1990

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Recommended Citation

George, R J. (1990), *Preliminary groundwater and salinity investigation in the eastern wheatbelt. 4. Kitto's Hillslope, Tammin - 1985-90*. Department of Agriculture and Food, Western Australia, Perth. Report 92.

ISSN 0729-3135
June 1990

Preliminary Groundwater and Salinity Investigations in the Eastern Wheatbelt 4: Kitto's Hillslope, Tammin - 1985-1990

Richard J. George

Resource Management Technical Report 92

Disclaimer

The contents of this report were based on the best available information at the time of publication. It is based in part on various assumptions and predictions. Conditions may change over time and conclusions should be interpreted in the light of the latest information available.

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1. Abstract

A groundwater and salinity investigation on a small (75 ha), salt-affected hillslope south of Tammin was commenced in 1985-

(i) to determine the relative contribution of the shallow and deep groundwater systems responsible for salinity;

(ii) estimate the quantities of salt and water involved;

(iii) study the geological controls of salinity and the hydrologic system at the site;

(iv) assess whether the salinity problem was likely to worsen; and

(v) recommend appropriate management systems for its control.

The investigation revealed that:-

(i) a deep, brackish to saline groundwater system and dolerite dyke, contained within the saprolite were responsible for the secondary salinity;

(ii) the annual discharge of water and salt at the seep from the deep groundwater system was about 2800 kL and 17 tonnes respectively; and

(iii) the water-tables were not rising and that the most appropriate management of the site was to plant salt tolerant forage plants in combination with trees.

2. Introduction

A groundwater and salinity investigation was carried out between 1985 and 1990 on a small hillslope (75 ha) within the Warrengidging Brook catchment ('45,000 ha) south of Tammin (Figure 1). The investigation site was one of three study areas chosen by the author to investigate the role of perched and deeper groundwater systems as a factor in the development of dryland salinity in south-western Australia. The other study sites are located near Narrogin and Bruce Rock (George, 1990; George, 1991a, b; George and Conacher, 1991a, b).

The study site was selected in March 1985 following consultation with Mr Tom Sweeney (Department of Agriculture) and local landholders Messrs Uppill and Kitto. The site was required to:

(i) be relatively small;

(ii) be a well defined hillslope or sub-catchment;

(iii) have developed secondary salinity;

(iv) have predominantly duplex soils;

(v) fall within the ownership of one landholder; and

(vi) be representative of the problems of the region.

The role of the shallow and deeper groundwater systems in the development of dryland salinity was actively debated in the 1970's and early 1980's. While today there is almost unanimous agreement about the primary role of the deep aquifer, in the previous decades the point was hotly contested.

Conacher (1975) published a review of the farmers' and scientists' data, concluding that to that point, the final evidence of successful reclamation noted by some farmers after adopting waterlogging control measures, was more conclusive than assertions published by numerous authors in scientific publications. However, over the next five or six years, several important experimental programmes were concluded which clearly indicated that while the shallow or perched aquifer contributed the majority of water to a saline area, it accounted for only a fraction of the salt involved in the salinity problem (Williamson and Bettenay, 1979; Holmes and Taisma, 1981).

During the same period, Conacher (1982) restated the farmers' case for a predominant role being played by the shallow aquifer, while highlighting the conclusions of the experimental data noted above. However, in both papers Conacher (1975, 1982) made a distinction between the landscapes of the western areas where much of the research was conducted and the eastern regions. In particular, the limited role of vertical flow through indurated and clay-rich valley soils where little upward hydraulic head existed, was re-emphasized. Similarly, the common occurrence of duplex (sand over clay soils) profiles, regular winter waterlogging and throughflow, and farmers assertions of some success with banks, led Conacher to conclude that the banks must have been of some value.

While it took until recent times for Barrett-Lennard (1986) to demonstrate the interaction between salt and waterlogging, and scientists to show the role of the deeper aquifers, there still exists many unanswered questions over the interactions which occur between the perched aquifer and the deeper system.

As suggested above, this study was one of three which sought to describe the role of the perched aquifer in the wheatbelt. The other studies at Narrogin (George and Conacher, 1991a, b) and at East Belka (George, 1990 and George, 1991a, b) describe in more detail, interactions between the two aquifers than is done so here.

2.1 Aims

The aims of the research conducted on Kitto's hillslope were to:-

(i) assess the relative contribution of perched (shallow) and deep groundwater systems to the salinisation of soils;

(ii) to estimate the input of salt and water from both aquifers;

(iii) to determine the cause of salinity (geological features) and assess the distribution of salt storage within the landscape; and

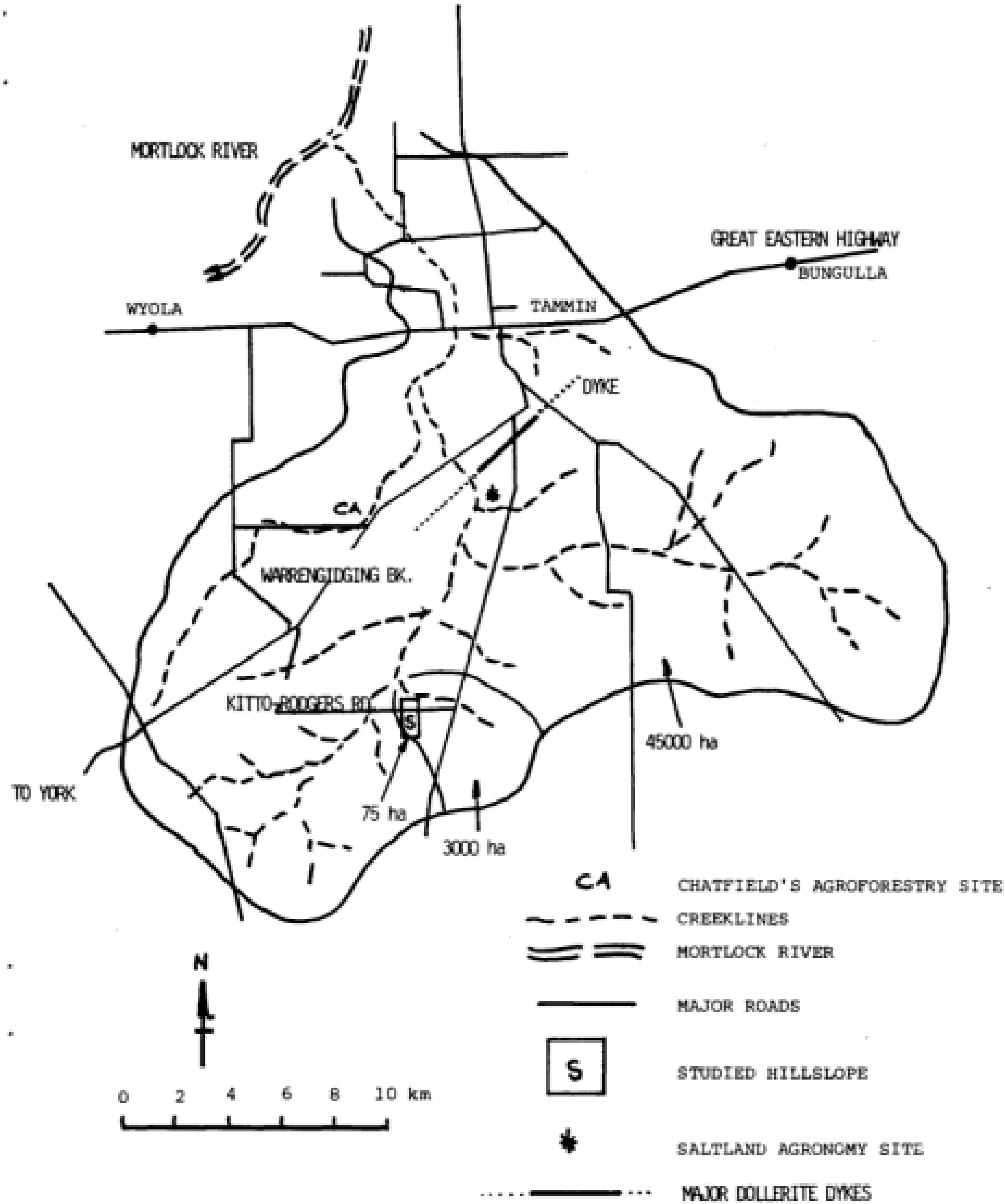
(iv) to monitor the change in piezometric and water-table levels of bores drilled on the hillslope.

At the end of the report, the data gathered from the project, and knowledge of salinity management systems used throughout the eastern and central wheatbelt regions, are used to present options for the management of the hillslope and saline area.

2.2 Location

The study site is located 12 km SSW of Tammin (31°46'S, 117°27'E) on Kitto-Rogers Road and is located in the Warrengidging Brook catchment (Figure 1). The hillslope has an area of approximately 75 ha, an average rainfall of 336 mm (1978-1989), potential evaporation of 2600 mm/yr and a northerly aspect. The hillslope drains towards an unnamed tributary of the Warrengidging Brook catchment. The tributary has a catchment of about 3000 ha and drains from the south-east towards the west. The Warrengidging Brook catchment has an area of over 45,000 ha and drains into the Mortlock River (East Branch) 10 km NW of Tammin.

FIGURE 1. LOCATION OF THE STUDIED HILLSLOPE WITHIN THE WARRENGIDG ING BROOK CATCHMENT



Dryland salinity is well developed on the lower 5 ha of the studied hillslope, along much of the unnamed tributary (several hundred hectares) and extensively (thousands of hectares) within the middle reaches of the Warrengidging Brook catchment. The area of dryland salinity is continuous from the hillslope studied, to just south of the Tammin to York, or Goldfields Road (Figure 1). At this point a large dyke can be observed striking SW-NE across the catchment. The dyke is associated with a narrowing of the catchment. Both features combine to form an extensive, waterlogged, eroded and saline valley landscape upstream. About 10% of the catchment above this point is affected by salinity.

2.3 Geology

The geology of the region has been briefly described by Chin (1986). Chin (1986) defines the region in which both the Warrengidging and hillslope catchments are located as lying within the Kellerberrin batholith, a large and relatively uniform senate adamellite. The adamellite is regularly traversed by SW-NE trending dykes of variable composition and width (< 1 m - 50 m). The adainellite, primarily composed of quartz, feldspar and micaceous minerals, is locally called "granite". The bedrock has been estimated to be approximately 2.8 billion years old (Chin, 1986). The in situ weathering products derived from the bedrock may be of a Tertiary age, while the valley and hillside sediments are predominantly of a Quaternary age.

Deeply-weathered lateritic materials (saprolite) ranging in depth from as little as 1 m, to at least 50 m, cover the basement (Engel et al., 1987). Within these materials occur at least four recognizable zones, whose distribution and composition vary across the wheatbelt region (George, unpublished data). Near the fresh bedrock, at depths of 10 to 50 m below ground level, occurs a coarse-textured, sand-like saprolite grit. This material is permeable and ranges in thickness from about 1 to 20 m.

Above this zone, a more weathered (1 to 10 m thick), clay-rich zone is found. Called the weathered zone, it differs from the overlying material, the pallid zone, by the limited degree of weathering of feldspar and mica. The pallid zone (10-30 m thick), by contrast has been intensely weathered. This white to buff coloured sandy clay is evident in many dams constructed throughout the catchment. Above the pallid zone, and usually occurring on the hillslopes, is a thin (1-5 m), mottled, sandy clay zone, which is itself overlain by gravel, sand or clay-textured surface soils (< 1 m thick). In some areas the sands can be very deep (1-9 m, sandplain) and host a perched aquifer responsible for dryland salinity (George, 1990; George, l99la, b).

The valley soils vary in texture from the heavy-textured clay soils in the lower reaches of the Warrengidging catchment (near Tammin), to sand-textured materials (often duplex profiles) in the middle of the catchment. Drilling conducted in similar valleys throughout the eastern wheatbelt, and the western tributary of the catchment (Chatfield's property) reveals deep sequences of sandy sediments. The depth of these valley sediments may range from 1-20 m. The sediments "fill-in" the valley, creating a very flat landscape prone to land degradation, especially salinity and waterlogging.

3. Methodology

3.1 Drilling

Drilling was carried out between April 15 and 18, 1985 using the Department of Agriculture's rotary auger drilling rig (Gemco HM7). Over this period, deep bore holes were also established on the major saltland agronomy site, 5 km SE of Tammin (Ward, Malcolm and Runciman - Department of Agriculture, Perth), just south of the major dyke on the Warrengidging Brook.

At Kitto's hillslope, nine piezometers were installed into the deeply-weathered materials at six sites (Figure 2). The piezometers were drilled in the middle of the gully draining the hillslope (north-south) and across the slope, immediately above the salt-affected area. Bores are labelled according to site and area name (eg. Tammin = T), position (N = north, E = east, etc) and depth installed. The depth of holes is indicated by the letters C (to bedrock), B (to an intermediate zone) and A (shallow onto clay beneath A-horizon soils). Shallow wells were installed on a 100 m grid across the hillslope, however, only ones installed at the top of the hillslope in deep sand ('l m deep) and those in the salt-affected area had water in them over the five year study period.

Piezometers were installed into a 100 mm hole at the completion of drilling. A one metre, hand slotted length of PVC pipe (40 mm) was joined to an appropriate length of PVC and lowered to the desired depth. Sand was then placed around the slots. The remainder of the annulus around the PVC was then back-filled with bentonite, cement and drill cuttings.

Piezometers were monitored on a monthly basis during 1985, which changed from bi-monthly to quarterly until 1989. No monitoring has been conducted since March 1989. Shallow wells were monitored monthly in 1985 and 1986, however, few ever developed water. A continuous water-level recorder was located immediately upslope from the salt-affected area, in soils considered likely to become waterlogged and contribute throughflow in wet years. However, the nature of the seasons, and occasional equipment failure, meant that no water-level data was obtained, apart from a knowledge of the duration of dry (no perched water) conditions.

The hydraulic conductivity (permeability) of the nine bores and shallow soils (12 sites) were determined from slug-tests (Bouwer and Rice, 1976) and constant-head permeameter tests (Reynolds et al., 1983).

3.2 Geophysics

3.2.1 Electromagnetics

An electromagnetic induction survey of the hillslope was conducted in 1986, using a Geonics EM34 and EM3]. terrain conductivity meters. The EM31 has a characteristic depth of influence of about 6 m, while in the orientation used, the EM34 had a depth of influence of 15 m (McNeill, 1980). Both EM instruments record how conductive the terrain is below the point of measurement. In Western Australian wheatbelt soils, a good relationship can be obtained between salt storage or profile salinity (< 6 to 15 m) and terrain conductivity from the EM machines (Engel et al., 1989).

A grid survey using five lines, 75 m apart and over a length of 2000 m (sampled every 20 m on each line) allowed a description of the patterns of salt storage to be obtained for the hillslope. The survey data was processed by the Geographic Information System group of the Department of Agriculture.

3.2.2 Magnetics

A ground magnetic survey of the hillslope was carried out on the same grid as that used for the electromagnetic survey. A portable Geometrics G8l6 proton precession magnetometer, with its sensor on a 2 m pole was used. The magnetometer was used to detect the location of dolerite (and other) dykes, observed elsewhere to be one of the many factors responsible for the location of saline areas (Engel et al., 1987). Magnetometers detect the highly magnetic characteristics of dolerite rocks. The dolerite materials usually occur as long (1-400 km), relatively thin (1-50 m) and linear intrusions through the bedrock.

They may be either positively or negatively polarized depending on the timing of their intrusion into the bedrock and the polarity of the earth at that time. Deep-weathering of these materials results in a material of lower permeability than the surrounding weathered materials developed from granites. When groundwaters flow up against these barriers, water-tables and pressures within the aquifer may rise, eventually causing groundwater discharge and salinity to occur.

3.3 Salinity Measurements

Soil samples were taken across the saline area and hillslope along a central transect to determine the salt content (as electrical conductivity ECe, EC 1:5 and Chloride %) and pH of the soils. Water samples were analysed by the Chemical Centre of Western Australia for the major elements. Soil samples were analysed by the Department of Agriculture and the author at the University of Western Australia.

4. Results

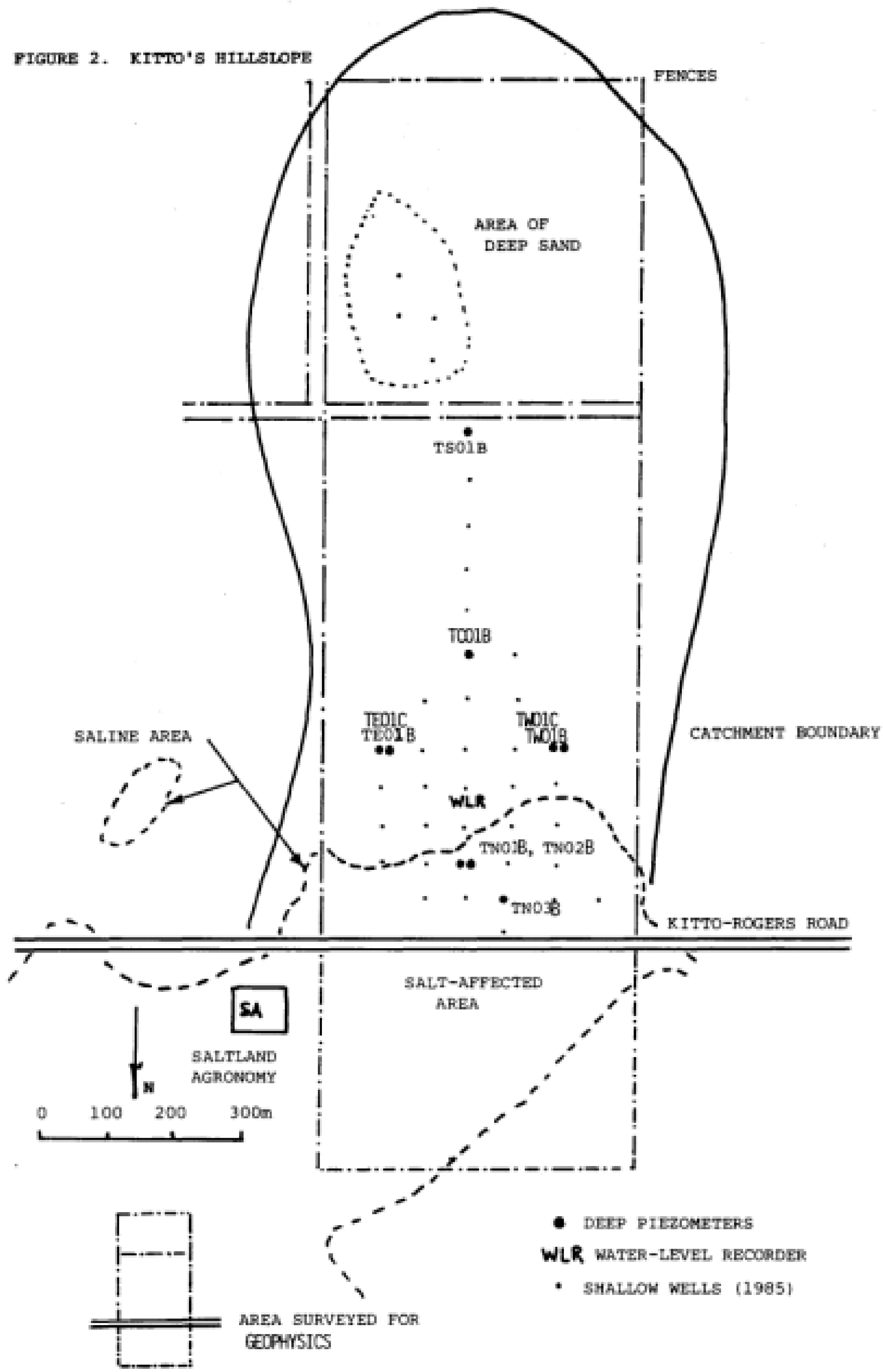
4.1 Drilling

Nine deep holes were drilled on the hillslope (Figure 2). The following notes briefly summarize the materials encountered at each site drilled.

TEO1C and TEO1B (Depths 21.97 and 8.45 m)

0.0- 0.3m	Sandy surfaced A-horizon, ironstone pebbles at depth.
0.3- 5.0m	Mottled sand clay. Iron-rich zone.
5.0- 6.0m	Contact between mottled, sandy clay and pallid zone.
6.0-18.0m	Pallid zone, white kaolinite-rich, sandy clay.
18.0-22.0m	Saprolite grits, coarse-textured, gritty sand.
22.0 m	Bedrock.

FIGURE 2. KITTO'S HILLSLOPE



TWO1C and TWO1B (Depths 19.57 and 6.00 m)

0.0- 0.2m	Sandy surfaced A-horizon, limited gravels.
0.2- 4.5m	Mottled, red-brown, Bandy clay. Iron-rich zones.
4.5- 5.0m	Contact between mottled and pallid zones.
5.0-18.0m	Pallid zone, white sandy clay.
18.0-20.0m	Saprolite grits, coarse-textured, gritty sand.
20.0 m	Bedrock.

TNO1B, TNO2B and TNO3B (Depths 1.80, 10.75 and 3.00 m)

0.0-0.4m	Sandy A-horizon.
0.4-1.6m	Mottled, grey, Bandy clay.
1.6-11.0m	Sandy, pale coloured materials. Augers make interpretation difficult. Probable pallid zone, however, sediments possible on northern edge of site.

TCO1B (Depth 9.65 m)

0.0-0.4m	Sandy surfaced A-horizon.
0.4-4.0m	Mottled, sandy clay, lower 2 m grading into pallid materials.
4.0-10.0m	Pallid zone.

TSO1B (Depth 5.12 m)

0.0-0.7m	Sandy surfaced, deeper A-horizon.
0.7-4.0m	Mottled, sandy clay.
4.0-5.0m	Hardpan - very hard to drill; perhaps bedrock, unknown? Siliceous zones throughout.

Apart from the unusual siliceous materials at TSO1B, the profiles drilled conformed to the standard, deep-weathered classification described in Section 3.0. The profile is dominated by the relatively clay-textured materials of the pallid and mottled zones. At the deep holes TEO1C and TWO1C the saprolite grits were thought to be clay-textured when drilled. However, later observations made at the Wallatin Creek and North Baandee catchments, indicated that the auger rig confuses the classification. The result is that the materials encountered were more likely to be coarse, sandy materials, with sufficient clay contamination to confuse interpretation during drilling.

4.1.1 Hydraulic Properties

Each of the boreholes were tested to determine the hydraulic conductivity of the aquifer and aquitard materials at the site. The test involved removing a volume of water (5 to 10 L) and measuring the recovery of the water-level within the bore. The results are presented in Table 1.

TABLE 1. HYDRAULIC CONDUCTIVITY OF AQUIFER AND SOILS

Bore Site #		Hydraulic Conductivity * (m/day)	Zone Slotted #
TEO1	C	0.06	Saprolite
	B	0.007	Pallid
TW01	C	0.07	Saprolite
	B	0.009	Pallid
TC01	B	0.004	Pallid/Sediments
TN01	B	0.06	Pallid/Sediments
TN02	B	0.009	Pallid
12 Shallow Sites (**)		0.65	A-horizon

* Saprolite and pallid zone permeability near the borehole is likely to have been reduced as a result of drilling method used.

** Shallow soil sites located randomly across the hillslope.

The measured hydraulic conductivities are likely to be an order of magnitude lower than the actual values as a result of the drilling method used (George, 1989). Results from drilling bores using an airblast rig throughout the Eastern and Central wheatbelt, revealed that the mean hydraulic conductivity of the pallid zone was 0.065 m/day, while the saprolite grits had a higher value of 0.57 m/day. Comparative studies showed that when using the auger rig, the results showed a mean hydraulic conductivity of only 0.009 and 0.057 m/day, respectively (George, 1989). The mean hydraulic conductivity of the shallow, A-horizon soils at the site was 0.65 m/day.

The vertical hydraulic gradient between bores TNO1 and TNO2, located in the salt-affected area, varied between 0.01 and 0.03 (upward flow) in summer and -0.01 (downward flow) following prolonged periods of rain during winter.

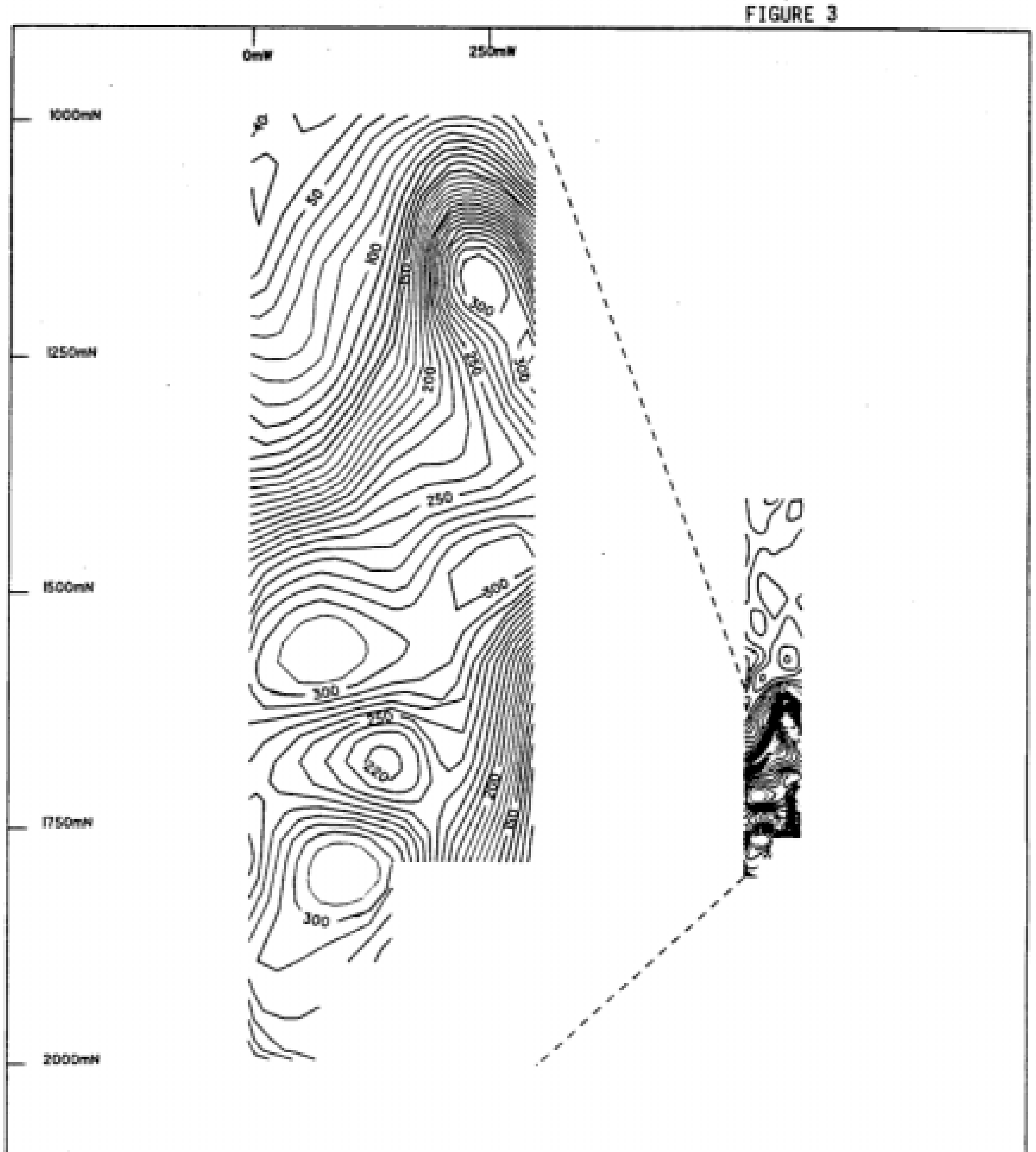
These estimates, corrected for the effects of differing groundwater salinities (densities) but not barometric efficiencies, indicate that the discharge area can also be a source of recharge to the water-table after winter rains. This would enhance waterlogging and mobilize salts stored near the soil surface, allowing both for their removal and dilution as shown in Tables 2 and 3 (Section 4.3).

4.2 Geophysics

4.2.1 Electromagnetics

The results of the electromagnetics surveys are presented in Figure 3 (EM31) and Figure 4 (EM34) and summarized in Figure 6. Both show an area of high salt storage, with an apparent electrical conductivity greater than 80 mS/m within the salt-affected area. The salt store peaks in the area upslope from the road which bisects the hillslope (valley soils) around 1400 metres North (mN).

FIGURE 3



TAMMIN CATCHMENT

ELECTROMAGNETIC SURVEY

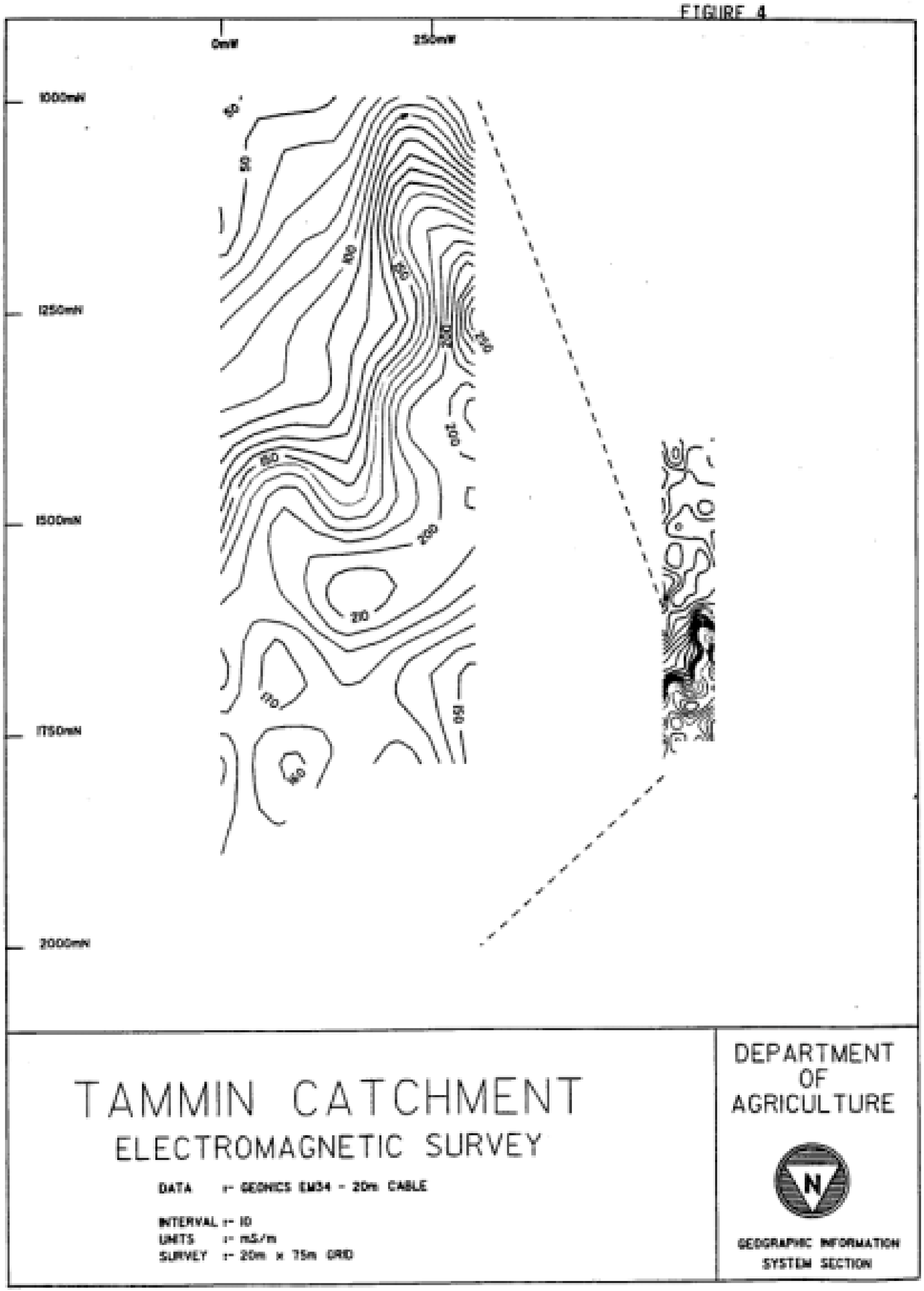
DATA :- GEONICS EM31

INTERVAL :- 10
UNITS :- mS/m
SURVEY :- 20m x 75m GRID

DEPARTMENT OF AGRICULTURE

GEOGRAPHIC INFORMATION SYSTEM SECTION

FIGURE 4


0mW
250mW
1000mN
1250mN
1500mN
1750mN
2000mN
TAMMIN CATCHMENT
ELECTROMAGNETIC SURVEY
DATA :- GEONICS EM34 - 20m CABLE
INTERVAL :- 10
UNITS :- mS/m
SURVEY :- 20m x 75m GRID
DEPARTMENT
OF
AGRICULTURE
GEOGRAPHIC INFORMATION
SYSTEM SECTION

Upslope and away from the salt-affected area, the average terrain conductivity readings are less than 30 mS/m. In these areas salt storages are likely to be very low, reflecting it being a recharge zone rather than a discharge zone. Values of 10 to 20 mS/m were obtained in an area of deep (-1 m) sand on the SE corner of the hillslope. Fresh, perched waters were noted to develop (above the hardpan) in this area briefly (1 to 10 days) each winter after heavy rainfalls.

Throughout the salt-affected area the EM31 indicated apparent terrain conductivity values of up to 320 mS/m, peaking at the base of the hillslope (1150 m N - 250 m W) and both north and south of the dolerite dyke (Figure 5). Across the dyke, and to the west of it, (not shown on Figure 6) terrain conductivities fall to 100 to 150 mS/m. By contrast, the EM34 indicates higher salt storage upslope of the dyke and lower values downslope and to the west.

Interpretation of the data suggest high values shown downslope of the dyke by the EM31 (300 mS/m) reflect near surface salt storage (0-6 m), associated with dryland salinity. By contrast, the lower EM34 values indicate a low storage deeper in the profile. This may reflect the existence of permeable sediments in the near-surface zone and the role of the dyke as a groundwater barrier.

4.2.2 Magnetics

Only one major anomaly was shown to occur on the hillslope and adjoining valley. The dolerite dyke, a wide (.50 m) negatively polarized anomaly (800 nT lower than surrounding rocks) runs east-west across the catchment, along the 1650 m N line (Figures 5 and 6). The effect of the dolerite dyke is indicated by a reduction in salt storage on (EM31) and below (EM34) the dyke, and an increase in salt storage upslope (EM31). The fence-lines and roadways produced small anomalies (Figure 6).

FIGURE 5

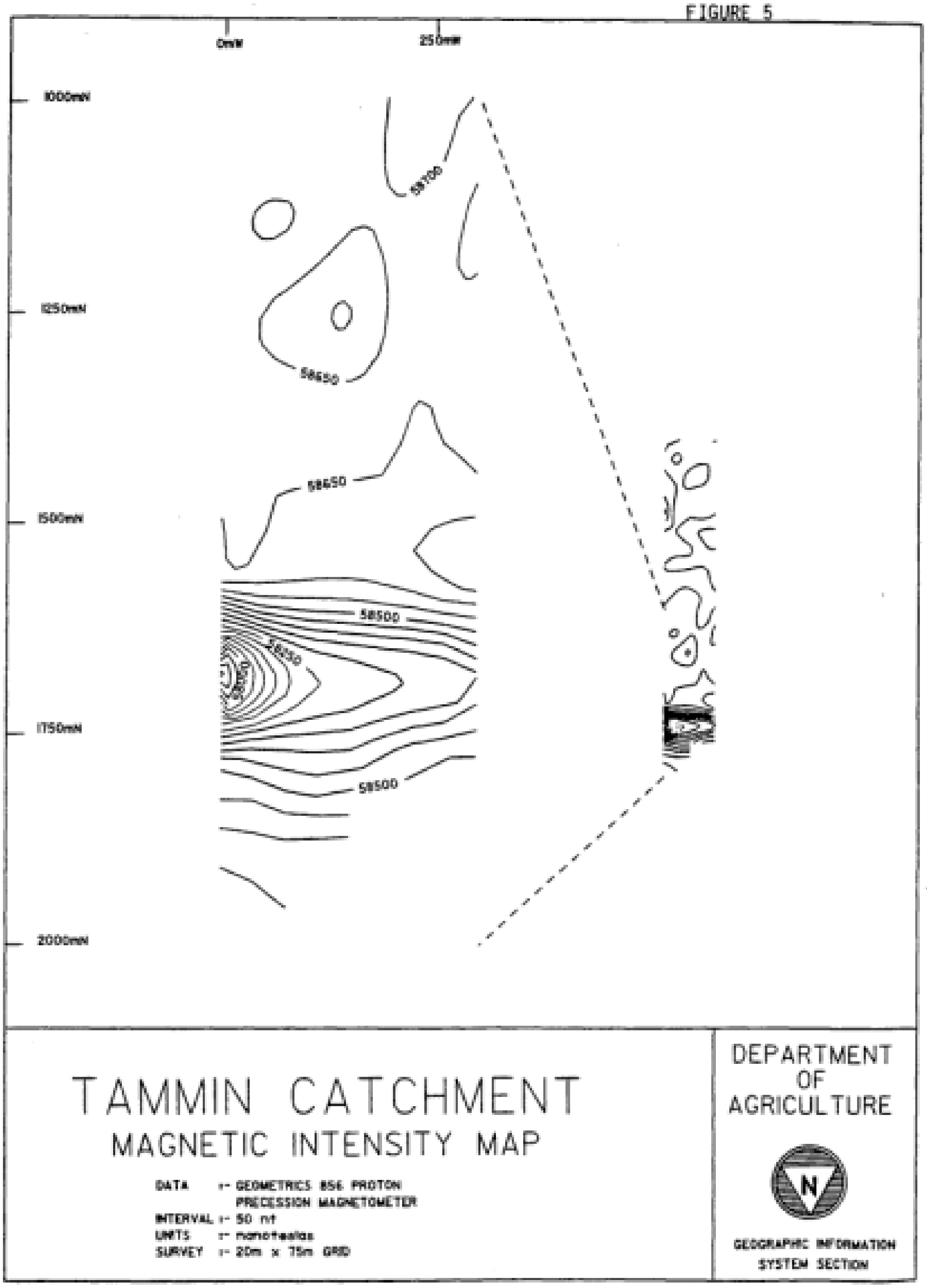
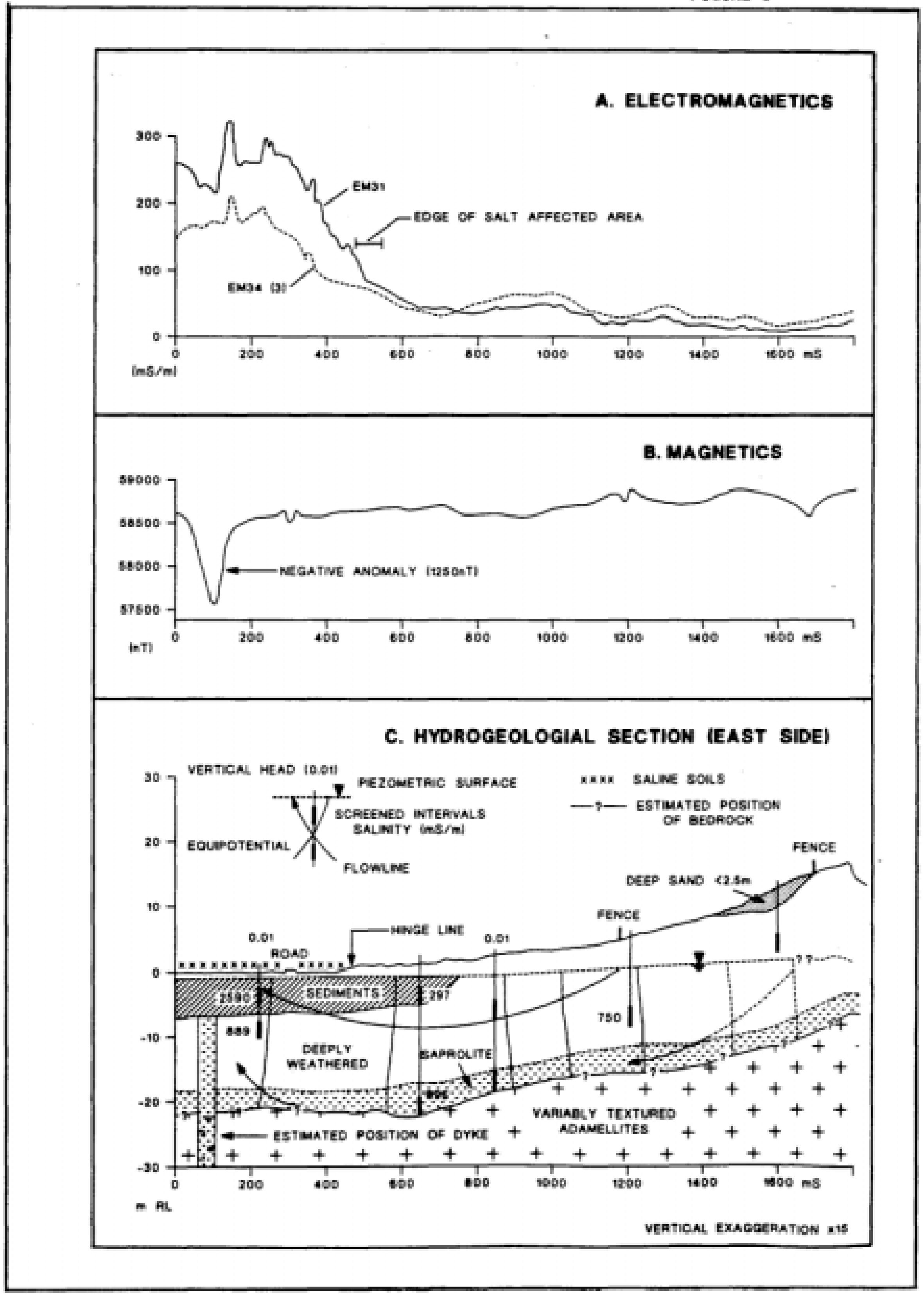

0mW
250mW
1000mN
1250mN
1500mN
1750mN
2000mN
58700
58650
58650
58500
58500
TAMMIN CATCHMENT
MAGNETIC INTENSITY MAP
DATA :- GEOMETRICS 856 PROTON PRECESSION MAGNETOMETER
INTERVAL :- 50 nt
UNITS :- nanoteslas
SURVEY :- 20m x 75m GRID
DEPARTMENT OF AGRICULTURE
GEOGRAPHIC INFORMATION SYSTEM SECTION

FIGURE 6


A. ELECTROMAGNETICS
EM31
EDGE OF SALT AFFECTED AREA
EM34 (3)
(mS/m)
0
100
200
300
0 200 400 600 800 1000 1200 1400 1600 mS
B. MAGNETICS
NEGATIVE ANOMALY (1250nT)
(nT)
57500
58000
58500
59000
0 200 400 600 800 1000 1200 1400 1600 mS
C. HYDROGEOLOGIAL SECTION (EAST SIDE)
VERTICAL HEAD (0.01)
PIEZOMETRIC SURFACE
SCREENED INTERVALS
SALINITY (mS/m)
EQUIPOTENTIAL
FLOWLINE
xxxx SALINE SOILS
ESTIMATED POSITION OF BEDROCK
FENCE
DEEP SAND <2.5m
FENCE
HINGE LINE
0.01
ROAD
0.01
SEDIMENTS
2590
297
689
750
DEEPLY WEATHERED
SAPROLITE
VARIABLY TEXTURED ADAMELLITES
ESTIMATED POSITION OF DYKE
-30
-20
-10
0
10
20
30
0 200 400 600 800 1000 1200 1400 1600 mS
m RL
VERTICAL EXAGGERATION x15

4.3 Salinity of Soils and Waters

4.3.1 Soil Salinity

Soil samples were taken on a transect down the centre of the hillslope (along the hydraulic section - Figure 6) from south of TSO1B to the Kitto-Rogers Road. Samples were taken at depths of 5 cm, 10 cm, 20 cm, 30 cm or 50 cm depending on the depth to the clay-rich subsoil. The results of the sampling carried out in April 1987 are presented in Table 2.

Results suggests that the hilltop to lower-slope soils contain very little salt in either the sandy A-horizon or clay B-horizon. Values of electrical conductivity range from only 1 to 7 mS/m, and would have no effects on the growth of crops or pastures. The pH is relatively consistent (5.0-6.0) and again would not limit agricultural production.

TABLE 2. SOIL SAMPLES - HILLSLOPE TRANSECT

Hillslope Position	**Sample Number**	**Depth (cm)**	**PH (H2O)**	**EC 1:5* (ms/m)**	**C1 (%)****	**Sat (%)*****	**Ece (ms/m)**
Hilltop (0m)	T1	5	5.2	4	< 0.01	31.7	35
		15	5.6	2	"	30.7	N/A
Hilltop (100m)	T2	5	6.4	5	<0.01	32.2	39
		20	6.1	3	"	29.7	30
Hilltop (200m)	T3	5	5.4	4	<0.01	33.6	N/A
		20	5.6	3	"	31.6	31
Upper-slope (300m)	T4	10	5.5	6	<0.01	34.1	75
		20	5.4	2	"	31.4	19
Upper-slope (400m)	T5	5	5.2	7	<0.01	38.3	N/A
		15	5.5	4	"	33.5	6
Upper-slope (500m)	T6	5	5.4	4	<0.01	38.5	N/A
		10	5.4	3	"	34.5	N/A
Mid-slope (600m)	T7	5	5.2	4	<0.01	32.7	N/A
		20	5.1	3	"	26.0	26
		30	5.6	2	"	29.5	17
		50	6.3	2	"	33.0	18

Hillslope Position	Sample Number	Depth (cm)	PH (H2O)	EC 1:5* (ms/m)	C1 (%)**	Sat (%)***	Ece (ms/m)
Mid-slope (700m)	T8	5	5.6	4	<0.01	28.5	40
		20	5.2	2	"	22.0	26
		40	5.9	2	"	27.1	17
Mid-slope (800m)	T9	5	6.1	7	<0.01	36.5	N/A
		20	5.5	2	"	24.7	16
		50	6.3	3	"	28.7	41
Mid-slope (900m)	T10	5	5.9	7	<0.01	32.5	N/A
		10	6.7	3	"	24.3	21
		20	5.4	3	"	21.3	24
		50	5.3	1	"	23.1	15
Lower-slope (1000m)	T11	5	5.4	3	<0.01	29.5	N/A
		20	5.7	2	"	34.0	15
Lower-slope (1100m)	T12	5	5.6	4	<0.01	32.1	N/A
		20	5.4	3	"	29.1	27
Lower-slope (1200m)	T13	5	5.2	6	<0.01	31.5	59
		20	5.4	3	"	26.5	34
		30	6.1	5	"	30.3	N/A
Saline area (1300m)	T14	5	6.1	178	0.22	25.4	2430
		20	7.1	54	0.07	20.4	770
		35	7.1	86	0.11	19.0	1497
Saline area (1400m)	T15	5	5.7	95	0.14	23.4	1416
		20	5.4	52	0.07	16.9	1012
Saline area (1500m)	T16	5	6.5	308	0.46	29.8	-
		20	5.3	46	0.06	16.6	980
		35	5.2	105	0.15	19.0	1882
S. Roadway (1600m)	T17	5	8.3	275	0.39	27.9	3400
		20	7.9	214	0.30	22.2	3610

N/A Not assessed.

* EC Electrical Conductivity (ECe of extract - mS/m).

** % Chloride by weight in sample.

*** Saturation %.

By contrast, soils in the area (T14-T17) are very saline in the 0-5 cm zone, but have considerably less salt at greater depths. Concentration by evaporation is indicated by the high values near the soil surface. Electrical conductivity (BC 1:5) values of over 80 mS/m could limit cropping for wheat. Values of over 120 mS/m could restrict the production of barley. When combined with waterlogging, lower salinities could also result in a loss of production.

Soil samples were also taken during the middle of February 1986 (February 16-17) after a period of approximately 100 days with only 2mm of rainfall. Four samples were collected from 0-5 cm on areas of saline land at points later to be sampled as Tl4, T15, T16 and T17 (Table 2). Samples were also collected at five sites on the upper-slopes, in an area of deep sand. These samples were taken from 0-10 cm at sites near T4 to TB. The results are presented in Table 3.

TABLE 3. SAMPLES TAKEN IN FEBRUARY 1986 ON THE SALINE AREA AND DEEP SAND UPSLOPE

SITE (Equivalent to Table 2)	**PH**	**EC 1:5**	**Depth (cm)**
T14	6.94	1091	0-5
T15	7.03	747	0-5
T16	6.46	715	0-5
Tl7	5.04	700	0-5
T4	6.23	5.2	0-10
T5	6.78	7.6	0-10
T6	6.99	14.2	0-10
T7	6.99	4.5	0-10
TB	7.01	4.8	0-10

The results indicated an increase in salt content of the 0-5 cm zone in the saline area over summer by a factor of 2 to 3 over the April 1987 samples (Table 2). Concentration due to evaporation is evident. In the upslope areas, the salt concentrations are approximately the same as those taken in April 1987.

4.3.2 Water Salinity

The waters are dominated by chloride, sodium, sulphate and magnesium (Table 4). They are high in silica and have a neutral pH. The sites upslope from the saline area (TE and TW) are of a quality suitable for livestock. In the saline area, the shallower bore (TNO1B) has a significantly higher salinity than that which occurs at depth. Like the soil samples (Tables 2 and 3), evaporative concentration is responsible for this increase as a result of groundwater discharge at the site. It could be expected that the water quality in the 0 to 6 m zone within the salt-affected area will continue to decline with time. This process may also affect deeper groundwaters.

TABLE 4. WATER CHEMISTRY OF SIX DEEP BORES AT THE HILLSLOPE

SITE	pH	EC (ms/m)	TDS* (mg/L**)	Ca**	Mg	Na	K	C1	SO_4	NO_4	SiO_2	Br
TE01B	7.0	297	1610	3	22	560	14	791	62	20	71	2.6
TE01C	6.7	896	5000	18	149	1640	46	2720	307	4	66	9.0
TTW01B	7.2	1710	9830	41	208	3440	65	5210	594	3	74	19.0
TW01C	6.7	1210	6730	25	185	2250	51	3640	440	5	74	14.0
TW01B	7.7	2590	16800	114	592	5250	69	8310	2300	3	44	20.0
TW02B	7.1	889	4870	22	111	1660	39	2670	234	2	77	9.4

* TDS - Total Dissolved Salts (milligrams per litre - mg/L)

** Ca = Calcium; Mg = Magnesium; Na = Sodium; K = Potassium; Cl = Chloride; SO_4 = Sulphate; NO_3 = Nitrate; $Si0_2$ = Silica; Br = Bromide (all in mg/L)

4.4 Hydrographs

Groundwater levels monitored from the nine bores installed on the hillslope are presented in Figures 3 to 9. The hydrographs show a pronounced rise in water-levels in 1986 and a smaller rise in 1988. Observations of the four to five year period indicate that there is no clear upward or downward trend in groundwater levels. This suggests that hillslope recharge and discharge may have been in equilibrium during the period of the investigation.

5. Discussion

5.1 Salt and Water Balance

In order to quantify the role of the perched and deeper aquifers, observations on the hydraulic conductivity (K) of the A-horizon, pallid and saprolite zones were made. Additional measurements relating to the thickness (b) and width (W) of each material and hydraulic gradient (i slope on the water-table or piezometric surface) were also made. Using the groundwater flow equation, Q = Kb x W x i, an estimate of the annual deep groundwater flow (Q) was made.

The average transmissivity (T = Kb) of the aquifer system was calculated from values of hydraulic conductivity obtained from the region, as use of the auger rig at the site meant that the local values were likely to be inaccurate. A value of 2 m/day was chosen on the basis of experience at a similar site north of Kellerberrin (George and Frantorn, 1990). By multiplying the average transmissivity of the aquifer (2 m^2/day) by the width of the hillslope contributing groundwater to the salt-affected area (300 m) and by the average hydraulic gradient (slope of water-table) 0.013, an estimated flux of 7.8 kL/day (7800 litres) is obtained. Therefore, an average flow of about 2800 kL passes into the salt-affected area each year.

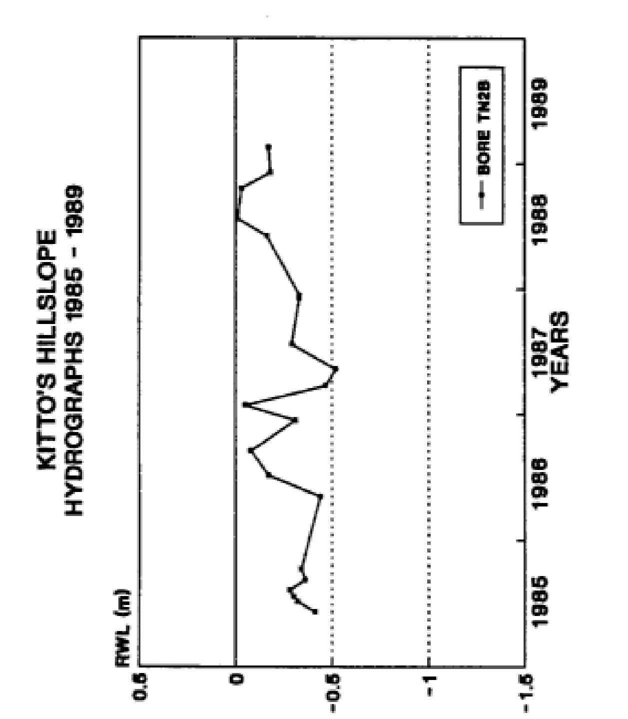
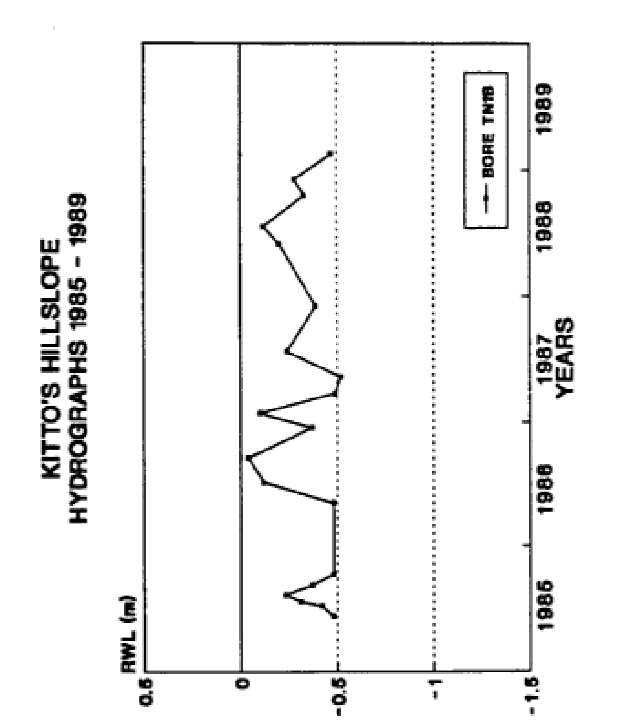
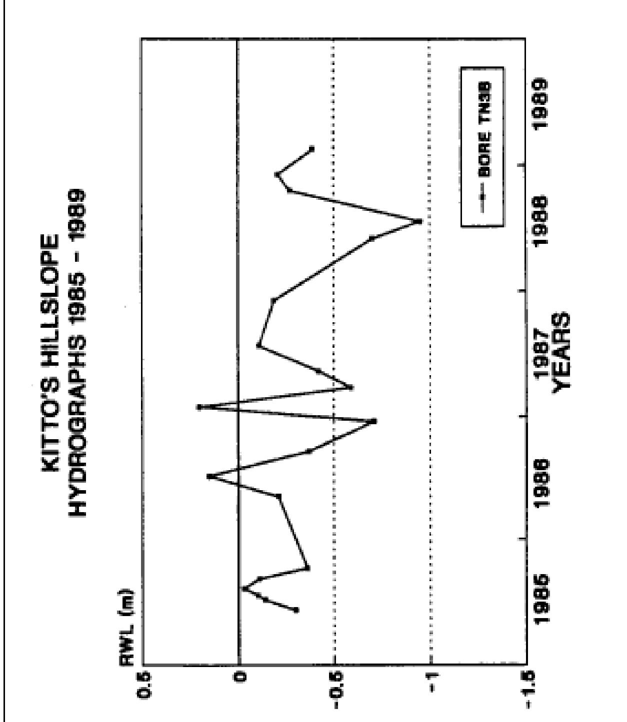


FIGURE 7: Hydrographs of bores installed in the salt affected area.





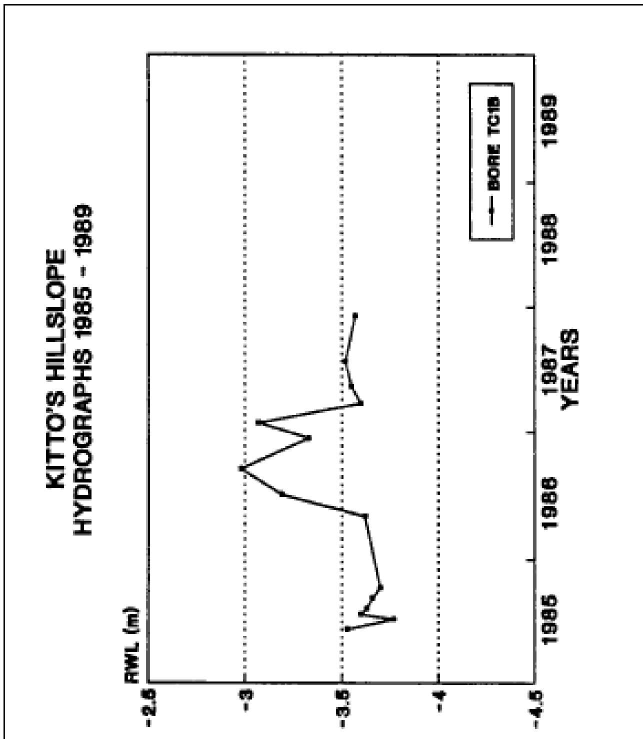
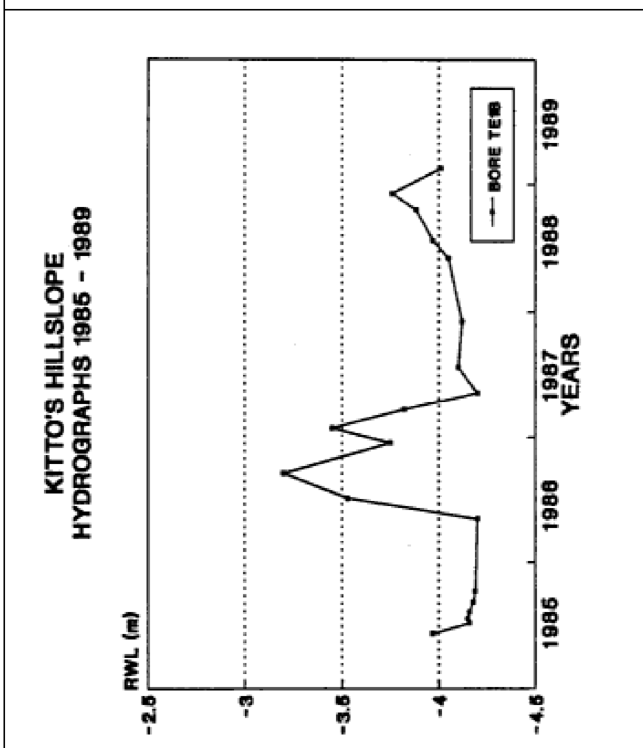
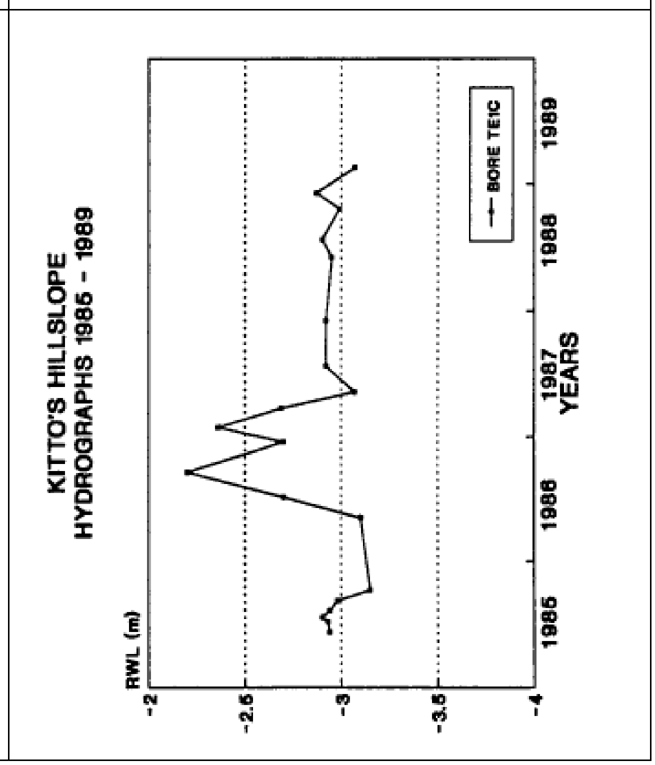


FIGURE 8: Hydrographs of bores installed on the eastern and central part of the hillslope





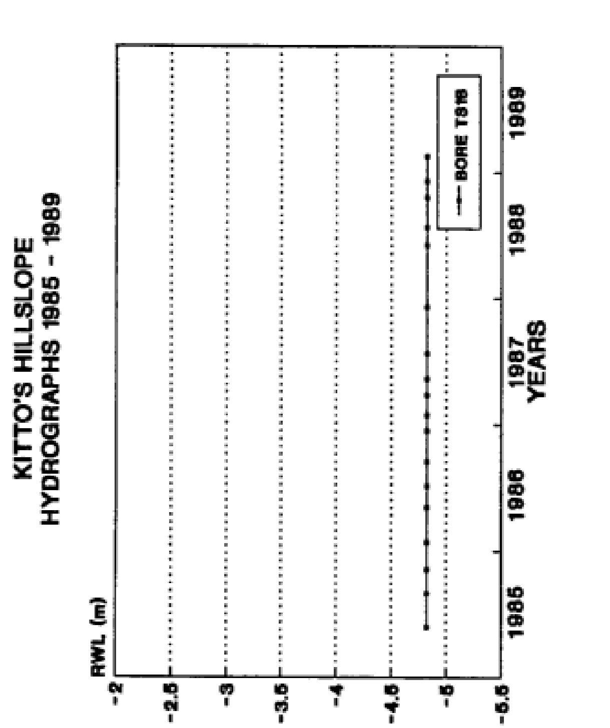
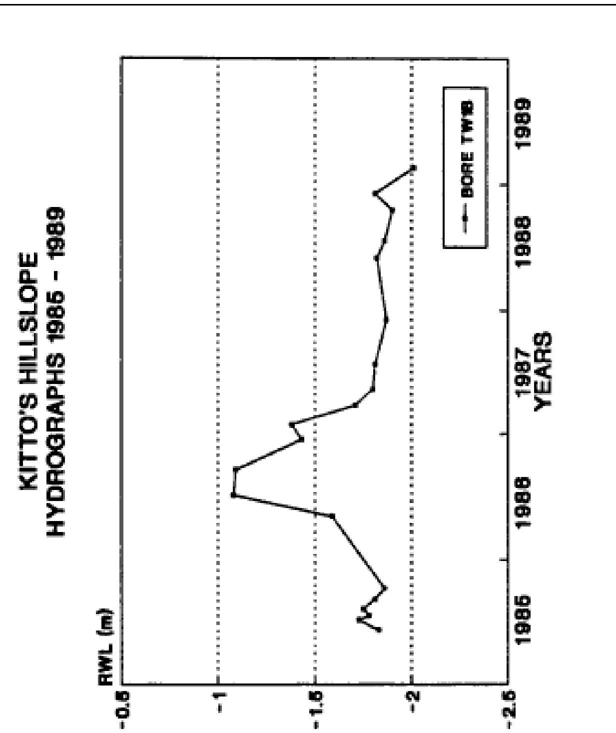
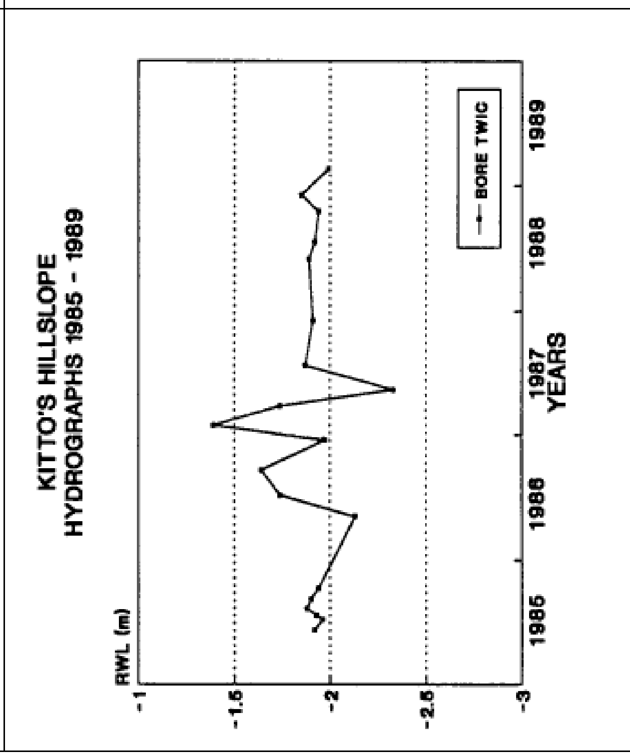


FIGURE 9: Hydrographs of bores installed on the western and southern portion of the hillslope.





By dividing the annual flow (2800 kL) by the size of the recharge area (75 ha) a mean annual recharge rate of 4 mm is achieved. Similarly, by multiplying the annual discharge (2800 kL) by the average groundwater quality of the deep aquifer ('.6000 mg/L - TNO2B, TEO1C and TWO1C) and dividing the discharge by the size of the discharge area (-10 ha) an annual flux of approximately 17 tonnes of salt is estimated to enter the saline area each year, while approximately 30 mm of discharge is required to balance the incoming recharge.

An alternative method of estimating the groundwater discharge rate can be obtained by calculating the vertical discharge rate. Multiplying the average vertical hydraulic gradient for the year (say 0.02 - Section 4.1), by the lowest permeability of the materials through which the groundwaters must pass to get to the soil surface (0.009 m/day - Table 1), a discharge rate of 0.066 m/yr or 66 mm/yr is obtained.

Given the difficulties in estimating an average vertical gradient and hydraulic conductivity, the estimated groundwater discharge rate could range between 30 mm/yr (vertical gradient 0.01, hydraulic conductivity 0.009 m/day) and 400 mm/yr (vertical gradient 0.02, hydraulic conductivity 0.06 m/day). The lowest rate compares favourably with the water balance estimate based on the calculation of horizontal flow (above), while the upper estimate would require an increase in recharge and groundwater transmission by a factor of ten. Given the physical constraints on groundwater flow caused by the low hydraulic gradients and hydraulic conductivities, a higher rate of transmission appears unlikely. At the discharge rates suggested (30 to 60 mm/yr), it requires less than 4% of the annual potential evaporation rate (2600 mm/yr) to provide the energy required to induce discharge. Similarly, evidence that the water-levels in monitored bores drops rapidly in summer (Figure 6) strengthens this argument.

Salt transport from the deeper groundwaters in the salt-affected area towards the soil surface (TNO2 - Table 4) of waters of 5000 mg/L, at an average discharge rate of 50 mm/yr, would allow the discharge of 0.25 kg/rn^2 of salt. At this rate, if 10% of the Warrengidging Brook catchment was salt-affected, approximately 11,000 tons of salt would be annually made available at the soil surface for removal to the drainage lines, or for concentration in the near-surface soils or root-zone. Given these conditions, salt concentrations would build rapidly during years of no dilution and significant run-off, and leach or be removed after very wet seasons. The near permanent condition of upward flow would quickly replace salts removed during wet periods.

Since little or no (detected) flow was recorded in the perched aquifer in the area immediately above the seep, its contribution to the water and salt balance at <u>this</u> site was negligible in the years studied. By contrast, the deep groundwater's role indicates the importance of this system in the development of secondary salinity.

6. Management Options

Management of the hillslope and salt-affected area can be undertaken with on-site (discharge area) and off-site (recharge area) control measures. The following notes summarize the preferred options for the hillslope.

6.1 On-site Options

The soil salinities (EC - Table 2) across the saline area range between 700 and 1100 mS/m in summer, reducing to between 100 and 300 mS/m in winter. At these levels, only salt tolerant plant species can survive. Saltland agronomy experiments nearby (middle of Warrengidging Brook catchment - 10 km north) suggest halophytes such as Atriplex amnicola, A.cinerea, A.undulata and A.lentiformus have grown very well on similar soils, with similar salinities.

Establishment of these species, especially A.amnicola, using a hand planter, along ripped (> 0.5 m), mounded and fertilized lines, on a 5 m by 5 m grid (400 plants per hectare), across the saline area (5 ha) would provide a significant amount of grazing value after 12 to 18 months of growth. After two to three years, the salt-affected land should have a similar production to that of a conventional pasture, if used during autumn and early winter.

As waterlogging is likely to be a problem in low-lying areas, establishment of the saltbush on mounds (0.25 m) is recommended. At BC levels of between 200 and 350 mS/m, and with frequent waterlogging, establishment without mounding would be poor. Higher areas within the salt-affected area could also be mounded (0.25-0.75 m) and salt tolerant Eucalypts established. Evidence from nearby sites suggest that Eucalyptus sarpentii, E.spathulata, E.camaldulensis, E.loxophleba, E.salicola, E.occidentalis, E.kondininensis, Casuarina obesa and Acacia saligna may be able to grow well. Planted in strips, of three to four lines of trees per strip and at a spacing of 30 m to 50 m between strips, the trees' groundwater consumption may help lower the water-table. Research into this 'agroforestry" method of salinity control is currently underway at the Chatfield's property, on Quinn-Rogers' Road, 10 km NW of the hillslope.

Drainage to prevent surface pending, waterlogging and flow onto the site from the hillslope above is highly recommended, as is the establishment of adequate fencing to ensure grazing of the saltbush can be managed. The type of drains recommended are grader-built seepage interceptors immediately above the seep and a main W-drain, connected to a downstream outlet.

6.2 0ff-site Options

Immediately above the saline area, in the first 50 m of non-saline soils, a five to eight row belt of high-water use, salt tolerant (West side) and non-salt tolerant trees (East side) could be planted to intercept some of the groundwater flowing from the hillslope above.

Inclusion of other species, (eg. E.cladocalyx nana), to those mentioned above and ones from the locality is recommended. This block may incorporate approximately 500 to 800 trees and shrubs.

Upslope from the tree belt, the aim is to improve plant water-use and thus reduce recharge. Cropping, for example, using a lupin-wheat rotation appears suitable and has been practiced since the early 1980's at the site. In the area of deeper sands (1 m) at the top of the hillslope (south-east corner) tagasaste could be established to increase the water-use and provide an area for summer and autumn grazing.

Additional measures such as establishing a belt of three to five rows of trees on the side of the laneways and fencing off the existing stands of trees (E.wandoo) should also be undertaken. Groundwater extraction for stock is possible in the mid to lower-slopes on the eastern hillslope, and would lessen the amount of groundwater entering the saline area. A low yielding (< 10 kL/day) bore could be drilled and cased for approximately $2000.

7. Conclusions

The salt-affected area developed on the experiment site, Kitto's hillslope, iB typical of many other hillslope-valley floor sites in the region. Groundwater (2800 kL/yr) developed from recharge on the slopes (-4 mm/yr) is transported, along with 17 tonnes of salt, into the saline area each year. Soil salinities of up to 1100 mS/m (ECe) occur in summer in the 0-5 cm zone, but decrease rapidly with depth. Similarly, groundwaters are very saline near the surface but are less saline at depth.

Electromagnetic and magnetic surveys revealed a high salt storage in the saline area and the existence of a dolerite dyke. Four years of water-level observations indicate that the catchment may have come to equilibrium and the groundwaters on the hillslope stabilized.

Management of the site should include a combination of saltland agronomy and tree planting on the saline soils, tree planting upslope of the seep and high water-use rotations. Drainage measures, including surface controls (W - drains, countour banks) deep aquifer controls (pumping for stock supplies) and fencing should also be undertaken.

Groundwater level monitoring within the hillslope should be continued for another five to ten years, on a bi-annual basis. Monitoring in mid-winter and at the end of summer should provide a record of the highest and lowest levels of the year. Monitoring should continue so that the effects of wet years can be established.

The site could provide a good location for a small, salinity management project for the local Land Conservation Group.

8. Acknowledgements

The project was undertaken while a student under the supervision of Assoc. Prof. A.J. Conacher and with the assistance of Dr Bob Nulsen (Department of Agriculture). In 1985 I began employment at Merredin (Department of Agriculture) and continued some investigations and monitoring. I would like to thank Allan Kitto for use of the site and his encouragement, and Dennis and Jos Chatfield for encouraging me to write up the results of the studies for the local Land Conservation Group. Dr Don McFarlane and Fay Lewis of the Catchment Hydrology group and Wendy Dymond, Regional Project Officer, kindly reviewed the manuscript.

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