5.9
NRH 4.4	60-140	1.05	5.99	Moderately saline	Many plants affected	7.6	6.9
NRH 4.5	140-150	1.06	7.00	Moderately saline	Many plants affected	8.3	7.5
NRH 4.6	150-200	0.92	6.07	Moderately saline	Many plants affected	8.5	7.7
NRH 4.7	200-300	0.82	5.41	Moderately saline	Many plants affected	8.7	7.9
NRH 5.1	0-5	0.07	0.71	Non saline	Negligible	6.3	5.3
NRH 5.2	5-15	0.05	0.51	Non saline	Negligible	6.6	5.4
NRH 5.3	15-40	0.03	0.26	Non saline	Negligible	6.8	5.5
NRH 5.4	40-95	0.23	1.13	Non saline	Negligible	5.1	4.1
NRH 5.5	95-150	0.33	1.88	Non saline	Negligible	5.3	4.2
NRH 5.6	150-200	0.31	2.05	Slightly saline	Sensitive plants affected	6.0	4.7
NRH 5.7	200-280	0.55	3.63	Slightly saline	Sensitive plants affected	6.8	5.7
NRH 6.1	0-5	0.07	0.71	Non saline	Negligible	6.0	4.9
NRH 6.2	5-10	0.06	0.61	Non saline	Negligible	6.2	5.0
NRH 6.3	10-25	0.07	0.87	Non saline	Negligible	6.8	5.5
NRH 6.4	25-40	0.21	1.39	Non saline	Negligible	7.6	6.3
NRH 6.5	40-80	0.55	3.14	Slightly saline	Sensitive plants affected	8.0	7.0
NRH 6.6	80-170	0.91	6.01	Moderately saline	Many plants affected	7.7	7.0
NRH 6.7	170-270	1.01	6.67	Moderately saline	Many plants affected	7.9	7.2
NRH 6.8	300+	1.20	7.92	Moderately saline	Many plants affected	8.0	7.3
NRH 7.1	0-8	0.04	0.41	Non saline	Negligible	6.3	4.9
NRH 7.2	8-20	0.13	1.33	Non saline	Negligible	7.7	6.3
NRH 7.3	20-30	0.36	2.77	Slightly saline	Sensitive plants affected	8.7	7.4
NRH 7.4	30-50	0.82	6.31	Moderately saline	Many plants affected	8.9	7.9
NRH 7.5	50-60	2.61	22.97	Highly saline	Salt tolerant plants affected	8.5	8.1
NRH 7.6	60-80	1.23	9.47	Moderately saline	Many plants affected	8.5	7.8

[1] Based on clay content (Cass *et al*. 1996) as measured by mid infrared (Janik *et al*. 1998)

Table 2. Chloride content, exchangeable cations, cation exchange capacity (CEC) and exchangeable sodium percentage (ESP)

Sample	Depth cm	Exchangeable cations cmol(+)/kg Ca	Mg	Na	K	Total	CEC (NH4)	ESP %
NRH 1.1	0-5	5.5	2.8	0.46	0.25	9.0	12.4	4
NRH 1.2	5-10	4.1	1.9	0.47	0.13	6.6	9.2	5
NRH 1.3	10-40	2.1	1.1	0.36	0.04	3.6	5.1	7
NRH 1.4	40-60	1.9	9.3	3.18	0.13	14.5	18.2	17
NRH 1.5	60-90	1.1	9.0	4.10	0.14	14.4	17.2	24
NRH 1.6	90-110	0.80	12.1	6.59	0.15	19.6	21.7	30
NRH 1.7	170-270	0.55	12.3	8.00	0.27	21.1	22.6	35
NRH 1.8	270+	0.57	9.2	5.98	0.25	16.0	15.8	38
NRH 2.1	0-5	3.5	2.0	0.41	0.23	6.2	10.2	4
NRH 2.2	5-10	4.0	1.3	0.50	0.14	6.0	9.1	5
NRH 2.3	10-25	3.8	2.8	0.78	0.08	7.5	9.5	8
NRH 2.4	25-40	2.0	8.8	2.53	0.10	13.4	15.7	16
NRH 2.5	40-80	0.62	8.2	3.49	0.07	12.4	12.6	28
NRH 2.6	80-170	0.12	6.5	4.17	0.21	11.0	11.3	37
NRH 2.7	170-250	0.09	7.6	5.12	0.22	13.0	13.7	37
NRH 2.8	250+	0.08	8.3	6.05	0.24	14.6	15.0	40
NRH 3.1	0-5	4.6	1.7	0.16	0.22	6.7	11.6	1
NRH 3.2	5-10	4.4	1.5	0.24	0.19	6.3	10.2	2
NRH 3.4	10-20	3.8	1.4	0.26	0.14	5.7	9.0	3
NRH 3.5	20-30	2.9	2.3	0.30	0.15	5.7	10.2	3
NRH 3.6	30-50	1.6	4.6	0.73	0.24	7.2	20.5	4
NRH 3.7	50-70	0.82	4.5	0.93	0.23	6.4	17.5	5
NRH 3.8	70-100	0.39	4.3	1.5	0.29	6.5	14.1	11
NRH 3.9	100-200	0.38	4.3	2.3	0.34	7.4	12.4	19
NRH 4.1	0-5	5.6	3.1	0.62	0.29	9.7	13.2	5
NRH 4.2	5-15	5.0	2.7	0.46	0.19	8.4	12.1	4
NRH 4.3	16-60	1.4	16.4	5.2	0.10	23.0	23.7	22
NRH 4.4	60-140	0.23	12.7	7.9	0.35	21.2	20.5	39
NRH 4.5	140-150	0.16	7.6	4.5	0.22	12.5	12.5	36
NRH 4.6	150-200	0.53	7.0	4.4	0.29	12.2	12.3	35
NRH 4.7	200-300	0.76	6.7	4.2	0.34	12.0	12.4	34
NRH 5.1	0-5	7.0	2.0	0.24	0.93	10.2	11.3	2
NRH 5.2	5-15	7.0	1.4	0.28	0.64	9.4	10.9	3
NRH 5.3	15-40	4.1	1.9	0.24	0.30	6.5	7.7	3
NRH 5.4	40-95	1.4	10.6	2.7	0.22	14.8	19.9	14
NRH 5.5	95-150	0.27	10.1	4.7	0.18	15.3	16.5	29
NRH 5.6	150-200	0.04	6.8	4.1	0.19	11.0	11.3	36
NRH 5.7	200-280	0.12	8.1	5.8	0.34	14.3	14.4	40
NRH 6.1	0-5	4.1	2.3	0.45	0.15	7.0	10.9	4
NRH 6.2	5-10	3.6	1.9	0.49	0.07	6.1	10.5	5
NRH 6.3	10-25	2.1	2.3	0.75	0.05	5.2	8.0	9
NRH 6.4	25-40	0.69	10.3	3.9	0.09	14.9	20.3	19
NRH 6.5	40-80	0.25	13.8	7.2	0.11	21.4	22.5	32
NRH 6.6	80-170	0.05	9.3	7.4	0.10	16.9	17.4	43
NRH 6.7	170-270	0.11	7.8	7.3	0.14	15.3	16.8	43
NRH 6.8	300+	0.22	10.2	8.6	0.21	19.3	20.3	43
NRH 7.1	0-8	1.9	3.3	0.43	0.25	5.9	9.2	5
NRH 7.2	8-20	1.7	4.6	1.5	0.07	7.9	11.3	14
NRH 7.3	20-30	0.88	7.1	4.5	0.10	12.6	13.8	33
NRH 7.4	30-50	0.54	6.9	7.2	0.12	14.8	14.9	49
NRH 7.5	50-60	0.68	3.7	4.5	0.14	9.0	8.9	51
NRH 7.6	60-80	0.88	5.3	6.1	0.19	12.4	12.9	47

Table 3. Chloride, sulfur, calcium, potassium, magnesium, sodium soluble salts and sodium adsorption ratio (SAR) from a 1:5 extract

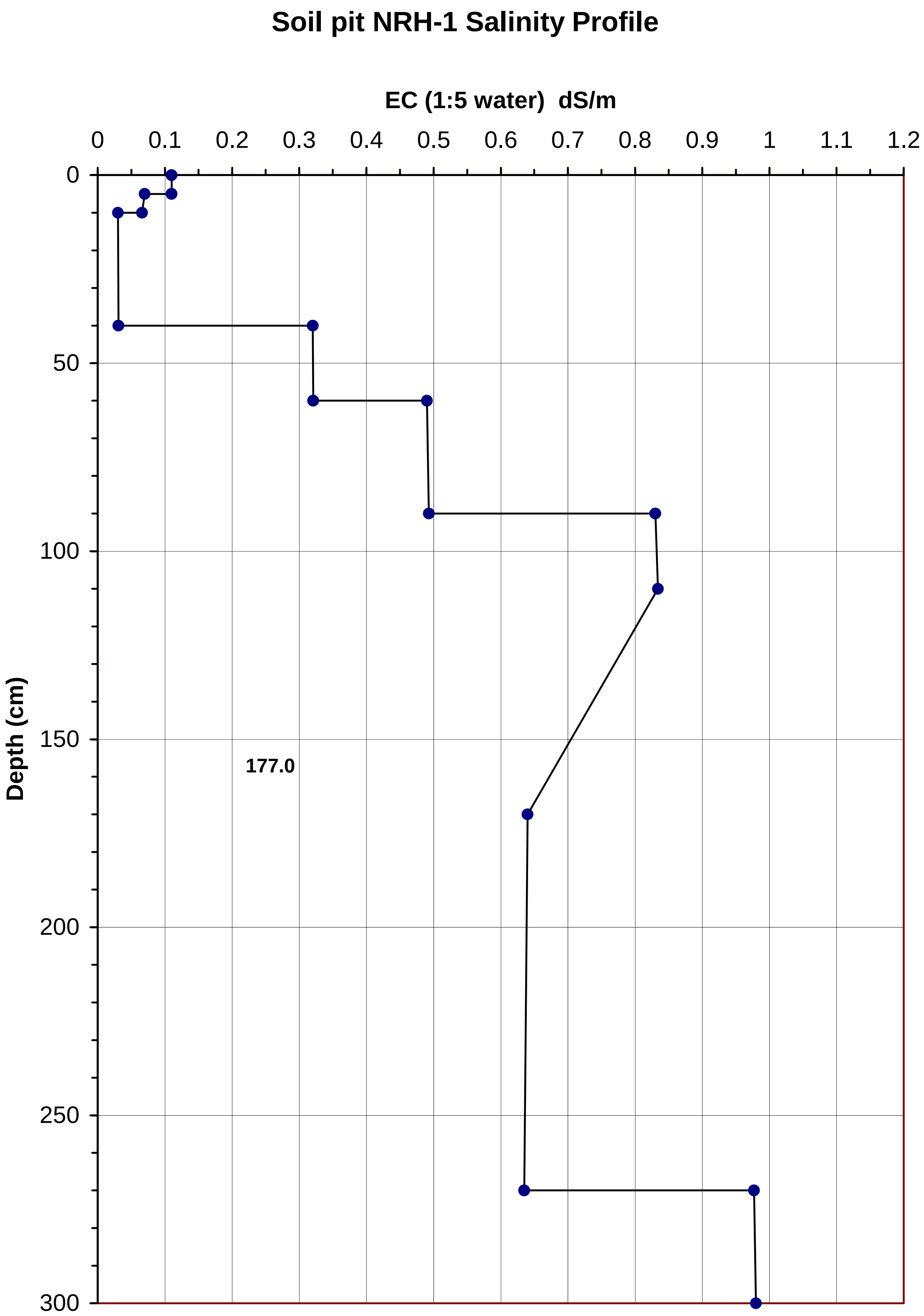
		Soluble salts in 1:5 extract						
Sample	**Depth cm**	**Cl mg/kg**	**S mg/L**	**Ca mg/L**	**K mg/L**	**Mg mg/L**	**Na mg/L**	**SAR**
NRH 1.1	0-5							
NRH 1.2	5-10							
NRH 1.3	10-40							
NRH 1.4	40-60							
NRH 1.5	60-90							
NRH 1.6	90-110	1020	14.1	<0.1	0.8	1.5	167	29.3
NRH 1.7	170-270							
NRH 1.8	270+	1220	10.3	0.2	1.9	3.1	192	22.8
NRH 2.1	0-5							
NRH 2.2	5-10							
NRH 2.3	10-25							
NRH 2.4	25-40							
NRH 2.5	40-80							
NRH 2.6	80-170	900	17.1	<0.1	0.5	1.3	150	28.3
NRH 2.7	170-250	860	14.8	<0.1	0.9	2.7	147	19.3
NRH 2.8	250+	1180	17.4	<0.1	1.2	1.6	191	32.6
NRH 3.1	0-5							
NRH 3.2	5-10							
NRH 3.4	10-20							
NRH 3.5	20-30							
NRH 3.6	30-50							
NRH 3.7	50-70							
NRH 3.8	70-100							
NRH 3.9	100-200							
NRH 4.1	0-5							
NRH 4.2	5-15							
NRH 4.3	16-60							
NRH 4.4	60-140	1190	28.7	<0.1	0.4	3.1	218	26.5
NRH 4.5	140-150	1360	21.3	<0.1	1.4	2.9	219	27.4
NRH 4.6	150-200	1180	12.0	0.1	1.9	1.8	184	29.2
NRH 4.7	200-300	1070	11.7	0.3	2.1	1.5	169	28.4
NRH 5.1	0-5							
NRH 5.2	5-15							
NRH 5.3	15-40							
NRH 5.4	40-95							
NRH 5.5	95-150							
NRH 5.6	150-200							
NRH 5.7	200-280	430	25.1	<0.1	1.8	3.2	106	12.7
NRH 6.1	0-5							
NRH 6.2	5-10							
NRH 6.3	10-25							
NRH 6.4	25-40							
NRH 6.5	40-80							
NRH 6.6	80-170	1040	17.7	<0.1	0.2	3.5	182	20.8
NRH 6.7	170-270	1270	19.0	<0.1	0.4	1.9	206	32.2
NRH 6.8	300+	1470	20.1	<0.1	0.8	2.0	241	36.4
NRH 7.1	0-8							
NRH 7.2	8-20							
NRH 7.3	20-30							
NRH 7.4	30-50	940	13.7	0.5	0.4	6.6	171	13.9
NRH 7.5	50-60	4050	24.6	2.0	1.5	13.4	546	30.7
NRH 7.6	60-80	1700	18.1	0.3	1.0	1.9	259	39.0

Table 4. Saturation percentage, pH (of the saturated paste), EC_{se} (of the saturation extract), soluble salts of calcium, potassium, magnesium, sodium, sulfur, chloride and sodium adsorption ratio (SAR) of the saturation extract

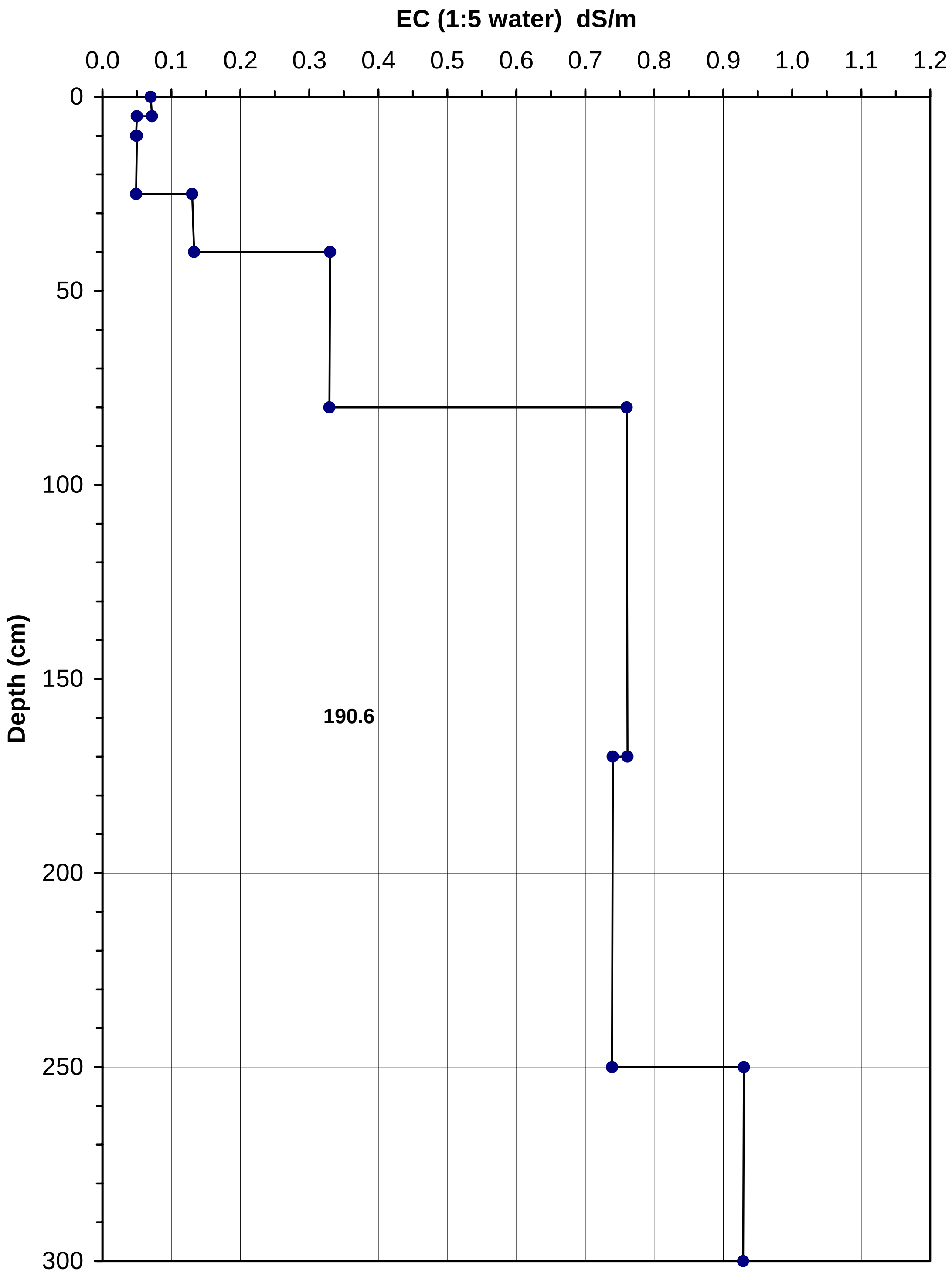
Sample	Depth cm	Satn %	pH Satn paste	EC_{se} dS/m	Soluble salts in the saturation extract: Ca mg/L	K mg/L	Mg mg/L	Na mg/L	S mg/L	Cl mg/L	SAR
NRH 1.1	0-5										
NRH 1.2	5-10										
NRH 1.3	10-40										
NRH 1.4	40-60										
NRH 1.5	60-90										
NRH 1.6	90-110	99	4.3	3.8	3.6	3.5	31	785	49	1170	29.1
NRH 1.7	170-270										
NRH 1.8	270+	58	6.8	7.8	8.4	13.6	92	1566	93	2390	34.1
NRH 2.1	0-5										
NRH 2.2	5-10										
NRH 2.3	10-25										
NRH 2.4	25-40										
NRH 2.5	40-80										
NRH 2.6	80-170	62	5.5	5.3	2.7	3.9	62	1125	105	1630	30.3
NRH 2.7	170-250	66	5.9	5.0	0.9	5.6	47	1058	84	1540	32.8
NRH 2.8	250+	64	5.9	6.5	1.8	8.3	73	1417	97	2120	35.4
NRH 3.1	0-5										
NRH 3.2	5-10										
NRH 3.4	10-20										
NRH 3.5	20-30										
NRH 3.6	30-50										
NRH 3.7	50-70										
NRH 3.8	70-100										
NRH 3.9	100-200										
NRH 4.1	0-5										
NRH 4.2	5-15										
NRH 4.3	16-60										
NRH 4.4	60-140	99	6.8	4.8	1.4	2.1	54	985	115	1400	28.6
NRH 4.5	140-150	80	7.4	6.1	3.1	7.9	82	1293	129	1910	30.2
NRH 4.6	150-200	73	7.6	5.7	7.6	11.4	62	1188	72	1820	31.2
NRH 4.7	200-300	78	7.8	4.8	6.8	11.0	44	984	59	1480	30.3
NRH 5.1	0-5										
NRH 5.2	5-15										
NRH 5.3	15-40										
NRH 5.4	40-95										
NRH 5.5	95-150										
NRH 5.6	150-200										
NRH 5.7	200-280	58	6.1	4.1	1.9	10.3	33	880	243	933	32.5
NRH 6.1	0-5										
NRH 6.2	5-10										
NRH 6.3	10-25										
NRH 6.4	25-40										
NRH 6.5	40-80										
NRH 6.6	80-170	83	7.0	4.9	1.1	1.0	43	1033	86	1490	33.7
NRH 6.7	170-270	70	7.2	6.4	3.1	2.3	59	1404	104	2050	38.5
NRH 6.8	300+	84	7.3	6.3	2.2	4.1	58	1385	102	2030	38.7
NRH 7.1	0-8										
NRH 7.2	8-20										
NRH 7.3	20-30										
NRH 7.4	30-50	75	8.0	4.8	3.4	1.3	26	1029	79	1430	42.0
NRH 7.5	50-60	42	7.7	26.6	90	12.8	495	5679	248	9720	51.9
NRH 7.6	60-80	59	7.7	10.0	18	7.2	95	2043	103	3160	42.4

Table 5. Clay, silt and sand content, bulk density, quartz, kaolinite, smectite and organic carbon content of soil samples

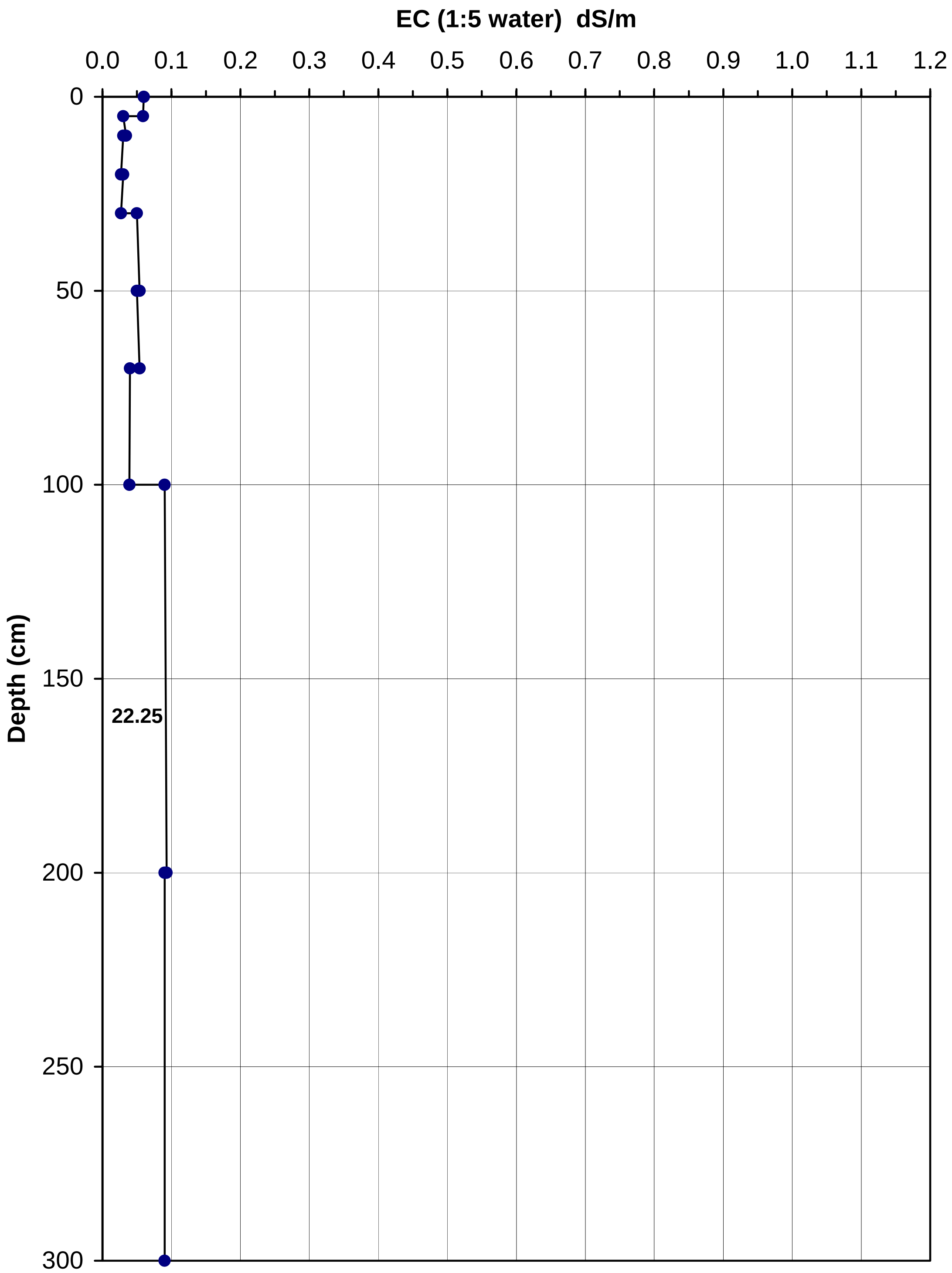
Sample	Depth cm	Clay %	Silt %	Sand %	Bulk Density g/cm3	Quartz %	Kaolinite %	Smectite %	Organic carbon %
NRH 1.1	0-5	14	17	69	1.16	75	7	18	3.46
NRH 1.2	5-10	12	15	73	1.32	70	12	18	2.26
NRH 1.3	10-40	9	12	79	1.60	72	12	16	0.93
NRH 1.4	40-60	51	28	21	1.46	44	29	27	0.59
NRH 1.5	60-90	46	21	33	1.59	50	24	26	0.47
NRH 1.6	90-110	53	21	26	1.57	41	27	32	0.37
NRH 1.7	170-270	49	42	9	1.39	40	23	37	0.26
NRH 1.8	270+	48	43	9	1.68	45	24	31	0.16
NRH 2.1	0-5	14	17	69	1.26	71	8	21	2.78
NRH 2.2	5-10	12	16	72	1.41	81	6	13	1.98
NRH 2.3	10-25	12	15	73	1.45	78	8	14	1.72
NRH 2.4	25-40	41	21	38	1.67	62	16	21	0.31
NRH 2.5	40-80	39	20	40	1.82	65	16	19	0.14
NRH 2.6	80-170	36	15	50	1.97	65	16	19	0.04
NRH 2.7	170-250	40	18	42	1.87	51	27	22	0.12
NRH 2.8	250+	42	31	27	1.86	38	37	25	0.08
NRH 3.1	0-5	23	27	50	1.17	67	12	22	3.09
NRH 3.2	5-10	24	28	48	1.35	69	12	19	2.14
NRH 3.4	10-20	22	25	52	1.42	68	14	17	1.46
NRH 3.5	20-30	40	31	30	1.42	57	20	23	1.05
NRH 3.6	30-50	58	36	6	1.33	36	31	33	1.05
NRH 3.7	50-70	53	43	4	1.43	41	30	29	0.79
NRH 3.8	70-100	44	54	2	1.33	37	28	35	0.37
NRH 3.9	100-200	45	55	0	1.53	42	27	31	0.37
NRH 4.1	0-5	18	16	65	1.04	64	11	24	3.55
NRH 4.2	5-15	18	17	65	1.21	68	12	20	2.67
NRH 4.3	16-60	55	35	11	1.45	43	26	31	0.49
NRH 4.4	60-140	53	33	14	1.70	45	26	29	0.21
NRH 4.5	140-150	46	49	5	1.75	43	27	30	0.13
NRH 4.6	150-200	43	53	4	1.75	45	28	28	0.16
NRH 4.7	200-300	42	53	5	1.84	39	31	30	0.07
NRH 5.1	0-5	19	16	65	1.16	71	9	20	3.26
NRH 5.2	5-15	17	19	65	1.23	69	13	18	2.56
NRH 5.3	15-40	21	19	60	1.48	63	20	17	1.06
NRH 5.4	40-95	63	28	9	1.31	31	33	36	0.71
NRH 5.5	95-150	52	32	16	1.47	43	27	30	0.44
NRH 5.6	150-200	45	52	3	1.62	47	24	29	0.23
NRH 5.7	200-280	46	53	1	1.61	43	26	31	0.26
NRH 6.1	0-5	12	9	78	1.28	74	8	18	2.85
NRH 6.2	5-10	11	9	80	1.31	74	9	17	2.70
NRH 6.3	10-25	10	9	81	1.46	79	9	13	1.78
NRH 6.4	25-40	41	19	40	1.54	56	20	24	0.92
NRH 6.5	40-80	52	22	26	1.67	47	23	29	0.30
NRH 6.6	80-170	45	18	37	1.90	56	19	25	0.10
NRH 6.7	170-270	45	27	28	1.77	38	35	27	0.18
NRH 6.8	300+	50	29	21	1.84	38	32	30	0.10
NRH 7.1	0-8	16	19	65	1.52	75	10	15	1.69
NRH 7.2	8-20	17	20	63	1.60	74	8	18	1.70
NRH 7.3	20-30	33	20	47	1.75	64	16	20	0.46
NRH 7.4	30-50	35	23	42	1.84	61	17	22	0.25
NRH 7.5	50-60	25	12	62	2.03	71	13	16	0.12
NRH 7.6	60-80	35	27	39	1.93	47	31	22	0.10


Soil pit NRH-1 Salinity Profile
EC (1:5 water) dS/m
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
0
50
100
150
200
250
300
Depth (cm)
177.0

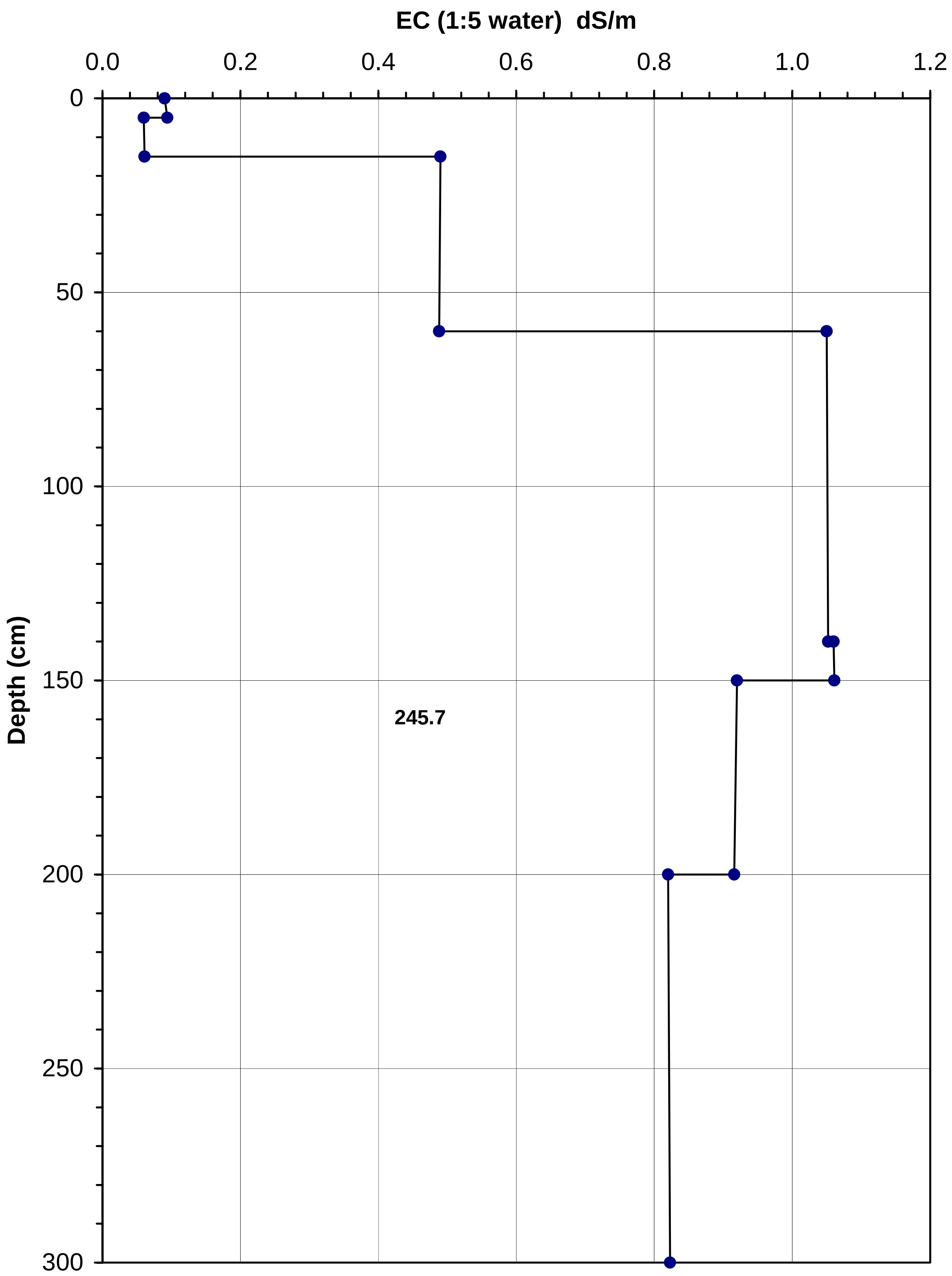
Soil pit NRH-2 Salinity Profile

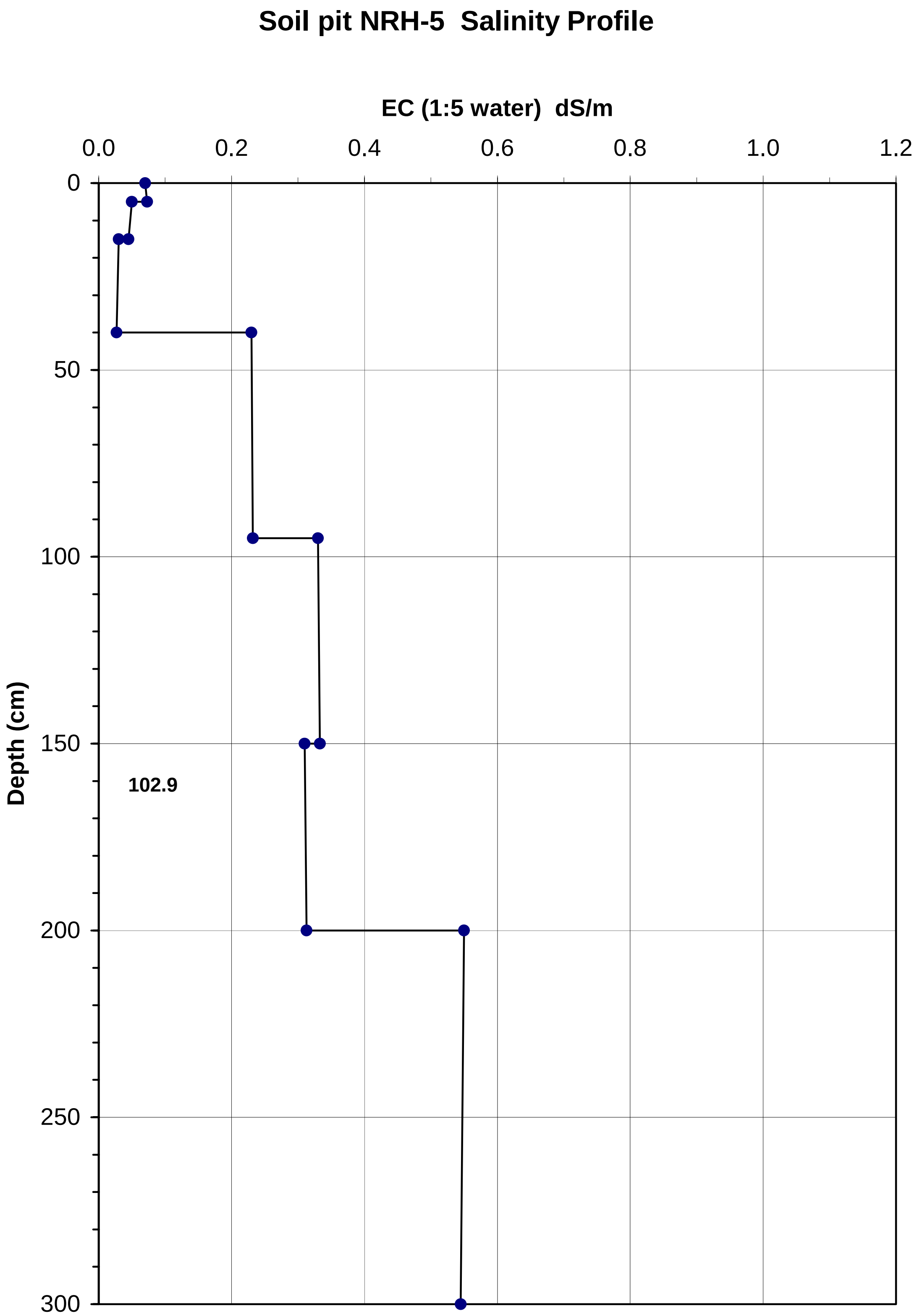


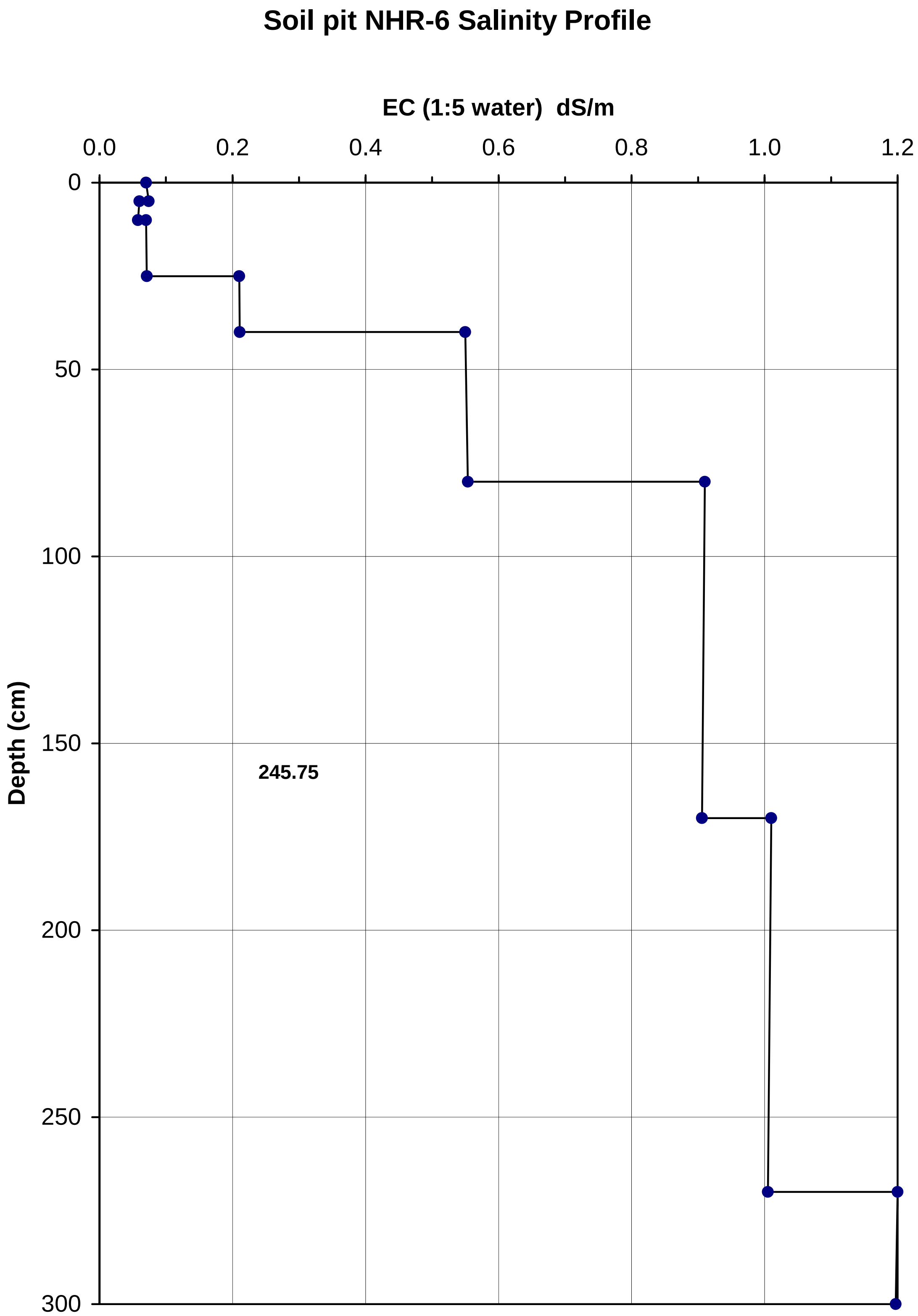
Soil pit NHR-3 Salinity Profile

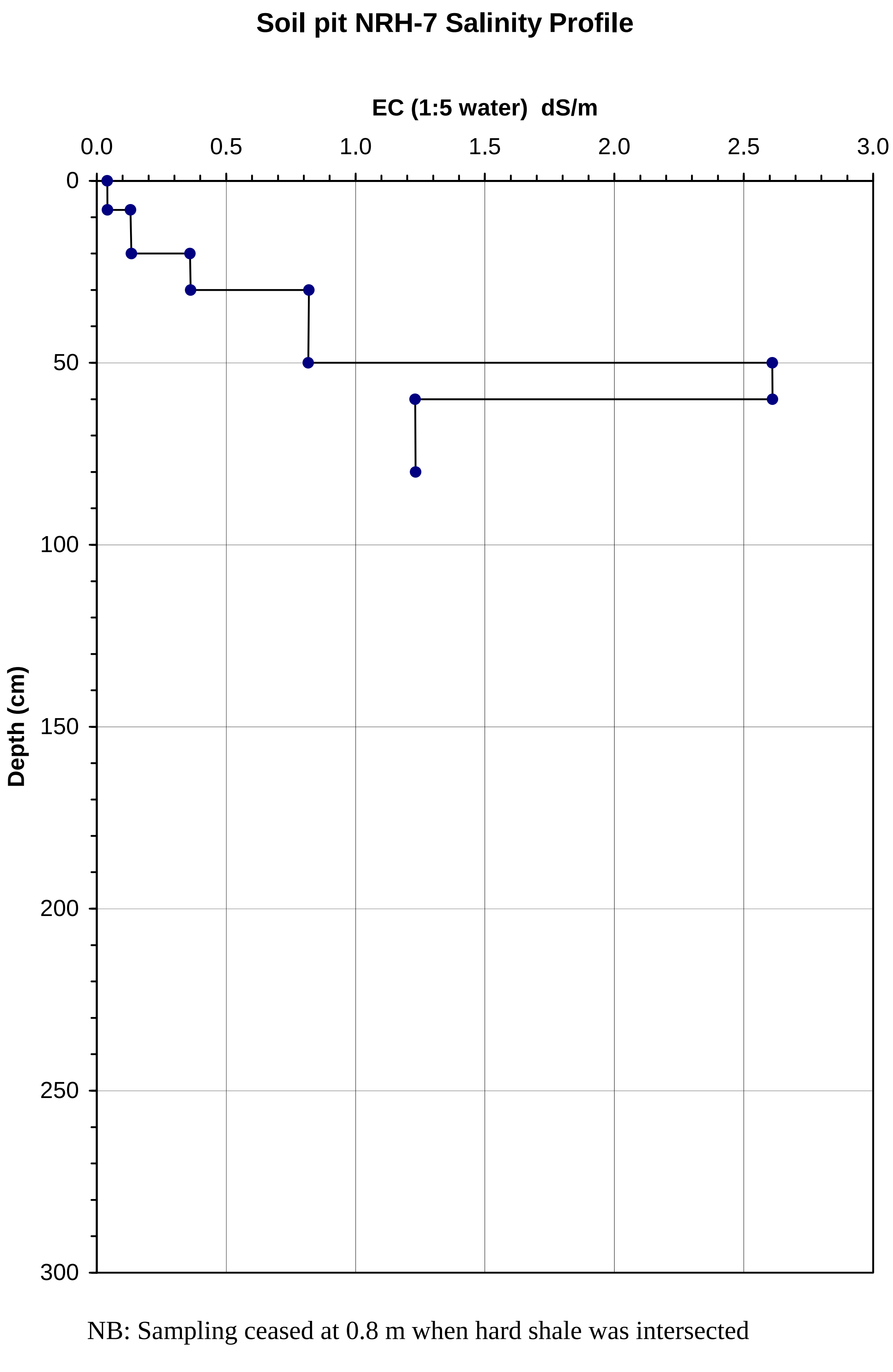


Soil pit NRH-4 Salinity Profile




Soil pit NRH-5 Salinity Profile
EC (1:5 water) dS/m
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Depth (cm)
0
50
100
150
200
250
300
102.9


Soil pit NHR-6 Salinity Profile
EC (1:5 water) dS/m
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Depth (cm)
0
50
100
150
200
250
300
245.75



NB: Sampling ceased at 0.8 m when hard shale was intersected

Appendix 3: Glossary

acid sulfate soils - saline soils or sediments containing pyrites, which once drained (as part of remedial land management measures, or as part of coastal development), become acidic releasing large amounts of acidity into the ecosystem with consequent adverse effects on plant growth, animal life, etc. These soils are widespread around coastal Australia (especially when associated with mangrove swamps) and occur to an unknown extent in inland areas.

potential acid sulfate soils (PASS) – in their pristine state, acid sulfate soils (also termed potential acid sulfate soils (PASS)), occur in saline wetland seeps or are buried beneath alluvium and:

(i) contain black sulfidic material (see below), are waterlogged and anaerobic;
(ii) contain pyrite (typically framboidal);
(iii) have high organic matter content;
(iv) have pH 6-8.

actual acid sulfate soils (ASS) - when PASS are disturbed:

(i) contain a sulfuric horizon (see below) because pyrite is oxidised to sulfuric acid (pH <3.5-4);
(ii) iron sulfate-rich minerals form, commonly as bright yellow or straw-coloured mottles containing jarosite, natrojarosite or sideronatrite.

classification, soil - the systematic arrangement of soils into groups or categories on the basis of their characteristics. Broad groupings are made on the basis of general characteristics and subdivisions on the basis of more detailed differences in specific properties. The USDA soil classification system of soil taxonomy was adapted for use in publications by the National Cooperative Soil Survey on 1 Jan. 1965. For complete definitions of taxa see: Soil Survey Staff (1999).

electrical conductivity (EC) - conductivity of electricity through water or an extract of soil. Commonly used to estimate the soluble salt content in solution.

EC_{se} - the electrical conductance of an extract from a soil saturated with distilled water, normally expressed in units of siemens (S) or decisiemens (dS) per meter at 25°C. A variety of other units, shown in Table 1 with conversion factors, have been used to describe salinity. Most scientists, planners and regulatory agencies endorse a strong plea for abandonment of these units in favour of standardisation on dS/m

Table 1: Factors for conversion of salinity units to dS/m

Salinity Unit	Multiply to get dS/m
µS/cm	0.001
mS/cm	1
mS/m	0.01
S/m	10
µmho/cm	0.001
mmho/cm	1
ppm	0.0016[(1)] to 0.0019[(2)]
mg/L	0.0016[(1)] to 0.0019[(2)]
grains/gal	0.023[(1)] to 0.027[(2)]

[(1)] Approximate conversion for natural surface and well waters.
[(2)]Approximate conversion for pure salt solutions of sodium and calcium chlorides

$EC_{1:5}$ - the electrical conductance of a 1:5 soil:water extract (i.e. soil is extracted with distilled water), normally expressed in units of siemens (S) or decisiemens (dS) per meter at 25°C. While the $EC_{1:5}$ method is quick and simple it does not take into account the effects of soil texture. It is therefore inappropriate to compare the $EC_{1:5}$ readings from two soil types with different textures. It is possible to approximately relate the conductivity of a 1:5 soil-water extract ($EC_{1:5}$) to that of the saturation extract (EC_{se}) and predict likely effects on plant growth (Table 6), and the ease of this method means that it is the most common way of assessing soil salinity.

Table 6: Criteria for assessing soil salinity hazard and yield reductions for plants of varying salt tolerance. EC_{se} is saturated paste electrical conductivity (after Richards, 1954) and $EC_{1:5}$ is the corresponding calculated electrical conductivity of a 1:5 soil:water extract for various soil textures.

Salinity hazard	EC_{se} dS/m	Effects on plant yield	1:5 Soil/Water Extract (dS/m) Loamy sand	Loam	Sandy clay loam	Light clay	Heavy clay
Non-saline	<2	Negligible effect	<0.15	<0.17	<0.25	<0.30	<0.4
Slightly saline	2-4	Very sensitive plants effected	0.16-0.30	0.18-0.35	0.26-0.45	0.31-0.60	0.41-0.80
Moderately saline	4-8	Many plants effected	0.31-0.60	0.36-0.75	0.46-0.90	0.61-1.15	0.81-1.60
Very saline	8-16	Salt tolerant plants unaffected	0.61-1.20	0.76-1.45	0.91-1.75	1.16-2.30	1.60-3.20
Highly saline	>16	Salt tolerant plants effected	>1.20	>1.45	>1.75	>2.30	>3.20

ECa - the electrical conductance of soil, normally expressed in units of siemens (S) or decisiemens (dS) per meter. ECa values >1.2 dS/m suggest the bulked soil over about 4 or 5 m will be saline and values above 1.6 dS/m, very saline, with respect to plant growth. However, the ECa reading is an integration of salinity over depth and does not describe the severity of salinity of each soil horizon (i.e. a soil profile with a high ECa reading may have some non saline layers). Thus $EC_{1:5}$ and EC_{se} are done on all horizons from soils collected from the soil pits.

gleyed - a soil condition resulting from prolonged soil saturation, which is manifested by the presence of bluish or greenish pigmentation through the soil mass or in mottles (spots or streaks). Gleying occurs under reducing conditions under which iron is reduced predominantly to the ferrous state.

natric horizon - a mineral soil horizon that satisfied the requirements of an argillic horizon, but that also has prismatic, columnar, or blocky structure and a subhorizon having >15% saturation with exchangeable Na^+.

saline seep - intermittent or continuous saline water discharge at or near the soil surface under dryland conditions which reduces or eliminates crop growth. It is differentiated from other saline soil conditions by recent and local origin, shallow water table, saturated root zone, and sensitivity to cropping systems and precipitation.

saline soil - a nonsodic soil containing sufficient soluble salt to adversely affect the growth of most crop plants. The lower limit of saturation extract electrical conductivity of such soils is conventionally set at 4 dS m^{-1}(at 25° C). Sensitive plants are affected at half this salinity and highly tolerant ones at about twice this salinity.

salinity, soil - the amount of soluble salts in a soil. The conventional measure of soil salinity is the electrical conductivity of a saturation extract.

sodic soil - a nonsaline soil containing sufficient exchangeable sodium to adversely affect crop production and soil structure under most conditions of soil and plant type. The exchangeable sodium percentage (ESP) is at least 15 or the sodium adsorption ratio (SAR) of the saturation extract is at least 13.

> **exchangeable sodium percentage (ESP) -** exchangeable sodium fraction expressed as a percentage.
>
> **sodium adsorption ratio (SAR) -** a relation between soluble sodium and soluble divalent cations which can be used to predict the exchangeable sodium fraction of soil equilibrated with a given solution. It is defined as follows, where concentrations, denoted by brackets, are expressed in mmoles per litre:

$$SAR = \frac{[\text{sodium}]}{[\text{calcium} + \text{magnesium}]^{1/2}}$$

soil horizon - a layer of soil or soil material approximately parallel to the land surface and differing from adjacent genetically related layers in physical, chemical, and biological properties or characteristics such as colour, structure, texture, consistency, kinds and number of organisms present, degree of acidity or alkalinity, etc.

soil texture - reflects the proportion of sand (2 – 0.02 mm), silt (0.02 – 0.002 mm) and clay (< 0.002 mm) in soil (see Table 7).

soil texture (**field method) -** is determined in the field by the following procedure:

- Take a sample of soil sufficient to fit comfortably into the palm of the hand (separate out gravel and stones). Moisten soil with water, a little at a time, and work until it just sticks to your fingers and is not mushy. This is when its water content is approximately at "field capacity".
- Continue moistening and working until there is no apparent change in the ball (bolus) of soil. This usually takes 1-2 minutes.
- Attempt to make a ribbon by progressively shearing the ball between thumb and forefinger.

The behaviour of the worked soil and the length of the ribbon produced by pressing out between thumb and forefinger characterises ten selected soil texture grades as shown in Table 7 (modified from McDonald *et. al*., 1990).

soil texture groups (according to Northcote, 1979):

> **1. The Sands** = sand (**S**), loamy sand **(LS**), clayey sand (**CS**).
> **2. The Sandy Loams =** sandy loam (**SL**).
> **3. The Loams** = Loam (**L**); sandy clay loam (**SCL**); Silty loam (**ZL**).
> **4. The Clay loams** = Clay loam (**CL**).
> **5. The Light Clays =** light clay (**LC**).
> **6. The Medium-Heavy Clays** = Medium clay (**MC**), Heavy clay (**HC**).

soil texture qualifiers - used as a prefix to refine texture description as follows:

> **Coarse sandy** - Coarse to touch; sand grains can be seen with the naked eye.
> **Fine sandy -** Can be felt and often heard when bolus is manipulated; sand grains seen under hand lens of 10 times magnification.
> **Gritty -** More than 35% very coarse sand and very fine (1-3mm) gravel.
> **Gravelly -** 35-70% of gravel by volume.

Stony - 35-70% of stones by volume.

Table 7. Soil texture from behaviour of a moist bolus (ball) (modified from McDonald *et al*., 1990)

Texture	**Code**	**Ribbon (mm)**	**Ball**	**Feel and approximate clay content**
Sand	S	nil	coherence nil to very slight	Cannot be moulded. Clay is < 5%.
Loamy sand	LS	5 mm	coherence nil to very slight	Cannot be moulded. Clay is 5-10%.
Clayey sand	CS	5-15 mm	coherence very slight	Cannot be moulded. Clay is 5-10%.
Sandy loam	SL	15-25 mm	coherence slight	Sandy to touch. Clay is 10-20%
Loam	L	25 mm	coherent and rather spongy	Smooth feel when manipulated but with no obvious sandiness; may be greasy to touch if organic matter is present. Clay is about 25%.
Silty Loam	ZL	25 mm	coherent and rather spongy	As above but more silky feel
Sandy clay loam	SCL	25-40 mm	strongly coherent	Sandy to touch; medium size sands grains visible in finer matrix. Clay is about 20% - 30%.
Clay loam	CL	40-50 mm	coherent and plastic	Smooth to manipulate. Clay is about 30% - 35%.
Light clay	LC	50-75 mm	plastic	Smooth to touch; slight to shearing between thumb and forefinger. Clay is about 35% - 40%.
Medium clay	MC	>75 mm	smooth plastic	Handles like plasticine and can be moulded into rods without fracture; has some resistance to ribboning shear. Clay is about 45% - 55%.
Heavy clay	HC	>75 mm	smooth plastic	Handles like stiff plasticine; can be moulded into rods without fracture; has firm resistance to ribboning shear. Clay is >55%

soil texture (laboratory method):

***sandy loam* -** soil material that contains 7-20% clay, >52% sand, and the percentage of silt plus twice the percentage of clay is 30 or more; or less than 7% clay, less than 50% silt, and more than 43% sand.

***clay loam* -** soil material that contains 27-40% clay and 20-45% sand.

***loam* -** soil material that contains 7-27% clay, 28-50% silt, and <52% sand.

***loamy sand* -** soil material that contains between 70-91% sand and the percentage of silt plus 1.5 times the percentage of clay is 15 or more; and the percentage of silt plus twice the percentage of clay is less than 30.

***sandy clay loam* -** soil material that contains 20-35% clay, <28% silt, and >45% sand.

***sandy loam* -** soil material that contains 7-20% clay, >52% sand, and the percentage of silt plus twice the percentage of clay is 30 or more; or less than 7% clay, less than 50% silt, and more than 43% sand.

The above information has been extracted and/or updated from:

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