Department of Conservation
and Land Management, W.A.

Peel-Harvey Catchment Demonstration Farm Hydrological Study Under National Afforestation Program Project 15

To

DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY, CANBERRA

PRELIMINARY REPORT
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1. INTRODUCTION:

1.1 The National Afforestation Programme

This project has been funded principally by the Federal Government through the National Afforestation Programme (Project 15) which has the aim of encouraging investment in forests. Extra contributions have been from the Water Authority of Western Australia and Departments of Agriculture, and Conservation and Land Management. It would not be possible without the co-operation of the property owners Richard and Aldo Caratti.

The NAP program in W.A. involves trial plantings throughout the south-west from Perth Metropolitan Area to the Albany area. It is hoped to encourage the use of trees for restoration of environmentally degraded areas such as the salt affected lands and eutrophic estuaries. This is the thrust of our project in the Peel-Harvey catchment and the upper Denmark catchment. The emphasis of the planting programme is on Eucalyptus Globulus for its potential as a paper-pulp crop, and hence commercial interest, although other species are planted where thought appropriate.

1.1.1 Hydrology Programme - (Peel-Harvey & Upper Denmark)

The NAP programme includes experimental catchment studies in two areas with water degradation problems. The problem of excess algal growth in the Peel-Harvey Estuary is now well known in W.A. It is resultant from excess nutrient applied as superphosphate fertilizer on the leaching sands of the coastal plain portion of the estuary catchment. A change of land use is required in the catchment, either to the method and type of fertilizer application or the agricultural industries in the area.

1.2 Aims of the experiment

The experiment aims to demonstrate the advantages of tree plantations to farmers particularly when arranged as a shelterbelt. These advantages are of the form of:

- shelter for stock
- reduction of wind damage to pasture and crops
- the trees can lower a saline watertable thus preventing or reducing loss of production
- they provide a direct financial return to farmers as a cash crop.

The specific aims of the experiment are, by means of a paired catchment study (thus simulating the effect on the whole Estuary catchment):

- to quantify the effect on the water table, surface water, and ground water (i.e. productive flats and wetlands) of planting at least 50% of the catchment to trees.
- to quantify changes in total phosphorus output, and ground water phosphorus content due to planting at least 50% of the catchment to trees.
- to quantify changes in production and commercial return to landholders and the community of planting trees
- to quantify the effect on production of surrounding land (particularly wetlands and fertile Joel flats) of planting trees on a large scale.

1.3 Method Outline

The method used in this experiment is the well established technique of a catchment pair. Two small catchments (about 25ha each) have been selected. They are both monitored under standard agricultural practice for several years. This establishes a calibration of one against the other. One catchment is then given the new treatment, in this case planting trees, and the two are compared under the new practice. This then can be used as a demonstration of how the trees have affected the catchment in which they are planted.

It is important that the 2 catchments are as similar as possible and that during the calibration period neither receives "out of the ordinary" special treatment.

The paired catchment study is to be run as follows:
- Full hydrological and phosphorus monitoring of both catchments for the first 6 years (at least 3 years after planting), followed by a lower level of monitoring until 2 years prior to harvest, when full monitoring should resume until a few years after harvest
- Planting of one catchment (probably the western catchment) to be undertaken in the fourth or fifth year
- Geophysical investigations (seismic, electrical resistivity, and electromagnetic soundings) to be undertaken
- Hardpan investigation to determine topography, extension and consistency of hardpan, and whether tree roots will penetrate it
- Catchment models to be produced as tool to aid understanding of impact of landuse changes

2. SITE SELECTION AND DESCRIPTION

2.1 The Coastal Plain Catchments

The major input of phosphorus to the estuary comes from the drains and rivers on the Swan Coastal Plain. Over much of the area both surface and groundwater gradients are very low (about 1/1000) and catchment boundaries ill-defined and often controlled by drains. The drains were constructed to control flooding and reduce winter waterlogging. Without these drains much of the agriculture would not be viable.

The soils of the Swan Coastal Plain vary greatly in their chemical and physical properties. This variation affects both their hydrology and their patterns of phosphorus export. The clayey soils of the Serpentine River association and the loamy Dardanup association have a high phosphorus absorption capacity. Despite many years of high rates of phosphorus application, drains whose catchments are largely of these soils have relatively low phosphorus loads.

Duplex soils of the Guildford association have a permeable shallow A horizon, but the clayey subsoil restricts infiltration. Drain flow, generated by both surface runoff and soil water through-flow, has intermediate phosphorus concentrations.

The coarse, highly permeable Bassendean sand associations are characterised by low sandy rises separated by sandy flats and swamps. These low lying areas are saturated in winter, and there are many permanent swamps. An extensive aquifer system exists at depth, often separated from the shallow perched system by an iron-organic podzolic hardpan.

Drains from the soils of the Bassendean association have the highest phosphorus concentrations and so have been targeted for special investigation.

2.2 Site Location

The site is on a farm owned by brothers Richard and Aldo Caratti, between Buller Road and the Harvey River. (See FIGURE 1) (Waroona Locations 911 and 1243.
ANG 386000 - 387500E; 6359000 - 63559700N.
CALMAP Sheet "McLarty",
Austmap 1:25,000 "Hamel" 2032-IISW)

Figure 1. Locality map, showing study area and extent of the Peel-Harvey Catchment.

Two similar catchments have been chosen, each approximately 25 ha in area, of a total instrumented area of 200ha.

2.3 Soils

The catchment soils are of Southern River association similar to Bassendean sand with coarse grey sandy rises separated by swampy sandy flats. At this site the rises are a Gavin sand with a bleached A horizon overlaying a brown to black iron-organic hardpan B horizon. The swampy Joel flats are dark, sandy, though richer in organic matter, and are saturated throughout winter. The hardpan B horizon tends to be harder, is closer to the surface and has a higher organic content than under the Gavin rises. Below the hardpan, is up to 20m of pale blue alluvial sand, very even textured and coloured throughout its depth.

To the south of the catchments, the soil is poorly drained, fine textured alluvial sand of the Serpentine River association on the Harvey River flat.

To the north the soils are of the Cannington association, poorly drained with calcareous substrate, often yellow duplex soil with red or black clays over limestone (DCE 1980).

2.4 Climate

The experimental site experiences a Mediterranean climate, with cool wet winters and hot dry summers. Long term average minimum and maximum temperatures in July are 8^{o} and 17^{o} respectively. Potential evaporation is estimated to be about 1300mm annually (from data supplied by the Commonwealth Bureau of Meteorology). From rainfall recorded at nearby towns Mandurah, Bunbury, Harvey and Waroona, annual mean precipitation over the period 1980-88 is estimated at 820mm, with nearly 90% falling in the period May to October.

2.5 Topography and Drainage

The total surface relief over the study site is approximately 6m (See FIGURE 2). The relief in the hardpan layer is considerably less than this.

The study area is bounded to the north by a drain and to the south by the Harvey River. The catchments within this area are drained artificially, the eastern catchment directly to the Harvey River, and the western catchment into an intermediate drain prior to joining the Harvey River downstream. The drain in the eastern catchment has been cut to the hardpan layer while that of the western catchment is somewhat shallower. The western catchment is of lower relief than the eastern one. The two catchments are separated by a sandy rise to about 10m AHD, 5m above the outlets of the catchments.

2.6 Vegetation and Land Use

Originally the open woodland of E. marginata, E. calophylla and banksia species dominated the dryer rises. The creek beds and fringing woodlands were of E. rudis, M. raphiophylla, M. preissiana, L. ellipticum and some Casuarina. Some remnant stands are on the site which was largely cleared in the early 1950's. The site has been grazed with sheep and cattle since then.

Through the 1960's and 70's an average annual application of fertilizer was "a bag per acre of superphosphate" or 18kg phosphorus per hectare. During the 1980's the farmer has reduced this to an application every 2 or 3 years. The site was last fertilized in 1987, and has been fertilized in 1990.

3. METHODOLOGY

The experiment is concerned both with the moisture status of the soil, the level of the water table and with the phosphorus transport from the site. In keeping with

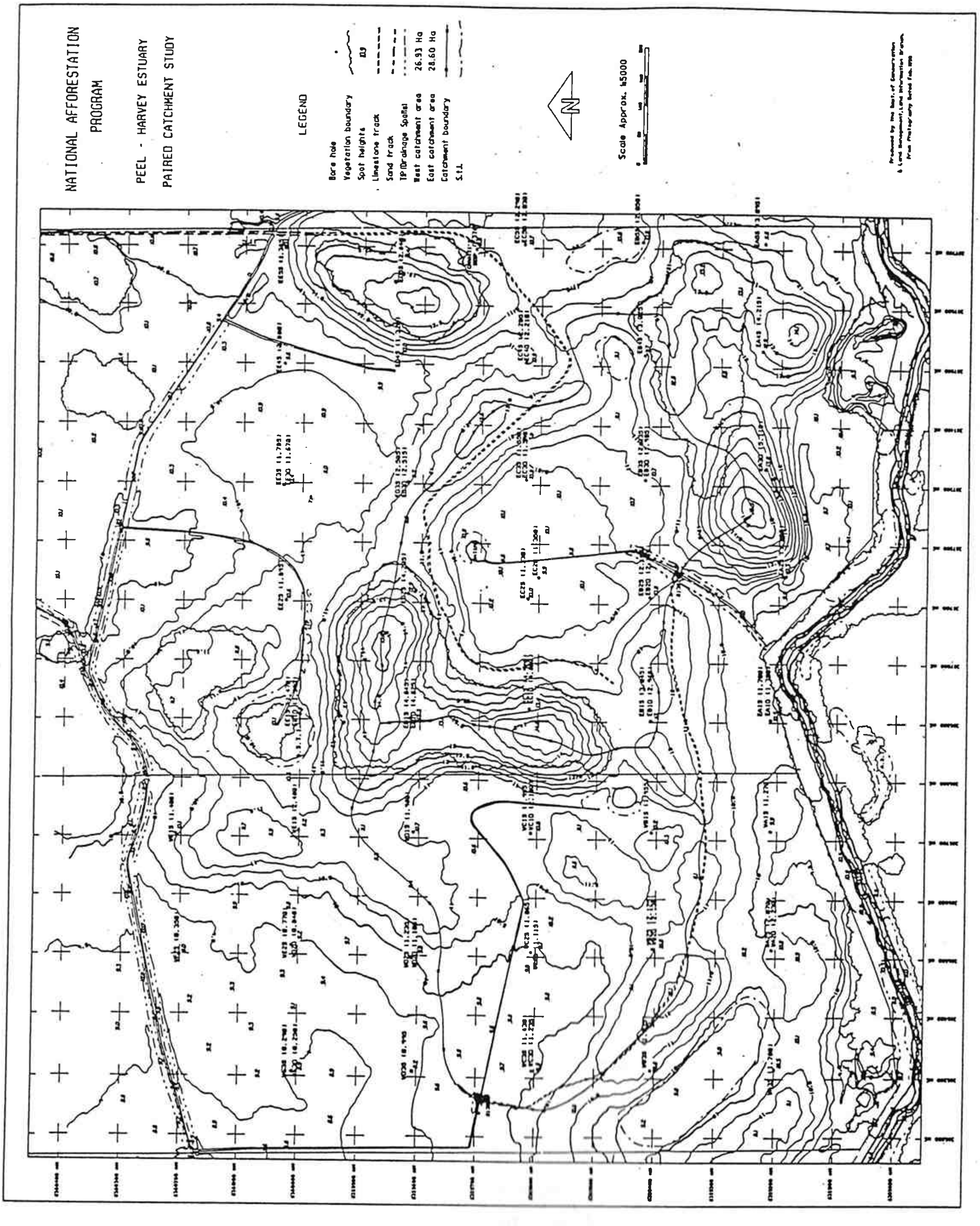


FIGURE 2. Site map showing contours, bore locations, drains and gauging station. (Scale Approx 1:10 000)

these aims, a piezometer field has been established and stream gauging stations installed.

3.1 Drain Gauging Stations

The Water Authority of Western Australia (W.A.W.A.) have installed (~~under contract to C.A.L.M.~~) a stream gauging station on each catchment drain. They are both broad crested V-notch weirs (See FIGURES 3a and 3b), although due to the different topographies of the catchments, they have quite different shapes. The eastern catchment drain is excavated to the hardpan and the drain deeply incised. The weir cease to flow level (CTF) is set at the hardpan level. The western catchment is flatter and the drain is wider, and not as steeply incised as the eastern. It also is not excavated to the hardpan, although the pad of the weir is set on the hardpan, at a depth of about 80cm below the CTF of the weir. This is in fact a possible source of error in the intercalibration of the two catchments. However, the data collected to date show that the catchments and gauging stations are well matched. (See Section 4)

Stage level is measured by Unidata shaft-level encoder logged digitally by Unidata 64 K data logger. The stage is sampled every 5 seconds. (See FIGURE 4)

A Leupold-Stevens A71 pen and ink chart recorder is used as a back-up to the logger. To date there have been no logger breakdowns.

Each gauging station has an associated Rimco tipping bucket pluviometer, with 0.2mm bucket. This is also logged by the data logger. The pluviometer is mounted in the field 1000mm above ground level, 20m from the station instrument shed.

At each gauging station an automatic water sampler (built by the W.A.W.A.) is programmed to sample every 24 hours

FIGURE 3a. Gauging weir of the eastern catchment.

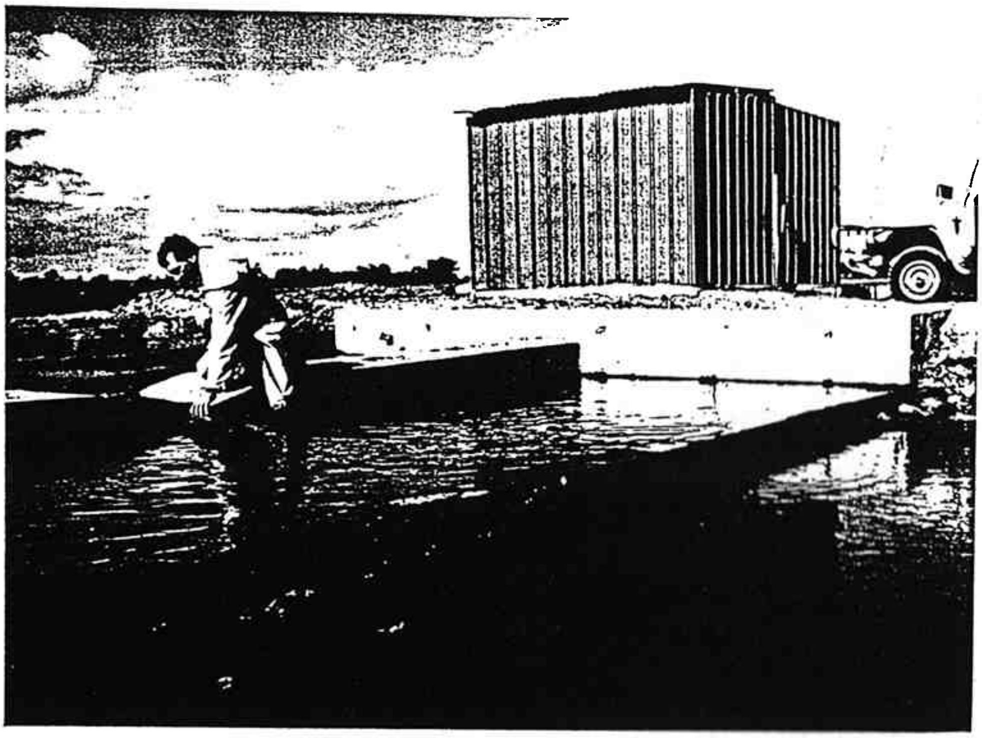


FIGURE 3b. Gauging weir of the western catchment.

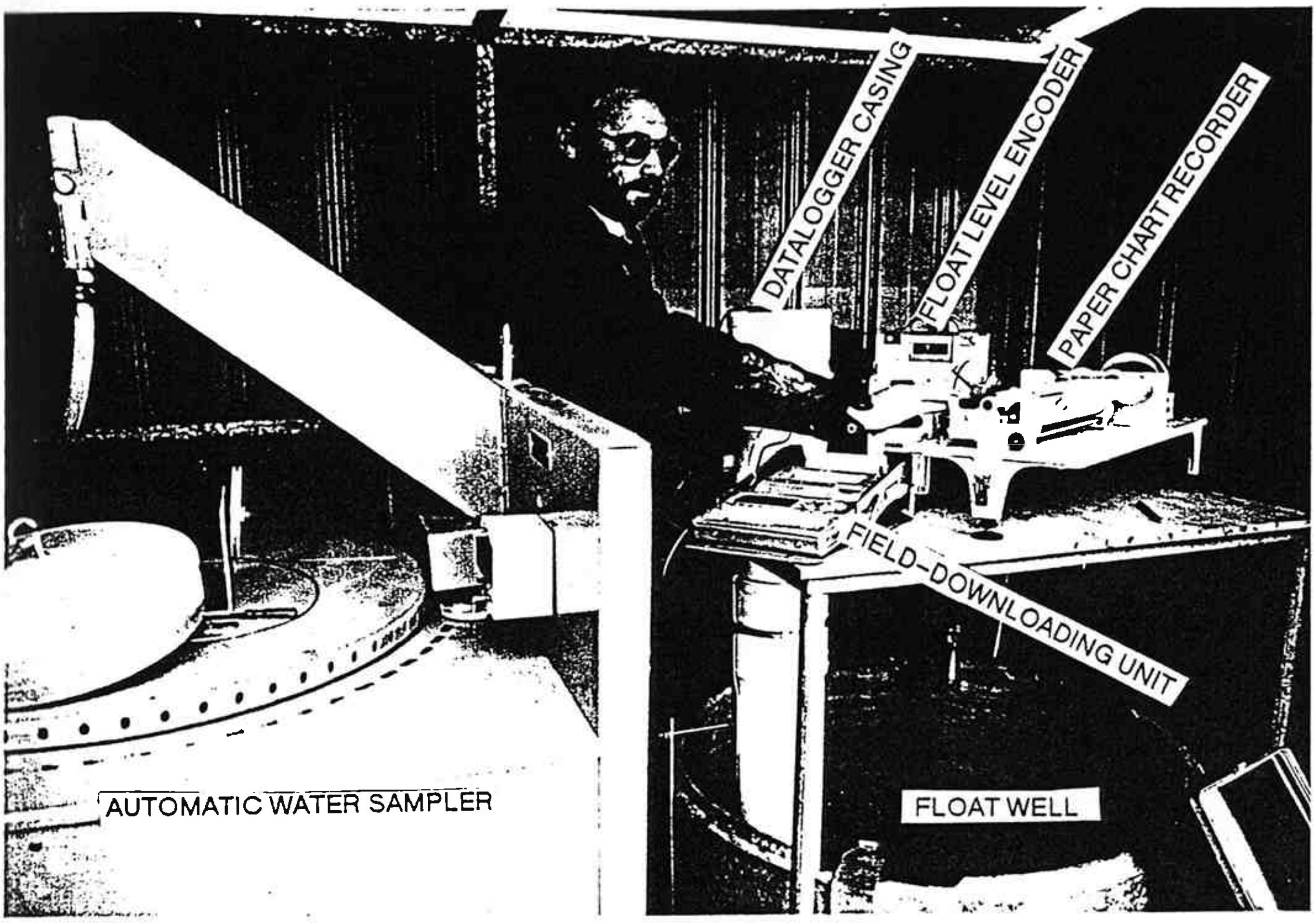


FIGURE 4. Inside the instrument shed.

at 0900 WST. In addition it is set to sample whenever the stream stage varies by more than a predetermined amount. (This sampling interval was initially set at 50mm but varied for special periods of investigation). Each sample is held in its own plastic bottle. The sampler has capacity for 64 samples. It is emptied at each station visit, every 21 to 28 days. The data logger records the time each sample is taken.

The water samples were analysed for pH, electrical conductivity at 25° C, turbidity and total phosphorus (unfiltered), by the W.A. Government Chemistry Centre.

3.2 Piezometer Field

A piezometer field on a 200m grid has been established over the site with a total of 63 monitoring piezometers. Of these, 20 were drilled to 11.8m, 2 were drilled to 20m and 41 were drilled to, and penetrating 15cm into, the hardpan (at a mean depth of about 2m). The piezometer grid extends up to 400m beyond the topographical catchment boundaries. This represents about half the width of the catchments again and is to ensure adequate subsurface monitoring as well as regional groundwater effects.

The deep bores were drilled with a trailer mounted Gemco 210B drilling rig, with 150mm hollow stem augers. The shallow bores were drilled with a Gemco HM7 truck mounted rig, with 65mm solid augers. The deep holes were all sealed within the hardpan (2m - 6m below surface) with bentonite clay. Attempts were made on several holes to take cores, particularly of the hardpan, but the material became too fluid and would not remain in the core barrel.

The piezometers were cased in 40mm Class 6 PVC pipe. A screen of Class 9 PVC pipe slotted with a hacksaw was installed at the base of each hole (2m for the deep holes, 1m for the shallow holes). It was not deemed necessary to use a graded sand screen as the deep and shallow aquifers are both made up of coarse sand. The bores have been topped with a screw cap with a breather hole drilled in to it.

The bores were all developed by airlifting for at least one hour. Samples were taken at the end of each airlifting period, and analysed for pH, electrical conductivity (at 25^{o} C), turbidity and total soluble phosphorus.

All bores were logged manually each month, and in addition 8 deep and 8 shallow piezometers were

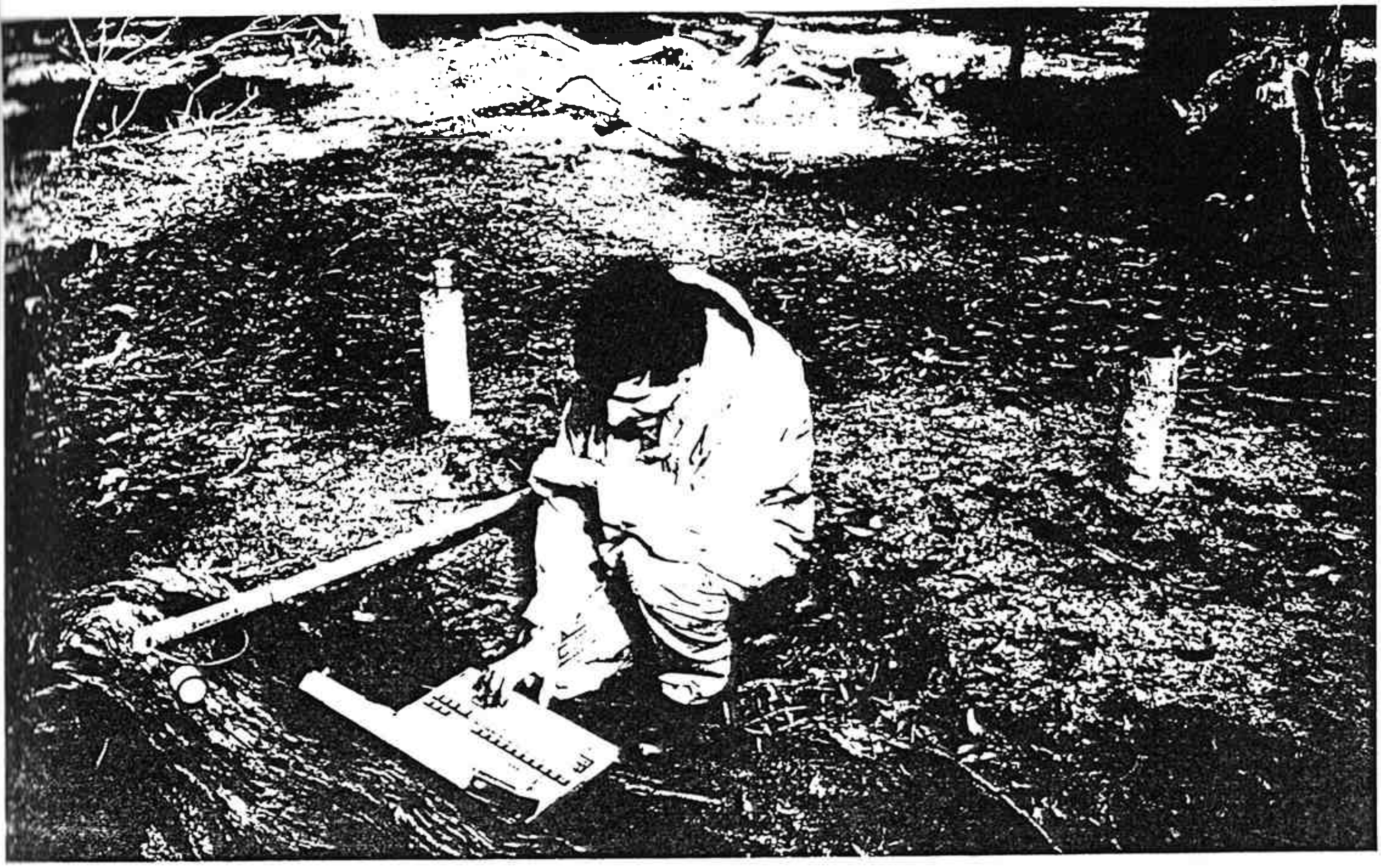


FIGURE 5. Down loading bore level loggers in the field.

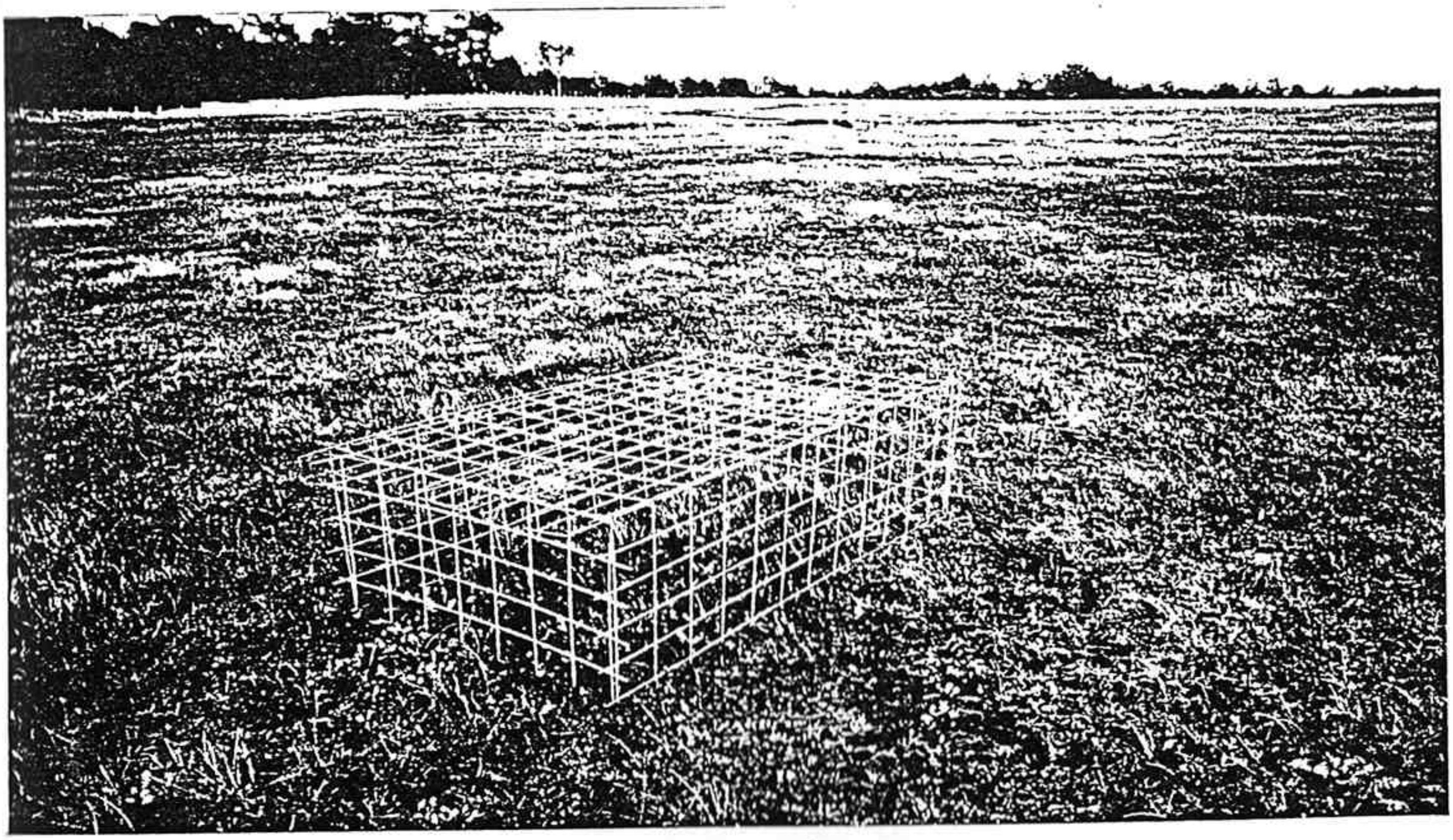


FIGURE 6. Pasture cage exclosures.

continuously logged with Wesdata capacitive probes and loggers. These fit entirely within the bore and are suspended from the cap by a cable. These are downloaded on site using a lap-top computer (See FIGURE 5). They functioned reliably apart from early battery problems. Occasionally a bore top was broken by cattle and had to be repaired.

In addition to the monitoring grid, 4 test wells were drilled to 11.8m, surrounding a production well the farmer had installed, in order to conduct a pump test on it.

3.3 Pasture Sampling

Ten pasture cages, each measuring 2m X 1m (See FIGURE 6) were placed on each catchment. These were to ensure stock did not eat pasture from a selected site. The cages were positioned so that each major soil type had representation in proportion to its area. The growth within each cage was cut every 6 weeks and the species mix determined. Total dry matter was also measured. After each sample was taken the cages were moved randomly, to another site on the same soil type. This method gives a reasonable comparison between sites, but does not give accurate total yields.

3.4 Fertilizer

The farmers have fertilized each 2 or 3 years as required in the past. The paddocks were fertilized in 1987 with Superphosphate as the rate of "1 bag to the acre" (or 18kg Phosphorus per hectare). In 1990 the paddocks were sampled by the farmer and tested by the Department of Agriculture, and after considering the advice the farmer opted to apply Superphosphate and Potash in the ratio 3:2, at the traditional rate, but only on the higher producing lower soils (Joel). This gave the following elemental applications:

phosphorus	11 kg/ha
potassium	40 kg/ha
sulphur	14 kg/ha

A total of 4 tonnes of the Superphosphate-Potash mix was applied to the western catchment and 3.5 tonnes to the eastern catchment.

The lower lying soils (Joels) of the eastern catchment were seeded with a mix including perennial pastures (including Strawberry clover, Richmond rye grass, balansa clover, trikkalla, Concorde rye and paspalum).

In August 1990, the farmer made an extra application of Superphosphate (with Potash 3:2) on the drier sands to promote clover growth on the eastern catchment only, at the rate of $^{3}/_{4}$ bag/acre (150 kg/ha).

3.5 Mapping

3.5.1 Topography and Cadastre

FIGURE 2 is a map of the site (for locality map see FIGURE 1), prepared from 1:5000 scale aerial photography and ground surface survey. As can be seen the catchments are almost entirely cleared. From the contours it can be seen that the relief is very low.

3.5.2 Soils

FIGURE 7 shows the site in relation to the soils of the Peel-Harvey catchment and FIGURE 8 the distribution of the soils over the experimental catchments. The soil codes follow Wells (1989) and King and Kipling (1989), and the descriptions are as follows:

B1 Very low relief dunes and areas of undulating sand plain, with deep bleached grey sands with either a pale yellow B horizon or an iron-organic hardpan at depths generally greater than 2m.

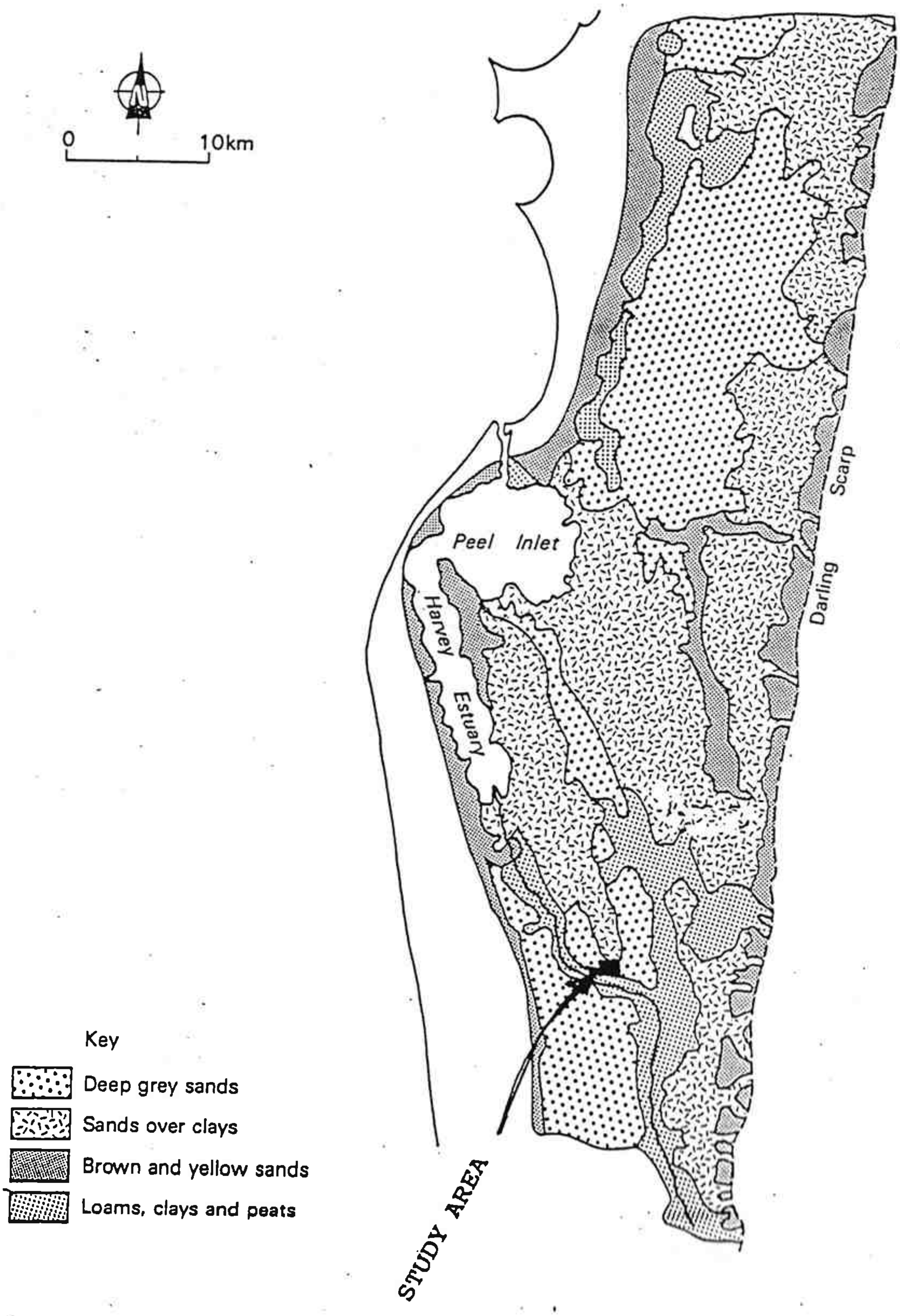


FIGURE 7. Map showing the soils of the Peel-Harvey catchment and the location of the experimental site.

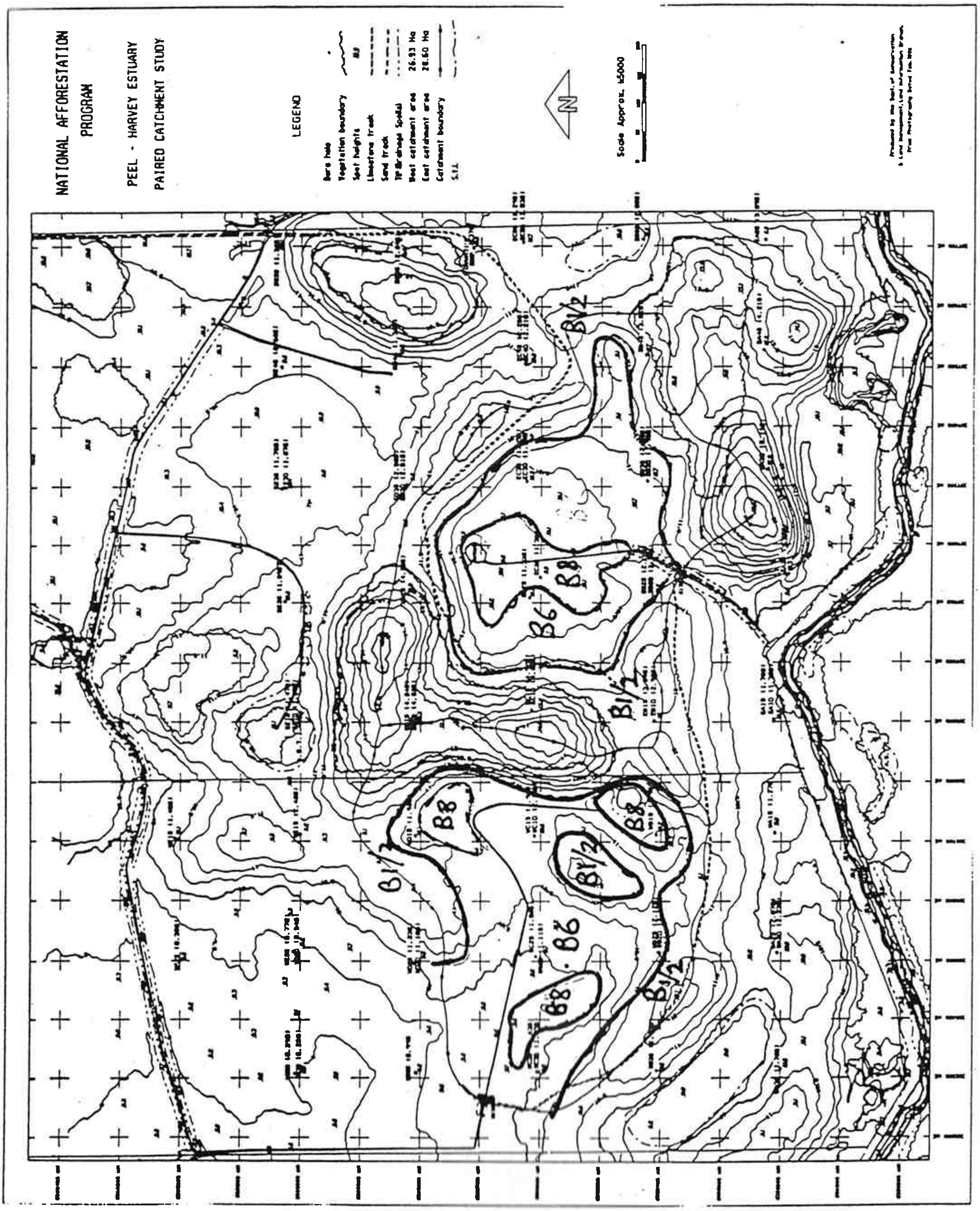


FIGURE 8. Site map showing soils, contours, drains, weirs, bore locations and vegetation.

B2 Sand plain with deep well drained bleached grey sand with an iron-organic hardpan or less commonly a pale yellow B horizon, generally at 1m-2m depth.

B6 Undulating sand plain with moderately deep to deep, moderately well drained grey and brown sands with an organic (or ironstone) pan, generally at depths less than 1m.

B8 Broad depressions and narrow swales between sand ridges with moderately deep to deep, very poor to poorly drained grey and brown sands with and iron-organic or siliceous hardpan, generally at depths less than 1m.

BS Seasonally inundated swamps and depressions with very poorly drained grey brown sands and peat on top of grey sand.

3.5.3 Hardpan

Due to the low surface relief and coarse textures soils of the site (and hence high rainfall infiltration rate) it was expected that shallow ground water movements may be significant for phosphorus transport from the site. An engineering penetrometer with a full probe depth capability of 6m was used to sound the hardpan on a grid of 50m X 50m across the 2 catchments.

3.6 Geophysical Surveys

3.6.1 Electromagnetic Survey

During November 1989 a survey of the site was undertaken with a Geonics EM31 electromagnetic probe. The principle of operation of the instrument is described by McNeill (1980a,b). The probe consists of two coils at a distance of 3.7m. The transmitter coil induces an electromagnetic field in the ground which is detected by the receiver coil. The ratio of the voltage detected to that transmitted is a measure of the, apparent bulk, soil electrical conductivity, and is read as electrical conductivity on the instrument meter. The theoretical penetration depth of this instrument is up to 6 m, depending on the soil and how the conductivity varies with depth. The majority of the returned signal comes from less than 3.7m depth (ie. a depth equivalent to the coil separation).

3.6.2 Electrical Resistivity Soundings

Two vertical soundings of electrical resistivity were carried out using a Schlumberger array (see, for example, Kollert, 1969) to test whether the technique would give information on the hardpan.

3.6.3 Seismic Refraction

A small seismic refraction survey was undertaken on the eastern catchment. (For the technique see, for example, Dobrin, 1960; or Redpath, 1973). A traverse from the centre of the catchment to the top of the divide between the two catchments was made, using a 12 channel seismograph, with a geophone spacing of 5m. Small gelignite charges were used which resulted in minimal surface expression. The aim of this survey was to supplement the hardpan probe survey and gain an estimation of the variability of the depth and thickness of the hardpan over a shorter interval than the 50m of the probe survey. It was also hoped to determine the variability in structure of the hardpan.

3.7 Soil Hydraulic Conductivity

3.7.1 Constant Head Permeameter Tests

Tests were conducted on 20 sites across the 2 catchments using a constant head permeameter, as described by Bell and Schofield (1989). The method consists of drilling a small hole (up to 1m depth, 45mm diameter) which is filled with water and the water level maintained using a syphon system (See FIGURE 9). The rate of water flow

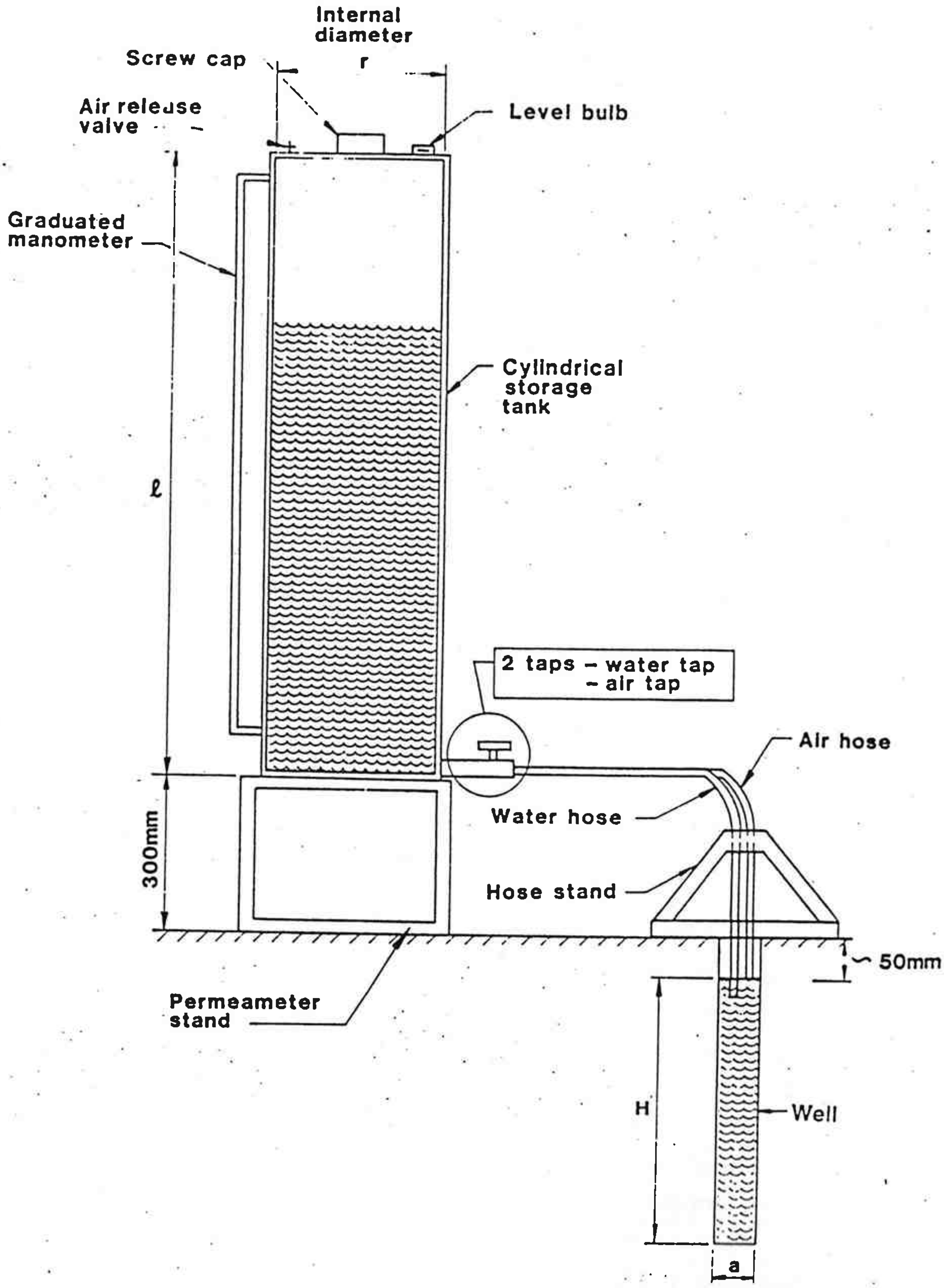


FIGURE 9. Constant head permeameter design.

required to maintain the head is equal to the rate of movement away from the water column in the soil. The saturated hydraulic conductivity is calculated using Equation 1 (Philip, 1985).

$$\frac{K_s}{Q_s} = \frac{\ln[\tau+(\tau^2-1)^{\frac{1}{2}}] - (1-\tau^{-2})^{\frac{1}{2}}}{4.117\ a^2\tau(\tau^2-1)^{\frac{1}{2}}\ (1-\tau^{-2})} \qquad \text{Eq. 1}$$

Where K_s is saturated hydraulic conductivity of the soil.
Q_s is steady discharge rate from the well.
a is the radius of the well.
$\tau = H/a$ where H is the constant head of water above the base of the well.

3.7.2 Pump Test

A pump test was conducted on a 100mm bore the farmer had had installed 2 or 3 years previously. The aim of the test was to determine (a) whether an hydraulic connection exists between the shallow and deep aquifers and (b) the hydraulic conductivity and transmissivity of the deeper aquifer.

Deep and shallow observation piezometers were established around the production well. The production bore was to a depth of 23m. Observation bores were drilled to 11.1m, and to the hardpan. Nearby piezometers from the monitoring grid were also used as observation wells for this test. A total of 6 deep observation wells and 11 shallow wells were used in addition to the pumped well. Twelve of these bores were continuously logged using digital data loggers. The layout is shown in FIGURE 10.

The test well was developed using a small centrifugal "fire pump" at a rate of 170m^3/day for a total period of 24 hours over several days.

The inlet of the test pump was set 9.11m below the outlet, or 8.47m below ground surface. A step drawdown test was performed first with 4 steps to maximum pump rate. The pump was set at a maximum rate and run for a total period of 120.2 hours. Unfortunately the pump rate varied quite a bit, apparently as aquifer material blocked the inlet to the pump. It had to be cleared several times by manipulating the outlet rate. This hampered the interpretation of results. Material up to 4mm came through the pump and so the condition of the screen must be queried.

4. RESULTS AND DISCUSSION

4.1 Drain Flow and Phosphorus Load

4.1.1 Rainfall and drain flow response

As would be expected, there was a high degree of correlation between the daily rainfall recorded in the two catchments. Over the season they recorded the same totals, although there was a slight variation through the season. The east catchment pluviometer was commissioned 2 weeks before the west, hence there was slightly higher rainfall recorded by this instrument. TABLE 1 gives the rainfall and flow data for the 2 catchments for 1989 and 1990. The table also gives, separately, data for the major flow period (13/6 - 25/9) for both years, in order to give a better comparison (since the data for 1990 include the previous summer).

As with the rainfall monitoring, full drain monitoring did not commence until the second week in June 1989. This meant that the first flush of winter was missed. This first flush has previously been found to carry the highest concentrations of nutrients from the sandy soils (EPA, personal comment), and in 1990 this was observed at this site. FIGURE 11 shows the rainfall and flow record for the West catchment from June 1989 on, and FIGURE 12 shows a similar plot for the East catchment. It can be seen that the catchments are similar and are very responsive to rainfall. FIGURE 13 shows the hydrograph for both stations during a typical storm event.

TABLE 1 : SEASONAL TOTALS
FOR 1989 (from June 6th) and 1990 (till Sept.25th).

	All recorded data		13/6 to 25/9	
	EAST	WEST	EAST	WEST
1989				
Rainfall (mm)	600	575	442	450
Flow ($x10^3$ m^3)	75.6	63.6	62.0	53.2
P Load (kg)	31.4	37.5	27.3	31.4
F.W.M.P.(mg/L)*	0.42	0.59	0.44	0.59
Runoff (mm)	264	237	217	198
Runoff/Rainfall	0.44	0.41	0.49	0.44
Pasture kg/ha	3107	2195		
1990				
Rainfall (mm)	781	752	366	426
Flow ($x10^3$ m^3)	46.2	31.0	42.5	30.7
P Load (kg)	34.7	22.4	30.5	22.1
F.W.M.P.(mg/L)*	0.75	0.72	0.72	0.72
Runoff (mm)	172	115	149	114
Runoff/Rainfall	0.22	0.15	0.41	0.27
Pasture kg/ha	3460	3580		

* FWMP = Flow Weighted Mean Phosphorus

The runoff coefficients of the 2 catchments are fairly similar, but when the flow period of 1990 is examined (TABLE 1), a distinct difference is noted. The major difference in the recorded streamflow is recorded baseflow which lingers after a storm event passes. The east catchment has a higher baseflow than the west. This is due to the nature of the drain construction. The

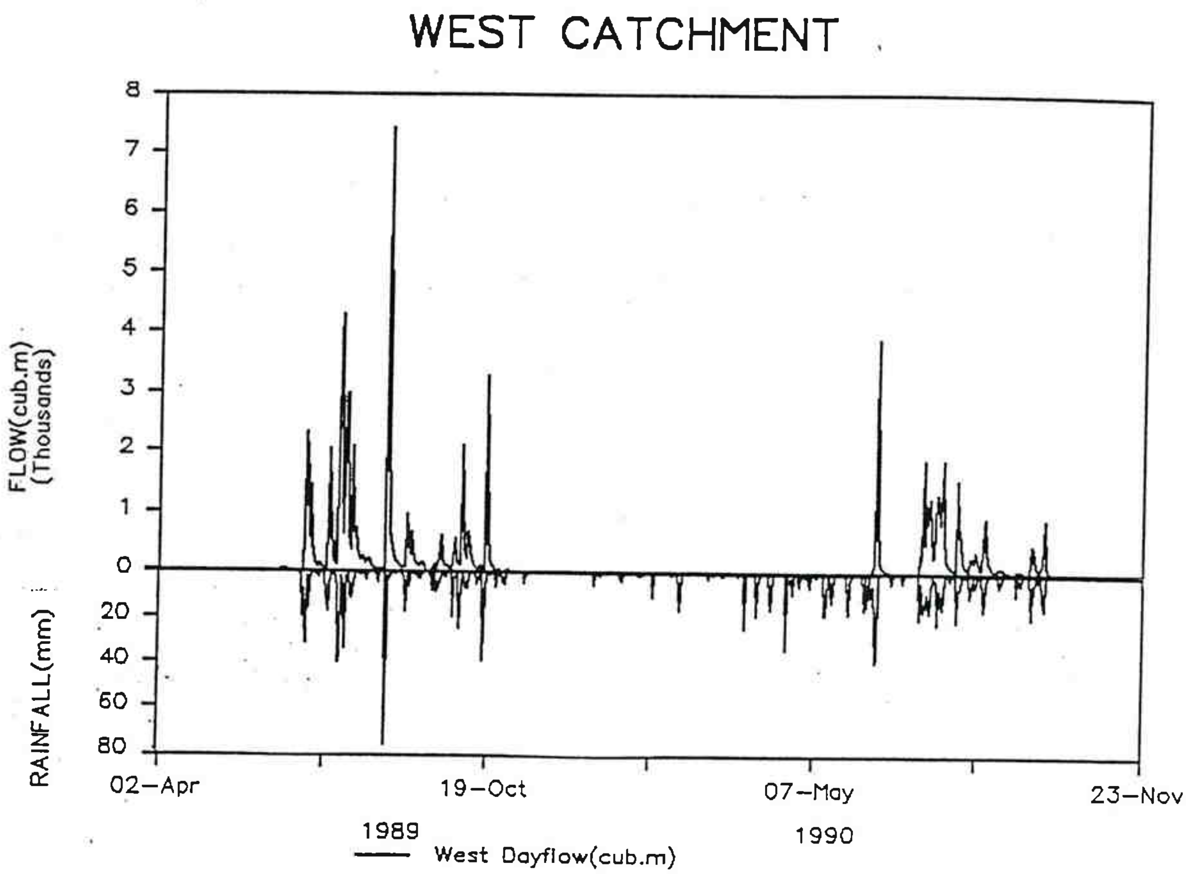


FIGURE 11. Daily flow and daily rainfall for the West experimental catchment to date.

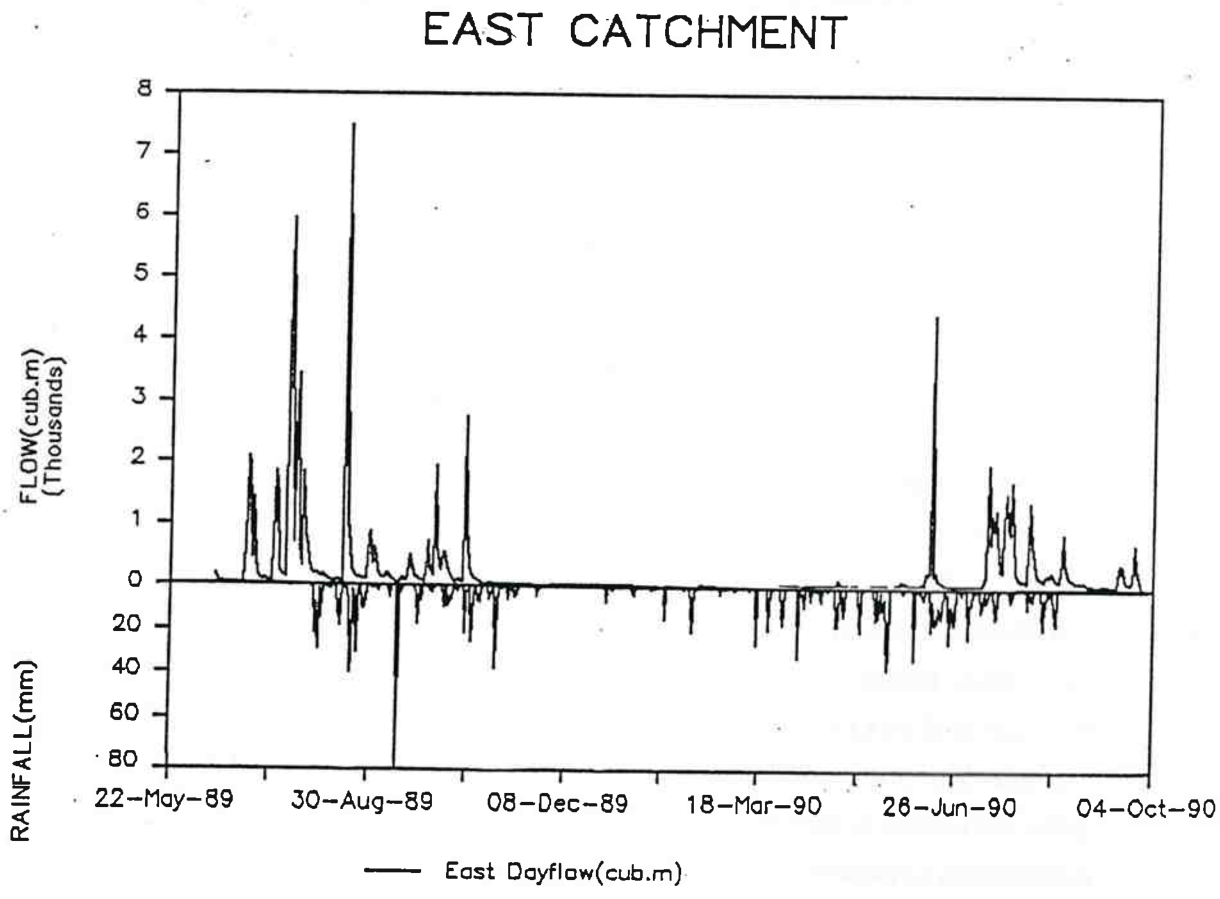


FIGURE 12. Daily flow and daily rainfall for the East experimental catchment to date.

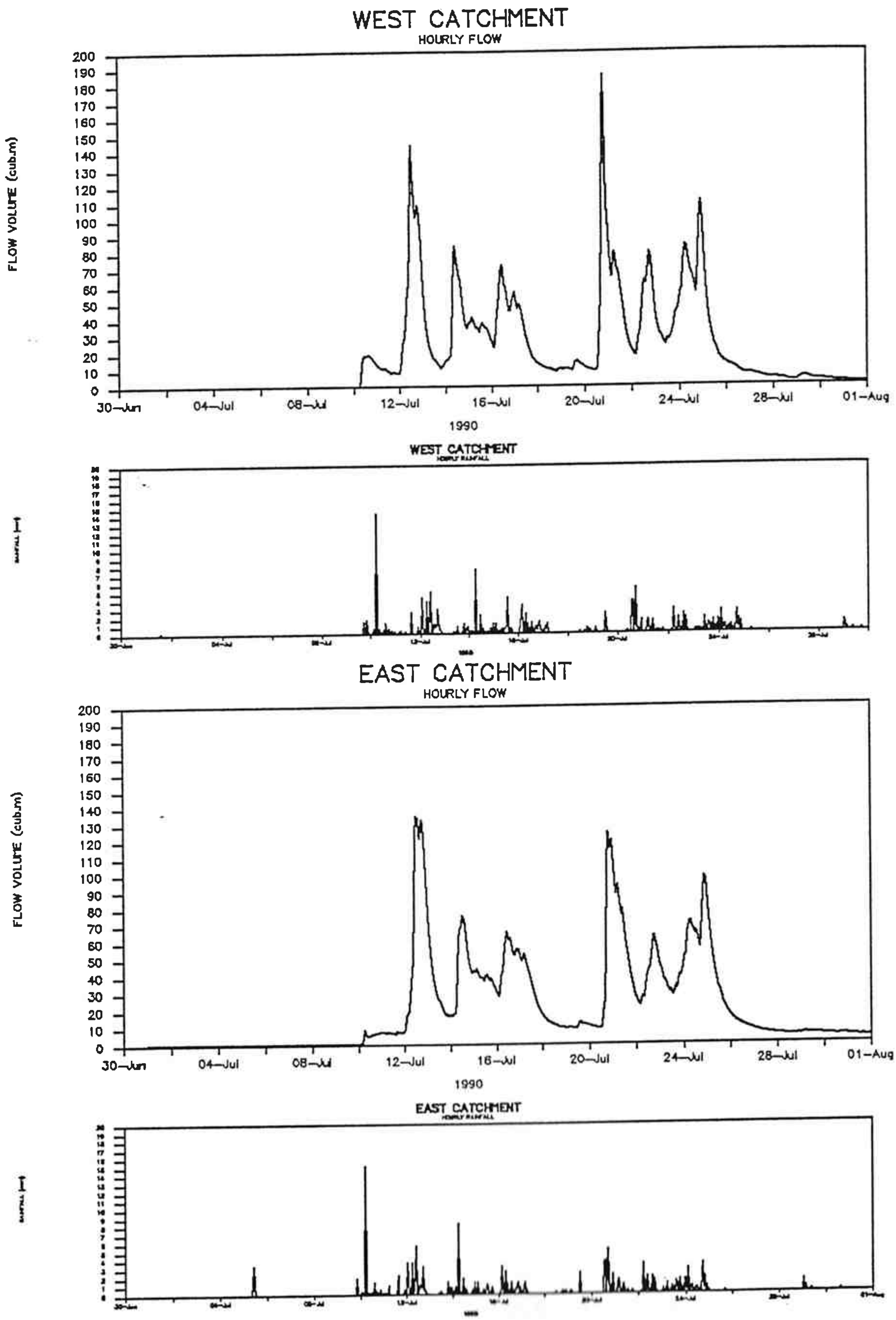


FIGURE 13. Storm hydrograph for the 2 stations.

drain from the east catchment is incised right to the hardpan, whereas that from the west catchment sits about 80cm above the hardpan. The result of this is that shallow subsurface water which is perched on the hardpan in the west catchment does not flow down the drain but through the soil around the weir and hence is not recorded by the gauging station. This flow can be estimated using saturated hydraulic conductivity measurements.

Statistical analysis of the data show a good correlation between the two catchments. Regression analyses of the daily total rainfall and drainflows were performed with the following results:

Rain

East=-0.123 + 1.022 X West R^2=0.99

Flow

East=0.044(±.034) + 1.080(±.030) X West R^2=0.911

4.1.2 Drain Phosphorus Load

Phosphorus Concentration

FIGURES 14 and 15 show the instantaneous phosphorus concentrations from the water as sampled. While there is an overall reduction over the winter season, there are easily seen "bursts" of higher concentrations, corresponding to the onset of storm events, particularly after extended dry spells. The high level of dissolved phosphorus in the eastern catchment runoff in the early part of 1990 is almost entirely due to summer mineralisation of bound phosphorus. This catchment flows much earlier than the western one, and the phosphorus concentration had halved by the time the main winter flow period had begun. It will be interesting to see to what extent this situation is repeated in 1991.

The impact of fertilizer application (10/05/90) is clearly visible on the eastern catchment figures, as a rise from around 0.5 mg/L P to around 1.5mg/L. The

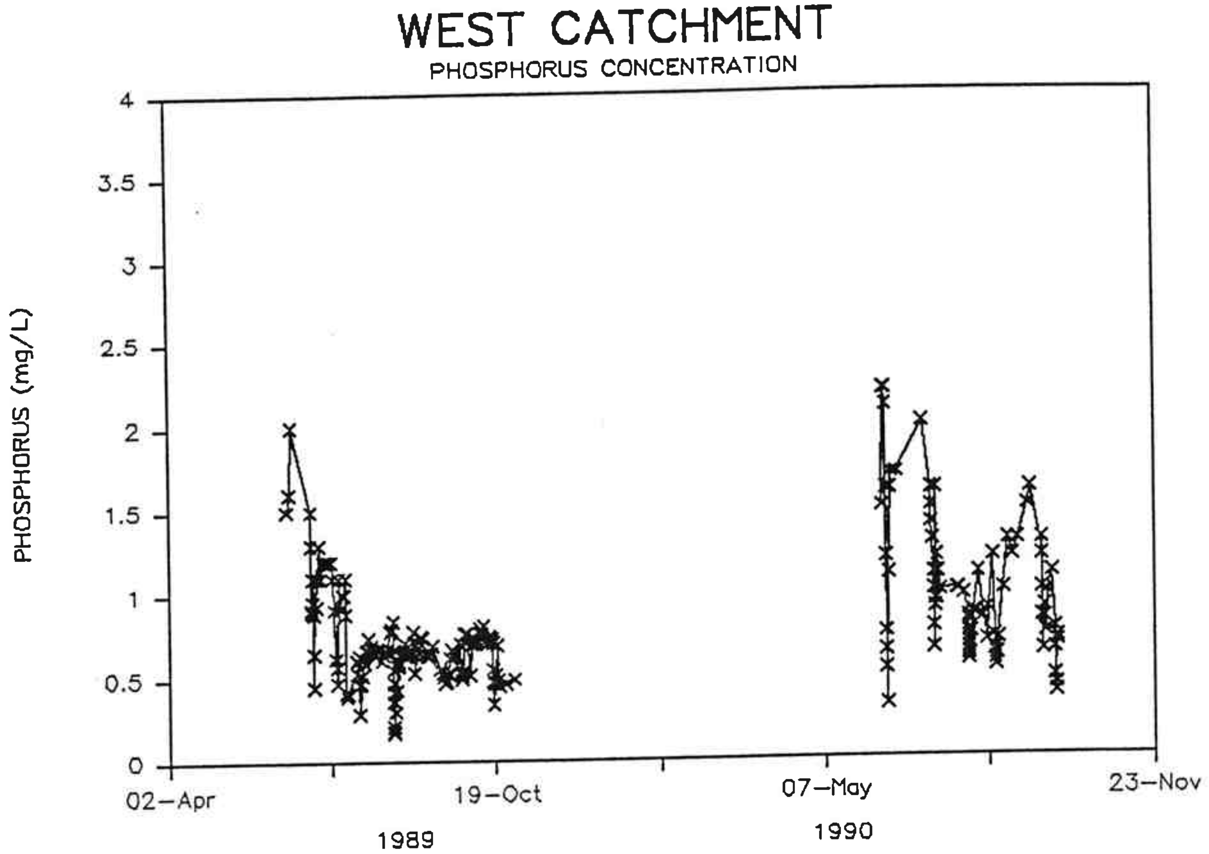


FIGURE 14. Instantaneous Phosphorus concentration of the drain from the West experimental catchment to date.

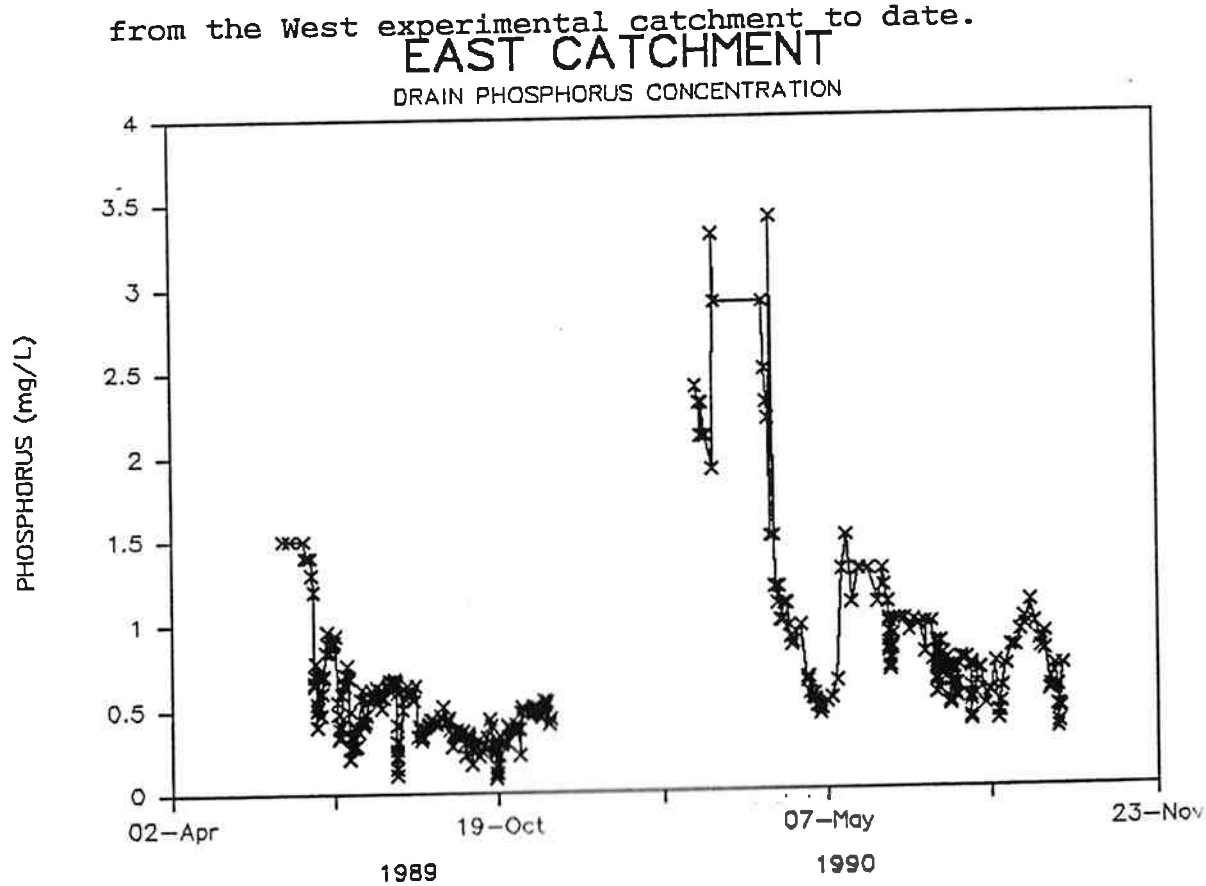


FIGURE 15. Instantaneous Phosphorus concentration of the drain from the East experimental catchment to date.

western catchment had not flowed prior to this and so a similar impact is not discernible. On the 8th of August, 1990, the farmers applied a further 1 tonne of Superphosphate-Gypsum (3:2) to the sand ridges of the eastern catchment. Although an apparent rise in phosphorus concentration is detectable immediately after this, a similar rise was also observed for the western catchment. It is probable, therefore, that this due to mineralisation during the dry spell which preceeded the late application.

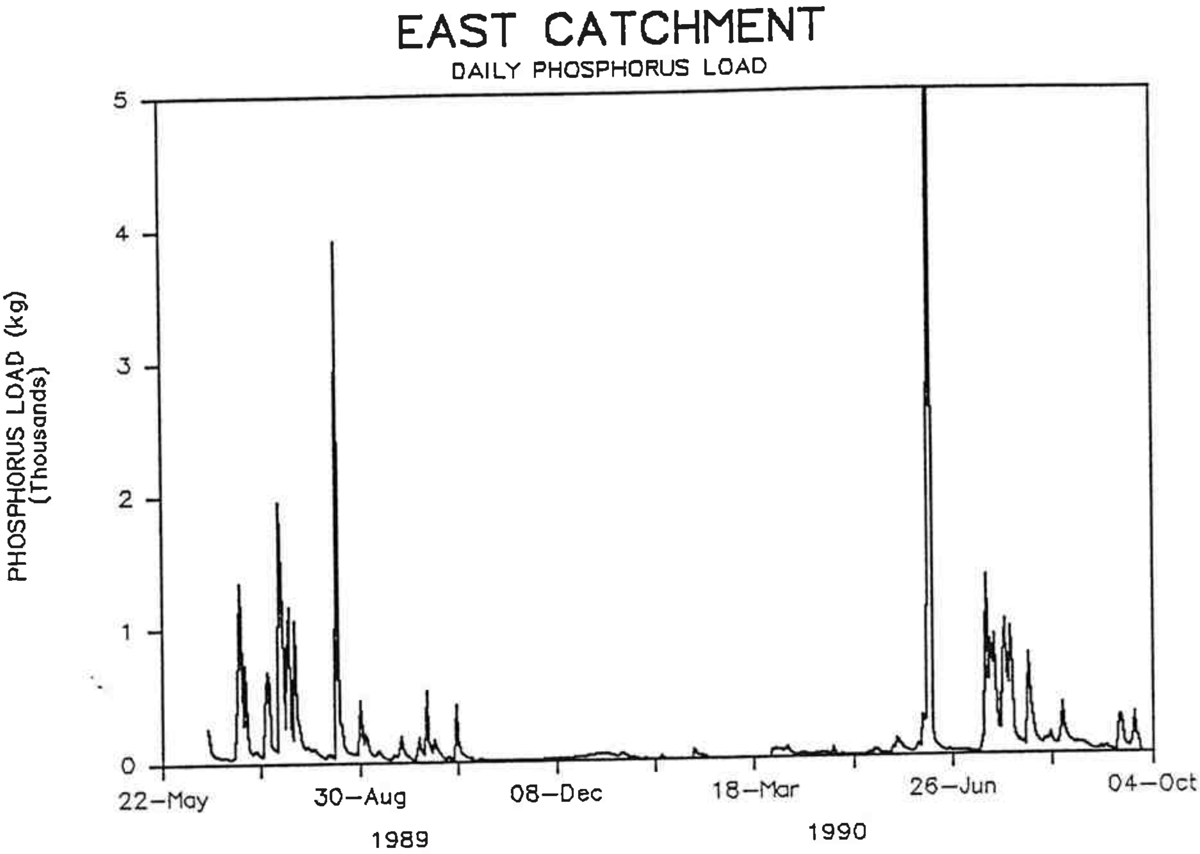
Phosphorus Loads

The total phosphorus loads for both catchments have been given in Table 1 above. The 1989 data showed the western catchment as having a similar total water run off but higher total phosphorus load, and hence a higher Flow Weighted Mean Phosphorus (FWMP) concentration. The data for 1990 are much more evenly matched, with the FWMP content being very similar for the 2 catchments.

FIGURE 16 shows the daily Phosphorus Load for the two catchments. It can be seen that the pattern for both catchments is similar.

One difference between the catchments which may have hydrological consequences is the depth of incision of the drain. The shallower drain from the west catchment probably means that more water is travelling through the soil, and may well be carrying more phosphorus with it. Examination of the ground water head across the site suggests a lateral through flow is taking place (see the next section), although this would be a minimal amount.

FIGURE 17 shows the cumulative phosphorus load plotted against cumulative drain flow for both catchments for both years.



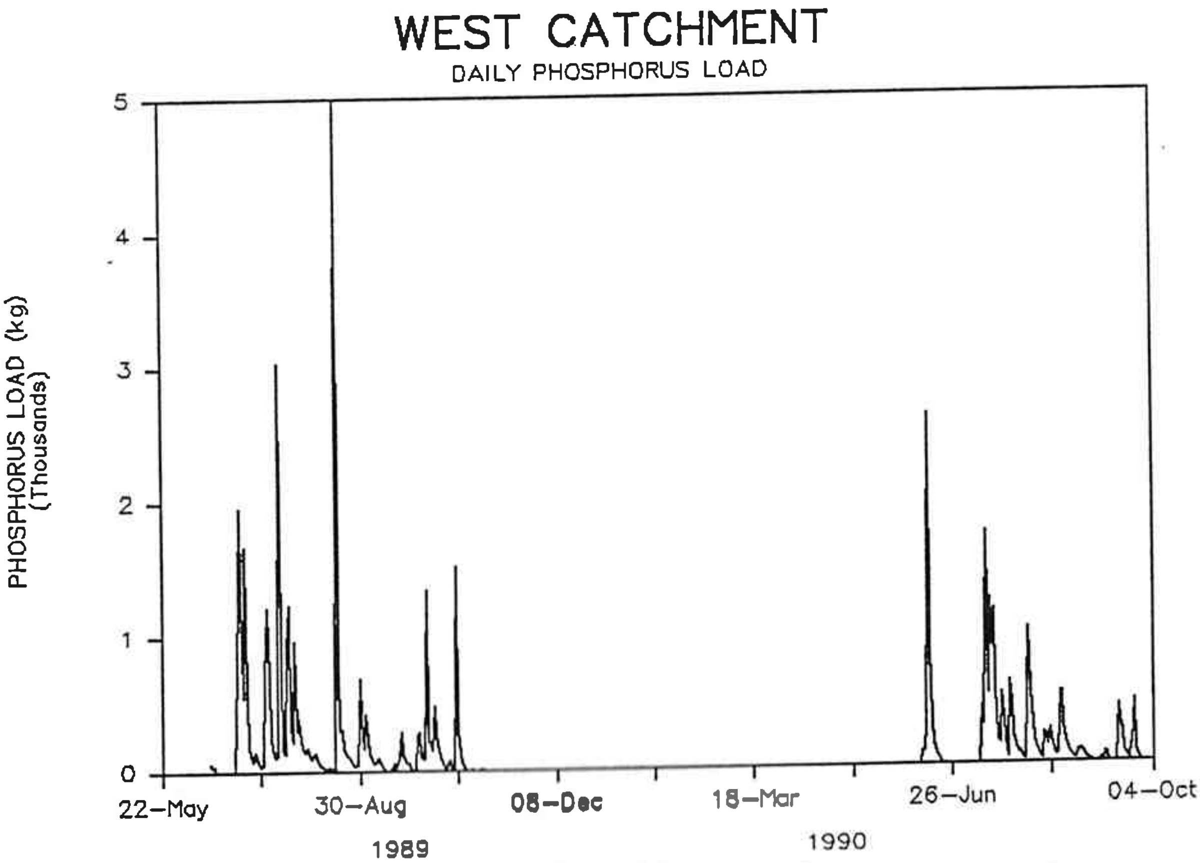


FIGURE 16. Daily phosphorus load for the two catchments.

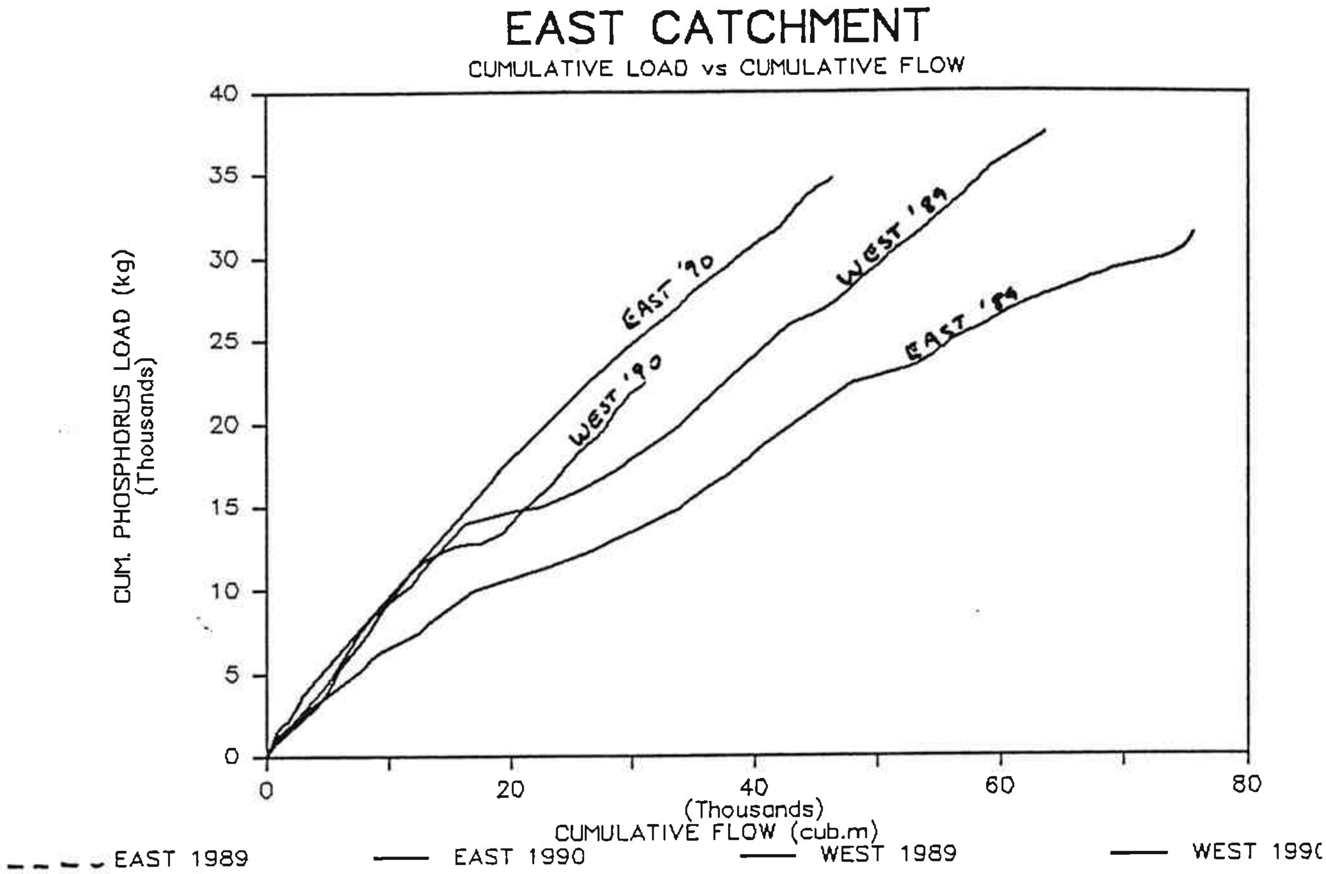
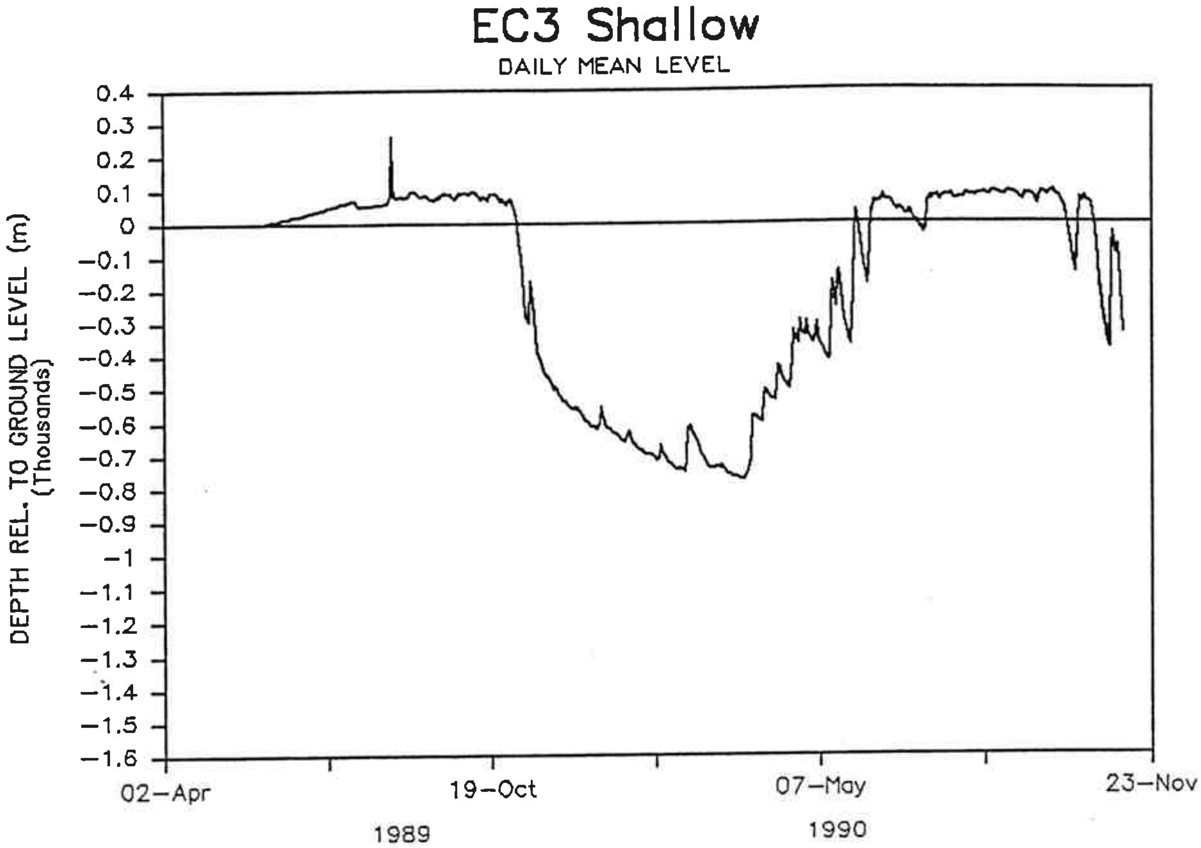


FIGURE 17. Cumulative Phosphorus load against cumulative drain flow for the two catchments for 1989 and 1990.

4.2 Groundwater

The results from the bore monitoring show that the shallow perched aquifer responds rapidly to rainfall, as would be expected. FIGURES 18 and 19 show typical hydrographs for two shallow and deep bore pairs over the period to date. The rapid response of the deeper system, below the hardpan, was a little surprising given the impermeable nature of the hardpan (see section 4.4.2).

FIGURE 20 shows hydrographs for one bore pair during a series of storm events in July 1990. The rapid response of the deeper aquifer is clearly visible. This gives cause for optimism in regard to tree growth in this area, as there is clearly some hydraulic connection in the area between the shallow and deep aquifer systems - enough to allow the rapid response exhibited here. FIGURE 21 shows



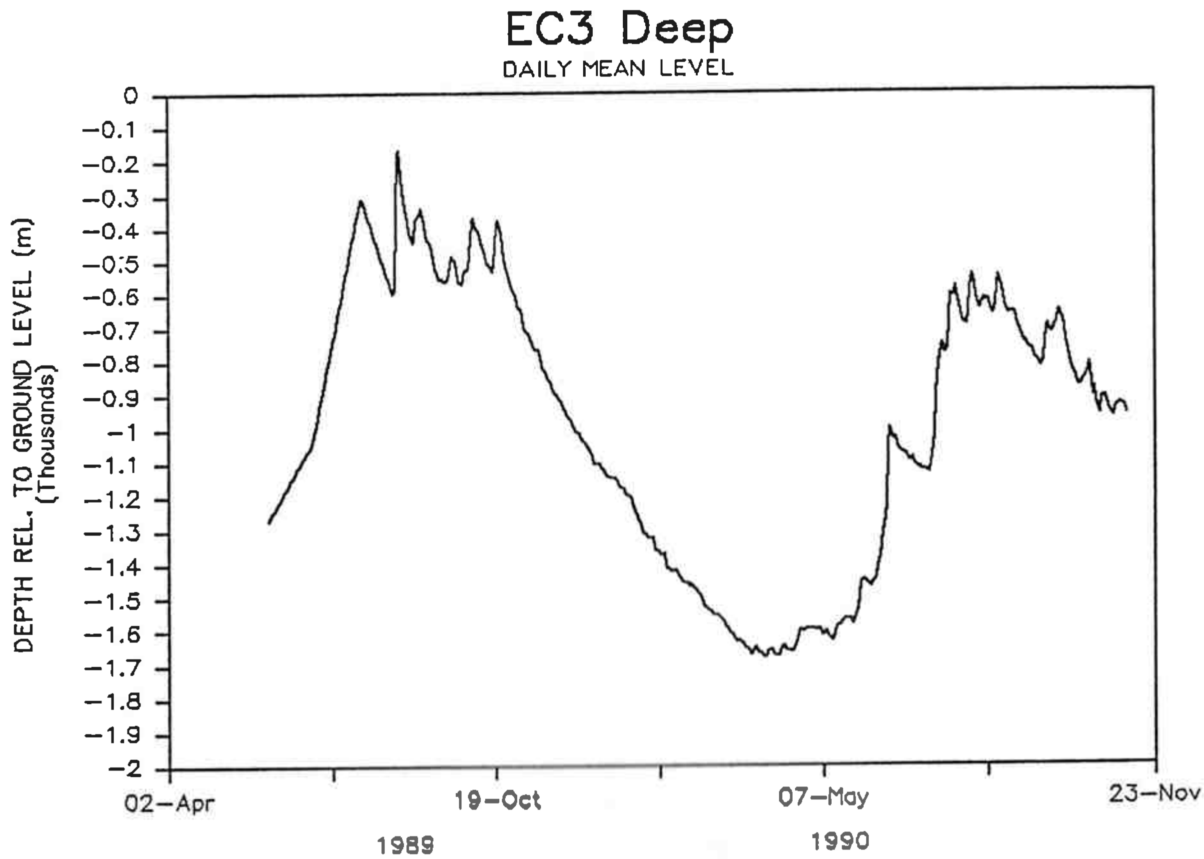
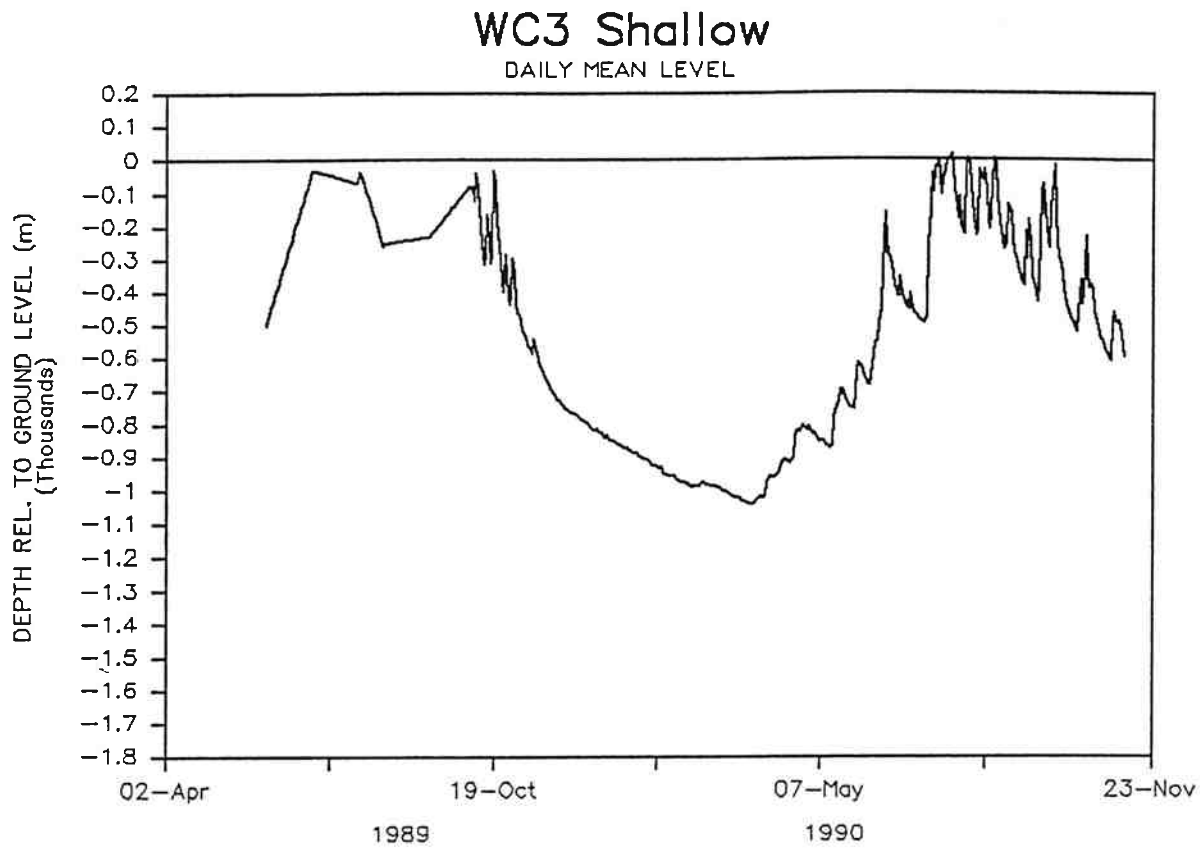


FIGURE 18. Hydrograph of **deep and shallow groundwater** systems at site EC3.



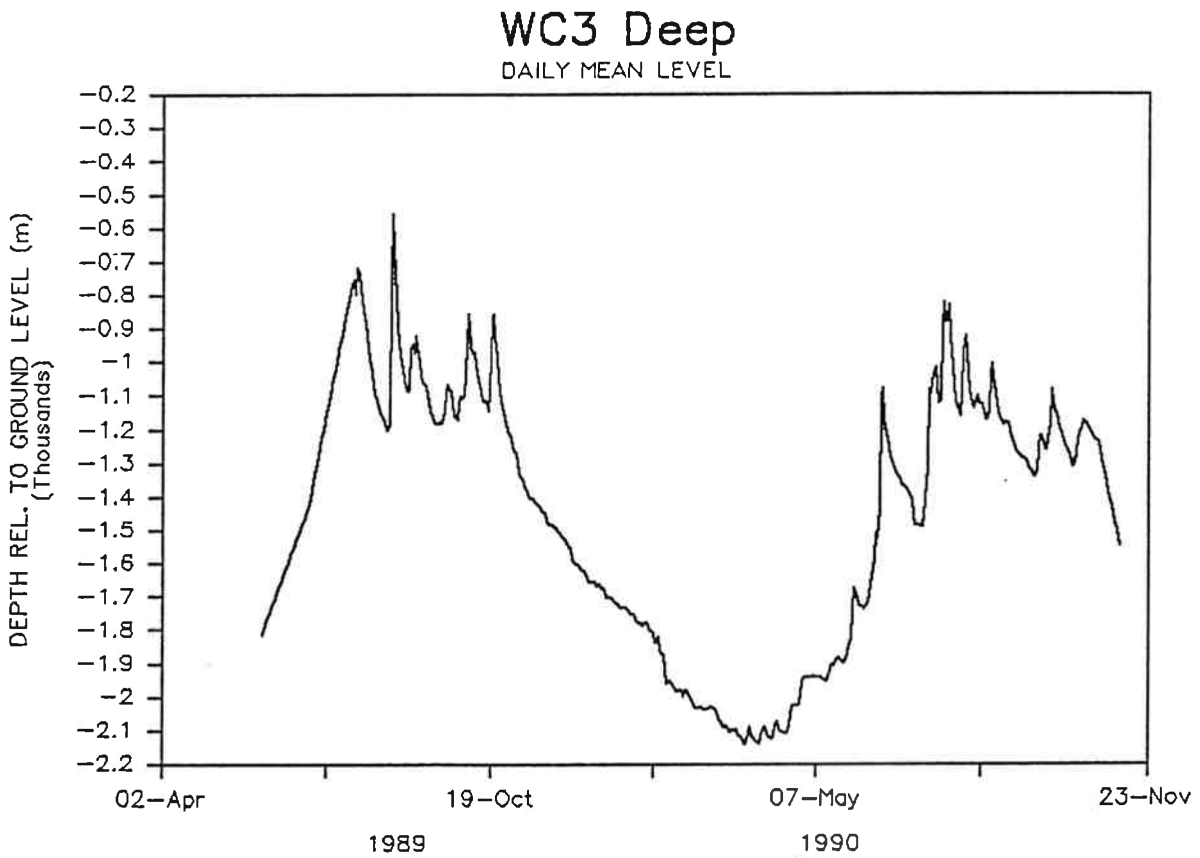


FIGURE 19. Hydrograph of deep and shallow groundwater systems at site WC3.

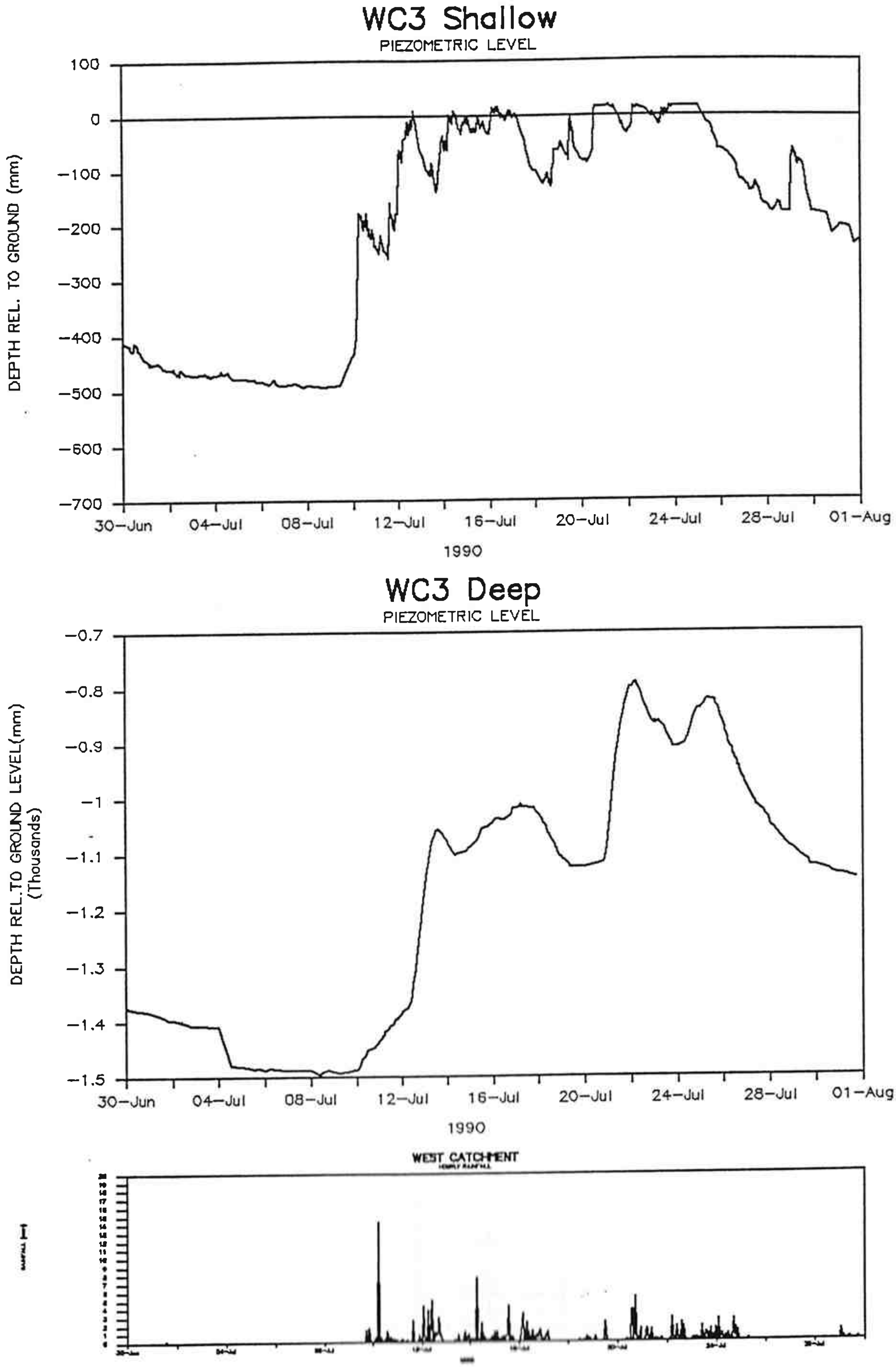


FIGURE 20. Response of deep and shallow piezometer to rainfall over two storm events.

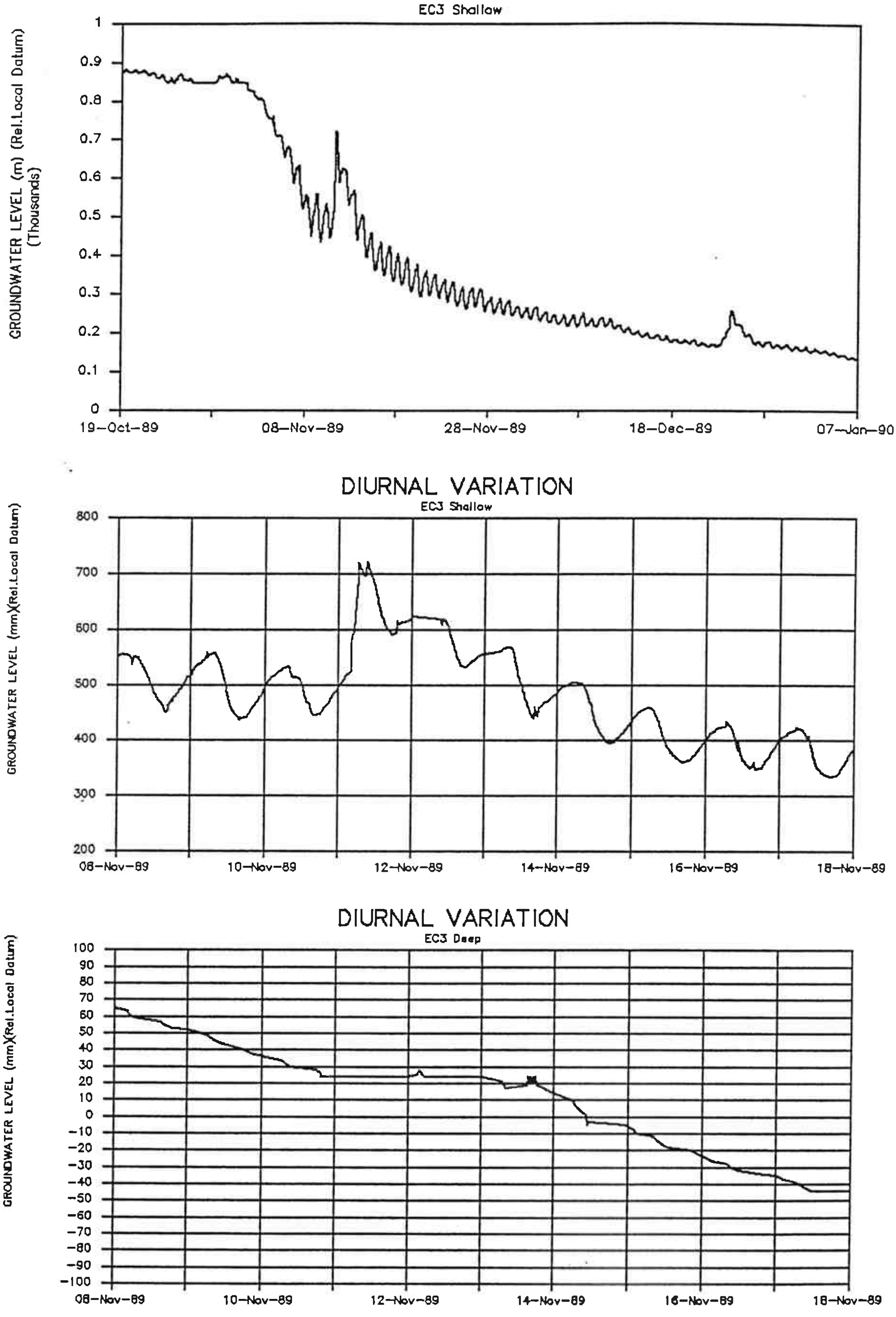


FIGURE 21. Diurnal variation of deep and shallow piezometers at site EC3.

the diurnal variation of one bore pair (EC3). This diurnal variation is evaporation driven, and also demonstrates that a connection exists.

There is clearly a rapid transfer of hydraulic pressure through the deeper aquifer, but it was not clear where the connection is between the deep and perched aquifers.

The groundwater levels at each shallow and deep piezometer were used to draw contours of the groundwater surface at different times of the year.

Deep Groundwater

FIGURE 22 shows the deep groundwater piezometric level contours at their lowest level. (The features are similar for each map drawn, with a base level raise or fall with season). The map shows a general east to west groundwater gradient, with a sharp fall to the south close to the Harvey River bed. The annual variation in piezometric level is the deeper aquifer ranges between 960mm and 2800mm, with a mean of 1600mm. This is generally greater than the variation in the shallow perched aquifer at all sites except two.

One remarkable feature is the groundwater high point at bore EC2D. It is difficult to explain how this could come about but it coincides with a large wet flat which remains moist all year round. The suggestion is fairly strong that this groundwater head is the cause of the area remaining moist throughout the year, and hence supporting the good summer pasture.

Shallow Groundwater

The variation in perched watertable varied between 800mm and 1600mm across the site except for two sites which never had perched water. The mean variation in depth was 1200mm.

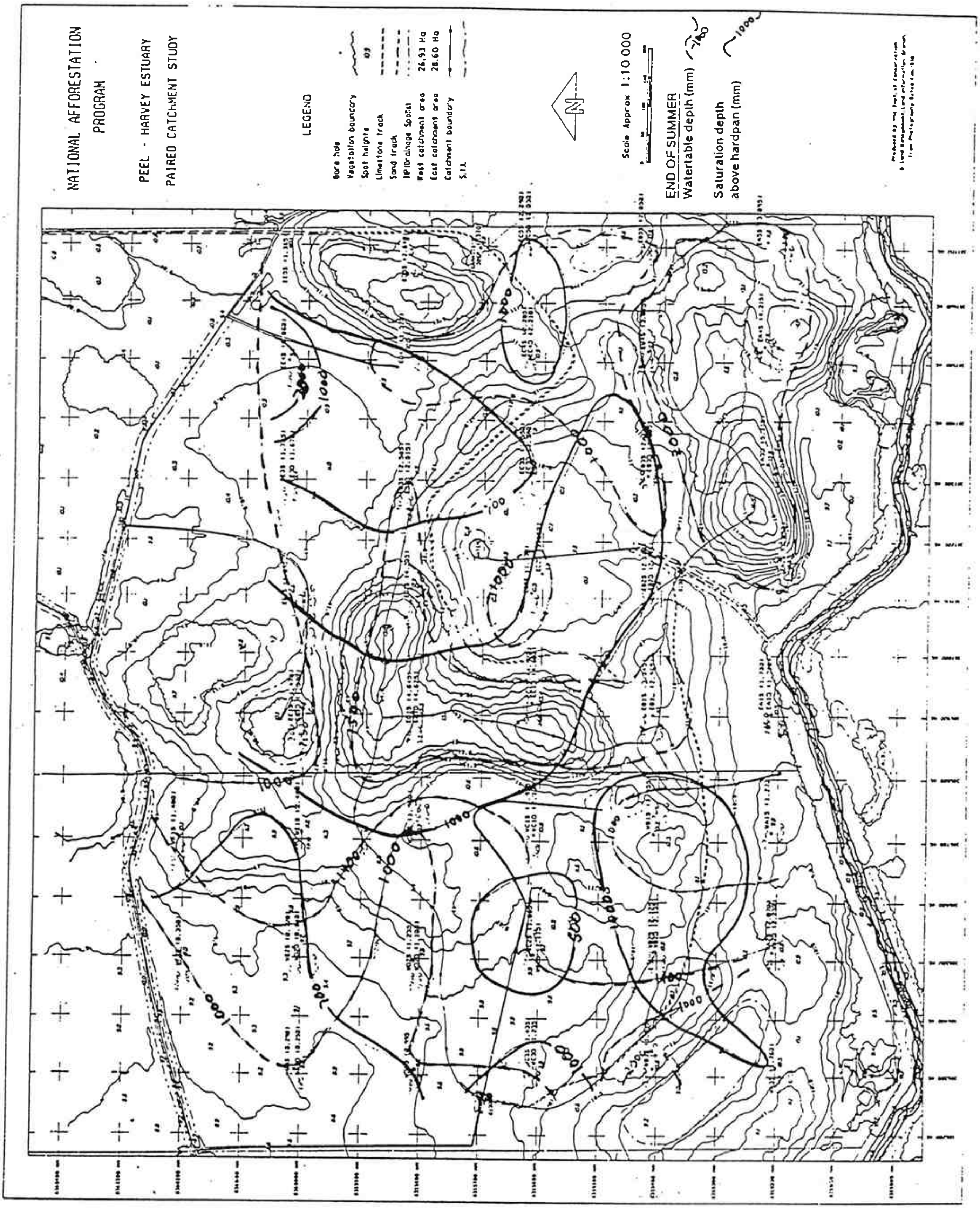


FIGURE 22. Depth to watertable and depth of water above the hardpan at the end of summer.

The perched watertable at the end of summer (hence its lowest level) varies from 700mm to 1400mm below the surface (FIGURE 23). The exception to this is under the sand ridges (as might be expected) when it drops to over 4000mm from the surface in places. At this time of year the water storage above the hardpan can be from 200mm to 420mm of water. This suggests that some areas of a large tree plantation may well suffer from drought stress at this time of year.

FIGURE 24 shows the perched groundwater levels at their lowest level. The influence of the drain in the eastern catchment is inferred near the outlet to the south, but the natural hydraulic gradient appears to be to the north. As will be discussed in a later section (4.3) the investigations of the hardpan have revealed that the subsurface catchment actually does drain to the north, and so the drain was originally constructed going the wrong way.

4.3 Hardpan Investigations

The shallow subsurface water perches on a sandy iron-organic hardpan. Excavations nearby with a bulldozer have revealed the hardpan to be continuous, without much root penetration or fractures. At one site a channel with roots in it was found under the hardpan, about 3m from the surface, and at another roots were found in auger spoil from 10 m. However, the layer is generally found to be impervious and hence would pose as a major barrier to root and water penetration.

4.3.1 Hardpan Mapping

The hardpan was probed at 50m intervals and its surface mapped (see FIGURE 25). The contours reveal, firstly, the hardpan has considerably less relief than the surface, with total variation of a little over 2m in the study area. The subsurface catchments are slightly smaller (12% for the eastern and 20% smaller for the

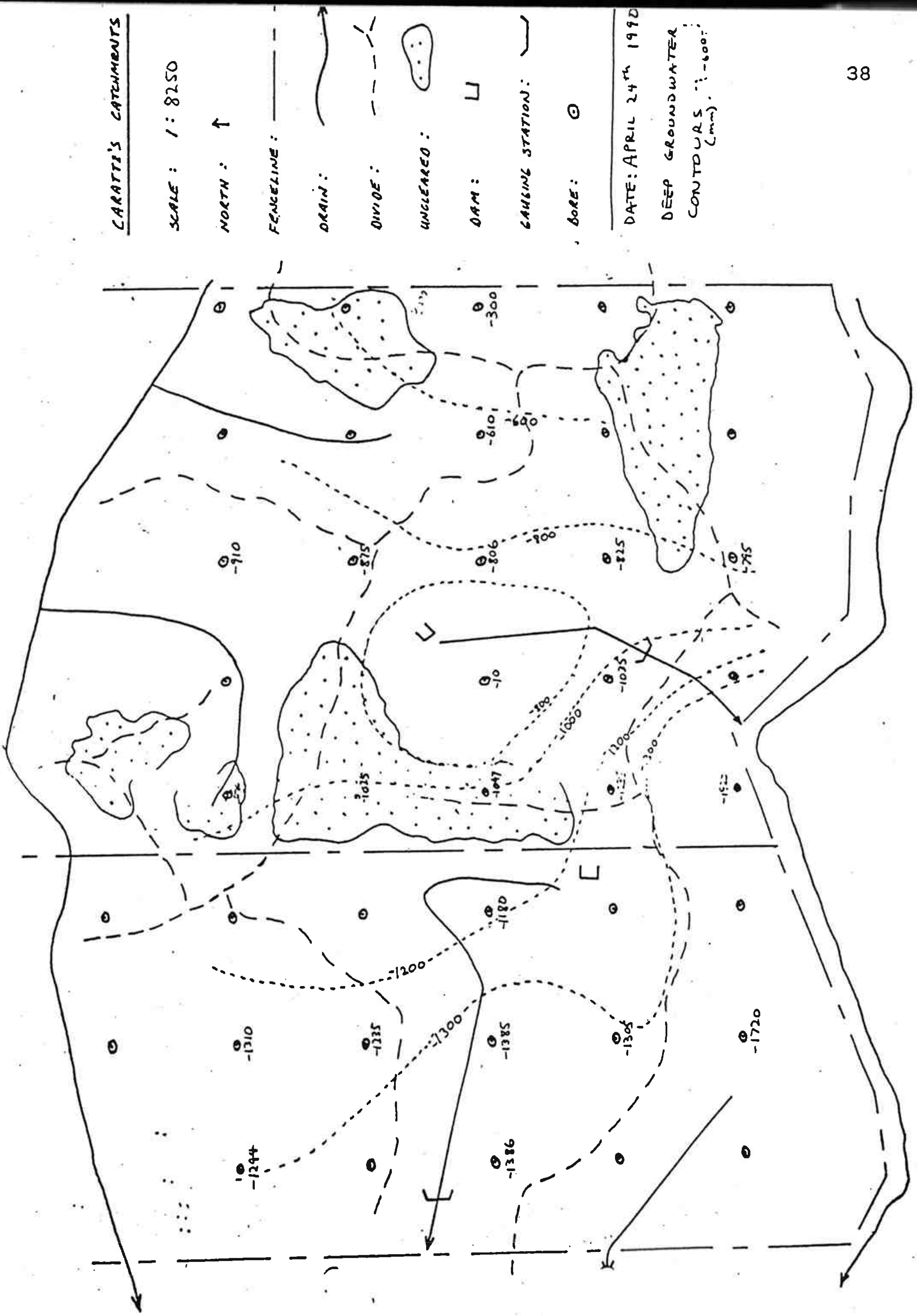


FIGURE 23. Map showing deep groundwater contours (mm) relative to local datum in April 1990.

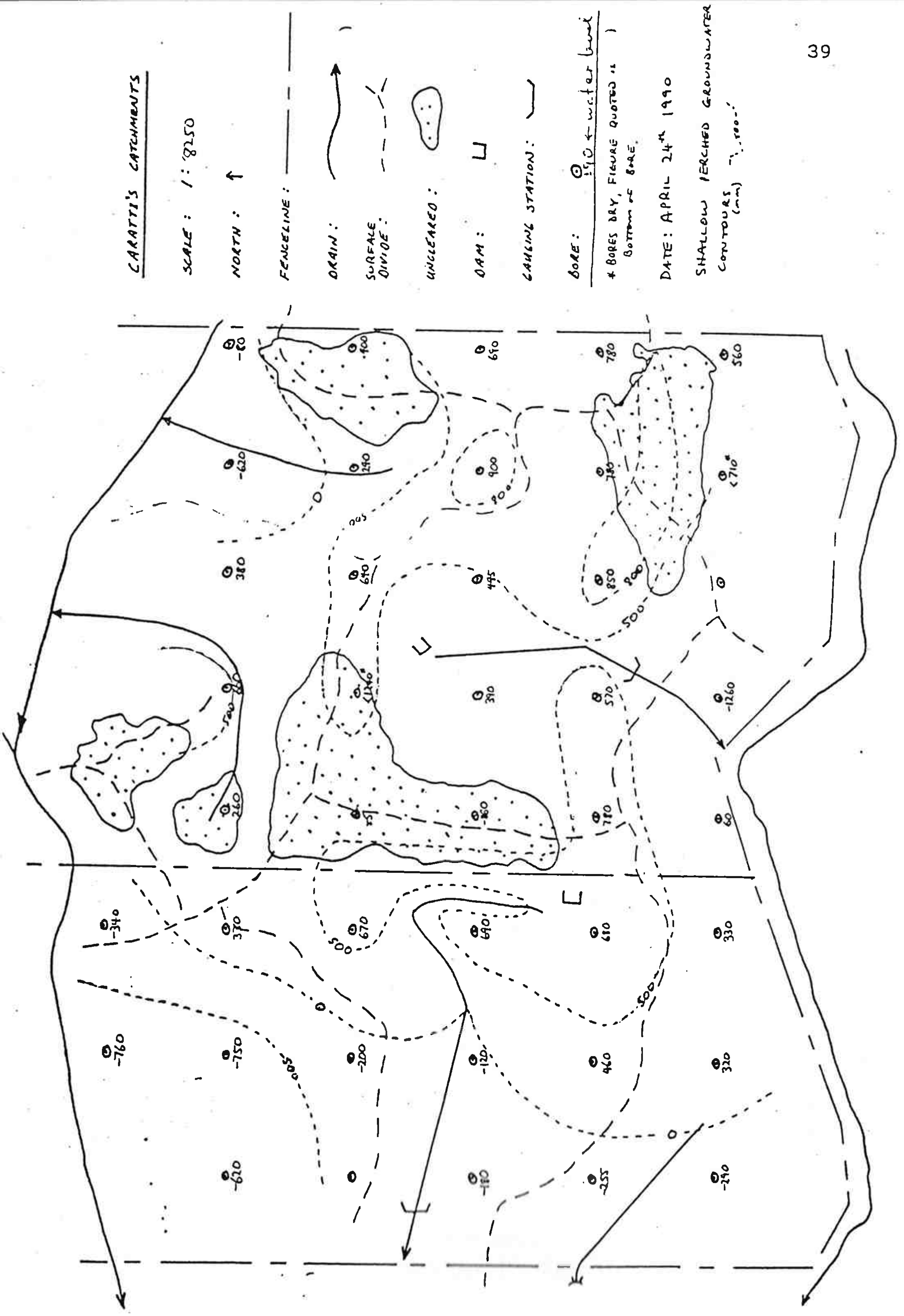


FIGURE 24. Map showing shallow perched groundwater contours (mm) relative to local datum in April 1990.

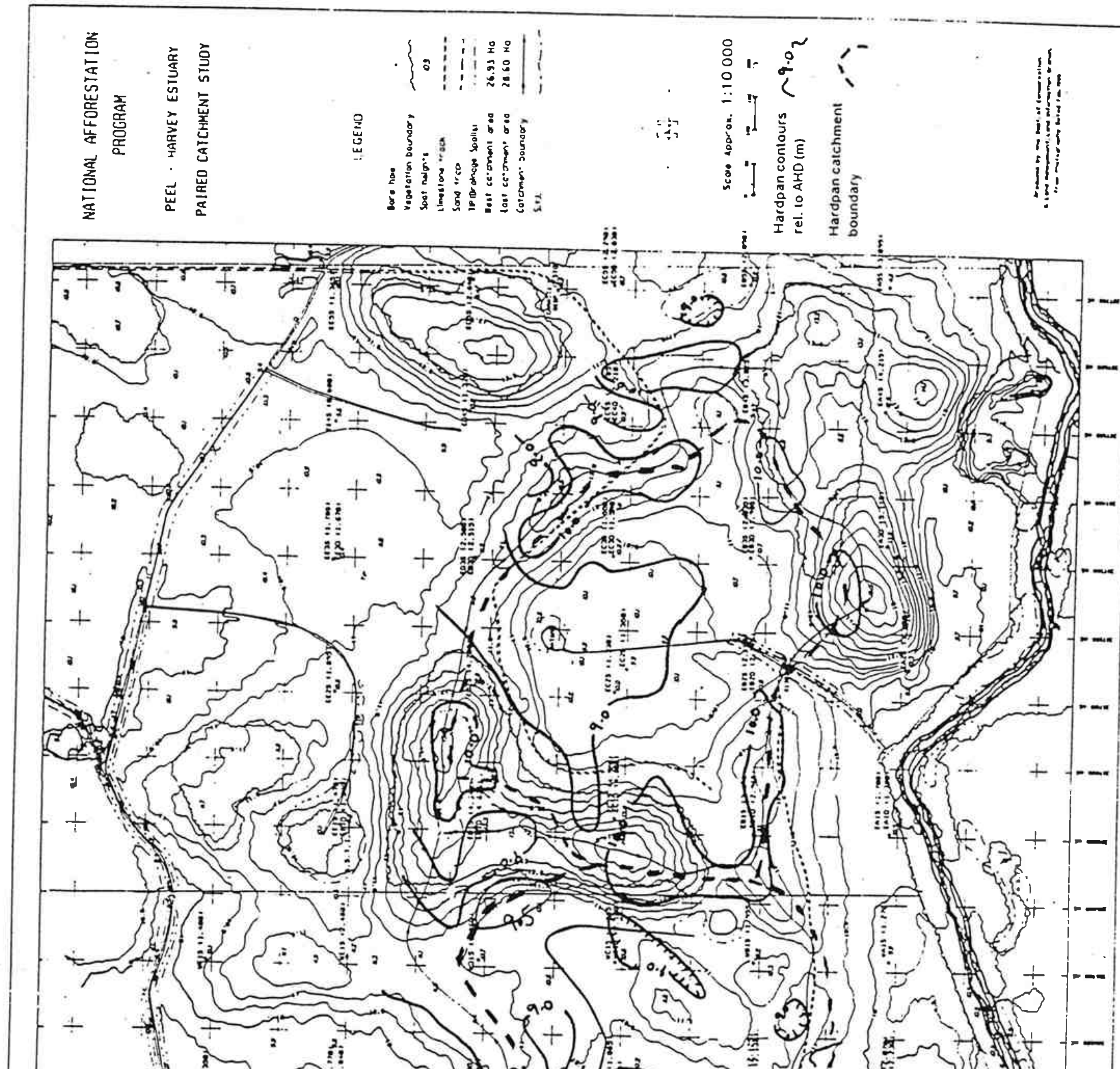


FIGURE 25. Map showing hardpan contours and "hardpan catchment" boundary.

western) than the surface topographic catchments. The western subsurface catchment outlet is near the surface outlet and gauging station. However, in the eastern catchment subsurface contours reveal that the subsurface outlet is actually to the north of the catchment, whereas the drain (and gauging station) was constructed draining the area south to the Harvey River. This probably explains why the catchment never dries out. It suggests also that shallow groundwater with dissolved phosphorus, may move north through the sandy ridge rather than south and out the drain. However, the gradients are so slight that this flow will be only a few percent of the total flow out of the catchment.

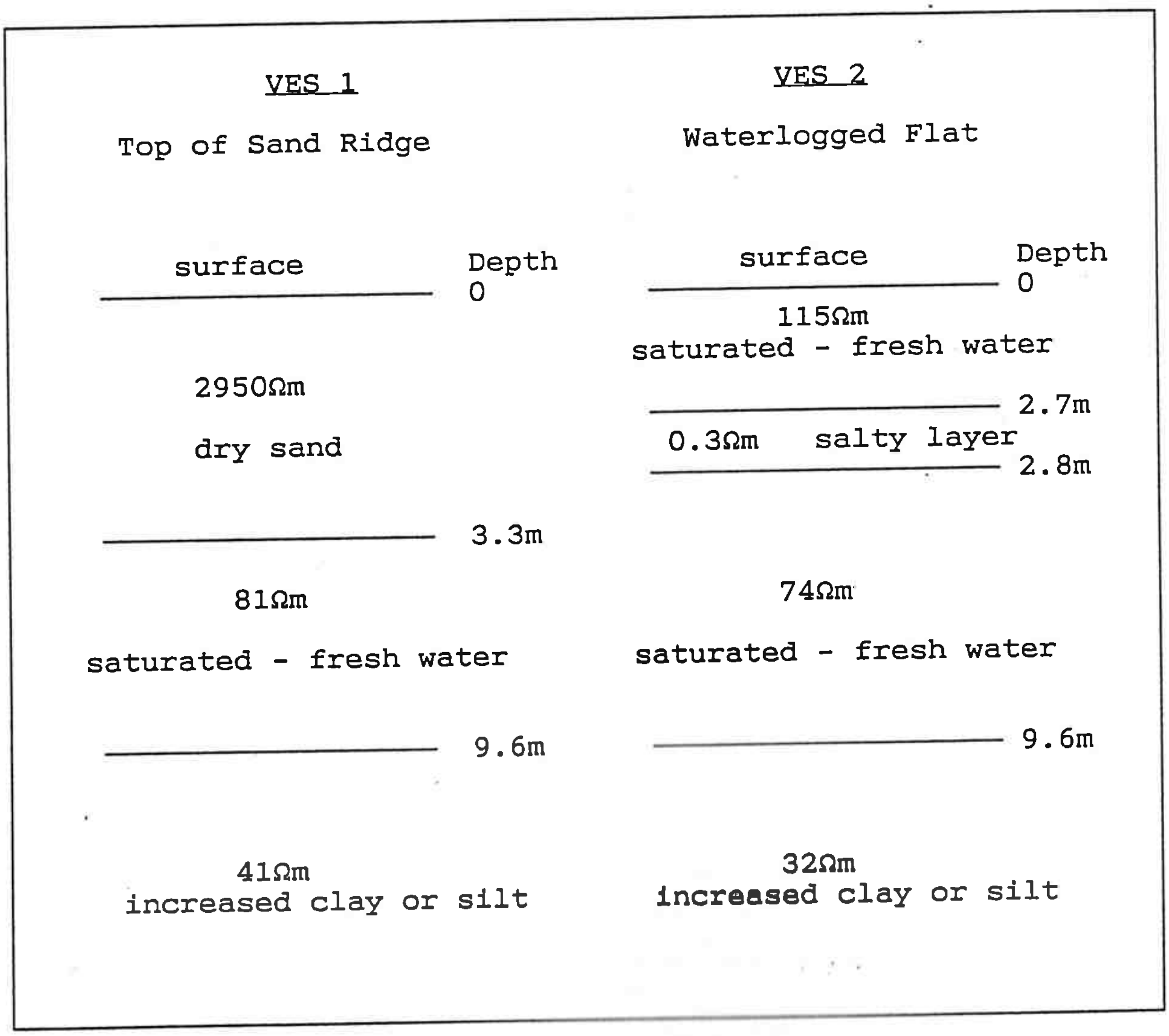


FIGURE 26. Results of the vertical Electrical Resistivity soundings (November 1989)

4.3.2 Electrical Resistivity (Schlumberger) Soundings

The vertical electrical soundings (FIGURE 26) revealed several layers, with a higher salt content in the hardpan. The depths of the layers determined varied quite markedly from those determined by other methods, and so these, due to the technique, must be treated with some caution. The survey suggested that under the waterlogged flats that the hardpan was 7m thick, and under the dunes 14m thick. This is undoubtedly an overestimate.

It is known from the drilling programme that the hardpan is seldom as thick as this. A thin layer of salt concentration was selected just above the hardpan at the swampy site. This may well be a layer of richer organic matter just above the hardpan.

4.3.3 Seismic Refraction

The seismic refraction survey revealed a great deal more information about the hardpan surface and structure. FIGURE 27 shows firstly, quite a variation in depth to the hardpan. The geophones were set 5m apart and this revealed the irregular hardpan surface. The survey also showed considerable variation in sound velocity within the hardpan. This sound velocity equates, to some extent, to hardness. A maximum velocity of 2250 ms^{-1} was found, which indicates a highly consolidated structure.

This confirms investigations which have already been made. The interest with this survey is that the degree of consolidation of the hardpan is variable with velocities of 1850 ms^{-1}, 1650 ms^{-1} and 1525 ms^{-1} also being measured. The lower velocities indicate somewhat less consolidation where they occur. These coincided with the dry sand ridge, and also an area just down slope of this ridge.

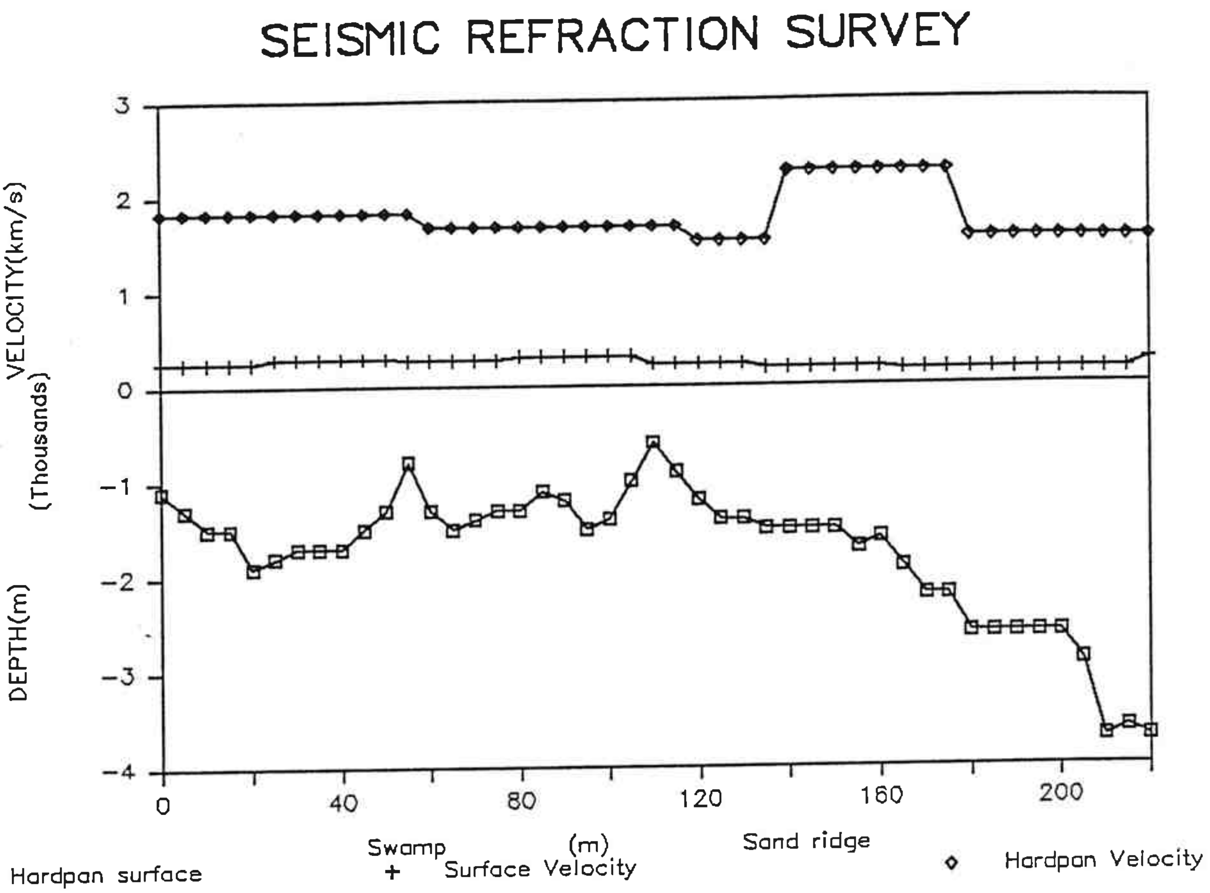


FIGURE 27. Seismic refraction survey results.

The lower surface sound velocities correspond to that of loosely packed dry sand, as is evident at the surface.

4.4 Electrical Conductivity Survey

The apparent soil electrical conductivity as measured by the EM31 probe is mapped in FIGURE 28. The main features which stand out are the high conductivity areas at the northern end on the eastern side (labelled "A"), the northwestern corner ("B") and on the Harvey River bed ("C"), to the southern end of the study area. The high conductivity of the Harvey River bed is most probably due to the finer textured more silty soils of that area, and not due to soil salinity. The other areas however may well be sites likely to become salt affected. Signs of surface accumulations of salt have been observed in the area near piezometer sites WE3 and EE4 which lie in the high conductivity areas shown. This survey suggests that

FIGURE 28. Apparent soil conductivity contours resulting from electromagnetic (EM31) survey.

this condition is unlikely to improve without a change in land use. A slight rise in conductivity is also evident around the centre of the eastern catchment ("D"). This is not a major feature, but may be symptomatic of a problem developing. When viewed in conjunction with the groundwater surface (see the next section), it suggests that a salinity problem may develop at this site.

4.5 Saturated Hydraulic Conductivity Tests

4.5.1 Constant Head Permeameter

The results of these tests were quite varied, as can be seen from Table 2 and FIGURE 29. The reason for the uncharacteristic low values for the Gavin sands is not clear but is probably due to the non-wetting character of the soils.

TABLE 2 : Hydraulic conductivity from constant head permeameter measurements

Soil Type	Permeameter Head (mm)	Ksat mm/hr	Ksat(m/s)
Gavin	500	632	0.176 E-03
	145	858	0.238 E-03
	110	11962	3.32 E-03
Mean*±σ		4484±5300	
Joel	335	505	0.140 E-03
	235	574	0.159 E-03
	120	3260	0.906 E-03
	130	5662	1.57 E-03
	110	11277	3.13 E-03
	220	3920	1.09 E-03
	260	1439	0.400 E-03
	212	3065	0.851 E-03
	260	217	0.0603E-03
	290	959	0.266 E-03
	330	1030	0.286 E-03
Mean*±σ		2900±3100	
Sandy clay	380	365	0.101 E-03
	520	209	0.0581E-03

* σ=standard deviation

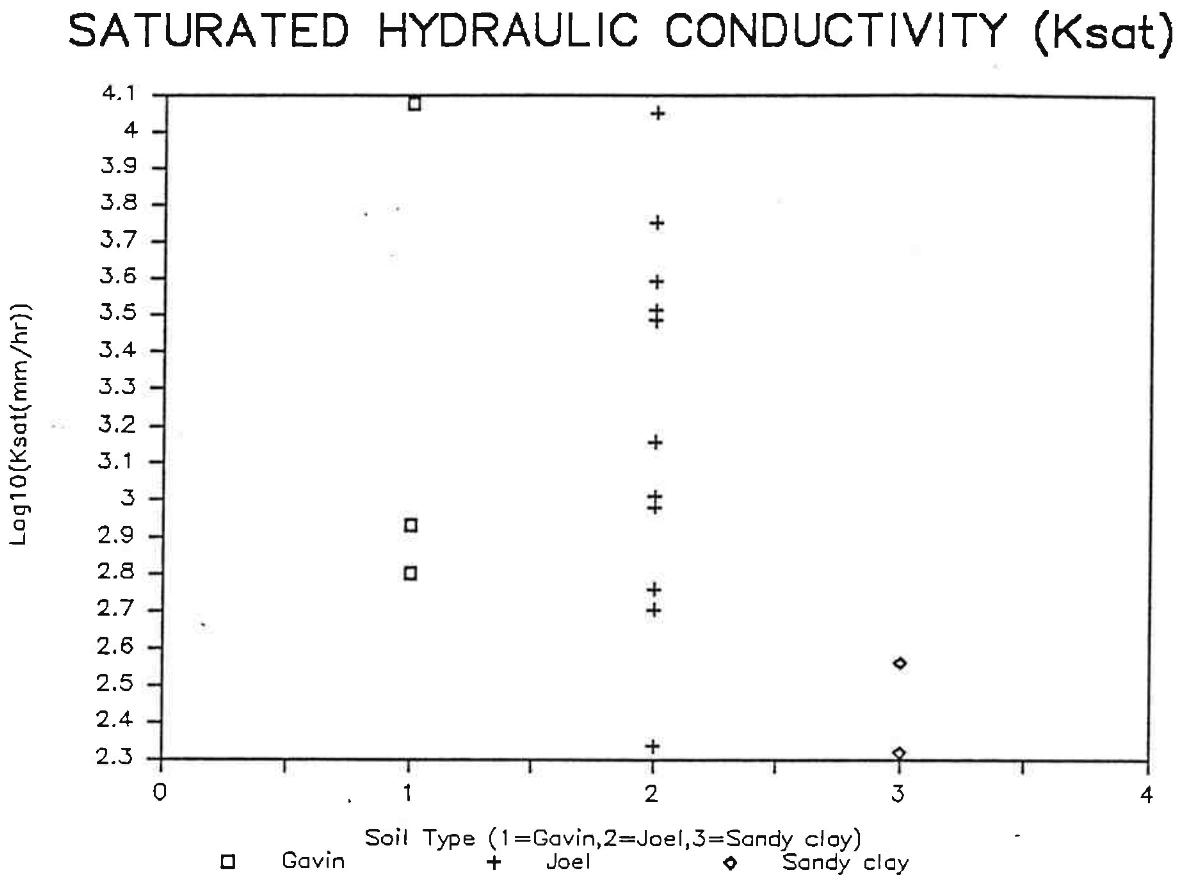


FIGURE 29. Saturated hydraulic conductivity by soil type.

Cameron and Ho (1984) reported saturated conductivity values of 30m day^{-1} (= 1.25m hr^{-1}) from laboratory tests on Gavin sand, and Bettenay, et al (1985) used this figure and 2.5m day^{-1} for Joel flats and swamp soils. The figures obtained at this site are much higher than those mentioned and used by Bettenay et al.

4.5.2 Well Pump Test

The interpretation of the pump test data was hampered by the variability of pump rate. The method of analysis followed that of Hazel (1975) (pp 62 - 120).

The primary reason for performing the pump test was to test whether there was any connection between the shallow and deep aquifers. The response of the deep piezometers to rainfall indicates that there is a connection but it may not allow any significant quantity of water to flow between the systems.

The results indicated no meaningful connection within 400m of the bump bore.

Analysis of the data also gave a saturated hydraulic conductivity of the deep aquifer of 30m day^{-1}.

4.6 Soil Phosphorus

The soil was sampled 3 times during the study period. In January, 1990, the farmer took soil samples from one of the sand ridges for processing by the Dept. of Agriculture. In May, 1990, immediately prior to fertilizer application, both catchments were sampled intensively. This was repeated in October. The results are given in TABLE 3.

TABLE 3 : Soil Phosphorus content data.

	EAST			WEST		
Soil	B1/B2	B6/B8	Total (kg)	B1/B2	B6/B8	Total (kg)
10/5/90						
Conc^n(kg/ha)	4.05	10.2		4.05	6.3	
P store(kg)	40.5	140.8	181±18	40.5	86.9	127±13
P added in May		200	200±20		200	200±20
P added in Aug	60±20		60±20			
less drain P			-35±4			-22±2
Total			406±62			305±35
6/10/90						
Conc^n(kg/ha)	8.25	11.25		2.25	4.2	
P store(kg)	82.5	155.2	238±24	22.5	58.0	80±8
Difference			168±86			225±43

4.7 Pasture Production

The total measured pasture production is given below. As stressed in section 3.3 these results do not give definitive answers to actual production from the farm, but merely a guide to the relative production of the 2 catchments.

Within the errors of the method, the 1990 production can be considered the same for both catchments, but clearly in 1989, the eastern catchment produced a great deal more pasture. The reason for this is not clear at time of going to press.

TABLE 4 : Total measured pasture production by soil type for the 2 catchments.

	1989		1990	
Soil	East	West	East	West
B1/B2	2110	2340	1950	2420
B6	1960	2470	4990	5390
B8	6760	790	3440	4570
Weighted Mean	3110	2200	3460	3580

5. SUMMARY

A good foundation has been laid for an on-going study of the effects of integrated tree plantations with traditional agriculture on the sandy soils of the Peel-Harvey catchment. The selected catchments appear well matched, despite slight differences in geomorphology, total runoff and phosphorus load.

The East catchment has had a higher runoff by an average of about 30% in both years. The cross calibration between the two catchments is not yet established. There is a significant difference in runoff coefficient which has not yet been totally explained, although it is probably due to the eastern drain not being set to the hardpan. The ratio of runoff coefficients has varied over the recording period, and more data are required to establish the relative characteristics of the catchments.

The flow weighted mean Phosphorus concentration (FWMP) has varied substantially. In 1989, the West catchment had a 40% higher FWMP than the East, while in 1990 when fertilizer was applied, the two catchments had essentially the same FWMP. A direct comparison was not absolutely valid due to an extra application of fertilizer which was made in August to the eastern catchment only. The high Phosphorus concentrations detected early in the season in the eastern catchment were prior to the application of fertilizer. These are due to the mineralisation of phosphorus over the hot summer period. This was not observed in the western catchment, but no flow was recorded during this period.

The reason for the high FWMP of the western catchment in 1989 has not been explained. The phosphorus data for 1991 will be keenly observed.

Although the pump test data did not detect a connection between the shallow and deep aquifers, the groundwater data show that a good link exists between the two aquifer systems. The location and character of this connection (whether by large preferred pathways or diffuse pores) has not been established. The character of this connection has implications for tree plantation establishment, as trees in a large plantation will probably need access to the deeper water system. Tree roots have been observed within and below the hardpan.

Considerable variability in sound velocity within the hardpan was detected by the seismic refraction survey. It is not known whether the variable degree of consolidation implied by this sound velocity variability would be enough to allow the tree roots to penetrate. A seismic survey on a site which could be excavated may be warranted to evaluate and calibrate the technique for this interpretation.

The economics of tree farming and integration of tree plantations on farms in the Peel-Harvey catchment has not been rigourously tested here. A complete study would include this aspect of the NAP programme.

6. RECOMMENDATIONS:

1. Calibration should continue for at least one more year, preferably two, prior to planting, to establish the relative runoff characteristics of the catchments and the relative phosphorus characteristics. Intensive drain monitoring should continue until 3 years after planting, and resume 2 years prior to harvest. In the intervening years a lower level may be acceptable.

2. During 1991 and possibly subsequent years, if flow does not occur in the western catchment at the time of commencement in the eastern catchment, shallow groundwater should be sampled in the western catchment as soon as flow begins in the eastern catchment. This can then be used to measure the mineralisation of phosphorus over summer and the phosphorus content in the shallow groundwater which may be moving out of the catchments through the soil.

3. Drain data should be reported every 3 months by the WAWA Harvey to the Supervising Authority and checked for consistency.

4. The piezometers with dataloggers should be downloaded every 3 months, and the data stored on the Water Authority's database. The data must be checked for adequate operation of the dataloggers. The batteries should be replaced early in 1991, and annually.

5. Ground water monitoring should continue, although this can be on a on a reduced basis.

6. Further investigation of the connection between the shallow and deep aquifers should be undertaken, to establish whether a treatment is required to allow tree root access through the hardpan to the deeper groundwater, or alternatively identify the areas likely to be most successful for tree growth.

7. A further seismic survey should be undertaken followed by excavation to calibrate the sound velocity with respect to degree of consolidation of the hardpan (perhaps with penetrometer), and penetrability by tree roots.

8. Soil sampling should continue at the beginning and end of each season, and good phosphorus budgets should be established.

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