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Bureau of Rural Sciences

Pilot Salinity Investigation Project – Cunningham Creek Catchment.

A report to the Harden Murrumburrah Landcare Group

Scott Macaulay

Postal address:
Bureau of Rural Sciences
GPO Box 858
Canberra, ACT 2601

Copies available from:
BRS Publication Sales
GPO Box 858
Canberra ACT 2601
Ph: 1800 020 157
Fax: 02 6272 2330

Email: salesbrs@brs.gov.au

Internet: http://www.affa.gov.au/brs

EXECUTIVE SUMMARY

Salinization of both ground and surface water resources is a major problem throughout Australia. The problem is often caused by rising groundwater tables saturating areas of the landscape where salt is stored, and if the water-tables rise high enough the saline water drains into the streams, creeks and rivers that many communities rely on for their water.

While community organizations like Harden Murrumburrah Landcare Group (HMLG) are trying to address the problem with projects designed to lower groundwater tables, there exists a real need for a better method or methods to identify where the salt is stored in the landscape. Understanding this means that intervention methods such as planting trees, lucerne or other pasture can be targeted to the areas of maximum benefit.

This study develops a methodology for quickly, simply and cheaply mapping where the salt may be stored in the landscape, and applies this method in the Cunningham Creek catchment of southern NSW. The methodology combines stream salinity sampling, drilling investigation holes, gamma logging, surface and downhole electromagnetic induction (EM39) and chemical analysis of samples.

The results of the study indicate that salt-stores in the Cunningham Creek catchment are strongly associated with the location of present-day surface water drainage lines. This suggests that where salt is present, it is stored in alluvial material deposited by the streams and creeks – however further work is necessary to confirm this. The results of the stream EC survey, along with geophysical logging using EM39, and measuring the salt-content of samples obtained by drilling suggests that the overall amount of salt stored in the catchment is quite low.

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1. INTRODUCTION

This study originated in the work discussed in two papers describing salinity investigations in the Murrumbidgee catchment in New South Wales. The first, "Chasing down the salt in Australia" (Dent and Braaten, 2000), noted that Jugiong Creek was one of the main suppliers of salt to the Murrumbidgee River. Because of this, the Harden Murrumburrah Landcare Group (HMLG) became interested in finding a method or methods for further refining the very large area of the Jugiong Creek catchment into smaller, more manageable areas that were definitely known to be contributing (and just as importantly those areas not contributing) salt to the Jugiong Creek system.

The second paper involved work done in 2001 by the Australian Geological Research Organization, detailed in Wilford et al (2001). This paper described a technique for developing thematic maps by combining regolith maps developed from radiometrics surveys with topographic indices to produce soil and salt mapping. Because this technique makes use of relatively cheap and readily available datasets, it has real potential as a possible method for identifying the areas of the landscape where salt may be stored.

Using maps derived from the technique discussed in Wilford et al (2001), an area in the north-west quadrant of the Cunningham Creek catchment (figure 1), was suggested as a likely contributor of significant quantities of salt to the Jugiong. However, discussion with landholders about the area identified using the residual-k mapping did not support this conclusion. In fact, anecdotal evidence suggested that this was not a particularly salty area at all. This section of the Cunningham Creek catchment was therefore selected for further investigation.

To determine whether or not this area was an area of significant landscape salt-store, the Harden Murrumburrah Landcare Group (HMLG) developed a project in conjunction with the Bureau of Rural Sciences (BRS) to directly measure landscape salt-stores in the Cunningham Creek catchment using a variety of simple, low-cost techniques. The project was designed to evaluate these different methods of measuring landscape salt-storage and then compare them with the residual-k mapping, to determine the most effective low-cost method for salt mapping in this area.

A combination of four different techniques was used and evaluated in the BRS study. The first was a simple stream EC survey, where a number of stream sampling sites were selected across the catchment – with each of these sites to be tested for salinity on a monthly basis by the members of the HMLG. Stream surveys of this type, using a simple handheld salinity meter accurate to within 100 µS/cm gave a 'first-pass' picture of potential salt-export from the catchment.

The second salt-mapping method was a series of EM31 (surface electromagnetic induction) surveys across the study area. Eighteen EM31 traverses were done across the area, and in conjunction with stream survey data and the residual-k mapping, a number of drilling targets were selected. Directly drilling the regolith, and testing the samples collected for salt was the third salinity investigation method used in the study.

Fourteen drill sites were selected across the study area and each of these drill-sites was logged using both gamma and EM39 (electrical conductivity) tools. These types of geophysical logs are used to determine both the types of materials (gamma) as well as its salt-content (EM39). Geophysical logging was the fourth investigation tool that BRS evaluated.

Figure 1 : Cunningham Creek Project Area

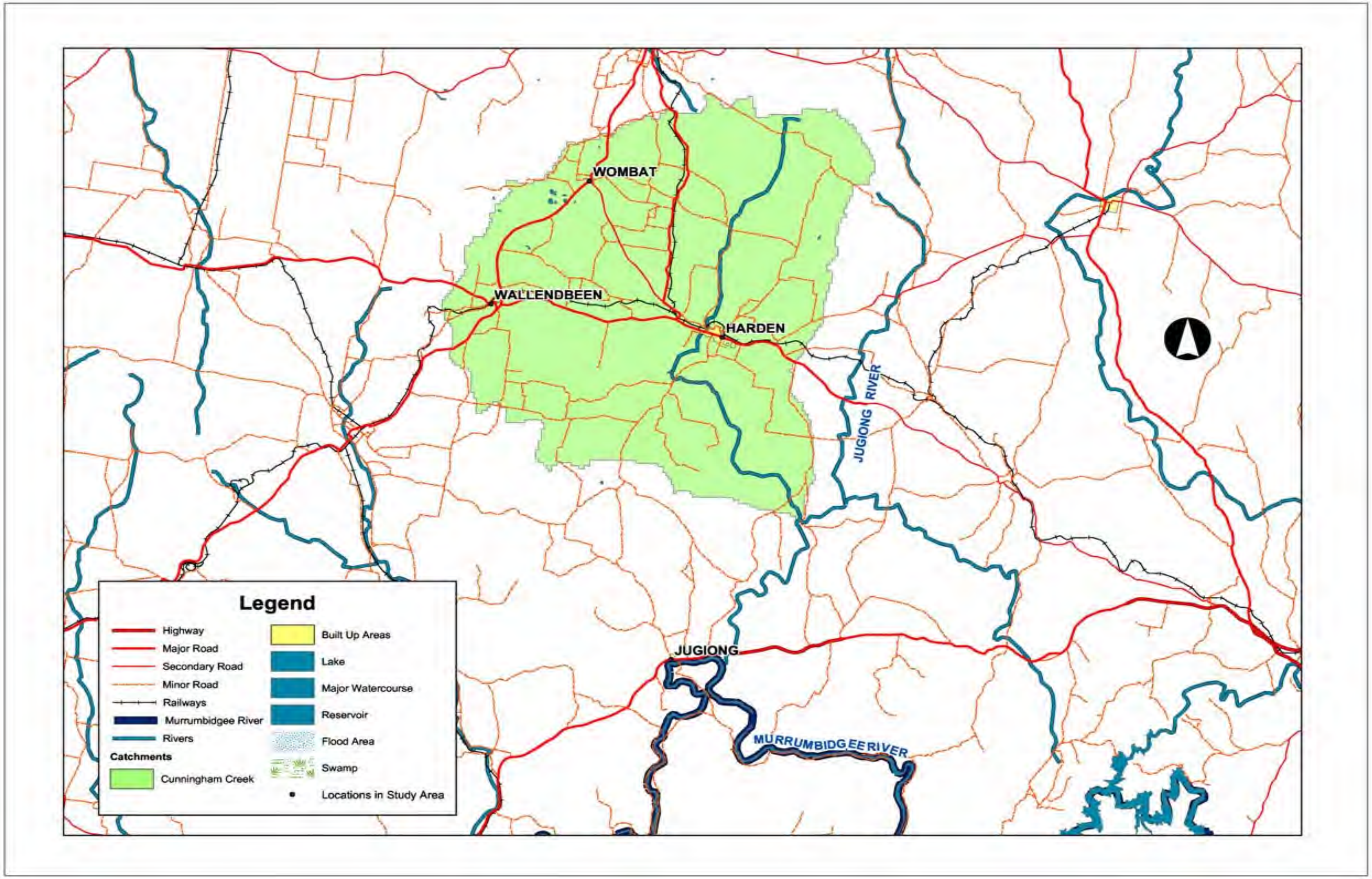
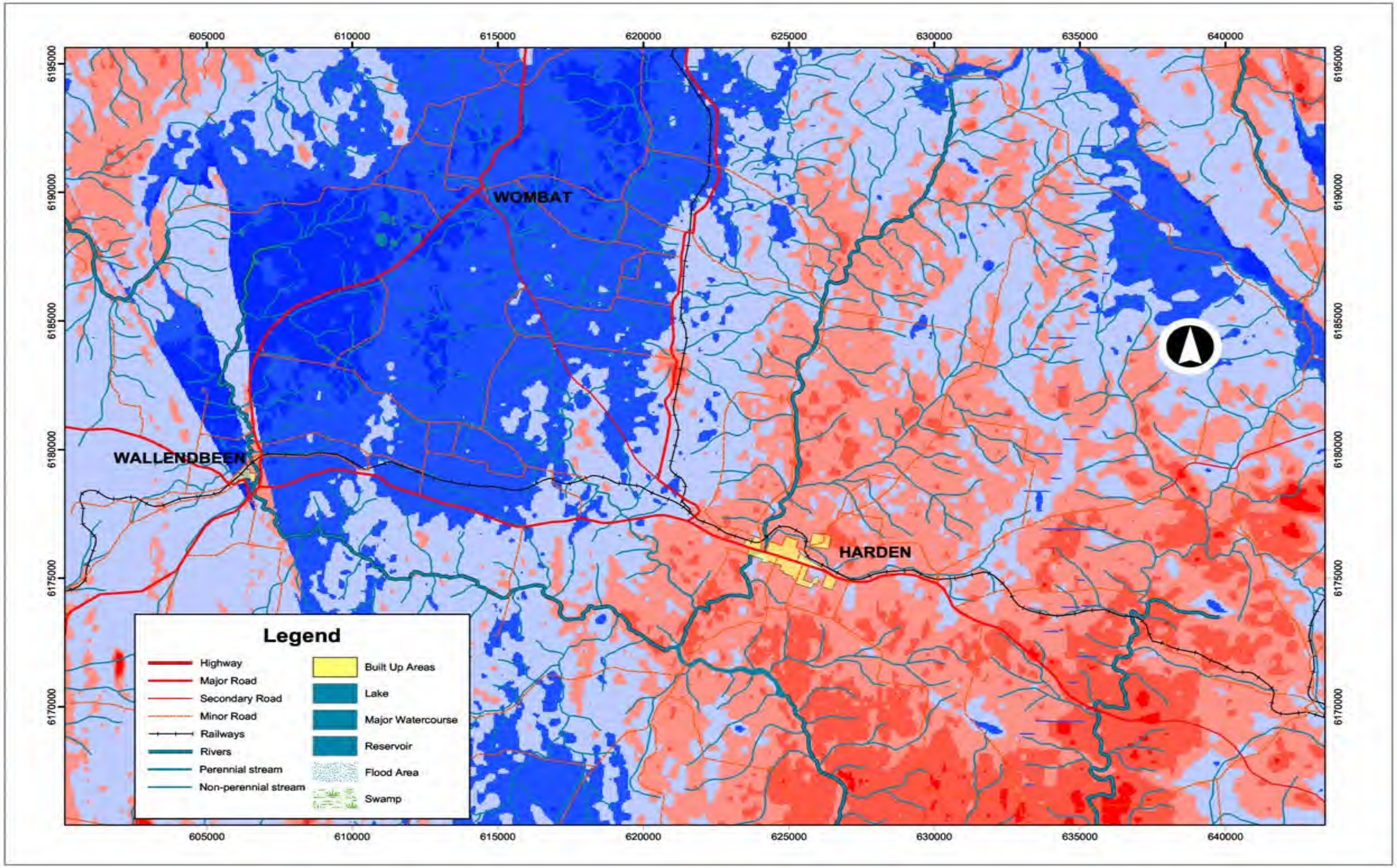


Figure 2 : Residual-K map of Cunningham Creek catchment* (Source CRC-Leme)



(* Blue – inferred areas of thick regolith : Red – inferred areas of thin regolith).

2. STREAM SALINITY SAMPLING

The initial stage of the mapping project was the establishment of a stream salinity-monitoring network across the study area.

Fourteen stream sampling sites were selected around the Cunningham Creek catchment (figure 3). These sites were selected by BRS and the Harden Murrumburrah Landcare Group (HMLG) to provide the best possible stream coverage, while keeping in mind that wherever possible the sampling sites needed to be easily accessible by the people doing the sampling. Each site was sampled monthly by volunteers from the HMLG for electrical conductivity (EC).

The purpose of the stream sampling program was to identify the catchments contributing salt to the overall Jugiong Creek system. Ideally, in surveys of this type, flow-rates as well as EC are measured so that a salt-load (a measure of the actual weight of salt moving down a stream) can be calculated. Note that the EC values collected in this survey are only a measure of the concentration of the salt in the water, which does not necessarily reflect salt-load (ie. low EC's can be the result of high flow-rates, even in quite saline catchments).

While EC can be easily and cheaply measured, determining salt loads is more complicated, requiring a stream EC reading, a flow-meter to measure the speed of water flow and a known stream cross-section so that a volume can be calculated. For this project, exact salt-loads could not be calculated because limited resources meant that only EC and not flow rate down the streams were measured. As such, the EC data can only be used as indicative of whether or not a catchment is saline – it is not in itself conclusive evidence. It should also be noted that anecdotal evidence suggests that other than after rain events, flow-rates down many of these creeks are quite low.

The stream-monitoring program commenced in March 2003 and concluded in March 2004. The initial set of readings taken in March 2003 was towards the end of a sustained period of low rainfall and stream salinities at this time would be reasonably indicative of the baseflow (seepage from groundwater) values of salinity.

2.1 Currawong Creek

The sampling points 5 and 6, located on Currawong Creek (figure 3) gave high EC readings (between 2300 and 3500 μS/cm) during the early stages of the survey, and both showed a marked improvement following good rain in May/June. This improvement in water salinity is most likely caused by the increased flow of fresh-water diluting the salt content coming in to the creek. Site 2, located lower in the catchment than sites 5 or 6, recorded consistently the highest EC water in the survey. The reason for this is not clear based on the limited dataset, but may reflect increased amounts of salt from the top of the catchment entering the system.

2.2 Demondrille Creek

Demondrille Creek is the main creek draining the large area of interpreted thick regolith in the north-west quadrant of the Cunningham Creek catchment (figure 2). There are six sampling sites on Demondrille Creek - 1, 4, 7, 7a,14 and 15. Of these sites, only 15, at the bottom of the catchment, demonstrated high (> 2000 μS/cm) 'baseflow' salinities across both the first two months of the monitoring program (March & April, 2003). This would be expected at the lower end of the catchment, reflecting the cumulative impacts of salt-flow down the stream.

Stream sampling site 1, the sampling site central in the Demondrille Creek catchment, recorded consistently low values. Interestingly and unlike the upstream site (site 7), this site did not improve after the rain but rather deteriorated slightly. This suggests that salt from higher up in the catchment is negating any improvement in water quality from the increase water flow caused by the rainfall.

2.3 Connaughtmans Creek

Site 10 on Conaughtmans Creek remained dry for most of the 2003 survey period – only carrying water immediately after rain events and drying up soon afterwards. This was despite the sampling site being located on the main channel of Conaughtmans Creek and having a large catchment area. Downstream of Connaughtman's Creek, immediately above Wallendbeen (site 8), a 'baseflow' value of 2500 µS/cm improved substantially after rain in May/June, while further downstream at site 3, an initial baseflow reading of 2100 µS/cm settled down to approximately 1500 µS/cm throughout most of the sampling period.

It should also be noted that in Dec 2003 both site 3 and site 13 experienced a marked drop; while a similar drop was not recorded at either site 15 (on Demondrille Creek) or 12 (Currawong Creek). This suggests a significant flow of fresh water down Conaughtmans Creek, confirmed by correspondence with Mr Mark O'Connor (pers comm.) who confirms that approximately 50mm rainfall fell 2 days before the stream EC readings were taken.

Using the ranges of acceptable salinity from the National Health and Medical Research Council as a guide (Table 1), - many of the samples taken fall outside the range of acceptable quality human drinking water. However, in the absence of flow-rate data, this cannot necessarily be translated as significant salt-export.

Table 1 : Salinity Ranges for Drinking Water

Description	Salinity (µS/cm)
Excellent Quality Drinking Water	≈ <120
Good Quality Drinking Water	≈ 120 – 750
Fair Quality Drinking Water	≈ 750 – 1200
Poor Quality Drinking Water	≈ 1200 – 1500
Unacceptable Quality Drinking Water	≈ > 1500

source NHMRC/ARMCANZ Australian Drinking Water Guidelines (1998)

The sites that consistently record the lowest levels of electrical conductivity were 6,7,7a and 10. The consistent factor in all of these sites is that they are located towards the top end of their respective catchments. The significance of this finding becomes more apparent when combined with the results of the EM31 survey.

A complete listing of all stream-survey EC data collected during the survey is given in Appendix 4.

3. EM31 (SURFACE ELECTROMAGNETIC INDUCTION) SURVEY

The surface electromagnetic values used in this report were taken using a hand carried EM31 unit. Surveys were conducted using the vertical dipole mode, which measures the apparent conductivity of the ground down to an approximate depth of around 6 metres. Linear survey traverses were walked along road reserves, with EM readings taken every ten metres and manually recorded. The locations of the lines were fixed using regular GPS coordinates. Values were assigned using a colour scale ranging between 0 and 600 µS/cm. This survey was not calibrated against core samples or any other form of direct sampling data.

Surface EM surveys are a very quick, simple way to measure near surface apparent conductivity. While salinity is the main factor that controls the electrical conductivity measured by EM31 surveys (Milford and Simons, 2002), other factors such as heavy clay soils and soil moisture content can also influence EM31 results. However, logging of investigation drill holes, conducted as part of this project (section 4), found the regolith to be dominated by sandy, granite derived material with low clay content so this is unlikely to be significant.

The EM-survey of the Cunningham Creek catchment noted a strong correlation between existing streams and creeks and shallow apparent conductivity, suggesting a relationship between the alluvial deposits associated with the streams and shallow salt stores.

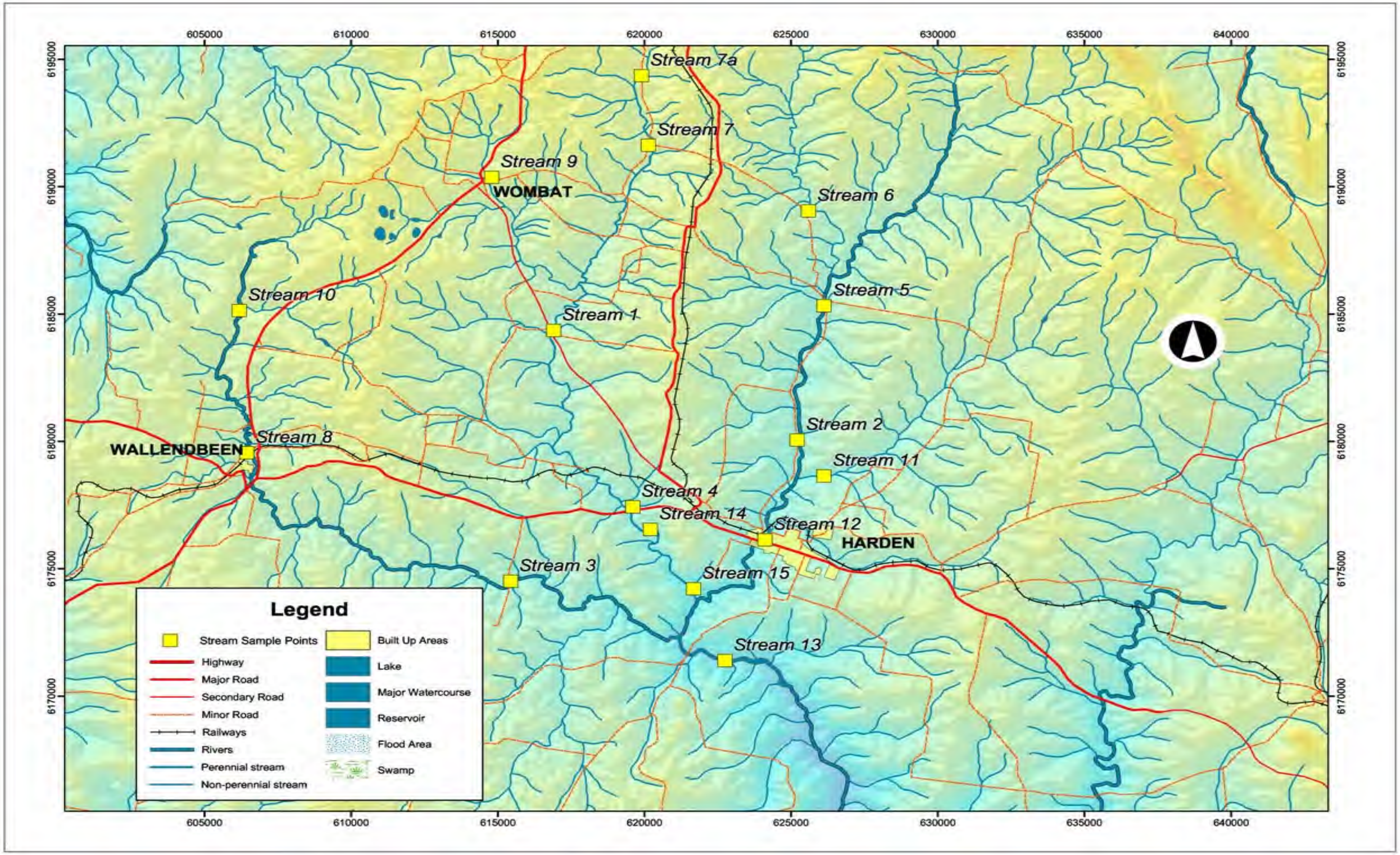
Eighteen separate EM31 lines were surveyed across the study area (figure 4), with each EM31 line plotted using a colour scale that ranged between blue (low conductivity) to red (high conductivity). Each of these lines was located primarily using the residual-k map developed using the techniques discussed in Wilford et al (2001), and were designed to transect across areas of different inferred regolith thickness and topographies. Each line is discussed in detail below.

1) Tiverton Road : This line intersected only minor areas of shallow apparent conductivity, with a strong correlation with to the location of stream lines. Three drilling targets were selected along this line, none of which intersected significant salt, either in the downhole conductivity logs or the direct samples.

2) & 3) Barwang Rd : Two EM31 lines were surveyed along Barwang Rd, at the top and bottom of the catchment. For both lines, significant correlation was again noted between stream locations and significant, shallow apparent conductivity. A lack of suitable drilling locations prevented any direct sampling of the EM31 line lower in the catchment, while the line at the top of the catchment was drilled at location HD13. HD13 was drilled to intersect an area of high apparent conductivity, however neither the downhole conductivity log or chemical analysis detected any significant salt.

4) Lynwood Rd : Lynwood Rd is at the bottom of the Currawong Creek catchment. Higher EM readings were encountered along sections of this line - again this correlated well with present-day streamlines. No drilling targets were selected on this line.

Figure 3 : Stream Salinity Survey Locations



5) & 6) Buoyeo Rd : Two lines were surveyed on Buoyeo Rd in the Cunningham Creek catchment, east of the Jugiong Reservoir, with a positive correlation between higher values of apparent conductivity and the location of streams. Hole HD16 was located to sample one of the high apparent conductivity zones picked up by the EM31, however neither the downhole conductivity logging nor the chemical analyses of samples taken from HD16 picked up any significant salinity.

7) Olympic Way : A short EM31 line was surveyed along the Olympic Way, within the Connaughtmans Creek catchment. This line detected significant shallow apparent conductivity, however due to budget limitations and a lack of suitable drill locations adjacent to the busy Olympic Way, no direct sampling was done.

8) & 9) Colorado Rd : Two EM31 lines were done along Colorado Rd. The western Colorado Rd line overlaps the Sherlocks Creek and Connaughtmans Creek catchment; the eastern line is in the Demondrille Creek catchment near the railway line. The western Colorado Rd line runs through the main body of inferred thick regolith and located significant shallow apparent conductivity. Both the western and the eastern line showed a strong correlation between the shallow conductivity and stream location. Hole HD4 was sited on an area of low EM31 response on the eastern line.

10) Bramshott Rd : A single EM31 line was run through the central area of inferred thick regolith in the north-western area of the Cunningham Creek catchment. A very good correlation was observed between the high EM response and existing surface-water drainage lines. Two holes, HD5 and HD6 were drilled on the Bramshott Rd line. HD5 was drilled in the area of high apparent conductivity on the southern end of the road, with the downhole conductivity log for this hole finding the same shallow conductivity that was detected by the EM31. The hole drilled on the northern side of Bramshott Rd, in an area of low EM31 response detected no conductivity.

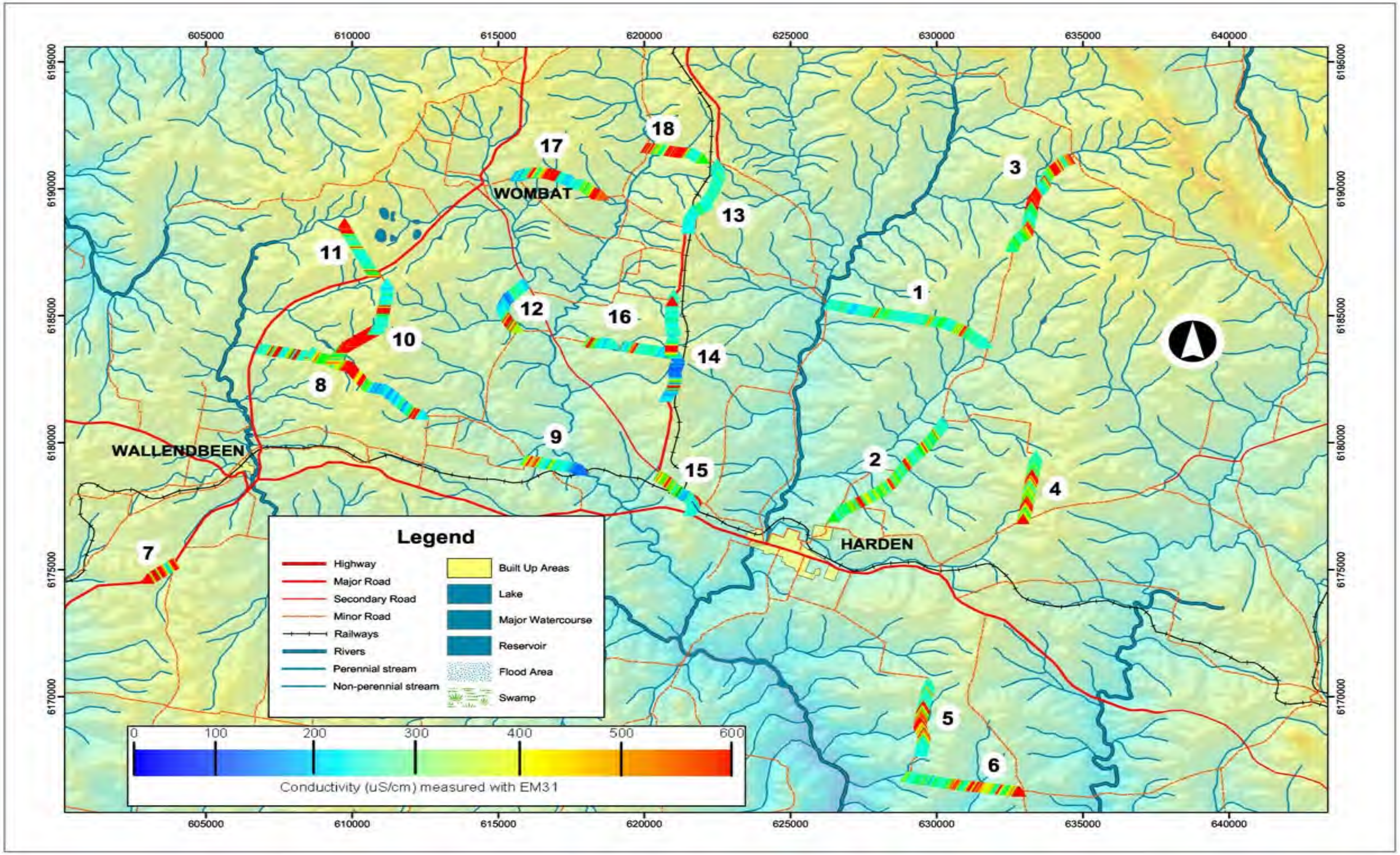
11) Koepang Rd : A single EM31 line was run along Koepang Rd through an area of thick inferred regolith. The EM31 showed a good correlation with surface stream location and no correlation with inferred regolith thickness. A test hole (HD7) was drilled at the northern end of Koepang Rd in the area of high apparent conductivity that detected the shallow conductivity identified in the EM31.

12) Chinaman Creek Rd : This line is over an area of reasonably thick inferred regolith – becoming shallower from west to east. Good correlation was observed between surface stream location and the high apparent conductivity observed from the EM31. No test holes were drilled on this line.

13), 14) & 15) Kingsvale Rd : Three EM31 lines were surveyed along Kingsvale Rd, transecting across different areas of inferred regolith thickness. The northern line intersected no shallow apparent conductivity, however the two southern lines detected some areas of apparent shallow conductivity that show a positive correlation with stream locations. Due to the difficulty in siting drill locations along Kingsvale Rd, no test holes were drilled on any of the Kingsvale Rd lines.

16) Redbridge Rd : One survey line was done along Redbridge Rd. This line showed a good correlation with surface stream location. Because of budget limitations, no test holes were drilled on the Redbridge Rd line.

Figure 4 : EM31 Survey Locations and Results



17) Gladstone Rd : One EM31 line was done on Gladstone Rd, immediately east of the town of Wombat. A strong relationship was observed between a high apparent conductivity mapped by the EM31 and surface stream locations. A test hole drilled on the Gladstone Rd line (HD8) confirmed this correlation, showing a shallow conductivity spike in an area that showed a high apparent conductivity response.

18) Bonnington Rd : A single EM31 line was done along Bonnington Rd, across an area of thick inferred regolith, with the EM31 response demonstrating a good correlation with surface stream locations. A test hole drilled at HD9, confirmed this correlation, intersecting a shallow conductivity bulge at the western end of the EM31 line, corresponding with the location of Demondrille Creek.

The results from the EM31 lines demonstrate a strong positive correlation between the location of shallow landscape conductivity and the location of present day streams and surface-water drainage lines. Note that while salinity is the main factor that influences the apparent electrical conductivity of the regolith measured by EM31 (Milford and Simons, 2002), the data can also be influenced by soil moisture content and/or the presence of heavy clay soils.

To confirm whether the highly conductive areas identified by the EM31 are caused by salinity or are the result of clay rich soils, a series of investigation holes were drilled, logged and sampled across the study area. However, based on the EM31 response, there is good evidence that any shallow salt-stores (which are more likely to be mobilized, than deeper stores) appear to be strongly associated with alluvial material deposited around creeks and streams.

4. DRILLING PROGRAM

An investigation-drilling program was conducted between Wednesday 27 August and Friday 29 August 2003, with locations chosen primarily using the results of the EM31 survey, but also to further test the correlation between the residual-k map of regolith thickness and the actual depth to basement.

All exploration holes were drilled to basement; this meant that the full thickness of unconsolidated regolith material was sampled until the drilling reached solid, competent rock. To save money and maximize the number of holes that could be drilled within the available drilling budget, all of the holes were left uncased. (ie. they weren't lined with PVC or similar bore casing material). Each hole was logged with both a gamma and a downhole induction logger immediately after it was drilled to determine both the types of materials (gamma log), and how conductive or salty the material was (induction log). Due to the relatively unconsolidated / sandy nature of the regolith, the absence of bore casing often meant some collapse of the holes before they could be logged – meaning most holes could not be logged all the way to basement. A list of depth to basement (drilled) and the depth each hole could be logged to is given in table 2.

The location of all investigation holes drilled during the survey is shown in figure 5.

4.1 Drilling Program (Downhole Gamma Logging)

Gamma logging is a process that measures the relative content of clay in the regolith material. This is caused by the clayeyer material having a higher level of natural radiation because of the radioactive decay of thorium and potassium minerals in clays. By contrast, sandier material has much lower levels of natural radioactivity and gives a lower gamma ray response.

All gamma logs in this report (Appendix 1) are referred to in API's, or American Petroleum Industry standard units. Using the API standard, high gamma response corresponds to higher clay content in the logged material. Broadly speaking when viewing a gamma log – left of the 100 API mark is relatively sandy, right of 100 API is relatively clayey.

Table 2: Drilled Depth & Logged Depth

Site Number	Location	Depth to Basement (metres)	Logged Depth (metres)
HD1	Nimby Creek Rd	8	4.57
HD4	Colorado Rd	23.5	20.44
HD5	Bramshott Rd	13	3.93
HD6	Bramshott Rd	25	22.69
HD7	Koepang Rd	58	40.63
HD8	Gladstone Rd	14	10.52
HD9	Bonnington Rd	29.5	8.40
HD10	Tiverton Rd	14	13.46
HD11	Tiverton Rd	24	22.42
HD12	Tiverton Rd	7	5.50
HD13	Barwang Rd	16	14.80
HD14	Lynwood Rd	34.5	19.50
HD15	Lynwood Rd	25.5	20.81
HD16	Buoyeo Rd	40	14.85

All holes drilled during the investigation were gamma logged to assess the lithology and relative clay content, with all holes demonstrating an overwhelmingly sandy lithology. This corresponded well with the physical specimens collected during drilling, which also demonstrated a dominantly sandy, granite-derived lithology, with a low overall clay content.

In only three of the holes that were logged did the gamma response approach or exceed 100 API – at sites HD11, HD12, HD16.

HD11 and HD12 were drilled on Tiverton Rd, north of the town of Harden. These holes were drilled as a transect along an area of high topography and relatively thin inferred regolith. As expected, HD12 was a shallow hole, drilled to only 7 metres before reaching bedrock (granite). This hole intersected a narrow (less than 1 metre) clay band at 3 metres. However, EC1:5 analysis (section 5) on the sample tested from this hole did not contain any significant salt. HD11 was also anticipated to be a shallow hole, however this site drilled to basement at 24 metres. The upper 10 metres of material in this hole was sandy, granite-derived material before it became slightly clayey at depth. Again, none of the samples tested from this site showed any significant salt-content.

The third site that intersected clay material was at HD16. Based on the map of residual-k, this site was expected to be extremely shallow. However, this was one of the deepest investigation sites that the project drilled (40 metres to bedrock), with a significant clay band at around 14 metres, overlain by much sandier material.

All other test-sites that were drilled intersected quite uniformly sandy, granite-derived materials throughout.

Gamma logs for all investigation sites that were drilled are included in Appendix 1.

4.2 Downhole Conductivity Logging

The location of landscape conductivity was mapped directly using a downhole conductivity-logging tool. As with the surface induction logging technique (EM31), the downhole (EM39) tool measures salinity by measuring the apparent electrical conductivity of the regolith. EM39 has an effective logging radius of 0.9 metres, (Milford and Simons, 2002), meaning the log is indicative of the material in a 1.8 metre diameter circle centred on the drill-site

The EM39 conductivity logs collected in this study can be broadly classified into two groups. Of the 14 investigation sites, 7 exhibited an electrical conductivity bulge greater than 800 µS/cm, with the apparent conductivity at the other 7 sites varying around 200 – 400 µS/cm with no appreciable bulges in conductivity.

Conductivity logs for all investigation drill sites is given in Appendix 2.

Group 1 : Conductivity 'bulge' > 800 µS/cm : This first group of sites (HD1, HD5, HD7, HD8, HD9, HD15, HD16) are distributed across a range of landscapes and drilling depths across the study area.

HD1 and HD16 : These two sites are south of the town of Harden.

> **HD1** is on Nimby Creek Rd in an area of anticipated thicker regolith based on the residual-k mapping (figure 2). This site was drilled adjacent to Barbers Creek and was anticipated to intersect alluvial material deposited by the creek. Higher moisture content was also anticipated. However, HD1 could only be drilled 8 metres before intersecting bedrock, and the regolith was uniformly sandy. The EM39 conductivity log detected a conductivity bulge in the upper 5 metres, however EC1:5 on a sample taken at 5m detected no significant salt.
>
> **HD16** is on Bouyeo Rd in an area interpreted as thin regolith. Again, this site was drilled adjacent to a creek (Station Creek), and was anticipated to intersect alluvial material and/or higher moisture. However this site intersected thick (40 metres) regolith with a conductivity bulge at approximately 13.5 – 14.5 metres, associated with a deeper band of more clay rich material.

HD5, HD7, HD8 and HD9 : These four sites are north west of Harden in the largest area of interpreted thick regolith.

> **HD5** : This site is on Bramshott Rd, sited in area of high, shallow apparent conductivity mapped by the EM31 survey, strongly associated with a branch of Connaughtmans Creek. This site was only drilled 13 metres to basement and was uniformly sandy across its entire depth. There was a shallow conductivity bulge logged by the EM39 between 2 - 2.5 metres.
>
> **HD7** : This was drilled on Koepang Rd and was the deepest drill site encountered during the investigation drilling stage. It was sited on an area of high, shallow apparent conductivity mapped by the EM31 survey. A shallow conductivity bulge was encountered between 4 and 6 metres, and the regolith material encountered was uniformly sandy, granite-derived material. This site also recorded the highest directly measured EC1:5 salinity in the study. Samples at the site were taken at 5, 10, 20, 30 ,40 and 50 metres depth, with a high of 312 µS/cm recorded at 10 metres. (A full record of all EC 1:5 results is given in Appendix 3). The EC1:5 results for HD7 indicates a shallow conductivity bulge around 10 metres. This correlates with the shallow conductivity mapped by the EM31 and EM39 logging.
>
> **HD8** : This site was drilled on Gladstone Rd, west of the town of Wombat. It was sited on an area of high apparent conductivity mapped using EM31 strongly associated with Wombat

Creek. This site was a relatively shallow hole, intersecting basement at 14 metres. Regolith was relatively sandy, granite-derived material, becoming slightly more clay-rich with depth. HD8 gave the highest EM39 response of any site logged during the study, 2300 µS/cm at 1.5 metres depth, declining rapidly to an EM39 response of around 400 µS/cm by a depth of approximately 6 metres. EC 1:5 samples tested at 5 and 10 metres did not record significant salinity.

HD9 : Sited on Bonnington Rd in an area of high EM31 response, this investigation hole was located close to Back Creek. Based on the residual-k map (figure 2) it was expected to intersect thick regolith, which was borne out by the drilling, intersecting basement at 29.5 metres. Regolith was sandy, granitic material with very low clay content. Because of the sandy nature of the regolith, most of the hole collapsed before it could be logged, and gamma and EM39 probes could only get down approximately 10.5 metres. A shallow conductivity bulge was logged between 3 – 3.5 metres, corresponding with the area of shallow apparent conductivity mapped using the EM31.

HD15 : This site is situated west of Harden on area of the residual-k map that indicates regolith material of intermediate thickness.

HD15 was drilled on Lynwood Rd, west of the town of Harden. Basement at this site was struck at 25.5 metres, making it one of the deepest holes drilled during the project. The hole was sited on an area of high EM31 response indicating shallow conductivity. The hole struck a shallow EM39 conductivity bulge was struck between 3 – 4 metres, dropping back to a baseline of around 400 µS/cm after approximately 5 metres – which corresponds well with the EM31 response. Gamma logging indicates that the regolith is mainly sandy material.

Group 2 : 'Baseline' conductivity values : As with the first group, these sites (HD4, HD6, HD10, HD11, HD12, HD13, HD14) are distributed across a range of landscapes and depths.

HD4 and HD6 : Both these sites are north-west of Harden in the largest area of interpreted thick regolith.

HD4 : This site was drilled on Colorado Rd in an area of the residual-k map that was interpreted as thick to moderately thick regolith. This hole was sited using the results of the EM31 survey to be on an area where there was no shallow conductivity recorded. There were no nearby streams or creeks at this site. Basement was struck at 23.5 metres, with the gamma log showing the material to predominantly sandy with minor clay content. No significant EM39 conductivity was logged and EC 1:5 results for samples taken at the site ranged between 7.42 – 10.50 µS/cm.

HD6 : This hole was located on Bramshott Rd using the results of the EM31 survey to test an area of low shallow apparent conductivity. There were no streams or creeks in the vicinity of the site and, based on the residual-k map, it was expected to intersect an area of thick regolith. The hole struck basement at 25 metres, with the gamma log showing sandy material the full length of the hole. No significant conductivity was detected by the EM39 although the log shows a lot of variability after approximately 11 metres. This site also recorded the second worse EC 1:5 sample in the project – 164 µS/cm at 10 metres. Note however that using the cut-offs given in the Australian Drinking Water Guidelines (table 1), even this 'bad' sample still falls within the range of good-quality drinking water.

HD10, HD11, HD12, HD13 and HD14. The remaining test-sites that exhibited only 'baseline' EM39 conductivities are all clustered in the same area (figure 5). With the exception of HD14, all of these sites were located using a combination of the residual-k map and the EM31 survey results.

HD10 , HD11 & HD12. These three sites were drilled on Tiverton Rd. Based on the residual-k map regolith thickness in this area was expected to vary from intermediate to thin. Based on the results of the EM31 survey, none of the sites were anticipated to show significant shallow salinity.

The three sites showed considerable variation in the depth to basement – considering that they were all drilled along the same road, however the different depths do seem to reflect the topography. The shallowest site (HD12 : 7 metres) is drilled on a topographic high point and based on this the regolith would be expected to be thinner. The two deeper sites (HD10 : 14 metres and HD11 : 24 metres) are in topographic valleys either side of HD12 and would be expected therefore to have thicker regolith deposits. While HD10 exhibited uniform, sandy material throughout, HD11 and HD12 both intersected lenses of more clay rich material. However, the presence or absence of these lenses of more clay rich material had no impact on either the EM39 or EC 1:5 measured conductivities.

HD13 was drilled on Barwang Rd, and as with the previous sites was located using a combination of the residual-k map and EM31 survey results. However, unlike the Tiverton Rd sites, HD13 was located in an area of high EM31 response, in close proximity to Irish Jacks Creek. The residual-k map predicted this to be in relatively thin regolith, while the EM31 survey was predicting a shallow conductivity 'bulge'. (HD13 is the only drilling target with a high EM31 response that did not show a shallow conductivity bulge on the EM39 log).

5. EC 1:5 RESULTS

EC 1:5 salinities are measured by diluting a sample of soil or regolith in distilled water at a ratio of 1 part soil or regolith to 5 parts of water, and are a representative standard of the salinity in soil or regolith testing.

EC1:5 measurements were taken from samples extracted during the investigation drilling program. These samples were taken at 1 metres intervals from natural surface to bedrock, however because of budget restrictions, samples were analyzed at either 5m or 10m intervals. A complete listing of all EC 1:5 results is given in Appendix 3.

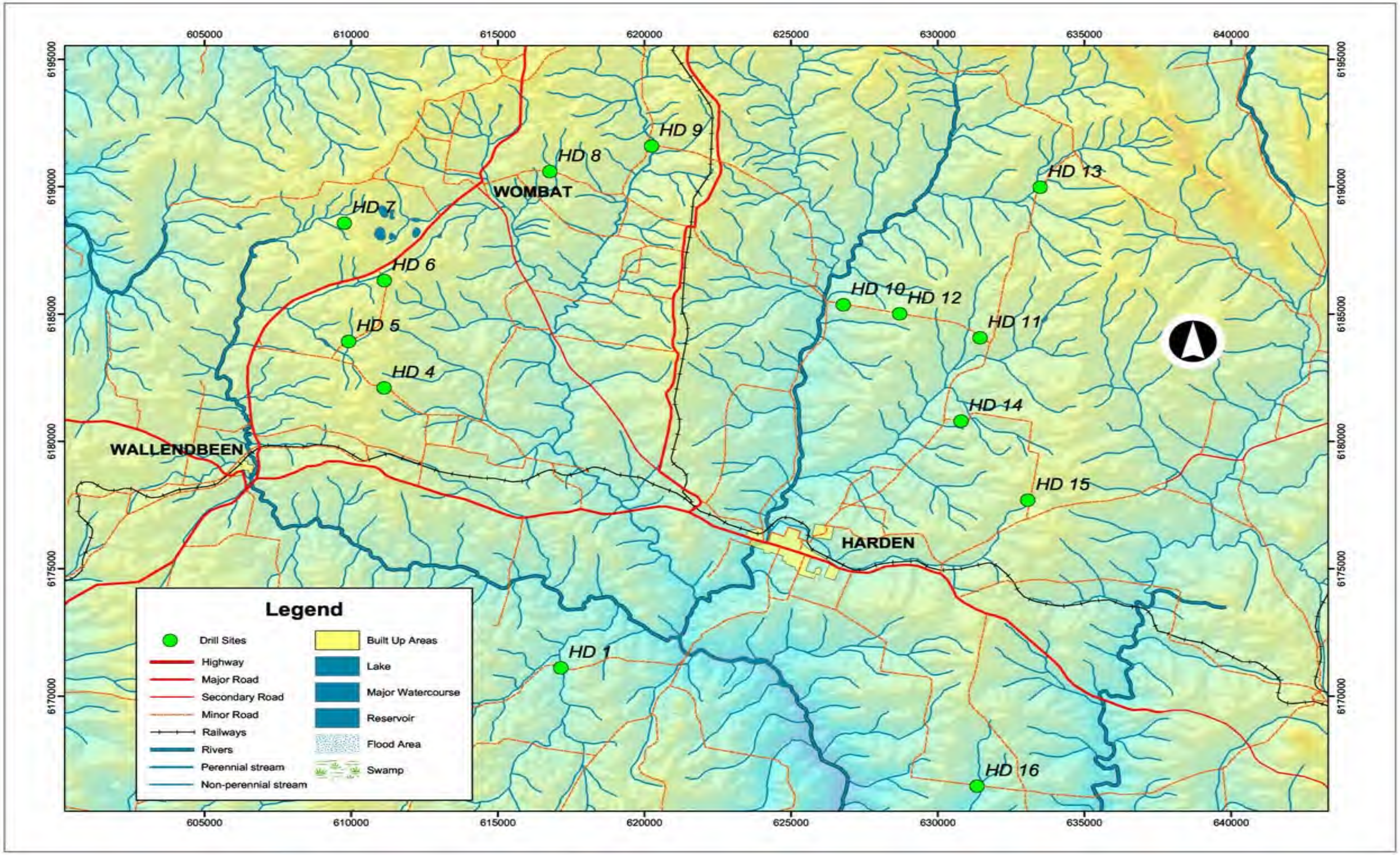
Taken in conjunction with the downhole EM39 logging, the results from these samples indicate quite conclusively the absence of any significant landscape salt-store within the study area. The EC 1:5 results obtained during the Cunningham Creek investigation ranged from 312 µS/cm at 10m depth in HD7, through 164 µS/cm at 10m in HD5, to a low value of 7.42 µS/cm at 5m in HD4. Only the two values mentioned – 312 µS/cm and 164 µS/cm, gave values greater than 100 µS/cm. All other values tested at less than 100 µS/cm, with a mean salinity of less than 40 µS/cm across all samples that were tested.

This indicates a very low level of landscape salt-store in the study area. By comparison, another BRS salt-mapping project in Billabung Creek (which is also in the Murrumbidgee catchment), found maximum water salinities of 9000 µS/cm (Dent 2003). There is no evidence of major landscape salt-storage in the Cunningham Creek catchment, however there is evidence of minor salt-storage in the material deposited along present-day streams and creeks.

6. DISCUSSION

The starting premises for this mapping project were twofold. One is that previous studies have indicated that Jugiong Creek is known to contribute a large proportion of the salt load to the Murrumbidgee, meaning that certain catchment(s) that drain into the Jugiong are contributing large amounts of salt. The second premise is that residual-k mapping like that described in Wilford et al (2001) suggested that the north-western quadrant of the Cunningham Creek catchment was a likely area for significant landscape salt to be stored.

Figure 5 : Investigation Drilling Sites



The residual-k map (figure 2) was developed for the study area from the techniques discussed in Wilford et al (2001), using a colour scale that ranges from dark-blue (inferred thick regolith) through to dark-red (inferred thin regolith). Theoretically, mapping the areas of thicker regolith is an effective method for mapping landscape salt-stores, and the mapping developed using this technique identified the north-western quadrant of the Cunningham Creek catchment as a large area of thick regolith. Field investigations using a variety of different techniques were undertaken to verify whether or not this area was actually storing and/or exporting salt.

The first stage of the investigation was stream-surveys using simple hand-held EC–meters. Stream surveys are a very cheap, very quick method of identifying whether or not particular stream catchments are exporting salt. The biggest drawback with this type of survey is that collecting the data is relatively time and labour intensive, however as was the case in Harden, it is a salt-mapping technique which landholders can undertake themselves after only minimal training.

The results of the stream survey conducted in the Cunningham Creek catchment strongly suggest that the north-western quadrant of the catchment is not exporting salt. Monitoring sites located on Demondrille Creek – the main creek draining the north-west quadrant - ranged from a maximum of 1900 µS/cm during dry periods to a minimum of 500 µS/cm after rain. While flow rate measurements are needed to calculate an actual salt-load, the relatively low EC figures do suggest that salt-export out of Demondrille Creek is probably low.

The second stage of the investigation was to conduct EM31 surveys across the study area. EM31 is a proven technique for mapping shallow (< 6 metres) landscape conductivity, which has a very good correlation with salinity (Milford and Simons, 2002). The results of the EM31 survey (figure 4) demonstrated a very strong correlation between shallow conductivity and the location of present-day surface-water drainage lines. This suggests that the bulk of near-surface salt (at greatest risk of being mobilized and exported) is stored in alluvial sediments associated with surface water systems. Therefore mapping these sediments using a tool such as EM31 has the potential to be a very effective salt-mapping technique.

To confirm the effectiveness of the EM31 survey and to further test the residual-k mapping, a series of test-holes were drilled across the study area. Drilling targets were located on both the conductive and non-conductive areas mapped by the EM31, as well as across a range of inferred regolith thickness's. Of the fourteen investigation holes drilled across the area, seven intersected a salt 'bulge' of greater than 800 µS/cm. The areas where salt bulges were logged had certain factors in common:

1) The salt bulges were thin (metres thick, not tens of metres)

2) All holes where EM39 conductivity 'bulges' were located corresponded with areas where the EM31 survey detected significant shallow landscape conductivity.

3) With the exception of HD13, all drilling targets located on areas with high EM31responses gave a high EM39 conductivity indicating landscape salinity.

4) Conversely, all holes that were drilled on low EM31 conductivity areas, failed to intersect significant landscape salinity.

5) With the exception of drill site HD16, all EM39 conductivity bulges were shallow (< 7 metres).

The EM39 logging confirms the results of the EM31 survey. Where it is present, landscape conductivity is shallow and strongly associated with present-day creeks and streams.

Samples were collected at each of the drill sites, and these samples were analyzed for salinity content (EC 1:5), showing very low EC levels. The highest two EC values from the samples that were tested, HD7 (312 µS/cm) and HD6 (164 µS/cm), are both within the range of good-quality drinking water, with all other samples testing as excellent quality drinking water (table 1). Average EC1:5 across all samples tested in the study is only 40 μS/cm.

While both the scope and the area of this study were limited (ie. investigation was concentrated in the Demondrille and Currawong creek areas of the Cunningham Creek catchment), and its findings cannot be conclusive, there is strong evidence that any landscape salt-storage in the study area is quite small and quite localized. The main finding of this study is that salt-stores are strongly associated with the material deposited around creeks and streams, and that mapping the areas of the catchment at greatest risk of contributing salt to the export salt-load flowing down Jugiong Creek should concentrate on these areas. With salt-store being predominantly shallow in the landscape, EM31 would be an effective tool for salt-mapping in the catchment, however further investigation work is necessary to confirm the relationship between salt stores and alluvial material.

While there is good evidence of salt-storage associated with alluvial deposits around the creeks and streams, there is no evidence of significant landscape salt-stores associated with the areas of thicker regolith that were identified using the residual-k mapping method. Also, while further data and further work is necessary to calculate the salt-load being exported from the Cunningham Creek catchment, it is doubtful that large-scale salt exports are occurring, based on the apparent absence of any major salt-stores in the catchment.

ACKNOWLEDGEMENTS

The Bureau of Rural Sciences would like to acknowledge the efforts of the Harden Murrumburrah Landcare Coordinator Louise Hufton, and other members of the HMLG who participated in this project.

REFERENCES

Dent D (2003). *Five Steps to Tackling Salinity. Billabung Creek case study, Murrumbidgee Catchment, NSW*. Science for Decision Makers – Australian Government, Bureau of Rural Sciences. http://www.daff.gov.au/corporate_docs/publications/pdf/rural_science/decision_maker/sfdm_salinity.pdf

Dent DL & Braaten RO (2000). *Chasing down the salt in Australia*. Proceedings Bureau of Rural Sciences Conference, Emerging technologies in Agriculture: From ideas to adoption. Canberra, July 2000

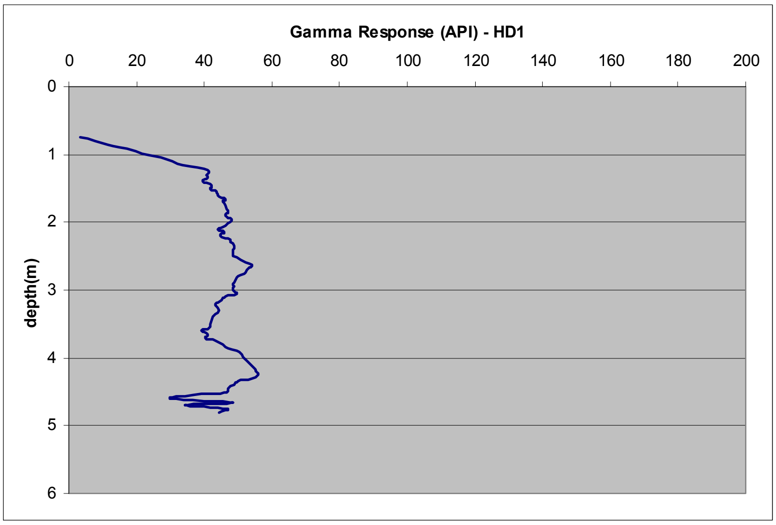
Milford HB & Simons N (2002). *The Salinity Soil Data Card – Supplement 1 to the 3rd Edition of the Soil Data Entry Handbook*. Department of Land and Water Conservation

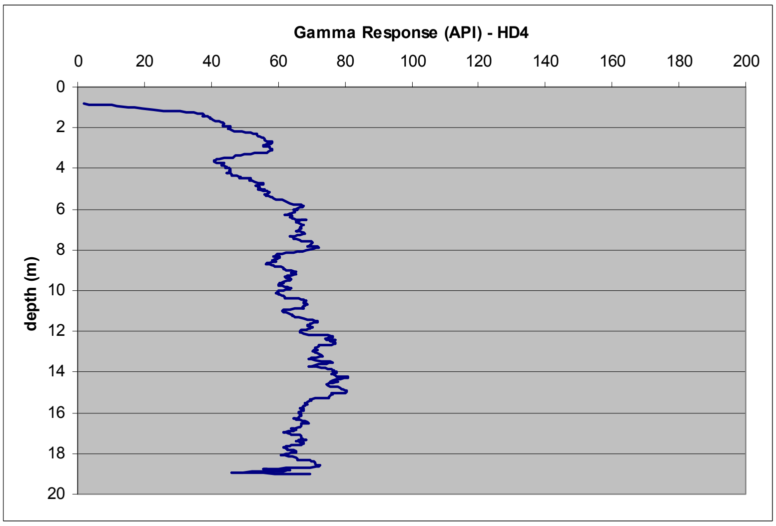
NHMRC / ARMCANZ (2001). *Australian Drinking Water Guidelines and Framework for Management of Drinking Water Quality*. National Health and Medical Research Council and the Agricultural and Resource Management Council of Australia and New Zealand.

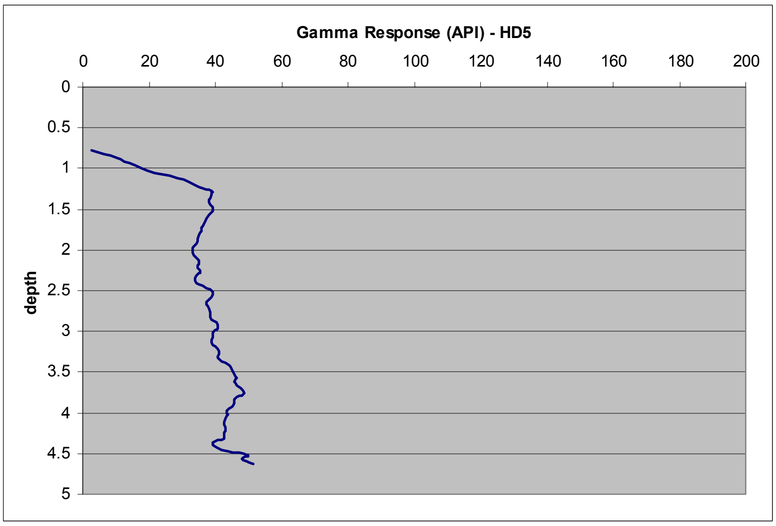
Salama RB & Bartle GA. (1998). *Comparative study of streamflow and salt load from selected catchments in the wheatbelt of Western Australia*. CSIRO Technical Report No. 23/98

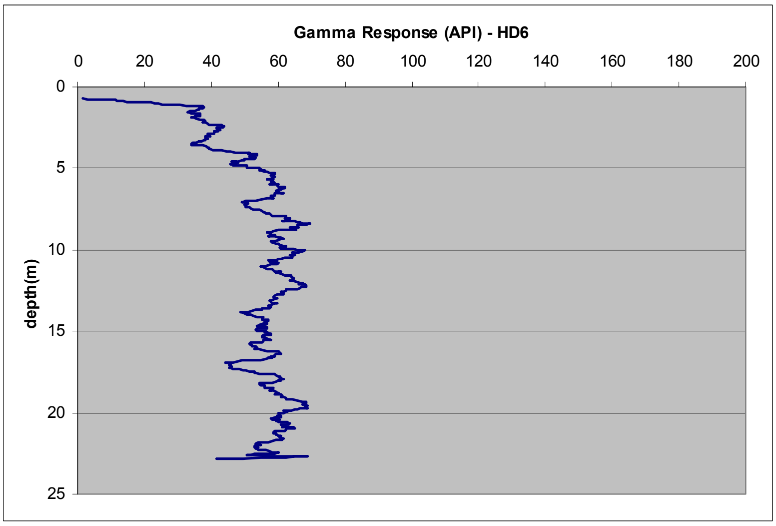
Wilford JR, Dent DL, Dowling T and Braaten R (2001) *Rapid mapping of soils and salt stores. Using airborne radiometrics and digital elevation models*. AGSO Research Newsletter, May 2001.

APPENDIX 1 : GAMMA LOGS








Gamma Response (API) - HD6
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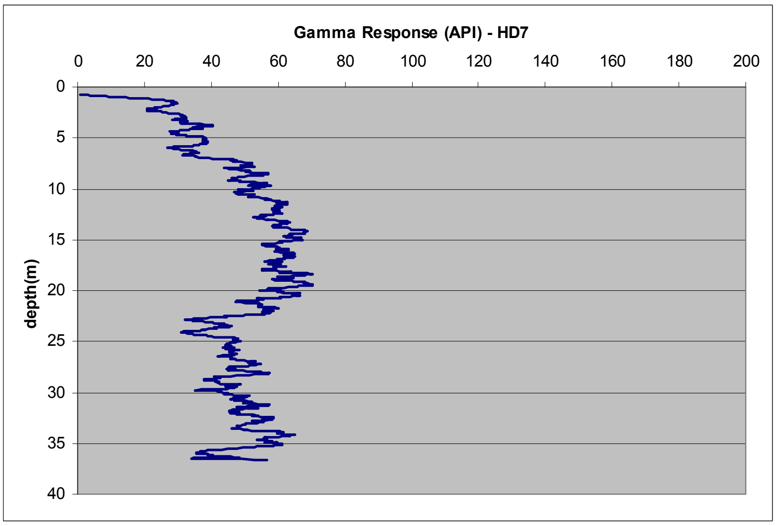
20
40
60
80
100
120
140
160
180
200
0
5
10
15
20
25
depth(m)


Gamma Response (API) - HD7
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140
160
180
200
0
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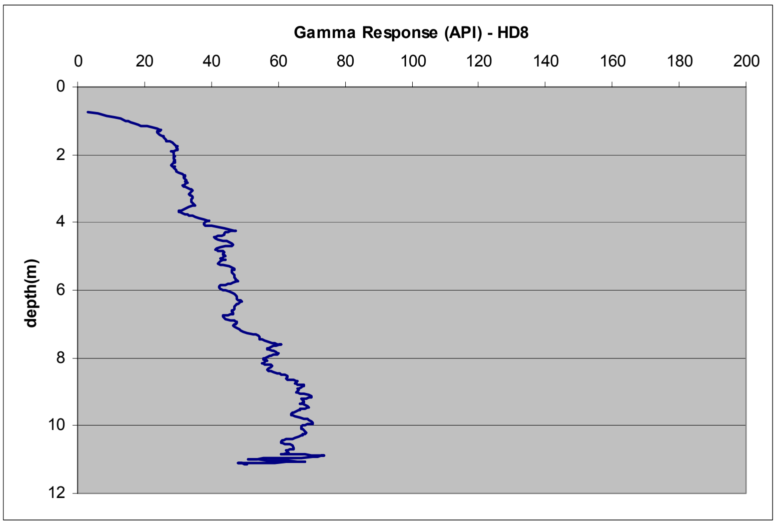
30
35
40
depth(m)


Gamma Response (API) - HD8
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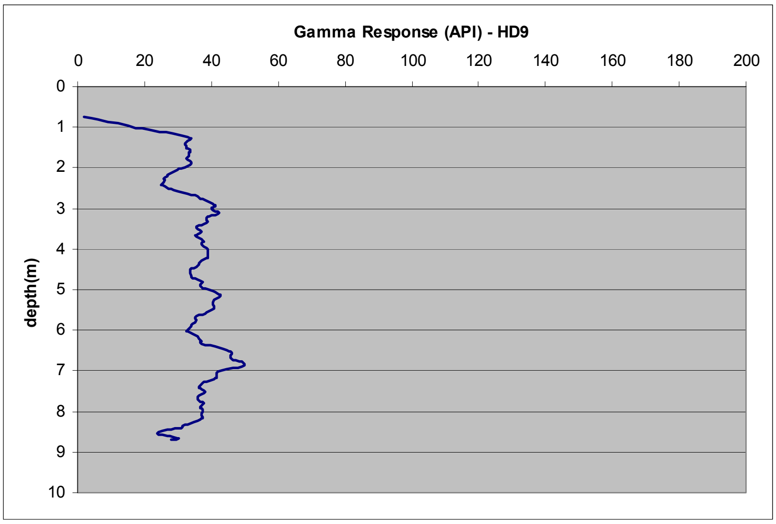
20
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12
depth(m)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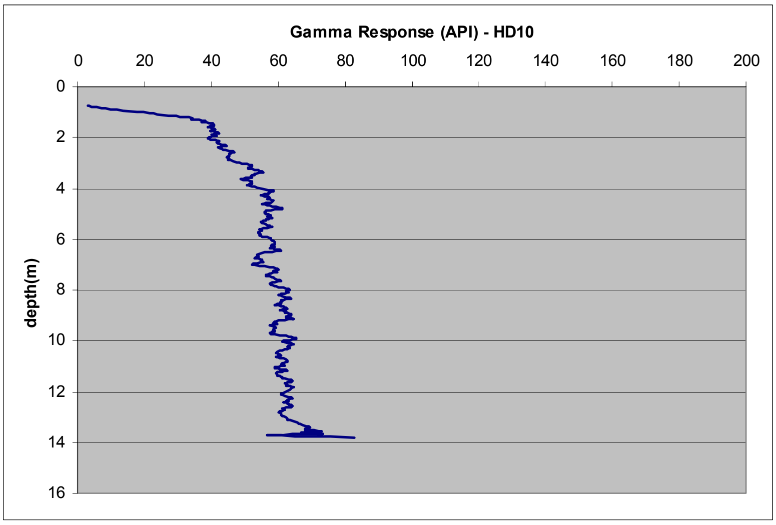
depth(m)
0 1 2 3 4 5 6 7 8 9 10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depth(m)
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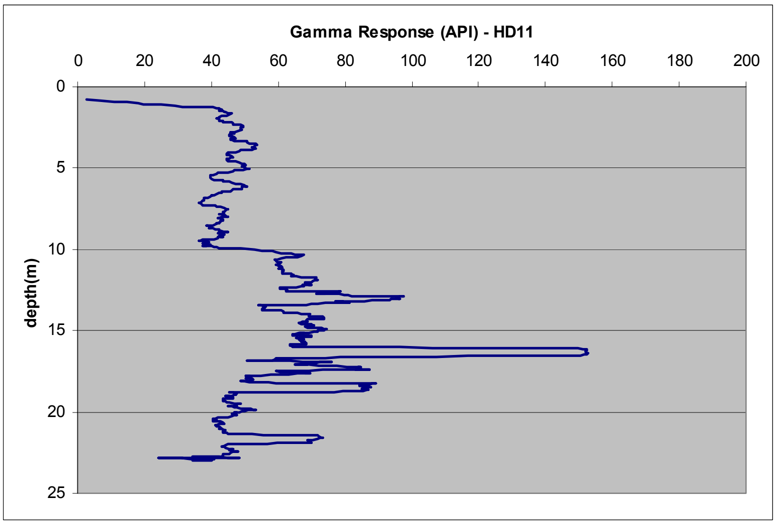
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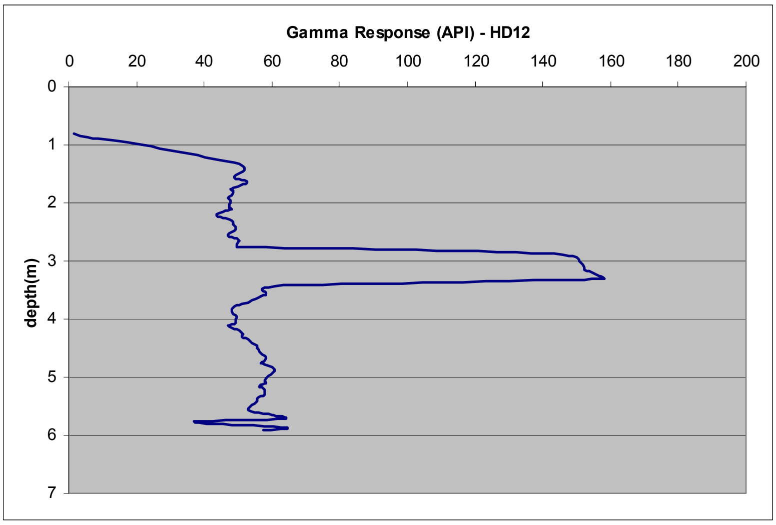
depth(m)
0 5 10 15 20 25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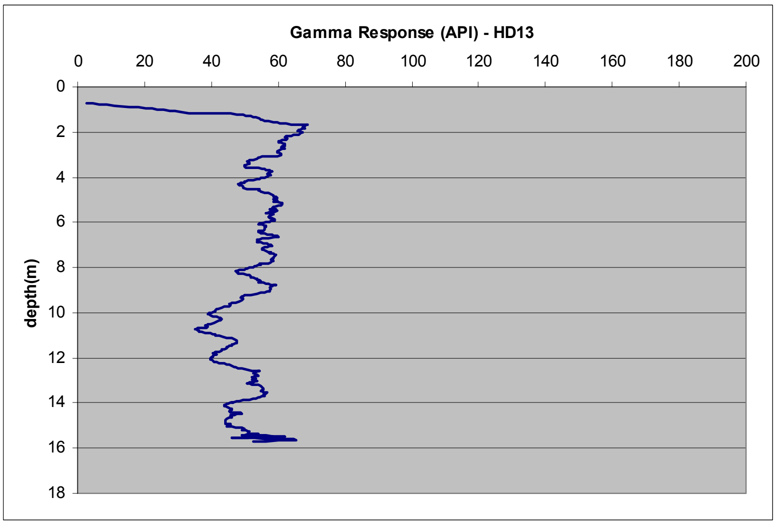
80
100
120
140
160
180
200
0
1
2
3
4
5
6
7
depth(m)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20
40
60
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100
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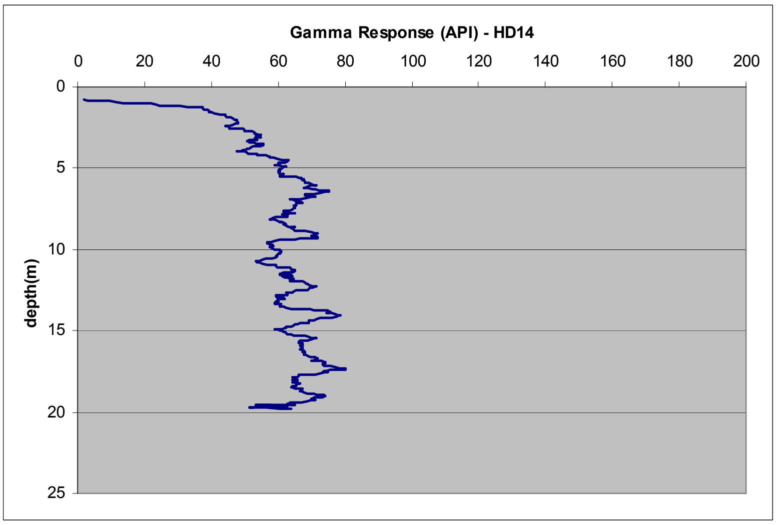
140
160
180
200
0
2
4
6
8
10
12
14
16
18
depth(m)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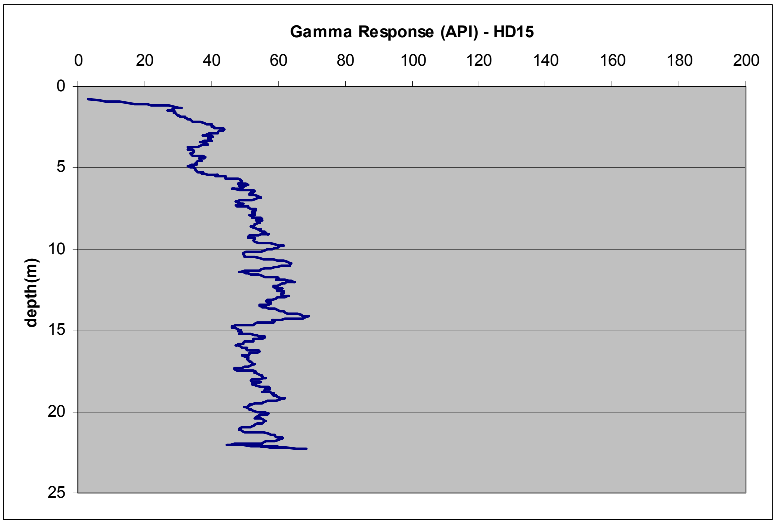
10
15
20
25
depth(m)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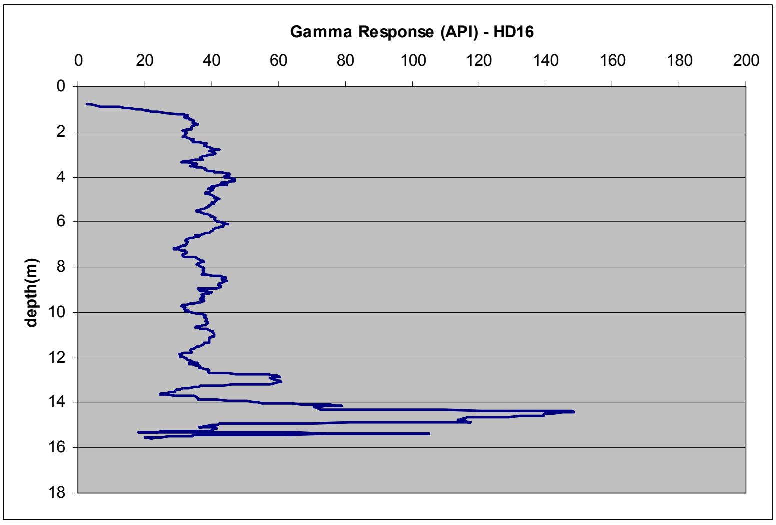
depth(m)


Gamma Response (API) - HD16
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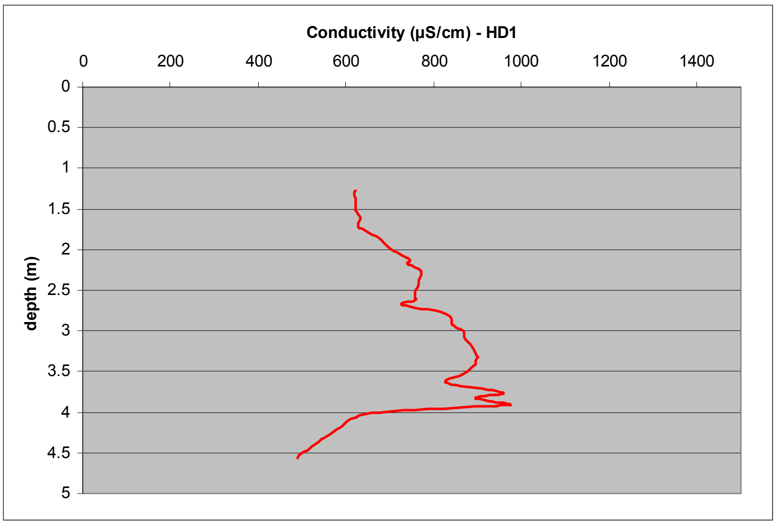
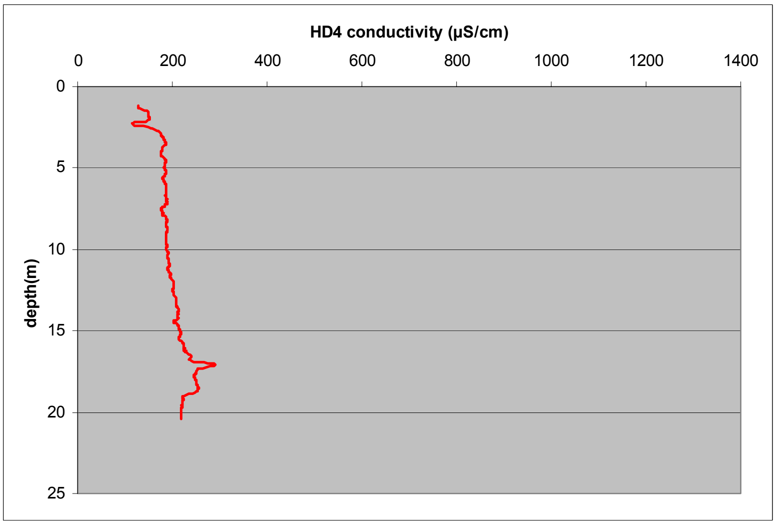
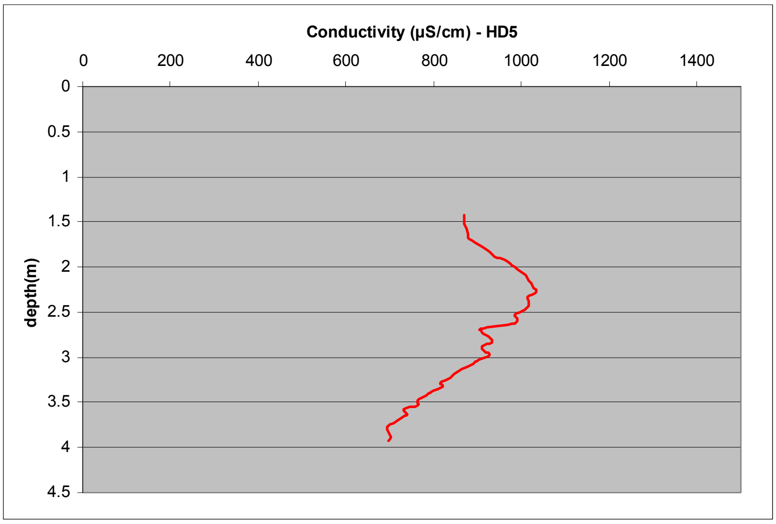
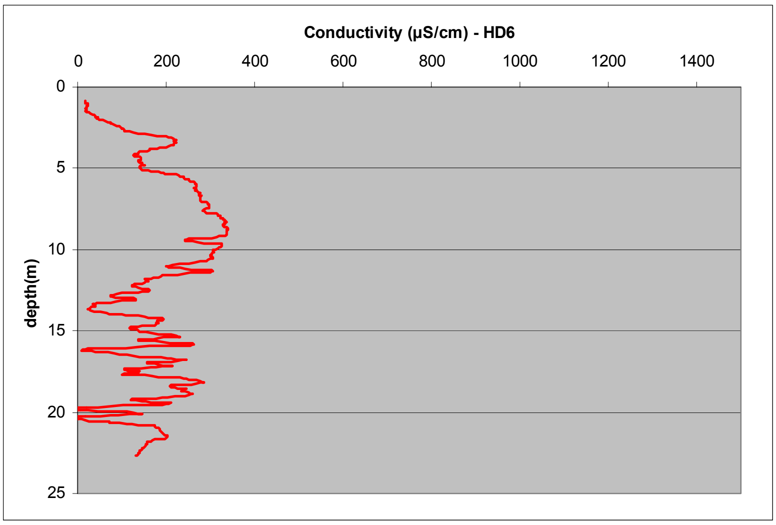
depth(m)

APPENDIX 2 : EM39 CONDUCTIVITY LOGS








Conductivity (µS/cm) - HD6
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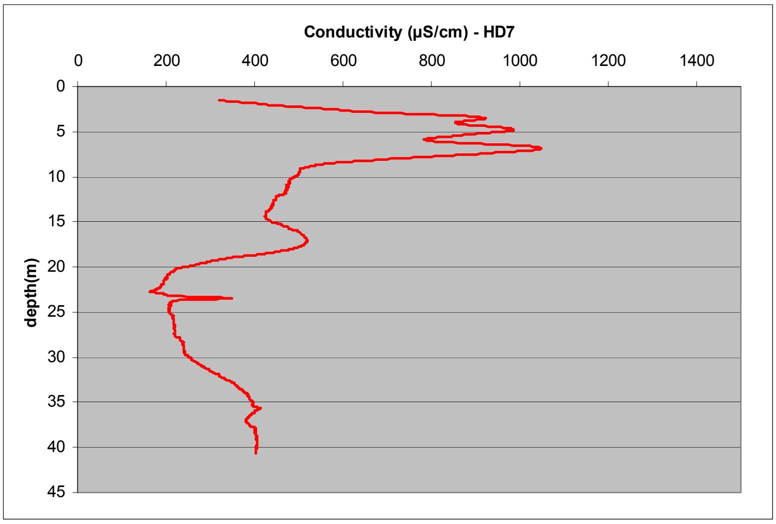
200
400
600
800
1000
1200
1400
depth(m)
0
5
10
15
20
25


Conductivity (µS/cm) - HD7
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400
600
800
1000
1200
1400
depth(m)
0
5
10
15
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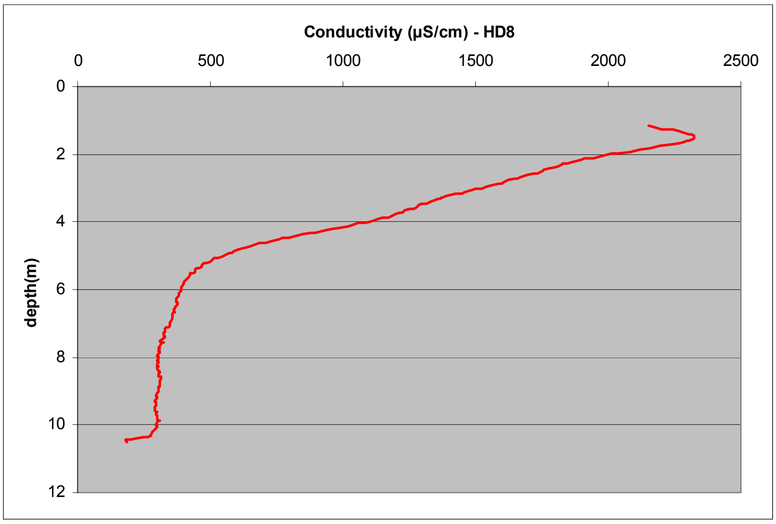
25
30
35
40
45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2000
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depth(m)
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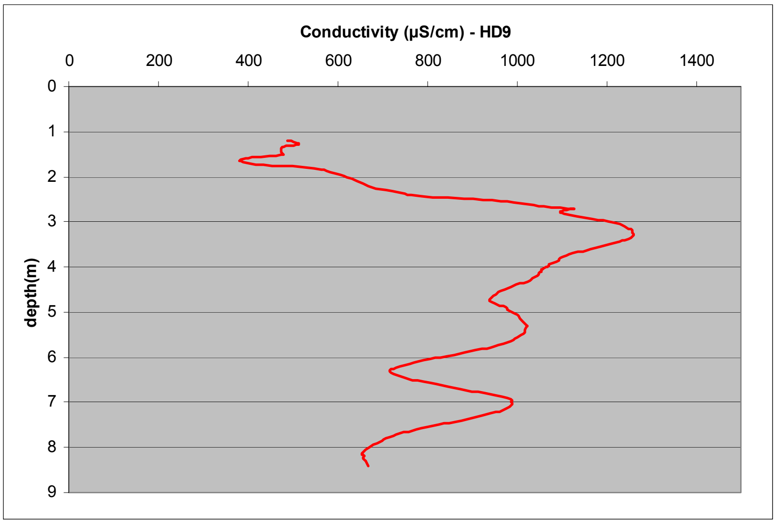
2
4
6
8
10
12


Conductivity (µS/cm) - HD9
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600
800
1000
1200
1400
depth(m)
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1
2
3
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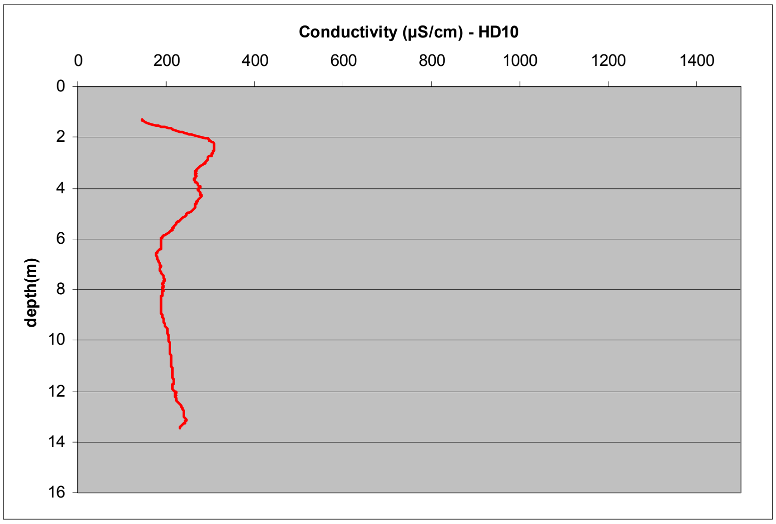
5
6
7
8
9


Conductivity (µS/cm) - HD10
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depth(m)
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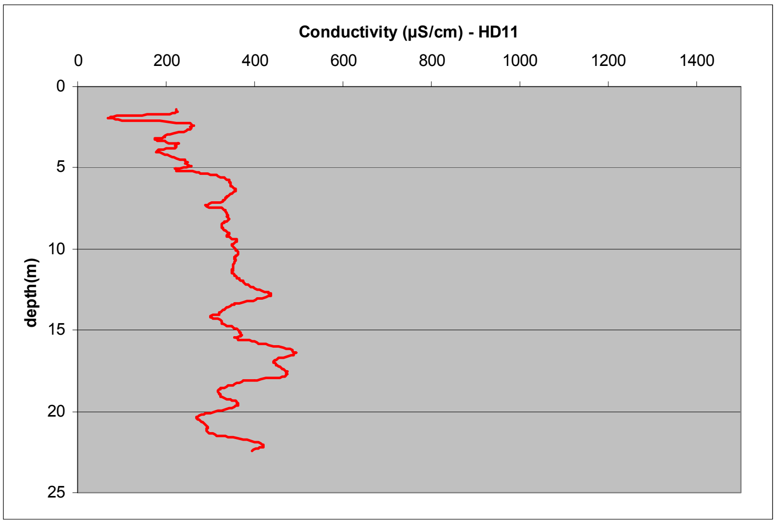
4
6
8
10
12
14
16


Conductivity (µS/cm) - HD11
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200
400
600
800
1000
1200
1400
depth(m)
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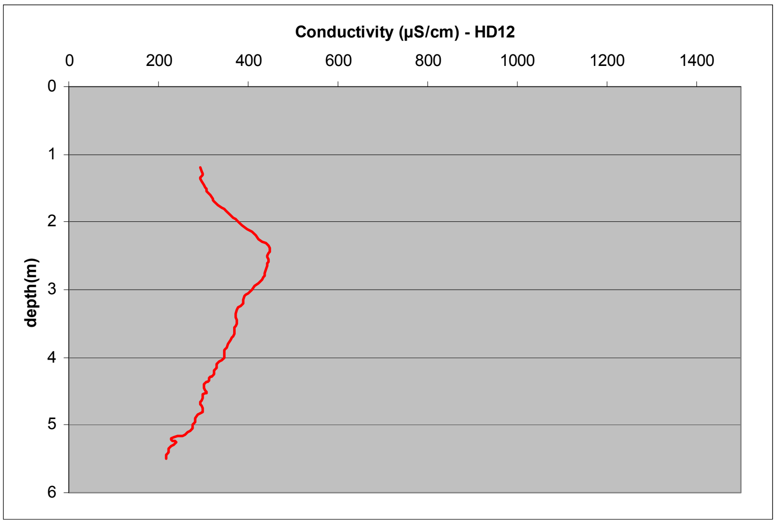
5
10
15
20
25


Conductivity (µS/cm) - HD12
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400
600
800
1000
1200
1400
depth(m)
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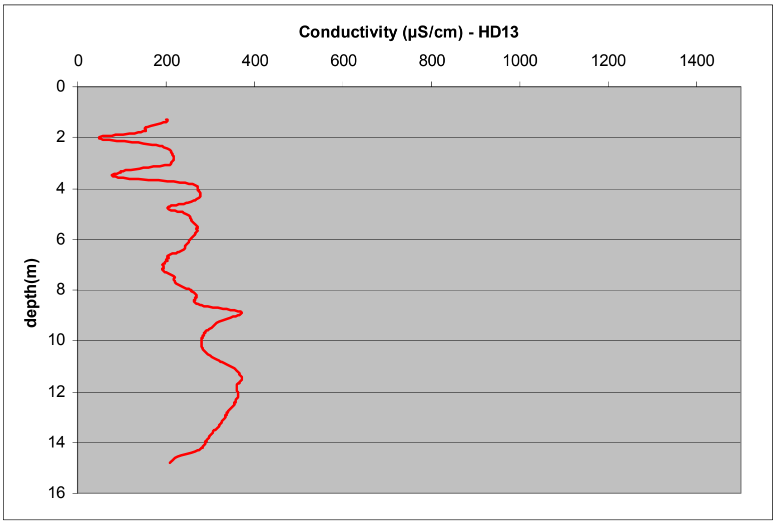
1
2
3
4
5
6


Conductivity (µS/cm) - HD13
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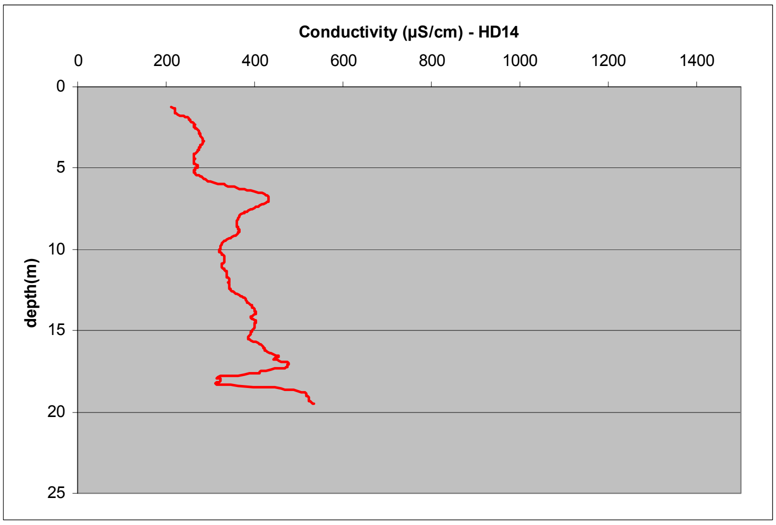
400
600
800
1000
1200
1400
depth(m)
0
2
4
6
8
10
12
14
16


Conductivity (µS/cm) - HD14
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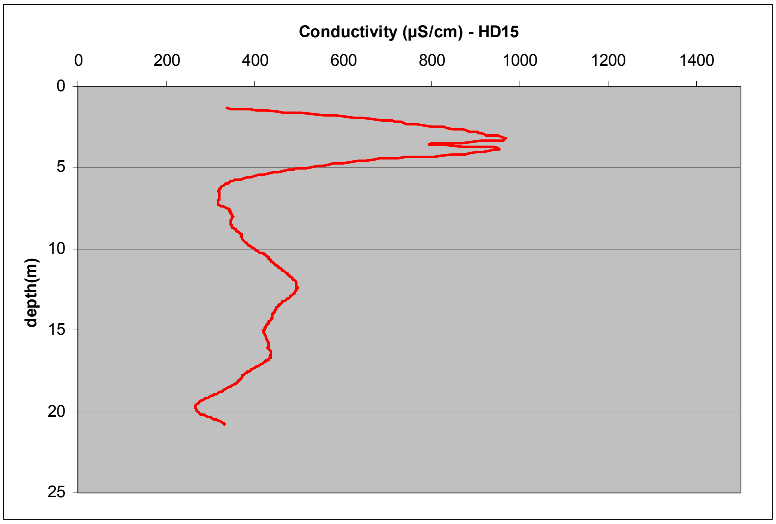
200
400
600
800
1000
1200
1400
depth(m)
0
5
10
15
20
25


Conductivity (µS/cm) - HD15
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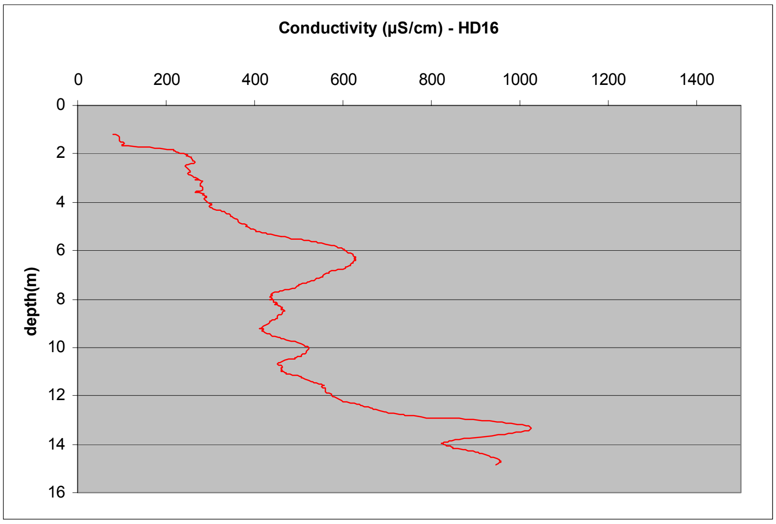
200
400
600
800
1000
1200
1400
0
5
10
15
20
25
depth(m)


Conductivity (µS/cm) - HD16
0
200
400
600
800
1000
1200
1400
0
2
4
6
8
10
12
14
16
depth(m)

APPENDIX 3 : EC 1:5 TEST RESULTS

Sample ID	EC 1:5 (µS/cm)		Sample ID	EC 1:5 (µS/cm)
HD1 – 5m	34.6		HD10 – 5m	7.81
			HD10 – 10m	12.6
HD4 – 5m	7.42			
HD4 – 10m	5.91		HD11 – 5m	9.93
HD4 – 20m	10.5		HD11 – 10m	12.2
			HD11 – 20m	18.2
HD5 – 5m	68.5			
HD5 –10m	37.0		HD12 – 5m	16.5
HD6 – 5m	24.3		HD13 – 5m	8.45
HD6 –10m	164		HD13 – 10m	9.92
HD6 – 20m	18			
			HD14 – 5m	31.6
HD7 – 5m	79.7		HD14 – 10m	77.5
HD7 –10m	312		HD14 – 20m	46.8
HD7 – 20m	62.0		HD14 – 30 m	43.9
HD7 – 30m	17.0			
HD7 – 40m	32.8		HD15 – 5m	24.8
HD7 – 50m	49.3		HD15 – 10m	18.1
			HD15 – 20m	23.5
HD8 – 5m	48.2			
HD8 – 10m	29.1		HD16 – 5m	23.4
			HD16 – 10m	20.3
HD9 – 5m	58.7		HD16 – 20m	23.4
HD9 – 10m	34.0		HD16 – 30m	13.6
HD9 – 20m	41.7		HD16 – 40m	16.2
HD9 – 29.5m	28.7			

APPENDIX 4 : STREAM SURVEY RESULTS*

Site	Easting	Northing	4/03/03	4/04/03	4/05/03	4/06/03	4/07/03	4/08/03	4/09/03	4/10/03	4/11/03	4/12/03	4/01/04	4/02/04	4/03/04
1	616909	6184362	1000	1000	1100	1200	1500	1200	1300	1400	1400	1400	-	1600	1300
2	625208	6180056	2400	2200	2100	2100	2200	1900	2100	2100	1800	1700	-	1800	1800
3	615451	6174517	2100	1100	1500	1500	1600	1600	1300	1400	1500	1000	-	1900	2400
4	619608	6177432	2100	1400	1200	1500	1400	1300	1300	1200	1400	1500	-	1600	Dry
5	626118	6185335	2300	2700	2300	1200	1300	1000	500	600	1000	200	-	1900	2100
6	625591	6189059	3500	2500	2300	1100	1000	800	600	700	1000	100	-	100	1100
7	620137	6191630	1900	1400	1300	600	500	500	400	600	600	-	-	-	-
7a	619904	6194369	1100	1100	1000	600	500	600	300	500	400	500	-	700	700
8	606469	6179563	2500	-**	1300	700	1200	1100	-	-	-	-	-	-	-
10	614807	6190376	Dry	-	-	Dry	300	Dry	-	-	-	-	-	-	-
11	626120	6178647	1600	1000	600	1900	1700	1800	1900	1800	180	170	-	180	1300
12	624103	6176145	2100	2000	1700	2100	1700	1700	1700	-	1500	1600	1900	1600	-
13	622745	6171400	1700	2000	-	-	1700	1700	1500	-	1500	900	1900	1700	-
14	620208	6176555	1700	1700	-	1500	1300	1300	1100	-	1500	1600	1900	1800	-
15	621672	6174223	2300	2300	-	1500	1700	1400	1200	-	1100	1300	2100	2100	-

***All stream survey electrical conductivities are given in μS/cm.**

**** '-' denotes no data**