Peel Harvey Estuary Studies Ground Water Investigations

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PEEL-HARVEY ESTUARY CATCHMENT STUDIES

GROUND WATER INVESTIGATIONS

by

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SUMMARY AND RECOMMENDATIONS

Assessment of the first two years of data collected from the experimental Talbot's farm site has given detailed insight into defining and quantifying the major processes of subsurface water movement and its contribution to surface water runoff.

Results of the monitoring programme have yielded estimates of groundwater storage increases of about 300 mm over the 1983 winter period compared to measured rainfall of about 470 mm.

Groundwater level increases resulted in flooding in much of the low lying Joel soil and swamp soil areas of the site. This was seen to result in surface flow and groundwater flow to the shallow drains discharging from the lower areas.

Hydraulic testing of the groundwater systems at two sites within the Bassendean association was undertaken during 1984. Results from this indicated that the deeper aquifer below the coffee rock had high transmissivity and the potential to transport large amounts of water (and phosphorus) to sink areas. Pumping however, could not induce any leakage of shallow groundwater (containing the phosphorus) through the coffee rock.

Assessment of groundwater phosphorus concentrations has enabled determination of the spatial distribution, and the time variation in phosphorus storage within the saturated soils.

Generally, high phosphorus storage was encountered in the SW 2 swamp soils where concentrations of up to 32 mg l^{-1} were recorded. These areas are generally inundated during winter. Concentrations in the Joel series were lower, rarely exceeding 7 mg l^{-1}. In SW 1 swamp soils adjoining the Meredith drain and in the higher Gavin soils,concentrations were generally low rarely exceeding 3 mg l^{-1}.

Phosphorus storage within the groundwater was estimated to increase from summer to the end of winter, being more related to groundwater storage increases rather than to concentration changes. Estimated storages were generally of the order of about 1 kg ha^{-1} to 15 kg ha^{-1} the lower estimates being on the north catchment and in areas adjacent to the Meredith drain.

These estimated storages are considerably less than the total inorganic and organic phosphorus storages of the Bassendean soils. Note that typical phosphorus application rates are 18 kg ha^{-1} yr^{-1}.

No significant changes in groundwater phosphorus storage were observed following superphosphate application to the south drain catchment in 1983 and 1984, however large temporal variations in phosphorus concentrations were noted following groundwater rising to the soil surface.

In summary, assessment of phosphorus redistribution within the groundwater has shown the complexity in describing the physical processes involved and their variability in space.

This is apparently due to the interaction of 'fixed' phosphorus and 'mobile' phosphorus stores and their relationships to variations in soil properties and seasonal hydrology of the shallow soil system.

The detailed definition of water processes resulting from this study has resulted in the formulation of a process-based groundwater/surface water flow model. This model has been used to simulate the hydrological responses on the Talbot's site and is capable of predicting:

- groundwater recharge/discharge.
- groundwater storage changes.
- unsaturated soil water storage change.
- groundwater flow to drains and swamps.
- surface water flow to drains.
- rates of horizontal groundwater redistribution given

detailed site characteristics and seasonal climatic data.

The model has been calibrated by comparison of predicted results with recorded hydrological responses in winter 1983.

Preliminary modelling results indicated that groundwater level changes can be predicted to within about 20%, and cumulative drain discharges were predicted to within about 25% of those observed over the first 82 days of the 1983 winter flow period.

Further improvement in matching observed responses will be achieved by developing the recharge relationships used in the model, and by comprehensively adjusting the spatial estimations of hydraulic parameters in relation to soil types and landscape positions.

The development of a process based model and its subsequent calibration to real field hydrology in this manner gives the researcher greater insight into identifying and quantifying the unmeasured mechanisms dominant in the hydrological system.

The water flow model is seen as a forerunner to the development of a phosphorus transport model. This model will be based on empirical relationships describing:

- the relationship between 'fixed' phosphorus in the soil profile and mobile phosphorus in the soil water, and rates of soil water movement.

- release of phosphorus from applied superphosphate to rainfall infiltration, plant uptake and to 'fixed' soil storage.

- phosphorus status in unsaturated soil profiles under varying conditions of climate, soils and hydrology.

It is expected that the large variability observed in phosphorus responses in a field situation may cause some problems in simulating farm behaviour in terms of phosphorus stores and phosphorus discharge to drain flow under different management practices.

Some catchment management practices which may reduce farm phosphorus export are apparent from the results of this study.

First, it is apparent that the total farm water (and phosphorus) yield to drain flow in any season, is highly dependent on, apart from rainfall, the depth to groundwater before the onset of winter rains. Hence if groundwater levels were reduced by one metre during the summer season, then it would require about an extra 100 mm of rain to occur prior to groundwater intersection of the surface, waterlogging and subsequent surface flow. The ability to achieve this would be dependent on the logistics of being able to lower water table levels and how to do it (e.g. by using deeper rooted summer pasture, trees, or summer irrigation from the shallow groundwater).

Second, drainage of internal swamps by discharging water of high phosphorus concentration to main drains is apparently a major source of nutrient to the estuary from the Bassendean association. Discharging the swamps on to soils which have the potential to adsorb phosphorus (e.g. SW 1 soils), if practical, would have the twofold benefits of reducing total phosphorus export and retaining phosphorus on the higher productive farm areas. Irrigation of these areas may be a practical solution. In summary, options relating to management of shallow groundwater to minimise surface flow need to be evaluated.

Future work to be undertaken in the groundwater studies programme is involved with examining the rundown of soil phosphorus on the untreated north catchment compared to the south catchment.

Particular studies should be undertaken. It is necessary to identify the presence and depth of the confining coffee rock over the entire Talbot's site. It is anticipated that this can be achieved by shallow seismic techniques using existing CSIRO equipment. As well as achieving these objectives the study should result in the development of these techniques so that they can be applied to other (study) areas. This would save considerable costs in drilling.

A study needs to be undertaken to determine the hydraulic properties of the shallow, above coffee rock, aquifer and the variability of these parameters in terms of soil types etc. Ideally, infiltration tests and constant head permeameter techniques could be evaluated and carried out in both summer and winter.

It is planned that the group will undertake groundwater aging studies to determine rates of water flow between the various aquifer sequences in different landscape positions. This may be achieved by tritium analysis, carbon dating or by application of radio-active phosphorus.

It is recommended that, following final acceptance of the surface water modelling results, a detailed review of (or workshop relating to) the possibility of modelling phosphorus transport processes, be undertaken. This will involve liason with other groups within and outside the Peel-Harvey Project. It should result in the formulation of a conceptual understanding of phosphorus redistribution such that a computer based model will be developed. The model should ultimately be capable of predicting the results of varying phosphorus management practices on pasture production, phosphorus storages on farmland, and phosphorus discharge to drain flow. This work would be carried out conjunctively with laboratory and field trials such as the Talbot's study, and should not be considered short term.

1. INTRODUCTION

1.1 General

This report has been complied by the groundwater studies group and integrates work that has been carried out both separately and conjunctively by the following personnel:

- CSIRO Division of Groundwater Research
  - Mr. Eric Bettenay
  - Mr. Maurice Height
  - Mr. Wally Russell
- CSIRO Division of Mathematics and Statistics
  - Dr. Tony Grassia
- Department of Conservation and Environment
  - Mr. Phillip Bayley
- Denis Hurle and Associates
  - Mr. Denis Hurle
  - Field Technicians

The groundwater studies reported here relate to two study sites, namely Talbot's (Karinga Downs) and Eastcott's, although the report has been concentrated on the paired catchments at Talbot's farm.

Parts of the study undertaken at the Eastcott's site are used in this report, namely system interpretation to provide a general understanding of the water flow components, and details of hydraulic testing at that site.

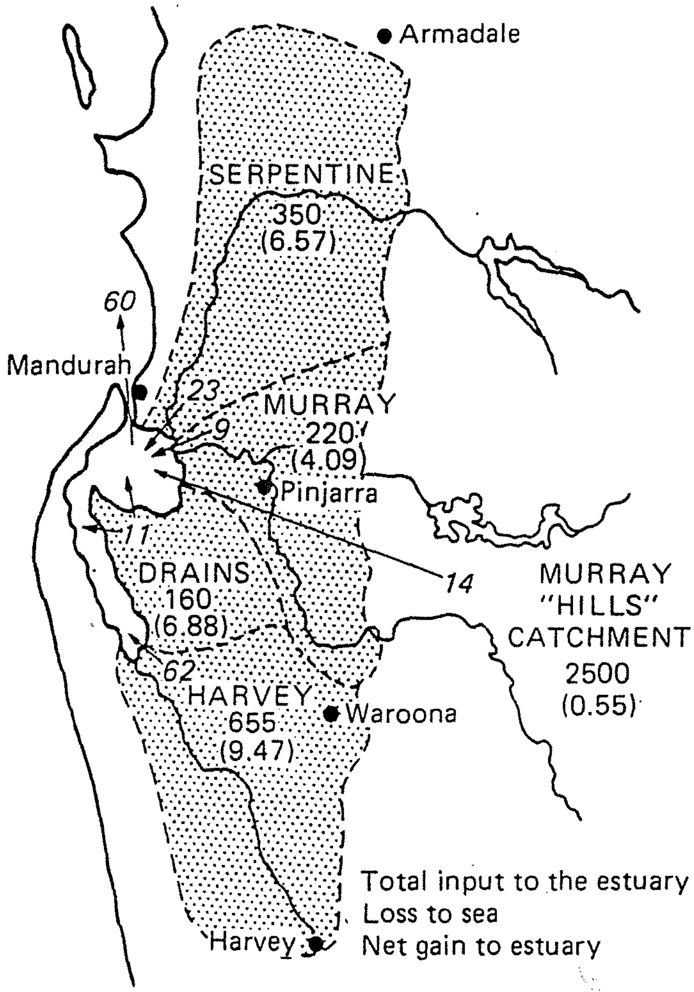
1.2 Background

Over a number of years, monitoring of rivers and drains converging on the Peel-Harvey Estuarine system, both regular sampling at gauged sites and opportunistic sampling at other sites, has indicated large differences in phosphorus concentrations.

The greatest part of the surface catchment of this system lies in the Murray-Hotham river system, to the east of the Darling Scarp. Although by far the greatest application of phosphate, largely as superphosphate, is made in this area, the major input of phosphorus to the Estuary comes from coastal plain drains and rivers (Figure 1.). Some 52% of phosphorus inputs to the Peel-Harvey system arrive via the Harvey River and Mayfields Drain within the Harvey catchment (1978 Budget Hodgkin et al. 1980).

The approximate boundaries of the various Swan Coastal Plain drains and rivers entering the Peel-Harvey system are shown in Figure 1. The catchment area is thought to be bounded to the west by the topographic high of the Spearwood dune system (further information on this is being sought through unpublished data of the Mines Department). To the north there is a low divide to the drainage of the Canning and Southern River Systems, while to the east the divide is marked by the Darling Scarp and to the south by a low divide from drains which discharge into the Harvey River Diversion Drain. Over much of the area both surface and groundwater gradients are very low (about 1:1000) and the boundaries between catchments are indefinite and frequently controlled by man made drains installed largely to reduce winter waterlogging.

Soils of the Peel-Harvey Catchment (Figure 2) vary in their chemical and physical properties, and this affects both their hydrological behaviour and their patterns of phosphorus export. Despite long continued and high phosphorus applications to irrigated areas, these loamy soils (largely Dardanup association) have not been found to export excessive quantities of phosphorus. This appears to be largely attributable to their very high capacity to adsorb phosphorus. More clayey soils of the Serpentine River association also have a strong capacity to adsorb phosphorus, and the surface runoff generated from these areas has low phosporus concentrations. Samson Brook North



Total input to the estuary	120 tonnes
Loss to sea	60
Net gain to estuary	60 tonnes

KEY

350 TONNES APPLIED

(6.57) % DISCHARGED TO ESTUARY

← 23 TONNES DISCHARGED

PEEL-HARVEY ESTUARY CATCHMENT STUDIES

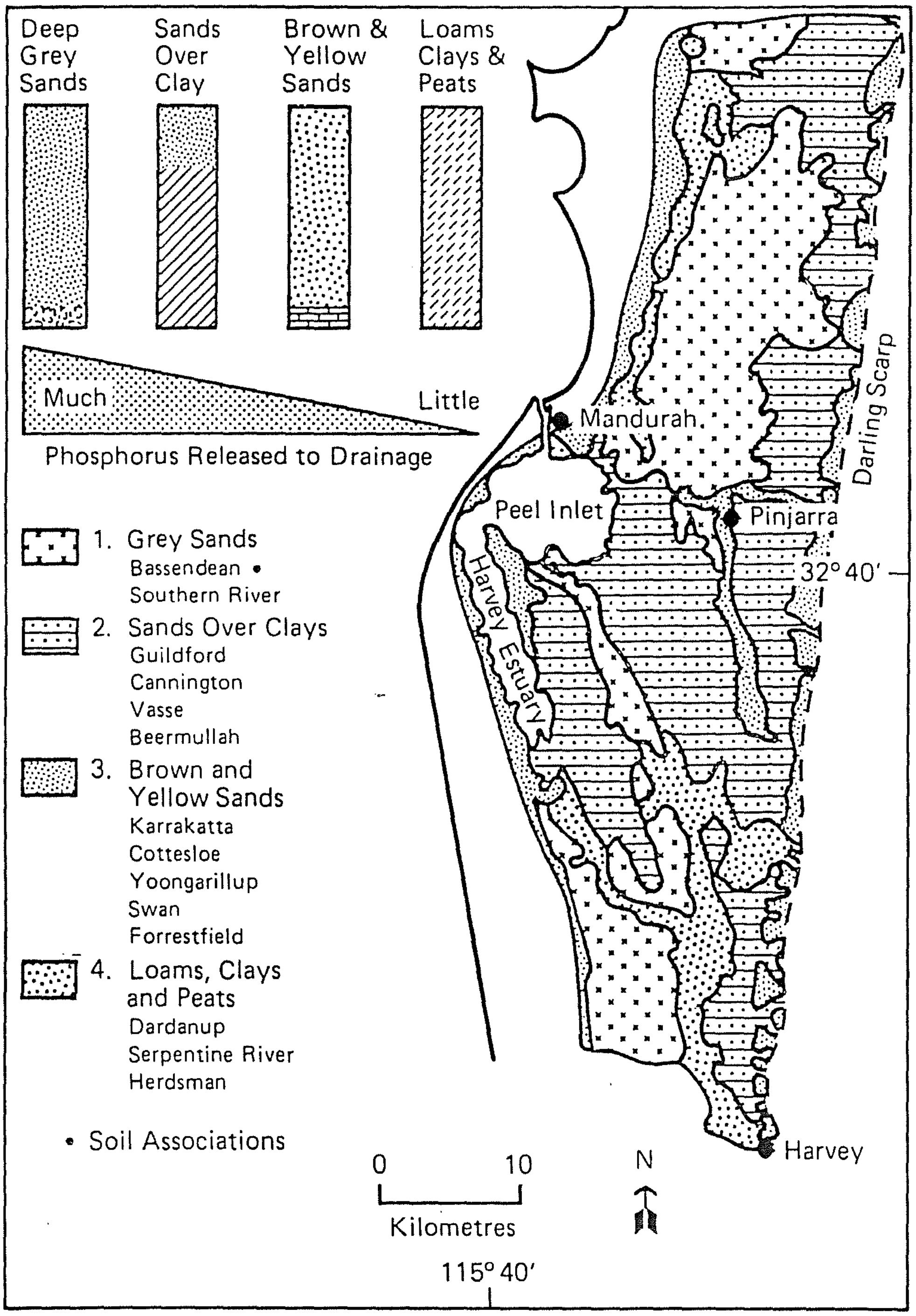
GROUNDWATER INVESTIGATIONS

TITLE: PEEL-HARVEY PHOSPHORUS BUDGET

CSIRO DIVISION OF GROUNDWATER RESEARCH
DENIS HURLE & ASSOCIATES (CONSULTANTS)

DRAWN: S.HALEY

FIGURE 1



PEEL-HARVEY ESTUARY CATCHMENT STUDIES
GROUNDWATER INVESTIGATIONS
TITLE: PEEL-HARVEY CATCHMENT SOIL MAP
CSIRO DIVISION OF GROUNDWATER RESEARCH DENIS HURLE & ASSOCIATES (CONSULTANTS)
DRAWN: S.HALEY — FIGURE 2

drain, which largely drains such loam and clay soils has a flow-weighted mean phosphorus concentration about 0.36 mg l^{-1} (Schofield et al, 1984).

Duplex soils (sandy surfaced soils with sandy clay subsoils) of the Guilford association have relatively permeable top soils, but infiltration is restricted by the subsoil and perched water tables develop in winter. Drain flow is generated by both surface and soil water flow and has intermediate phosphorus concentrations. Mayfields Sub-G drain, which drains soils of this type, has a flow-weighted mean phosphorus concentration of about 0.52 mg l^{-1}. However, because of the large area of such soils under agriculture, they are very important in terms of total inputs to the Estuary and are the subject of a separate detailed study.

Sandy soils of the Bassendean association are characterised by low sandy rises, with intervening flats and swamps which also have largely sandy soils. There is an extensive shallow aquifer system and seasonal and permanent swamps represent areas where groundwater intersects the surface at various times of the year. In areas where these soils are developed for agriculture, groundwater with phosphorus concentrations of up to 30 mg l^{-1} have been recorded. Meredith drain, the catchment of which comprises areas of native vegetation as well as extensive development for agriculture on these Bassendean soils, has a mean flow-weighted phosphorus concentration of about 1.7 mg l^{-1}. This relatively large input of phosphorus to the estuarine load has lead to the detailed study which is the subject of this report.

1.3 Scope of the Studies

The overall objective of these groundwater studies is to investigate the leaching of fertilisers from agricultural areas of permeable grey sands of the Swan Coastal Plain.

Measurement of sources of nutrient (phosphate) to the Peel-Harvey drainage system show that these areas of infertile low phosphate fixing soils contribute significantly to total phosphorus yield.

The groundwater studies, in detail, involved:

- selection of paired catchments on which different phosphorus management strategies could be evaluated. This selection was done jointly with personnel from DCE and other groups involved in the study programme.

- installation of networks of groundwater observation bores on the pair of experimental catchments.

- monitoring of groundwater and groundwater phosphate responses to seasonal climatic forcing.

- evaluation of the above responses such that a conceptual understanding of the hydrology and phosphorus transport processes can be formulated.

- development of a computer based model of the transport processes such that the observed components of phosphorus redistribution from soil to drains could be simulated.

- utilisation of the model to predict phosphorus rundown times and dominant processes of water and phosphorus movement, under different fertiliser management practices.

Consequently the groundwater studies are dependent on data and results provided by the other project groups, particularly the climatic and runoff data reported by DCE and PWD personnel.

2. THE STUDY PROGRAMME

2.1 Site Description - Talbot's

2.1.1 Location

Talbot's farm (Karinga Downs) which has a total area of 200 ha lies to the north of the Bagieau Rd - Alexander Rd alignment, and straddles the boundary of the Karrakatta and Bassendean soil associations. Meredith D drain flows from south to north approximately along this boundary. A major stream gauging station and sampling site is situated on Meredith drain on the south side of Johnston Rd. Approximately 70 ha of Karinga Downs, together with a part of the property adjoining to the east, has been instrumented for a detailed hydrological study. This area was chosed particularly because it is considered to be representative of normally farmed Bassendean association for the district, and because of the presence of two farm drains which made possible separate gauging and experimentation within the Talbot's site. Figure 3 shows the general features of the Meredith drain catchment and locations of both Talbot's and Eastcott's experimental sites.

2.1.2 Soils and Topography

The soils to the east of Meredith drain are typical of the Bassendean association developed on an approximately north-south set of dunes and swales with a relief of about 5 m. This compares to survey information (Department of Administrative Services) giving an altitude range from 34 m on the sandy rises to 12 m AHD in the swamps, within the Meredith drain area generally. Data collected at the same time on swamp heights, extending from the divide south of Riverdale Rd to Johnston Rd, indicate a gentle gradient of 1:1500 to the north-west. This approximates the gradient along Meredith drain. Soils of the dunes range from Jandakot sand, with a yellow-brown weakly cemented B horizon, on the crests, to Gavin sand (Ga S) with a thick and strongly bleached A2 horizon overlying a brown organic, or iron organic (coffee rock) hardpan B horizon. Joel loamy sand (JLS) and sandy loam (JSL) profiles occupy the swales. These have more organic A1 horizons, and an A2 with a patchy bleach overlying the coffee rock B horizons. There are seasonal swamps (SW 2) containing sandy and peaty soils in which the coffee rock pan is at best weakly developed. A low lying flat area adjoining Meredith drain has a variety of swamp soil profiles (SW 1) in which clay size materials are present at or near to the surface, and in which coffee rock is generally absent. Soils have been mapped (Figure 4) on general morphological properties, organic matter content, presence and depth of coffee rock, texture and colour etc.

2.1.3 Development of Agriculture and Drainage

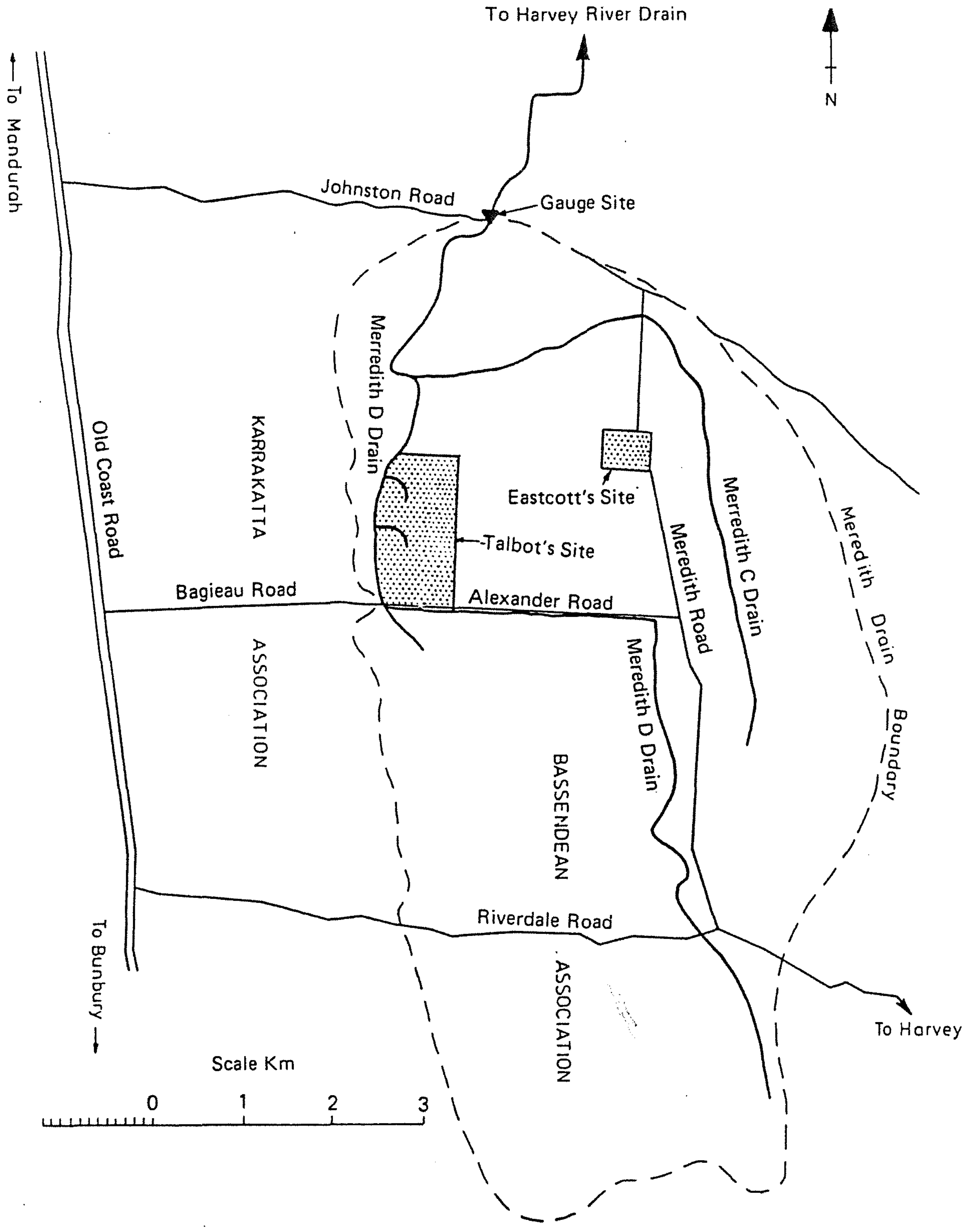
These sandy and loamy areas are drained to Meredith drain by a number of shallow drains which flow during most of the winter and spring period, but are dry in summer and autumn. Meredith drain intersects the permanent groundwater, at least in some sections, and has perennial flow. Talbot's site has been cleared of native vegetation and farmed since 1968. Pastures range from sparse cape weed pastures on the dunes to good stands of sub-clover in the swales. Perennial white clover and seradella, together with thick stands of rushes, occur on some of the swamp soils. Pastures are grazed, and/or cut for hay.

The area to the east (Bellair's property) was largely uncleared at the start of the investigation. Native vegetation consists of Jarrah-Banksia woodland, with a groundcover including some legumes, on the dunes, with trees and shrubs of *Melaleuca* and *Leptospermum* on the swales, and with rushes and sedges in the swamps.

2.2 Site Description - Eastcott's

2.2.1 Location

Eastcott's experimental site (see Figure 3) straddles Meredith Rd



PEEL-HARVEY ESTUARY CATCHMENT STUDIES

GROUNDWATER INVESTIGATIONS

TITLE: LOCATION MAP OF EXPERIMENTAL SITES

CSIRO DIVISION OF GROUNDWATER RESEARCH
DENIS HURLE & ASSOCIATES (CONSULTANTS)

DRAWN: S. HALEY | FIGURE 3

approximately half way between Johnston Rd and Alexander Rd. It is centrally situated within the Bassendean soil associatio

2.2.2 Soils and Topography

Both soils and topography are similar to those at Talbot's site. Gavin and Jandakot sands occur on dunes, with seasonal swamps (SW 2 soils) occupying minor depressions. No SW 1 soils have been identified. Joel loamy sands and sandy loams occur on intervening flat areas. A permanent swamp forms the eastern boundary of the area. Maximum elevation differenc between dunes and swamps are less than 6 m.

2.2.3 Development of Agriculture and Drainage

Eastcott's site has been developed for agriculture with largely annual pasture stands ranging from moderate in low lying areas to sparse on the dunes. Some large Jarrah trees have been left, particularly on the dunes. Rushes and paper bark (*Melaleuca*) trees and shrubs of *Leptospermum* occur in and around swamps. The area is not traversed by a major drain but shallow (less than 1 m) drains have been installed to reduce winter flooding.

2.3 Site Instrumentation - Talbot's

2.3.1 Hydrological Installations

The Talbot's site has been instrumented to determine water and phosphorus budgets as well as describing phosphorus transport processes in more detail.

Instrumentation was undertaken by all groups involved in the catchments studies, namely CSIRO, DCE, Department of Agricultu and PWD. A brief list of the overall instrumentation, and authority responsible is given:

- gauging stations and surface water sampling sites on the north and south drains as well as a major drain gauging site on the Meredith Drain (PWD, DCE).

- fully slotted observation bores extending to, or into, the coffee rock. These bores were located on 200 m or 100 m intervals over the two paired catchments and the Meredith main drain. Following evaluation of the data collected during 1983, part of the bore grid was reduced to 50 m intervals in summer 1984 in order to assess the observed high variability of phosphorus storage (CSIRO).

- nests of piezometers slotted over defined soil intervals were installed in order to determine phosphorus storages with depth (CSIRO).

- production bores and observation piezometer nests were installed (on both Talbot's and Eastcott's) to quantify hydraulic properties particularly leakage of water and phosphorus to/from deeper aquifers (CSIRO).

- raingauges were installed to measure both total rainfall and rainfall intensities. Evaporation from a Class A pan was also recorded on site (DCE).

2.3.2 Observation Bore Network & Construction Details

Observation bores were constructed from 32 mm PVC pipe fully slotted from about 0.25 m below ground surface to bottom. At the bore location the hole was drilled by hollow stemmed auger to or into the coffee rock pan. In cases where the pan was not encountered, the hole was terminated at about 0.5 metres below the shallow water table. Following drilling, the block bit was removed, the bore placed down the inside of the augers and then the augers were removed. The hole was backfilled using the drilling spoil, and the bore was cleaned of sand using a bailer. A hole was cut in the PVC above ground level to ensure that air pressure could not build up in the pipe and give erroneous depth to water.

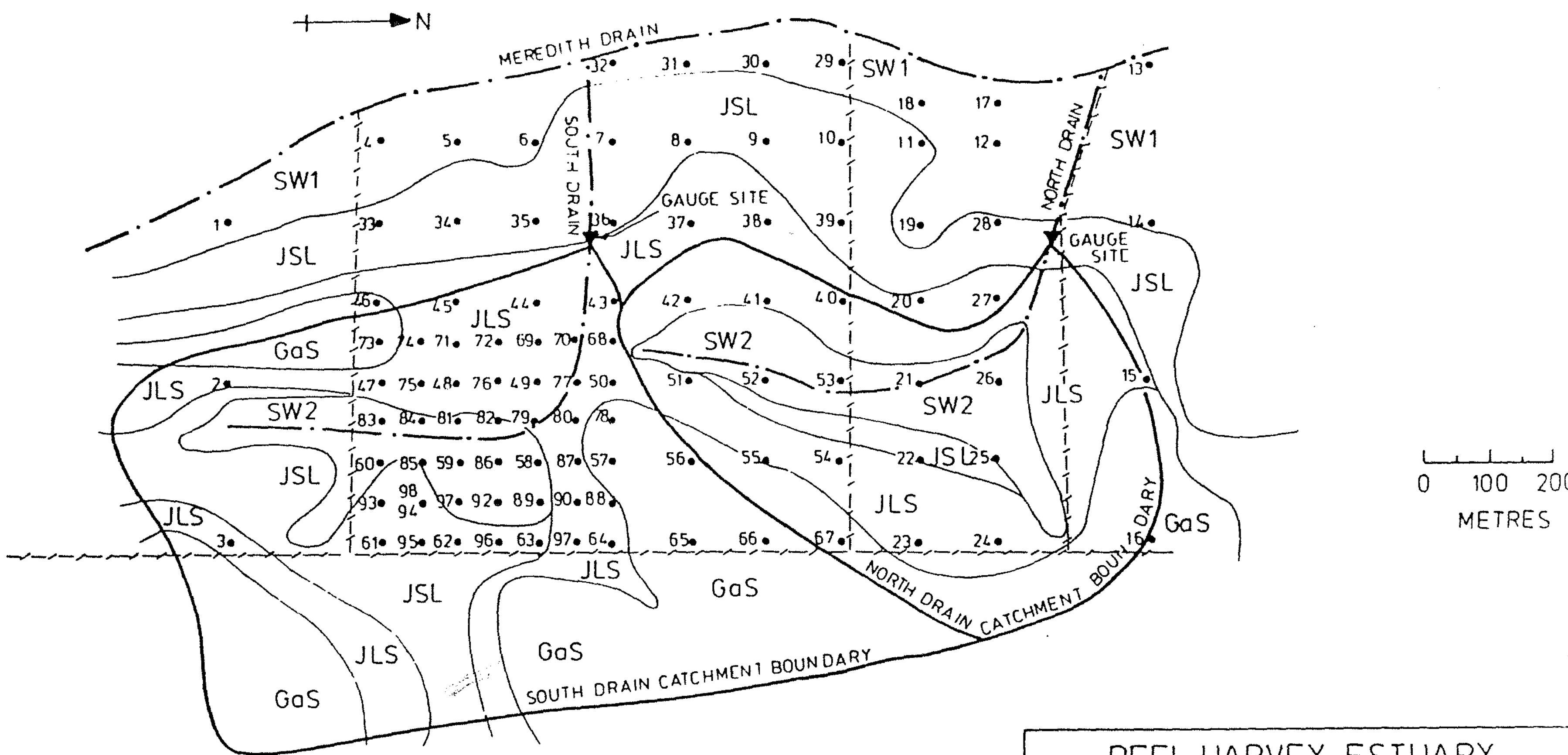
The observation bores were located on a 100 m square grid covering both the north and south drain catchments, as well as in the area between the western margins of the catchments' boundaries and the Meredith drain. On the northern and southern ends of the site, two additional lines of observation bores were installed in an east-west direction, two hundred metres to the north and south of the main grid respectively (Figure 4).

2.4 Routine Monitoring and Methods

Each observation bore was surveyed to a common datum. Both the level of top of bore (measuring point) and the ground surface level at the bore were recorded. Measurements of depth to groundwater at each bore are then converted to relative level of groundwater such that potentimetric groundwater surfaces could be interpolated.

The observation bores were installed on the Talbot's site during April-May, 1983 prior to any significant rainfall. The 67 bores were monitored on an approximately weekly frequency from May 25 to September 22, following which approximately monthly readings were made.

Following measurement of depth to groundwater, the bore was bailed and a 125 ml sample of groundwater taken after recovery. These samples were analysed for ortho-phosphate using the Murphy and Riley method.



LEGEND

—·—	DRAIN
——	SURFACE CATCHMENT BOUNDARY
——	SOIL TYPE BOUNDARY
43 •	OBSERVATION BORE NUMBER
—/—/—	FENCE LINE
▼	GAUGE SITE

SOIL TYPES

Ga S	GAVIN SAND
JSL	JOEL SANDY LOAM
JLS	JOEL LOAMY SAND
SW 1	SWAMP 1
SW 2	SWAMP 2

PEEL-HARVEY ESTUARY CATCHMENT STUDIES

GROUNDWATER INVESTIGATIONS

TITLE: TALBOT'S SITE SOIL MAP AND MONITORING INSTALLATIONS

CSIRO DIVISION OF GROUNDWATER RESEARCH
DENIS HURLE & ASSOCIATES (CONSULTANTS

DRAWN: S.HALEY

FIGURE 4

3. RESULTS

3.1 Groundwater Observations

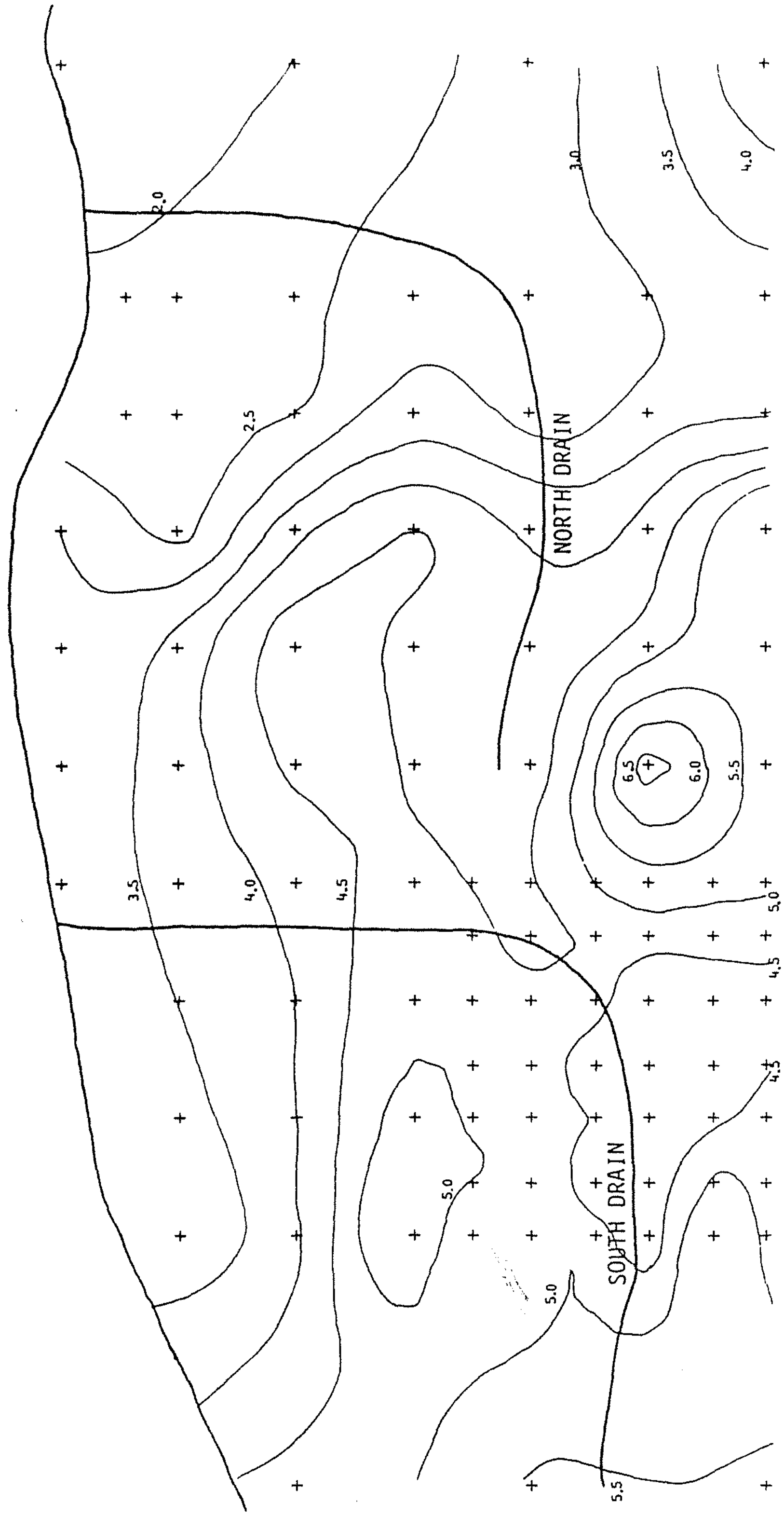
Figure 5 shows a contour map of ground surface elevations which was generated from surveyed heights at observation bore sites. All levels reported are relative to an arbitary datum.

Figure 6 shows a contour map of depths to groundwater below ground surface on May 25th, 1983 prior to any significant rainfall.

Generally groundwater levels reflected ground surface elevations, relative levels of groundwater varying from more than 4.5 metres above datum under the Gavin dunes on the southern catchment to less than 1 metre on the northern edge of the north catchment (Figure 7). This shows an average groundwater gradient of about 5×10^{-3} m m^{-1}. Thus there is a trend for groundwater flow in a north to north-westerly direction; however on a smaller scale groundwater flows towards the swamps and drains including the Meredith main drain are apparent.

Groundwater responses to winter rainfall in 1983 were seen to be relatively uniform across the study area, except in areas where groundwater levels were near to the ground surface. In these lower swampy areas, levels rose to ground surface (or slightly above) early in winter and remained near the surface over winter. Figure 8 shows observed groundwater responses in Gavin sand (bore 56), Joel loamy sand (bore 45), and SW 2 soils (bore 59) on the south catchment for 1983. Apart from the initial slower response to rainfall in the Gavin soils, which is probably due to storage of infiltration in the unsaturated profile, the responses are similar for the remainder of the season.

The storage of groundwater at the times of measurement have been estimated for the north and south catchments and for the adjacent areas between the western boundaries of the catchments and the Meredith drain. This was achieved by



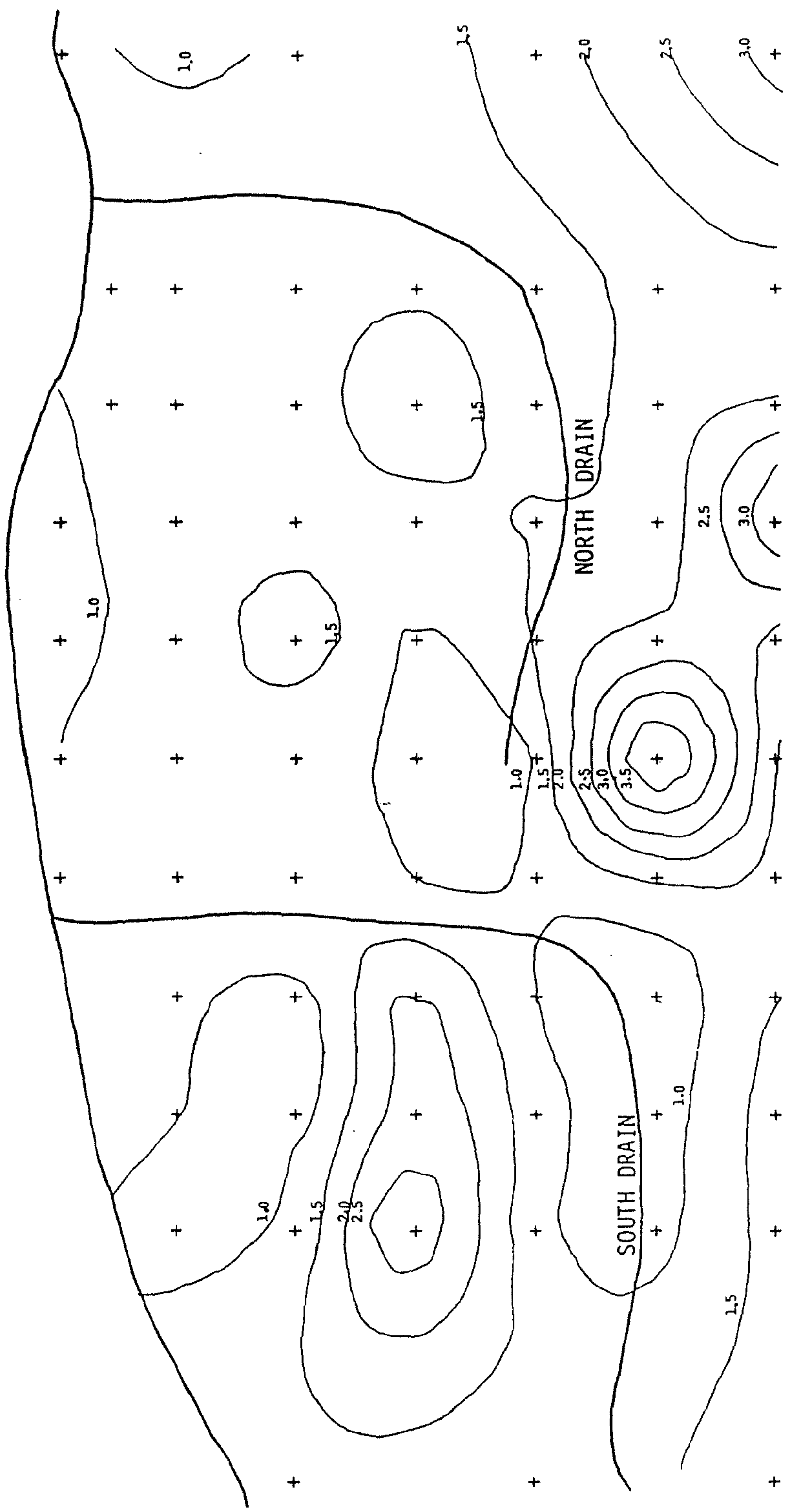
PEEL-HARVEY ESTUARY
CATCHMENT STUDIES

GROUNDWATER INVESTIGATIONS

TITLE: TALBOT'S SITE
GROUND LEVELS - 0.25m CONTOURS

CSIRO DIVISION OF GROUNDWATER RESEARCH
DENIS HURLE & ASSOCIATES (CONSULTANTS)

DRAWN: S.HALEY | FIGURE 5



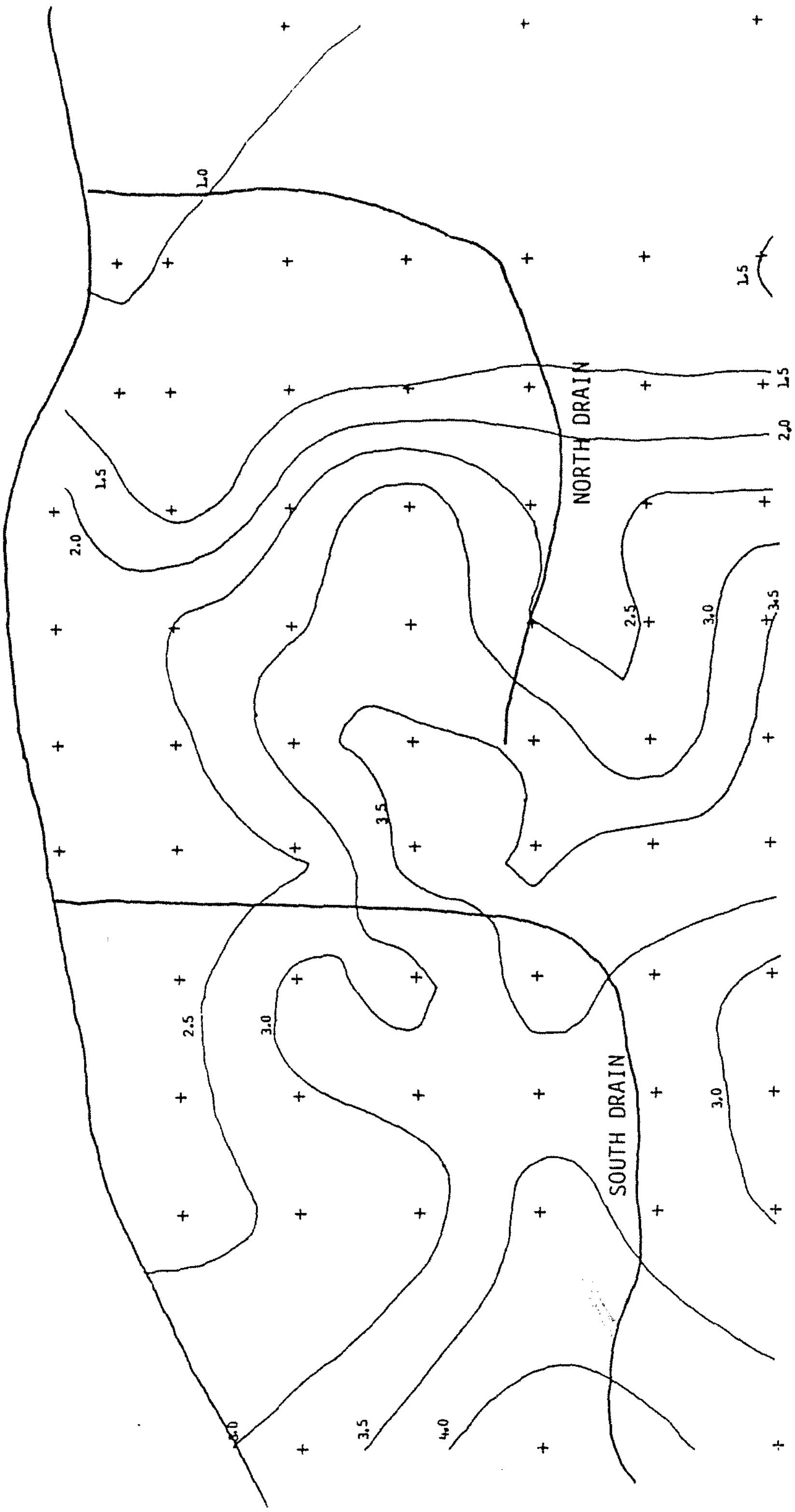
PEEL-HARVEY ESTUARY
CATCHMENT STUDIES

GROUNDWATER INVESTIGATIONS

TITLE: TALBOT'S SITE
DEPTH TO GROUNDWATER - 25.5.83
0.25m CONTOURS

CSIRO DIVISION OF GROUNDWATER RESEARC
DENIS HURLE & ASSOCIATES (CONSULTANT

DRAWN: S.HALEY | FIGURE 6



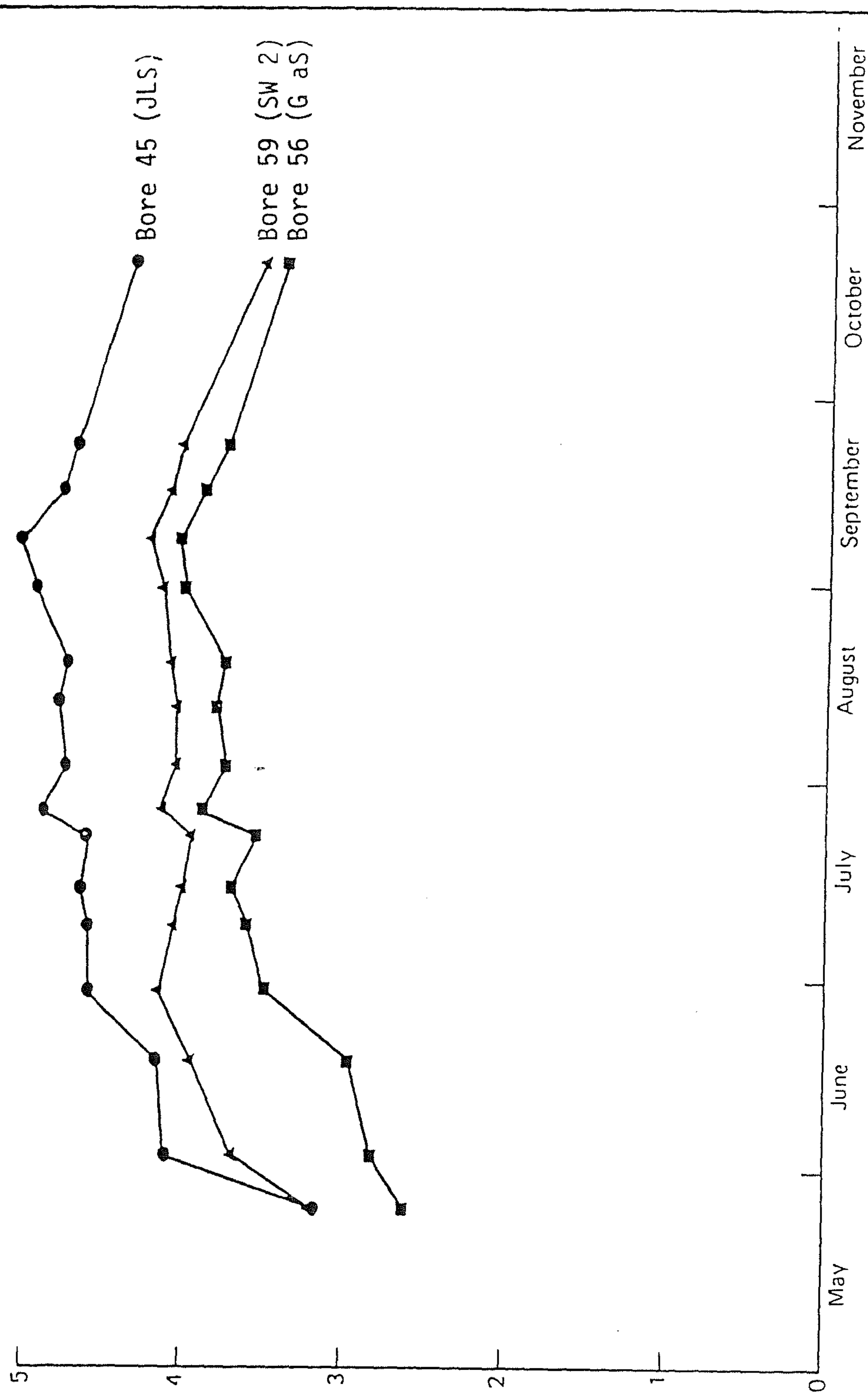
PEEL-HARVEY ESTUARY
CATCHMENT STUDIES

GROUNDWATER INVESTIGATIONS

TITLE: TALBOT'S SITE
RELATIVE LEVELS OF GROUNDWATER -
25.5.83(late summer) 0.25m CONTOURS

CSIRO DIVISION OF GROUNDWATER RESEARCH
DENIS HURLE & ASSOCIATES (CONSULTANTS)

DRAWN: S.HALEY | FIGURE 7



PEEL-HARVEY ESTUARY
CATCHMENT STUDIES

GROUNDWATER INVESTIGATION

TITLE: TYPICAL GROUNDWATER RESPONSES ON MAJOR SOIL TYPES

CSIRO DIVISION OF GROUNDWATER RESEA
DENIS HURLE & ASSOCIATES (CONSULTA

DRAWN: S.HALEY

FIGURE 8

determining water stored in the profile between the top of the hardpan and the groundwater surface.

At locations where the hardpan was not detected during bore installation, the hardpan surface was interpolated from adjacent hardpan elevations. An average fillable porosity of 0.3 $m^3 m^{-3}$ was used to estimate volumetric water content.

Groundwater storage over the entire monitored area (all bores) was estimated to vary from about 0.069 metres on the 25th May, 1983 to a maximum of 0.375 metres during winter on 7th September 1983. This storage estimate declined over summer 1983-1984 to a minimum of 0.084 metres on 23rd March, 1984, and a similar pattern of groundwater storage changes was observed during winter 1984.

Consecutive changes in groundwater storage over the monitoring periods were estimated for all bores, bores in the north drain catchment, the south drain catchment, and for bores in the area adjacent to the two catchments. These values are used in water budget calculations, and are listed in Table 1.

TABLE 1

ESTIMATED CHANGES IN GROUNDWATER STORAGE

1983 & 1984

(METRES)

DATE	NORTH DRAIN Δh	NORTH DRAIN ΔS	SOUTH DRAIN Δh	SOUTH DRAIN ΔS	OUTSIDE Δh	OUTSIDE ΔS	ALL BORES Δh	ALL BORES ΔS
25.5.83	-	-	-	-	-	-	-	-
2.6.83	0.31	0.003	0.38	0.114	0.30	0.090	0.32	0.096
17.6.83	-0.08	-0.024	0.09	0.027	0.03	0.009	0.06	0.018
28.6.83	0.49	0.147	0.54	0.162	0.59	0.177	0.55	0.165
8.7.83	-0.06	-0.018	-0.02	-0.006	-0.13	-0.039	-0.09	-0.027
14.7.83	-0.11	-0.033	-0.07	-0.021	-0.13	-0.039	-0.10	-0.030
22.7.83	0.01	0.003	-0.01	-0.003	-0.02	-0.006	-0.01	-0.003
26.7.83	0.19	0.057	0.20	0.060	0.27	0.081	0.23	0.069
2.8.83	-0.15	-0.045	-0.12	-0.036	-0.19	-0.057	-0.16	-0.048
12.8.83	0.11	0.033	0.09	0.027	0.11	0.033	0.10	0.030
18.8.83	-0.05	-0.015	-0.04	-0.012	-0.07	-0.021	-0.05	-0.015
30.8.83	0.09	0.027	0.13	0.039	0.17	0.051	0.13	0.039
7.9.83	0.05	0.015	0.05	0.015	0.04	0.012	0.04	0.012
15.9.83	-0.13	-0.039	-0.17	-0.051	-0.17	-0.051	-0.15	-0.045
22.9.83	-0.21	-0.063	-0.15	-0.045	-0.26	-0.078	-0.22	-0.066
21.10.83	-0.23	-0.069	-0.30	-0.090	-0.25	-0.075	-0.26	-0.078
6.12.83	-0.19	-0.057	-0.27	-0.081	-0.06	-0.018	-0.14	-0.042
13.1.84	-0.03	-0.009	-0.09	-0.027	-0.12	-0.036	-0.09	-0.027
16.2.84	-0.06	-0.018	-0.13	-0.039	-0.03	-0.009	-0.07	-0.021
23.3.84	-0.05	-0.015	-0.06	-0.018	-0.03	-0.009	-0.04	-0.012
25.4.84	0.08	0.024	0.08	0.024	0.04	0.012	0.06	0.018
9.5.84	0.27	0.081	0.23	0.069	0.33	0.099	0.29	0.087
29.5.84	0.24	0.072	0.33	0.099	0.17	0.051	0.23	0.069
14.6.84	0.11	0.033	0.18	0.054	0.16	0.048	0.15	0.045
4.7.84	0.07	0.021	0.11	0.033	0.05	0.015	0.70	0.021
17.7.84	-0.17	-0.051	-0.10	-0.030	-0.22	-0.066	-0.17	-0.051
2.8.84	0.09	0.027	0.06	0.018	0.08	0.024	0.08	0.024
20.8.84	0.05	0.015	0.07	0.021	0.09	0.027	0.07	0.021

Δh average change in aquifer thickness

ΔS average change in groundwater storage

$\Delta S = (\Delta h \times 0.30)$

Variations of phosphorus concentration in observation bores throughout the winter of 1983 are shown in Figure 9 for locations under the Gavin sands (bore 56), Joel sands (bore 45) and the high concentration swamp area (bore 59) of the south catchment.

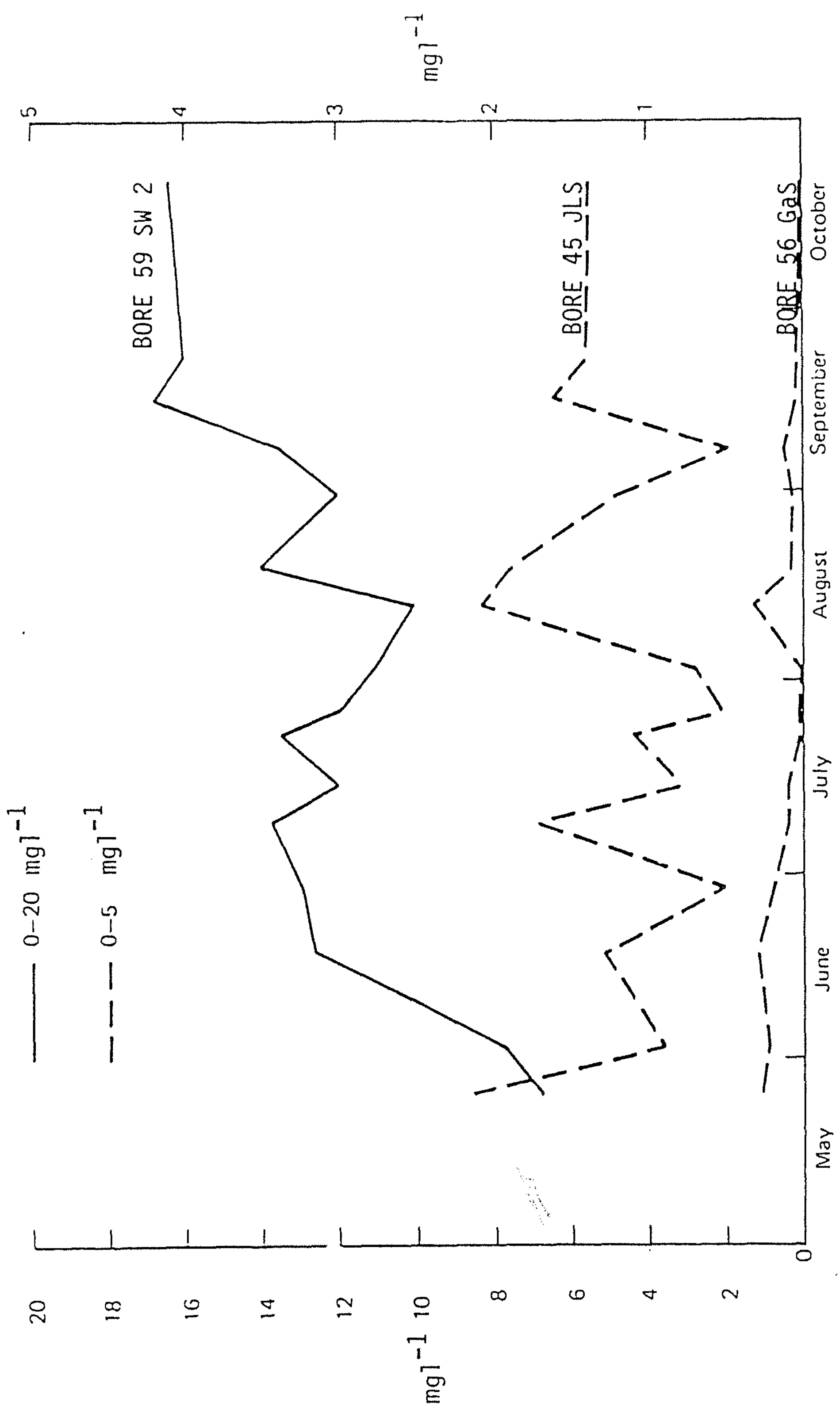
In the higher concentration areas, when groundwater intersects or rises near to the ground surface, concentrations within the bore become highly variable in time. This is thought to be due to the adsorption/desorption processes associated with rainfall events and the phosphorus storage of the surface soil horizons.

Interpretation of the bore phosphorus concentrations is further complicated by the length of slotted interval which may result in differential contribution of water from various soil horizons having different phosphorus concentrations.

The areal distribution of concentration is shown for 14th July, 1983 and 30th July, 1983 in Figures 10 and 11 respectivel These two contour maps represent the groundwater concentration before and after the application of phosphatic fertiliser on the southern catchment over the period 18th July - 21st July, 1983. From the contour maps it can be seen that the areas of high concentration persist, and there is no major change in th pattern of groundwater phosphorus concentration due either to fertiliser application or high rainfall.

The seasonal trend during 1983 mean phosphorus concentrations on each catchment is shown in Figure 12. The variability of the concentration data is so high that it tends to mask any spatial correlation structure.

Although there are strong indications that the individual concentrations for each piezometer are log-normally distribut the catchment mean concentrations are normally distributed. Hence the standard errors of the mean concentrations for each catchment at each sampling date can be calculated (see Table 2). Examination of the results shows that changes



PEEL-HARVEY ESTUARY
CATCHMENT STUDIES

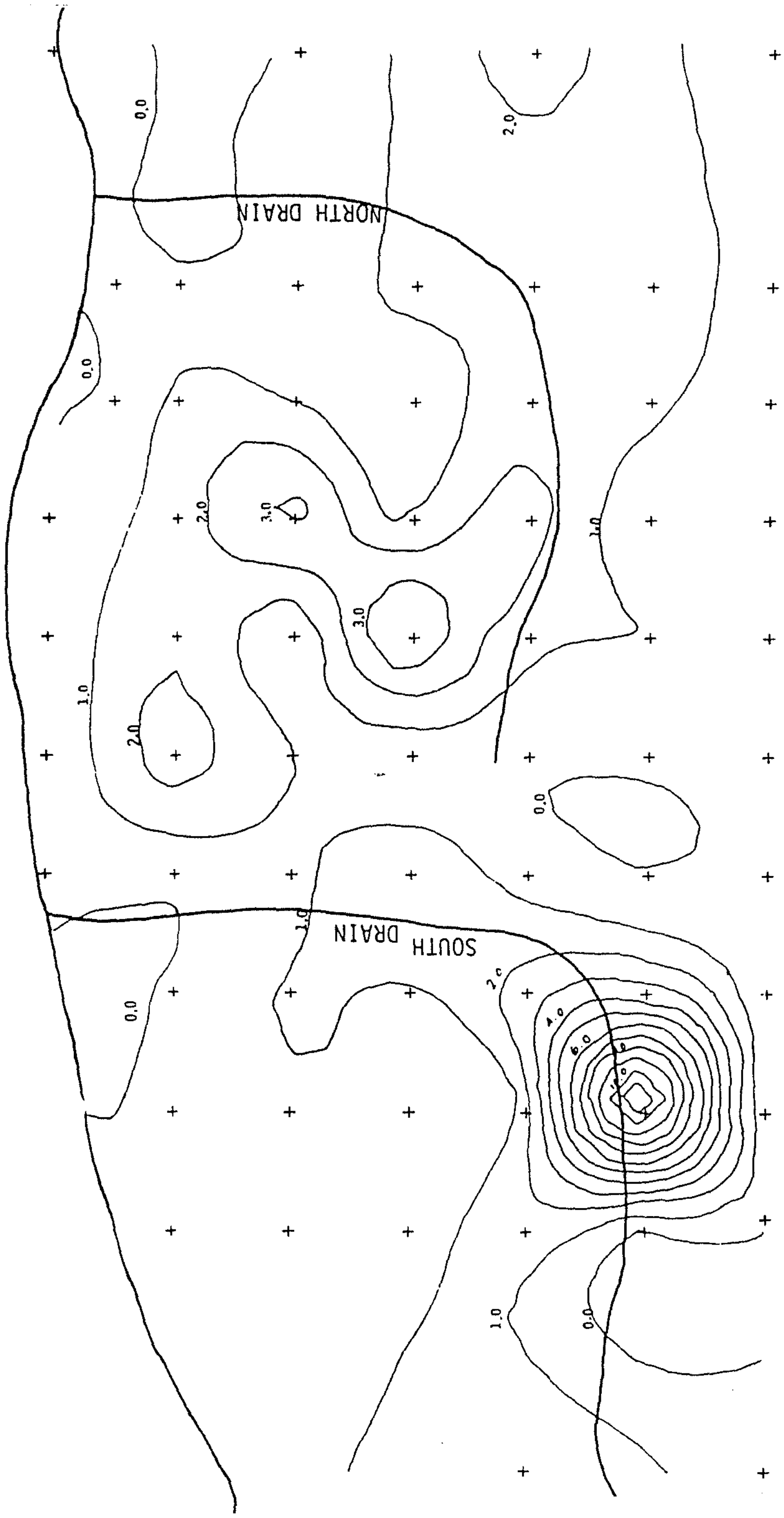
GROUNDWATER INVESTIGATIONS

TITLE:

PHOSPHORUS CONCENTRATIONS
IN BORES

CSIRO DIVISION OF GROUNDWATER RESEARCH
DENIS HURLE & ASSOCIATES (CONSULTANTS)

DRAWN: S.HALEY	FIGURE 9



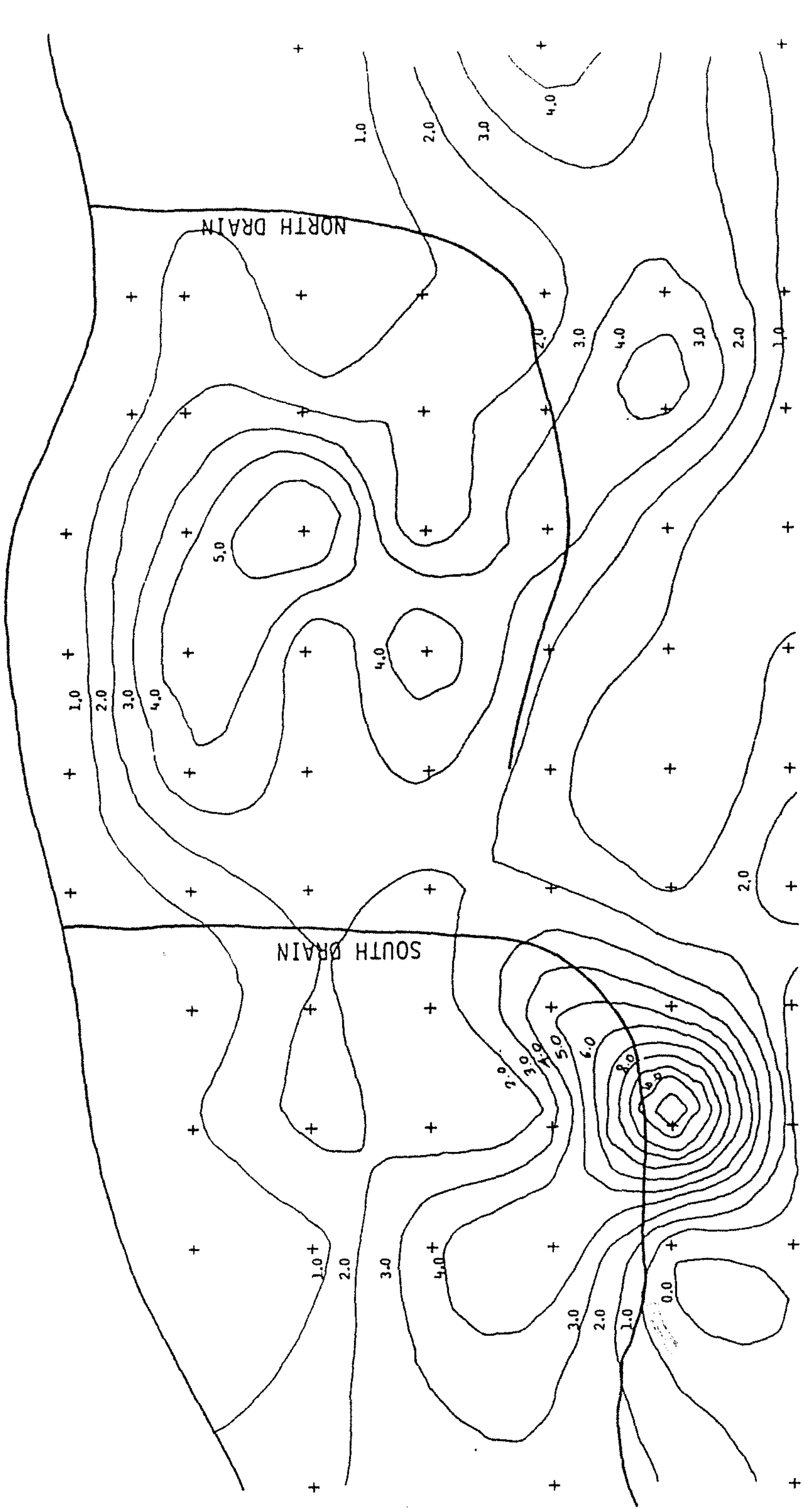
PEEL-HARVEY ESTUARY
CATCHMENT STUDIES

GROUNDWATER INVESTIGATIONS

TITLE: TALBOT'S SITE
GROUNDWATER PHOSPHORUS CONCENTRATIONS
14.7.83 0.5 mgl^{-1} CONTOURS

CSIRO DIVISION OF GROUNDWATER RESEARC
DENIS HURLE & ASSOCIATES (CONSULTAN

DRAWN: S. HALEY | FIGURE 10



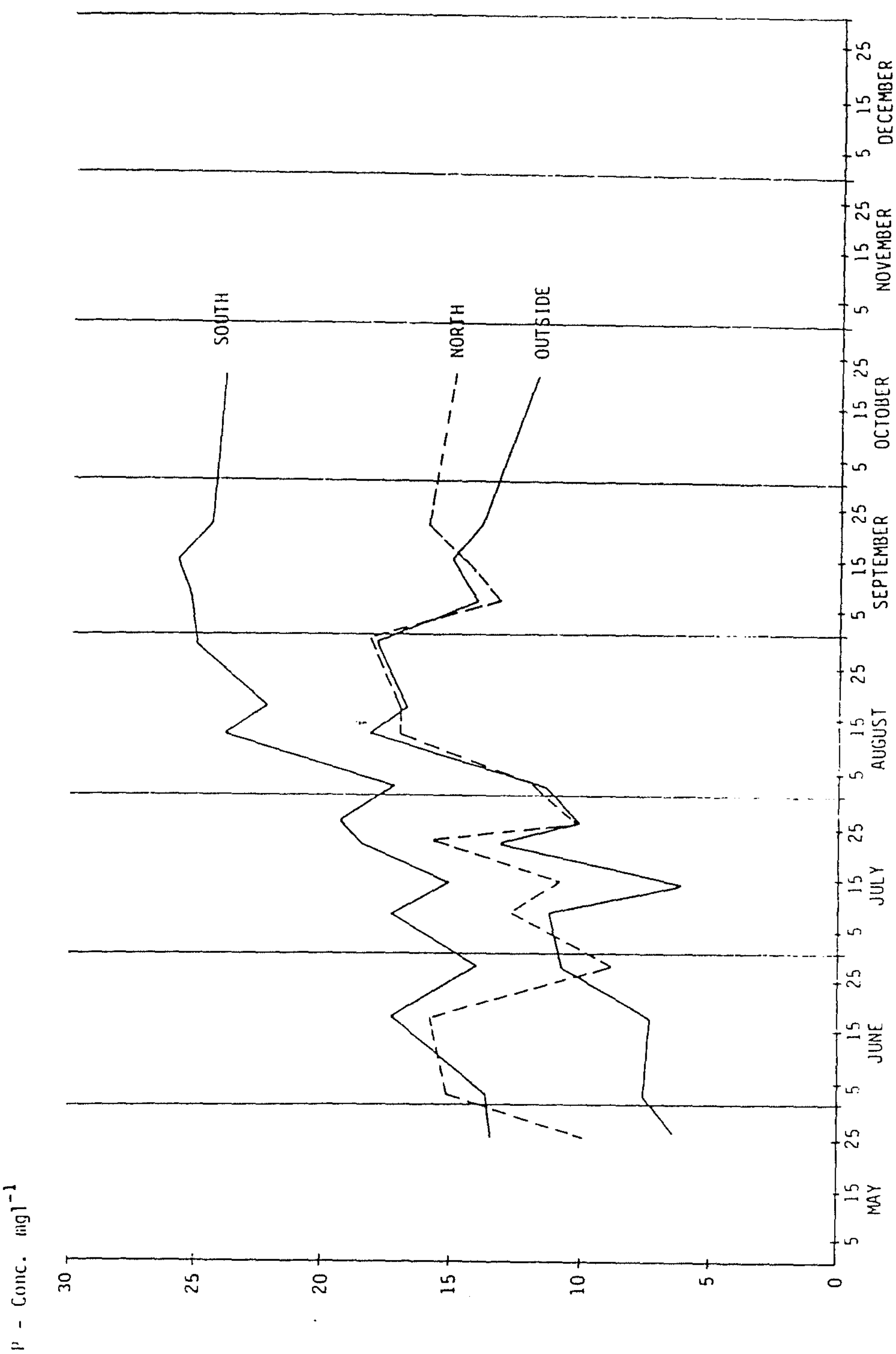
PEEL-HARVEY ESTUARY
CATCHMENT STUDIES

GROUNDWATER INVESTIGATIONS

TITLE: TALBOT'S SITE
GROUNDWATER PHOSPHORUS CONCENTRATIONS -
30.8.83 0.5 mgl^{-1} CONTOURS

CSIRO DIVISION OF GROUNDWATER RESEARCH
DENIS HURLE & ASSOCIATES (CONSULTANTS)

DRAWN: S.HALEY | FIGURE 11



PEEL-HARVEY ESTUARY
CATCHMENT STUDIES

GROUNDWATER INVESTIGATIONS

TITLE: TALBOT'S SITE
1983 MEAN GROUNDWATER PHOSPHORUS CONCENTRATIONS WITHIN & OUTSIDE CATCHMENTS (mgl^{-1})

CSIRO DIVISION OF GROUNDWATER RESEAR
DENIS HURLE & ASSOCIATES (CONSULTAN

DRAWN: S.HALEY | FIGURE 12

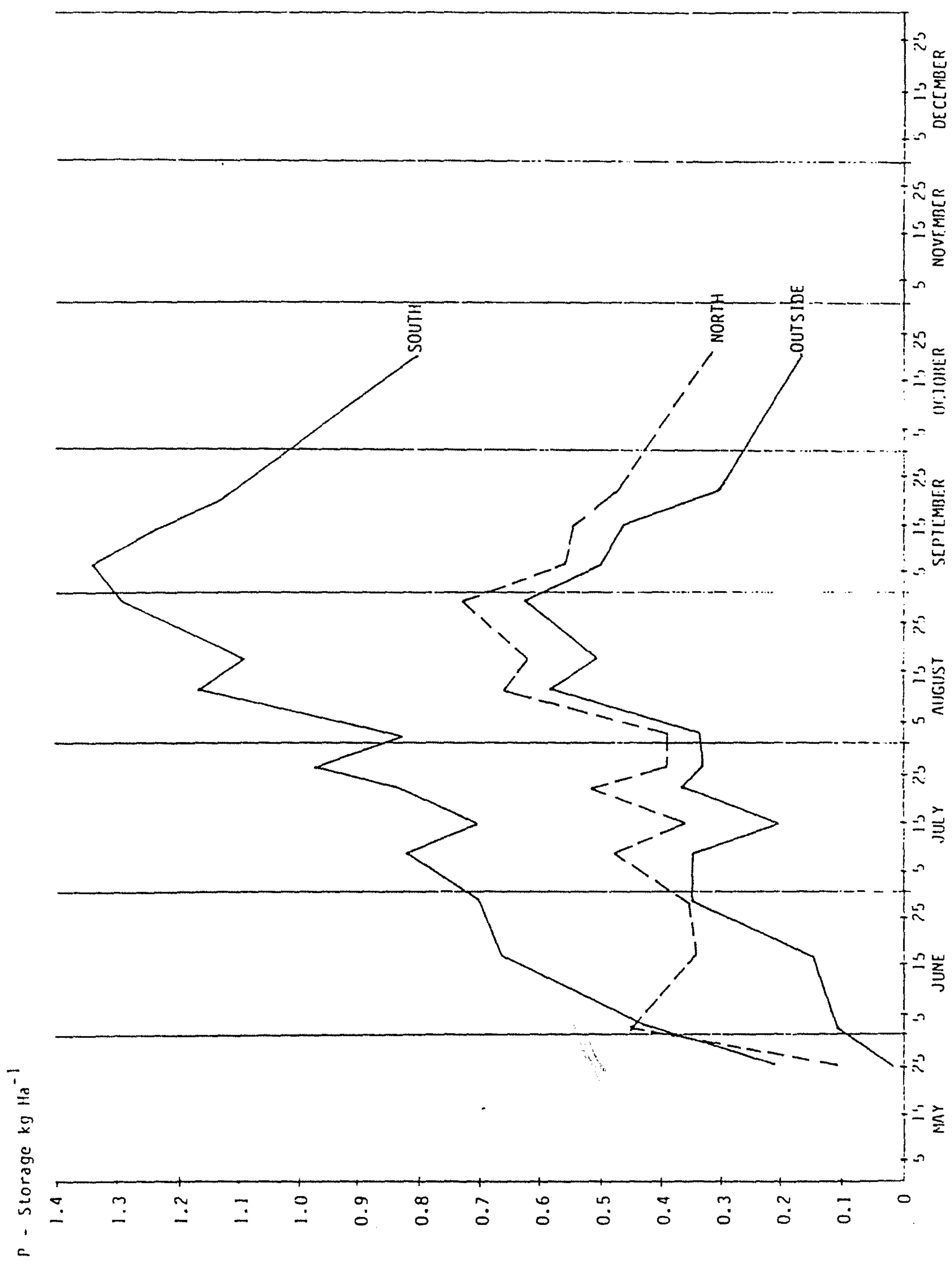
in the mean concentration for the southern catchment after the application of fertiliser were not statistically significant.

Results from groundwater phosphorus analyses, when integrated with the estimates of water storage, enable changes in phosphorus storage to be made for north and south catchments and the adjacent areas to the west of these catchments. The seasonal variation of phosphorus storage in the saturated profile above the hardpan is shown in Figure 13. The mean phosphorus storages for each sampling date are listed in Table 3. The larger phosphorus storages on the southern catchment are due to higher mean concentrations and greater depth of saturated profile above the hardpan.

TABLE 2

MEAN GROUNDWATER PHOSPHORUS CONCENTRATIONS
TALBOT'S 1983 & 1984

DATE	NORTH DRAIN (20 BORES)		SOUTH DRAIN (17 BORES)		OUTSIDE (30 BORES)		ALL BORES (67 BORES)	
	MEAN (mg l^{-1})	S.E. (%)	MEAN (mg l^{-1})	S.E. (%)	MEAN (mg l^{-1})	S.E. (%)	MEAN (mg l^{-1})	S.E (%)
25.5.83	0.96	27.4	1.32	17.8	0.63	14.7	0.90	11.[illegible]
2.6.83	1.49	19.1	1.36	17.0	0.75	17.4	1.12	13.[illegible]
17.6.83	1.58	18.8	1.73	19.3	0.73	25.8	1.24	12.[illegible]
28.6.83	0.88	25.4	1.39	22.7	1.01	24.5	1.07	21.[illegible]
8.7.83	1.26	22.0	1.73	22.3	1.08	24.5	1.30	19.[illegible]
14.7.83	1.07	21.6	1.50	21.8	0.69	22.1	1.01	20.[illegible]
22.7.83	1.57	19.4	1.85	21.5	1.31	24.4	1.53	17.[illegible]
26.7.83	1.00	23.8	1.92	19.8	1.02	24.5	1.24	18.[illegible]
2.8.83	1.15	22.8	1.74	21.0	1.14	23.6	1.30	16.[illegible]
12.8.83	1.71	16.2	2.40	16.7	1.83	14.7	1.94	10.[illegible]
18.8.83	1.70	19.8	2.23	18.8	1.67	19.6	1.82	14.[illegible]
30.8.83	1.83	17.8	2.49	17.8	1.80	16.6	1.99	12.[illegible]
7.9.83	1.32	22.4	2.52	14.5	1.41	17.4	1.67	15.[illegible]
15.9.83	1.45	20.2	2.57	16.5	1.50	18.3	1.76	16.[illegible]
22.9.83	1.61	19.1	2.46	17.4	1.38	21.7	1.72	16.[illegible]
21.10.83	1.50	18.8	2.41	19.1	1.18	20.6	1.59	17[illegible]
23.3.84	1.97	16.9	2.92	14.8	1.14	20.7	1.84	14[illegible]
25.4.84	1.72	17.4	2.85	15.3	0.93	21.4	1.65	18[illegible]
29.5.84	1.74	17.9	2.71	16.9	1.66	22.3	1.95	14[illegible]
4.7.84	1.73	18.6	3.07	18.2	1.99	18.5	2.19	14[illegible]



PEEL-HARVEY ESTUARY
CATCHMENT STUDIES

GROUNDWATER INVESTIGATIONS

TITLE: TALBOT'S SITE
1983 MEAN PHOSPHORUS STORAGE IN
GROUNDWATER ABOVE HARDPAN (kg Ha^{-1})

CSIRO DIVISION OF GROUNDWATER RESEARCH
DENIS HURLE & ASSOCIATES (CONSULTANTS)

DRAWN: S.HALEY

FIGURE 13

3.3 Hydraulic Testing

3.3.1 General

Groundwater production bores and observation piezometer nests were constructed on both the Talbot's and Eastcott's experimental sites.

On Talbot's, the production bore was located on the northern catchment about 50 metres east of bore 15. On Eastcott's, the production bore was located on the Joel soils at the foot of a Gavin dune.

Hydraulic testing of the production bores was carried out in order to quantify:

- the hydraulic properties of the various aquifer sequences, namely permeability or transmissivity.
- the interconnection between groundwater in the shallow surficial sands and the deep aquifers underlying the coffee rock.

3.3.2 Construction Details

For the production bores and deep piezometers, holes were drilled by mud rotary techniques.

The production bores were constructed from 150 mm Class 12 PVC casing with three metres of 150 mm stainless steel inline screen installed in the coarse sands of the underlying strata. The bores were developed clean of sand by airlifting and surging.

Deep observation piezometer holes were drilled in the same way, although these were constructed from 32 mm Class 12 PVC casing. The piezometers were hand slotted, generally over a two metre section in the strata to be monitored.

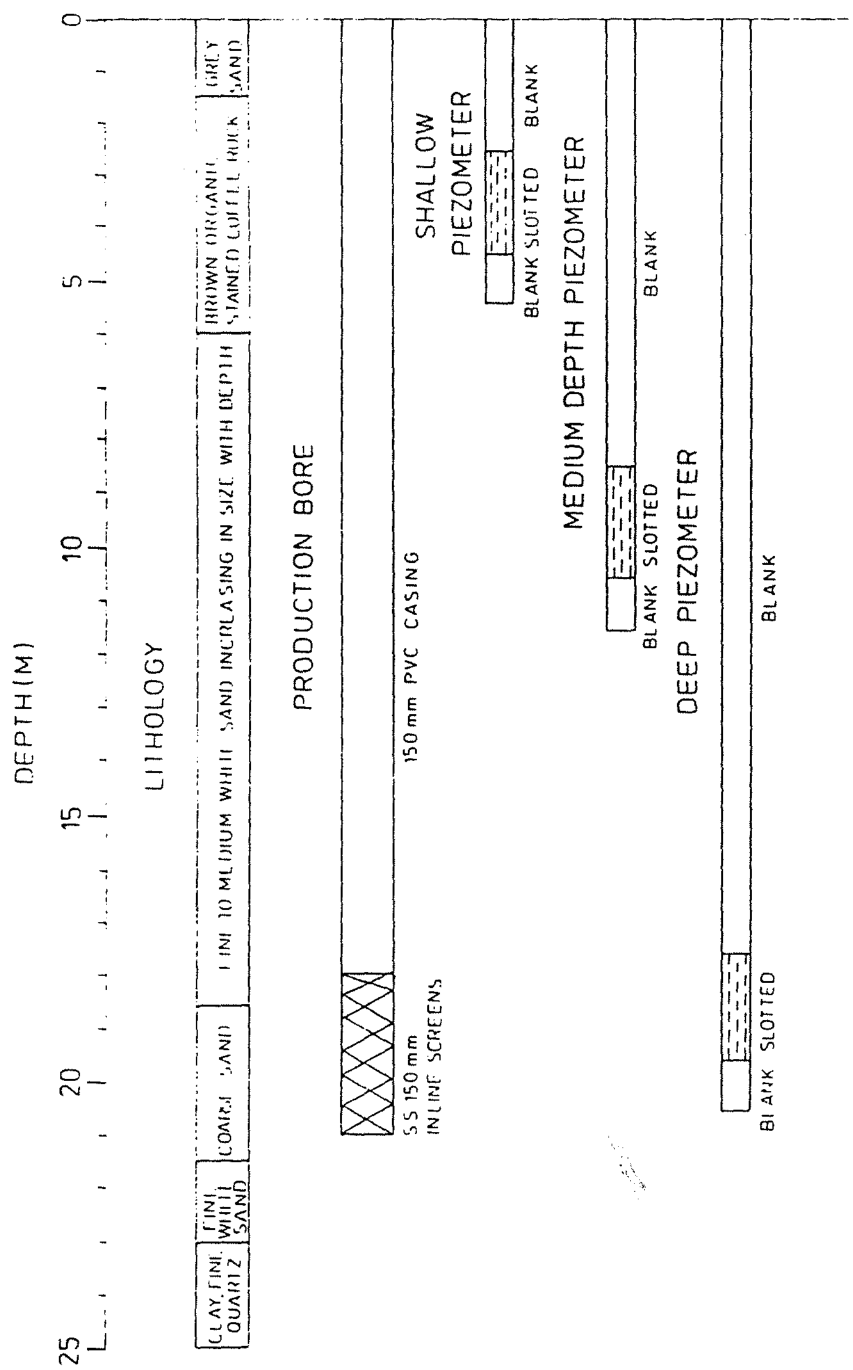
Details of piezometer and production bore construction on Talbot's and Eastcott's sites are given in Figures 14 and 15 respectively.

The profile lithology at the bore sites may be generally described as rounded grey quartz sands having some organic material in the top few centimetres overlying the coffee rock. At both drilling locations the coffee rock extended from about 1.5 metres below ground surface to 5.5 metres.

At Talbot's the sands below the coffee rock were white and largely of fine to medium size rounded quartz grains (0.15 mm to 0.8 mm) increasing in size with depth to about 18.5 metres below surface. Below this depth a coarse sand layer of well rounded quartz grains (2.0 mm to 3.5 mm) extended to 21.5 metres below surface. Underlying this zone was a layer of medium to coarse white sand with clays and calcareous marls and shell fragments of the deep formations. Drilling was terminated following intersection of the clay.

At Eastcott's the profile was similar in lithology except that a medium to coarse sand layer extended from 17.5 metres to a depth of 19.5 metres. The sands in this layer were generally finer (less than 2.0 mm) than those drilled at Talbot's and were underlain by calcareous sands containing some shell fragments.

Soil and water reactions were generally acid near the surface (pH $\sim$ 6.5). At depths of 17.5 metres at Talbot's and 7.5 metres at Eastcott's, alkaline reactions (pH 8.0 - 9.0) were encountered, although calcareous materials were not met until below this depth as indicated above.



PEEL-HARVEY ESTUARY
CATCHMENT STUDIES

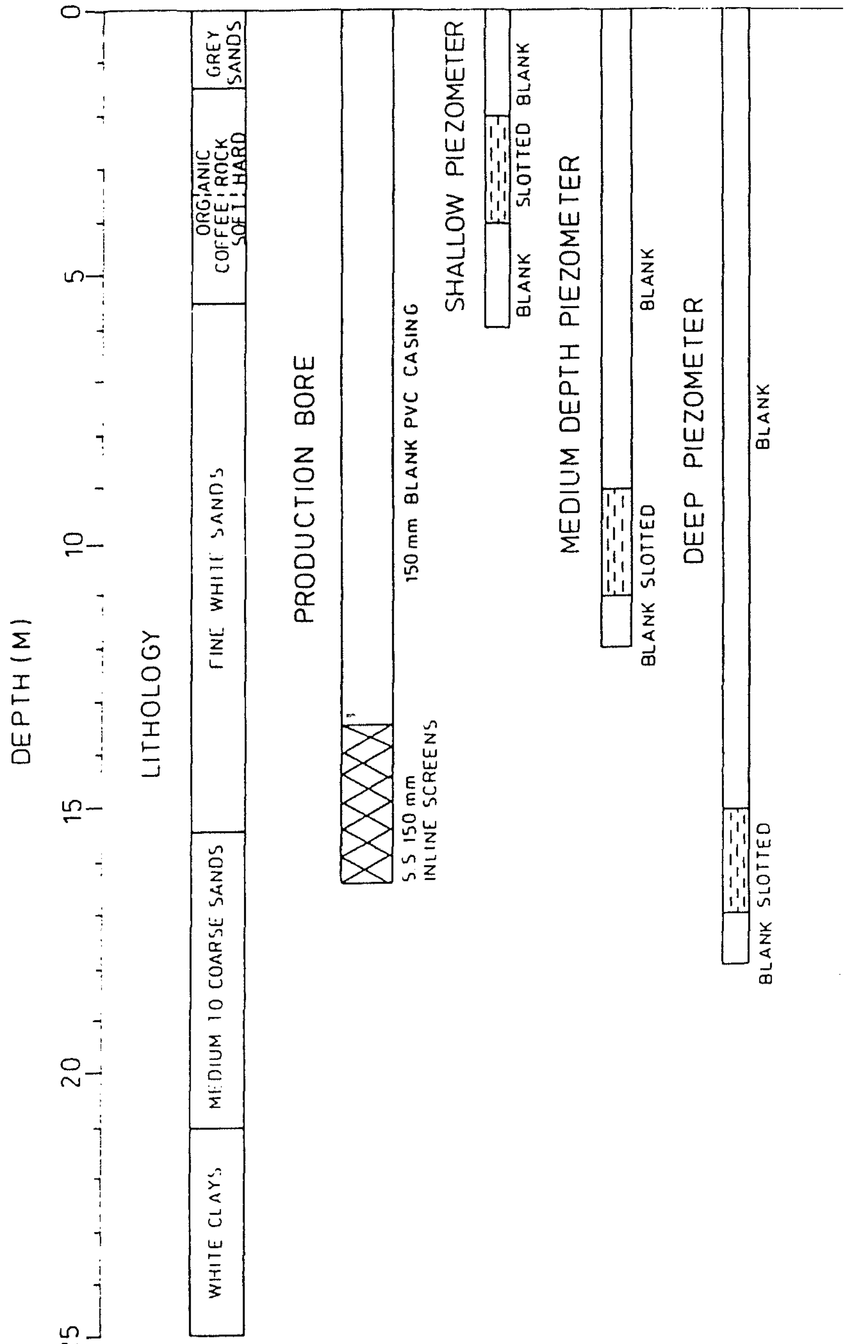
GROUNDWATER INVESTIGATIONS

TITLE: TALBOT'S SITE
PIEZOMETER AND PRODUCTION BORE
CONSTRUCTION DETAILS

CSIRO DIVISION OF GROUNDWATER RESEARCH
DENIS HURLE & ASSOCIATES (CONSULTANTS)

DRAWN: S.HALEY

FIGURE 14



PEEL-HARVEY ESTUARY
CATCHMENT STUDIES

GROUNDWATER INVESTIGATIONS

TITLE: EASTCOTT'S SITE
PIEZOMETER AND PRODUCTION BORE
CONSTRUCTION DETAILS

CSIRO DIVISION OF GROUNDWATER RESEARCH
DENIS HURLE & ASSOCIATES (CONSULTANTS)

DRAWN: S.HALEY | FIGURE 15

3.3.3 Results

Pumping tests were carried out on both Talbot's and Eastcott's sites in November - December 1984. The bores were pumped at the largest rate possible using the CSIRO electrosubmersible pump. At both sites this pumping rate was 346 $m^3\ d^{-1}$ and was measured using a differential pressure cell and orifice plate. Pumped discharge water was carried from the pumping site by means of layflat plastic pipe.

Pumping was carried out for 4040 minutes (67 hours) at Eastcott's and for 965 minutes (16 hours) at Talbot's. Water levels (drawdowns) were monitored in all the observation piezometers, the production bores and selected observation bores in the above coffee rock aquifer at each location.

Results of the hydraulic testing programme indicated that the sandy aquifer underlying the coffee rock was confined and highly permeable. Values of transmissivity calculated from drawdown analyses were 340 $m^2\ d^{-1}$ at Eastcott's and 465 $m^2\ d^{-1}$ at Talbot's. These correspond to an average aquifer permeability of 20 $m\ d^{-1}$ and 30 $m\ d^{-1}$ respectively.

All piezometers and observation bores screened in the above coffee rock aquifer did not respond to this long term pumping. This indicates that, under the conditions imposed by the tests, there was no vertical flow of water through the coffee rock layer. Additionally, drawdown curves calculated for piezometers below the coffee rock did not exhibit any delayed yield under these pumping conditions, again indicating that there was no vertical (downwards) flow.

4. HYDROLOGICAL MODELLING

4.1 Objectives

Conventional groundwater modelling techniques have been applied to simulate groundwater responses in the shallow aquifers associated with the Bassendean sands. The model has been developed to include vertical forcing by recharge attributed to rainfall redistribution and discharge attribute to evapotranspiration.

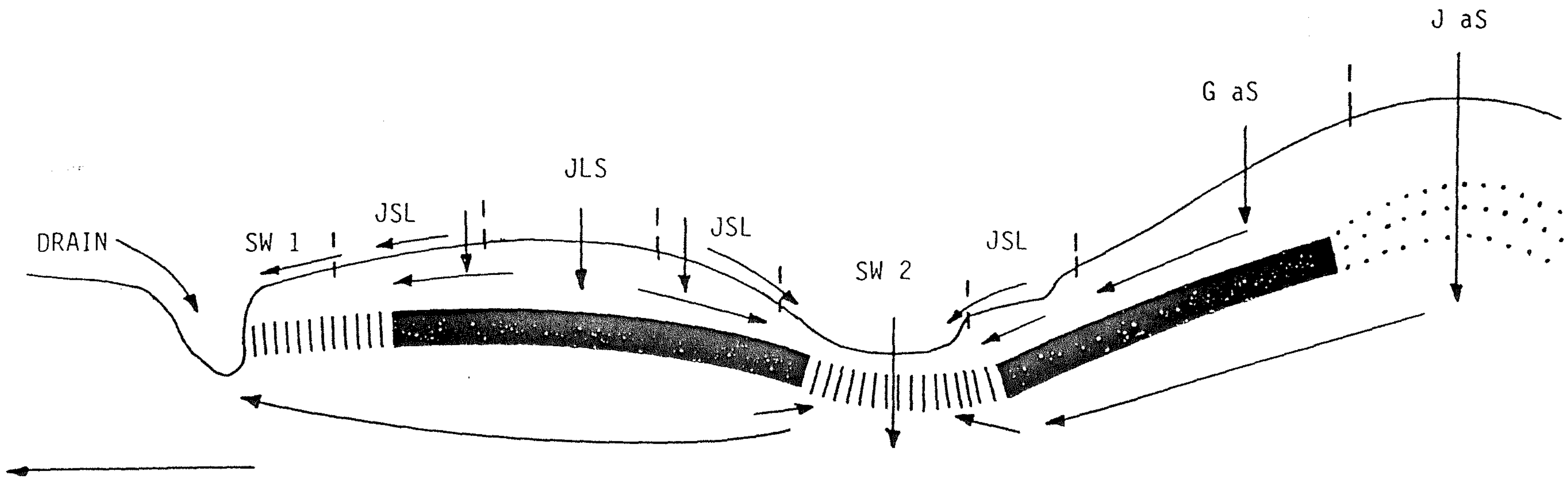
The objectives of the modelling were to develop relationships describing the flow of water in the shallow groundwater syst which is forced by recharge and discharge, resulting in a quantitive description of rates of redistribution of water to catchment sink areas such as swamps and drains.

Ideally, the model is seen as a forerunner to the developmen of a process based phosphorus transport model. The hydrolog model has been developed in order to match predicted hydrolo- gical responses with those observed on the extensively monit site at Talbot's farm. Results of the simulations are to predict surface and subsurface water budgets, leading to prediction of the groundwater transport contribution of the phosphorus to drain flow, and to catchment phosphorus rundow under different management practices.

4.2 Conceptual Description of Hydrological Processes

Dominant processes involved in water movement from the grou surface, through the soil and to the various sinks of drain flow and evapotranspiration may be described by consideratio of the hydrological properties of the Bassendean sand syste and the climatic water cycle of the area (Figure 16).

The Bassendean sand systems as described in Section 1.2 of this report comprise a sand or sandy loam overlying (in low landscape areas) a layer of organic coffee rock of thicknes ranging from less than 1 metre to more than 3 metres. Bene



LEGEND

SOIL SURFACE

YELLOW-BROWN B HORIZON

COFFEE ROCK HARDPAN

WEAKLY DEVELOPED HARDPAN

FLOW PATHS

PEEL-HARVEY ESTUARY
CATCHMENT STUDIES

GROUNDWATER INVESTIGATIONS

TITLE: CONCEPTUAL WATER MOVEMENT - BASSENDEAN ASSOCIATION

CSIRO DIVISION OF GROUNDWATER RESEARCH
DENIS HURLE & ASSOCIATES (CONSULTANTS)

DRAWN: S.HALEY

FIGURE 16

the higher dunes the coffee rock may be absent but there is a ferrugenous sandy B horizon. Beneath the coffee rock there is a deep (order 20 metres), highly permeable sand aquifer which overlies the basal silts, clays and calcareous materials.

Recharge to the deep aquifer probably takes place through the highest points in the landscape where coffee rock is absent. Elsewhere water continuity between the ephemereal surficial aquifers is thought to be minimal due to the confining nature of the coffee rock layer. This is borne out by results from the hydraulic testing study. Consequently, subsurface redistribution of phosphorus is thought to be confined to the above coffee rock flow system. At the end of summer, the groundwater in the surface sands is at its lowest level, and in some areas may be as deep as the hardpan layer.

Rainfall infiltrates the permeable sands rapidly and initially wets up the unsaturated zone to 'field capacity' (Schofield in prep.). Additionally, infiltration is thought to recharge the shallow groundwater causing water level rises. These increases in groundwater level lead to:

- discharge of shallow groundwater to shallow drains and lower lying areas.

- groundwater intersection of the ground surface leading to surface ponding of water and overland flow.

Results from the groundwater monitoring programme indicate that groundwater responses to winter rainfall under the Gavin-Jandakot dunes are generally slower than within the Joel areas. This is thought to be due to the larger storage capacity of a greater thickness of unsaturated sands overlying the groundwater in these areas. In the lower Joel soils winter rainfall is sufficient to maintain groundwater at, or near to, the ground surface. Flooding in these lower areas results in rainfall contributing directly to surface flow, and consequently drain flow.

Drain flow then, can be seen to be made up to two components, the high frequency runoff component attributed to rainfall discharge from the flooded lower areas, and lower frequency component attributed to groundwater discharge to the drains, swamps and seasonally flooded areas.

4.3 Numerical Formulation of the Hydrological Model

The numerical formulation of the hydrological system at Talbot's farm first requires the discretisation of the area into elements or cells to which the general equations of flow and mass balance can be applied.

This discretisation is made in both space (cells) and time (time steps) over which the relevant parameters and variables are averaged.

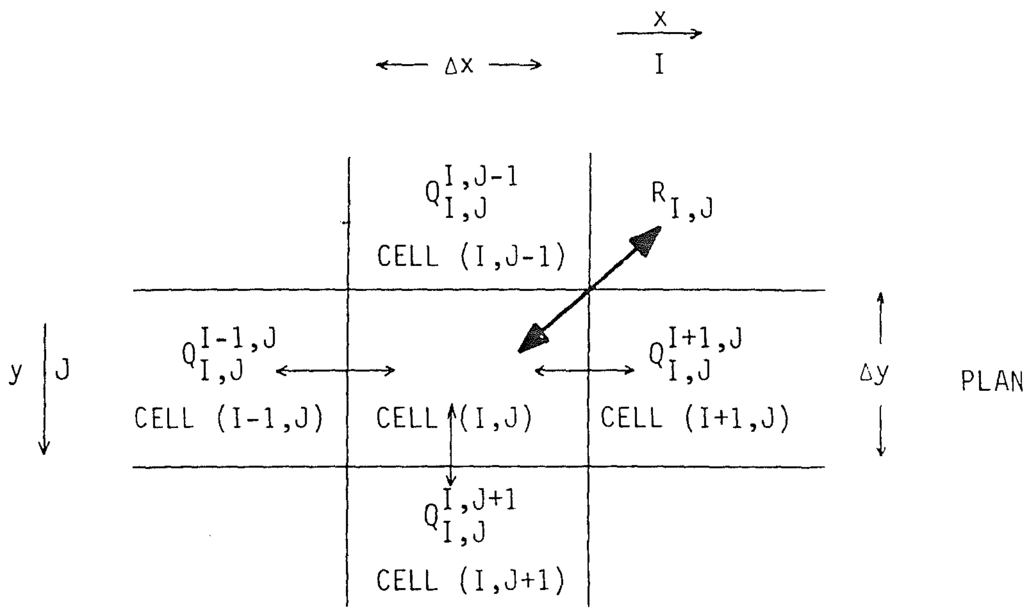
The components of water flow that may be applicable to any representative cell are given as (see Figure 17):

- accretion of water attributed to recharge of redistributed rainfall.

- depletion of water attributed to discharge by evapotranspiration or loss of groundwater across the ground surface to surface runoff.

- groundwater flow to/from the cell across its sub-surface boundaries. This water movement is described by Darcy's Law. In the case where a cell adjoins an area (another cell) which represents a surface drain, groundwater flow to the drain cell results in drain flow.

The vertical forcing associated with recharge/discharge is dominant component producing groundwater level changes. Hence the development of relationships between groundwater recharge and measured rainfall and evapotranspiration, and site variables such as soil type, depth to water etc., is an important part of the modelling study.



PEEL/HARVEY ESTUARY CATCHMENT STUDIES

GROUNDWATER INVESTIGATIONS

TITLE: COMPUTER CELL FLOW COMPONENTS

CSIRO DIVISION OF GROUNDWATER RESEAR[CH]
DENIS HURLE & ASSOCIATES (CONSULTAN[TS])

DRAWN: S.HALEY

FIGURE 17

The algorithm used for recharge/discharge prediction in the model to date is described as follows.

Within a cell all hydraulic and geometric variables are assumed to be constant (for any time step).

Geometric variables for any cell are listed as:

- relative level of ground surface (constant in time) (GL).

- relative level of the confining coffee rock layer (constant in time) (BOT).

- relative level of groundwater (variable in time) predicted by the model (H).

Hydraulic parameters assigned to each cell are listed as:

- permeability (constant in time) (K).

- storativity (constant in time) (S).

Inputs to the algorithm (SUBROUTINE ACCRET) are:

ZZ - Depth to water below ground surface
PANEV - Pan evaporation
PREC - Rainfall
WCIJ - Water content of unsaturated profile
WCMIN - Minimum water content under field conditions
WCMAX - Field capacity water content of unsaturated profile
CFH - Capillary fringe height for max water content
USLIM - Max depth to water for evaporation from soil surface

Using these variables at each cell location, the rainfall redistribution algorithm used is described in detail.

The subroutine calculates the net recharge to groundwater at that cell (RNET).

Case 1 When groundwater is within 0.1 metres of the ground surface (i.e. if the depth to groundwater is less than the capillary fringe height for maximum soil water content).

Evapotranspiration	=	Pan evaporation
Infiltration	=	Rainfall
Water content of unsaturated profile	=	Field capacity water content of unsaturated profile

Case 2 When groundwater is between 0.1 metre and 1.0 metres of the ground surface.

Evapotranspiration	=	Linear function of depth from ground surface which decays fr a maximum at 0.1 metres to zer at 1.0 metres.
Infiltration	=	Rainfall

Case 3 When groundwater is greater than 1.0 metres below ground surface.

Evapotranspiration	=	Zero
Infiltration	=	Rainfall

Following examination of these conditions the algorithm adjus the groundwater recharge (RNET = Infiltration loss evapotranspiration) and calculates the new water content of the unsaturated profile.

Following calculation of recharge/discharge at each cell the model calculates groundwater flow between cells.

The partial differential equation describing the transient flow of groundwater in a unconfined, non-homogeneous water table aquifer is given by:

$$s \, \delta h/\delta t = \delta/\delta x \, \{K(h-d) \, \delta h/\delta x\} + \delta/\delta y \, \{K(h-d) \, \delta h/\delta y\} + R(x,y,t)$$

where s = aquifer storativity (specific yield in water table aquifers)

h = hydraulic head above datum [L]

d = height of aquifer basement (coffee rock) above datum [L]

K = hydraulic conductivity of aquifer $[LT^{-1}]$

R = recharge/discharge forcing term $[LT^{-1}]$

Although there is no general solution to this equation when applied to realistic geometries, it is possible to obtain numerical solutions in space and time by representing the flow system and water balance components by an equivalent set of discrete elements and step functions.

This finite difference (in both space and time) representation of the physical flow system is derived using Darcy's Law and the principle of conservation of mass.

The conservation of mass for groundwater flow can be described by taking any cell representing part of the modelled area and quantifying the groundwater flow components.

Groundwater mass balance for any cell [designated (I,J)] can be written as:

$$\Delta S^{I,J}/\Delta t = Q^{I,J}_{I+1,J} + Q^{I,J}_{I-1,J} + Q^{I,J}_{I,J+1} + Q^{I,J}_{I,J-1} + R^{I,J}$$

where $\Delta S^{I,J}$ = change in groundwater storage over a time period Δt

$Q^{I,J}_{I+1,J}$ = groundwater flow rate from cell I,J to/from adjoining cell I+1,J

$Q^{I,J}_{I-1,J}$ = groundwater flow rate from cell I,J to/from adjoining cell I-1,J

$Q^{I,J}_{I,J+1}$ = groundwater flow rate from cell I,J to/from adjoining cell I,J+1

$Q^{I,J}_{I,J-1}$ = groundwater flow rate from cell I,J to/from adjoining cell I,J-1

$R^{I,J}$ = rate of groundwater accretion/depletion by the recharge/discharge algorithm

Δt = discretised time interval

These groundwater flow rates can be approximated in finite difference form using Darcy's Law as follows:

$$Q^{I,J}_{I+1,J} \cong F^{I,J}_{I+1,J} \, (h_{I+1,J} - h_{I,J})$$

where $F^{I,J}_{I+1,J}$ is the harmonic mean transmissivity between the I,J and I+1 cells which has been scaled according to the variable grid size dimensions (i.e.)

$$F^{I,J}_{I+1,J} = \frac{2 * T_{I,J} * T_{I+1,J} * \Delta y_{I,J}}{T_{I,J} * \Delta x_{I+1,J} + T_{I+1,J} * \Delta x_{I,J}}$$

$T_{I,J}$ = transmissivity of I,J cell given by

$$T_{I,J} = (h_{I,J} - d_{I,J}) * K_{I,J}$$

$\Delta x_{I,J}$ = I dimension of I,J cell

$\Delta y_{I,J}$ = J dimension of I,J cell

Various boundary conditions may be applied to the groundwater flow system. First, it is necessary to assume that the entire groundwater flow system being modelled is bounded by zero flow conditions. i.e. there is no groundwater inflow/ outflow across the aquifer boundaries. This condition is made by setting transmissivities between 'active' cells and the boundary cells to zero.

It may be necessary to represent constant head conditions in instances where the aquifer is intersected by permanent drains. In this case, the condition is achieved by setting the storage coefficient of cells representing the constant head areas equal to a very large positive number (i.e. 10^{50}) such that groundwater inflow (or outflow) to the constant head cells does not cause any significant change in head levels in those cells. Flow to drain cells from adjoining cells can then be calculated by means of Darcy's Law.

The total groundwater flow equation can then be expressed in finite difference form by discretising the time interval to advance the solution in time given an initial distribution of hydraulic head throughout the aquifer.

The iterative alternating direction implicit method used to solve the equation involves, for a given time increment, calculating the harmonic mean transmissivity distribution from the predicted heads, and then reducing the large set of simultaneous equations by solving the node equations for each individual column or row by Gauss elimination. This method has been extensively used and the numerical procedures have been fully documented by Prickett and Lonnquist (1971). This total process is repeated a sufficient number of times in order to satisfy the convergence criteria, which has been set as an error condition on successive prediction of heads.

Total catchment (or area) water balance is then calculated for each numerical time step as follows:

$$\Delta S = R_g + R_u - E - Q_d$$

where

ΔS - total change in catchment water storage over time interval

R_g - recharge to groundwater

R_u - recharge to unsaturated zone

E - evapotranspiration

Q_d - groundwater discharge to drain cells

Hence it is possible, at any time step to calculate drain flow derived from groundwater seepage, and to identify those areas contributing. This drain flow, coupled with rainfall to fully saturated areas, predicts measured drain flows from each catchment.

4.4 Simulation of Hydrological Responses

Simulation of the winter period beginning 18th June, 1983 (which corresponds to commencement of rainfall measurement) to the 14th August, 1983 was undertaken. This period was used to calibrate the model by adjusting:

- estimates of hydraulic properties of the surficial sand (permeability and specific yield).

- unsaturated storage of water in the sand profile and minimum and maximum water storage capacities of the unsaturated zone.

- the relationships between estimated recharge/discharge and rainfall and evaporation.

Inputs to the model were:

- initial hydraulic heads obtained from interpolation of measurements made on 18th June, 1983.

- ground level elevations interpolated from ground contours.

- aquifer basement geometry interpolated from levels of coffee rock encountered during drilling the observation bore network.

- estimates of hydraulic conductivity (K) for the various soil types as follows:

SW 1 Soils	$K = 2.5\ m\ d^{-1}$	$s = 0.13\ m\ m^{-1}$
SW 2 Soils	$K = 2.5\ m\ d^{-1}$	$s = 0.13\ m\ m^{-1}$
Joel Soils	$K = 2.5\ m\ d^{-1}$	$s = 0.09\ m\ m^{-1}$
Gavin Soils	$K = 30.0\ m\ d^{-1}$	$s = 0.20\ m\ m^{-1}$

Results of simulating groundwater responses can be assessed by comparing predicted heads and observed heads at the times of measurement. Table 4 summarises catchment averaged values for the period 17.6.83 to 7.9.83, for the north catchment, south catchment and bores outside the catchment boundaries within the

TABLE 4

COMPARISON OF PREDICTED AND OBSERVED GROUNDWATER LEVELS

IN OBSERVATION BORES

DATE	NORTH CATCHMENT MEAN LEVELS IN 19 BORES (m)		SOUTH CATCHMENT MEAN LEVELS IN 15 BORES (m)		OUTSIDE CATCHMENT MEAN LEVELS IN 27 BORES (m)	
	PREDICTED	OBSERVED	PREDICTED	OBSERVED	PREDICTED	OBSERVED
28.6.83	3.58	3.62	4.67	4.64	3.11	3.16
8.7.83	3.59	3.62	4.60	4.61	3.03	3.01
14.7.83	3.64	3.51	4.60	4.53	3.02	2.88
22.7.83	3.66	3.50	4.59	4.52	3.00	2.86
26.7.83	3.85	3.74	4.79	4.74	3.14	3.13
2.8.83	3.78	3.59	4.65	4.59	3.01	2.94
12.8.83	3.80	3.70	4.61	4.70	2.98	3.05
18.8.83	3.85	3.63	4.65	4.65	3.01	2.99
30.8.83	3.94	3.78	4.76	4.77	3.09	3.15
7.9.83	3.98	3.83	4.81	4.82	3.12	3.19

area modelled.

Generally, average predicted heads on the north catchment overestimated those observed. However, there was a reasonable match on the south catchment and in bores outside the catchments (average standard deviation of difference were less than 0.15 metres after 82 days of simulation).

Matching is expected to be improved by fine adjustment of hydraulic parameters according to landscape position, soil types and modification to the parameters controlling prediction of recharge and discharge.

Water balance components within the catchment are also predicted by the model.

Predicted estimates of recharge to groundwater by rainfall, discharge from the groundwater by evapotranspiration and drain flows for each of the north and south catchments are listed for the simulation period. Table 5 shows these estimates over periods between monitoring visits and compares them to measured rainfall.

Recharge to groundwater was predicted to mostly exceed about 70% of measured rainfall. Total water balance for each site is determined by the modelling procedures by calculation of changes in storage of water within both the saturated and unsaturated soil profiles.

Discharge of water from the groundwater by evapotranspiration was predicted to be a small component of the water balance, at least over the winter rainfall period simulated.

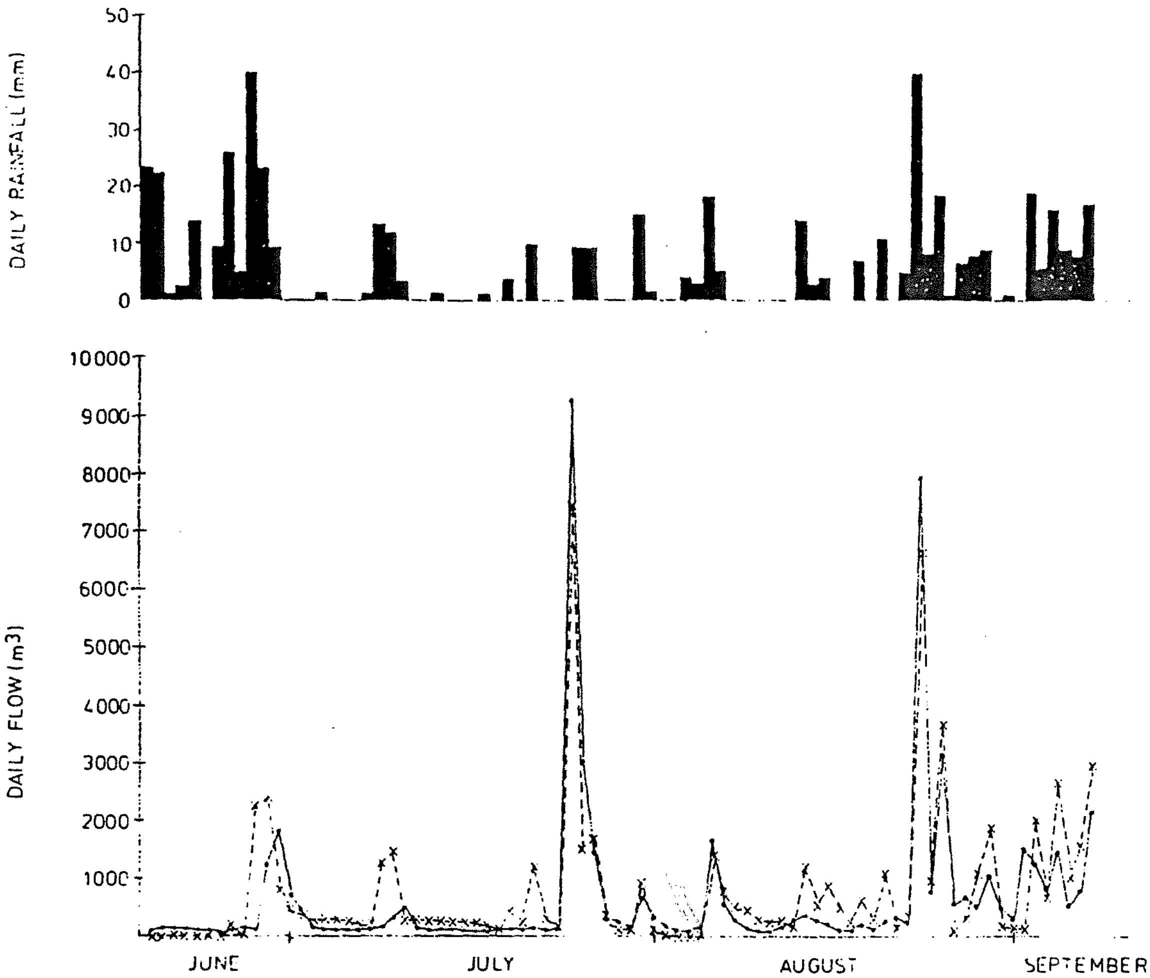
Drain flows were predicted on a daily basis over the 82 day period. On the north drain, cumulative predicted drain flow was seen to exceed measured flows by about 18%, whereas on the south drain, predicted cumulative flows underestimated those measured by 26%.

Daily flow predictions were graphed against measured flows and are given in Figure 18 for the north catchment and Figure 19 for the south catchment.

TABLE 5

PREDICTED CATCHMENT WATER BALANCE COMPONENTS

PERIOD	MEASURED RAINFALL (mm) (MODEL INPUT)	PREDICTED RECHARGE TO GROUNDWATER (mm) NORTH	PREDICTED RECHARGE TO GROUNDWATER (mm) SOUTH	PREDICTED DISCHARGE FROM GROUNDWATER (mm) NORTH	PREDICTED DISCHARGE FROM GROUNDWATER (mm) SOUTH	PREDICTED DRAIN FLOWS (mm) NORTH	PREDICTED DRAIN FLOWS (mm) SOUTH
17.6.83 - 28.6.83	164.6	85.3	97.6	0.1	0.8	21.7	26.5
28.6.83 - 8.7.83	22.9	15.1	12.7	4.4	4.1	19.6	21.1
8.7.83 - 14.7.83	15.3	13.1	12.4	1.6	1.5	12.5	15.4
14.7.83 - 22.7.83	15.0	11.3	9.8	1.8	1.4	12.0	12.5
22.7.83 - 26.7.83	68.6	64.2	63.5	0.4	0.3	46.1	49.8
26.7.83 - 2.8.83	15.2	9.5	7.9	11.3	11.5	6.1	13.0
2.8.83 - 12.8.83	27.7	17.6	15.0	6.2	5.0	18.6	20.7
12.8.83 - 18.8.83	28.6	17.9	14.7	3.2	2.3	18.5	14.5
18.8.83 - 30.8.83	109.4	83.3	81.8	12.0	10.9	71.9	71.3
30.8.83 - 7.9.83	76.1	47.1	45.5	2.9	2.6	49.4	50.9
TOTAL	543.4	364.4	360.9	43.9	40.4	276.4	295.7



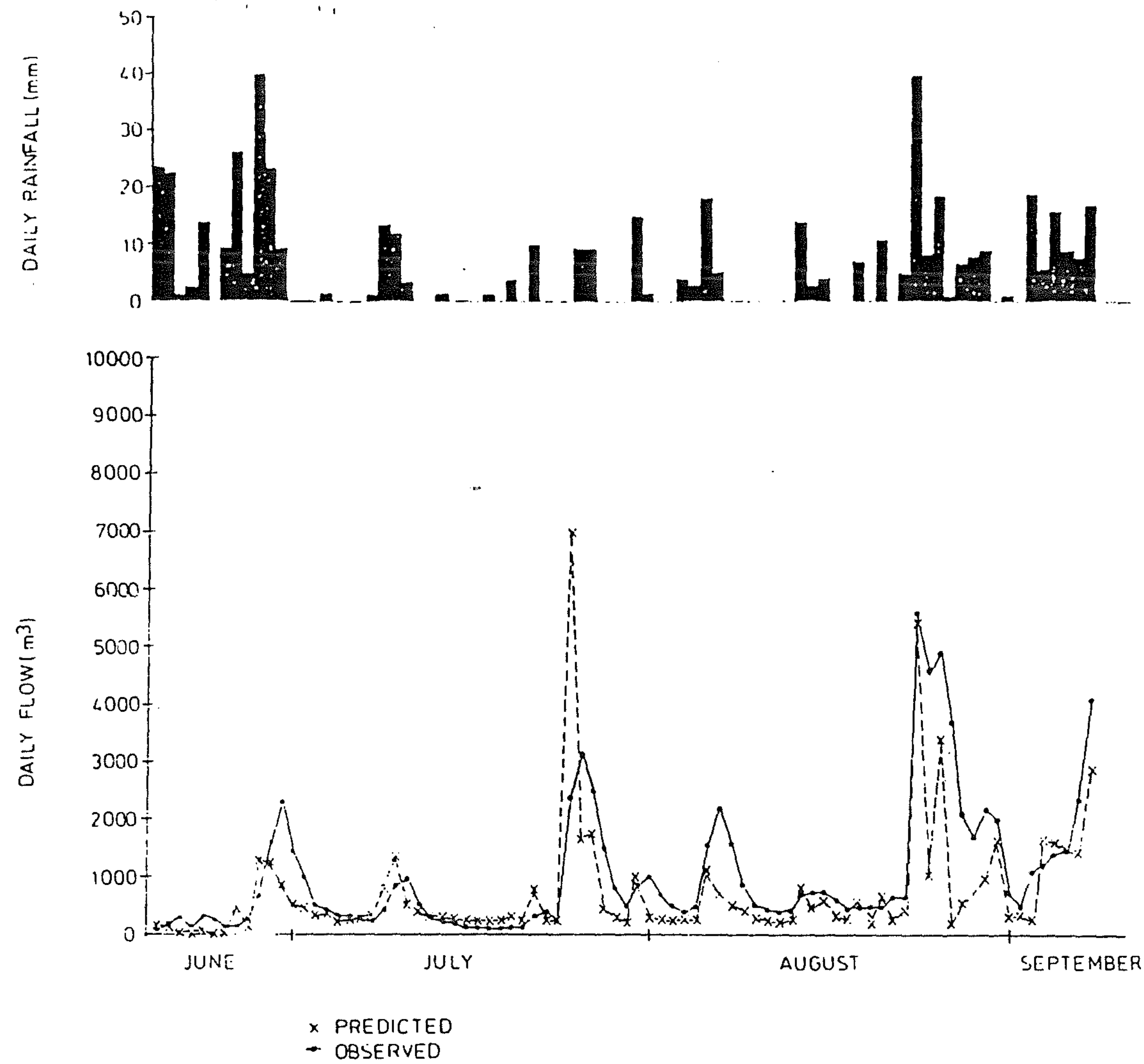
PEEL/HARVEY ESTUARY
CATCHMENT STUDIES

GROUNDWATER INVESTIGATIONS

TITLE: PREDICTED AND OBSERVED DRAIN FLOWS - NORTH CATCHMENT

CSIRO DIVISION OF GROUNDWATER RESEARCH
DENIS HURLE & ASSOCIATES (CONSULTANTS)

DRAWN: S. HALEY | FIGURE 18



PEEL/HARVEY ESTUARY
CATCHMENT STUDIES

GROUNDWATER INVESTIGATIONS

TITLE: PREDICTED AND OBSERVED DRAIN FLOWS - SOUTH CATCHMENT

CSIRO DIVISION OF GROUNDWATER RESEAR(
DENIS HURLE & ASSOCIATES (CONSULTAN'

DRAWN: S.HALEY

FIGURE 19

On the north drain initial flows were overestimated by predictions, whereas the 'spiky' high flow events later in the season were underestimated by the model. Predicted base flows were generally higher than those measured as were the predicted flows late in the simulation.period.

On the south drain predicted drain flows were generally more 'spiky' than those measured and resulted in a general underestimate of total flow during peak flow events. Predicted base flows also generally underestimated those measured.

In summary, initial attempts to match the observed hydrological behaviour of the site has resulted in acceptable simulation of hydraulic heads and surface water runoff.

Further calibration of the model can be achieved by adjustment of hydraulic parameters to more closely simulate groundwater responses. This in turn will result in a better match between observed and predicted drain flows. This will provide more accurate estimates of water balance component, enabling estimation of the dominant water flow processes contributing to drain flow.

5. SUMMARY AND RECOMMENDATIONS

Assessment of the first two years of data collected from the experimental Talbot's farm site has given detailed insight into defining and quantifying the major processes of subsurface water movement and its contribution to surface water runoff.

Results of the monitoring programme have yielded estimates of groundwater storage increases of about 300 mm over the 1983 winter period compared to measured rainfall of about 470 mm.

Groundwater level increases resulted in flooding in much of the low lying Joel soil and swamp soil areas of the site. This was seen to result in surface flow and groundwater flow to the shallow drains discharging from the lower areas.

Hydraulic testing of the groundwater systems at two sites within the Bassendean association was undertaken during 1984. Results from this indicated that the deeper aquifer below the coffee rock had high transmissivity and the potential to transport large amounts of water (and phosphorus) to sink areas. Pumping however, could not induce any leakage of shallow groundwater (containing the phosphorus) through the coffee rock.

Assessment of groundwater phosphorus concentrations has enabled determination of the spatial distribution, and the time variation in phosphorus storage within the saturated soils.

Generally, high phosphorus storage was encountered in the SW 2 swamp soils where concentrations of up to 32 mg l^{-1} were recorded. These areas are generally inundated during winter. Concentrations in the Joel series were lower, rarely exceeding 7 mg l^{-1}. In SW 1 swamp soils adjoining the Meredith drain and in the higher Gavin soils,concentrations were generally low rarely exceeding 3 mg l^{-1}.

Phosphorus storage within the groundwater was estimated to increase from summer to the end of winter, being more related to groundwater storage increases rather than to concentration changes. Estimated storages were generally of the order of about 1 kg ha^{-1} to 15 kg ha^{-1} the lower estimates being on the north catchment and in areas adjacent to the Meredith drain.

These estimated storages are considerably less than the total inorganic and organic phosphorus storages of the Bassendean soils. Note that typical phosphorus application rates are 18 kg ha^{-1} yr^{-1}.

No significant changes in groundwater phosphorus storage were observed following superphosphate application to the south drain catchment in 1983 and 1984, however large temporal variations in phosphorus concentrations were noted following groundwater rising to the soil surface.

In summary, assessment of phosphorus redistribution within the groundwater has shown the complexity in describing the physical processes involved and their variability in space.

This is apparently due to the interaction of 'fixed' phosphorus and 'mobile' phosphorus stores and their relationships to variations in soil properties and seasonal hydrology of the shallow soil system.

The detailed definition of water processes resulting from this study has resulted in the formulation of a process-based groundwater/surface water flow model. This model has been used to simulate the hydrological responses on the Talbot's site and is capable of predicting:

- groundwater recharge/discharge.
- groundwater storage changes.
- unsaturated soil water storage change.
- groundwater flow to drains and swamps.
- surface water flow to drains.
- rates of horizontal groundwater redistribution given

detailed site characteristics and seasonal climatic data.

The model has been calibrated by comparison of predicted results with recorded hydrological responses in winter 1983.

Preliminary modelling results indicated that groundwater level changes can be predicted to within about 20%, and cumulative drain discharges were predicted to within about 25% of those observed over the first 82 days of the 1983 winter flow period.

Further improvement in matching observed responses will be achieved by developing the recharge relationships used in the model, and by comprehensively adjusting the spatial estimations of hydraulic parameters in relation to soil types and landscape positions.

The development of a process based model and its subsequent calibration to real field hydrology in this manner gives the researcher greater insight into identifying and quantifying the unmeasured mechanisms dominant in the hydrological system.

The water flow model is seen as a forerunner to the development of a phosphorus transport model. This model will be based on empirical relationships describing:

- the relationship between 'fixed' phosphorus in the soil profile and mobile phosphorus in the soil water, and rates of soil water movement.

- release of phosphorus from applied superphosphate to rainfall infiltration, plant uptake and to 'fixed' soil storage.

- phosphorus status in unsaturated soil profiles under varying conditions of climate, soils and hydrology.

It is expected that the large variability observed in phosphorus responses in a field situation may cause some problems in simulating farm behaviour in terms of phosphorus stores and phosphorus discharge to drain flow under different management practices.

Some catchment management practices which may reduce farm phosphorus export are apparent from the results of this study.

First, it is apparent that the total farm water (and phosphorus) yield to drain flow in any season, is highly dependent on, apart from rainfall, the depth to groundwater before the onset of winter rains. Hence if groundwater levels were reduced by one metre during the summer season, then it would require about an extra 100 mm of rain to occur prior to groundwater intersection of the surface, waterlogging and subsequent surface flow. The ability to achieve this would be dependent on the logistics of being able to lower water table levels and how to do it (e.g. by using deeper rooted summer pasture, trees, or summer irrigation from the shallow groundwater).

Second, drainage of internal swamps by discharging water of high phosphorus concentration to main drains is apparently a major source of nutrient to the estuary from the Bassendean association. Discharging the swamps on to soils which have the potential to adsorb phosphorus (e.g. SW 1 soils), if practical, would have the twofold benefits of reducing total phosphorus export and retaining phosphorus on the higher productive farm areas. Irrigation of these areas may be a practical solution. In summary, options relating to management of shallow groundwater to minimise surface flow need to be evaluated.

Future work to be undertaken in the groundwater studies programme is involved with examining the rundown of soil phosphorus on the untreated north catchment compared to the south catchment.

Particular studies should be undertaken. It is necessary to identify the presence and depth of the confining coffee rock over the entire Talbot's site. It is anticipated that this can be achieved by shallow seismic techniques using existing CSIRO equipment. As well as achieving these objectives the study should result in the development of these techniques so that they can be applied to other (study) areas. This would save considerable costs in drilling.

A study needs to be undertaken to determine the hydraulic properties of the shallow, above coffee rock, aquifer and the variability of these parameters in terms of soil types etc. Ideally, infiltration tests and constant head permeameter techniques could be evaluated and carried out in both summer and winter.

It is planned that the group will undertake groundwater aging studies to determine rates of water flow between the various aquifer sequences in different landscape positions. This may be achieved by tritium analysis, carbon dating or by application of radio-active phosphorus.

It is recommended that, following final acceptance of the surface water modelling results, a detailed review of (or workshop relating to) the possibility of modelling phosphorus transport processes, be undertaken. This will involve liason with other groups within and outside the Peel-Harvey Project. It should result in the formulation of a conceptual understanding of phosphorus redistribution such that a computer based model will be developed. The model should ultimately be capable of predicting the results of varying phosphorus management practices on pasture production, phosphorus storages on farmland, and phosphorus discharge to drain flow. This work would be carried out conjunctively with laboratory and field trials such as the Talbot's study, and should not be considered short term.

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