Assessment of hydraulic conductivity in coastal floodplain acid sulfate soils on the north coast of NSW

REPORT PREPARED FOR THE SIX NORTH COAST COUNCILS OF NSW, MARCH 2009

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Cover design by the Publication and Communications Industry & Investment NSW. Cover photos: Groundwater sampling in the Kempsey Frogmore site by Belinda Allman. Insert photo one, is surface iron deposits found at Roches in the Manning, photo two, macropores visible in a ped in the Richmond, photo three, corrosion of a concrete fence post in an acid sulfate soil environment on the Clarence. Photographs in report by principle author.

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Assessment of hydraulic conductivity in coastal floodplain acid sulfate soils on the North Coast of NSW

Report prepared for the six north coast councils of NSW

Prepared by:
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March 2009

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1. Introduction

Estuarine wetlands are characterised by complex interactions between vegetation type, surface water fluxes and porewater movement. Hydrology is a key determinate in species distribution, in wetland biomass productivity, nutrient cycling and availability. To be able to understand the intimate relationship between estuarine wetland ecology and hydrology, knowledge of wetland hydrology is critical if we are able to predict and manage change in wetland environments. These include both long-term gradual changes such as climate change and projected sea-level rise, and sudden changes resulting from human interference such as hydraulic modifications to drainage systems and or tidal flow (Hughes et al. 1998).

Saturated hydraulic conductivity (K_{sat}) is a measure (quantitative expression) of a saturated soil's ability to transmit water when subjected to a hydraulic gradient. Influences include gradients, soil ripeness, macropores, soil type, flow direction, flow rates. K_{sat} is a critical variable affecting the hydrology and acid export dynamics of drained acid sulfate soils (ASS). Assessment of K_{sat} in ASS is important in order to design appropriate management strategies for broadacre remediation projects. It has a controlling influence upon the lateral movement of solutes and rates of acidic groundwater drainage plus the behaviour of the groundwater table relative to adjacent drains (Cook et al. 1999; Cook and Rassam, 2002; Johnston et al. 2004).

1.1 Hydraulic conductivity of acid sulfate soils

Acidic groundwater seepage towards drains: In ASS the two main hydrological pathways for acid export are surface runoff and groundwater seepage (Fig. 1). When deep, artificial drains intersect sulfuric horizons with high K_{sat}, groundwater seepage is likely to be a major component of the acid flux and drain water acidity can be acute (Johnston et al. 2002). This is particularly the case if the sulfuric horizons are significantly higher in elevation than tidally influenced low water levels in the adjacent drain (Fig. 1).

Saline seepage from drains to soils: High hydraulic conductivity increases the connectivity between drains and adjacent groundwater levels in ASS backswamps. Whilst tidal drawdown in the drain can lower groundwater levels, resulting in a pathway for acidity and other oxidation products, and conversely, high drain water levels can help recharge shallow groundwater and seepage of saline drain water solutes into shallow groundwater for significant distances across the backswamp (Johnston et al. 2005).

Shallow groundwater (<1m from the surface) in a backswamp can have high concentrations of acidic metal cations such as iron and aluminium. When combined with a dense drainage network and high hydraulic conductivity soils, groundwater seepage can be an efficient pathway for rapid acid export.

Figure 1 following illustrates some typical dynamics and features associated with the two main pathways of acid flux from ASS, groundwater seepage and surface run-off.

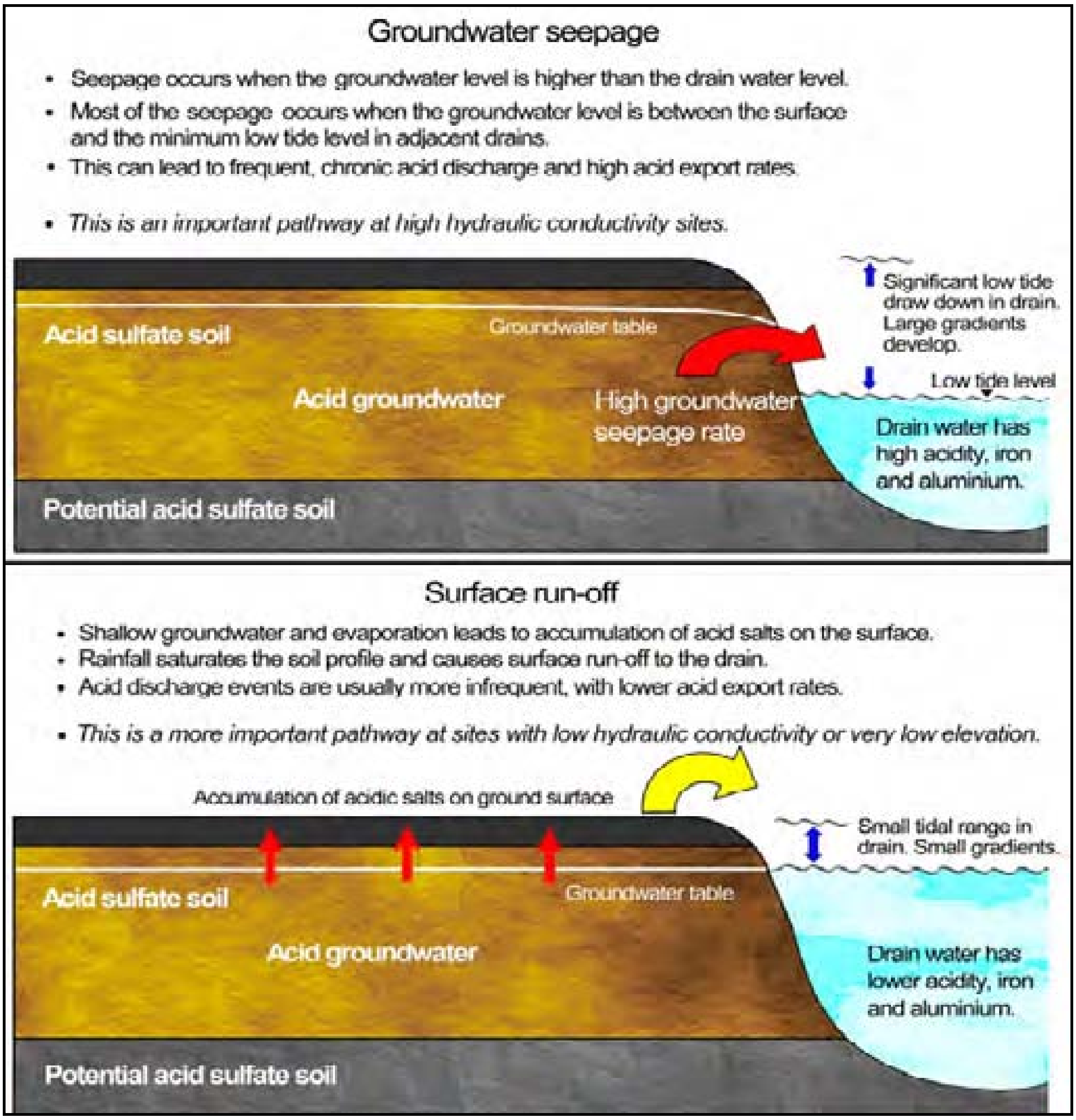

Figure 1. Groundwater seepage pathways.
(source: Johnston et al., 2003b)

The K_{sat} of sulfuric horizons in coastal ASS is a critical factor governing the hydrological behaviour of ASS backswamp groundwater. Therefore some site specific knowledge of K_{sat} is ideally required to identify skilful management options for the remediation of ASS sites, particularly with regards to:

Identifying pathways of acid export (groundwater seepage vs surface water runoff)
Identifying different types of containment strategies
Opening floodgates and potential for lateral salt seepage.

Current knowledge of the range and spatial variability of K_{sat} in sulfuric horizons within ASS in NSW is very limited. To date there have been no systematic spatial surveys of K_{sat} in coastal ASS floodplains using consistent methodology. There is currently little data on the variability of sulfuric horizon K_{sat} within floodplain geomorphic units or across individual coastal ASS floodplains.

1.2 Aims

This study aims to conduct a quantitative strategic assessment of the range and spatial variability of saturated hydraulic conductivity (K_{sat}) in shallow sulfuric horizons at important coastal acid sulfate soil (ASS) locations on the North Coast of NSW.

A major component of the project is the informal, hands-on training opportunity for local council floodplain officers to conduct the simple and semi-quantitative form of this test (Johnston and Slavich, 2003), and to analyse and interpret data from the K_{sat} pit tests.

2. Methodology

2.1 Study area

The study area consists of six catchments on the North coast of NSW (Tweed, Richmond, Clarence, Hastings, Macleay, and Manning). A number of sites were selected within each catchment in high risk ASS areas in consultation with local council floodplain officers.

K_{sat} can be highly variable over short distances and often varies vertically down the soil profile according to the characteristics of the soil horizons. K_{sat} can also be different in the horizontal and vertical planes within an individual soil horizon. In ASS backswamps K_{sat} may be related to the geomorphic history and origins of the underlying sediments, and thus may show some trends related to site topography. Typically, K_{sat} is highly spatially heterogeneous. The number of pit-tests conducted and location of pits should be related to your data needs. If you want some idea of the variability of K_{sat} it will be important to construct a number of pits across a site.

Figure 2. Broadwater wetland on the Clarence.

Figure 3. Northern NSW study area.

2.2 Hydraulic conductivity

Saturated hydraulic conductivity ($K_{sat)}$ is a measure (quantitative expression) of a saturated soil's ability to transmit water when subjected to a hydraulic gradient. Factors which influence K_{sat} include -soil structure, soil texture, soil ripeness, macropores and soil type. The field measurement of saturated hydraulic conductivity normally combines both macropore and soil matrix flow. Macropores are defined as large voids in the soil, such as from decayed root channels, worm holes or crab burrows and may include structural cleavage or cracks (Australia Soil and Land Survey, 1984). Water flux which is the quantity of water moving through a cross-sectional area per unit time, and is commonly expressed on a volume basis $m^3m^{-2}s^{-1}$, this simplifies to a velocity unit ms^{-1}. Flux is not a velocity rate but represents a volume (discharge) through a cross-sectional area per unit time measure.

The (K_{sat}) of sulfuric horizons documented in this report was measured using an *in-situ* recovery test based on shallow pit-bailing techniques (Bouwer and Rice, 1983; Boast and Langebartel, 1984; Johnston and Slavich, 2003 pp.1-9).

The Pit-test method (Appendix 9) was selected in part for its simplicity and practicality as a training tool and extension technique. In addition, it is a relatively large scale method, better able to account for high degrees of spatial heterogeneity typical in many soil properties. This is an important consideration for coastal ASS landscapes which may have extensive macropore networks (Johnston et al. 2004). The spatial heterogeneity of K_{sat} in shallow coastal ASS aquifers means that realistic field scale estimates based on small scale methods (i.e. auger hole slug tests, permeameters, particle size analysis) can be unrepresentative (Millham and Howes, 1995). This is particularly true when groundwater flow is dominated by macropores whose size and spatial variability are high relative to the size of area sampled (Bouma, 1991). For this reason, tests which average aquifer response over larger areas (i.e. pit bailing or tidal signal damping) are far more likely to be representative of actual field K_{sat} values. This field pit test has a number of advantages and limitations listed in Johnston and Slavich 2003. It was chosen for this project because a) it is amenable to providing an informal learning opportunity, b) it is useful as an extension tool, c) the water level recovery data can be quantitatively analysed using well established methods (i.e. Bouwer and Rice, 1983; Boast and Langebartel, 1984) it is well suited to assessing shallow sulfuric horizons. This single technique was replicated in all six catchments, for comparative assessment.

2.2.1 Pit geometry

Shallow rectangular pits (up to 0.6 m deep and 0.5 m^2) were excavated at strategic locations in each surveyed backswamp, with sites chosen in consultation with local council officers. Pit dimensions and the equilibrium water level before bailing were recorded (Fig. 3). The water was bailed rapidly using a 10 L bucket to remove ~50-90% of the total water in the pit. Water level recovery was measured every 5 or 20 seconds on a ruler with 1mm graduations. Two tests were conducted in each pit. K_{sat} was quantitatively calculated according to the methods of Bouwer and Rice (1983) and Boast and Langebartel (1984). In the latter case shape factors developed specifically for rectangular pit geometries were used (Boast and Langebartel 1984, pp 12). Pit dimensions were chosen to reduce the range of L/W (Fig. 3) encountered and thus constrain the range of shape factors employed by the different methods.

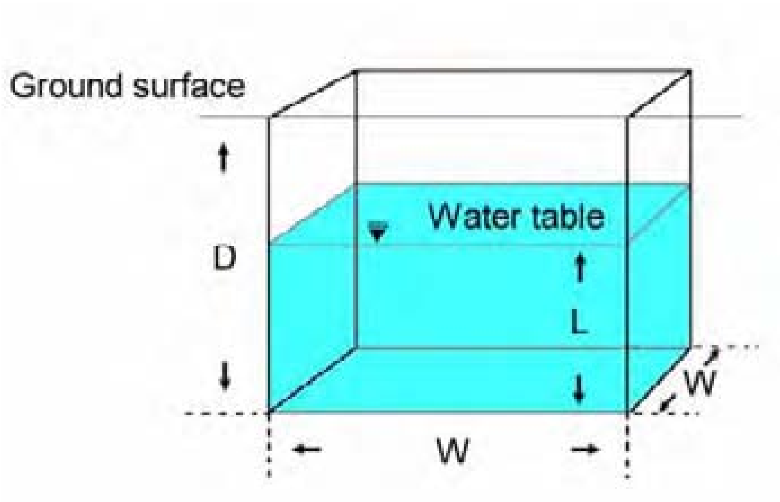

Figure 4. The geometry of excavations used in pit bailing methods.

A full description of the physical aspects of the method provided in Appendix 9.

Figure 5. Thor Aaso using a gouge auger in a K_{sat} pit, in the Hastings.

2.2.2 Additional data collected

Additional information collected in the field with the pit infill data includes:

1. A soil profile description,
2. A sample of groundwater (GW) collected from infill after bailing. Measurements include pH, and Electrical Conductivity (EC), with a TPS 90FLMV portable water quality meter.
3. The Geonics EM38 electromagnetic induction meter used to determine rootzone salinity in areas with shallow saline water tables. This EM38 survey technique used at a number of K_{sat} sites to survey apparent soil EC, both at the surface and at a depth of ~1 m. The EM38 is non-invasive, is timely and allows surveys over a wide area.
4. GPS co-ordinates of sites listed in appendix 1.

Figure 6. Chrisy Clay and Phil Hirst with EM38 meter.

3. Interpreting data

3.1 K_{sat} graphs

The pit refill graphs indicate the raw values collected in the field. The resultant plot shows the normalised pit refill rate verses time. The plot line will fall into one of four broad categories listed below which *approximate* the following K_{sat} ranges. Note that this method of plotting the data provides an approximation only. Actual quantitative K_{sat} values are listed in Tables and are derived using two methods - Bouwer and Rice, 1983 and Boast and Langebartel, 1984.

Low = less than 1.5m day^{-1}
Medium = 1.5 to 15m day^{-1}
High = 15 to 100m day^{-1}
Extreme = greater than 100m day^{-1}

3.2 Graph and Table interpretation

Sites with Low range K_{sat}, the risk of lateral water seepage is likely to be minimal, either influent (i.e. the drain water level is higher than the groundwater level) or effluent.

For sites in the medium K_{sat} range, further quantitative assessment of K_{sat} may be warranted in order to assess the risk of lateral salt seepage due to a floodgate opening. Monitoring the response of drain and ground water levels during a freshwater floodgate opening event may also be useful.

If a sites K_{sat} falls in the high to extreme range there is a substantial probability that groundwater seepage may be a major hydrological pathway of acid export. If the shallow groundwater is also highly acidic then a containment strategy will likely be an important management option. This includes options such as containing groundwater by a) reducing drainage density via infilling or shallowing drains, or b) by using a retention structure to keep drain water levels high and stable to prevent the development of effluent groundwater gradients through tidal drawdown. If floodgates opened and saline water introduced into a drain there is also a possibility that this saline water could move laterally away from the drain over considerable distances.

Other factors to consider which will influence a sites hydrological behaviour include,

the elevation of acidic horizons relative to local low tide levels in adjacent drains,
whether the drain intercepts those high K_{sat} soil horizons,
whether there is the existence of semi-confining layers via pugging and blockages of macropores at the drain bank face,
post-deposition vegetation history.

3.3 EM38 charts

The Geonics electromagnetic induction soil conductivity meter, measures apparent electrical conductivity (ECa) of soil in situ. Two types of ECa measurements can be made, horizontal readings (EMh) for surface salts and vertical readings (EMv) measures from 1m to 1.5m at depth. If EMh>EMv then salts are highest near the surface. In low lying floodplain environments high ECa readings are often correlated with acidic and/or marine solutes and thus can be a useful surrogate to indicate oxidised acid sulfate soils or areas of past/present tidal inundation.

Table 1. Apparent Electrical Conductivity (mS/m) categories in estuarine clay.

Coastal floodplain	Low	Medium	High	Very High
Estuarine clay dominate landscape	<100	100-200	200-400	>400

Figure 7. EM38 at Farlows on the Clarence.

4. Results

4.1 Tweed River Catchment Sites

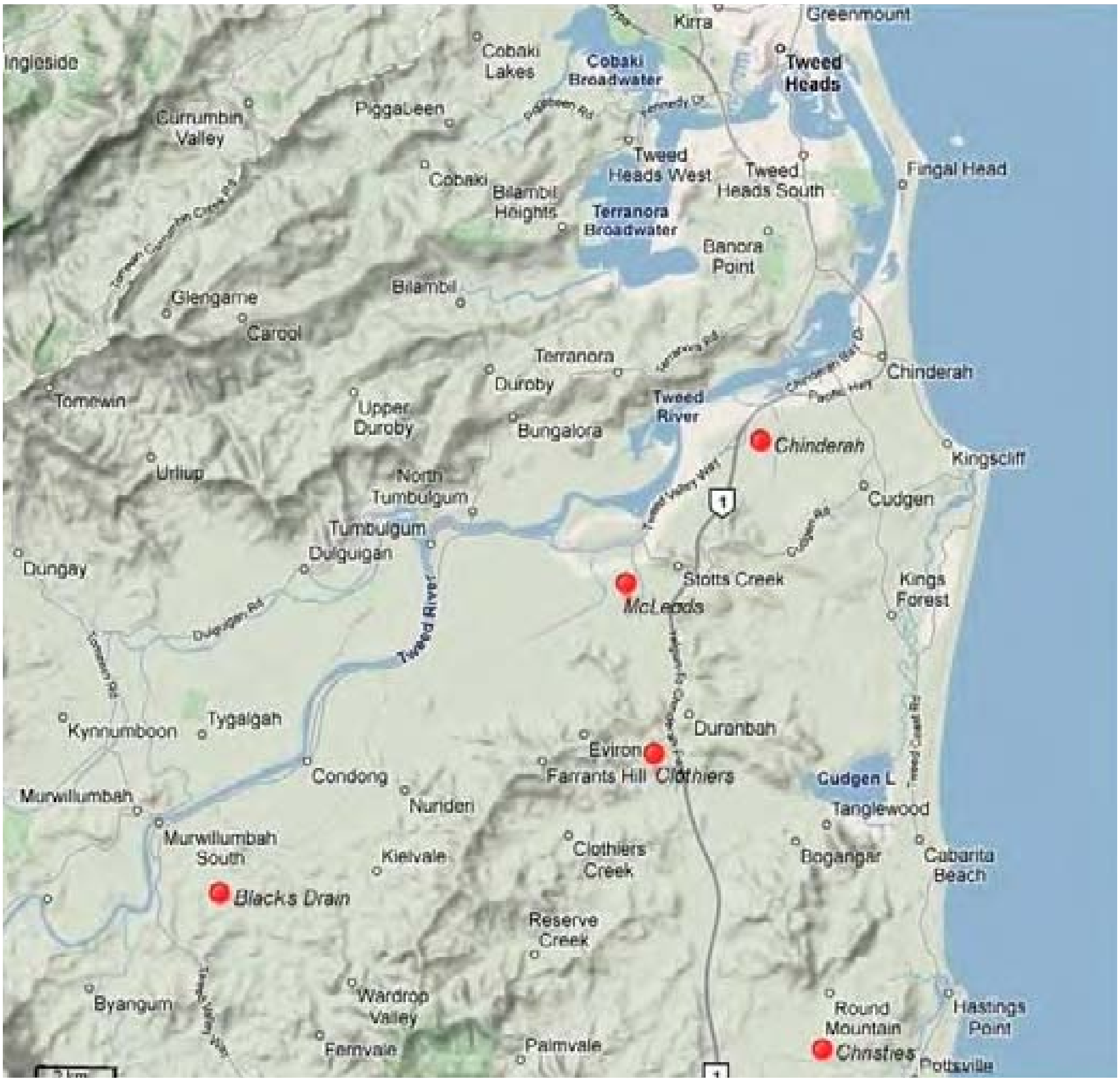

Figure 8. Tweed site

4.1.1 Blacks Drain

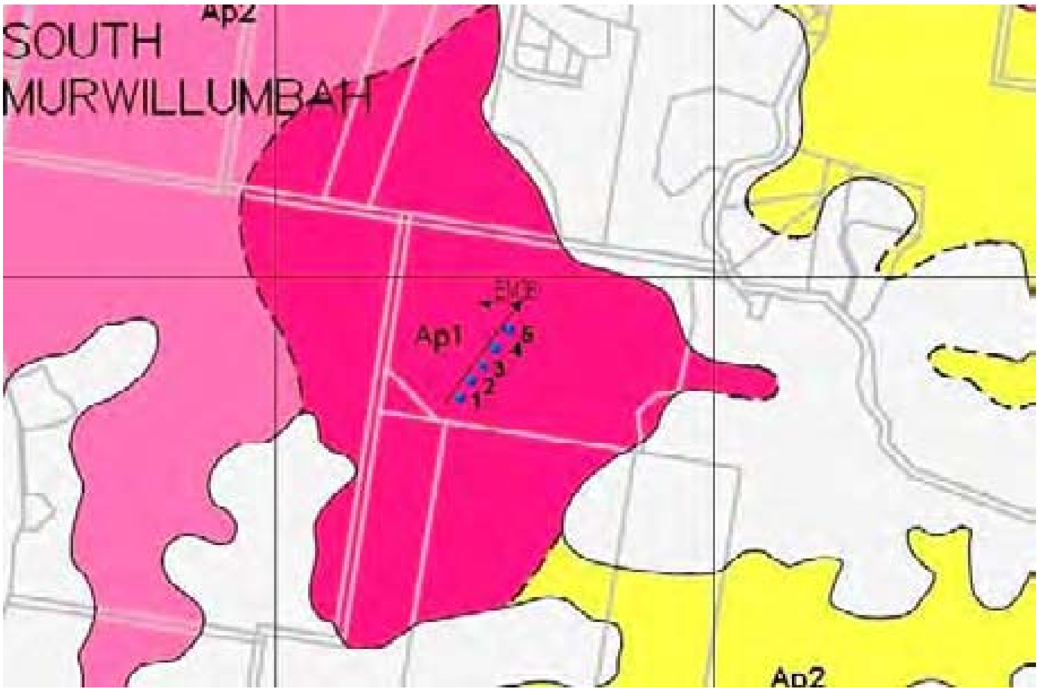

Figure 9. Five K_{sat} pit locations and two EM38 transects (Legend: appendix 7).
(source: Naylor et al., 1998)

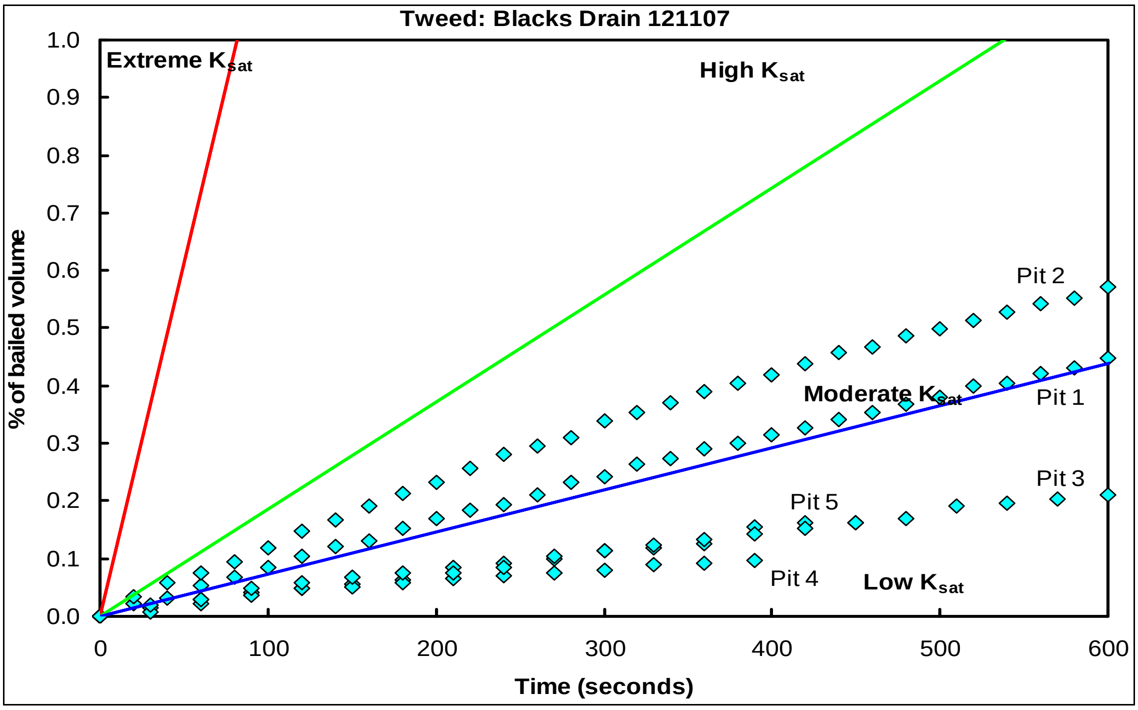

Figure 10. Normalised water level recovery rate over time, Stainley cane field.

Soil description: Few to common mottling in all pits, macropores both vertical and horizontal orientation, few in abundance but fine to medium in diameter. Occasional old solid roots at depth, may indicate old forest area.

Table 2. Blacks Drain at Tweed, pit water quality and quantitative K_{sat} data.

Pit No.	Pit depth (cm)	Water table depth (cm)	Ground water quality		Hydraulic conductivity (m day^{-1})		
			pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	55	34.4	3.63	1.39	3.25	4.59	0.66
2	50	25.0	3.60	2.06	5.04	7.12	0.77
3	50	34.3			1.65	2.00	0.42
4	57	18.4	4.00	0.65	1.03	1.88	0.93
5	60	46.3	3.65	2.40	1.30	1.82	0.44

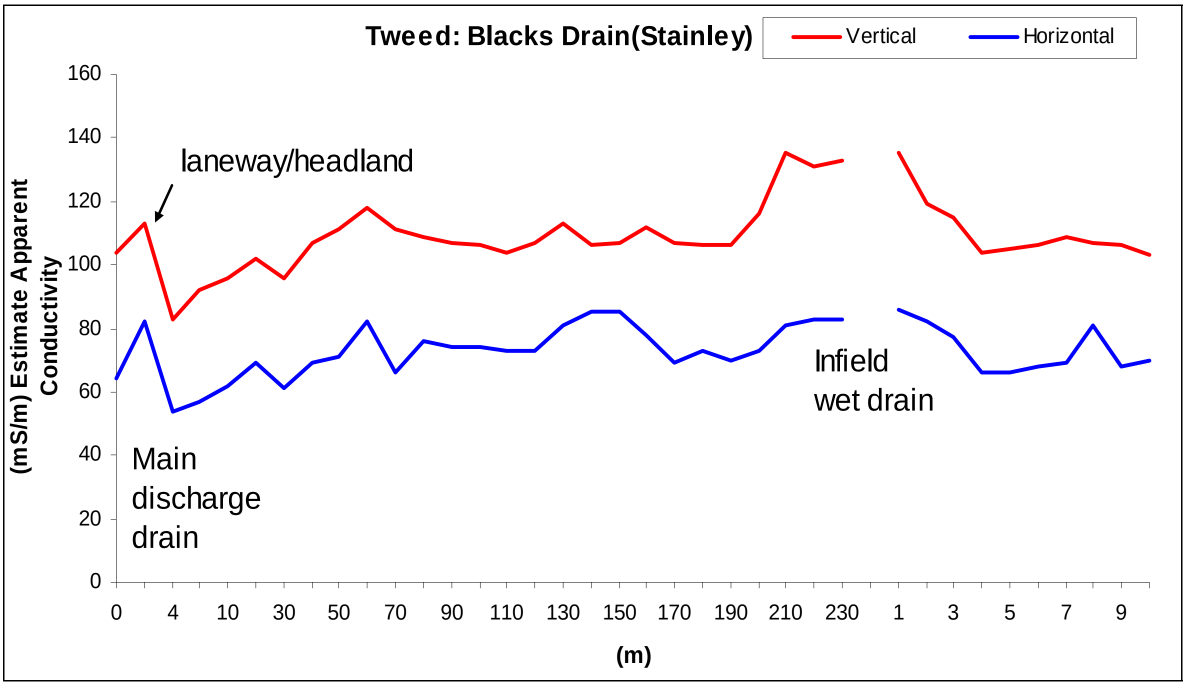

Figure 11. Blacks drain transect across cane field.

Transect from main drain to lower elevation area, intersects infield drain at 230m, drain holding water. Second transect continues perpendicular to infield drain finishing in centre of mounded cane bed.

4.1.2 McLeods Creek

Figure12. Seven K_{sat} pit locations and an EM38 transect at McLeods Creek.
(source: Naylor et al., 1998)

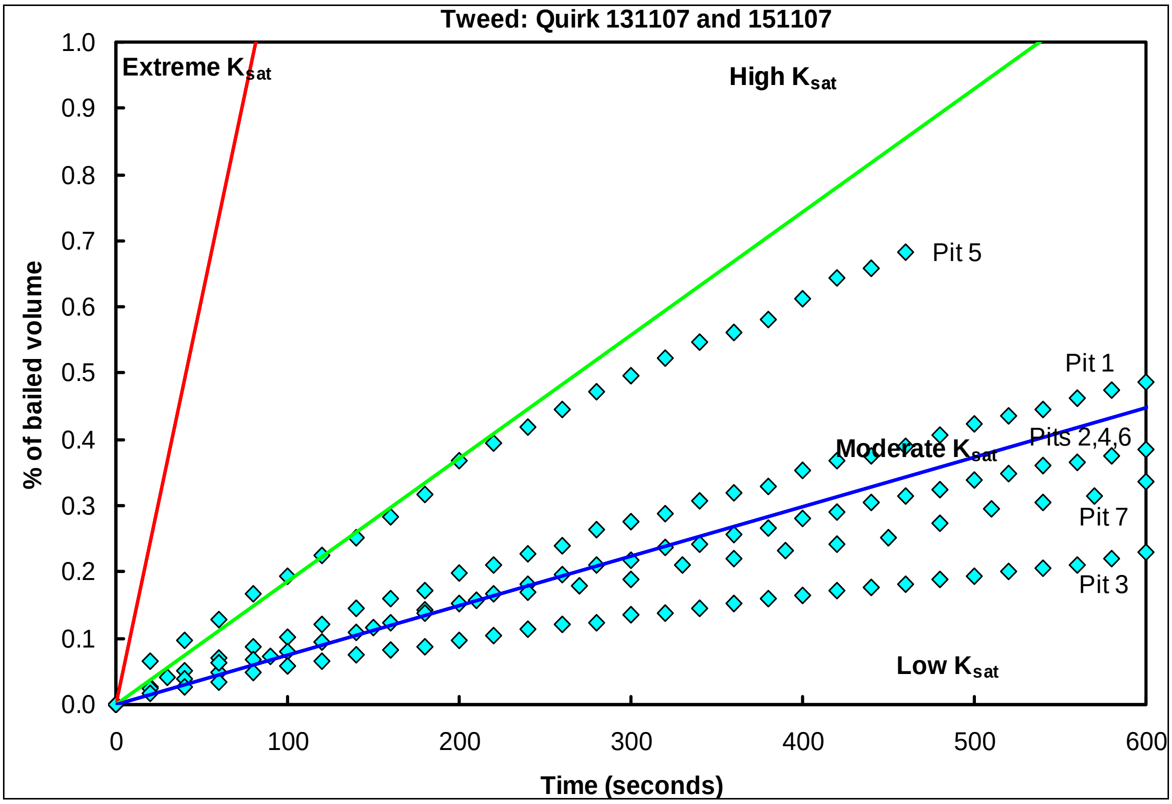

Figure 13. Normalised water level recovery rate over time, Quirks cane field.

Pits located in ratoon cane paddock adjacent to tidal main drain.

Soil description: Alluvial topsoil to medium clay subsoil. Few orange red mottles present in all pits. Macropores common, fine diameter, vertical orientation more dominate, pores visible above water table. Jarosite and old reed/root remnants found at depth.

Table 3. Quirks at Tweed, pit water quality and quantitative K_{sat} data.

Pit No.	Pit depth (cm)	Water table depth (cm)	Ground water quality		Hydraulic conductivity (m day^{-1})		
			pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	56	21.9	4.02	3.23	3.27	6.14	1.12
2	51	24.9	3.71	3.49	3.20	5.27	0.76
3	50	18.5	3.62	3.70	1.59	3.41	0.91
4	63	20.9	3.76	7.03	3.94	8.09	1.07
5	60	42.3	3.71	5.43	6.60	10.83	0.65
6	65	54.3	3.78	8.14	3.47	4.05	0.35
7	60	47.9	3.83	7.03	3.12	3.73	0.37

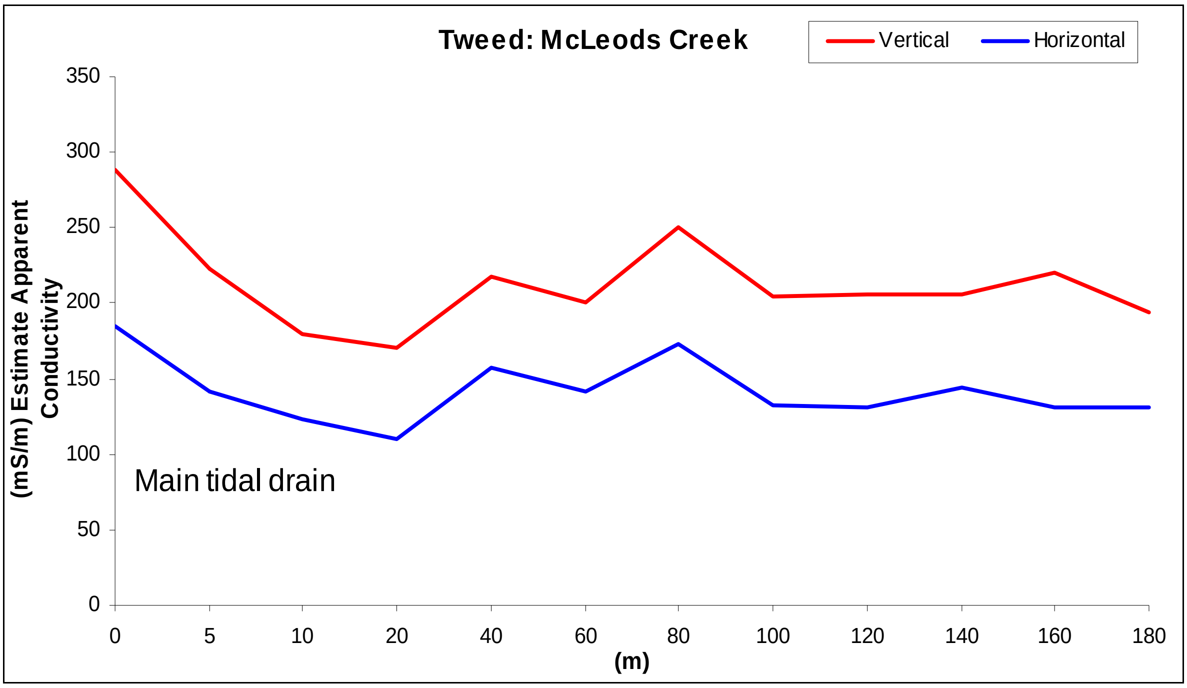

Figure 14. EM38 Quirk cane field.

EM38 transect from main tidal drain moving perpendicular into lower elevation area of cane field.

4.1.3 Clothiers Creek

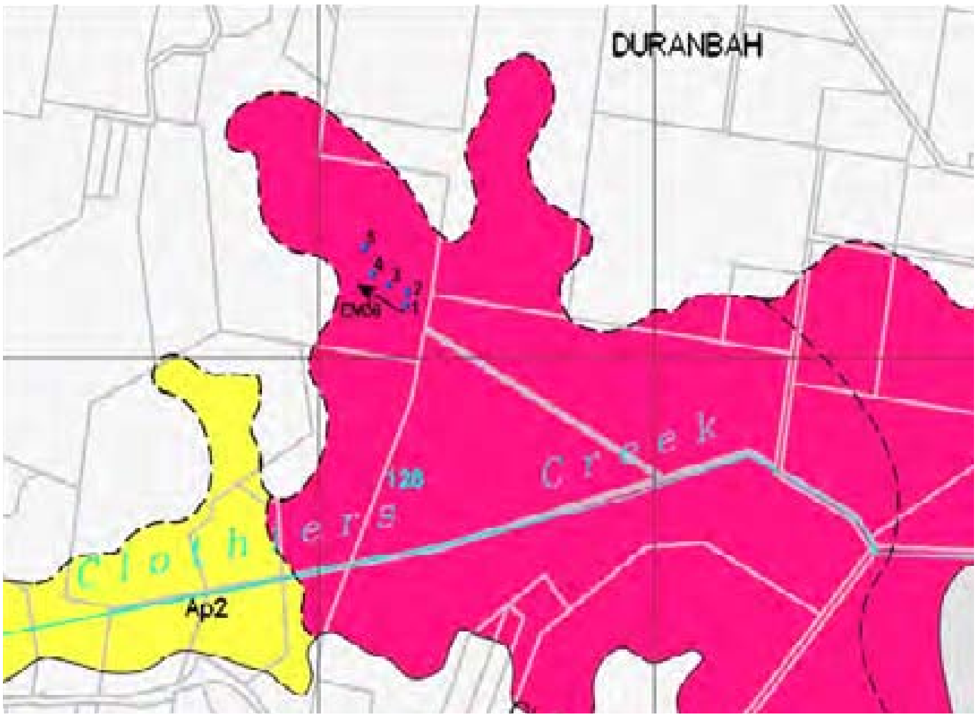

Figure 15. Five K_{sat} pits and an EM38 transect.
(source: Naylor et al., 1998)

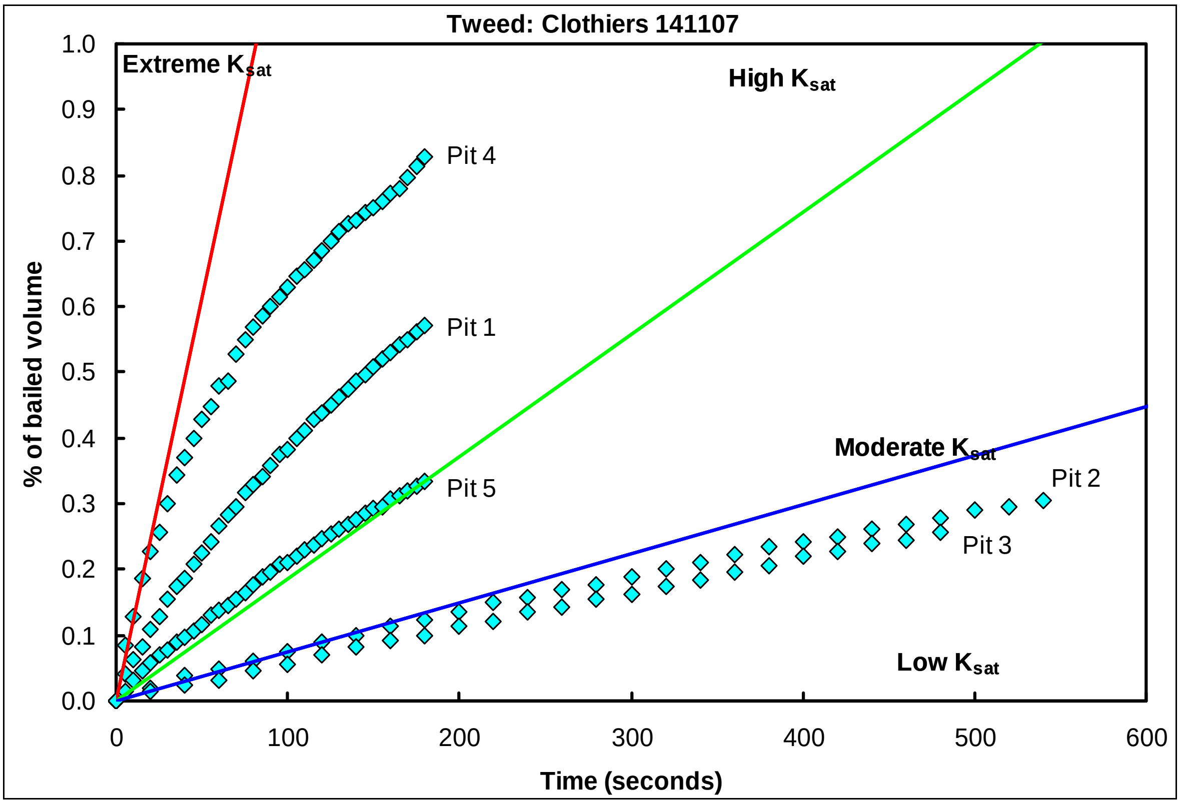

Figure 16. Normalised water level recovery rate over time, at Clothiers.

Clothiers hotspot remediation site, number of drains filled in, extensive soil disturbance reflected in range of K_{sat} rates and soil profile descriptions.

Soil description: Alluvial/peat topsoil with peat to depth. Little to no mottling observed, medium to common macropores, horizontal orientation the common.

Table 4. Clothiers at Tweed, pit water quality and quantitative K_{sat} data.

Pit No.	Pit depth (cm)	Water table depth (cm)	Ground water quality		Hydraulic conductivity (m day^{-1})		
			pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	38	11.5	3.13	4.19	19.34	33.03	0.75
2	46	18.7	3.86	1.50	3.15	6.41	0.76
3	44	6.9	3.06	3.89	2.19	5.14	1.05
4	53	10.2	3.16	3.93	56.25	104.46	1.06
5	44	16.9	3.25	2.43	10.32	16.98	0.75

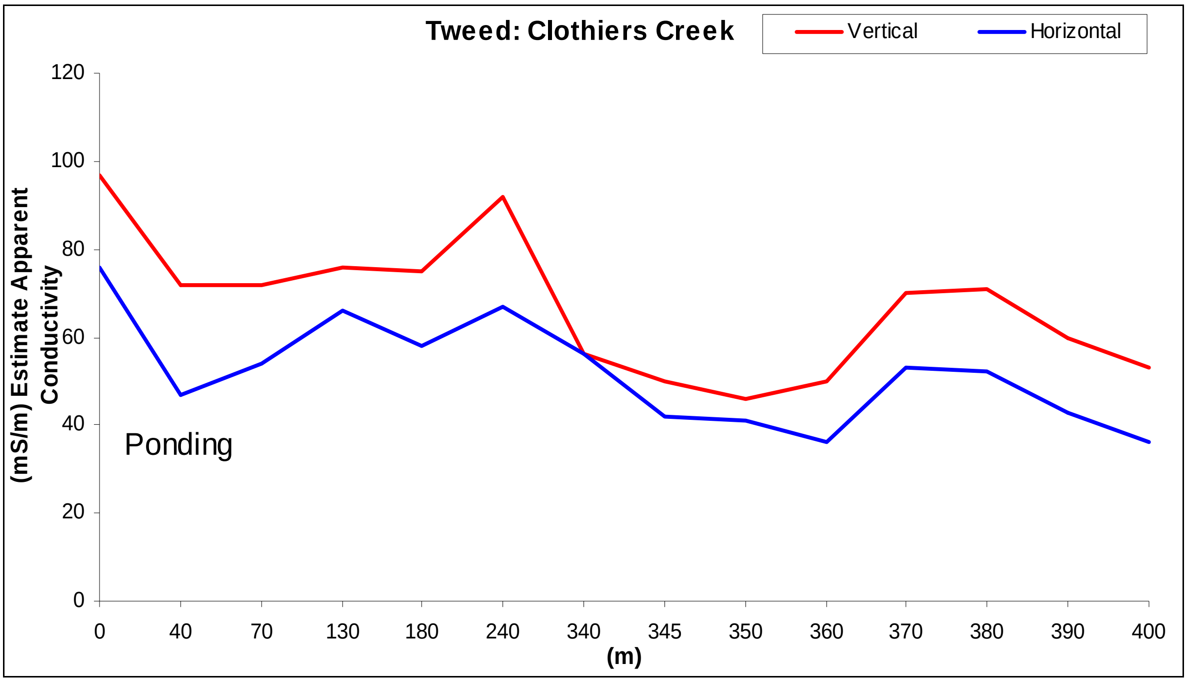

Figure 17. Clothiers Creek EM38 transect.

Transect, between ponded areas abundant with water couch, crossing drain at about 340m.

4.1.4 *Chinderah*

Figure 18. Five K_{sat} pits and an EM38 transect.
(source: Naylor et al., 1998)

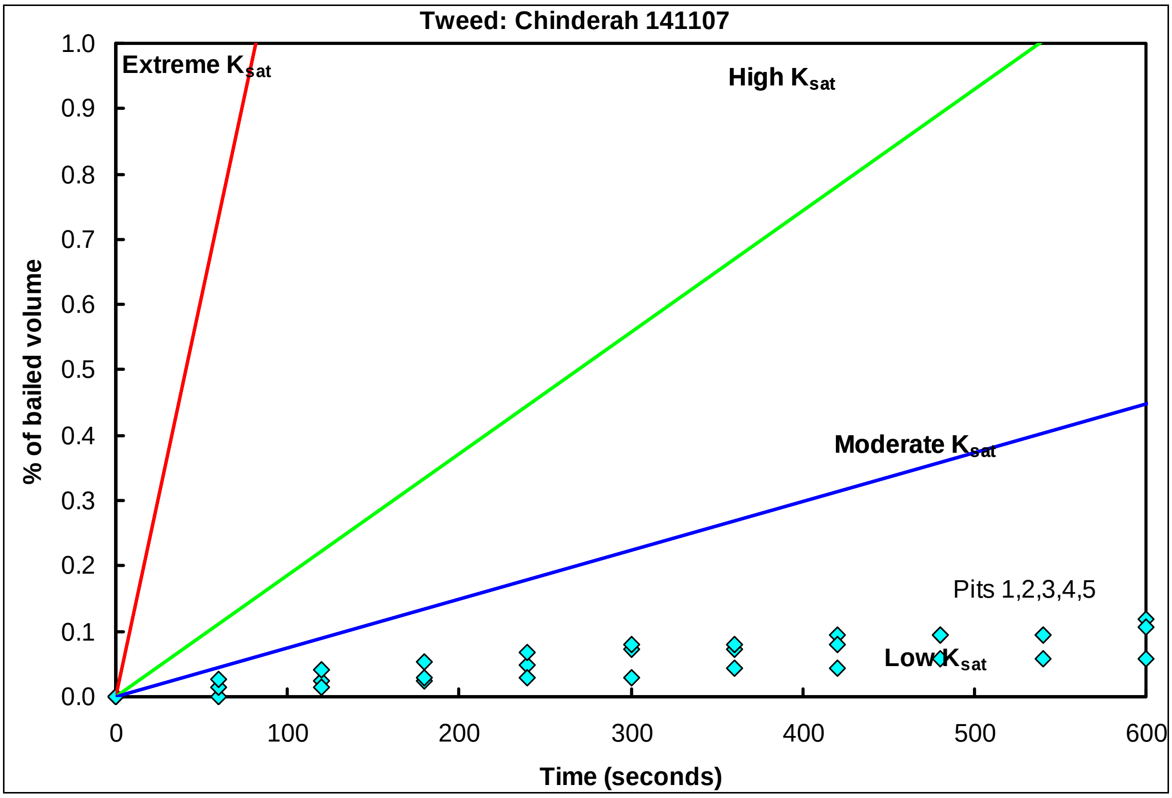

Figure 19. Normalised water level recovery rate over time, Chinderah cane field site.

Soil description: Soil sandy alluvial to a yellow sand at depth. Very few mottles, orange in color, very few macropores. Slight slumping of pit sides in water table and only one pit bailing per pit completed.

Table 5. Chinderah at Tweed, pit water quality and quantitative K_{sat} data.

Pit No.	Pit depth (cm)	Water table depth (cm)	Ground water quality		Hydraulic conductivity (m day^{-1})		
			pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	65	58.6	4.17	0.306	1.17	1.06	0.21
2	65	56.1	4.66	0.157	1.02	0.95	0.24
3	57	46.0	4.60	0.195	0.50	0.51	0.33
4	55	41.3	4.60	0.224	0.83	0.86	0.40
5	60	40.1	4.65	0.160	0.44	0.59	0.62

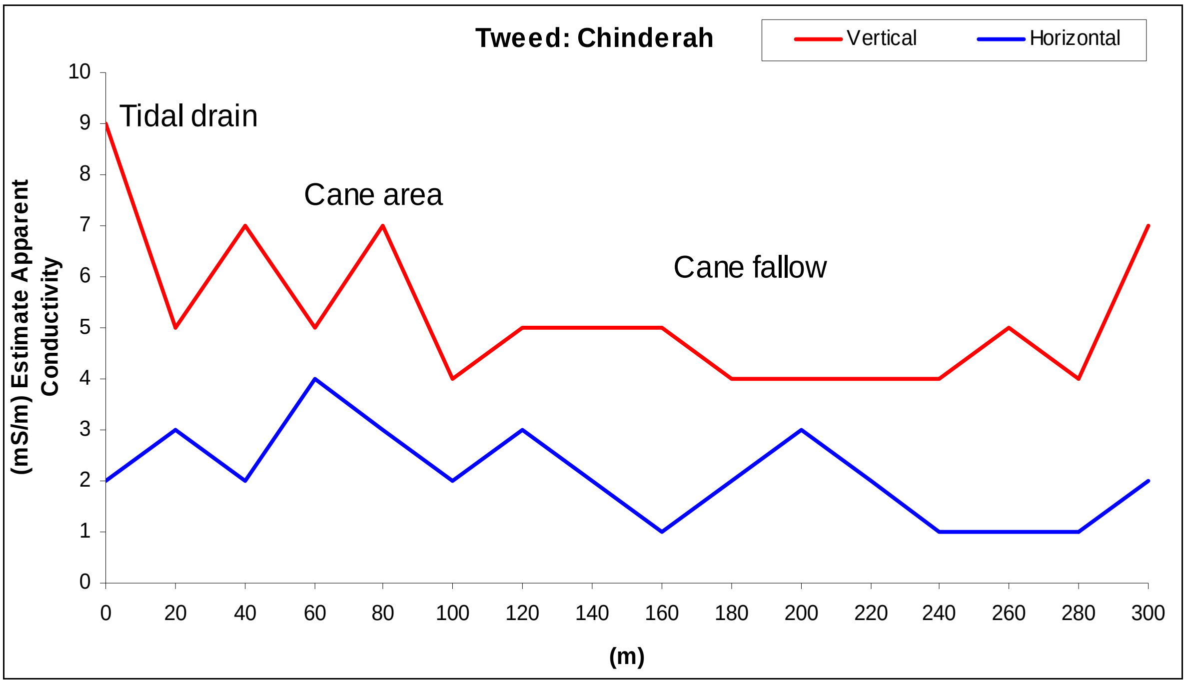

Figure 20. Chinderah EM38 transect

Transect across cane field from tidal drain to cane fallow area, finishing next to infield drain. Low Apparent EC levels indicated. Sand dominate profile.

4.1.5 Christies

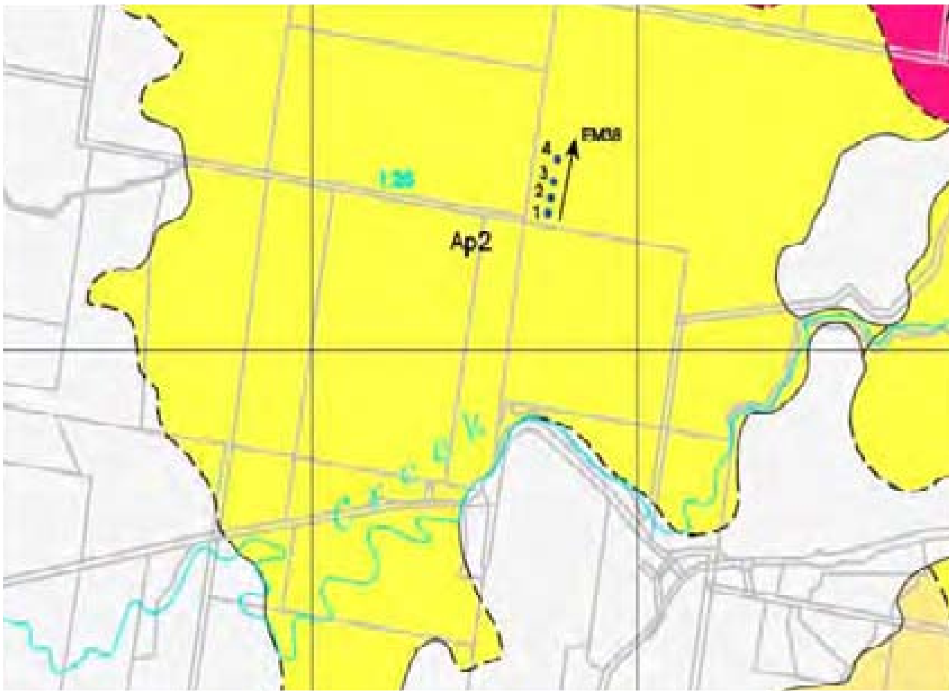

Figure 21. Four K_{sat} pits and an EM38 transect, at Christies coastal oak forest.
(source: Naylor et al., 1998)

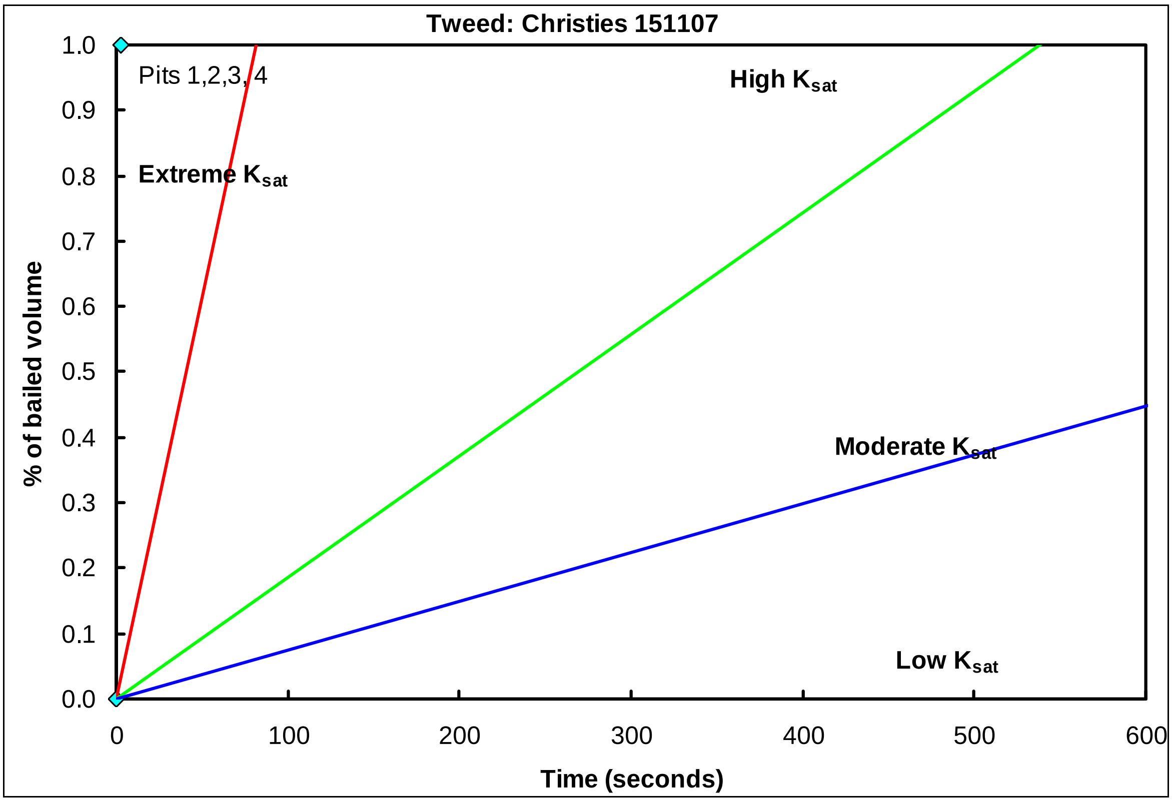

Figure 22. Normalised water level recovery rate over time, at Christies.

Soil description: Soil a black silty peaty loam to depth. Weak mottling found, jarosite at depth. Pits rapid infill, many macropores i.e. coarse diameter with dominate horizontal orientation.

Site description: An extreme site (highest recorded in survey) to sample, difficult to bail pit due to extremely rapid infil. Pit walls began to crumble from groundwater movement due to soils peat content. Site heavily forested with a dense green broadleaf ground cover. Site on western side of coastal forest, 2.4km from coast.

Table 6.Christies at Tweed, pit water quality and quantitative K_{sat} data.

			Ground water quality		Hydraulic conductivity (m day^{-1})		
Pit No.	Pit depth (cm)	Water table depth (cm)	pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	50	38.6	3.56	4.13	>500	>500	0.33
2	51	37.9	3.61	6.61	>500	>500	0.42
3	50	36.4	3.80	4.98	>500	>500	0.40
4	56	36.3	3.91	4.52	>500	>500	0.51

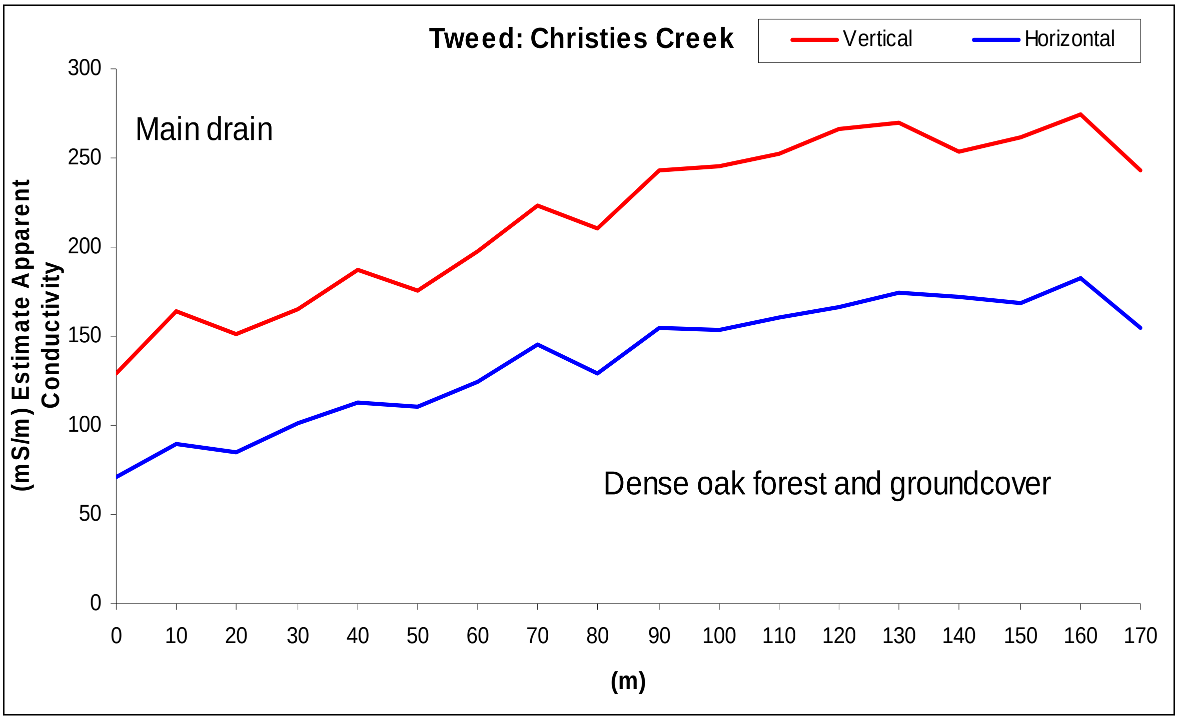

Figure 23. EM38 transect, Christies Creek.

EM38 readings consistent (i.e. between Vertical and Horizontal readings), EC increasing moving further into oak forest under forest canopy.

4.2 Richmond River Catchment Sites

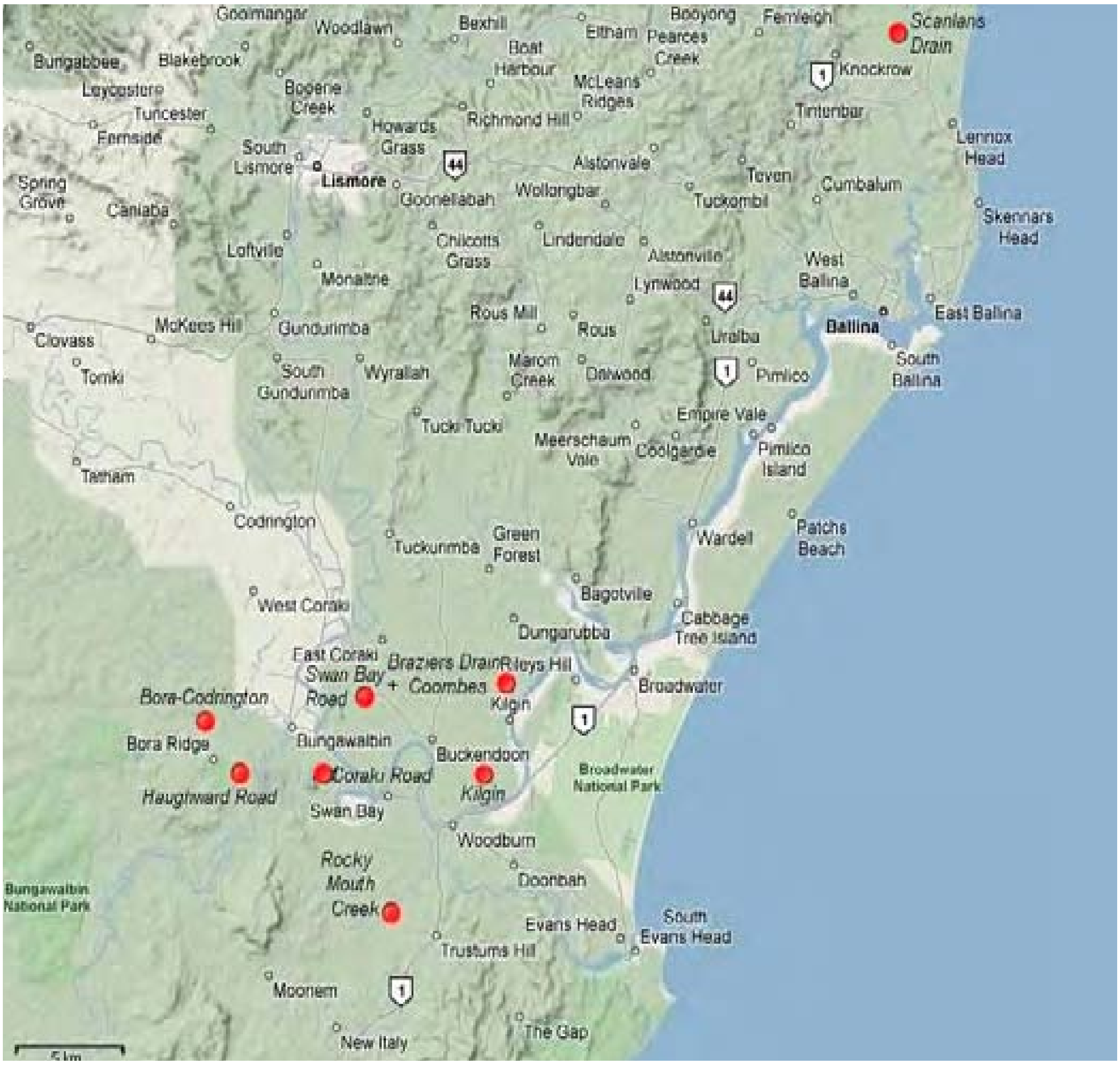

Figure 24. Richmond sites.

4.2.1 Scanlans drain

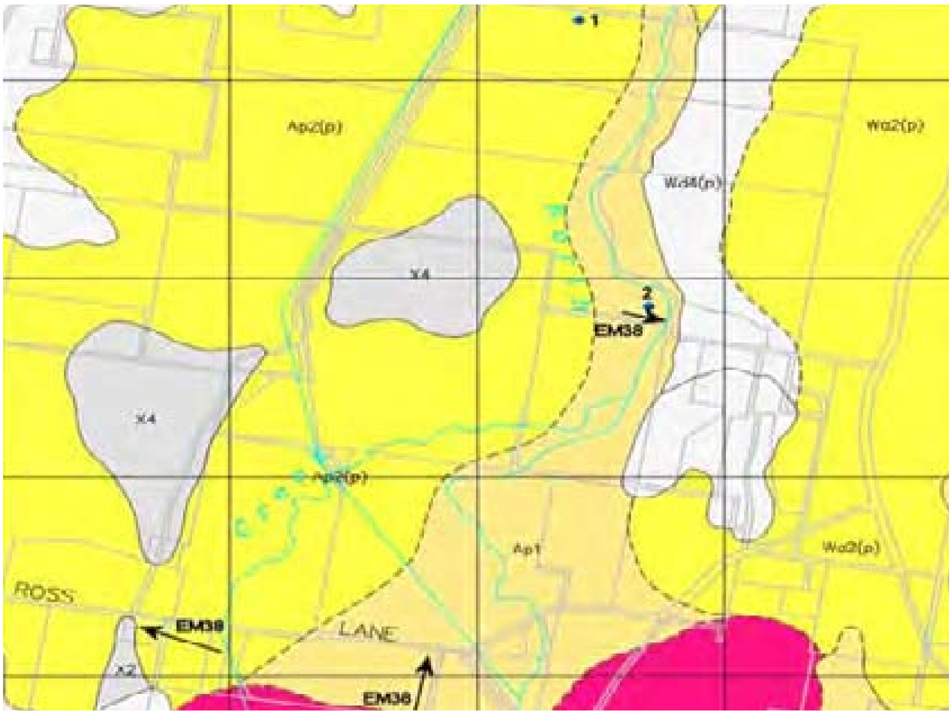

Figure 25. Two K_{sat} pits plus three EM38 transects.
(source: Naylor et al., 1998)

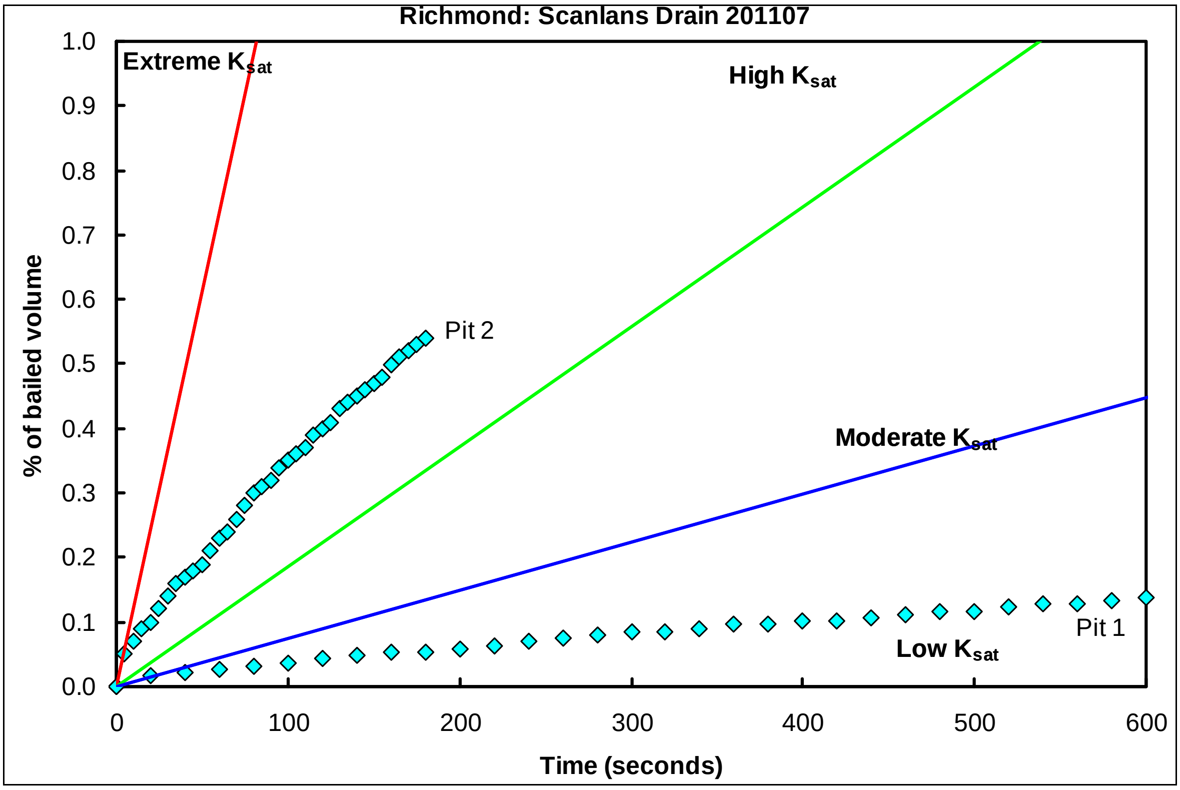

Figure 26. Normalised water level recovery rate over time, Scanlans two sites.

Pit 1 edge of cane field and drain, and Pit 2, in forest area 100m from Scanlans drain.

Soil description: Pit 1, Black topsoil to a brown peat and into a dark clay peat at depth, abundant roots to depth. No mottling or macropores visible. A low K_{sat} site. Vegetation a mix of setaria and paspalum. Pit 2, Black topsoil to a light coloured clay to a clay sand at depth. Very few reddish mottles. Fine common macropores, visible, both vertical and horizontal orientation.

Table 7. Scanlans Drain at Richmond, pit water quality and quantitative K_{sat} data.

			Ground water quality		Hydraulic conductivity (m day^{-1})		
Pit No.	Pit depth (cm)	Water table depth (cm)	pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	48	25.95	4.31	0.49	1.13	1.45	0.60
2	40	28.25	3.47	1.19	18.03	20.46	0.37

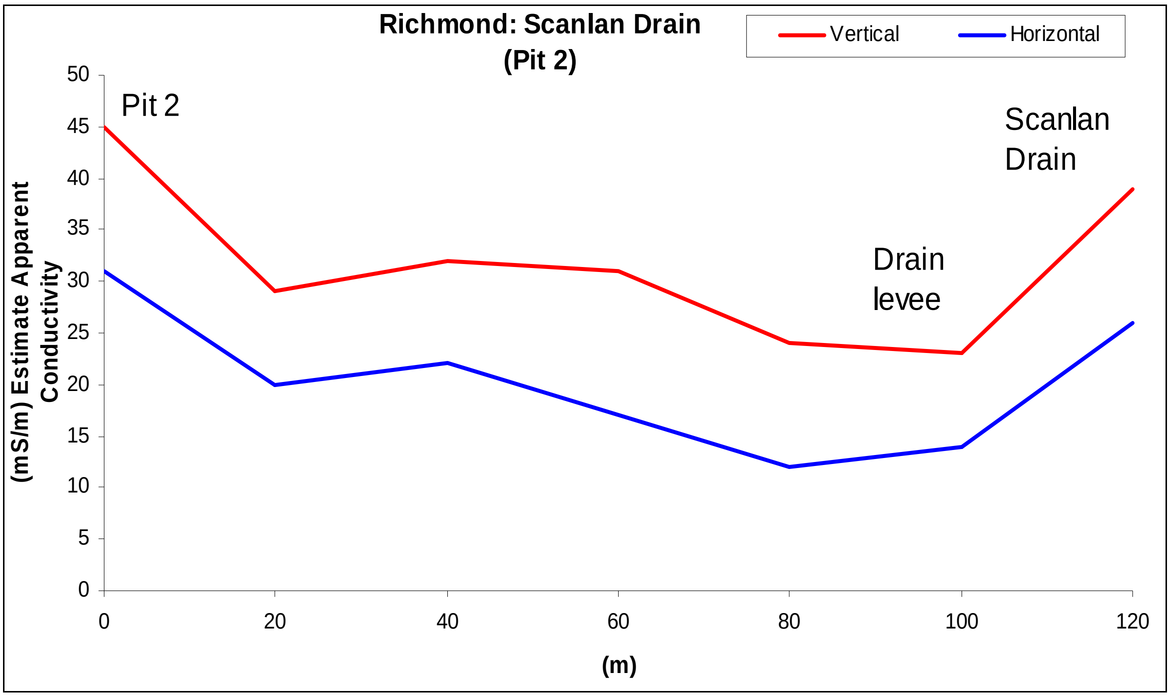

Figure 27. EM38 transect from pit 2.

From a mixed forest of melaleuca, casuarina, and camphor laurel, to main drain.

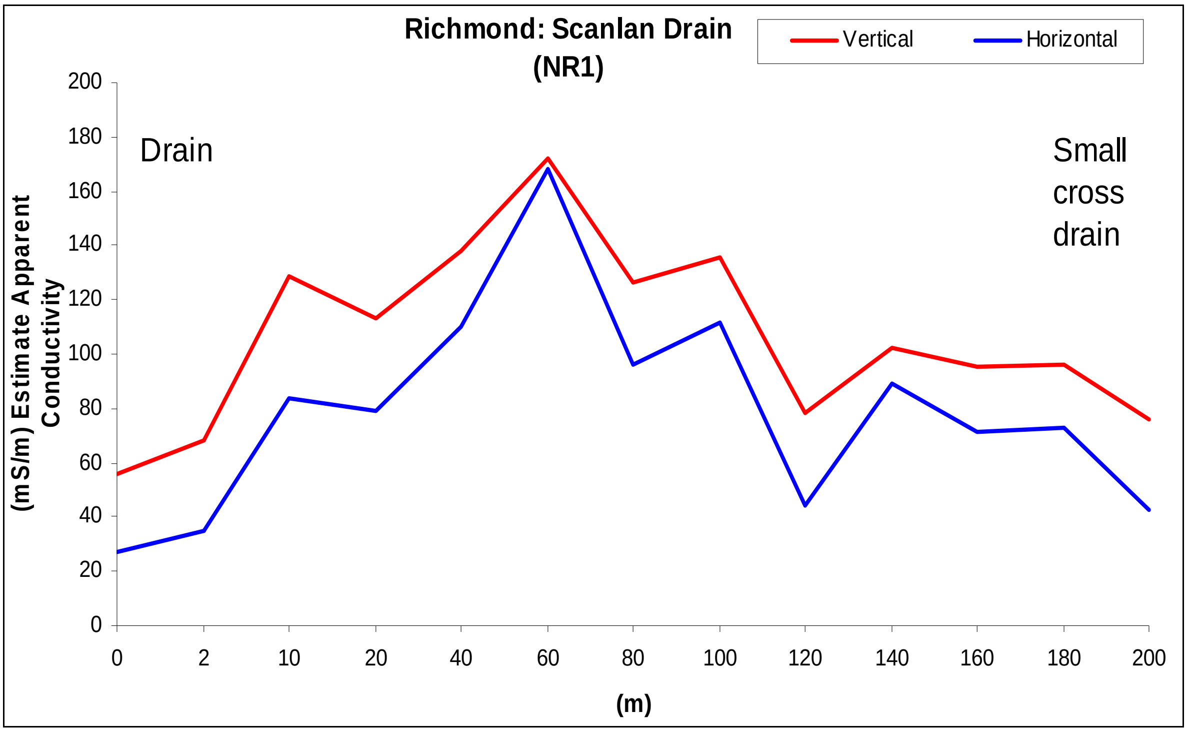

Figure 28. EM38 transect from main drain to a cross drain along cane headland.

Transect parallel to drain and next to cane field. Casuarina seedlings invading cane field. Management of drain under review.

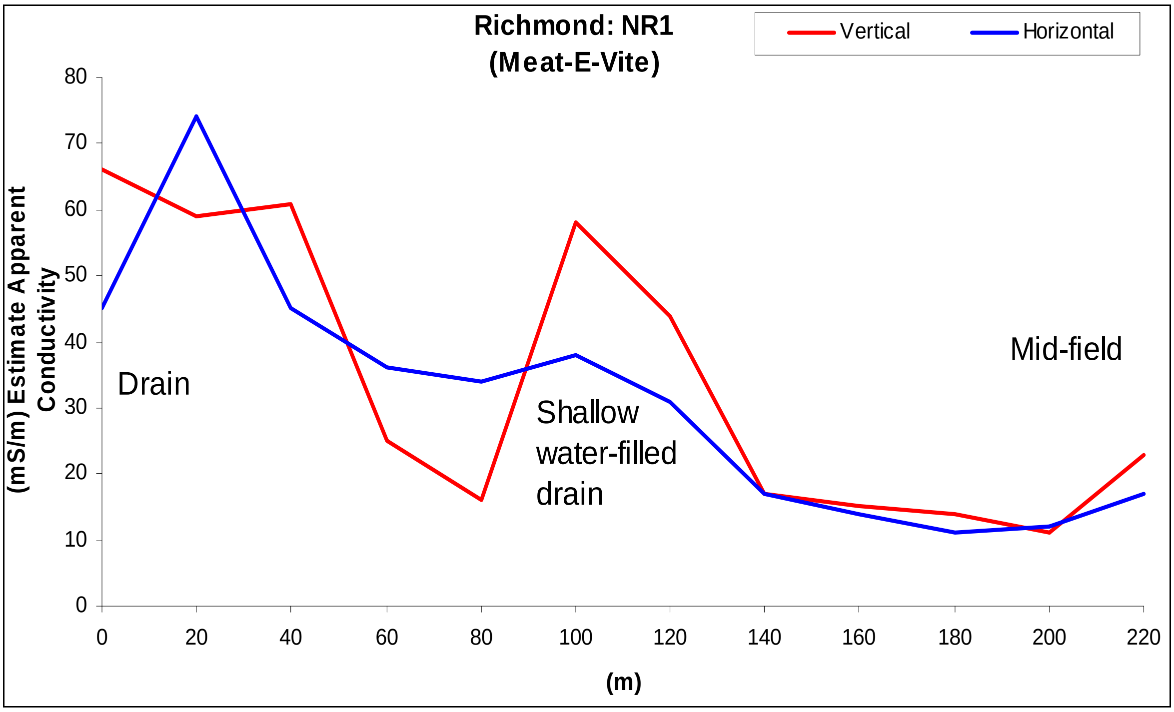

Figure 29. EM38 transect moving away from drain to middle of field.

Possibly lower elevation away from the shallow water-filled drain. Hill area approximately 500m further on, with a draft plan subdivision.

4.2.2 Haughwood road and Bora-Codrington

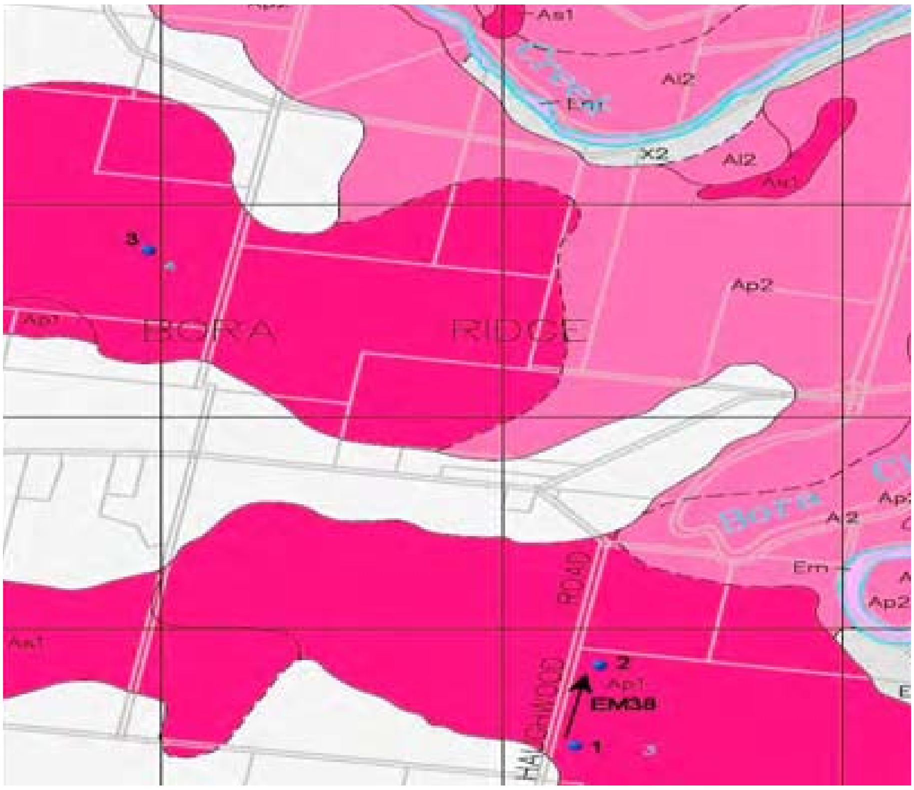

Figure 30. Two K_{sat} pits at Haughward road and one at Bora-Codrington.
(source: Naylor et al., 1998)

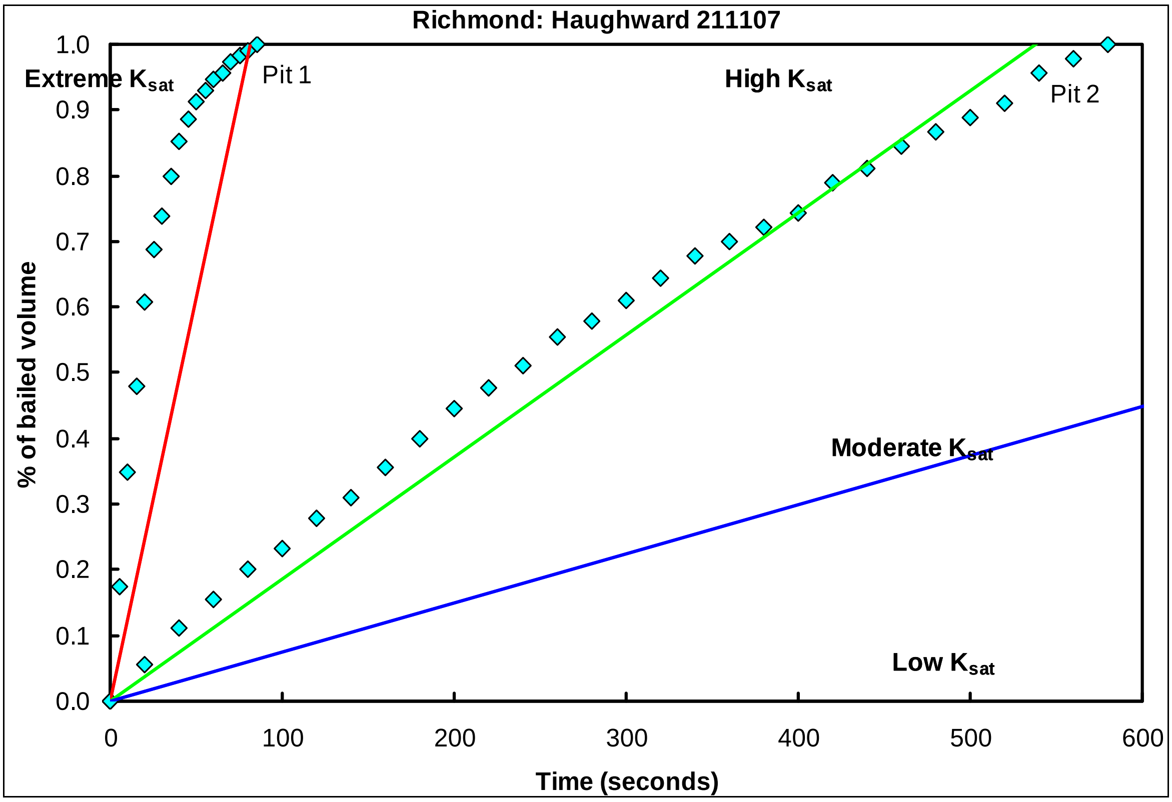

Figure 31. Normalised water level recovery rate over time, at Haughward.

Pit 1 about 30m from main drain, Pit 2 about 400m from drain.

Soil description: At south pasture, a black peat clay to a clay loam at depth. Roots abundant to depth, mottling in root channels, few reddish mottles. Few fine macropores both vertical and horizontal, jarosite at depth.

Table 8. Haughward at Richmond, pit water quality and quantitative K_{sat} data.

			Ground water quality		Hydraulic conductivity (m day^{-1})		
Pit No.	Pit depth (cm)	Water table depth (cm)	pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	55	37.9	3.37	1.97	174.28	231.19	0.54
2	60	48.0	3.59	1.84	11.33	12.71	0.40

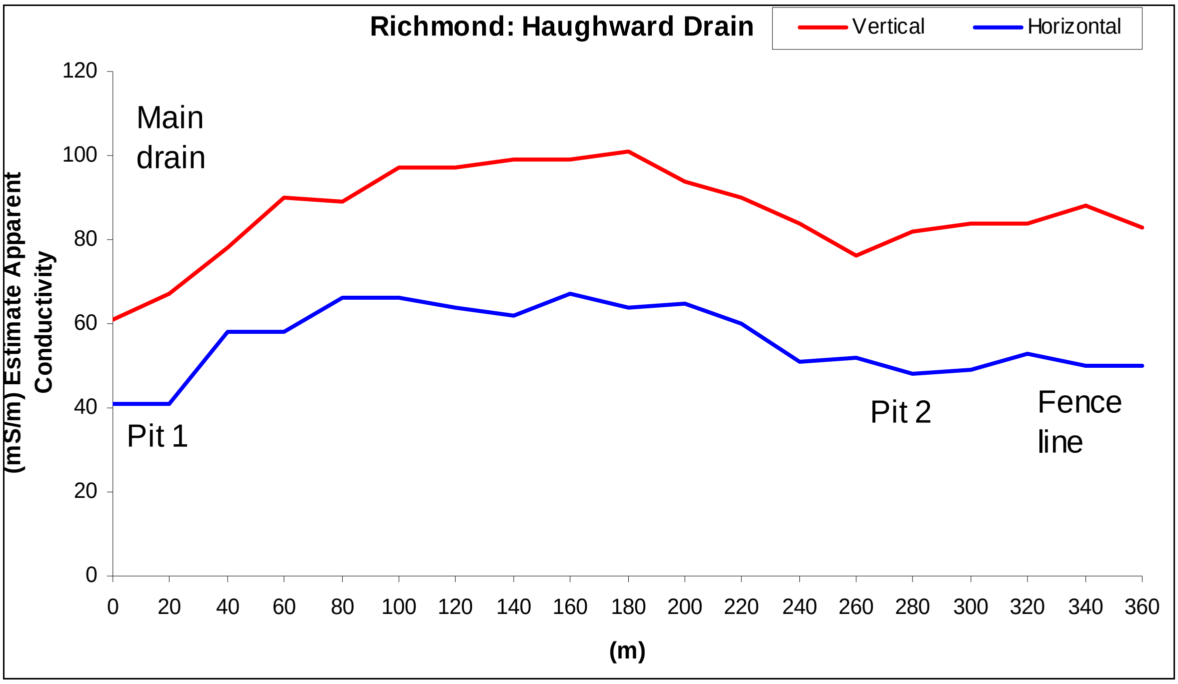

Figure 32. EM38 transect at Haughward Drain.

Pasture area, history of chronic black water events. Possible old cropping area due to observations of mounded beds. (i.e. shallow surface drains every 20m).

4.2.3 Kilgin near Woodburn

Figure 33. Three K_{sat} pits plus two soil pits for profile description.
(source: Naylor et al., 1998)

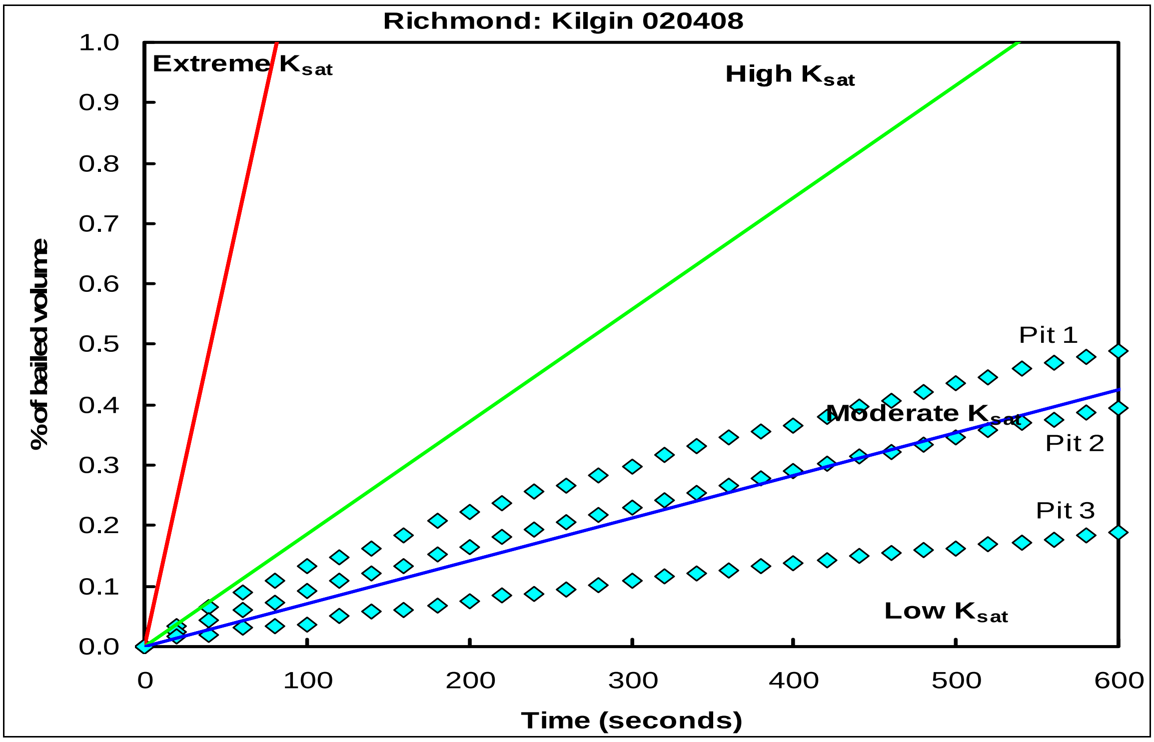

Figure 34. Normalised water level recovery rate over time, at Kilgin.

Coombes pasture block at Kilgin, encompassed by cane fields.

Soil description: Pits in the moderate K_{sat} range, but all soil profiles show evidence of Fe migration. Few bright orange and prominent mottles. Fine common macropores with greater vertical orientation. Iron (Fe) in swirls and nodules (coarse grit), at mid depths and Jarosite at depth. Pit 3 nearest main drain.

Table 9. Coombes at Richmond, pit water quality and quantitative K_{sat} data.

Pit No.	Pit depth (cm)	Water table depth (cm)	Ground water quality		Hydraulic conductivity (m day^{-1})		
			pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	50	27.75	5.22	5.43	4.30	6.28	0.67
2	50	30.9	5.51	3.25	3.40	4.51	0.56
3	50	20.2	3.73	7.02	1.76	2.72	0.76

4.2.4 Gollan and Swan Bay

Figure 35. First K_{sat} pit on Coraki road at Gollan second pit at Swan bay road.
(source: Naylor et al., 1998)

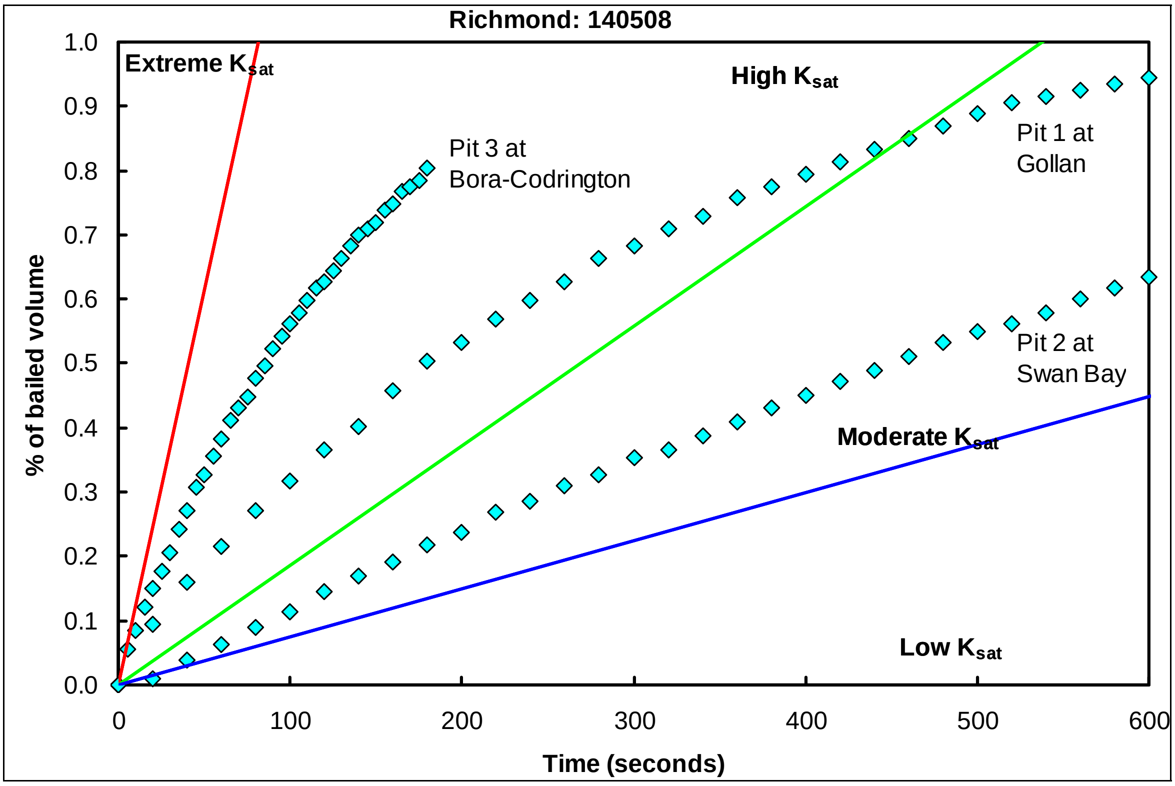

Figure 36. Normalised water level recovery rate over time, in Woodburn area.

Pit 1 west of Woodburn, next to laneway and drain. Pit 2 north-west of Woodburn in a low fallowed cultivated cane field. Pit 3 at Bora-Codrington.

Soil description: Pit 1, edge of laneway between cane and shallow drain. Compacted surface layers to 50cm, strong H_2S odour. Black topsoil to grey clay to orange peat to clay peat at depth. Mottling very few dull red. Vertical few and fine macropores. Pit 2, Black soil down to 1m, to orange peat clay to black peat clay at depth. Possible soil disturbance in this low area. No mottles but horizontal fine few (3 large pores prominent) macropores. Infield drain 10m holding water, thick Fe flocc coating drain walls and water crystal clear. Pit 3 open pasture black peat topsoil to grey clay to peat clay at depth. Very few mottling in old root channels. Vertical medium few macropores.

Table 10. Woodburn area at Richmond, pit water quality and quantitative K_{sat} data.

			Ground water quality		Hydraulic conductivity (m day^{-1})		
Pit No.	Pit depth (cm)	Water table depth (cm)	pH	EC ($ds\ m^{-1}$)	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	55	41.9	3.00	2.10	13.83	15.72	0.42
2	64	39.4	3.70	1.67	4.92	7.65	0.78
3	39	25.9	3.62	1.18	29.26	30.80	0.42

4.2.5 *Rocky Mouth Creek*

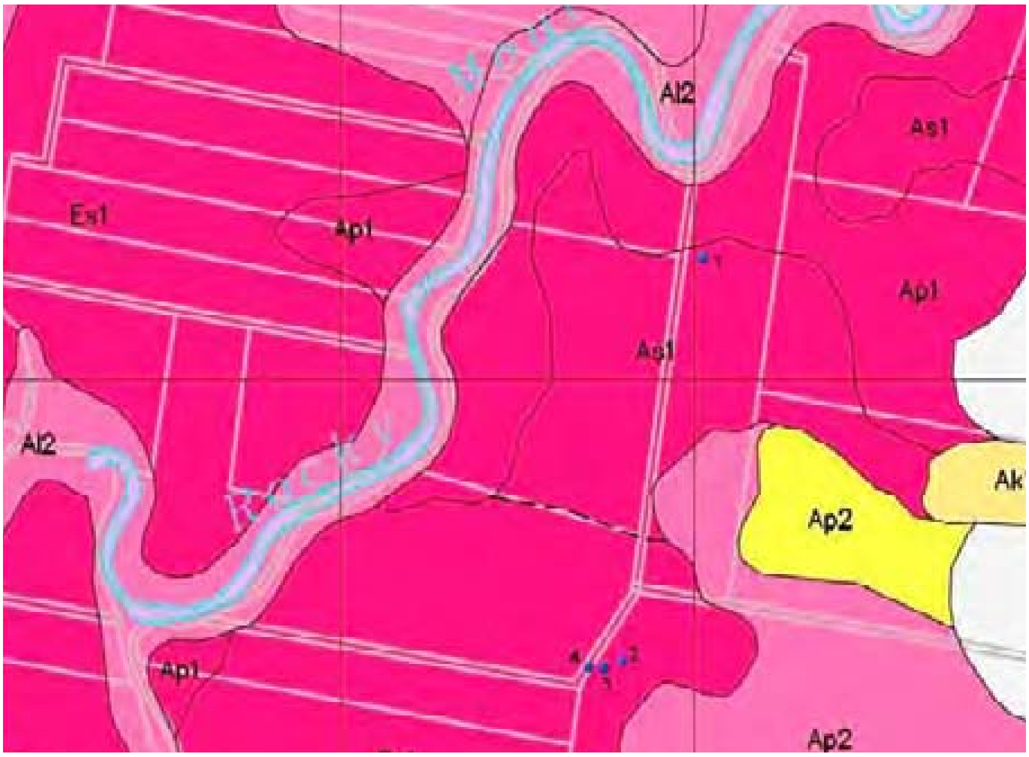

Figure 37. Four K_{sat} pits at Rocky Mouth Creek.
(source: Naylor et al., 1998)

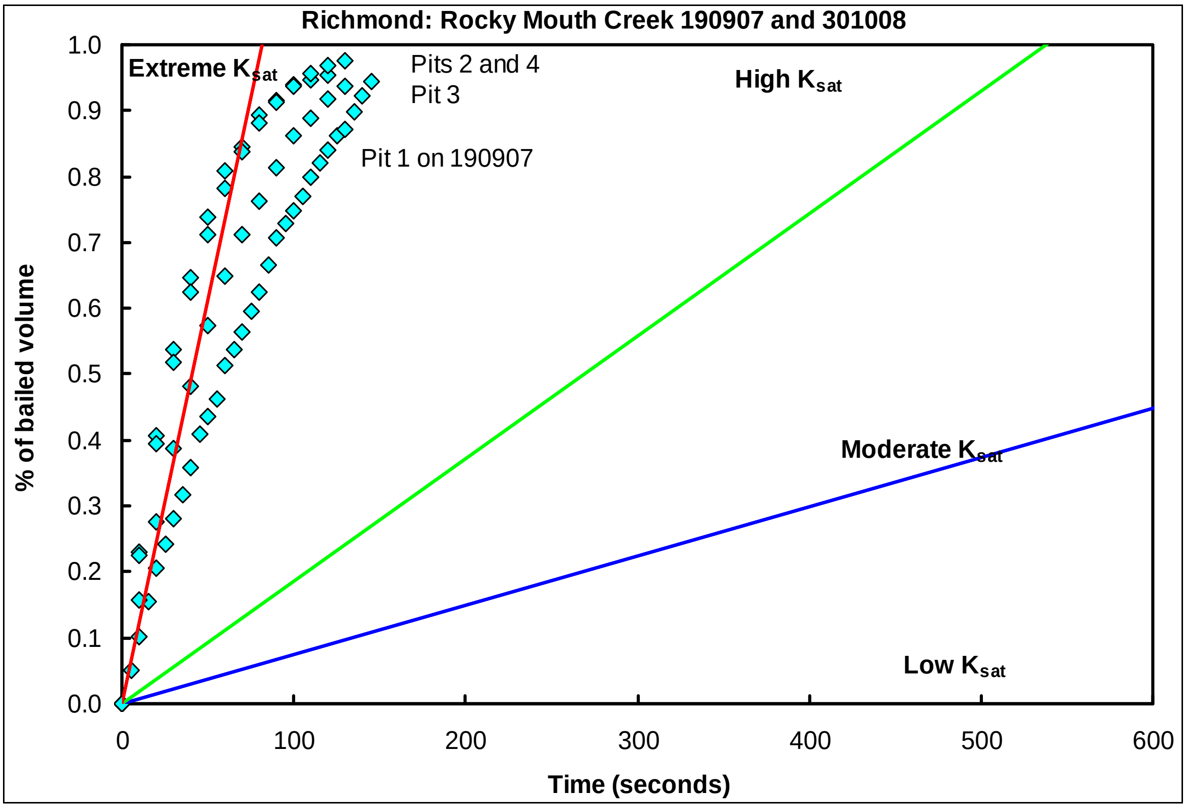

Figure 38. Normalised water level recovery rate over time, at Rocky Mouth Creek.

Site description: Pit located approximately 40m from new weir structure. Result indicates the potential for high connectivity for this large wetland.

Table 11. Rocky Mouth Creek at Richmond, pit water quality and quantitative K_{sat} data.

			Ground water quality		Hydraulic conductivity (m day^{-1})		
Pit No.	Pit depth (cm)	Water table depth (cm)	pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	45	23			36.94	58.78	0.73
2	72	53	3.59	4.98	133.89	160.66	0.48
3	70	48	3.66	5.49	75.68	98.38	0.54
4	64	41	3.78	5.45	109.96	148.91	0.59

4.2.6 Braziers Drain

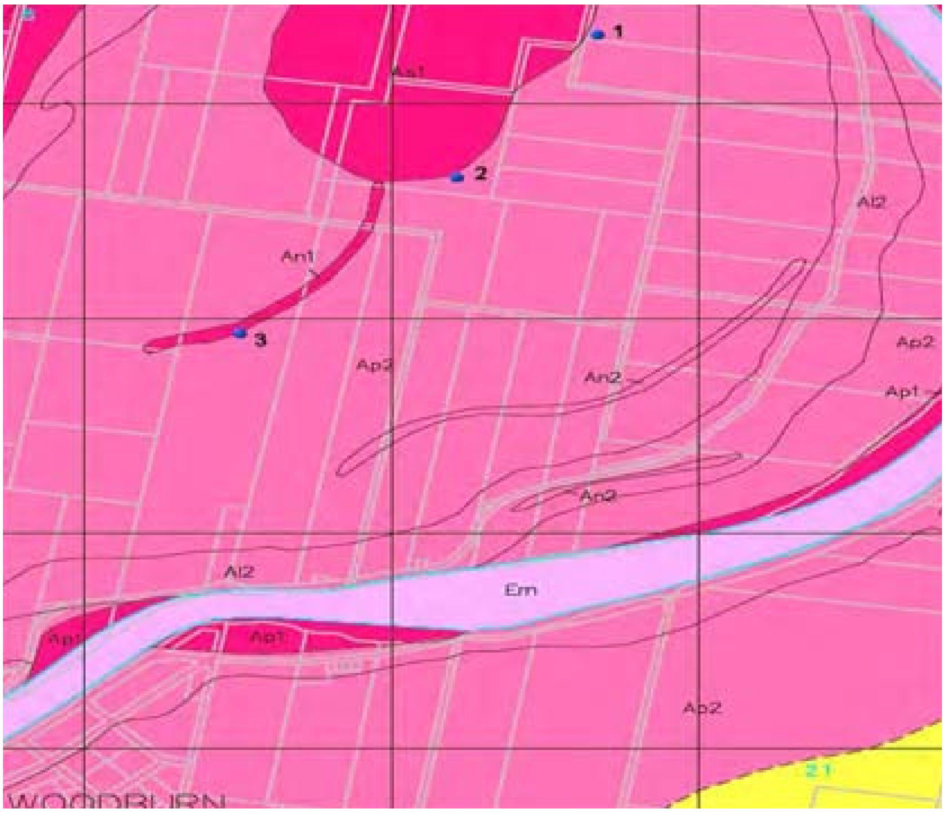

Figure 39. Three K_{sat} pits in Kilgin area.
(source: Naylor et al., 1998)

Table 12. Braziers Drain at Richmond, pit water quality and quantitative K_{sat} data.

			Ground water quality		Hydraulic conductivity (m day^{-1})		
Pit No.	Pit depth (cm)	Water table depth (cm)	pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
3	50	50	3.74	4.93			

4.3 Clarence River Catchment Sites

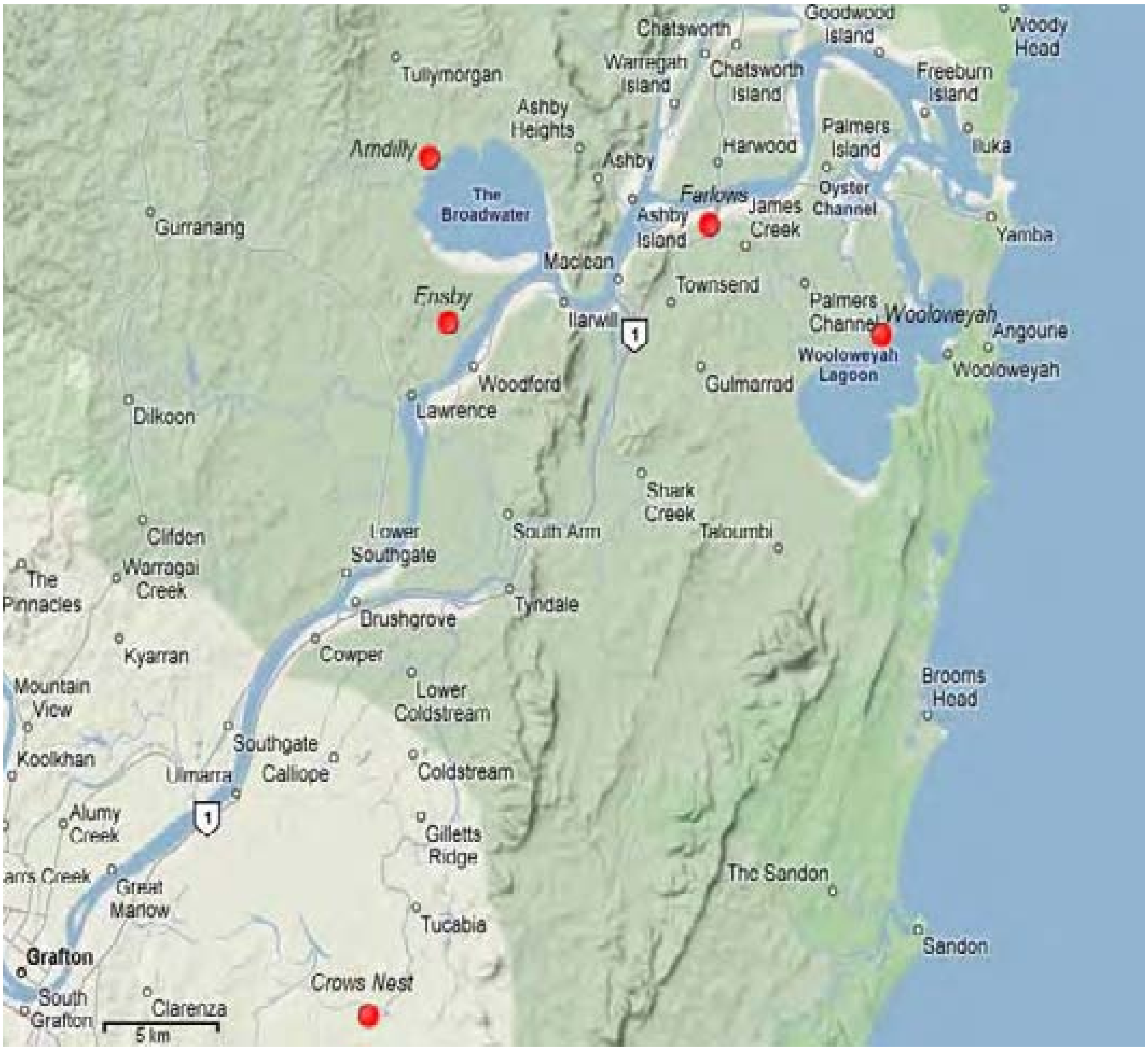

Figure 40. Clarence sites.

4.3.1 Clarence Site at Ensbys

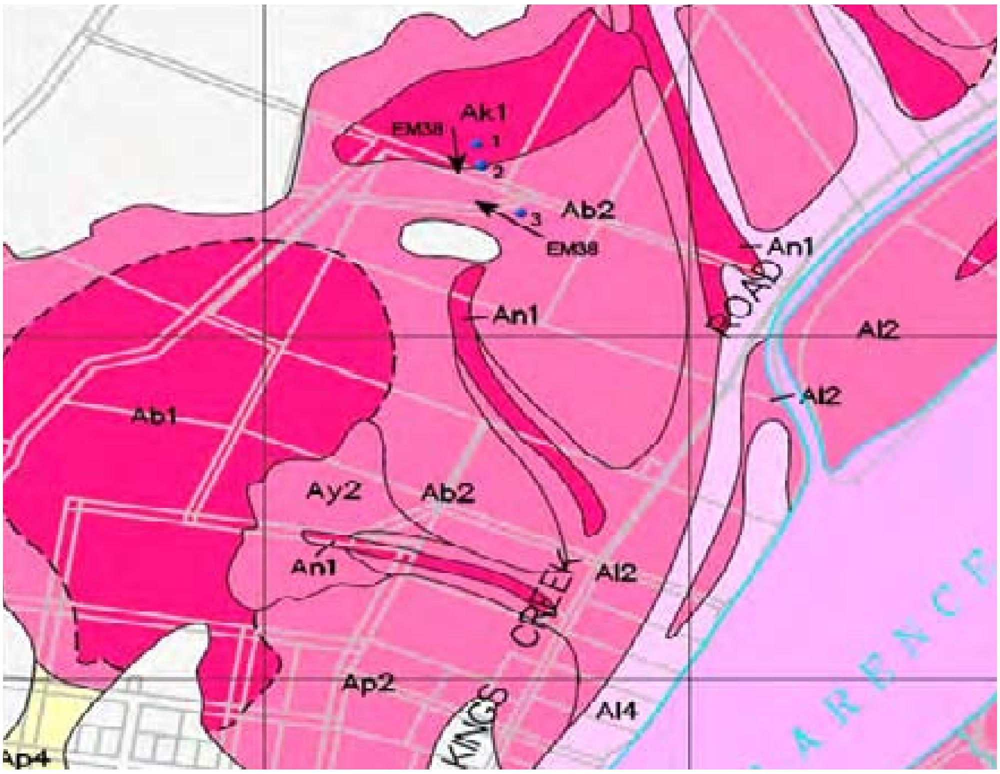

Figure 41. Three K_{sat} pits in Ensbys backswamp plus two EM38 transects. (source: Naylor et al., 1998)

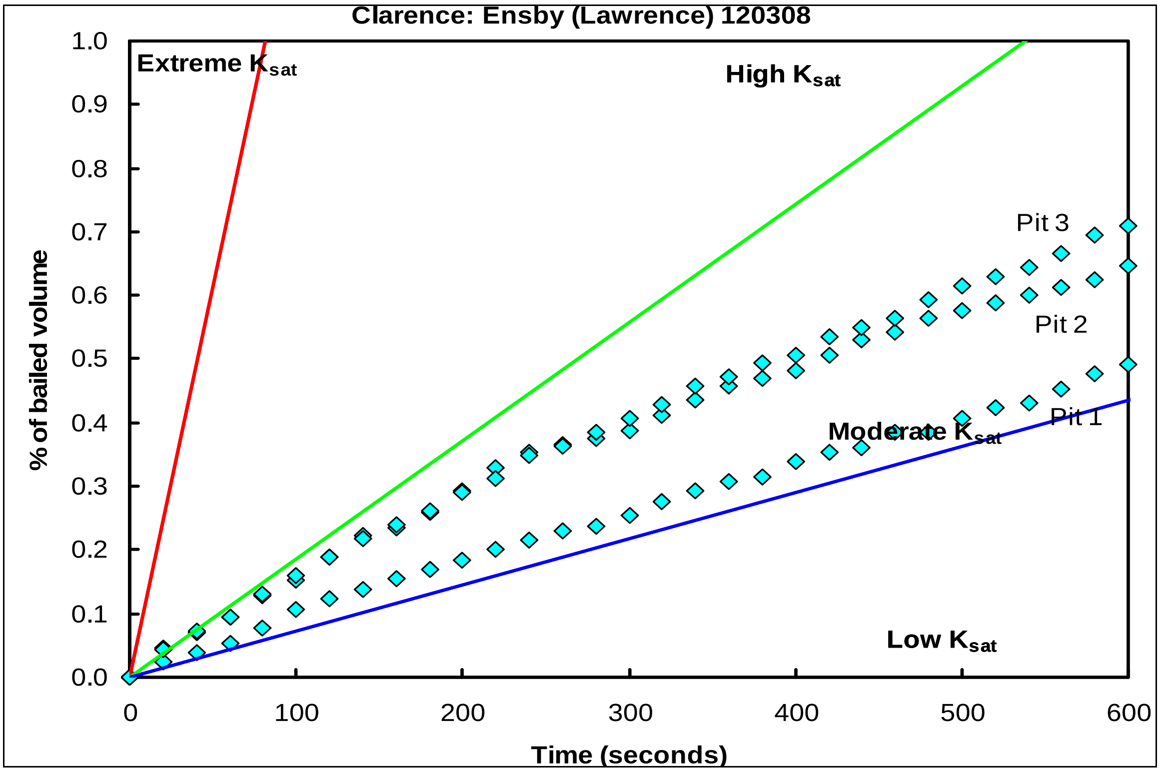

Figure 42. Normalised water level recovery rate over time, at Ensby Lawrence.

Soil description: Soil profile black alluvial topsoil down to medium clay subsoil, thin sand lens about 60-70cm depth. Pits 1 and 2 mottling many and prominent orange colour. Pit 3 in second paddock, very few mottles dark red in color. Macropores both vertical and horizontal in orientation.

Table 13. Ensby at Clarence, pit water quality and quantitative K_{sat} data.

Pit No.	Pit depth (cm)	Water table depth (cm)	Ground water quality		Hydraulic conductivity (m day^{-1})		
			pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	47	32.5	3.95	4.98	4.39	5.77	0.45
2	50	40.9	4.00	4.78	6.65	7.31	0.30
3	52	38.0	4.98	4.58	5.95	7.68	0.45

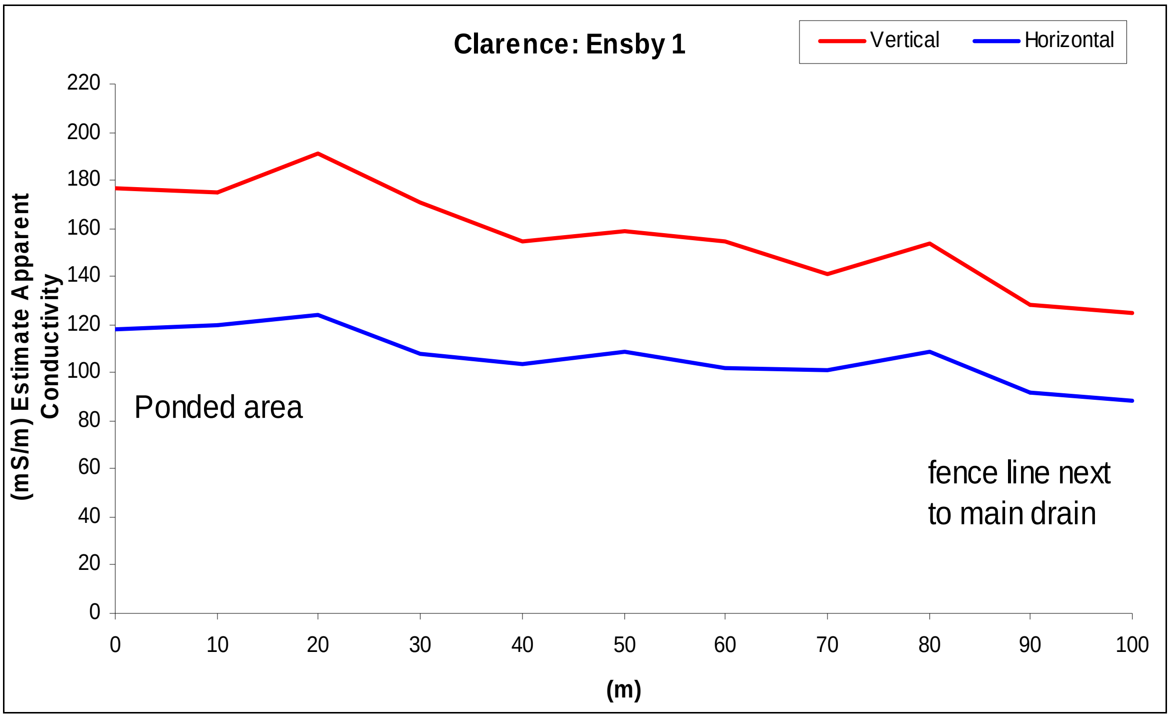

Figure 43. EM38 transect in pasture area from swamp to fenced main drain.

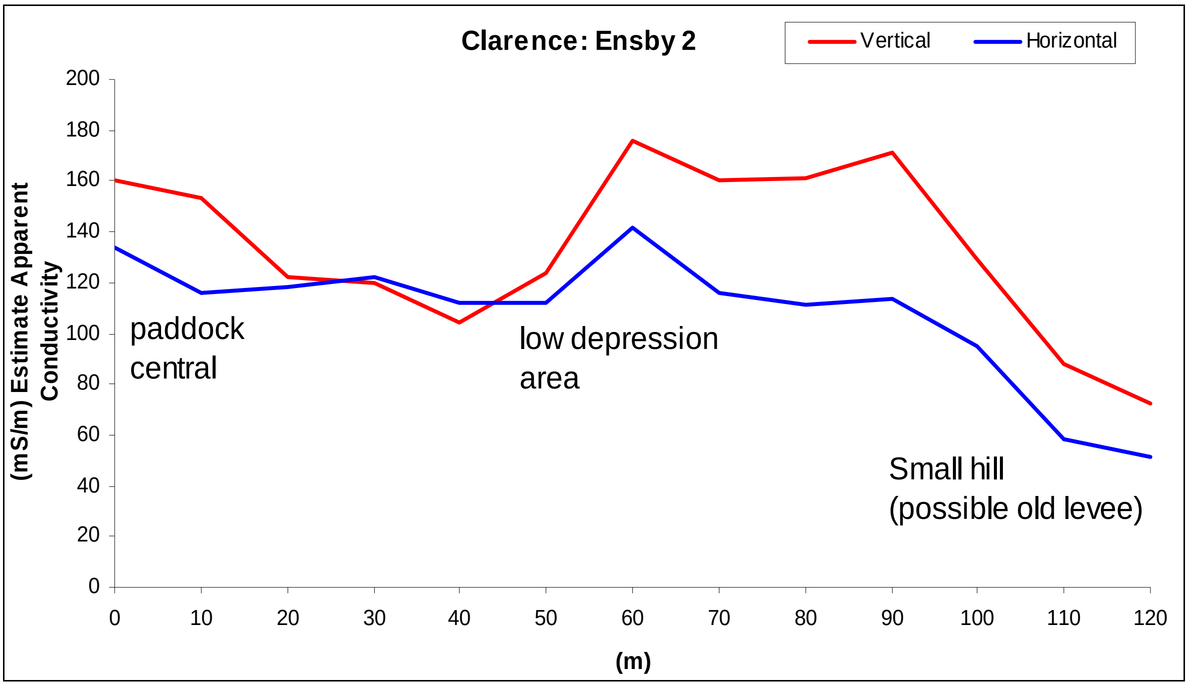

Figure 44. EM38 transect in pasture area.

Transect passes through a drained depression area.

4.3.2 Wooloweyah Lagoon

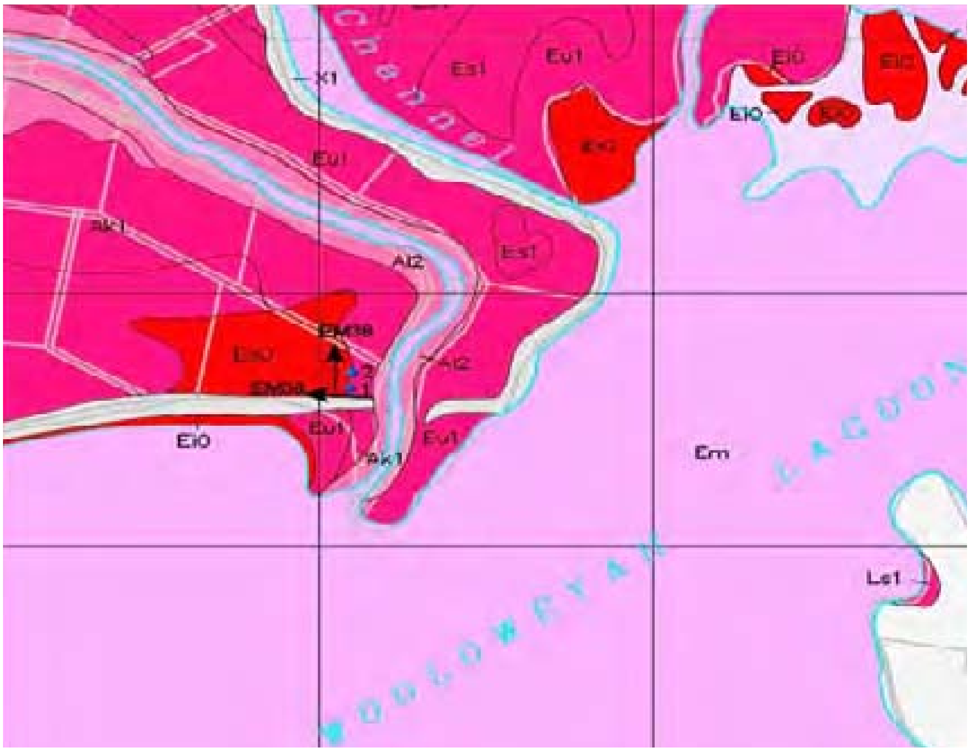

Figure 45. Two K_{sat} pits and two EM38 transects at Wooloweyah Lagoon.
(source: Naylor et al., 1998)

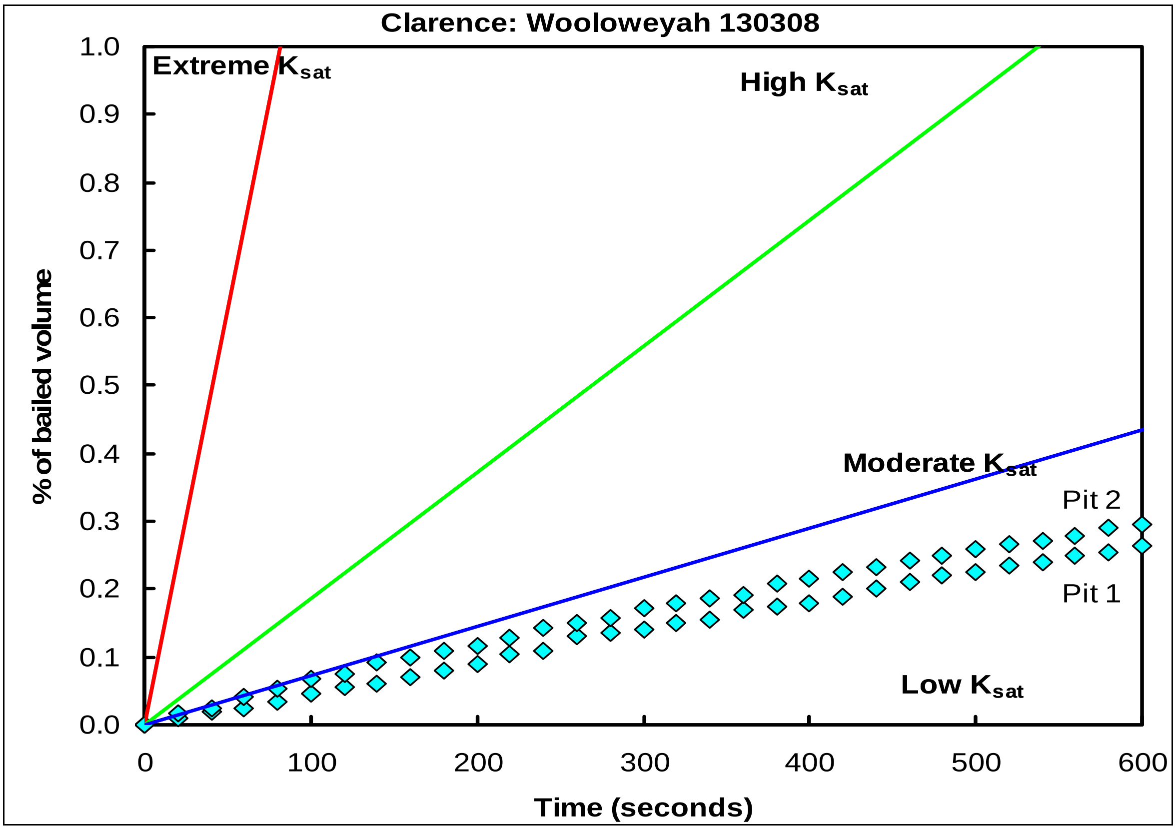

Figure 46. Normalised water level recovery rate over time, at Wooloweyah Lagoon.

Pits located between Wooloweyah Lagoon and Palmers channel.

Soil description: Couch pasture, soil profile from dark grey black topsoil to silty grey clay increasing in sand content. No mottling observed with very few macropores evident.

Table 14. Wooloweyah at Clarence, pit water quality and quantitative K_{sat} data.

			Ground water quality		Hydraulic conductivity (m day^{-1})		
Pit No.	Pit depth (cm)	Water table depth (cm)	pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	55	32.32	6.11	45.0	1.59	2.22	0.69
2	48	22.2	6.15	38.2	2.16	3.03	0.76

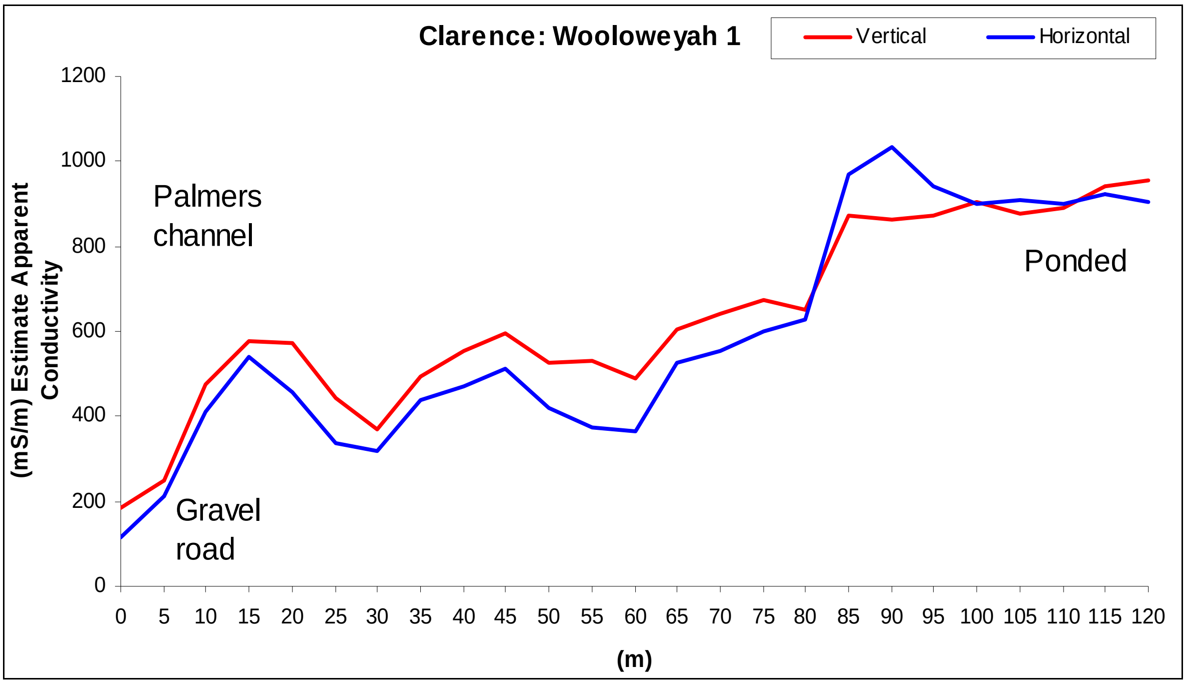

Figure 47. EM38 transect one at Wooloweyah.

Transect from palmers channel across gravel road to ponded area. Transect approximately 100m from shoreline of lake. Salt water intrusion possible at peak tides. Extremely high values consistent with marine salt intrusion at both depth and on the surface.

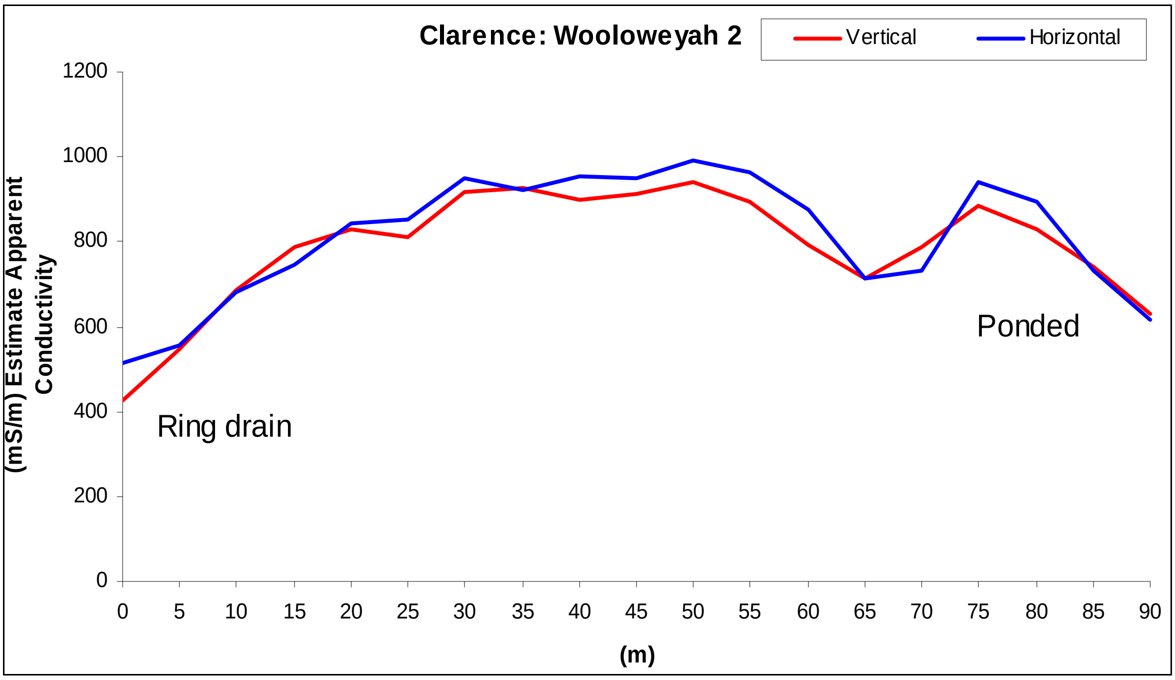

Figure 48. EM38 transect two at Wooloweyah.

Second transect perpendicular to first transect. Originates at ring drain (approximately 80m from palmers channel) finishing at a ponded area.

4.3.3 Crows Nest at Tucabia

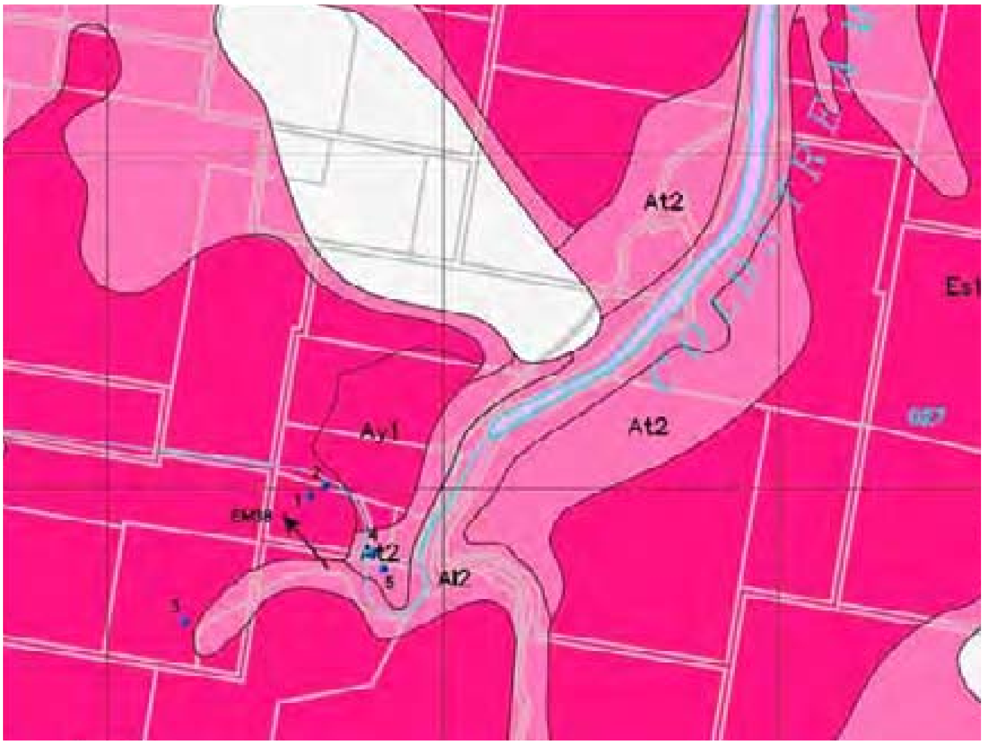

Figure 49. Three K_{sat} pits in and one EM38 transect at Crows Nest.
(source: Naylor et al., 1998)

Pits located in estuarine swamp, on alluvial toe.

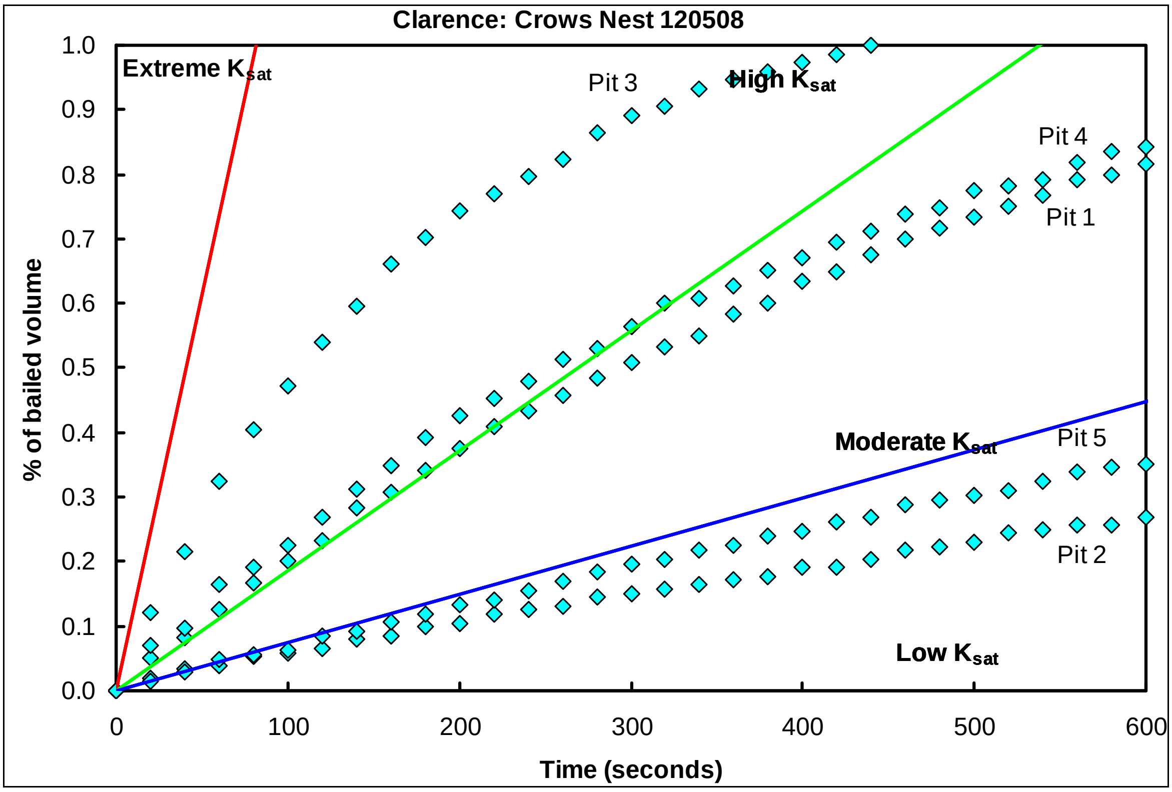

Figure 50. Normalised water level recovery rate over time, at Crows Nest wetland,

Soil description: Pit 2, located 30m from floodgates, possible previous soil disturbance, compared to Pit 1, located 60m from floodgates, abundant fine old root channels. Pit 3 mid wetland, history of long periods of inundation, macropores common with vertical orientation with some dull red mottling. Pit 4 located in shallow drain, few red mottles with vertical macropores. Pit 5, in shallow scald depression, few vertical macropores with very few orange/red mottles. Soil Profil, black topsoil to medium clay gels at depth.

Table 15. Crows Nest at Clarence, pit water quality and quantitative K_{sat} data.

			Ground water quality		Hydraulic conductivity (m day^{-1})		
Pit No.	**Pit depth (cm)**	**Water table depth (cm)**	**pH**	**EC (ds m^{-1})**	**Bouwer and Rice (1983)**	**Boast and Langebartel (1984)**	**L/W**
1	34	20.3	5.65	6.53	9.02	10.61	0.39
2	44	26.1	5.41	5.45	1.70	2.26	0.54
3	30	19.6	5.09	3.36	36.00	34.74	0.26
4	33	19.1	4.56	5.69	11.28	12.78	0.40
5	38	22.4	4.58	6.37	3.22	3.94	0.48

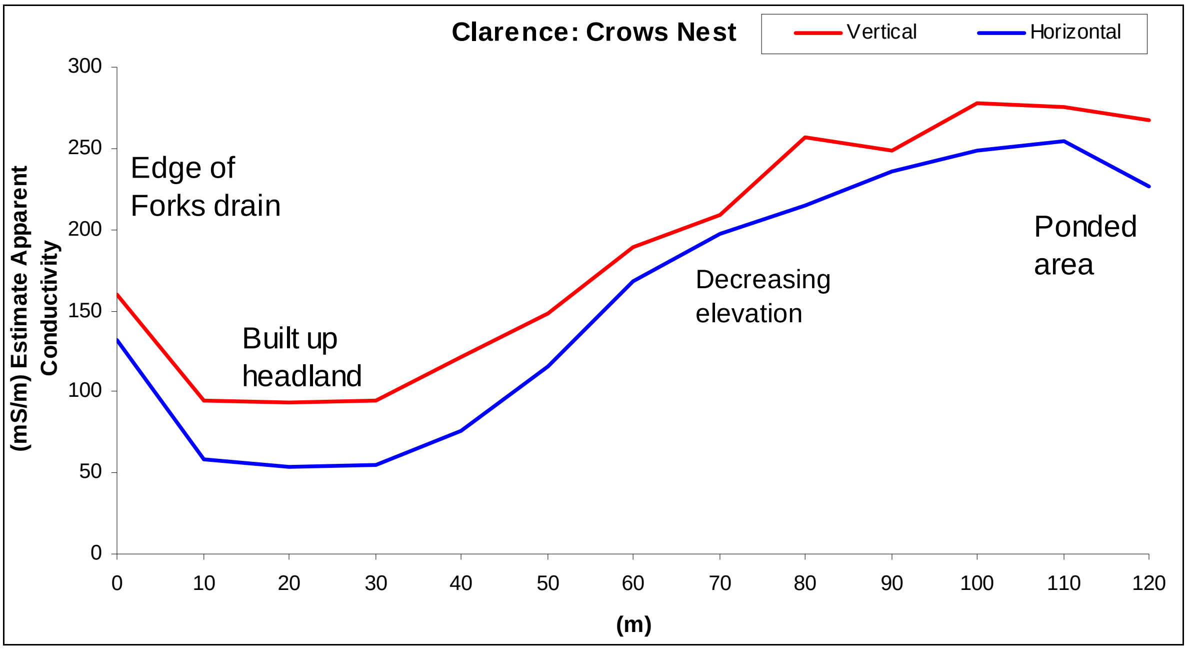

Figure 51. EM38 transect at the forks on the coldstream.

Transect from the edge of the Forks drain over a wide built-up (possible drain spoil) headland out into pasture finishing on edge of ponded area. Note the increase in Apparent EC progressing into wetland.

4.3.4 The Broadwater at Arndilly

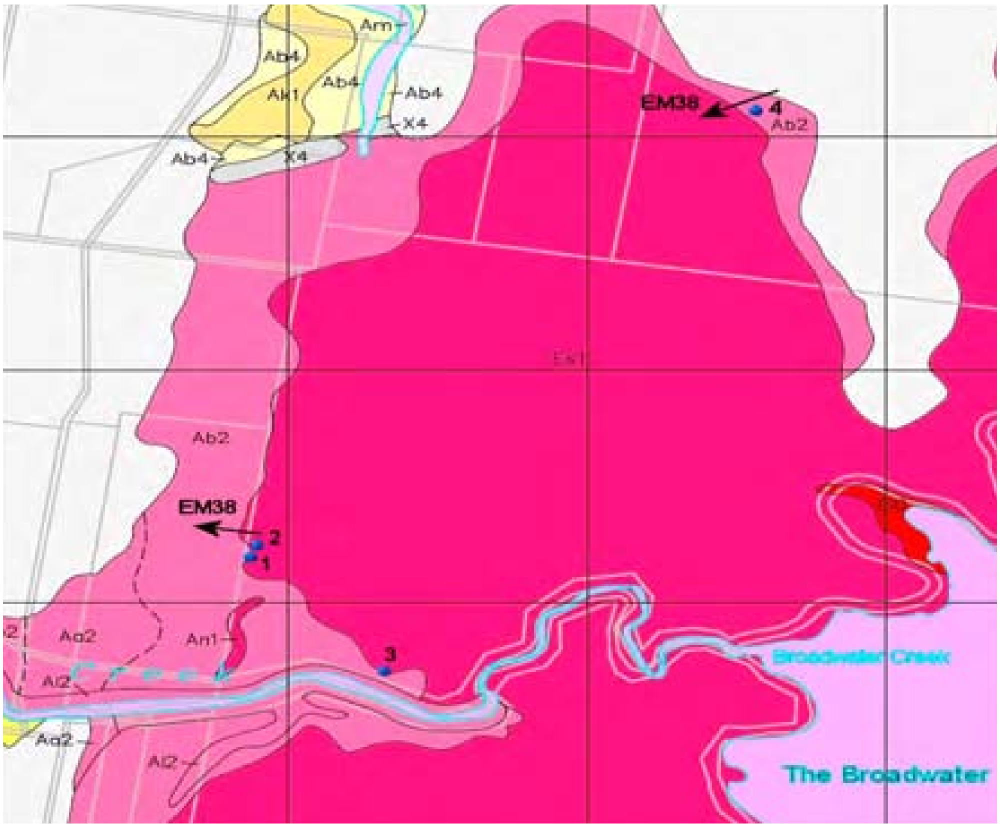

Figure 52. Four K_{sat} pits and two EM38 transects at Arndilly.
(source: Naylor et al., 1998)

Pits located between estuarine swamp and alluvial floodplain.

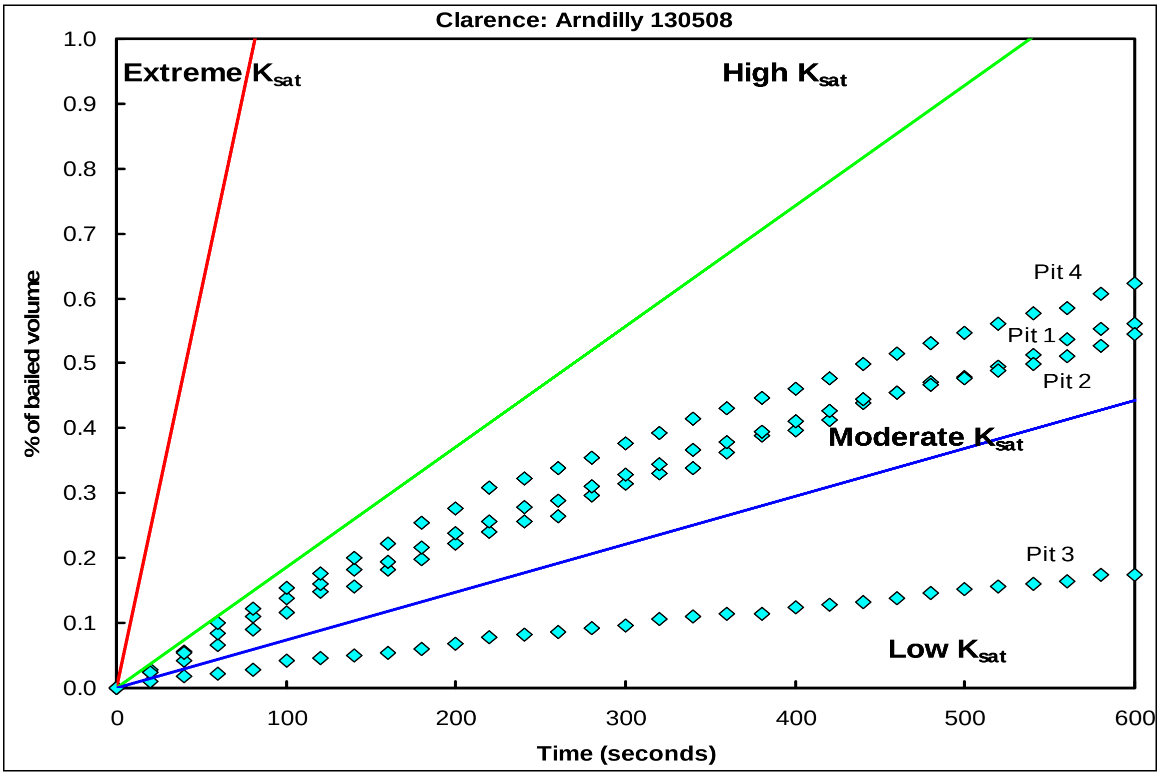

Figure 53. Normalised water level recovery rate over time, at Arndilly.

Soil description: Pits 1 and 2 Surface scalds, medium clay subsoil, mottles abundance common, colour pale yellow to yellow, few visible macropores with vertical and horizontal orientation. Pit 3, peat surface into clay sand profil, no visible macropores. Pit 4 salt water couch dominate, mottles with vertical macropores.

Table 16. Arndilly at Clarence, pit water quality and quantitative K_{sat} data.

Pit No.	Pit depth (cm)	Water table depth (cm)	Ground water quality		Hydraulic conductivity (m day^{-1})		
			pH	EC ($ds\ m^{-1}$)	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	42	27.55	3.87	23.3	5.93	6.97	0.41
2	34	14.07	3.81	23.4	5.77	7.90	0.57
3	49	24.54	5.22	22.8	1.31	2.16	0.76
4	40	24.25	3.75	22.6	6.20	7.75	0.46

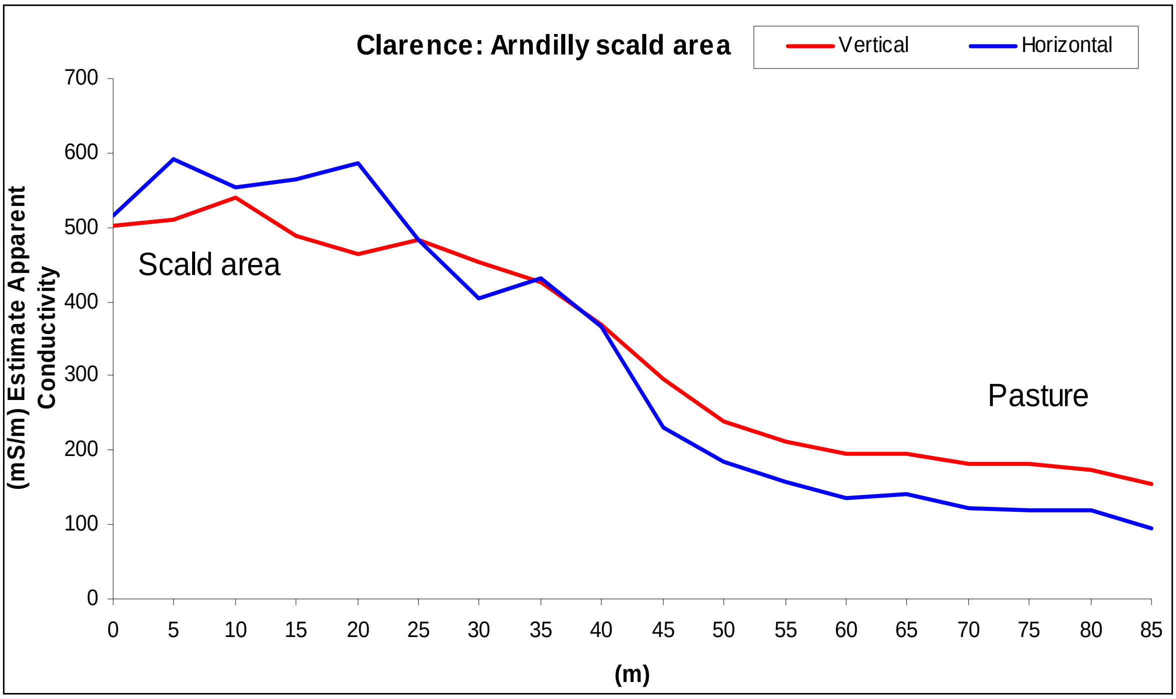

Figure 54. EM38 transect one at scald site, Arndilly.

Iron (Fe) salts present on surface in scald area. High EM38 values indicate both acid and marine salts present supported by observations and high groundwater Electrical Conductivity values (Table 16).

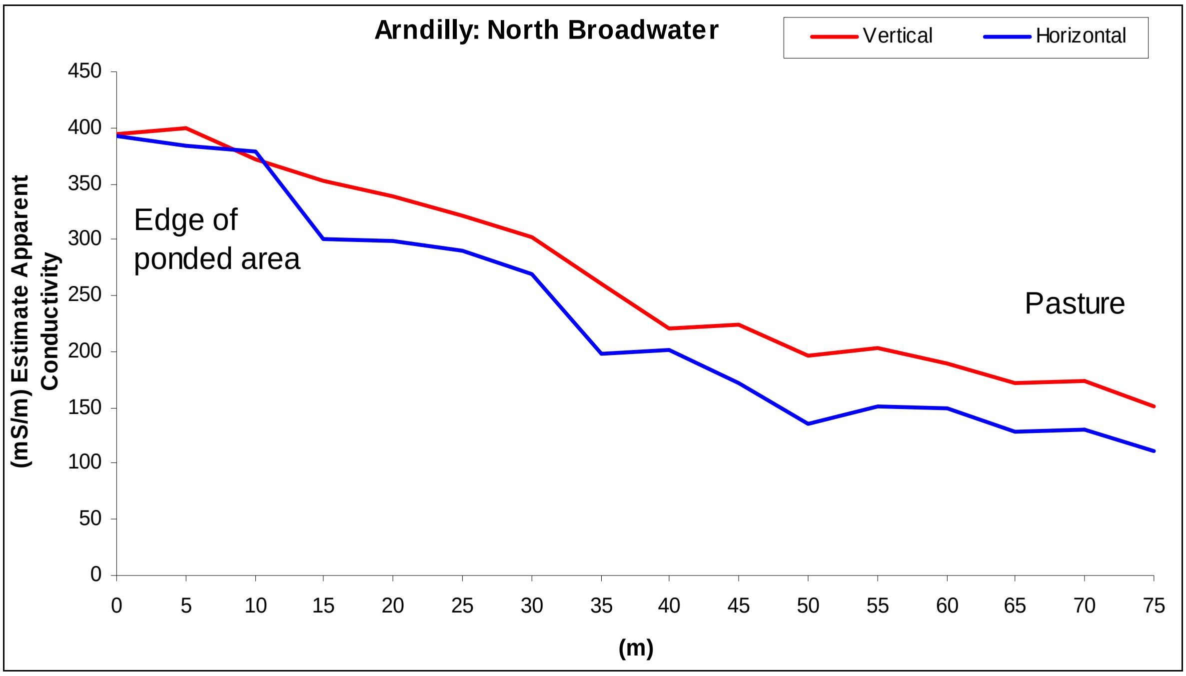

Figure 55. EM38 transect on north side of The Broadwater.

Possible combination of salts present due to the close proximity of The Broadwater, tidal lagoon.

4.3.5 Farlows next to the pacific highway

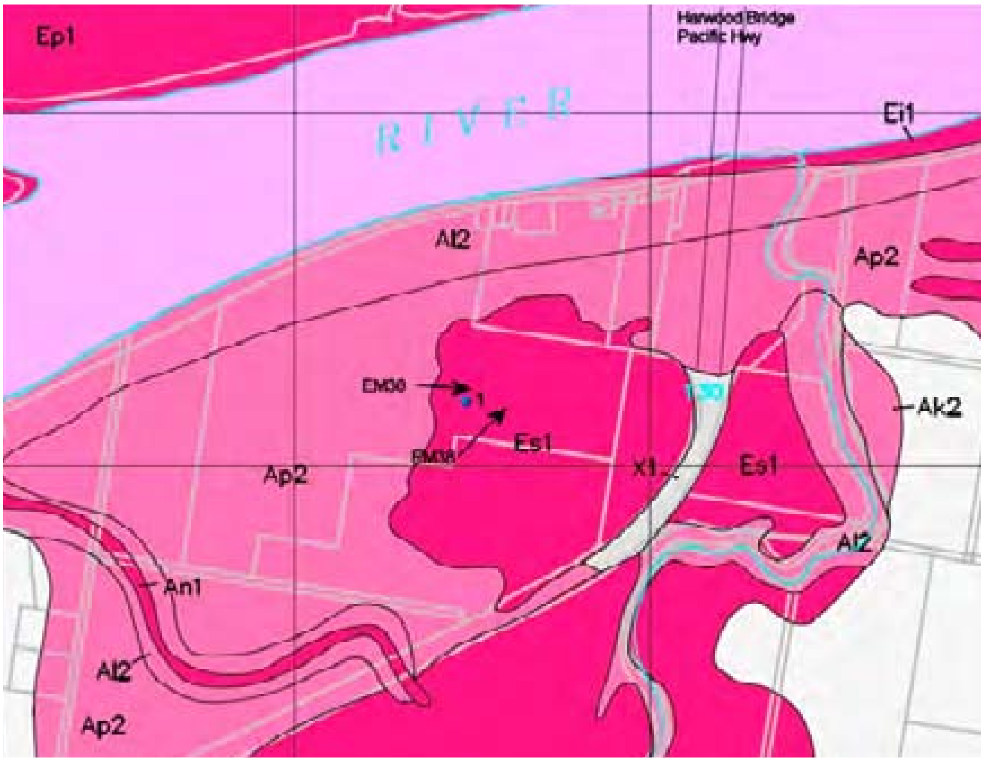

Figure 56. One K_{sat} pit and two EM38 transects, at Farlows.
(source: Naylor et al., 1998)

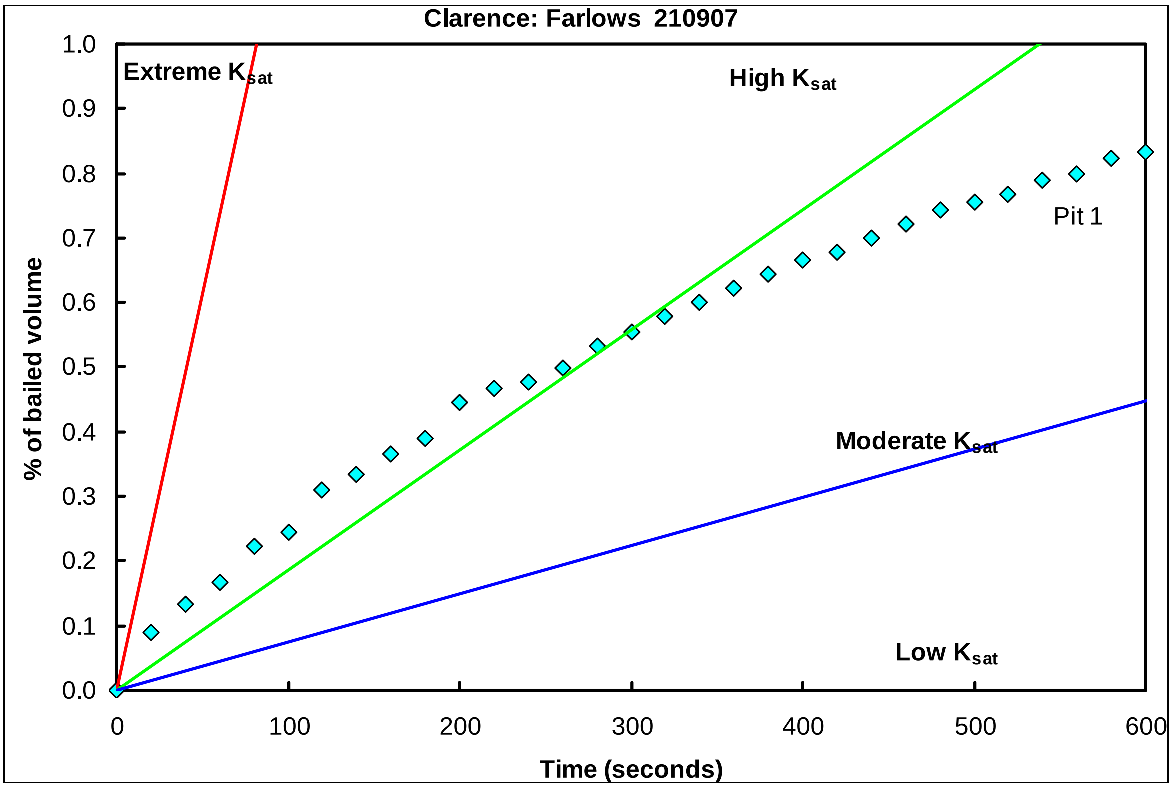

Figure 57. Normalised water level recovery rate over time, at Farlows.

Soil description: Forest (Pit 1 site) appears to be in transition from Melaleuca to Casuarina stand of trees. High incident of dead Melaleucas, being replaced by thick stand of young Casuarinas. Black topsoil, Fe staining on surface and in profile, few macropores.

Table 17. Farlows at Clarence, pit water quality and quantitative K_{sat} data.

			Ground water quality		Hydraulic conductivity (m day^{-1})		
Pit No.	Pit depth (cm)	Water table depth (cm)	pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	43	31.7			12.55	12.79	0.32

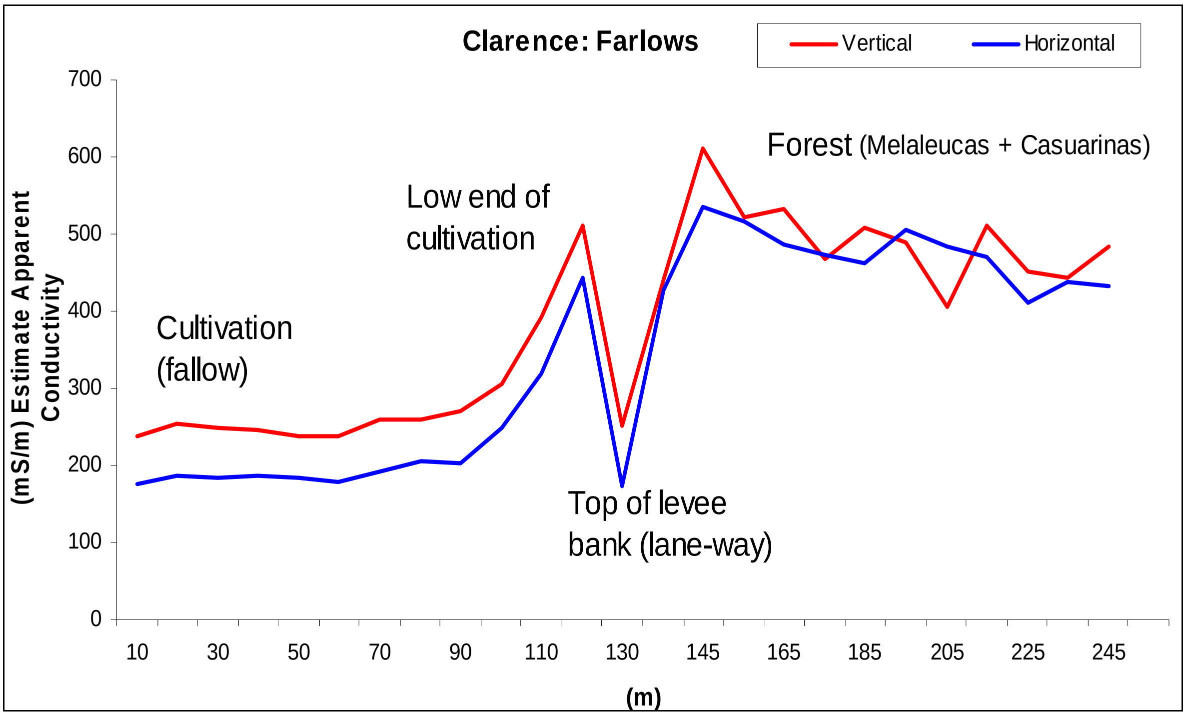

Figure 58. EM38 transect at Farlows.

Farlows transect from fallow cane field across levee and drain into forest area. Anecdotal history of marine salt intrusion from chronic leaking floodgates into survey area.

Figure 59. Clarence site, effect of marine salt intrusion on Melaleuca forest.

4.4 Macleay River Catchment Sites

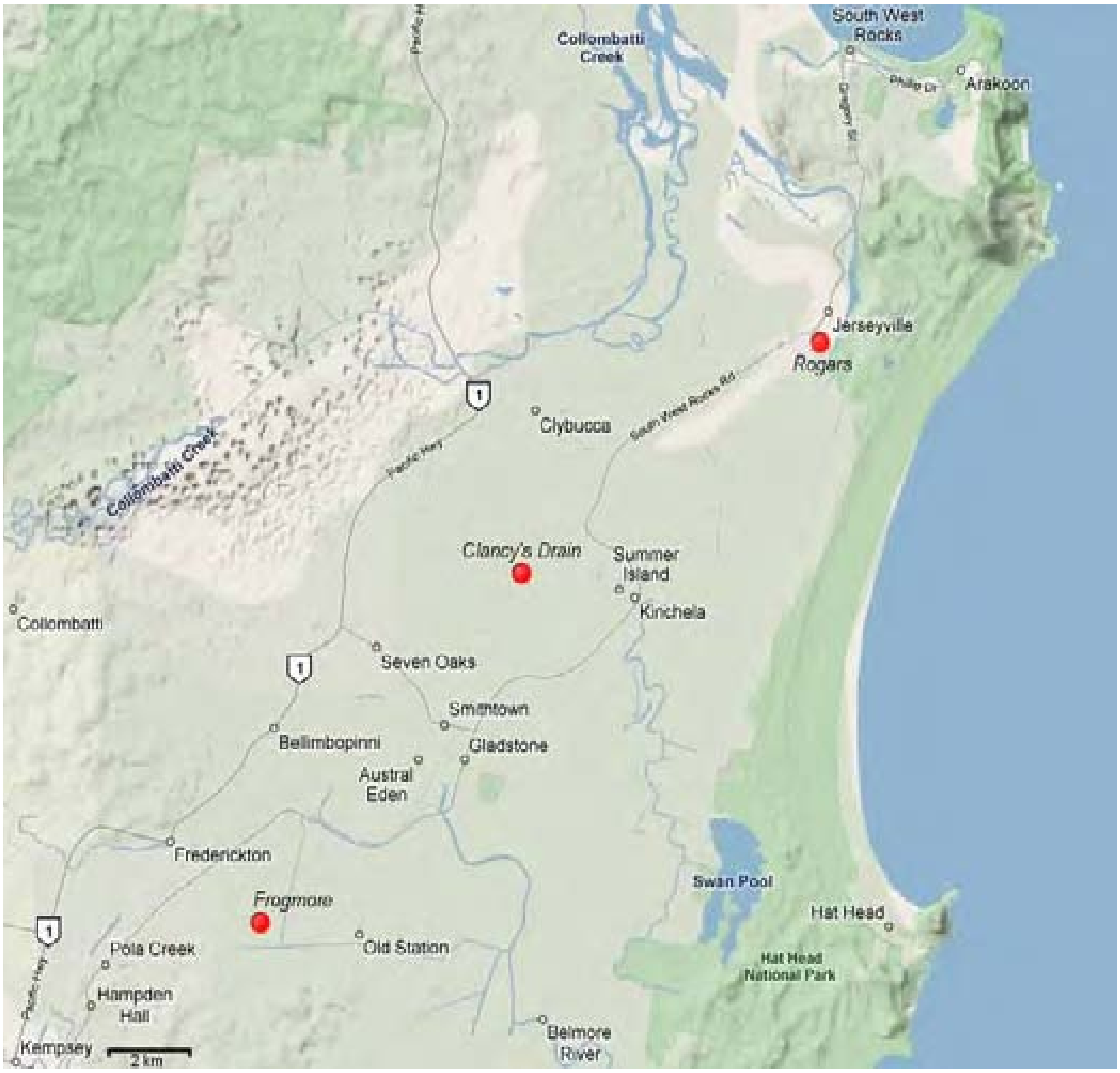

Figure 60. Macleay sites.

4.4.1 Rogars property

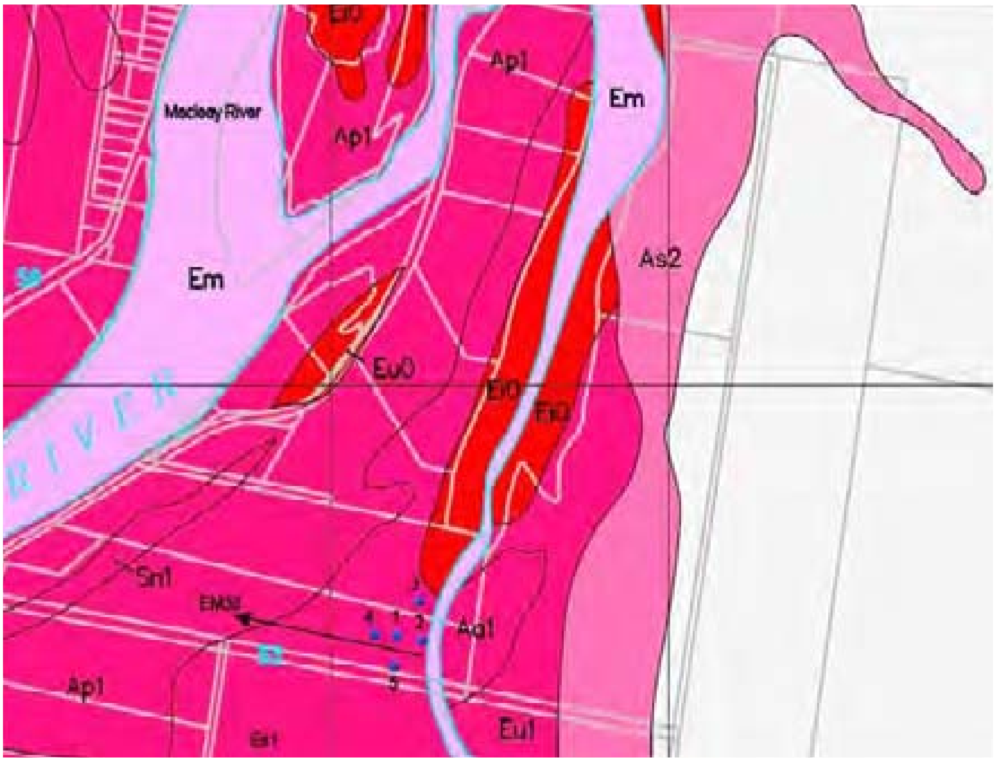

Figure 61. Five K_{sat} pits and one EM38 transect, at Rogars.
(source: Naylor et al., 1998)

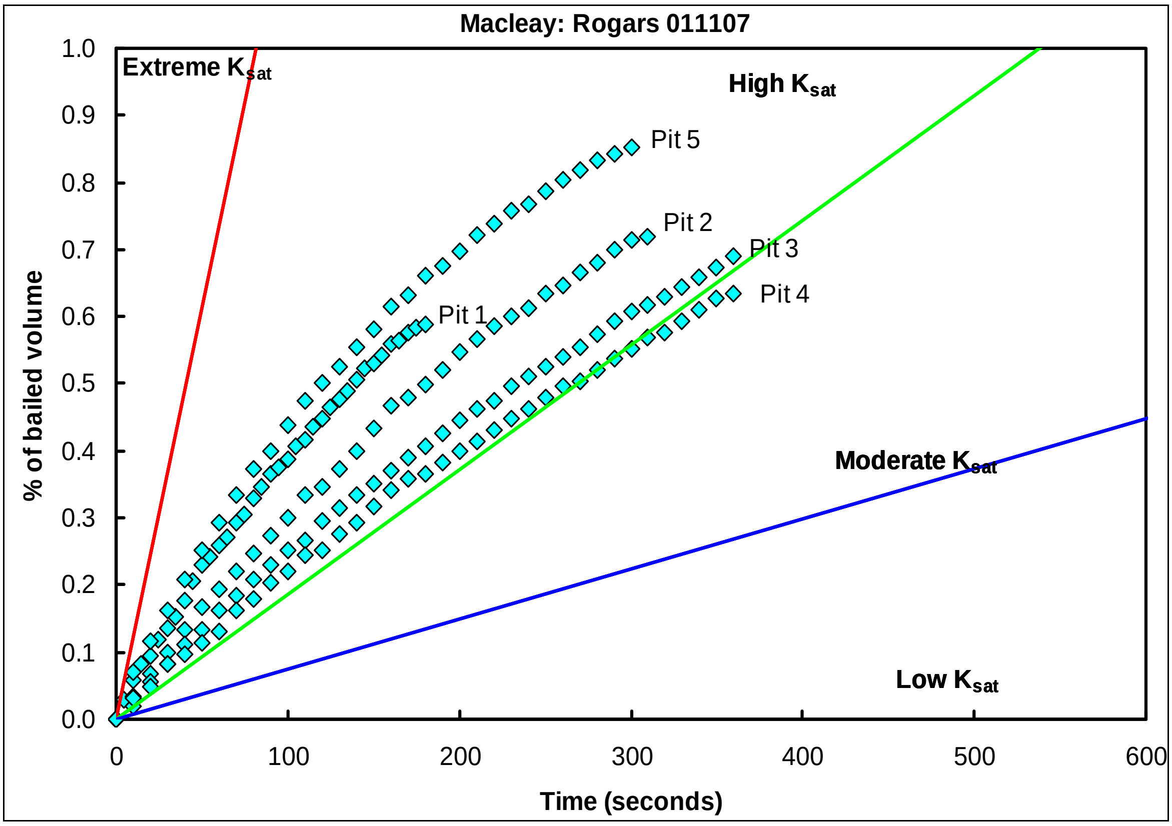

Figure 62. Normalised water level recovery rate over time, on Rogars wetland.

Consistent high K_{sat} pits located in the Jerseyville/Kitchener area.

Soil description: Past marine intrusion (anecdotal from owner). Soil silty clay loam topsoil to medium clays with sand lenses at varying depths. Few mottles dark red to orange, common abundance and diameter of macropores, jarosite at depth, iron coated root channels, abundant roots both vertical and horizontal root direction.

Table 18. Rogars at Macleay, pit water quality and quantitative K_{sat} data.

Pit No.	Pit depth (cm)	Water table depth (cm)	Ground water quality		Hydraulic conductivity (m day^{-1})		
			pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	35	15.0	3.85	12.67	19.59	28.30	0.50
2	46	30.0	3.78	21.53	17.05	19.62	0.54
3	50	24.6	3.92	19.5	18.43	28.07	0.62
4	35	22.2	3.68	27.43	12.27	15.05	0.56
5	50	24.9	3.91	8.19	21.13	32.80	0.55

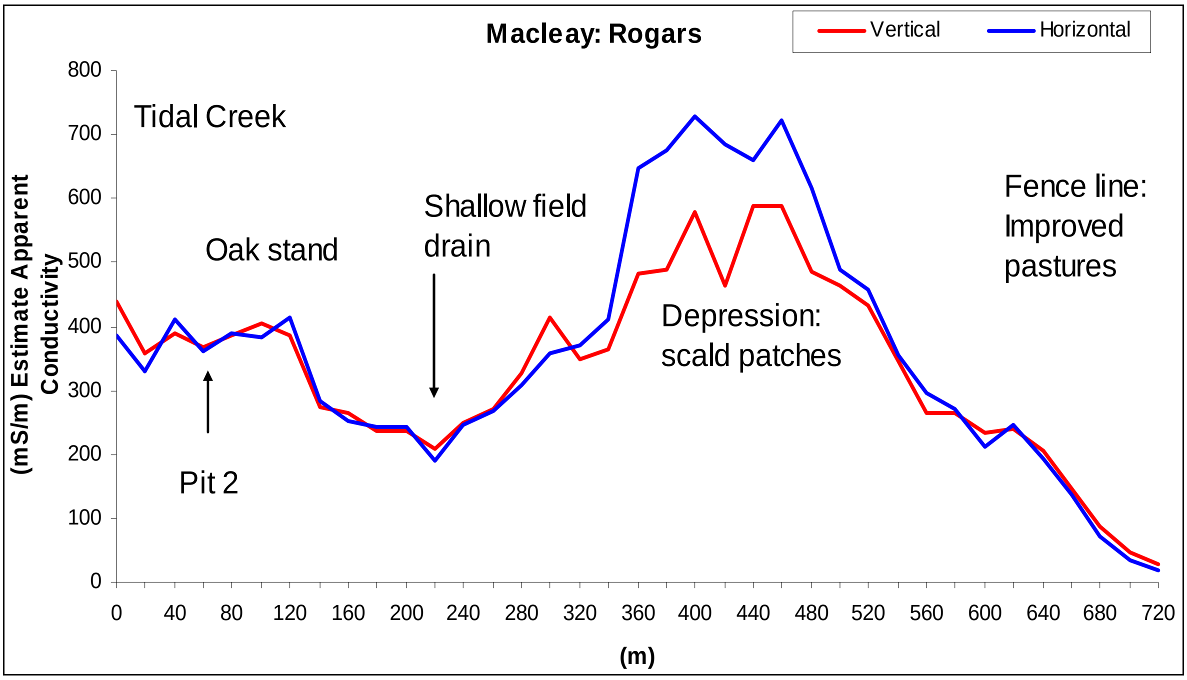

Figure 63. EM38 transect at Rogars property.

History of salt water intrusion anecdotal by owner. Creek is tidal, position in estuary near river entrance. High values indicate acid and marine salts present. Scald area low elevation, with high EM38 and groundwater EC values. Dominate Juncus sp. in clumps with some Phragmities regrowth.

4.4.2 Clancys Drain

Figure 64. Five K_{sat} pits and an EM38 transect.
(source: Naylor et al., 1998)

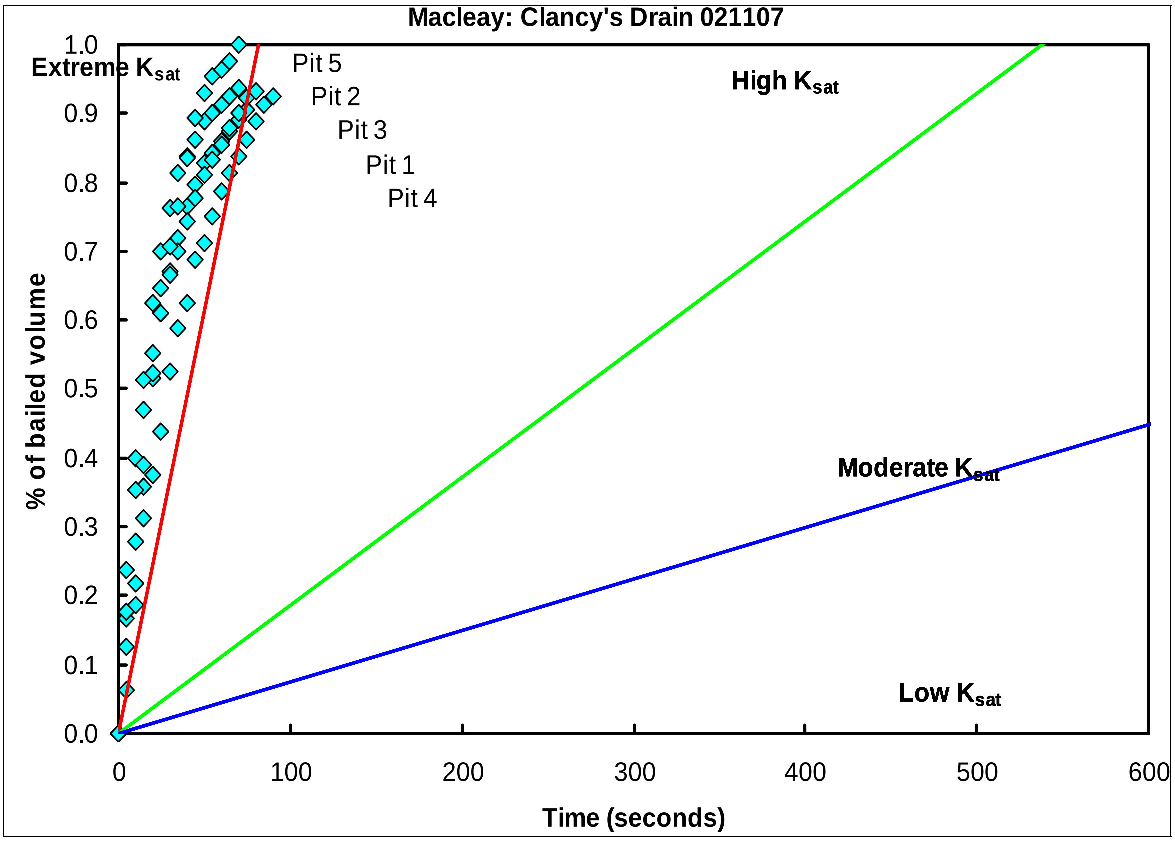

Figure 65. Normalised water level recovery rate over time, at Clancys Drain.

Pasture area, with consistent extreme K_{sat} rates.

Soil description: Black topsoil to medium clay subsoil. Few to common mottling, reddish in colour. Few to common macropores abundance with medium diameter size (i.e. a few major contributing pores). Vertical and horizontal macropores, abundant vertical roots, with jarosite swirls at depth.

Table 19. Clancys Drain at Macleay, pit water quality and quantitative K_{sat} data.

			Ground water quality		Hydraulic conductivity (m day^{-1})		
Pit No.	Pit depth (cm)	Water table depth (cm)	pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	55	42.5	3.85	4.89	156.98	154.77	0.40
2	60	48.6	3.70	6.91	216.93	222.78	0.36
3	58	46.1	3.94	7.59	143.07	148.09	0.38
4	42	31.1	3.95	4.94	111.47	127.41	0.35
5	42	29.9	4.00	4.34	196.49	216.14	0.36

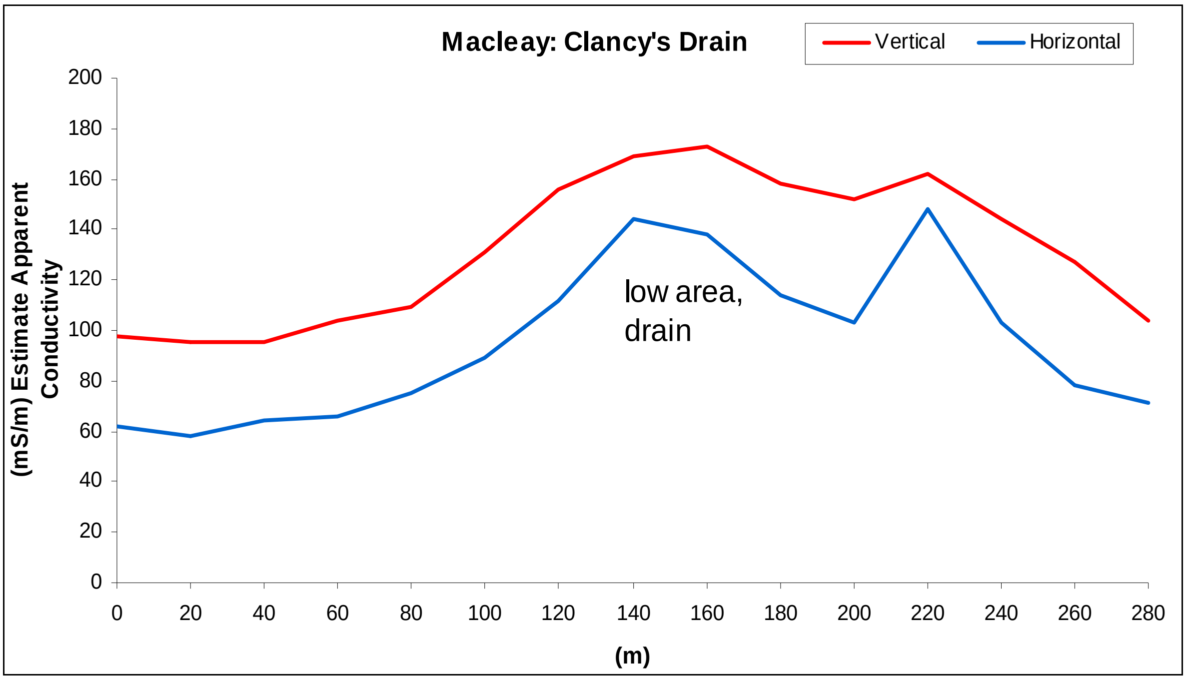

Figure 66. EM38 transect at Clancys drain.

Pasture area with EM38 transect perpendicular to shallow field drain. Large expanse of pasture area, new floodgate structure in place.

4.4.2 *Frogmore area*

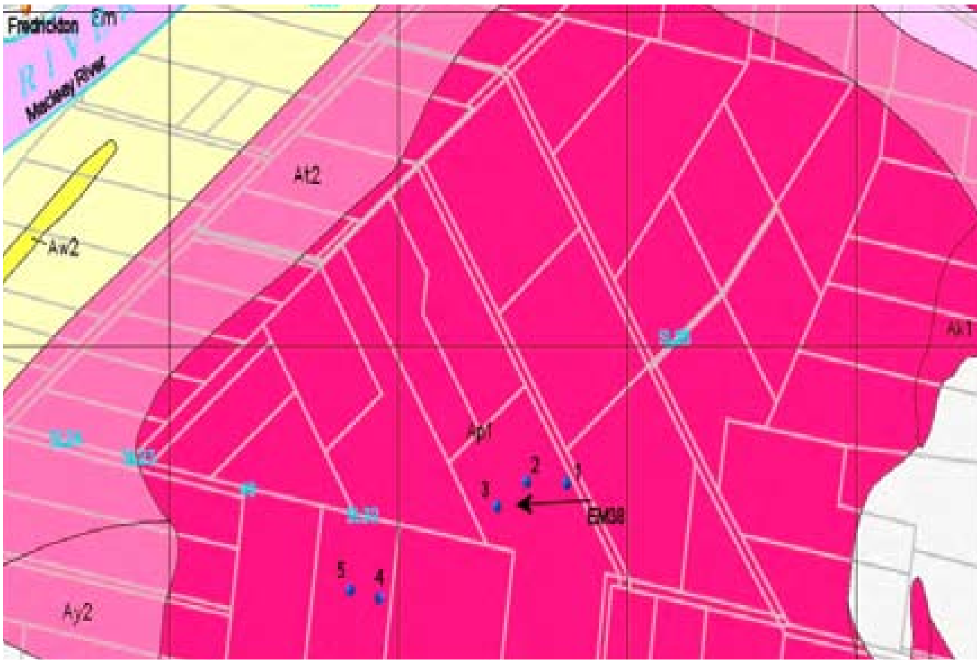

Figure 67. Five K_{sat} pits and an EM38 transect.
(source: Naylor et al., 1998)

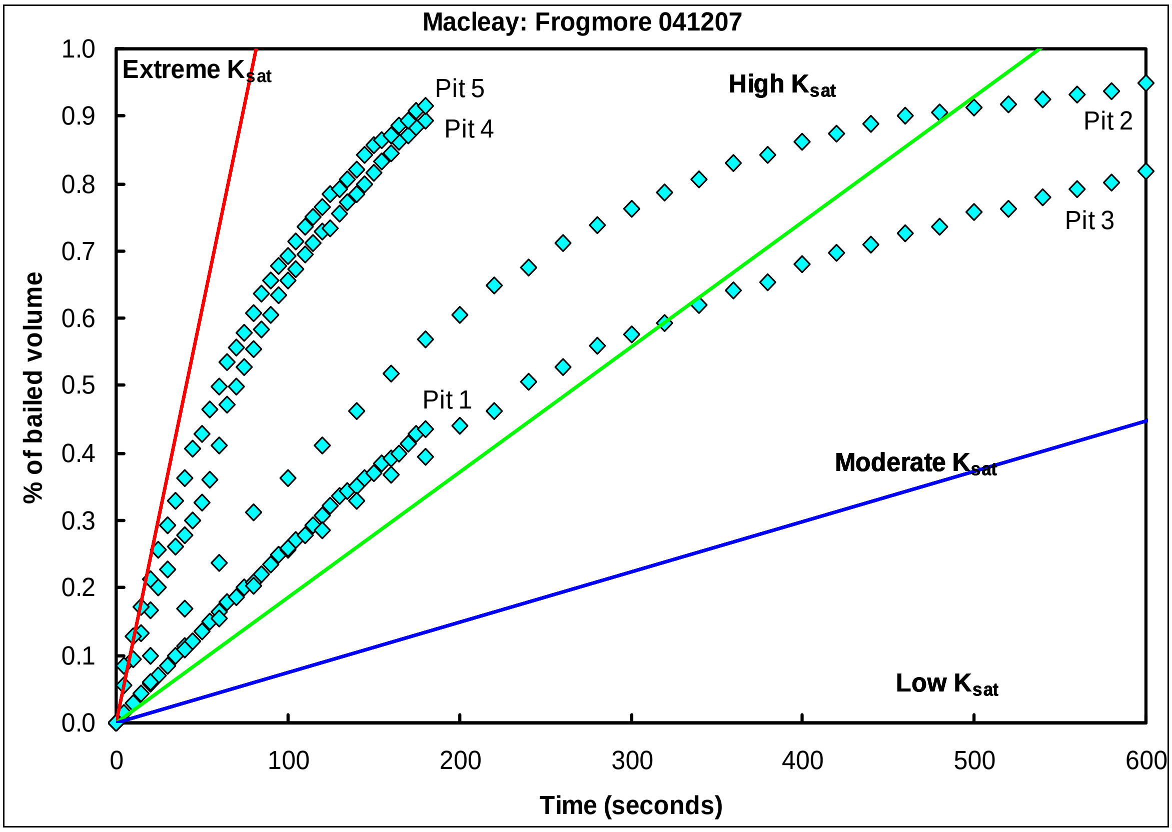

Figure 68. Normalised water level recovery rate over time, Frogmore pasture area.

Pits 1, 2 and 3 at Lancaster Drain, adjacent to drain depression. Pits 4 and 5 in upper Frogmore area.

Soil description: Pits 1 to 3. Black topsoil to clay/medium clay subsoil. Little to no mottling, very fine to few macropores, both vertical and horizontal pores. Iron staining in root channels. Pits 4 and 5. Soils mix of charcoal, light and grey clays. Very fine to few macropores, both vertical and horizontal pores. Abundant vertical roots.

Table 20. Frogmore at Macleay, pit water quality and quantitative K_{sat} data.

			Ground water quality		Hydraulic conductivity (m day^{-1})		
Pit No.	Pit depth (cm)	Water table depth (cm)	pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	32	16.4	3.84	1.59	11.76	15.32	0.50
2	38	19.8	4.06	2.00	18.86	26.02	0.54
3	41	20.7	4.08	2.05	11.21	15.34	0.62
4	38	17.6	4.32	2.58	41.90	58.58	0.56
5	41	24.1	4.20	2.69	42.22	53.81	0.55

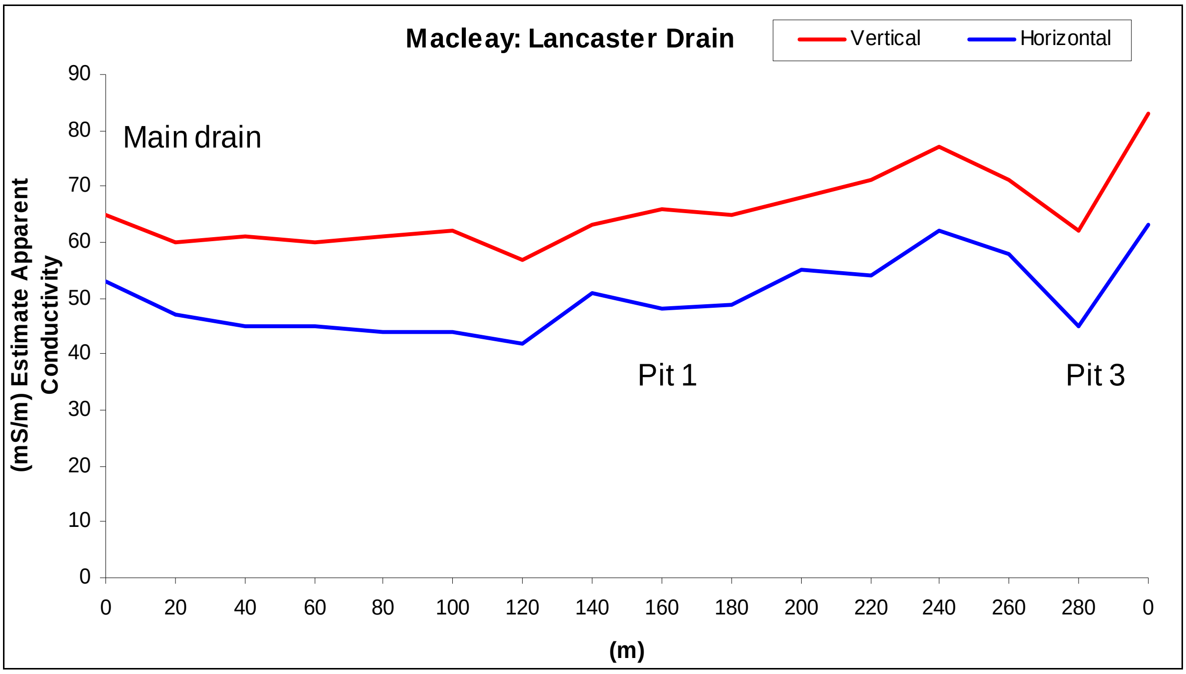

Figure 69. EM38 transect at Lancaster Drain.

Transect along edge of drain depression passing next to K_{sat} pits. Open pasture grazing area, beef and dairy cattle present.

4.5 Hastings River Catchment Sites

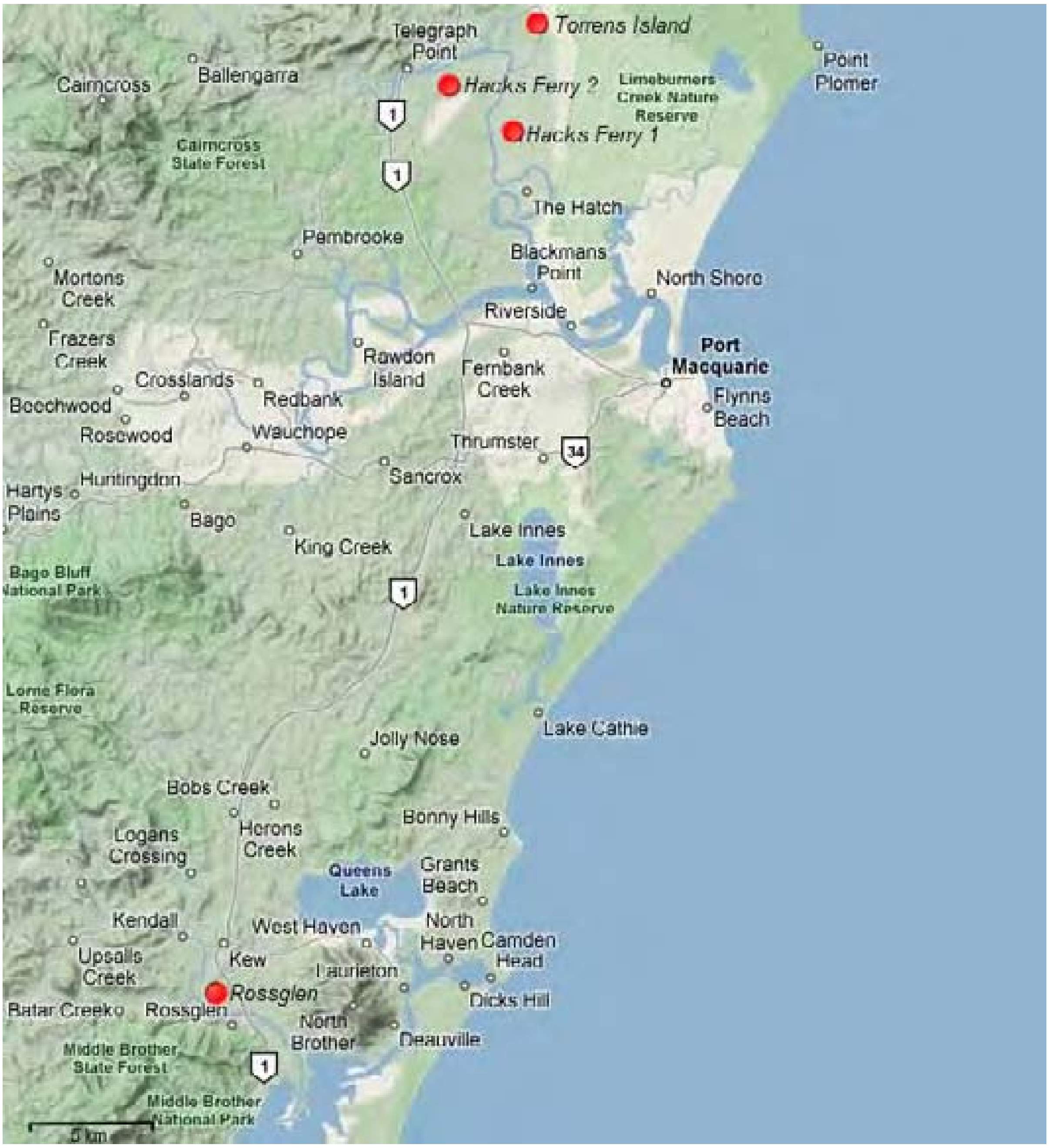

Figure 70. Hastings sites.

4.5.1 Rossglen

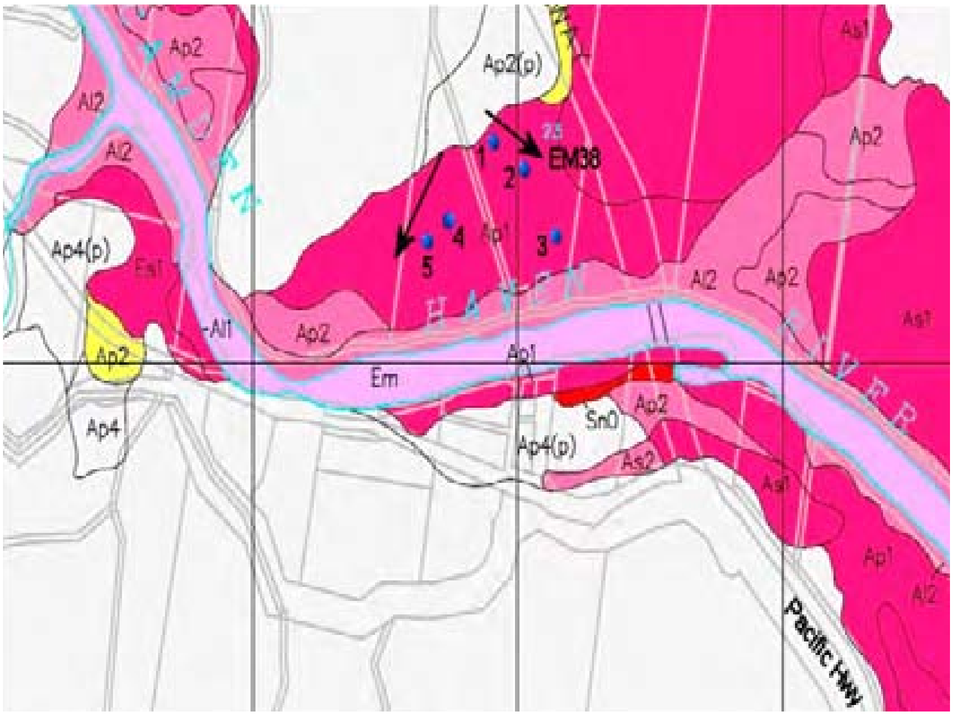

Figure 71. Five K_{sat} pits and two EM38 transects, at Rossglen.
(source: Naylor et al., 1998)

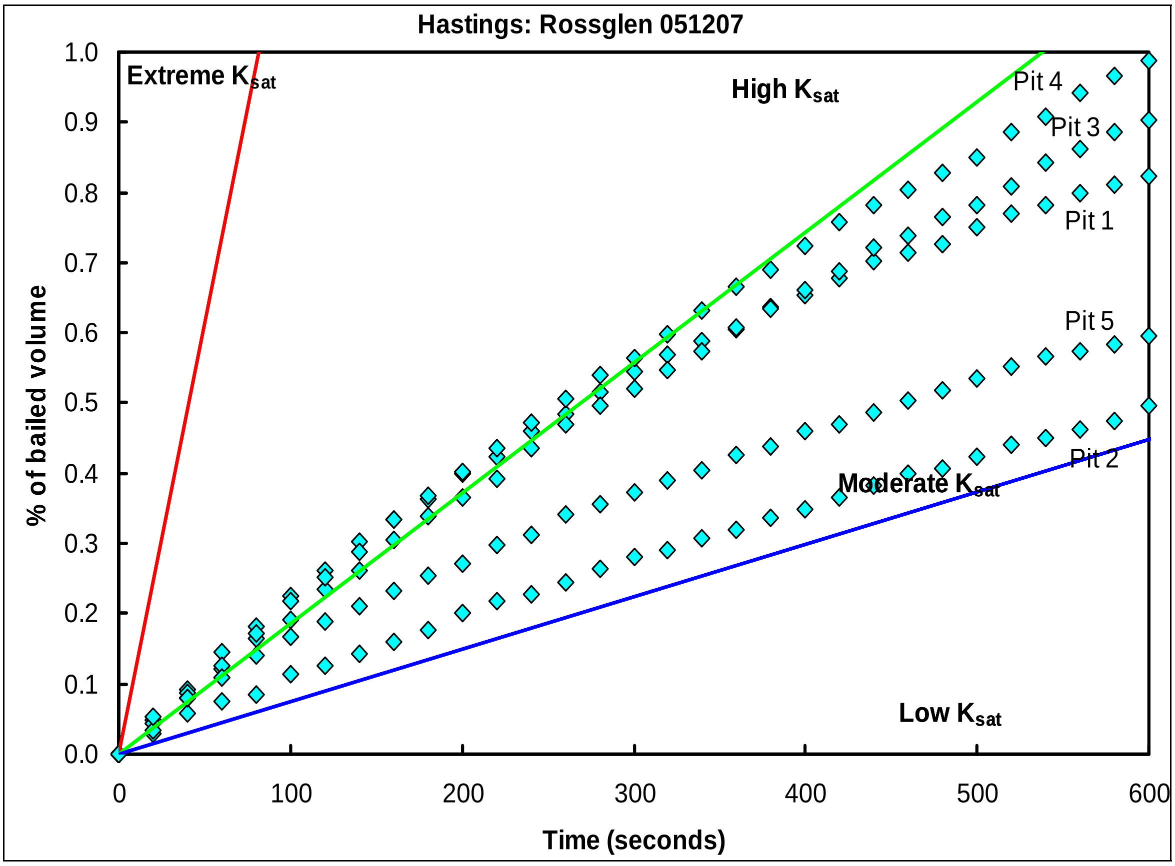

Figure 72. Normalised water level recovery rate over time, at Rossglen.

a hotspot remediated site,

Soil description: Pits 1, 2, and 3 on east side of road. Wet area, Black topsoil to grey clay to medium clay with Fe staining. Mottling from little to few, dark red to orange. Few to fine macropores with more vertical orientation. Roots vertical growth to depth. Pit 3 adjacent to weir, only OM present as a red colour as Fe flocc.

Pits 4 and 5 west side of road open pasture, old race course area. Black topsoil to light grey medium clay. Few to common mottles reddish/orange in colour. Few to fine macropores with more vertical orientation. Fe staining in old root channels and jarosite swirls and concretions at depth.

Table 21. Rossglen at Hastings, pit water quality and quantitative K_{sat} data.

			Ground water quality		Hydraulic conductivity (m day^{-1})		
Pit No.	Pit depth (cm)	Water table depth (cm)	pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	40	21.55	3.63	6.91	10.07	13.03	0.55
2	40	20.70	3.55	6.08	6.26	7.51	0.39
3	36	22.90	4.08	5.45	10.52	12.05	0.36
4	30	19.75	3.36	5.84	12.69	12.80	0.3
5	32	11.60	3.26	7.79	6.82	9.34	0.56

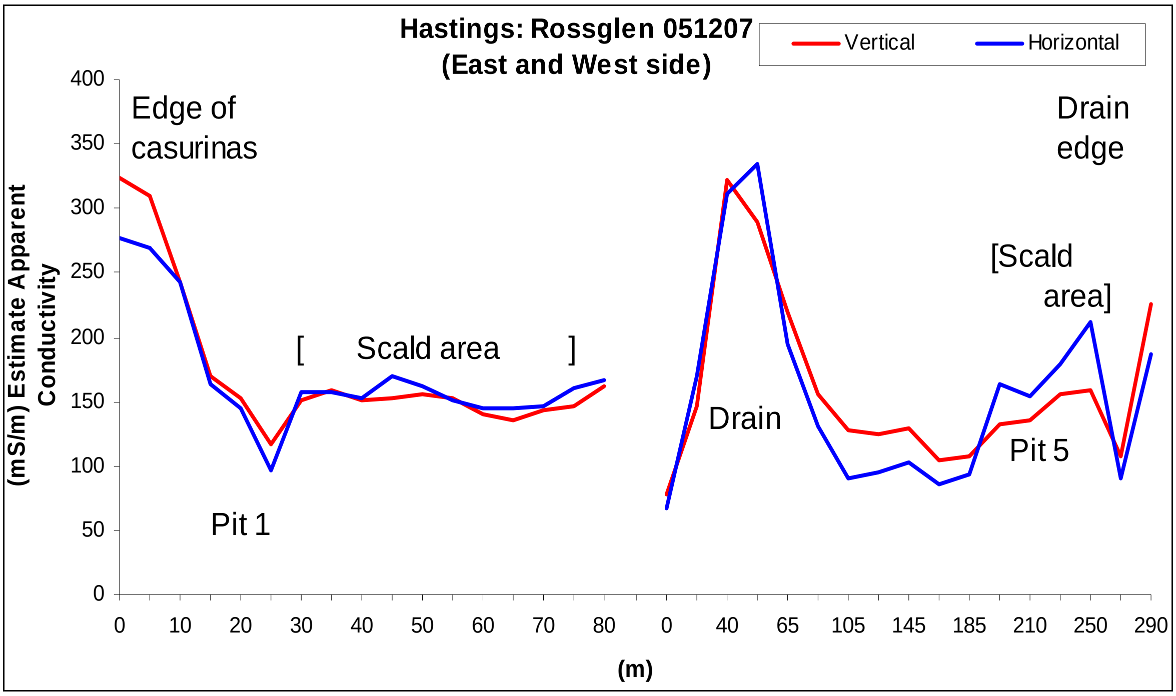

Figure 73. Two EM38 transects at Rossglen.

Surface scalds present along both transects.

4.5.2 Hacks Ferry and Torrens Island

Figure 74. Hacks ferry K_{sat} pits.
(source: Naylor et al., 1998)

Pits 1 and 2 located in ti-tree plantation and pits 4 and 5 in low swamp area.

Figure 75. One K_{sat} pit in a previous scald area at Torrens Island.
(source: Naylor et al., 1998)

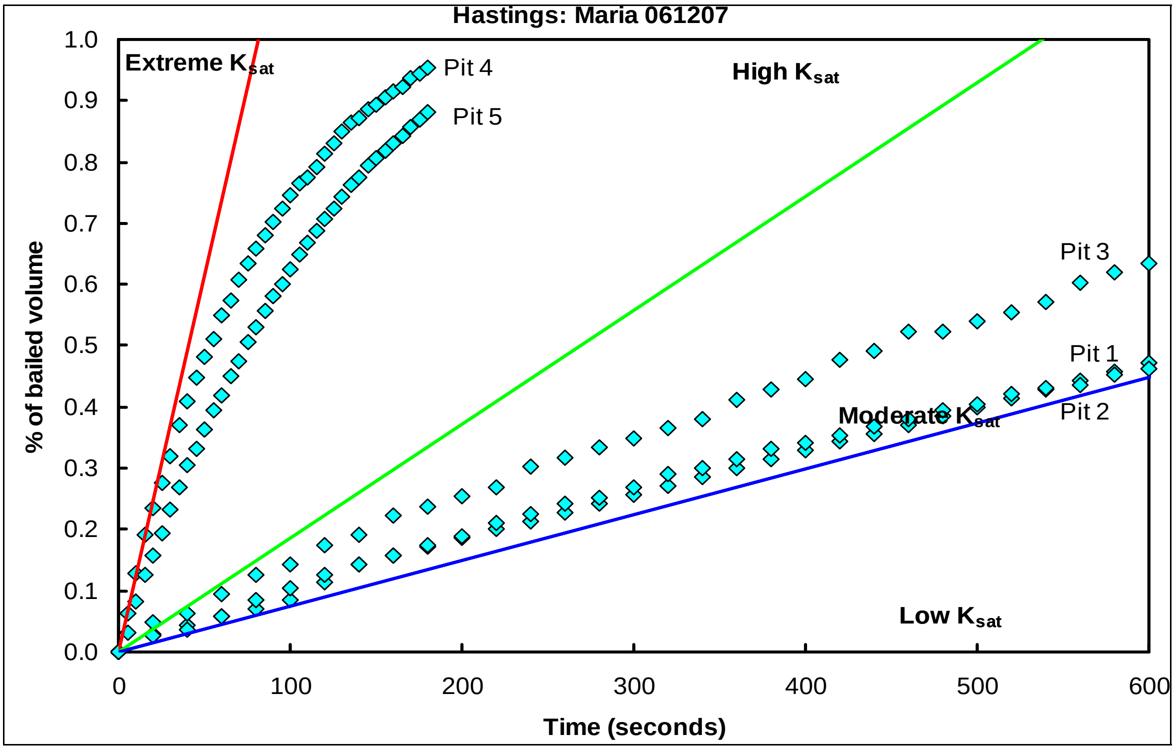

Figure 76. Normalised water level recovery rate over time, at Hastings.

Soil description: Pit 1 and 2, edge of drain on Ti-tree plantation, Maria River. Black topsoil to light grey clay to plastic medium clay at depth. Fe coated root channels, very few to common mottles reddish colour. Few, fine to medium macropores with both horizontal and vertical orientation. Possible marine influence.

Pit 3 Torrens Island previous scald now grazing area, water couch dominate. Dark brown topsoil to silty clay to a fine sand clay at depth. Roots abundant to depth. Very few mottles, dark red colour, Fe staining in old root channels at depth. Few to fine macropores with more vertical orientation.

Pits 4 and 5 Hacks Ferry hotspot area, light to nil grazing pressure. Surrounded .by melaleuca and casuarina forests. Black peat topsoil, to light grey clay to plastic medium clay at depth. Few to common mottles red to orange in colour. Fe concretions at 50-80cm. Many to medium macropores both vertical and horizontal orientation.

Table 22. Maria River at Hastings, pit water quality and quantitative K_{sat} data.

Pit No.	Pit depth (cm)	Water table depth (cm)	Ground water quality		Hydraulic conductivity (m day^{-1})		
			pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1	45	35.3	4.40	19.56	4.24	3.95	0.32
2	40	17.6	4.86	17.84	4.83	6.19	0.57
3	52	42.5	4.70	16.84	6.11	5.29	0.33
4	30	5.1	4.01	0.62	55.13	77.89	0.69
5	25	6.9	4.20	0.42	37.98	47.66	0.51

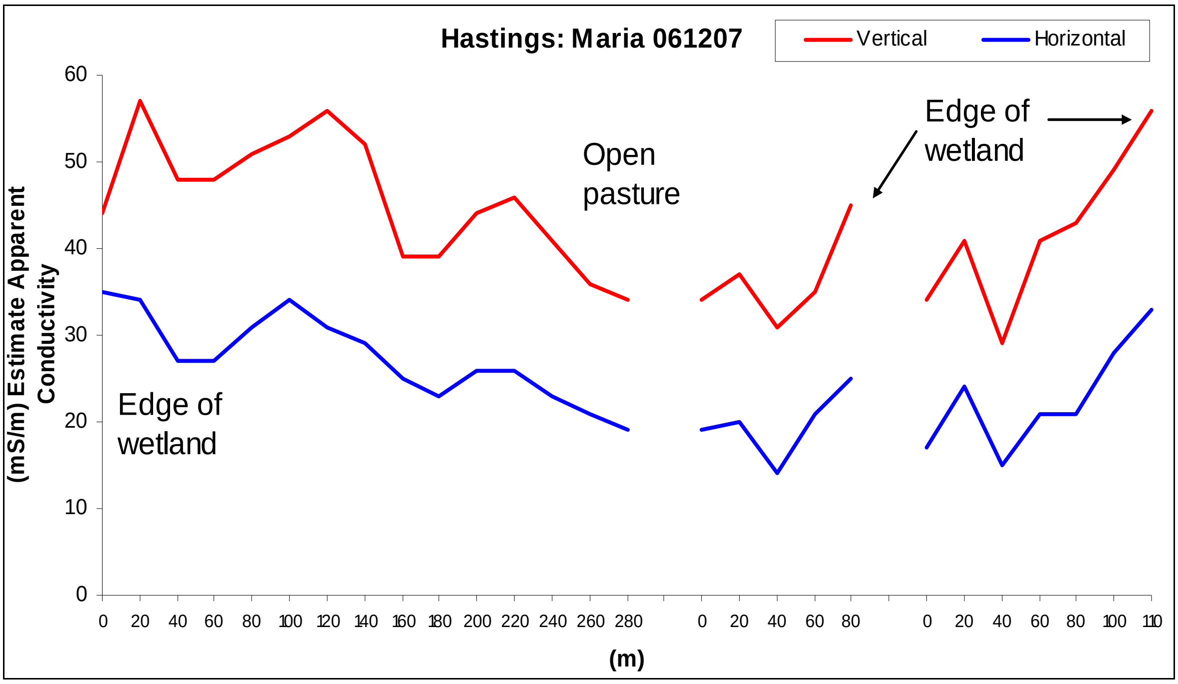

Figure 77. EM38 transects at Hacks Ferry on the Maria River system

Triangular transect origin on the edge of wet area moving into open pasture area then back to a second wet area, returning through a casuarina forest, back to the edge of the originating wet area.

Figure 78. Infilling pit in the Hastings catchment.

4.6 Manning River Catchment Sites

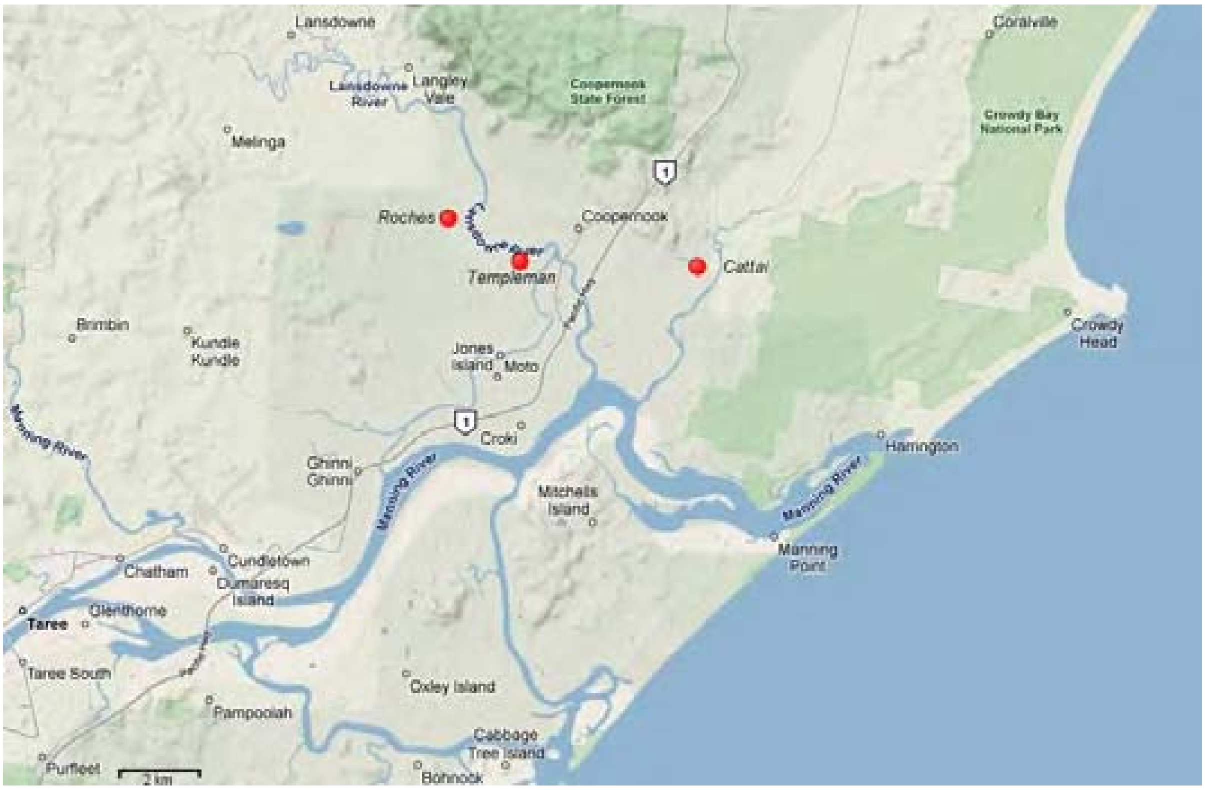

Figure 79. Manning sites.

4.6.1 Cattai Creek

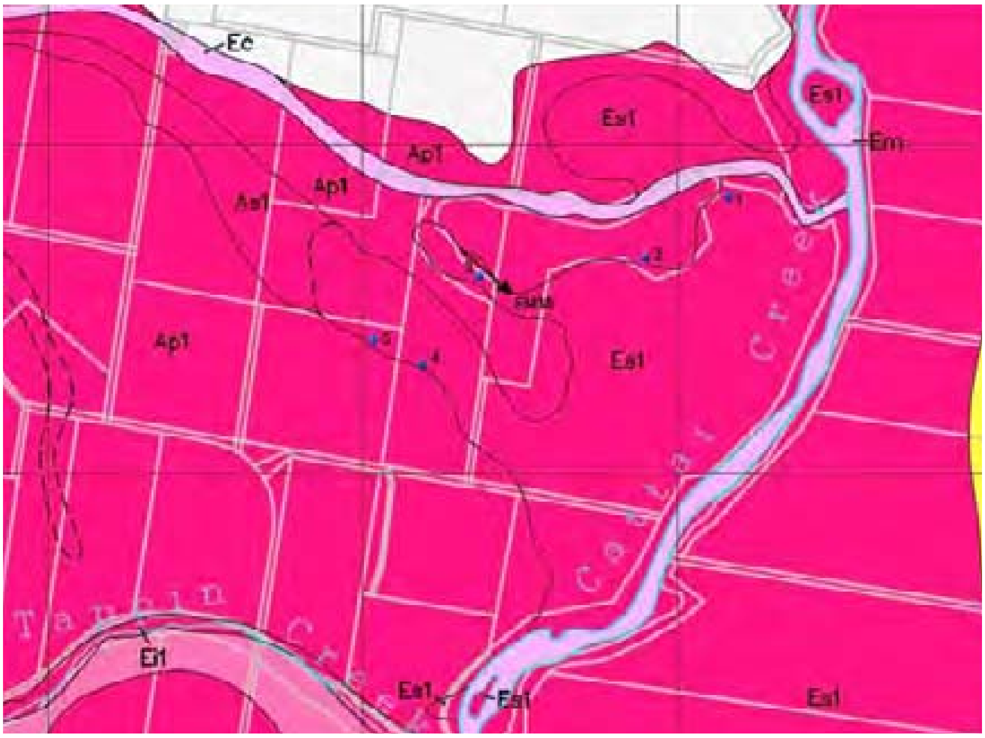

Figure 80. Five K_{sat} pits and one EM38 transect, at Cattai Creek.
(source: Naylor et al., 1998)

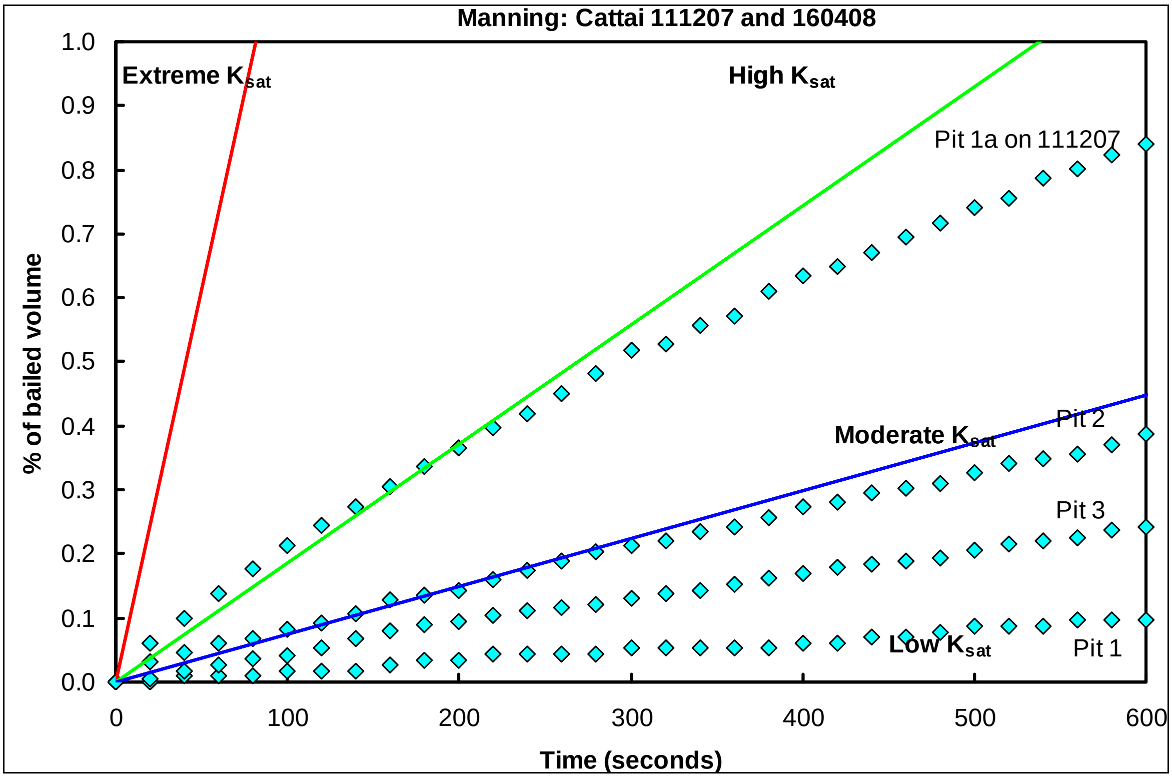

Figure 81: Normalised water level recovery rate over time, at Cattai creek.

Soil description: Pit 1a completed on 11/12/07. Mid location in wetland, salt water couch area. Black brown topsoil to light grey to dark grey medium clay at depth. Fine sand at 105cm. Very few to few red orange mottles. Abundant vertical roots, Fe staining and concretions in old root channels. Few to common and fine to medium macropores both vertical and horizontal.

Pit 1 located between finger toe and ponded area. Second pit in this area to confirm slow rate of infil. Black topsoil to dark grey to grey clay, appears mixed soil at depth (i.e. swirls of black soil mixed in). Common red orange mottling. Few to fine vertical macropores.

Pit 2 edge of casuarinas and drain, marine influence possible. Black topsoil to light coloured clay and to a dark grey sand. Common red yellow mottles, yellow swirls at depth. Few to very fine more horizontal macropores.

Pit 3 narrow leaf melaleuca expansion area. Black topsoil to coarse sand, grey to dark blue grey sand. No mottling, roots vertical. Few to very fine more vertical macropores. Vertical roots Pit 4 very slow rate of infil, not completed.

Table 23. Cattai at Manning, pit water quality and quantitative K_{sat} data.

Pit No.	Pit depth (cm)	Water table depth (cm)	Ground water quality		Hydraulic conductivity (m day^{-1})		
			pH	EC (ds m^{-1})	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1a	35	21.6	3.69	21.30	9.14	10.86	0.43
1	40	26.7	4.52	9.83	0.86	1.07	0.43
2	39	24.0	4.45	18.40	2.79	3.36	0.42
3	53	27.8	4.24	2.28	1.30	1.88	0.83

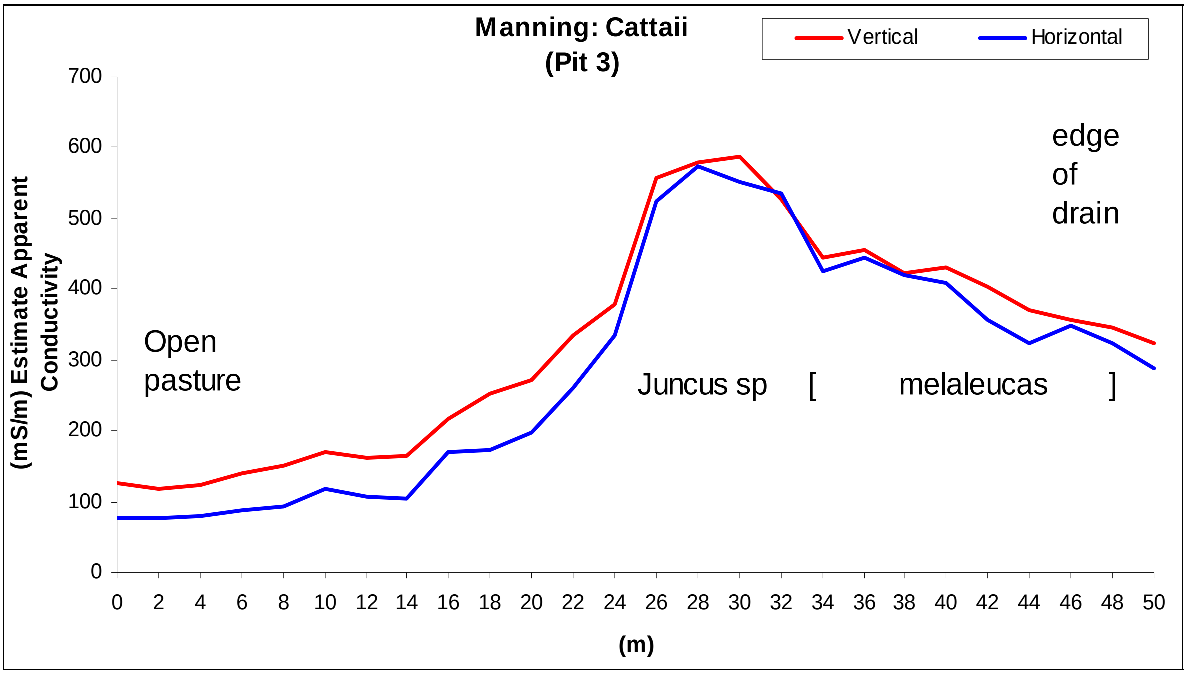

Figure 82. EM38 Cattai transect from open pasture into Juncus sp and Melaleucas.

Possible decline in elevation from pasture into a young thick patch of melaleucas, possible marine salt intrusion from drain.

4.6.2 Templeman

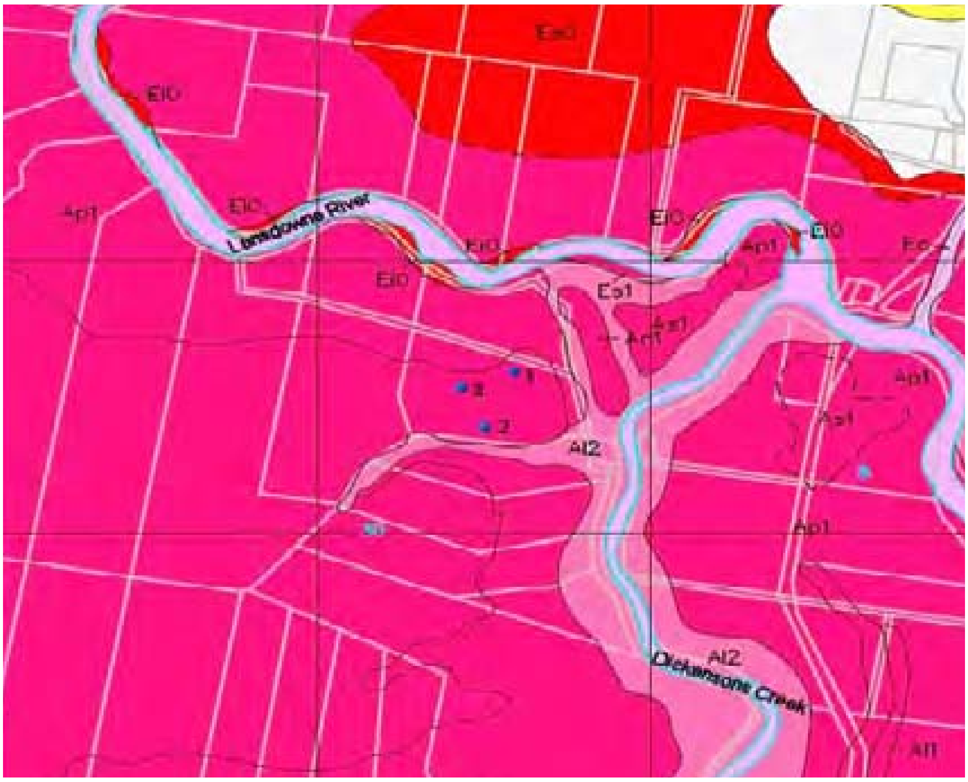

Figure 83. Three K_{sat} pits, at Templeman.
(source: Naylor et al., 1998)

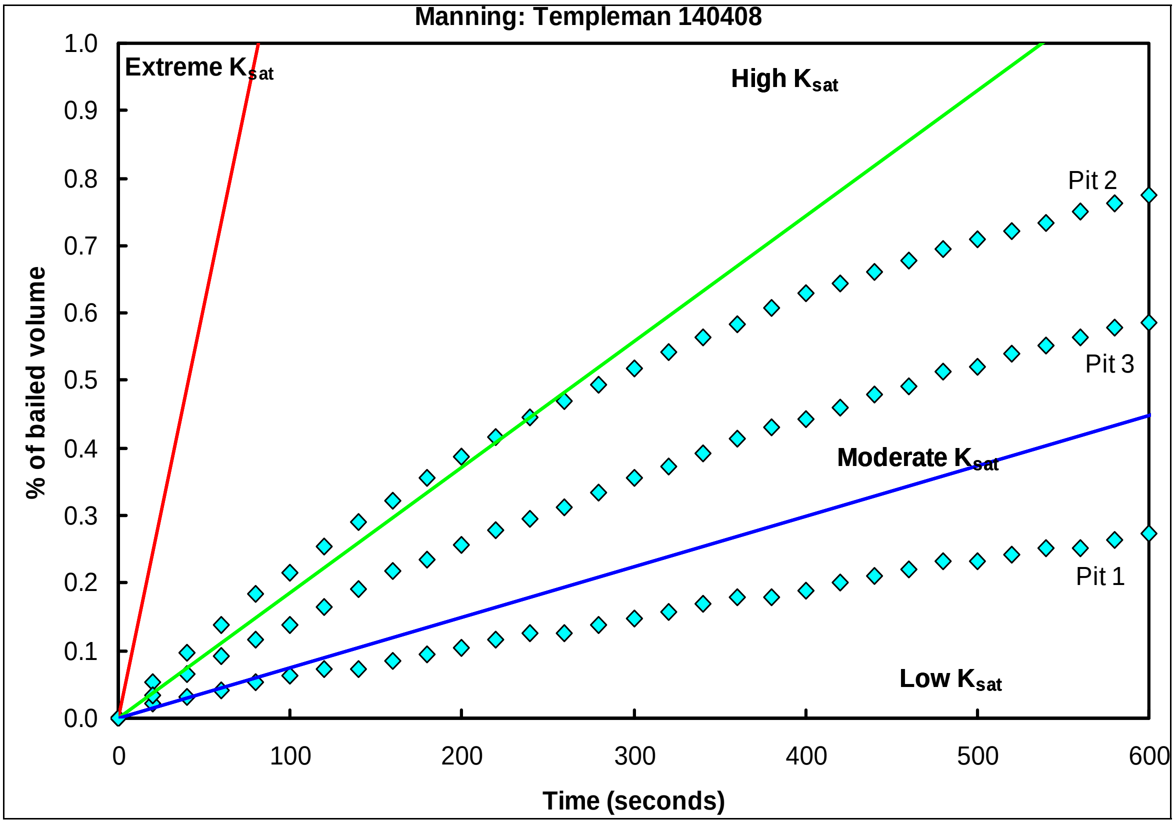

Figure 84. Normalised water level recovery rate over time, at Templeman.

Soil description: Pit 1 located on old headland. Topsoil black mixed with clay to light grey yellowish clay to medium clay with jarosite swirls at depth. No mottling or macropores observed.

Pits 2 and 3 black topsoil to light coloured clay to heavy plastic dark grey clay at depth. Jarosite swirls plus some jarosite in old root channels, gritty texture. No mottling found. Common Fine macropores with both vertical and horizontal orientation. Pit 3 near drain. Abundant roots both vertical and horizontal in all pits

Table 24. Templeman at Manning, pit water quality and quantitative K_{sat} data.

			Ground water quality		Hydraulic conductivity (m day^{-1})		
Pit No.	**Pit depth (cm)**	**Water table depth (cm)**	**pH**	**EC (ds m^{-1})**	**Bouwer and Rice (1983)**	**Boast and Langebartel (1984)**	**L/W**
1	28	17.0	4.04	11.06	3.15	3.21	0.31
2	30	3.7	3.66	3.37	9.87	14.70	0.71
3	31	5.5	4.02	7.05	6.09	8.57	0.67

4.6.3 Roches

Figure 85. Eight K_{sat} pits and two EM38 transects, at Roches.
(source: Naylor et al., 1998)

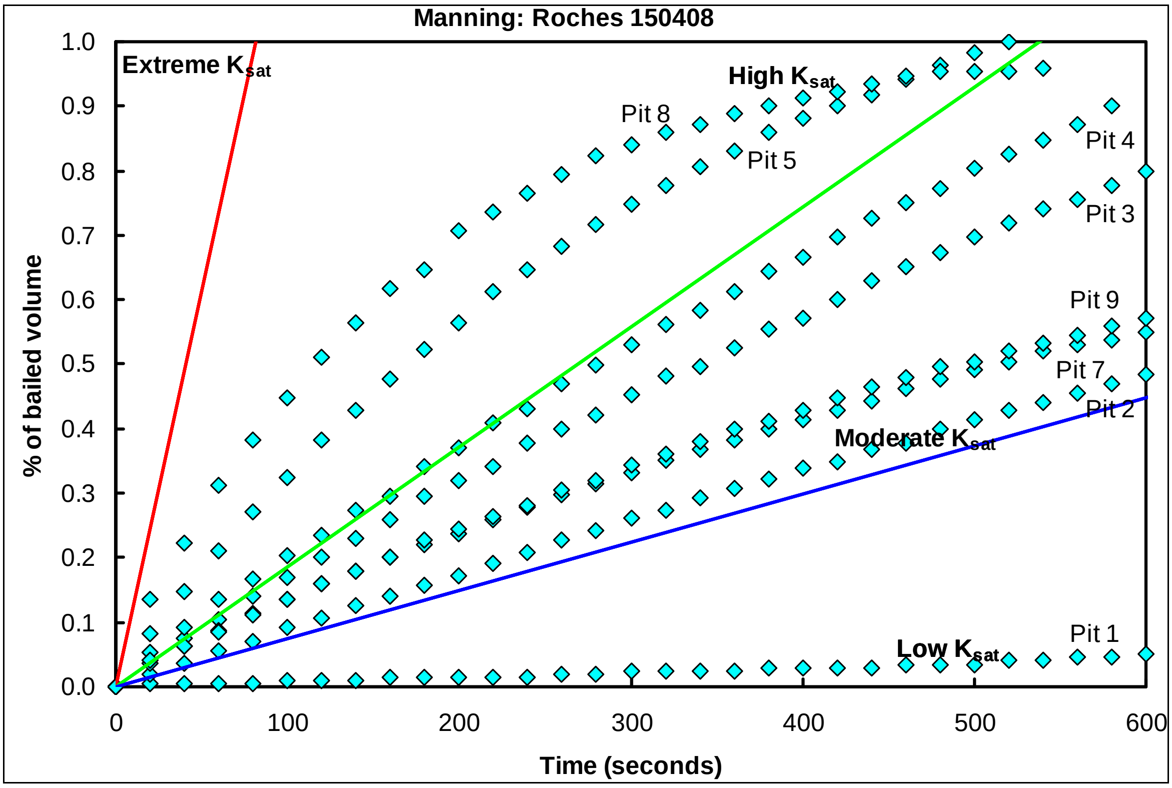

Figure 86. Normalised water level recovery rate over time, at Roches.

K_{sat} results indicate site variability.

Soil description: Pits 1, 7, 8 and 9 within a 40m area. Pit 1 black brown colours topsoil to blue grey clay with fine sand at depth. No mottling. Few to very fine macropores, jarosite swirls at depth. Pit 1 with the occurrence of fine sand at depth may indicate previous soil disturbance. In contrast pits 7, 8 and 9 higher infill rate, black topsoil to light grey clay to blue grey medium clay. Jarosite swirls and paste at depth. Common red mottling, Fe coated root channels. Common to medium course macropores, both vertical and horizontal orientation.

Pit 2 scald area, new ti-tree regrowth area. Topsoil Fe staining on surface Peat black charcoal topsoil to light grey to darker medium clay with bright yellow jarosite paste at depth. Few reddish mottling. Common, fine to medium macropores, both vertical and horizontal.

Pit 3 scald area new regrowth ti-trees, Mono-sulfidic Black Ooze(MBO) visible on surface, Fe flocc coated on surface with yellowish paste (jarosite) under this coat. Dark black topsoil to light grey clay to dark medium clay with abundant jarosite paste at depth. Vertical roots common. Few red mottles. Common medium macropores, vertical orientation.

Pit 4 pasture, black topsoil to light grey clay to dark clay with jarosite mottles gritty at depth. Medium, few to common yellow mottles. Common fine macropores more vertical orientation.

Pit 5 open pasture, black topsoil to light clay to dark medium clay with yellow jarosite swirls and gritty at depth. Common medium macropores vertical.

Table 25. Roches at Manning, pit water quality and quantitative K_{sat} data.

Pit No.	Pit depth (cm)	Water table depth (cm)	Ground water quality		Hydraulic conductivity (m day^{-1})		
			pH	EC ($ds\ m^{-1}$)	Bouwer and Rice (1983)	Boast and Langebartel (1984)	L/W
1(6)	56	33.1	4.92	28.32	0.44	0.80	0.74
2	46	22.0	3.36	28.20	3.57	6.26	0.71
3	31	15.9	3.13	20.28	8.65	11.28	0.40
4	43	29.9	3.20	9.23	9.27	11.12	0.38
5	28	9.0			15.43	21.80	0.58
7	40	4.6	3.38	31.60	4.84	9.31	0.98
8	40	19.8			22.33	29.03	0.60
9	41	14.0			5.45	8.87	0.72

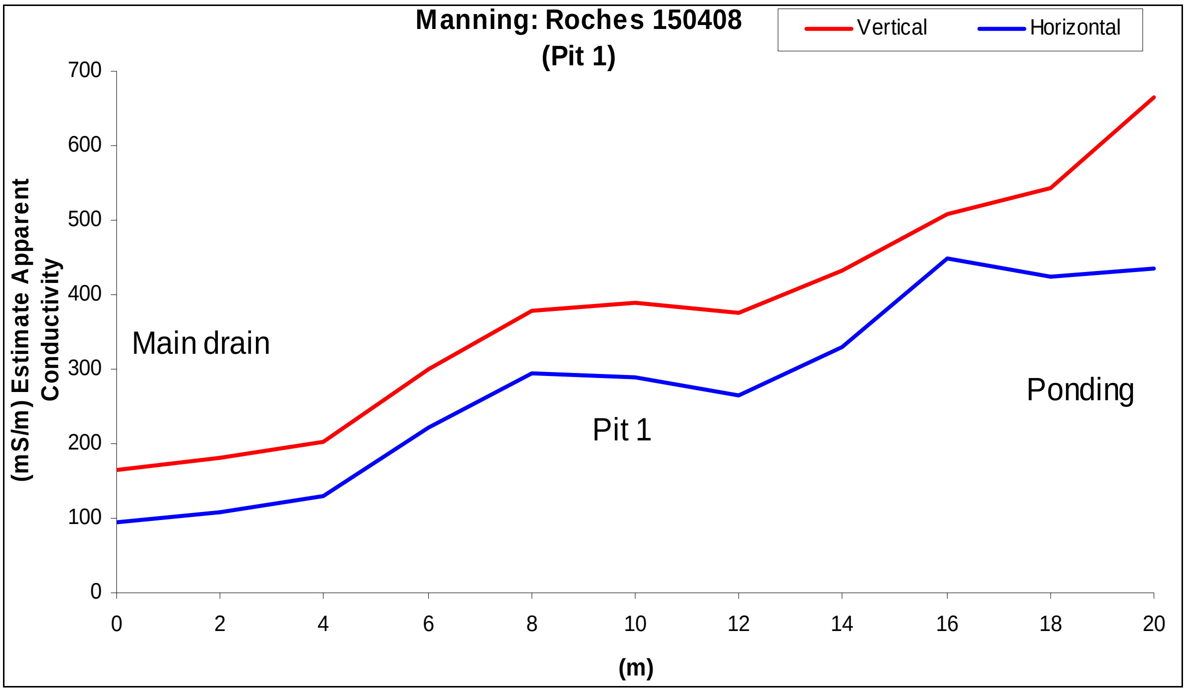

Figure 87: EM38 transect, at Roches.

Transect bisects pits 1, 7, 8 and 9. Transect from main discharge drain to ponded area.

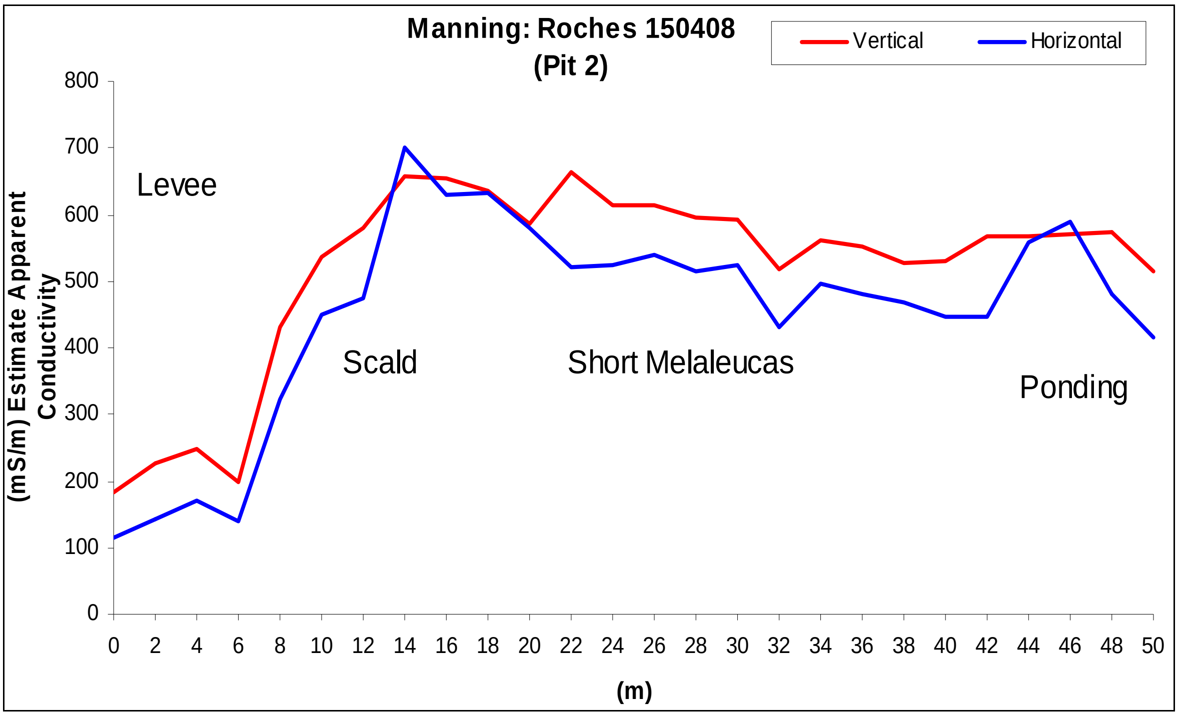

Figure 88. Roches pit 2 EM38 transect.

Scald in old Melaleuca regrowth area. Possible soil disturbance from cropping activity.

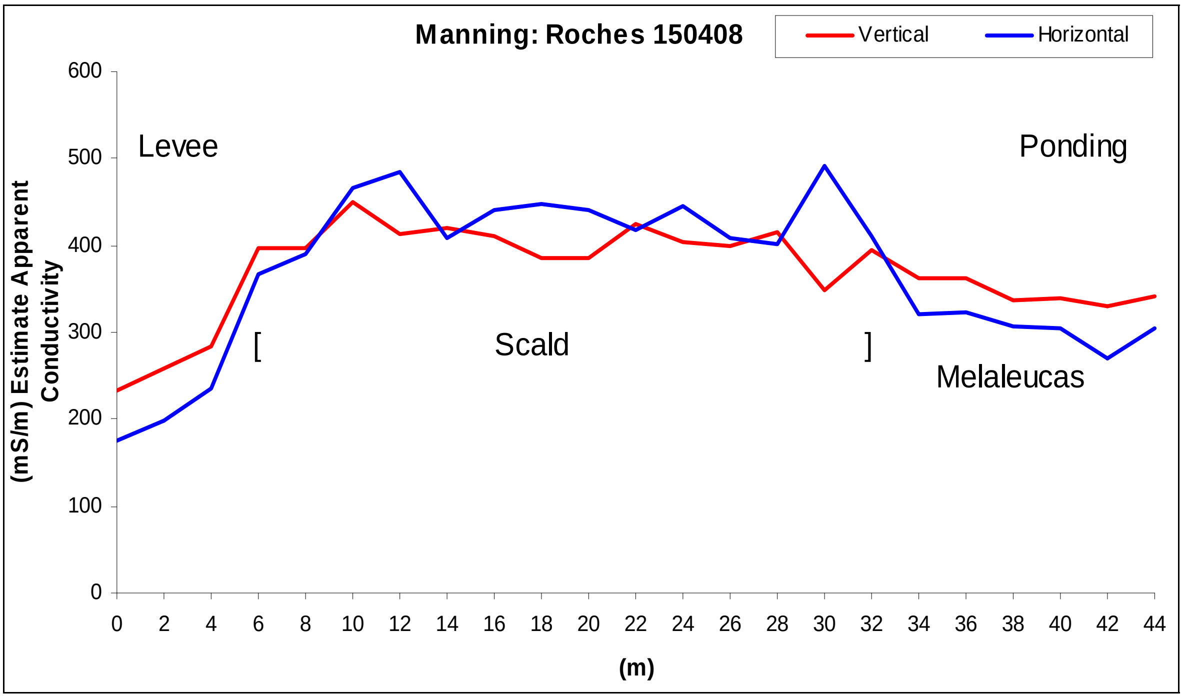

Figure 89. Roches pit 3 EM38 transect.

Severe scald regrowth Melaleuca area. Transect from drain levee to ponded water. Thick coating of orange Fe flocc on surface.

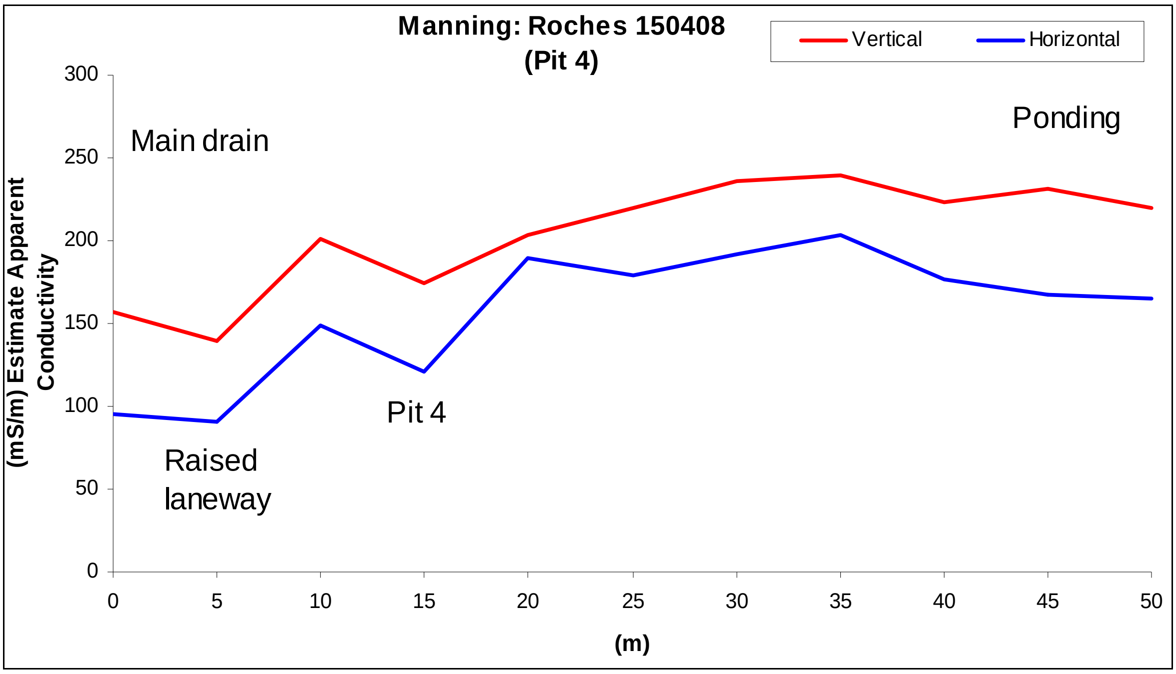

Figure 90. Roches EM38 transect pit 4.

Transect from main drain with a built-up laneway/levee into open pasture up to ponded area.

Figure 91. Roches pit 2 in the Manning.

5. Summary data and discussion

This chapter summarizes all the data collected for the project including an overall summary of K_{sat}, individual pit frequency, cumulative frequency, standard deviation and ground water means for pH and electrical conductivity. All summary charts are based on the Bouwer and Rice (1983) method for quantitative K_{sat} calculation as it is slightly more conservative (i.e. generally produces lower values) than Boast and Langebartel (1984) method due to differences in the calculation of shape factors.

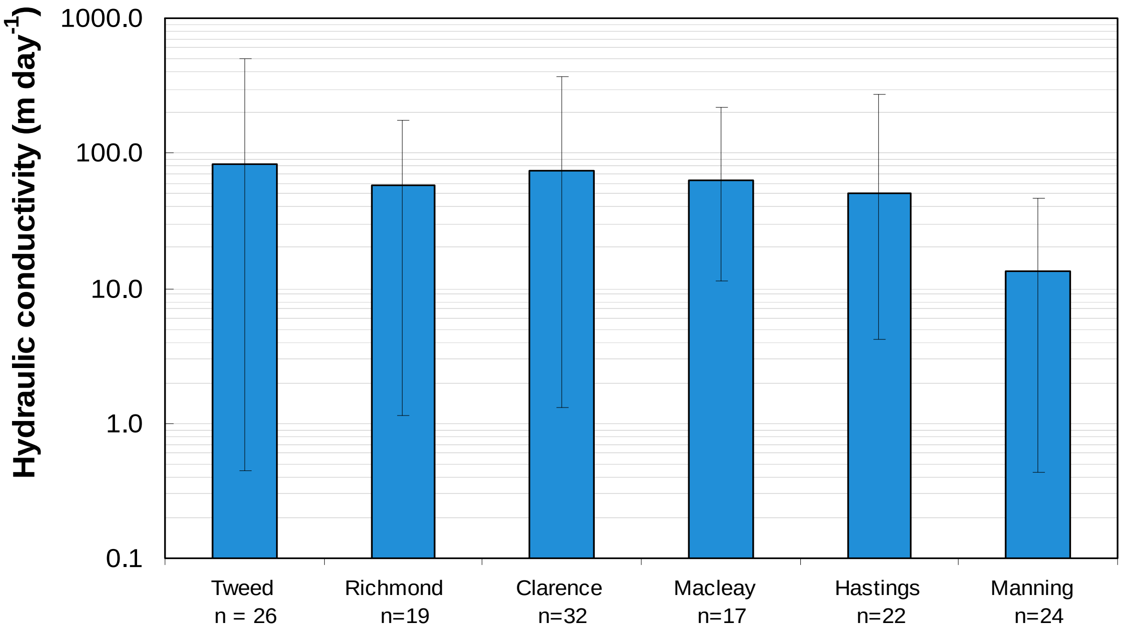

Figure 92. Catchment mean hydraulic conductivity (note: log scale on the y-axis).
(Error Bars indicate the range of Ksat values encountered within each catchment)

Two important points emerge from Figure 92:

The range of values encountered within each catchment floodplain is large. Sulfuric horizon K_{sat} is highly varied, both within individual floodplain coastal ASS geomorphic units and across whole floodplains.

Sulfuric horizon K_{sat} is capable of being extraordinarily high, and some locations with very high K_{sat} values were found on each floodplain.

This highlights the need for appropriate scale *in situ*, site specific investigations of soil hydraulic properties prior to implementing acid management strategies. This is particularly important if those strategies include attempts to contain acidic solutes within the landscape or involve floodgate opening and exchange of saline estuarine waters within drains.

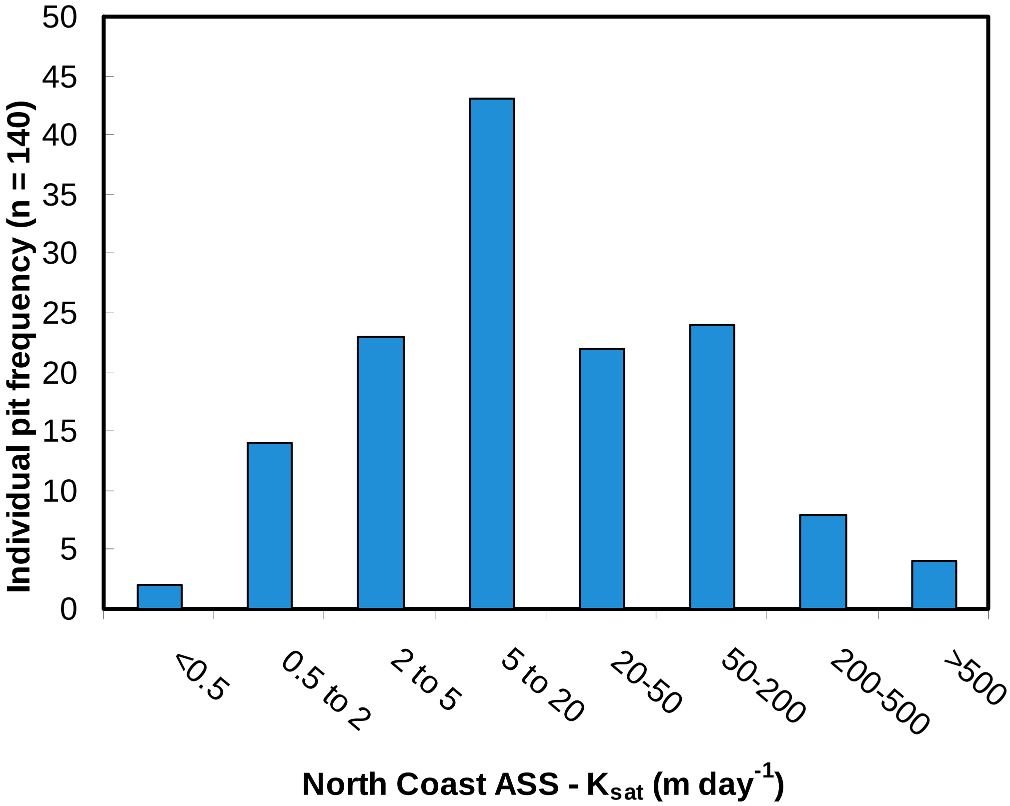

Figure 93. The frequency distribution of K_{sat} values for individual pits.

Figure 93 demonstrates that sulfuric horizon K_{sat} values measured in this study span over four orders of magnitude (<0.5 m day^{-1} to >500 m day^{-1}). The distribution of values follows a log normal trend, which is typical for K_{sat} spatial variability. In addition, the majority of individual pit values fall in the 5 to 20 m day^{-1}, which corresponds to *Intermediate* to *High* K_{sat} range.

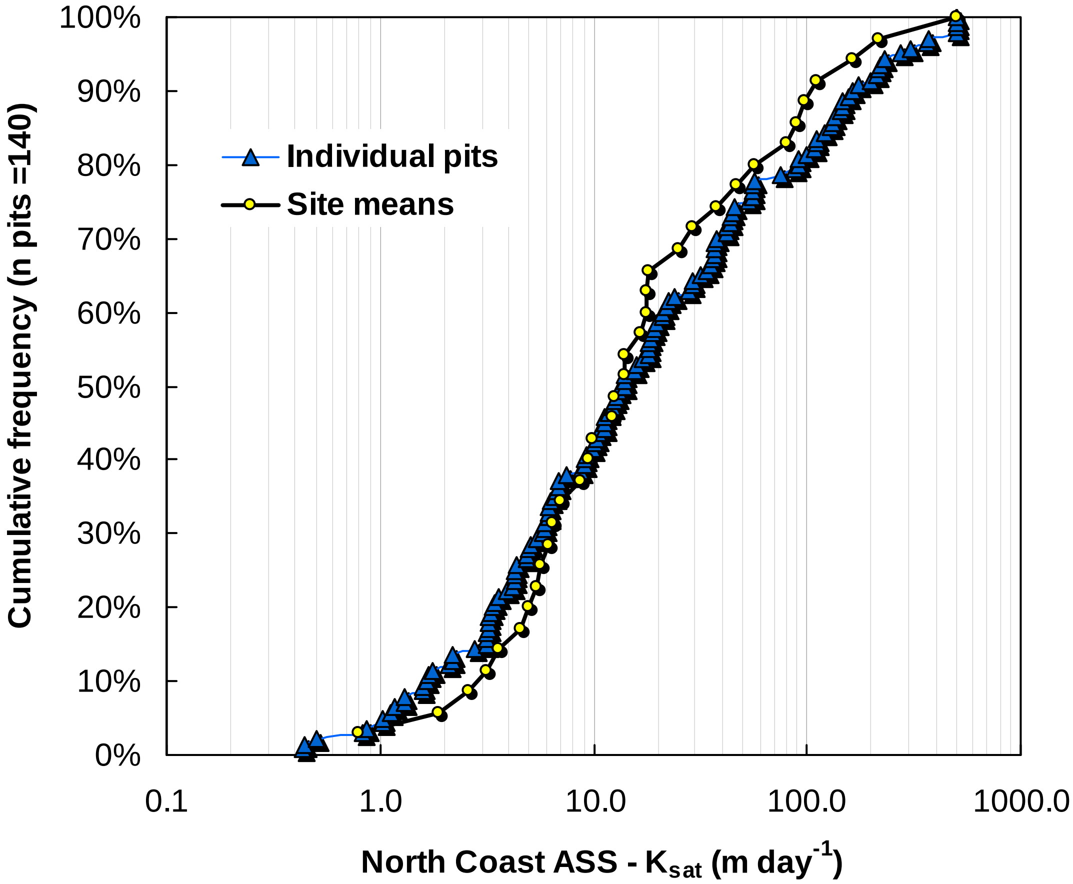

Figure 94. The cumulative frequency of K_{sat} for individual pits and site means (note: log scale on the x-axis).

Figure 94 illustrates that:

A similar K_{sat} distribution pattern is evident between individual pits and site means

About 52% of pits had K_{sat} values less than 15 m day^{-1}, while 48% have values greater than 15 m day^{-1} (*High K_{sat} range*).

More significantly, about 18% of pits have K_{sat} rates greater than 100 m day^{-1} (*Extreme K_{sat} range*).

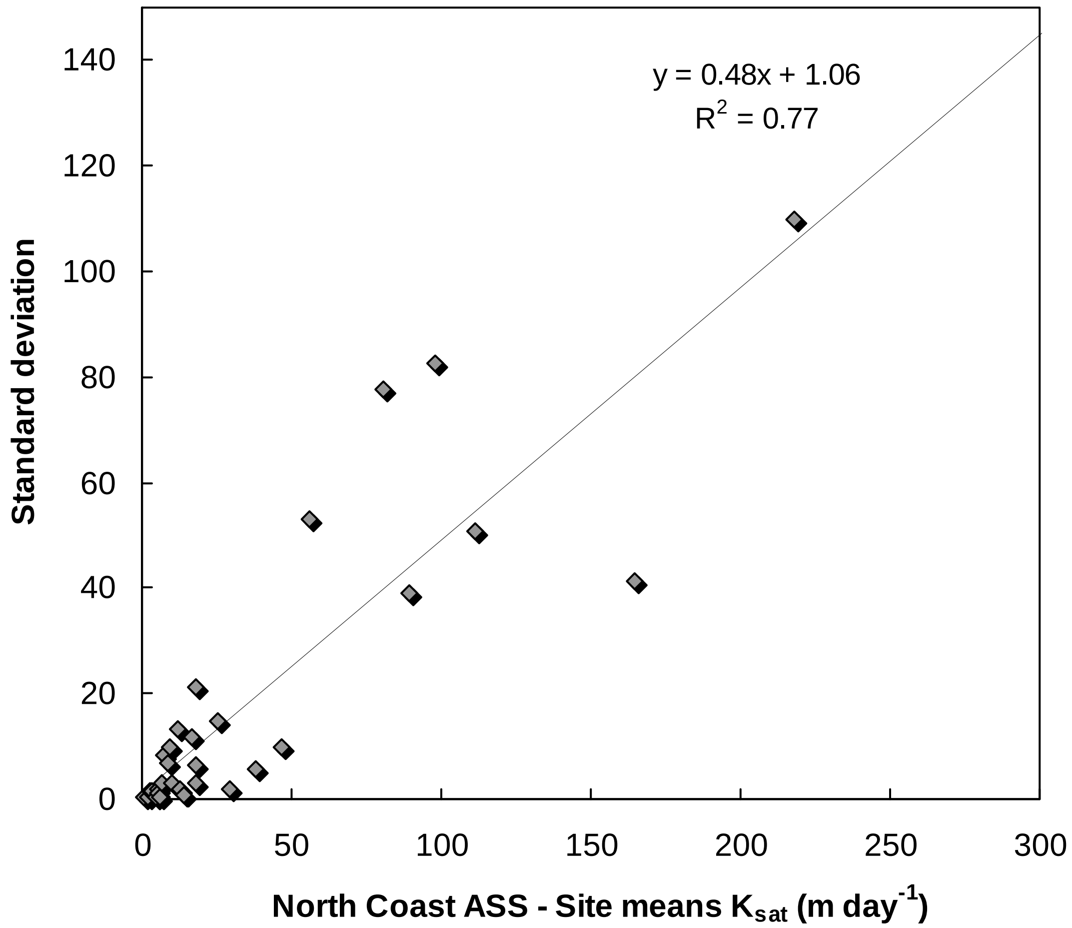

Figure 95. Standard deviation analysis on K_{sat} site means.

The solid line in Figure 95 indicates that standard deviations exhibit a strong positive relationship (r^2 = 0.77) with site mean K_{sat}, further demonstrating the inherently high degree of landscape variability in K_{sat} values. It also reflects the resilience of the pit bailing technique in contrasting ASS backswamp environments.

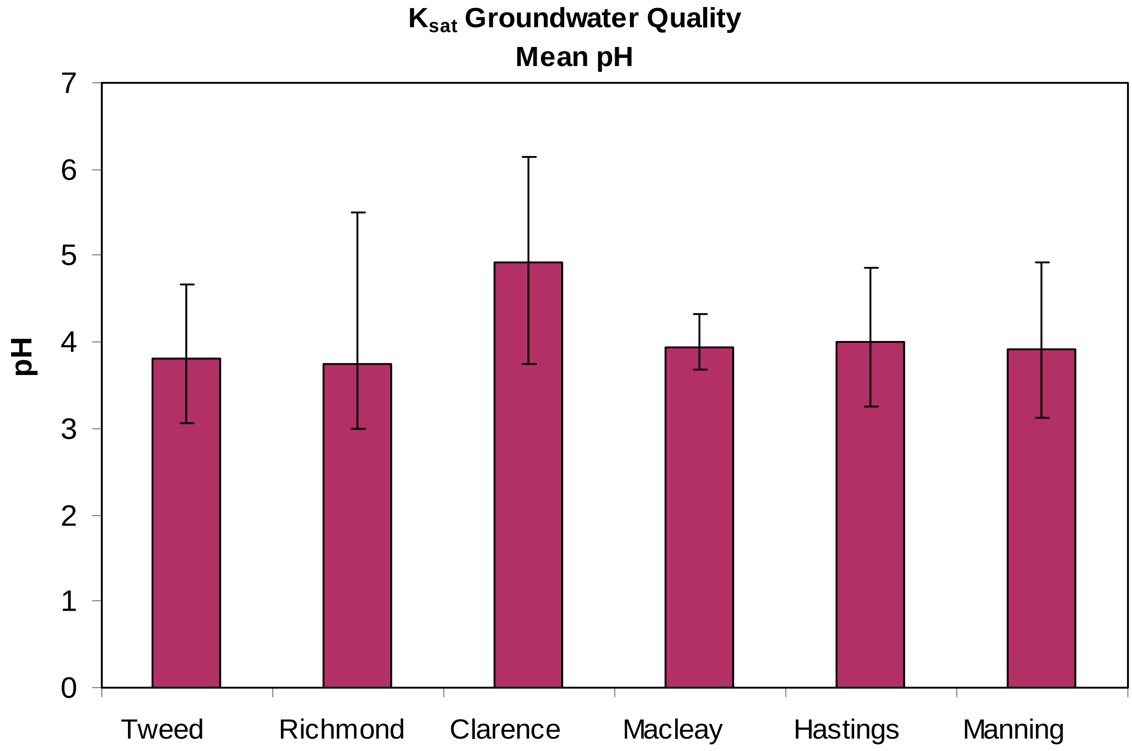

Figure 96. pH means of groundwater from K_{sat} pits per catchment.
(Error bars indicate the range of pH values from each catchment)

Groundwater quality means from pH 3.8 to 4.8. Error bars range from pH 3 to 6 depending on site and catchments.

Indicates that groundwater from the coastal acid sulfate landscapes surveyed are generally low in pH, which is consistent with the occurrence of sulfuric horizons.

Site selection had a large influence on means. For example, the Clarence at Lake Wooloweyah, with periodic tidal inundation in close proximity to river entrance accounts for an elevated mean pH for this catchment.

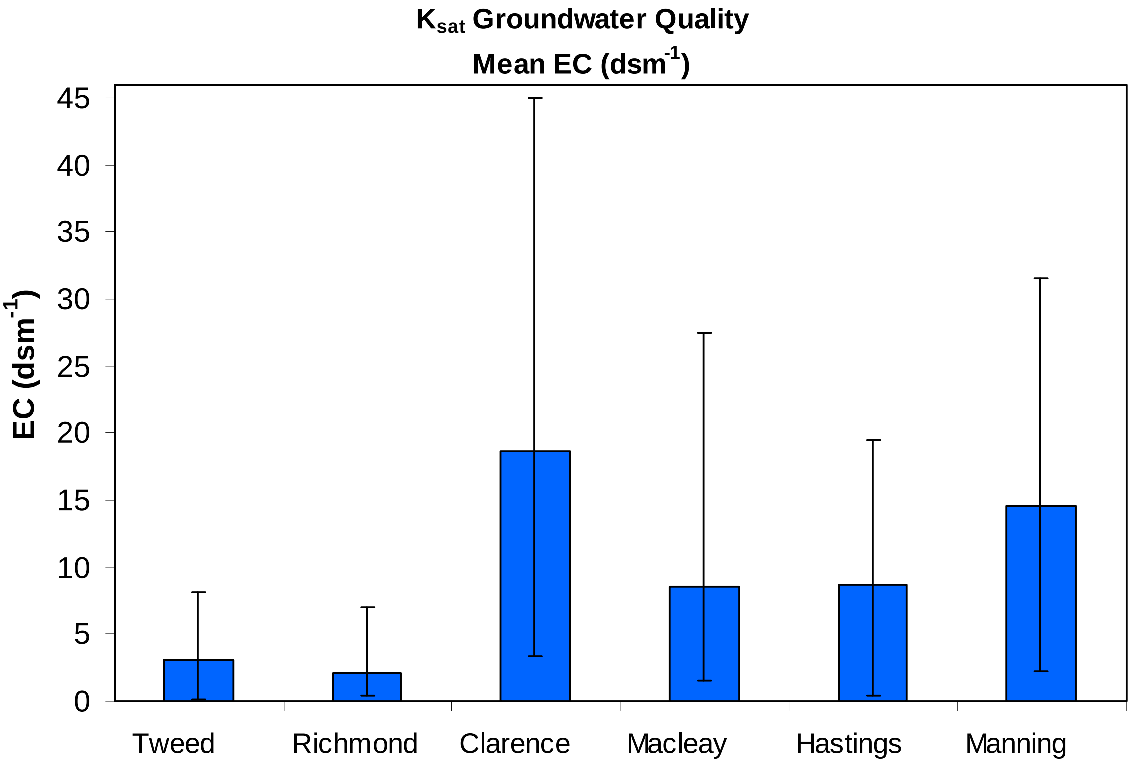

Figure 97. EC means of groundwater from K_{sat} pits per catchment.
(Error bars indicate the range of EC values from each catchment)

Groundwater Electrical Conductivity is highly variable both between and within catchments.

Influencing factors include: site in relation to estuary entrance; distance from drains and river, degree of connectivity to river, current management plans.

EC is highly site dependent (mean trends consistent with pH factors).

6. Conclusions

This study has provided an in-depth examination of the range and spatial variability of saturated hydraulic conductivity (K_{sat}) in shallow sulfuric horizons at important acid sulfate soil (ASS) locations on the North Coast of NSW.

There is an extremely high spatial variability of K_{sat} values in North Coast ASS backswamps ranging from 0.44 up to >500 m day^{-1}. Values span four orders of magnitude and vary both within individual floodplains and across geomorphic units. This has important implications for assessment of K_{sat} on a catchment level and highlights the need for appropriate scale *in situ*, site specific investigations of soil hydraulic properties prior to implementing acid management strategies.

The extreme values (>100 m day^{-1}) are comparable with what might be expected from poorly sorted gravel. Many of the K_{sat} values presented here are substantially higher than would be predicted on the basis of texture alone. The strong association between very high K_{sat} and the occurrence of large tubular macropores appears to be an important feature of the coastal ASS examined in this study. This behaviour is consistent with preferential flow dynamics in soils with macropores where a small number of large pores can contribute large quantities of water, as the liquid transmission capacity of pores is proportional to r^4 for tubular channels (r = radius) and d^3 for planar voids (d = width) (Bouma, 1991).

Backswamps vary in size, geomorphic and hydrological complexity. This data demonstrates soil hydraulic properties in sulfuric horizons can be complex, requiring either intensive *in situ* assessment and/or a compilation of a number of indicators. Assessment of factors such as K_{sat}, soil profile and drain elevations, water table ranges, local climatic data (Rainfall, ET), EM38 monitoring pre and post changes may be required in order to appropriately characterise the local sulfuric horizon hydrology to assess management implications.

Sites with high to extreme K_{sat} sites are less amenable to a DACS (dry acid containment model approach - Tualu 2007), simply due to the higher degree of connectivity between drains and adjacent shallow groundwater that results from higher sulfuric horizon K_{sat}. While ever hydraulic gradients are effluent in such landscapes - which is periodically unavoidable due to seasonal rainfall - there is a very high likelihood of uncontrolled acid groundwater discharge.

In contrast, the Wet Acid Containment Strategy (WACS) objective is to contain acid and other oxidation products within the soil and surface waters (Tualu 2007), effective in soils with high to extremely high K_{sat} rates. Acid groundwater may be contained by infilling or shallowing drains or by using in-drain retention structures to keep drain water levels high and stable during key periods thus preventing the development of effluent groundwater gradients through tidal drawdown.

The highest frequency distribution of individual pits is in the 5 to 20 m day^{-1} which corresponds to *Intermediate* to *High* K_{sat} range. Management of such sites require a thorough assessment to determine most appropriate management options.

The table below lists the percentages of pits in each K_{sat} category referenced in the field excel spreadsheet.

Table 26. Summary of K_{sat} rates from survey grouped into categories.

	($mday^{-1}$)	Pits	%	
Extreme	>100	26	18.6%	48.6%
High	15-100	42	30.0%	
Mod	1.5-15	61	43.6%	43.6%
Low	<1.5	11	7.9%	7.9%

The K_{sat} range categories shown in Table 26 are in broad agreement with the cumulative frequency distribution analysis of quantitative K_{sat} values shown in Figure 89. This survey of coastal ASS sites indicates that 48% of pits in the range of High to Extreme. About 18% of data come from locations with K_{sat} rates greater than 100 m day^{-1} (*Extreme K_{sat} range*), thus demonstrating that sulfuric horizon K_{sat} is capable of being extraordinarily high and that high K_{sat} is relatively common.

The Low category represents 8% of total pits sampled. For sites with Low K_{sat} rates (<1.5 m day^{-1}), the risk of lateral salt seepage into soil profile if floodgate structures opened is likely to be minimal. Moderate to High K_{sat} values account for 73% of results, providing evidence that groundwater seepage is likely to be more common than previously appreciated.

The fact that moderate K_{sat} values account for 43% of sites has implications for assessment. Such areas may require more intensive sampling and assessment to identify site variability and range of K_{sat} values. Assessment may include identifying potential hotspots such as scalds, ti-tree areas and low depression areas, topography, drainage patterns and position of site in the estuary. Quantifying shallow groundwater acidity and examining drainage water acidity dynamics over time may give clues about a sites likely hydrological behaviour and provide indications about the degree of connectivity between drains and sulfuric horizon groundwater. Additional indicators to observe during pit excavations may include soil texture and identifying macropore numbers, abundance and size.

Remediation of an ASS wetlands should be based on adaptive management principles and include a monitoring program that provides feedback on the effectiveness of the management strategy, to provide signs of any environmental degradation or improvements and to evaluate and modify the management of the project as necessary (Tulau 2007).

The EM38 conductivity meter was used to determine root zone salinity in areas with shallow saline water tables. Previous research indicate strong relationships are possible between soil EC (1:5 extract) in the upper 1m of the soil profile and mean EC as determined by EM38 in coastal ASS landscapes (Johnston et al. 2004). This makes the EM38 meter a useful tool for monitoring potential saline seepage and is conducive to rapid spatial surveys over time.

Additional comparisons from this study include:

1. There is a low overall predictive capacity by relating elevation/landform codes from ASS risk maps with site mean K_{sat} values. This may improve with a higher number of samples and more site intensive assessment.

2. The weak relationship between K_{sat} and geomorphic units is possibly more of a reflection on the origin and genesis of macropores at each site. This is an area requiring further research. It reinforces the extreme variability of K_{sat} and the need for K_{sat} assessment on a site specific basis. For example the Tweed floodplain is strongly influenced by varied land-use such as infilled drains, constructed levees and vehicle access roads, resulting in highly variable K_{sat} values. The effect of compaction on macropores is a factor contributing to variability which enhances the need for site specific assessment.

Sulfuric horizon K_{sat} in ASS is a critical variable due to its controlling influence upon the lateral movement of solutes. This study has shown that there is extreme variability in the sulfuric horizon K_{sat} on the coastal floodplains of northern NSW. Therefore, the results of this study indicate that site specific assessments of sulfuric horizon K_{sat} via pit techniques or other similar *in situ* K_{sat} assessment techniques need to be included as a standard part of *risk management analysis* when making changes in backswamp hydrology during broad acre ASS remediation projects.

7. Acknowledgements

This project was an initiative of the Floodplain Network Consultative Group in association with the North Coast Catchment Management Authority. The Floodplain Network is a group of predominantly local government floodplain resource managers who work on the floodplains from the Camden Haven River to the Tweed River. The group meets regularly to exchange ideas and methods on floodplain management. The Northern Rivers Catchment Management Authority coordinates the group with individual councils organising field trips and meetings.

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Appendix 1: K_{sat} Survey Project GPS Co-ordinates

Grid Lat/Lon hddd-mm.mmm'
Datum WGS 84

Date in Field	Latitude	Longitude	Type	Pit No.	Catchment	Area
14-Sep-07	S29 31.855	E153 12.639	Moloneys In-drain weir		Clarence	
12-Mar-08	S29 28.318	E153 07.194	Ksat	1	Clarence	Ensby
12-Mar-08	S29 28.350	E153 07.195	Ksat	2	Clarence	Ensby
12-Mar-08	S29 28.457	E153 07.263	Ksat	3	Clarence	Ensby
13-Mar-08	S29 28.811	E153 18.683	Ksat	1	Clarence	Wooloweyah
13-Mar-08	S29 28.779	E153 18.683	Ksat	2	Clarence	Wooloweyah
12-May-08	S29 42.161	E153 05.432	Ksat	1	Clarence	Crows Nest
12-May-08	S29 42.157	E153 05.448	Ksat	2	Clarence	Crows Nest
12-May-08	S29 42.349	E153 05.180	Ksat	3	Clarence	Crows Nest
12-May-08	S29 42.257	E153 05.523	Ksat	4	Clarence	Crows Nest
12-May-08	S29 42.271	E153 05.533	Ksat	5	Clarence	Crows Nest
13-May-08	S29 25.229	E153 05.541	Ksat	1	Clarence	Arndilly
13-May-08	S29 25.196	E153 05.550	Ksat	2	Clarence	Arndilly
13-May-08	S29 25.503	E153 05.822	Ksat	3	Clarence	Arndilly
13-May-08	S29 24.249	E153 06.602	Ksat	4	Clarence	Arndilly
12-Mar-08	S29 28.320	E153 07.198	EM 38	Start	Clarence	Ensby
12-Mar-08	S29 28.372	E153 07.190	EM 38	Stop	Clarence	Ensby
12-Mar-08	S29 28.465	E153 07.278	EM 38	Start	Clarence	Ensby
12-Mar-08	S29 28.434	E153 07.229	EM 38	Stop	Clarence	Ensby
13-Mar-08	S29 28.809	E153 18.751	EM 38	Start	Clarence	Wooloweyah
13-Mar-08	S29 28.805	E153 18.677	EM 38	Stop	Clarence	Wooloweyah
13-Mar-08	S29 28.825	E153 18.685	EM 38	Start	Clarence	Wooloweyah
12-May-08	S29 42.277	E153 05.455	EM 38	Start	Clarence	Crows Nest
12-May-08	S29 42.232	E153 05.417	EM 38	Stop	Clarence	Crows Nest
13-May-08	S29 25.198	E153 05.548	EM 38	Start	Clarence	Arndilly
13-May-08	S29 25.186	E153 05.495	EM 38	Stop	Clarence	Arndilly
13-May-08	S29 24.248	E153 06.603	EM 38	Start	Clarence	Arndilly
13-May-08	S29 24.224	E153 06.638	EM 38	Stop	Clarence	Arndilly
05-Dec-07	S31 39.245	E152 43.532	Ksat	1	Hastings	Rossglen
05-Dec-07	S31 39.276	E152 43.560	Ksat	2	Hastings	Rossglen
05-Dec-07	S31 39.405	E152 43.650	Ksat	3	Hastings	Rossglen
05-Dec-07	S31 39.385	E152 43.434	Ksat	4	Hastings	Rossglen
05-Dec-07	S31 39.399	E152 43.396	Ksat	5	Hastings	Rossglen
06-Dec-07	S31 20.607	E152 50.402	Ksat	1	Hastings	Maria river
06-Dec-07	S31 20.630	E152 50.393	Ksat	2	Hastings	Maria river
06-Dec-07	S31 18.264	E152 51.011	Ksat	3	Hastings	Maria Torrens
07-Dec-07	S31 19.759	E152 48.838	Ksat	5	Hastings	Maria Hacks
07-Dec-07	S31 19.877	E152 48.785	Ksat	6	Hastings	Maria Hacks
07-Dec-07	S31 19.730	E152 48.849	EM 38	Start	Hastings	Maria Bob K
07-Dec-07	S31 19.870	E152 48.841	EM 38	Stop/Start	Hastings	Maria Bob K
07-Dec-07	S31 19.861	E152 48.798	EM 38	Stop/Start	Hastings	Maria Bob K
07-Dec-07	S31 19.816	E152 48.820	EM 38	Stop	Hastings	Maria Bob K
05-Dec-07	S31 39.225	E152 43.526	EM 38	Start	Hastings	Rossglen
05-Dec-07	S31 39.275	E152 43.552	EM 38	Stop	Hastings	Rossglen
05-Dec-07	S31 39.310	E152 43.437	EM 38	Start	Hastings	Rossglen
05-Dec-07	S31 39.414	E152 43.351	EM 38	Stop	Hastings	Rossglen

K_{sat} Survey Project GPS Co-ordinates

Grid	Lat/Lon hddd-mm.mmm'
Datum	WGS 84

Date in Field	Latitude	Longitude	Type	Pit No.	Catchment	Area
1/11/2007	S30 56.688	E153 01.996	Ksat	1	Macleay	Rogars
1/11/2007	S30 56.699	E153 02.082	Ksat	2	Macleay	Rogars
1/11/2007	S30 56.648	E153 02.032	Ksat	3	Macleay	Rogars
1/11/2007	S30 56.656	E153 01.962	Ksat	4	Macleay	Rogars
1/11/2007	S30 56.708	E153 01.937	Ksat	5	Macleay	Rogars
2/11/2007	S30 59.363	E152 57.466	Ksat	1	Macleay	Clancys
2/11/2007	S30 59.284	E152 57.517	Ksat	2	Macleay	Clancys
2/11/2007	S30 59.197	E152 57.568	Ksat	3	Macleay	Clancys
2/11/2007	S30 59.007	E152 57.677	Ksat	4	Macleay	Clancys
2/11/2007	S30 58.921	E152 57.697	Ksat	5	Macleay	Clancys
4/12/2007	S31 03.092	E152 54.281	Ksat	1	Macleay	Lancaster
4/12/2007	S31 03.071	E152 54.142	Ksat	2	Macleay	Lancaster
4/12/2007	S31 03.069	E152 54.003	Ksat	3	Macleay	Lancaster
4/12/2007	S31 03.478	E152 53.684	Ksat	4	Macleay	Lancaster
4/12/2007	S31 03.455	E152 53.597	Ksat	5	Macleay	Lancaster
1/11/2007	S30 56.700	E153 02.113	EM 38	Start	Macleay	Rogars
1/11/2007	S30 56.631	E153 01.731	EM 38	Stop	Macleay	Rogars
2/11/2007	S30 59.278	E152 57.611	EM 38	Start	Macleay	Clancys
2/11/2007	S30 59.298	E152 57.458	EM 38	Stop	Macleay	Clancys
4/12/2007	S31 03.075	E152 54.374	EM 38	Start	Macleay	Lancaster
4/12/2007	S31 03.082	E152 54.210	EM 38	Stop	Macleay	Lancaster
11/12/2007	S31 50.001	E152 38.590	Ksat	1	Manning	Cattai
14/04/2008	S31 50.108	E152 35.670	Ksat	1	Manning	Templeman
14/04/2008	S31 50.203	E152 35.601	Ksat	2	Manning	Templeman
14/04/2008	S31 50.161	E152 35.551	Ksat	3	Manning	Templeman
15/04/2008	S31 49.619	E152 34.413	Ksat	2	Manning	Roches
15/04/2008	S31 49.633	E152 34.215	Ksat	3	Manning	Roches
15/04/2008	S31 49.737	E152 34.291	Ksat	4	Manning	Roches
15/04/2008	S31 49.717	E152 34.632	Ksat	5	Manning	Roches
15/04/2008	S31 49.594	E152 34.653	Ksat	6(1)	Manning	Roches pits
15/04/2008	S31 49.606	E152 34.664	Ksat	7	Manning	Roches
15/04/2008	S31 49.582	E152 34.660	Ksat	8	Manning	Roches
15/04/2008	S31 49.585	E152 34.698	Ksat	9	Manning	Roches
16/04/2008	S31 50.125	E152 38.197	Ksat	5	Manning	Cattai
16/04/2008	S31 50.121	E152 38.183	Ksat	2	Manning	Cattai
16/04/2008	S31 50.089	E152 38.480	Ksat	1	Manning	Cattai
16/04/2008	S31 50.364	E152 38.076	Ksat	4	Manning	Cattai
16/04/2008	S31 50.285	E152 37.976	Ksat	3	Manning	Cattai
15/04/2008	S31 49.623	E152 34.220	EM 38	Start	Manning	Roches Pit 2a
15/04/2008	S31 49.641	E152 34.201	EM 38	Stop	Manning	Roches
15/04/2008	S31 49.735	E152 34.279	EM 38	Start	Manning	Roches pit 4
15/04/2008	S31 49.744	E152 34.314	EM 38	Stop	Manning	Roches
16/04/2008	S31 50.113	E152 38.159	EM 38	Start	Manning	Cattai
16/04/2008	S31 50.125	E152 38.197	EM 38	Stop	Manning	Cattai

Ksat Survey Project GPS Co-ordinates

Grid	Lat/Lon hddd-mm.mmm'
Datum	WGS 84

Date in Field	Latitude	Longitude	Type	Pit No.	Catchment	Area
19/09/2007	S29 06.208	E153 19.179	Ksat	1	Richmond	Rocky Mouth Cr
30/10/2008	S29 06.774	E153 19.016	Ksat	2	Richmond	Rocky Mouth Cr
30/10/2008	S29 06.776	E153 19.005	Ksat	3	Richmond	Rocky Mouth Cr
30/10/2008	S29 06.772	E153 18.980	Ksat	4	Richmond	Rocky Mouth Cr
20/11/2007	S28 45.623	E153 34.146	Ksat	1	Richmond	Scanlans
20/11/2007	S28 46.370	E153 34.299	Ksat	2	Richmond	Scanlans
21/11/2007	S29 00.810	E153 22.189	Ksat	1	Richmond	Braziers
21/11/2007	S29 01.137	E153 22.382	Ksat	2	Richmond	Braziers
21/11/2007	S29 03.385	E153 14.358	Ksat	1	Richmond	Haughwood
21/11/2007	S29 03.271	E153 14.406	Ksat	2	Richmond	Haughwood
1/04/2008	S29 00.920	E153 22.692	Ksat	1	Richmond	Coombes
1/04/2008	S29 01.028	E153 22.556	Ksat	2	Richmond	Coombes
1/04/2008	S29 01.082	E153 22.535	Ksat	3	Richmond	Coombes
4/04/2008	S29 02.449	E153 22.012	Ksat	1	Richmond	Kilgin
4/04/2008	S29 02.449	E153 22.010	Ksat	1	Richmond	Kilgin
4/04/2008	S29 03.170	E153 21.290	Ksat	2	Richmond	Kilgin
4/04/2008	S29 02.962	E153 21.563	Ksat	3	Richmond	Kilgin
14/05/2008	S29 01.584	E153 18.693	Ksat	1	Richmond	Gollan
14/05/2008	S29 03.103	E153 16.952	Ksat	1	Richmond	Swan Bay
14/05/2008	S29 02.256	E153 13.607	Ksat	1	Richmond	Bora Codrington
20/11/2007	S28 46.369	E153 34.300	EM 38	Start	Richmond	Scanlans
20/11/2007	S28 46.408	E153 34.327	EM 38	Stop	Richmond	Scanlans
20/11/2007	S28 47.495	E153 33.717	EM 38	Start	Richmond	NR1
20/11/2007	S28 47.390	E153 33.726	EM 38	Stop	Richmond	NR1
20/11/2007	S28 47.393	E153 33.241	EM 38	Start	Richmond	NR1
20/11/2007	S28 47.302	E153 33.144	EM 38	Stop	Richmond	NR1
21/11/2007	S29 03.384	E153 14.359	EM 38	Start	Richmond	Haughwood
21/11/2007	S29 03.200	E153 14.408	EM 38	Stop	Richmond	Haughwood
4/04/2008	S29 02.947	E153 21.556	EM 38	Start	Richmond	Kilgin
4/04/2008	S29 02.961	E153 21.583	EM 38	Stop	Richmond	Kilgin

Ksat Survey Project GPS Co-ordinates

Grid	Lat/Lon hddd-mm.mmm'
Datum	WGS 84

Date in Field	Latitude	Longitude	Type	Pit No.	Catchment	Area
12/11/2007	S28 20.511	E153 24.815	Ksat	1	Tweed	Blacks Dr
12/11/2007	S28 20.504	E153 24.823	Ksat	2	Tweed	Blacks Dr
12/11/2007	S28 20.492	E153 24.831	Ksat	3	Tweed	Blacks Dr
13/11/2007	S28 20.482	E153 24.845	Ksat	4	Tweed	Blacks Dr
13/11/2007	S28 20.457	E153 24.841	Ksat	5	Tweed	Blacks Dr
13/11/2007	S28 17.024	E153 30.470	Ksat	1	Tweed	McLeods
13/11/2007	S28 17.022	E153 30.447	Ksat	2	Tweed	McLeods
13/11/2007	S28 17.022	E153 30.425	Ksat	3	Tweed	McLeods
13/11/2007	S28 17.019	E153 30.401	Ksat	4	Tweed	McLeods
13/11/2007	S28 17.018	E153 30.383	Ksat	5	Tweed	McLeods
15/11/2007	S28 17.008	E153 30.411	Ksat	6	Tweed	McLeods
15/11/2007	S28 17.030	E153 30.409	Ksat	7	Tweed	McLeods
14/11/2007	S28 19.204	E153 30.801	Ksat	1	Tweed	Clothiers
14/11/2007	S28 19.187	E153 30.812	Ksat	2	Tweed	Clothiers
14/11/2007	S28 19.118	E153 30.762	Ksat	3	Tweed	Clothiers
14/11/2007	S28 19.105	E153 30.740	Ksat	4	Tweed	Clothiers
14/11/2007	S28 19.055	E153 30.727	Ksat	5	Tweed	Clothiers
14/11/2007	S28 15.406	E153 32.265	Ksat	1	Tweed	Chinderah
14/11/2007	S28 15.402	E153 32.250	Ksat	2	Tweed	Chinderah
14/11/2007	S28 15.403	E153 32.238	Ksat	3	Tweed	Chinderah
14/11/2007	S28 15.399	E153 32.216	Ksat	4	Tweed	Chinderah
14/11/2007	S28 15.395	E153 32.192	Ksat	5	Tweed	Chinderah
15/11/2007	S28 22.508	E153 32.865	Ksat	1	Tweed	Christies
15/11/2007	S28 22.481	E153 32.865	Ksat	2	Tweed	Christies
15/11/2007	S28 22.465	E153 32.869	Ksat	3	Tweed	Christies
15/11/2007	S28 22.451	E153 32.874	Ksat	4	Tweed	Christies
13/11/2007	S28 20.529	E153 24.801	EM 38	Start	Tweed	Blacks Dr
13/11/2007	S28 20.528	E153 24.805	EM 38	Stop	Tweed	Blacks Dr
13/11/2007	S28 17.027	E153 30.480	EM 38	Start	Tweed	McLeods to pit 5
14/11/2007	S28 19.207	E153 30.809	EM 38	Start	Tweed	Clothiers
14/11/2007	S28 19.137	E153 30.768	EM 38	Stop	Tweed	Clothiers
15/11/2007	S28 15.404	E153 32.276	EM 38	Start	Tweed	Chinderah
15/11/2007	S28 15.383	E153 32.125	EM 38	Stop	Tweed	Chinderah
15/11/2007	S28 22.518	E153 32.856	EM 38	Start	Tweed	Christies
15/11/2007	S28 22.454	E153 32.880	EM 38	Stop	Tweed	Christies

Appendix 2: Summary of completed field work.

Catchment	Site	Field Date	Pits Completed	Details
Tweed	Stainley	12/11/07	5	Ksat + EM38
	Quirk	13/11/07	7	Ksat + EM38
	Clothiers Ck	14/11/07	5	Ksat + EM38
	Chinderah	14/11/07	5	Ksat + EM38
	Christies Ck	15/11/07	4	Ksat + EM38
Richmond	Scanlans	20/11/07	2	Ksat + EM38
	Haughward	21/11/07	2	Ksat + EM38
	Braziers	21/11/07	2	Soil Profile
	Coombes	1/4/08	3	Ksat
	Crusio	4/4/08	3	Soil Profile
	Gollan	14/5/08	1	Ksat
	Gardiner	14/5/08	1	Ksat
	Davies	14/5/08	1	Ksat
	Rocky MC	19/9/07	4	Ksat
Clarence	Ensby	12/3/08	3	Ksat + EM38
	Wooloweyah	13/3/08	2	Ksat + EM38
	Crows Nest	12/5/08	3	Ksat + EM38
	Crows Nest N	12/5/08	2	Ksat + EM38
	Arndilly	13/5/08	4	Ksat + EM38
Macleay	Rogars	1/11/07	5	Ksat + EM38
	Clancys Dr	2/11/07	5	Ksat + EM38
	Frogmore Dr	4/12/07	3	Ksat + EM38
	Frogmore Up	4/12/08	2	Ksat +EM38
Hastings	Rossglen	5/12/07	5	Ksat + EM38
	Maria Tea	6/12/07	2	Ksat + EM38
	Maria Torans	6/12/08	1	Ksat + EM38
	Maria Hacks	6/12/08	1	Ksat + EM38
Manning	Cattai	11/12/07	1	Ksat
	Templeman	14/4/08	3	Ksat + EM38
	Roches	15/4/08	8	Ksat + EM38
	Cattai	16/4/08	4	Ksat + EM38
			Total = 95	Ksat
			Total = 5	Soil Profile

Appendix 3: Glossary

Soil Horizons:
O: Horizons: horizons dominated by organic materials in varying stages of decomposition that have accumulated on the mineral soil surface.
P Horizons: Peat horizons dominated by organic materials in various stages of decomposition that have accumulated either under water or in conditions of excessive wetness.
A: Horizons: horizons either consisting of one or more surface mineral horizons with some organic accumulation and darker in color than the underlying horizons, or consisting of surface and subsurface horizons that are lighter in color but have a lower content of silicate clay and/or sesquioxides than the underlying horizons.
B: Horizons: horizons consist of one or more mineral layers such as a concentration of silicate clay, iron, aluminium and organic material. Horizon may consist of 3 sub-horizons B1, B2 and B3.
G: Horizon indicating pyritic material in gel form, associated with Potential Acid Sulfate Soil (PASS).

Horizon suffixes:
g: strong gleying. Gleying is indicative of permanent or periodic intense reduction due to wetness and is characterised by greyish, bluish or greenish colors, generally of low chroma. Mottling may be prominent. Roots may have rusty or yellowish outlines.
p: ploughing, tillage practices or other disturbance by man such as deep ripping, laneways.
j: presence of jarosite, occurring generally in acid sulfate soil oxidation processes.

Field Texture: Soil texture is determined by the size distribution of mineral particles finer than 2mm.

L: Loam about 25% clay content
CL: Clay Loam from 30% to 35% clay
SC: Sandy Clay from 35% to 40% clay
LC: Light Clay from 35% to 40% clay
MC: Medium Clay from 45% to 55% clay
HC: Heavy Clay from 50% or more clay

Mottles: Mottles are spots or blotches or streaks of subdominant colors different from the matrix color and also different from the color of the ped surface, nodules or concretions.

Mottle abundance:

0	No mottles	
1	Very few	<2%
2	Few	2% to 10%
3	Common	10% to 20%
4	Many	20% to 50%

Mottle size:

1	Fine	<5mm
2	Medium	5-15mm
3	Coarse	15-30mm
4	Very coarse	>30mm

Mottle contrast:

F Faint indistinct
D Distinct readily evident
P Prominent striking and conspicuous

Mottle color:

R Red
O Orange
B Brown
Y Yellow
G Grey etc

Voids: A general term for pore space and other openings in soils not occupied by solid mineral mater. Two basic types, cracks and pores which are approximately circular in cross-section.

Pores are divided into: Micropores less than 0.075mm diameter and
Macropores greater than 0.075mm diameter,

Quantity of macropores: Very fine and fine macropores less than 2mm diameter
and medium coarse macropores greater than 2 mm diameter

1	Few	<1 per 100mm2
2	Common	1-5 per 100mm2
3	Many	>5 per 100mm2

Diameter of macropores:

1	Very fine	0.075-1mm
2	Fine	1-2mm
3	Medium	2-5mm
4	Coarse	>5mm

Orientation:

V Vertical
H Horizontal

Segregations refers to discrete segregations that have accumulated in the soil because of the concentration of some constituent, usually by chemical or biological action.

Forms of segregation includes:

C Concretions crudely concentric internal fabric can be seen with naked eye
N Nodules no concentric or symmetric internal fabric, can have hollow interior.
V Vein
T Tubules

Roots vary in orientation (Horizontal to Vertical), size (from very fine to coarse) and abundance (no roots to abundant).

Appendix 4: Field Notes

1. Site selection:

Selection of individual pits within a site proved a challenge on a number of occasions. Water table height proved to be the major factor when visiting a site to undertake pit tests. (Ideal WT 5cm to 50cm from soil surface). Added factors that may influence pit sites include:

1. Wetland areas not symmetrical, some areas small and shaped while others elongated meandering in relation to creeks/rivers, others with depositional fingers transecting wet areas,
2. Access to areas, barriers such as fences, drains, forest,
3. Vegetation from open grassland to dense forest,
4. Variable water table depth, i.e. ponded areas to WT 60cm below surface,
5. Soil type may vary, from clay to sand subsoil,
6. Greater the gradient, increase in potential ground water flow rates,
7. Elevation changes at times difficult to determine on site,
8. Vegetation type, past and present, and influence of tree roots,
9. Laneways and compaction issues and some sites with high drain-banks,
10. Previous soil disturbance not readily visible such as drain infilling, tree removal, laser levelling,
11. Distances between sites, may result in less pits with increase in distances to travel,
12. Identify point sources of acid discharge,
13. Rainfall events.

2. Pit test observations:

1. Initial indicators of water table prior to digging maybe drain or furrow water levels, surface ponding,
2. Pits with low to medium K_{sat} ranges i.e. relatively slow infil rate are easily dug too deep, therefore WL may increase in pit that is outside the ratio 0.2 to 0.75 i.e. WL in pit (L) over average pit width ((W+B)/2). Square pits make field calculation simpler,
3. Flat shovel preferred when squaring sides of pits, curved (fencing) shovel an advantage in initial digging of pit especially with a thick cover of vegetation such as couch,
4. Waterproof material to kneel on or lie on when reading measurements off ruler during a timed infill event,
5. Gouge auger valuable in measuring depth to sulfidic and observing change in soil profil at depth,
6. Some sites ideal to dig a number of sites consecutively then return to start for infil readings. (Note 2, digging pits deeper than required, possibly outside of pit ratio range),
7. Low Ksat sites, pit bailings between runs left until WL approaches static i.e. to allow WT to stabilise in the immediate area,
8. Pits all have GPS readings for reference, and compare with ASS risk maps.
9. Observe for: drains or creek interference, vegetation changes,
10. Variable infill rates between pits may require additional pits. A small number of sites had visible macropores above the water table indicating that further pit testing may be required at a later date.

3. Soil observations:

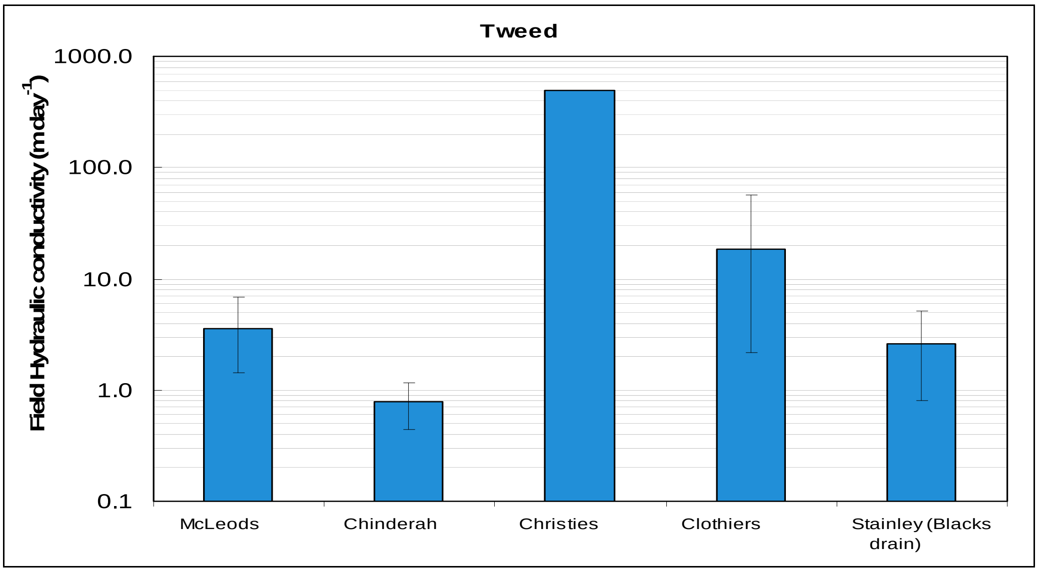
The geomorphology of deposition of material is extremely variable between pit sites, wetlands and catchments.

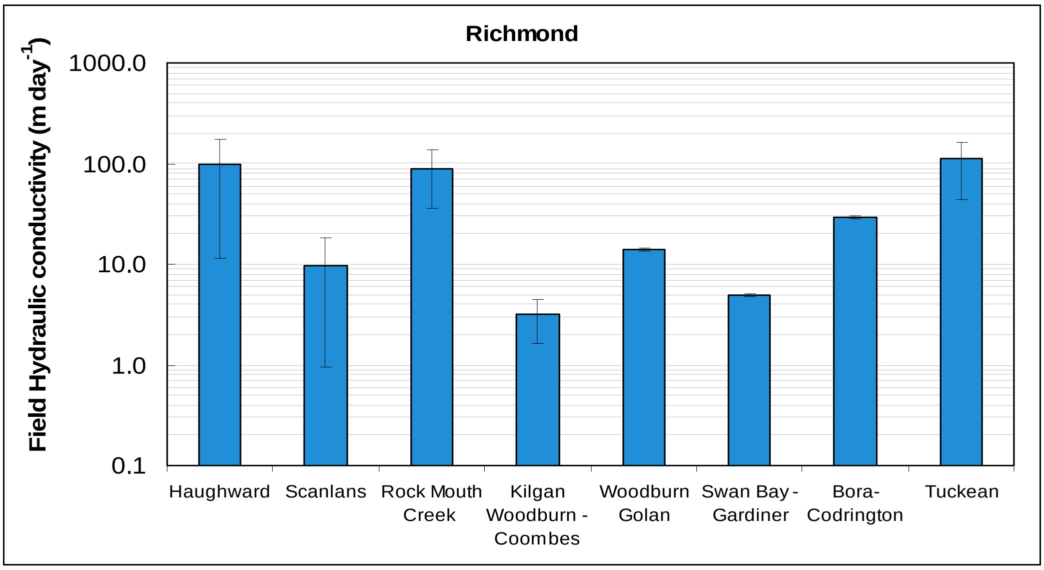
- Sites investigated ranged from course sands, silty clay loams to medium/heavy clays with occasional sand lenses at depth,
- Majority of soil profiles consist of OM horizon, a black alluvial topsoil to light grey clays into a heavier darker clay at depth (Appendix 8),
- Macropores found in *majority* of soil pits, orientation both Vertical (V) and/or Horizontal (H), from few to many in abundance and range in diameters. High infill flow rates can be achieved with a small number of large macropores,
- Connectivity of macropores, evident by high K_{sat} pits which can be bailed out a number of times followed by a rapid, infil with a short settlement period,
- Fe coated macropores common, generally as a dull red color, lightly coated to heavy coated pipe tubules formation i.e. pipe construction which can be difficult to crush with finger pressure. Fe coatings visible in crack like plates in soil, mottled in soil profile and can be gritty to feel,
- Jarosite commonly found ranging from specs to light mottling, to swirls, gritty congregations, from depth up to relatively close to soil surface.

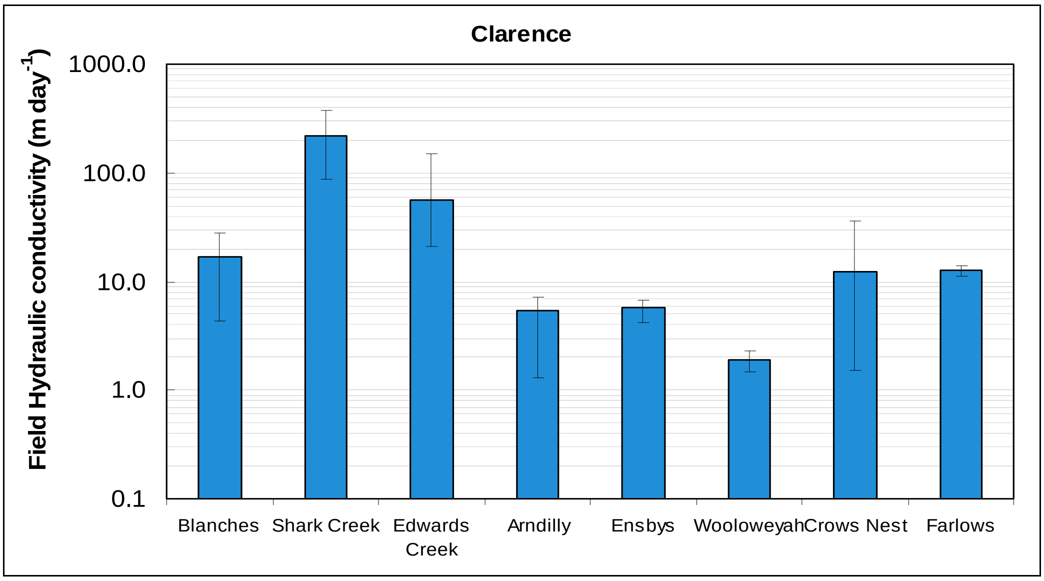
4. Project work

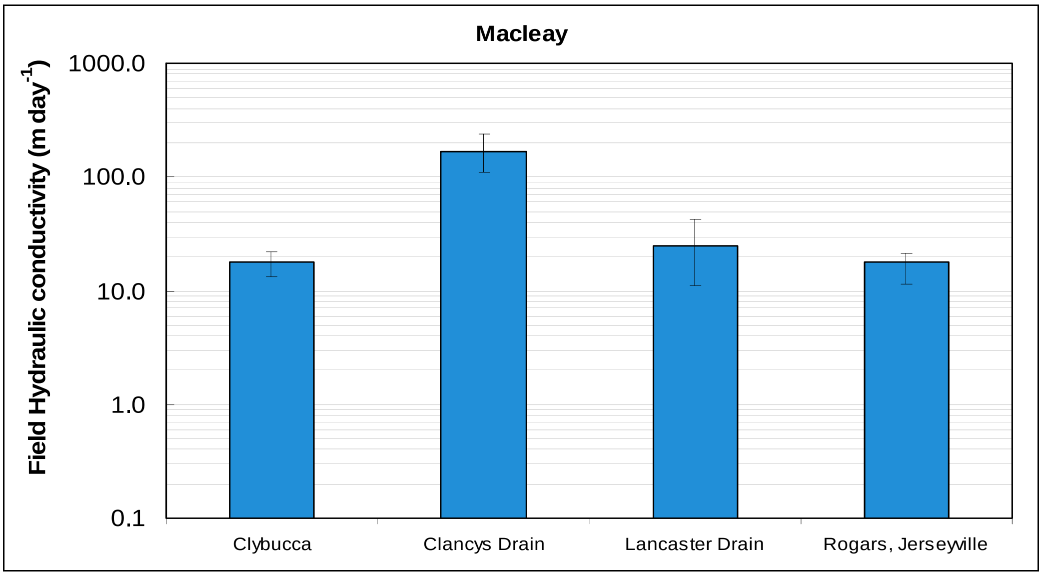
It is suggested that a comprehensive K_{sat} survey be undertaken on a per site basis. The major advantage to survey a key site is in selecting field survey periods to best coincide with ground water levels in relation to soil surface. Additional factors may include tide influence, AHD levels, access, size of survey area, identifying point sources of acid discharge.

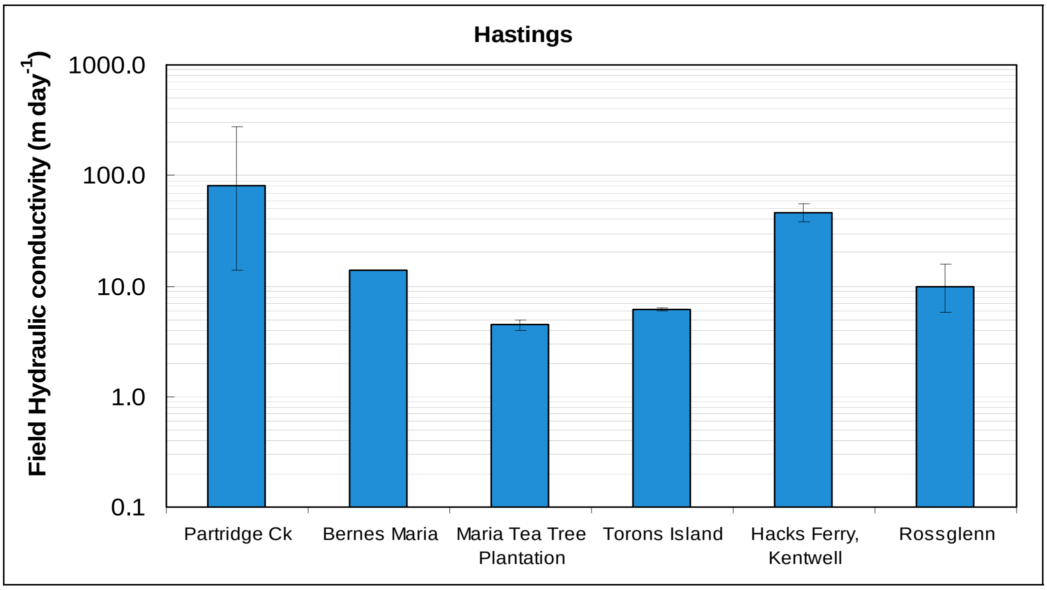
Appendix 5: K_{sat} site means per catchment.

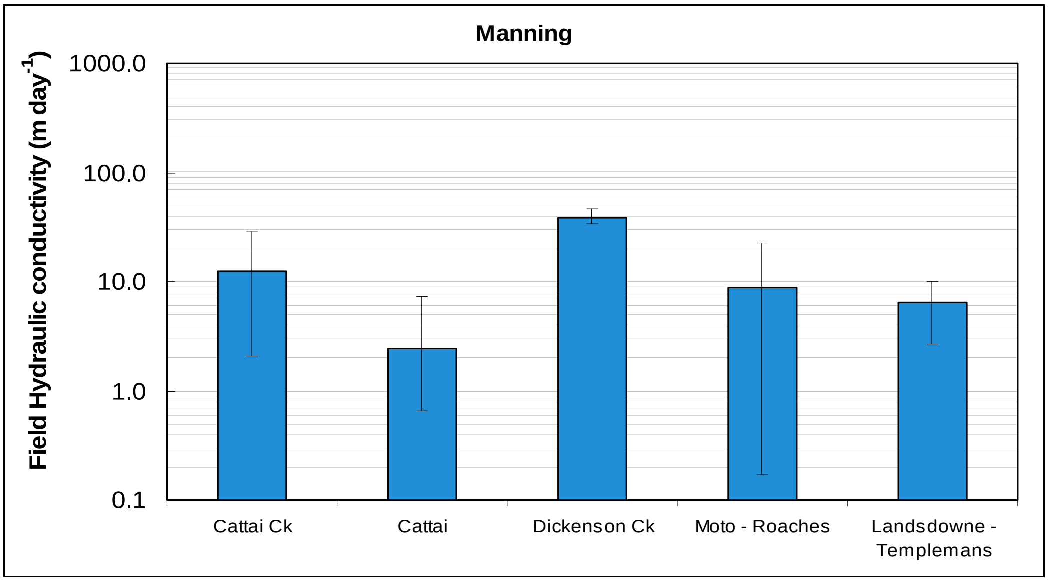







Macleay
Field Hydraulic conductivity (m day-1)
1000.0
100.0
10.0
1.0
0.1
Clybucca
Clancys Drain
Lancaster Drain
Rogars, Jerseyville


Hastings
Field Hydraulic conductivity (m day-1)
1000.0
100.0
10.0
1.0
0.1
Partridge Ck
Bernes Maria
Maria Tea Tree Plantation
Torons Island
Hacks Ferry, Kentwell
Rossglenn


Manning
Field Hydraulic conductivity (m day-1)
1000.0
100.0
10.0
1.0
0.1
Cattai Ck
Cattai
Dickenson Ck
Moto - Roaches
Landsdowne - Templemans

Appendix 6: Soil profile description at Braziers Drain Richmond.

Table R6: Pit located between cane field and open pasture.

Catchment:	Richmond
Location:	Braziers Drain (North)
Site	Between pasture area and cane fields separated by large drain
Date	21/11/2007
Time	11:30 — Note: pit in drain depression, profil description only
Pit number	1

Hor Depth (cm)	Details	Mottles Ab (0-4)	Mottles Color	Macropores Dia (1-4)	Macropores Oreint (H-V)	Macropores Ab (1-3)	
0-25	Black to grey topsoil	1	dull red				Abundant roots
25-40	Med to heavy clay	3	dull red				no visible signs of pores, fine roots
40+	light clay sand						light coloured grey

Table R6a: Pit soil data, water table below limits of test. Pit located in cane inter-row, recently harvested in wet conditions and Fe staining on soil surface to infield drain.

Catchment:	Richmond
Location:	Braziers Drain (North of Sykes Shed)
Site	Between pasture area and cane fields separated by large drain
Date	21/11/2007
Time	11:30 — Note: profil description only
Pit number	2 — Ratoon cane, Recently harvested in wet conditions, surface Fe staining in tracks

Hor Depth (cm)	Details	Mottles Ab (0-4)	Mottles Color	Macropores Dia (1-4)	Macropores Oreint (H-V)	Macropores Ab (1-3)	Particulars
0-15	Black topsoil	1					slight mottling
15-45	MC	3	dark red	1	H=V	1	dark color
45+	MC						Light colored

Appendix 7: Acid Sulfate Soil Risk Map Codes

Map Class Description	Depth to Acid Sulfate Soil Materials	
HIGH PROBABILITY High probability of occurrence of acid sulfate soil materials within the soil profile. The environment of deposition has been suitable for the formation of acid sulfate soil materials. Acid sulfate soil materials are widespread or sporadic and may be buried by alluvium or windblown sediments.	Below water level	Bottom sediments.
		At or near the ground surface.
		Within 1 metre of the ground surface.
		Between 1 and 3 metres below the ground surface.
		Greater than 3 metres below the ground surface.*
LOW PROBABILITY Acid sulfate soil materials are widespread or sporadic materials within the soil profile. The environment of deposition has generally not been suitable for the formation of acid sulfate soil materials. Soil materials are often Pleistocene in age. Acid sulfate soil materials, if present, are sporadic and may be buried by alluvium or windblown sediments.	Below water level	Bottom sediments.
		At or near the ground surface.
		Within 1 metre of the ground surface.
		Between 1 and 3 metres below the ground surface.
		Greater than 3 metres below the ground surface.*
NO KNOWN OCCURRENCE Acid sulfate soils are not known or expected to occur in these environments.		No known occurrences of acid sulfate soil materials.

LANDFORM CODES

Landform Process Class	Landform Element		Elevation#
W.................. Aeolian	b................Backplain	t................Levee Toe	0.............0–1 m
A.................. Alluvial	k................Backswamp	o................Ox–bow	1.............1–2 m
B.................. Beach	m...............Bottom Sediments	p................Plain	2.............2–4 m
E.................. Estuarine	n................Channel	a................Sandplain	4.............>4 m
L.................. Lacustrine	d................Dune	s................Swamp	
S.................. Swamp	r................Interbarrier Swamp	y................Splay	**Additional Descriptive Codes**
	i................Intertidal Flat	u................Supratidal Flat	
	g................Lagoon	w................Swale	(p).......Pleistocene
X..................Disturbed Terrain*	l................Levee	c................Tidal Creek	(s).......Acidic Scald

*Elevation levels given on the map refer to the elevation of the ground surface at the time of mapping. Depending on the nature of the disturbance, these elevation levels may or may not represent the original ground surface elevation.

#Approximate AHD

Appendix 8:   Soil Profile Pit Descriptions

APPENDIX 8:   SOIL PIT PROFILE DESCRIPTION

Catchment: Tweed

		Horizon	Hor. Depth (cm)	Details	Mottles Abundance (0-4)	Mottles Color	Macropores Dia (1-4)	Oreint. (H-V)	Abundance (1-3)	Particulars
Location:	**Blacks Drain**									
Site	Stainley	A	0-30	Black mature peat						old ti-tree area (old roots at depth)
Date	12/11/2007	Bg	30-100	light grey	2		2	H=V	1	mottling, tubules 2-3mm dia and
Time	15:00	Bj	100-106	MC (some slaking?)						wall thickness, strong structurally
Pit number	1									2-3 pores main pores infilling
Site	Stainley	A	0-30	Black mature peat						Cane field
Date	12/11/2007	Bg	30-80	light grey	2		2	H=V	1	mottling, tubules 2-3mm dia and
Time	15:45	Bj	80-106	MC (some slaking?)						wall thickness, strong structurally
Pit number	2	Gr	106+							2-3 pores main pores infilling
Site	Stainley	A	0-30	Black mature peat						
Date	12/11/2007	Bg	30-70	light grey	2		2	H=V	1	mottling, tubules 2-3mm dia and
Time	16:20	Bj	70-106	MC						wall thickness, strong structurally
Pit number	3	Gr	106+							2-3 pores main pores infilling
Site	Stainley	A	0-40	Black mature peat						
Date	13/11/2007	Bg	40+	light grey	2		2	H=V	1	pipe structures easily visible
Time	9:28		106+							
Pit number	4									
Site	Stainley	A	0-40	Black mature peat						
Date	13/11/2007	Bg	40+	light grey	2		2	H=V	1	pipe structures easily visible
Time	10:00		106+							
Pit number	5									
Location:	**McLeods Ck**									
Site	Rob Quirk	A	0-30	Alluvial/topsoil						Ratoon cane field
Date	13/11/2007	Bg	30-80	Clay,mottling	1	orange/red	1	H<V	1	pores visible above water table
Time	11:20	Bj	80-106	Clay	2	red/pale swirls				mottles + jarosite
Pit number	1	Gr	106+	Clay						blue/grey
Site	Rob Quirk	A	0-25	Alluvial						
Date	13/11/2007	Bg	25-40	Clay,mottling	1	orange/red	2	H=V	1	pores visible above water table
Time	12:00	Bj	40-85	Clay	2	red/pale swirls				mottles + jarosite
Pit number	2	Gr	85+	PASS						blue/grey
Site	Rob Quirk	A	0-30	Alluvial						2-3 main pores discharging
Date	13/11/2007	Bg	30-75	Light grey,mottl	1	orange/red	2	H=V	1	pores visible above water table
Time	13:00	Gr	75+	M/H Clay						mottles + jarosite
Pit number	3									blue/grey, old reed roots
Site	Rob Quirk	A	0-30	Alluvial						2-3 main pores discharging
Date	13/11/2007	Bg	30-70	Light grey	1	orange/red	2	H<V	2	weak mottling, pores visible
Time	13:30	Bj	70-90	MC						mottles + jarosite
Pit number	4	Gr	90+	PASS						blue/grey, old reed roots
Site	Rob Quirk	A	0-25	Alluvial						2-3 main pores discharging
Date	13/11/2007	Bg	20-50	Light grey	1	orange/red	2	V>H	2	moderate mottling, pores visible
Time	14:30	Bj	50-80	MC						weak mottles + jarosite
Pit number	5	Gr	80+	PASS						blue/grey
Site	Rob Quirk	A	0-25	Alluvial/black topsoil						2-3 main pores discharging
Date	15/11/2007	Bg	20-60	Light grey	1	orange/red	2	V>H	2	moderate mottling, pores visible
Time	14:00	Bj	60-90	MC						strong jarosite
Pit number	6	Gr	90+	PASS, blue/grey						root/reed reminates at depth
Site	Rob Quirk	A	0-25	Alluvial/black topsoil						2-3 main pores discharging
Date	15/11/2007	Bg	20-60	Light grey	1	orange/red	2	V>H	2	moderate mottling, pores visible
Time	14:30	Bj	60-90	MC						strong jarosite
Pit number	7	Gr	90+	PASS						blue/grey, root/reed reminants
Location:	**Clothiers Ck**									
Site	Hotspot rem.	O	0-2	couch/ carpet grass						ponded water
Date	14/11/2007	A	2-53	Black peat			3	H	1	
Time	11:00	Bj	53-83	light grey color						
Pit number	1	Gr	83+							
Site	Hotspot rem.	O	0-2	couch/ summer grass						
Date	14/11/2007	A	2-25	Mixed clay						
Time	11:30		25-40	peat colored			nil			
Pit number	2		40-55	Extensive layer peat						old ti-tree bark and roots
		Gr	55+	Blue grey						

Catchment: Tweed

		Horizon	Hor. Depth (cm)	Details	Mottles Abundance (0-4)	Mottles Color	Macropores Dia (1-4)	Oreint. (H-V)	Abundance (1-3)	Particulars
Site	Hotspot rem.	O	0-2	couch/ summer grass						
Date	14/11/2007	A	2-36	peat/alluvial			2	H	1	2 large pores
Time	12:35	B	36-45	peat colored						
Pit number	3	Bg	45-60	Extensive layer peat						
		Gr	60+	Blue grey						
			86	sand grit in grey/blue gel						
Site	Hotspot rem.	O	0-2	couch/ summer grass						
Date	14/11/2007	A	2-25	black peat			4	H	1	2 large pores
Time	13:00	B	25-30	peat colored						
Pit number	4	Bg	30-60	Extensive layer	1	reddish				light mottling
		Gr	60+	Blue grey						
Site	Hotspot rem.	O	0-2	couch/ summer grass						dense pasture
Date	14/11/2007	A	2-35	black peat			2	H=V	2	several pores
Time	13:30	B	35-40	peat colored						
Pit number	5	Bg	40-60	Extensive layer	1	reddish				light mottling
		Bj	60-80							
			80+	Blue grey						
Location:	**Chinderah**									
Site	Cane Area	A	0-25	Sandy alluvial						plant cane
Date	14/11/2007	B	25-60	sandy clay	1	orange				
Time	15:30	B1	60-80	pure sand			nil			crumbly
Pit number	1		80+	Yellowish sand						
Site	Cane Area	A	0-25	Sandy alluvial						plant cane
Date	14/11/2007	B	25-60	sandy clay	1	orange				
Time	16:00	B1	60-80	pure sand			nil			minor slumping
Pit number	2		80+	Yellowish sand						
Site	Cane Area	A	0-25	Sandy alluvial						plant cane
Date	14/11/2007	B	25-60	sandy clay	1	orange				
Time	16:00	B1	60-80	pure sand			nil			minor slumping
Pit number	3		80+	Yellowish sand						
Site	Cane Area	A	0-20	Sandy alluvial						fallow
Date	14/11/2007	B	20-50	Grey mottling	1	orange	1	H=V	1	Fe deposit around pore
Time	16:00	B1	50+	pure sand			nil			slumping edges at depth
Pit number	4									
Site	Cane Area	A	0-20	Sandy alluvial						fallow
Date	14/11/2007	B	20-50	Grey mottling	1	orange				
Time	16:28	B1	50-80	pure sand			nil			slumping edges at depth
Pit number	5		80+	bluish sand						
Location:	**Christies Ck**									
Site	Oak Forest	O	0-4							
Date	15/11/2007	A	4-36	black loam			4	H	3	rapid refill
Time	10:30	B	36-80	silty loam						
Pit number	1	Bj	80-90	jarosite						
			90+	PASS						
Site	Oak Forest	O	0-4	organic peat						
Date	15/11/2007	B	4-80	Peat layer			4	H	3	rapid
Time	11:00	Bj	80-100	jarosite content						
Pit number	2	Gr	100+							
Site	Oak Forest	O	0-4							
Date	15/11/2007	A	4-80	peaty,weak mottling			4	H	2	
Time	11:30	Bj	8-95	jarosite present						
Pit number	3	Gr	95+							
Site	Oak Forest	O	0-4							
Date	15/11/2007	A	4-80	peat/weak mottling			4	H	2	many pores, 3 large pores
Time	12:00	Bj	80-100	clay						eg 5cm * 2.5cm
Pit number	4		100+							

Catchment: Richmond

		Horizon	Hor. Depth (cm)	Details	Mottles Abundance (0-4)	Mottles Color	Macropores Dia (1-4)	Macropores Oreint. (H-V)	Macropores Abundance (1-3)	Particulars
Location:	**Newrybar**									
Site	Scanlans Dr	O	0-1							Setaria and paspalum
Date	20/11/2007	A	1-20							
Time	9:30	B	20-47							
Pit number	1	B1	47-85	Brown peat	nil		nil			Roots abundant
		Bg	85-115	Dark clay peat						
Site	Scanlans Dr	A	0-20		1	reddish				Forest area
Date	20/11/2007	B	20-90	Light colored clay			2	H=V	2	visible pores
Time	11:00	B1	90-100	Clay sand						
Pit number	2									
Location:	**Haughward Drain South**									
Site	Main drain	O	0-2	Organic/brown loam						
Date	21/11/2007	B	2-53	peaty loam	2	reddish	2	H=V	1	Strong mottling in root channels
Time	13:30	Bg	53-75	Black/peat clay						roots to depth
Pit number	1	Gr	75+	MC gel						
Site	Main drain	O	0-2	Organic/brown loam						
Date	21/11/2007	A	2-15	Black/peat clay						
Time	15:00	Bg	15-100	Peat clay loam	2	reddish	2	H=V	1	roots abundant to depth,
Pit number	2	Gr	>100	jarasite evident						mottling in root channels
Location:	**Kilgin**									
Site	Coombes	A	0-20	Black soil						Drain depression
Date	1/04/2008	B	20-35	Plastic clay	2	dull orange				
Time	10:30	B2	35-45	Med Clay	4	orange+	2	V>H	2	Fe swirls
Pit number	1	B3	45-120	MC to HC						Fe swirls
		Bg	120-125	MC to HC						Fe nodules, course grit
			125-145	MC to HC						Dark Fe and jarosite
			145+	MC to HC						plastic texture, dryer
Site	Coombes	A	0-18	Black soil						drain depresson
Date	1/04/2008	B	18-50	Grey clay	3	orange	1	V>H	1	
Time	11:30	B2	50-65	Black silty clay						
Pit number	2	Bg	65-110	Clay						Fe deposites
			110-130	Clay						Fe + Jarosite deposites
			130-140	Clay						Fe deposites
Site	Coombes	A	0-20	Black topsoil						Drain depression, white salts on surface
Date	1/04/2008	B	20-35	grey clays						
Time	13:00	B2	35-50	grey clays/ color	4	orange+	2	V>H	2	Bright Fe lens
Pit number	3	B3	55-60	grey sand lens						Possible an old drain crossing
		Bg	60-90	Grit layer						Fe and Jarosite
		Gr	90+	MC						Grey color, less Fe
										Evidence of strong Fe migration
										Many visible maropores not flowing
Location:	**Woodburn Area**									
Site	Gollan	A	0-100	Black soil	0		2	H	1	Cultivation, low area
Date	14/05/2008	B	100-140	Orang peat/clay layer						3 large pores infilling
Time	9:00	Bg	140-150	Black peaty clay						
Pit number	1									
Site	Nev Gardiner	A	0-15	Black soil						
Date	14/05/2008	Ap	15-70	grey/black	1	dull red	2	V	1	compacted layer to 50cm
Time	11:15	B	70-84	Orange peat						1 macropore
Pit number	1	B3	84-100	clay peat						infil from peat, odour plus
Site	Boro-Cod	A	0-50	Black/peat soil	0		3	V	1	Open pasture
Date	14/05/2008	B	50-60	Grey clay						
Time	13:15	B3	60-85	peat clay						orange fleck, some Fe
Pit number	1	Bg	85-115	peat orange						in root channels
Location:	**Braziers Drain (North)**									
Site:	Cane/pasture	A	0-25	Topsoil	1	dull red				Abundant roots
Date	21/11/2007	B	25-40	M to H clay	3	dull red	nil			no visible signs of pores,fine roots
Time	11:30		40+	light clay sand						light colored grey
Pit number	1									
Site:	Cane/pasture									
Date	21/11/2007	A	0-15	Topsoil	1					slight mottling
Time	12:00	Bg	15-45		3	dark red	1	H=V	1	dark color
Pit number	2		45+	MC						Light colored

Catchment: Richmond

		Horizon	Hor. Depth (cm)	Details	Mottles Abundance (0-4)	Mottles Color	Macropores Dia (1-4)	Macropores Oreint. (H-V)	Macropores Abundance (1-3)	Particulars
Location:	**Kilgin**									
Site	Crusio	B	0-39	mottles plus	4	dark red/oran	2-3	H=V	3	Extensive mottling and Jarasite
Date	4/04/2008	Bg	>39				2	H=V	2	deposites in root/old reed channels
Time	10:00									prolific roots, even into pyritic layer
Pit number	1									*profil: wetting and drying cycle*
Site	Crusio	A	0-30	black alluvial						prolific roots at depth
Date	4/04/2008	B	30-50	layering	3	dark red	1	H=V	1	strong layers, charcoal layers,
Time	11:00	Bg	50+	dark grey color						tree reminants, Fe staining
Pit number	2									roots and staining to depth
Site	Crusio	AB	0-70	Fe staining	4	dark red/oran	1	H=V	1	Extensive Fe staining, + Jarasite
Date	4/04/2008	Bg	70-100	& MBO's						slow transition to Gr
Time	12:00	Gr	100-120							Fe + Jarasite swirls at depth
Pit number	3									
Location:	**Rocky Mouth Creek**									
Site	RMC	O	0-2	Organic						Dense pasture growth
Date	30/10/2008	A	2-30	Black alluvial						Abundant roots
Time	11:15	B	30-65	MC grey	3	yellow swirls	3	H>V	2	concretions/pipes
Pit number	2	G	65-104	MC to HC						grey brown clay
		Gr	104 +	HC						Dark balck grey
Pit number	3	Gr	90+	HC						Dark balck grey
Pit number	4	Gr	85+	HC						Dark balck grey

Catchment: Clarence

		Horizon	Hor. Depth (cm)	Details	Mottles Abundance (0-4)	Mottles Color	Macropores Dia (1-4)	Macropores Oreint. (H-V)	Macropores Abundance (1-3)	Particulars
Location:	**Kings Creek Road, Lawrence**									
Site	Nathan Ensby	O	0-2	Couch						Swamp area
Date	12/03/2008	A	2-14	Black alluvial						Abundant roots
Time	11:00	B	14-28	clay	4	orange	1	V>H	1	jarasite evidence
Pit number	1	B2	28-65	Clay white						
		Bg	65-80	Sand grey						
		Gr	80-	Black mud						
Site	Nathan Ensby	O	0-2	couch						Near main drain
Date	12/03/2008	A	2-28	Black alluvial						
Time	12:30	B	28-34	Clay	4	dark orange	1	H=V	1	Prominent mottles
Pit number	2	B2	34-70	Clay						
		Bg	70-84	Grey sand						
		Gr	84-	MC						
Site	Rod Ensby	O	0-2	Couch						Pasture area
Date	12/03/2008	A	2-32	Black alluvial						low depression in shallow drain
Time	14:30	B	32-64	dull mottling	1	dark red	1	H=V	1	
Pit number	3	Bg	64-88	MC grey blue						
		Gr	88-	sand						
Location:	**Lake Wooloweyah**									
Site	Ring Drain	O	0-1	OM couch						couch browned off
Date	13/03/2008	A	1-15	dark topsoil	0					ie flooding/army worms
Time	13:00	B1	15-70	silty clay grey			1	V>H	1	plastic, sparse orange streaks
Pit number	1	C	70-	sand						no structure
Site	Ring Drain	O	0-1	OM						couch browned off/army worms?
Date	13/03/2008	A	1-18	Topsoil browny/black						roots vertical with Fe staining
Time	13:40	B	18-60	clay with sand grit			1	H=V	0	slow discharge
Pit number	2	B2	60-80	sandy clay						
		B3	80-100	grey sand lens						
		Bg	100-140	sandy peat more clay						

Catchment: Clarence

		Horizon	Hor. Depth (cm)	Details	Mottles Abundance (0-4)	Mottles Color	Macropores Dia (1-4)	Oreint. (H-V)	Abundance (1-3)	Particulars
Location:	**Coldstream**									
Site	Crows Nest Swp	O	0-1	OM						Couch and water couch
Date	12/05/2008	A	1-20	Black soil						Abundant roots
Time	9:30	B	20-70	Black/grey soil	0		1	H=V	1	old root channels barely visible
Pit number	1	Bg	70-100	light orange grey clay						
		Gr	100+	Blue grey						
Site	Crows Nest Swp	O	0-1	OM						Couch pasture
Date	12/05/2008	A	1-25	Blach topsoil						Fine roots
Time	10:00	B	25-40	Mix black/grey	0		1	V>H	1	Fine old root channels
Pit number	2	Bg	40-110	light orange grey clay						
		Gr	110+	clay gel						
Site	Crows Nest Swp	O	0-1							Water couch and common couch
Date	12/05/2008	AB	1-110	Black soil	1	Dull Or/red	2	V	2	Abundant roots, Faint mottles
Time	12:30	Gr	110+	clay gel						in old root channels
Pit number	3									Some roots visible
Site	Crows Nest Swp	O	0-2	OM						Dead couch material
Date	12/05/2008	A	2-30	Black soil	2	Dark red	1	V	1	Abundant roots/ soil cracks
Time	13:30	B	30-100	Light black soil						Some visible maropores, old roots
Pit number	4	Gr	100+	Clay gel						Gradual change to gel
Site	Crows Nest Swp	O	0-1	OM						Dead plant material, salt wicking
Date	12/05/2008	A	1-9	Black topsoil						Abundant roots
Time	14:30	B2	9-11	Sand lense						Course white sand
Pit number	5	B	11-60	Black/orange cl	1	Or/red	1	V	1	Mottling in old root channels
		B3	60-100	Dark black						and soil cracks
		Bg	100+	clay						
Location:	**The Broadwater**									
Site	Arndilly	A	0-15	Black soil						Scald, Fe staining on surface
Date	13/05/2008	B	15-40	plastic grey/bla	3	Pale yellow	1	H=V	2	some roots
Time	10:45	B2	40-70	MC grey						odd roots, no Fe staining
Pit number	1	Bg	70+	course grey sand						prominent change
Site	Arndilly	A	0-15	Black soil						Scald, Fe surface staining
Date	13/05/2008	B	15-30	Greyish brown	3	pale yellow	1	H=V	2	macropores not readily visible
Time	11:30	Bg	30-85	Grey clay, L/MC						some roots, no mottles
Pit number	2	Gr	85+	course grey sand						
Site	Arndilly	P	0-2	Peat						Scald, dead leaf mat
Date	13/05/2008	A	2-18	Black soil	1	dull red				
Time	14:00	B	18-34	Grey plastic cla	1	yellow				Yellow swirls and mottles
Pit number	3	B2	34-80	Course sand						Prominent change
		B3	80-100	Black sand						
		Gr	100+	Blue grey gel/clay						basic consistency
Site	Arndilly	O	0-2	OM						Salt water couch
Date	13/05/2008	A	2-15	Black soil						
Time	14:30	B	15-65		3	yellow	1	V	1	mottles and swirls
Pit number	4	Bg	65-100	Grey clay						
		Gr	100-102	Gritty Jarasite layer						swirls
			102-110	slow change to gel						
			110+	Gel						

Catchment: Macleay

		Horizon	Hor. Depth (cm)	Details	Mottles Abundance (0-4)	Mottles Color	Macropores Dia (1-4)	Oreint. (H-V)	Abundance (1-3)	Particulars
Location:	**Jerseyville/Kitchener**									
Site	Bob Rogars	O	0-2		0					past marine intrusion
Date	1/11/2007	B	2-10		1	reddish				Fe deposits in root channels
Time	12:00	Bg	10-20	light grey color	2	reddish	2	H>V	2	Abundant roots at depth to
Pit number	1	Bg	20-40	L to MC			2	H>V	2	sulfidic horizon
		Bj	40-62	Clay sand						jarasite st 60cm
			62+							Grey sandy Clay
Site	Bob Rogars	A	0-5	Topsoil						Fe in fine root channels
Date	1/11/2007	B	5-15	Burnt peat laye	2					(Oak area)
Time	12:00	Bg	15-20	LC	3	red/orange				Fe in root channels dominate
Pit number	2		20-50				3	H=V	1	
			50+	Silty sand						
Site	Bob Rogars	O	0-2	organic	0					(open area)
Date	1/11/2007	A	2-10	Silty loam						
Time	14:00	B	10-50	Silty LC			1	H	2	roots vertical
Pit number	3	B3	50-70	sand lens						Fe flocc in older
		Bg	70+	Dark grey silty sand						decayed root channels

Catchment: Macleay

		Horizon	Hor. Depth (cm)	Details	Mottles Abundance (0-4)	Mottles Color	Macropores Dia (1-4)	Oreint. (H-V)	Abundance (1-3)	Particulars
Site	Bob Rogars	O	0-2	organic						
Date	1/11/2007	B	2-20		3	Dark red				
Time	14:40	Bg	20-40	MC	2	Dark red	1	H<V	2	Old root channels + soil cracks
Pit number	4	Bg1	40-55	MC	0		1	H<V	1	
			55+	Black material/sand						
Site	Bob Rogars	O	0-2							
Date	1/11/2007	A	2-18		1	Dark red				Abundant roots
Time	15:00	B	18-50	LC	3	Dark red	1	H=V	1	Root channel Fe
Pit number	5	B2	50-60	Sand lens						
		B3	60-75	Clay sand						
		Bg	75+	Dark grey Clay sand						
Location:	**Clancys Drain**									
Site	M&S Argue	O	0-2	OM						Pasture area
Date	2/11/2007	A	2-6	LC	1					
Time	9:45	B	6-42	MC	2	reddish	1	V=H	2	charcoal layer at 20cm
Pit number	1	Bg	42-100	MC	2	reddish	3	V<H	2	A few major contributing pores
		Bj	100-125	MC						Jarasite present,
			125+							in root channels
Site	M&S Argue	O	0-2	OM						
Date	2/11/2007	A	2-6	LC	1					
Time	10:30	B	6-42	MC	2	reddish	1	V=H	2	
Pit number	2	Bj	42-120	MC	2	reddish	4	H>V	1	A few major contributing pores
			120+	MC						Jarasite increase from 80cm,
										in root channels
Site	M&S Argue	O	0-2	OM						
Date	2/11/2007	A	2-6	LC	1					
Time	11:00	B	6-42	MC	2	reddish	1	V=H	2	
Pit number	3	Bj	42-125	MC	2	reddish	4	H>V	1	A few major contributing pores
			125+	MC						Jarasite abundant from 65cm,
										in root channels
Site	M&S Argue	O	0-1	OM						
Date	2/11/2007	A	1-22	black color	2	reddish	1	V=H	2	Abundant vertical roots
Time	12:00	B	22-30	to light grey	3	reddish				A few major contributing pores
Pit number	4	Bg	30-80	MC	3	reddish	4	H>V	1	Abundant mottles
		Bj	80+							start of Jarasite swirls
Site	M&S Argue	O	0-1	OM						
Date	2/11/2007	A	1-22	black color	2	reddish	1	V=H	2	Abundant vertical roots
Time	13:00	B	22-30	to light grey	3	reddish				A few major contributing pores
Pit number	5	Bg	30-70	MC	3	reddish	4	H>V	1	Abundant mottles
		Bj	70+							Jarasite swirls
Location:	**Lancaster Dran Laterial 1**									
Site	Frogmore	O	0-5	Couch						Pasture area/dairy
Date	4/12/2007	A	5-15	Black soil						
Time	11:42	B	15-37	some Fe srainii nil		dark red in root channels				
Pit number	1	Bg	37-60	one large macropore at depth			1	V>H	1	mixed profil Clay and charcoal
Site	Frogmore	O	0-4	OM, couch, smartweed						
Date	4/12/2007	A	4-9	Black soil						
Time	12:15	B	9-50	Light clay	0		1	V>H	1	minor Fe in root channels
Pit number	2	Bg	50-70							minor Fe in root channels
			70+							Vert roots
Site	Frogmore	O	0-2							
Date	4/12/2007	A	2-20	Black topsoil	1	reddish				minor Fe in root channels
Time	13:50	Bg	20-82	LC			1	V=H	1	minor Fe in root channels
Pit number	3		82-102	Light grey clay						at 36cm, large pores visible
Site	S & H Prop.	O	0-5	Couch/smartweed						Pasture area/beef
Date	4/12/2007	A	5-20	Mixed profile, light colored lens						
Time	15:15	B	20-90	Mixed profile, charcoal and clays			1	H>V	1	3-4 main pores contributing
Pit number	4									
Site	S & H Prop.	O	0-2							
Date	4/12/2007	A	2-6		1	reddish				roots vertical
Time	13:45	B	6-22		1	reddish				slight mottling, old root channels
Pit number	5	Bj	22-75	Mixed/ Clay and charcoal			1	H=V	2	several main porse contributing
			75+	MC						

Catchment: Hastings

		Horizon	Hor. Depth (cm)	Details	Mottles Abundance (0-4)	Mottles Color	Macropores Dia (1-4)	Oreint. (H-V)	Abundance (1-3)	Particulars
Location:	**Rossglen**									
Site	Barry Par	O	0-2	Kikuyu/sedge						
Date	5/12/2007	A	2-14	Black alluvial						vertical roots
Time	9:00	B	14-24	Light grey clay/mixed orange						
Pit number	1	B1	24-40	light grey clay						
		Bg	40-80	Fe staining in MC			1	V>H	1	
			80-	MC and roots						
Site	Barry Par	O	0-2							paspalum/soft rush+
Date	5/12/2007	A	2-16	Black color	2	dark red/orange				umbrella sedge
Time	10:00	B	16-26	Black color						
Pit number	2		26-28	Ash layer/ yellow orange						
		B1	28-30	Black color						
		Bg	30-40	light grey color			1	V>H	1	Fe staining
			40-90	light grey color/	2	dark red/orange				Fe staining in root channels
			90-	light grey MC						
Site	Barry Par	O	0-2	Dead veg, red color						
Date	5/12/2007	A	2-18	Black topsoil						
Time	11:00	B	18-55	light grey			1	V>H	2	vertical roots
Pit number	3	B2	55-85	soft sandy lens						Fe staining, reddish
		Bj	85-	PASS/ some Fe						Roots growing into fissures
Site	Barry Par	O	0-2	Dark						West side of road
Date	5/12/2007	A	2-20	Dark/some mot	1	reddish				
Time	13:00	Bg	20-32	light grey	3	reddish	1	V>H	2	Fe staining
Pit number	4	Bj	32-90	light MC						Fe staining
Site	Barry Par	O	0-2	Dark color						
Date	5/12/2007	A	2-18	Dark color						some root channel Fe staining
Time	14:00	Bg	18-30	light grey/MC	2	red/orange	1	V>H	1	
Pit number	5	Bj	30-90	jarosite mottling						swirls and concretions
			90-	PASS/ old root channels						
Location:	**Maria River**									
Site	tree Plantation	A	0-20	mud/alluvial black						Drain depression/next to ti-trees
Date	5/12/2007	B	20-36	high in OM, black						
Time	9:00	Bg	36-50	light grey clay	1	reddish	1	H>V	0-1	some Fe mottling
Pit number	1	C	50-115	plastic MC	no mottling					no mottling
		Gr	115-	PASS						
Site	tree Plantation	A	0-15	Black mud						Abundant roots
Date	5/12/2007	B	15-30	Fe in root channe	1	reddish	1	V=H	2	
Time	10:00	Bg	30-60	mottles and swirl	3	reddish				
Pit number	2	G	60-120	MC no mottles						
		Gr	120-	Pass						
Site	Torons Island	O	0-2	Water couch/sedge						previous scald area
Date	6/12/2007	A	2-26	dark grey/browı	nil					roots abundant to depth
Time	12:00	B	26-50	SC to CS	1	dark red				Fe staining along old root channels
Pit number	3	Bg	50-85			orange light	1	V>H	1	very small pores
		C	85-130	Clay sand/fine						no Fe staining in new root growth
Site	Hacks Ferry	O	0-2	OM and peat						Abundant WC, previous hotspot
Date	7/12/2007	A	2-28	Black soil						Abundant roots
Time	9:00	B	28-50	light grey color	1	dull red	3	H=V	2	Fe staining in root channels +
Pit number	4	Bj	50-80	Fe concretions	3	Bright orange mix				several major pores
			80+	MC, light grey color						plastic
Site	Hacks Ferry	O	0-2	OM						carpet grass, water couch
Date	7/12/2007	A	2-22	Black/alluvial						Abundant roots/ vertical
Time	10:00	Bj	22-80	light grey clay	3	orange	2-3	H=V	2-3	Fe concretions, bright orange swirls
Pit number	5		80-90	plain grey	0					
			90+							

Catchment: Manning

		Horizon	Hor. Depth (cm)	Details	Mottles Abundance (0-4)	Mottles Color	Macropores Dia (1-4)	Oreint. (H-V)	Abundance (1-3)	Particulars
Location:	**Lansdowne River**									
Site	Templman	A	0-33	Black soil, mixec	no					Abundant roots H & V
Date	14/04/2008	B	33-55	Light brown, yellowish clay			nil			
Time	14:00	Bj	55-105	Clay, jarasite swirls			nil			swirls with gritty feel
Pit number	1									
Site	Templman	A	0-25	Black soil, Abundant roots						Carpet grass dominate area,
Date	14/04/2008	B	25-50	Grey black	no		2	H=V	2	slight elevation increase
Time	14:00	B3	50-80	clay brown						
Pit number	2	Bj	80-110	grey clay,jara swirls						Jarasite swirls plus gritty feel
Site	Templman	A	0-28	Black topsoil						Abundant roots to depth
Date	14/04/2008	Bj	28-45	light colored clay	no		2	H=V	1	patchy macropores
Time	14:00	Bj	45-90	Jarasite swirls						
Pit number	3	Gr	90+	dark grey						some jarasite in old root channels

Catchment: Manning

		Horizon	Hor. Depth (cm)	Details	Mottles Abundance (0-4)	Color	Macropores Dia (1-4)	Oreint. (H-V)	Abundance (1-3)	Particulars
Location:	**Motto Area**									
Site	Roches	O	0-3	Peat, fine leaf juncus						
Date	15/04/2008	A	3-23	Black to brown colors						Mixed colors
Time	13:00	B	23-80	Fine sand in clay			1	H=V	1	Fe staining in root channels
Pit number	1 (6)	Bj	80-130	Jarasite swirls						Jarasite swirls,mottles
		Gr	130+	Blue grey color						in root channels
Site	Roches	P	0-5	Peat, Fe staining	1	reddish				Old ti-tree area
Date	15/04/2008	A	5-15	Black, some charcoal						
Time	9:00	B	15-45	Light grey	2	reddish	3	H=V	2	Abundant jarasite,
Pit number	2	B2	45-65	Changing to darker grey						mottling and sheet(soil fructures)
		Bj	65-90	MC						jarasite bright yellow swirls
			90-130	jarasite abundant						and Fe staining root channels
Site	Roches	P	0-3	Peat, Fe staining						Old ti-tree area
Date	15/04/2008	A	3-15	Dark Black						
Time	12:00	B	15-30	Light grey	2	red	3	V>H	2	Abundant vertical roots
Pit number	3	Bj	30-110	semi dark MC						Abundant jarasite paste
		Gr	110	dark grey						some jarasite swirls
Site	Roches	P	0-4	Peat						Carpet grass
Date	15/04/2008	A	4-14	Black topsoil						Vertical roots
Time	11:30	B	14-24	LC, light grey						Dull Fe staining, abundant roots
Pit number	4	Bg	24-60	MC	2	yellow	2	V>H	2	Jarasite mottles
		Bj	60-62	MC	3	yellow				Jarasite mottles and grit layer
		Bj	62-130	MC						jarasite swirls
		Gr	130	Dark grey						
Site	Roches	O	0-4	Peat, carpet grass						Abundant roots
Date	15/04/2008	A	4-14	Black topsoil						
Time	12:40	B	14-16	LC						
Pit number	5	B1	16-21	black charcoal color						possible fire period
		B2	21-50	Light colored clay			3	V>H	2	
		Bg	50-85	MC, dark grey						Jarasite swirls and grit
		Bj	85-118	Dark grey						Yellow jarasite
Site	Roches	O	0-3	Peat, thin needle sedge						
Date	15/04/2008	A	3-20	Dark black topsoil						
Time	14:30	B	20-50	light grey clay	3	dull red	3	H=V	2	root channel
Pit number	7	Bj	50-86	LC/MC						jarasite paste dominate
		Bj	86-110	MC						some jarasite evident
		Gr	110	Dark grey/blue						
Site	Roches	O	0-3	peaty						pasture
Date	15/04/2008	A	3-20	Black topsoil						
Time	15:00	B	20-80	Light colored C	2	dull red	4	H=V	2	large pores, Fe coating+jarasite
Pit number	8	Bj	80-110	Dark grey						Jarasite swirls
		Gr	110	Blue grey						
Site	Roches	O	0-3	Peaty						pasture
Date	15/04/2008	A	3-20	Topsoil						
Time	15:30	B	20-45	Light colored C	3	dull red	4	H=V	2	large pores, Fe coating + jarasite
Pit number	9	Bj	45-77	MC						more jarasite swirls, vertical roots
		Gr	77-110	Blue grey MC						more jarasite swirls, vertical roots
Location:	**Cattai Wetland**									
Site	Lower wetland	O	0-2	Peaty soil						Salt water couch, Juncus
Date	11/12/2007	A	2-12	Black/brown color						Abundant roots, vertical
Time	9:00	B	12-28	brown soil	1	dark red	1	H=V	1	Fine macropores, Fe lining rt ch
Pit number	1	Bj	28-45	light grey color	2	dark red	3	H=V	2	Fe staining, fine macropores
		Bg	45-105	nodules, concret	3	red/orange				plastic, L/MC. roots, sand grit
		Gr	105+	dark grey						sand evident, SLC
Site	Sth Side	A	0-20	Black topsoil						Roots vertical, peat layer 0-3 cm
Date	16/04/2008	B	20-70	Dark grey	2	dull red	1	V	1	
Time	12:00	B3	70-120	mixed soils	3	dull orange				sticky plastic, vertical black
Pit number	1	Bg	120-140	grey clay						soil swirls
Site	Sth Side	A	0-20	Black topsoil						Ab fine roots, peat layer 0-3cm
Date	16/04/2008	B	20-105	light grey clay	3	dull red+ye	1	H>V	1	Yellow swirls increase with depth
Time	11:00	Bg	105-122	Dark grey sand						course sand lense
Pit number	2									
Site	Sth Side	A	0-25	Black topsoil						Roots vertical, OM peat layer
Date	16/04/2008	B	25-90	Course sand			1	V>H	1	Small pores, Fe staining in rt ch
Time	15:00	B3	90-126	Grey sand						No mottling or fleck color
Pit number	3	Bg	126	Dark blue grey						
Site	Sth Side	O	0-6	OM peat						
Date	16/04/2008	A	6-20	Black topsoil						Fibrous roots
Time	14:30	B	20-50	CS +fine clay	1	orange				very few roots
Pit number	4	B3	50-78	CS + clay						
		Bg	78	grey sand						pure grey sand, no mottling

Appendix 9:

Hydraulic conductivity – a simple field test for shallow coastal acid sulfate soils

Hydraulic conductivity – a simple field test for shallow coastal acid sulfate soils

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1. Outline of the method, its limitations and uses.

This is a simple, semi-quantitative field method for assessing the likely range of saturated hydraulic conductivity (K_{sat}) in shallow coastal acid sulfate soils (ASS). It has been developed for extension officers, landholders and field workers who work with ASS. It is based on established field based methods for assessing K_{sat} in shallow pits (Bouwer and Rice, 1983; Boast and Langebartel, 1984). K_{sat} is a critical variable affecting the hydrology and acid export dynamics of drained ASS. Assessment of K_{sat} in ASS is important in order to design appropriate management strategies for broad acre remediation projects.

K_{sat} can vary greatly, particularly in ASS, which undergo unique, one way structural changes due to chemical dissolution of clay minerals, precipitation of iron minerals and physical ripening processes. While K_{sat} can often be low (<1 m day^{-1} -Cook and Rassam, 2002), recent work has demonstrated that K_{sat} can be extraordinarily high (>100 m day^{-1}) in the sulfuric horizons in some drained ASS backswamps (Johnston *et al*., 2003). High values are generally associated with extensive soil macropore networks (Hamming and van den Eelaart , 1993; Johnston *et al*., 2003).

The spatial heterogeneity of K_{sat} in shallow coastal ASS aquifers means that realistic field scale estimates based on small scale methods (ie slug tests, permeameters, particle size analysis) can be subject to significant errors (Millham and Howes, 1995). This is particularly true when groundwater flow is dominated by macropores whose size and spatial variability are high relative to the size of area sampled (Bouma, 1991). For this reason, tests which average aquifer response over larger areas (ie pit bailing or tidal signal damping) are more likely to be representative of actual field K_{sat} values. This method is designed to complement existing methods. It has a number of advantages and limitations which are listed below. These should be understood before conducting the test.

Advantages

- It allows rapid, *semi-quantitative* assessment of K_{sat} in shallow ASS environments.
- It is simple to conduct, only very basic equipment is required.
- It avoids complex mathematics.
- Data collected in this method can be used* to derive a quantitative measurement of K_{sat} based on Bouwer and Rice (1983) or Boast and Langebartel (1984). (*Use in this fashion is user dependant).

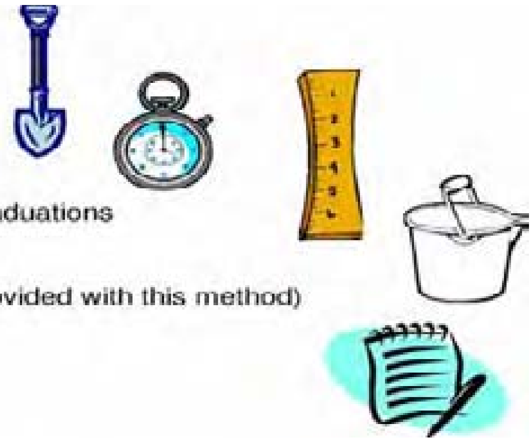
- It can be useful as an extension tool to undertake with landholders.
- It can help assess whether substantial lateral groundwater seepage (to the drain / from the drain) is likely to occur (ie during opening of floodgates).
- It can help assess what hydrological pathway (groundwater seepage or surface runoff) may dominate the acid flux at a given site.

Limitations

- It can only be used to assess K_{sat} in shallow soil horizons (ie not more than about 0.6 m below the ground surface).
- It can only be used when the water table is *below* the ground surface, but no deeper than 0.5 m from the surface.
- In this form it is *semi-quantitative* only and provides a K_{sat} estimate within certain ranges (ie Low / Medium / High / Extreme).
- It requires the user to stay within defined ranges for pit size, water levels and bail out volumes.
- It is a 'bulk' estimate and does not allow discrimination between horizontal and vertical flow components.

2. Equipment required

- A flat shovel
- Stopwatch
- 50 cm ruler with 1 mm graduations
- 10 L bucket
- Recording data sheet (provided with this method)
- Pen/pencil
- Two people



3. Soil features to look out for

Soil texture, soil structure and visible soil features such as macropores are important to look out for. Macropores can play a very important role in water movement through ASS. Tubular macropores associated with old root channels greater than 20 mm in diameter have been observed in some ASS. The existence of clearly visible soil pores rapidly discharging groundwater after bailing the pit can be an excellent indicator of high K_{sat} soils. When excavating the pit notes should be made on the following features according to MacDonald *et al*. (1998).

- Soil texture
- Ripeness (Dent, 1986)
- Macropores – size, shape, density, orientation
- Water flow via visible pores
- Peat, organic matter, root material.

4. Locating your pit

Choose sites that are representative of the area you wish to assess. K_{sat} can be highly variable over short distances and often varies vertically down the soil profile according to the characteristics of the soil horizons (Fig. 1). For example, K_{sat} is often low in the unoxidised, gel-like sulfidic horizons. K_{sat} can also be different in the horizontal and vertical planes within an individual soil horizon. In ASS backswamps K_{sat} may be related to the geomorphic history and origins of the underlying sediments, and thus may show some trends related to site topography. The number of tests you conduct and where you locate them should be related to your data needs. If you want some idea of the variability of K_{sat} it will be important to construct a number of pits across the site.

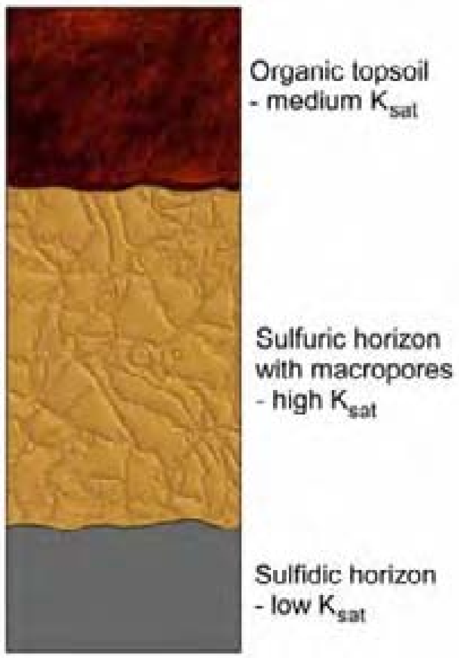
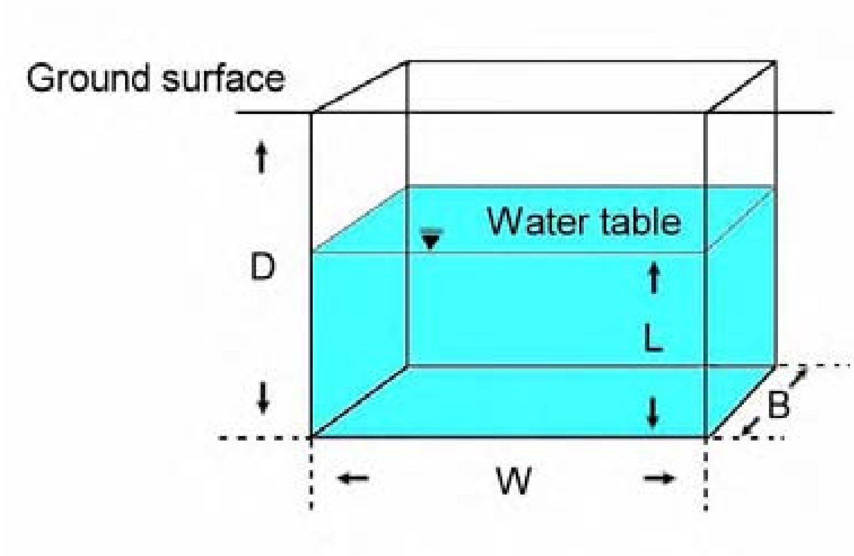


Fig. 1. Schematic diagram of how hydraulic conductivity may vary with depth. The sulfuric horizon is most significant from an acid export point of view as it may contain a large store of acid groundwater, and being closer to the ground surface, is more likely to be intercepted by a drain.

5. Pit construction – dimensions, size limits, water table boundaries

While the data analysis component of this test avoids complex mathematics, it has been field calibrated only within a certain range of pit dimensions and water table heights. *This point is important*. *Pit excavation should follow these instructions closely (see Fig. 2)*. *Failure to do so will compromise the accuracy of the test.*

- The pit should be as square as possible with vertical sides and a ‘flat’ (as possible) bottom (see Fig. 2 for pit geometry and abbreviations). Avoid excessive smearing of pit faces.
- Minimum area of 30 cm x 30 cm (W x B).
- Maximum area of 50 x 50 cm (W x B).
- Maximum depth of pit from ground surface (D) = 60 cm.
- A minimum of 10 cm water depth is required in the bottom of the pit (L) at equilibration with the surrounding water table.



D= *to base of pit below ground surface*

W = width

B = breadth

L = depth to base of pit below equilibrium water table

Fig. 2. Example of pit geometry and abbreviations.

- B and W should be as equal as possible (ie a square pit).
- The ratio L/W *must* be between 0.2 and 0.75. This is important as the data processing is calibrated to these ranges. See Table 1 for example pit dimensions which generate an acceptable L/W ratio.
- The pit water level at equilibration with surrounding water table must be at least 5 cm below ground surface.
- Bail out between 50% to 90% of water volume in the pit.

Table 1: Example of pit dimensions (L, W) which generate acceptable ratios of L/W (0.2 to 0.75).

	L (cm)					
W (cm)	**10**	**15**	**20**	**25**	**30**	**35**
30	*0.33*	*0.50*	*0.67*	-	-	-
40	*0.25*	*0.38*	*0.50*	*0.63*	-	-
50	*0.20*	*0.30*	*0.40*	*0.50*	*0.60*	*0.70*

6. Recording field information

- When recording L (where L = average depth to base of pit below equilibrium water table, see Fig. 2) make at least 10 random measurements across the pit. More can be made if required. The mean of these measurements will be used in the data analysis component of this test. This will help reduce errors from having a slightly uneven pit base.
- Record pit dimensions on the record sheet provided with this method as per the example of pit geometry provided in Fig. 2. The mean of several measurements of B and W may be required if the pit is slightly uneven. Use your discretion.

7. Conducting the test

- Dig the pit so that the dimensions accord to the instructions outlined in section 5 'Pit construction'. Observe and record soil features as outlined in section 3.
- Wait until the pit water level has reached equilibration with the surrounding water table.
- Record the pit dimensions and water table depth parameters on a record sheet (provided with this method).
- Insert the 50 cm ruler *vertically* several centimetres into sediment in the base of the pit in one corner where you can easily read it. Make sure the ruler is stable. **Note** – make sure you record the **raw** equilibrium water level depth on the ruler. (ie L might be ~20 cm but you insert the ruler several cm into the sediment so the **raw** water level reading on ruler before bailing is 24 cm). This is vital for later calculations.
- Rapidly bail out the water in pit using 10 L bucket. Be slow and steady during the last bail to minimise 'sloshing' and water level oscillation in the pit.
- Have one person start the stopwatch immediately after the last bail and begin counting the seconds out loud. Have the other person watching the water level on the ruler and recording the level *from zero seconds onwards*.
- Record the water level approximately every 5 seconds (on record sheet) for a minimum of 3 minutes or until at least ~80% of the pit bail out volume is replaced, up to a maximum of 30 minutes if required.
- If the pit infill rate is slow, then record the water level at time intervals which are long enough to allow accurate measurement (ie rise in water level of at least 1 mm per time increment). Adjust the time intervals on your record sheet accordingly.
- Wait until equilibrium level is obtained and repeat the test at least once in the same pit.

8. Data entry and plotting

The data you record should be entered onto the Excel spreadsheet provided with this method. Instructions for data entry are provided within the spreadsheet (**Ksat pit test data analysis.xls**). Read the instructions thoroughly *before* entering data. The spreadsheet also calculates the ratio L/W and the percentage of the pit water volume you bailed out so that you can check to see if it is within the permissible ranges listed in section 5 'Pit construction'.

The spreadsheet will perform very simple calculations and plotting automatically. *No responsibility is taken if you alter the calculations in any way!* After you enter your data the resultant plot will show the normalised pit refill rate vs time and should look something like Fig. 3. The plot line will fall into one of four pre-set categories listed below which *approximate* the following K_{sat} ranges*.

- Low = less than 1.5 m day^{-1}
- Medium = 1.5 to 15 m day^{-1}
- High = 15 to 100 m day^{-1}
- Extreme = greater than 100 m day^{-1}

***Note:** This is an approximation only. Quantitative assessment of K_{sat} *from the data collected in this method will require the user to apply the calculation method(s) outlined in Bouwer and Rice (1983) or Boast and Langebartel (1984).*

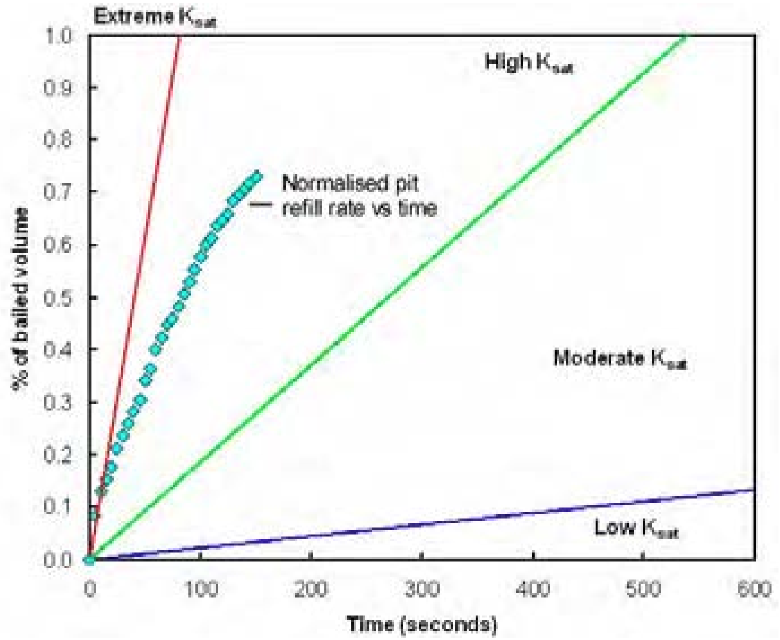


Fig. 3. An example of pit refill data after plotting in spreadsheet.

9. Interpreting data and assessing K_{sat}

The example pit refill data shown in Fig. 3 shows a K_{sat} in the high range (ie between approximately 15 to 100 m day^{-1}).

If a sites K_{sat} falls in the high or extreme range, then depending on other factors (ie elevation of acid horizons relative to local low tide levels, whether the drain intercepts those high K_{sat} soil horizons, any 'pugging' and blockage of macropores at the drain bank face), there is a very real probability that groundwater seepage may be a major hydrological pathway of acid export. In this case, a containment strategy will likely be an important management option. Acid groundwater may be contained by infilling or shallowing drains, or by using a retention structure to keep drain water levels high and stable and prevent the development of effluent groundwater gradients through tidal drawdown (Fig. 4).

High or extreme range K_{sat} also means that if floodgates are opened and saline water introduced into a drain there is a possibility that this saline water could move laterally away from the drain over substantial distances. However, this will also be dependant on the driving head and will only occur *if the gradients are influent* (ie the drain water level is higher than the groundwater level).

If a sites K_{sat} falls in the low range then the risk of lateral salt water seepage if floodgates are opened is likely to be minimal.

If a sites K_{sat} falls in the medium range then further quantitative assessment of K_{sat} may be warranted in order to assess the risk of lateral salt water seepage due to floodgate opening. Monitoring the response of the water table adjacent to the drain during a freshwater floodgate opening event may also be useful.

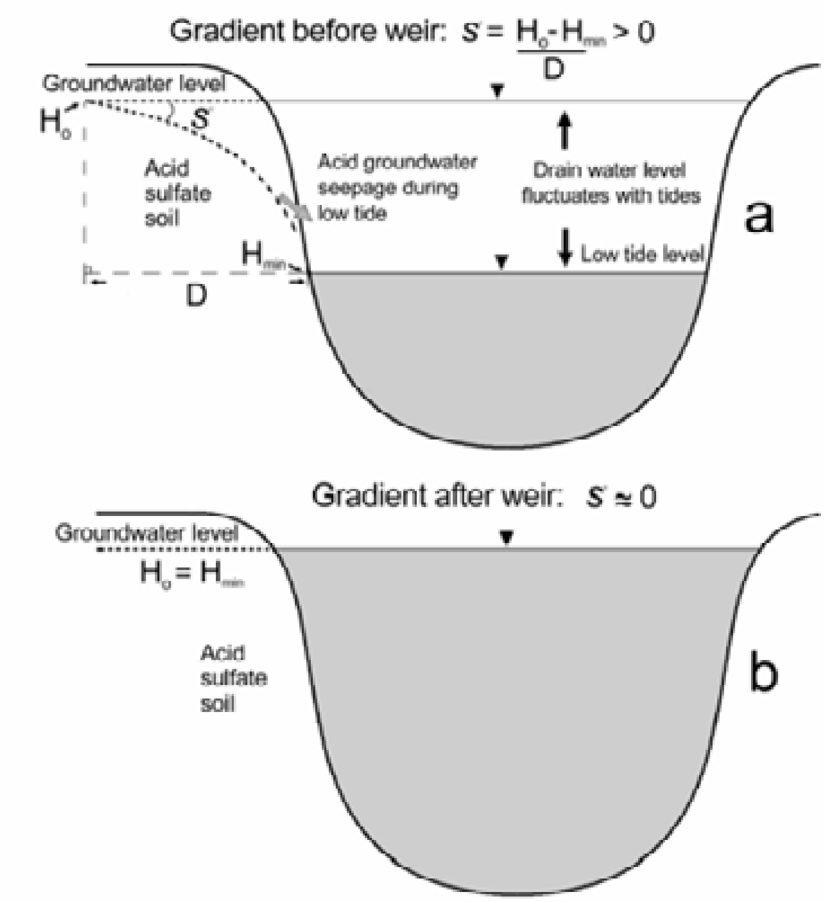


Fig. 4. A schematic representation of (a) the development of effluent groundwater gradients during low tides, leading to acid groundwater seepage and (b) the use of a retention structure (weir) to prevent tidal draw down in drain water levels and thereby reduce gradients and subsequent groundwater seepage.

10. Availability of this method

This method, including these instructions, recording sheets and an Excel spreadsheet for data entry, is available on CD from NSW Agriculture at Wollongbar Agricultural Institute. Alternatively, copies of the above can be downloaded for free at www.agric.nsw.gov.au/reader/floodgate-guidelines.

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Assessment of hydraulic conductivity in coastal floodplain acid sulfate soils on the north coast of NSW

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