PEEL-HARVEY SYMPOSIUM

28 & 29 November, 1983

Department of Conservation & Environment
Perth, Western Australia.

Hodgkin

INTRODUCTION

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Last December's Symposium reviewed progress of Phase 2 of the Peel-Harvey Estuarine System Study and concentrated largely on efforts to find out how best "to reduce the quantity of phosphorus discharged to the estuary from agricultural land", as recommended by the Estuarine and Marine Advisory Committee (DCE Bulletin No.88, 1981). It is evident from the papers submitted here that there has been great progress towards this objective. There are still obvious gaps in our knowledge and some uncertainties, many of them because this year's data has still to be fully analysed, and in consequence some of the judgments we have to make may still be premature and must be recognised as such.

This year's Symposium has a much wider scope. The aim is to review all research which has any relevance to management of the present eutrophic condition of the estuary and then to decide what recommendations can now be made with respect to management (Phase 3), and what further Phase 2 type studies are necessary. Clearly a two-year study into how to manage such a complex ecosystem as that represented in Figure 1, which has been mis-managed or not managed at all for half a century, cannot be expected to have all the answers. There are still far too many areas of uncertainty for the comfort of most scientists involved, particularly with respect to the agricultural aspects.

Predictions as to what can be achieved by alterations to a complex biological system will, at best, be only as good as the data on which they are based. In the past we have failed to predict major changes to the estuarine ecosystem and it would be unwarranted and conceited to assume that we can do so now with certainty, despite our much greater knowledge. Nevertheless we have to make recommendations for management - recommendations as to what can be achieved and what measures are required in order to achieve them - recommendations which if implemented could cost the State millions of dollars. It is not our job to say what will be done, that is beyond the scope of this exercise.

This is not to suggest an ivory tower approach, we must obviously be aware of social, financial and other constraints and make due allowance for them, but in making judgements we need to be conscious of the assumptions we have made. As an extreme example, the commitment to having both a viable agricultural industry on the coastal plain and a healthy, largely weed-free, estuary is an assumption. Other people, farmers, Mandurah residents, politicians may justifiably question our assumptions and place a different set of values on them - they are value judgments which will influence decisions as to what should be done.

It is well to be clear at the outset what our objectives for management are, and to be agreed on them. They are listed in the Croft - Humphries report as follows:

Proposed Management Objectives

1. The environmental impact from any strategy adopted should be far less than the existing impact caused by the present nutrient problems.

2. Cyanobacterial blooms are not to occur with a frequency greater than one year in five. A bloom is defined as a peak cyanobacterial chlorophyll$_a$ concentration of 20 $\mu g l^{-1}$ or greater.

3. Macroalgal populations should not cause fouling of the populated estuarine beaches.

4. Public access to the estuary by water or land should not be reduced.

5. Productivity of the estuarine fishery should not be reduced.

6. Productivity of coastal plain agriculture should be maintained.

7. Changes to surrounding natural ecosystems should be avoided.

8. Introduction of exotic plants and animals should be avoided.

9. Major physical changes to the estuary, for example new channels, islands of dredge spoil, increased depth, changed bottom morphology, salinity and temperature regimes, should only occur for attainment of the objectives stated above.

The cause of the algal problems was identified in the December 1980 report on Phase 1 as being the large quantity of phosphorus discharged to the estuary from agricultural drainage. The logical solution was obvious from the first: reduce the input of fertilizer - derived phosphorus to the point at which it will no longer result in blooms of nuisance algae. To do this requires an agricultural revolution, something that is possibly long overdue but cannot be achieved overnight. It also requires a detailed understanding of the behaviour of the phosphate ion in the highly complex media of plants and soils in the paddocks, something that is not available from text books.

The management studies indicate that the input of phosphorus to the estuary cannot be reduced sufficiently to prevent algal blooms by agronomic measures, at least within an acceptable time.

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Of course this does not mean that such measures should not be pursued actively, it does however mean that other measures to reduce the phosphorus available to algae will have to be employed in order to achieve the management objectives. Acceptance of this fact means that other measures have to be evaluated for their capacity to contribute to a reduction in nutrient levels in estuary water sufficiently without undue disruption to the ecosystem, and again within an acceptable time.

It is unlikely that any measure we can recommend will achieve a significant reduction in the eutrophic condition of the estuary within the next three to five years. We must, therefore also consider what measures can be taken to ameliorate the worst effects of the algal blooms in the interim, again with the minimum damage to the ecosystem.

The papers presented here, whether or not they say so explicitly, relate to these management considerations and should be read for their contribution to determining what recommendations can be made for management at this time.

What follows are intended merely as thought starters - the facts will be found in papers that follow this introduction and the figures used here are mostly only approximations, near enough I hope for the validity of the arguments presented.

The catchment source

There have been Nodularia blooms in the estuary in every year from 1978 - except in 1979. The estimated input of phosphorus in that year (1979) was 46t to Harvey Estuary. In 1981, still a year of only marginally above average river flow, the figure was 124 tonnes of phosphorus, nearly three times the 1979 figure. In the absence of any better criterion, the requirement of a 70% reduction on present loads is therefore regarded as the maximum acceptable phosphorus input if Nodularia and other cyanobacterial blooms are not to occur more frequently than about one year in five.

Given that the minimum quantity of phosphate fertilizers are used to maintain production on the coastal plain and that only slow release fertilizers are used, the release of phosphorus to drainage could immediately be about 30%. This low response is mainly because about 70% of the phosphorus lost from paddocks comes from the soil store, the farmers' 'super bank' which has built up over many years. Only 30% is accounted for by fertilizer applied in the current year.

In 1982, experimental work in the catchment concentrated mainly on the deep grey (Bassendean) sands (Figure 2) because of the high leaching losses from them (Table 1). The 1983 studies have been extended to the sands over clays (Coolup) soils from which leaching is less. But because of the greater area of these soils they contribute a larger proportion of the phosphorus load. Although the leaching rate from the other soil types on the coastal plain is low they do make a significant contribution to phosphorus input to drainage and cannot be neglected in any measures to reduce the phosphorus load to the estuary.

Table 1. Estimated Phosphorus export from the Harvey River and Mayfields Drain catchments to Harvey Estuary[1]. 1982

	Catchment area		Fert. appl.	Phosphorus to drainage			
				Rate		Quantity	
	km^2	%	kg/ha	kg/ha	%	tonnes	%
Deep grey sand	143	22.4	4.6	1.4	30	20	33)
Sand over clay & B & Y sand	213	33.4	11.5	1.3	11	28	46) 79
Clays & loams	143	22.4	15.4	0.7	5	10	16
Foothills	139	21.8	-	0.2	-	3	5
	638	100				61	100

1. The Harvey River and Mayfields Drain catchments represent about 80% of the total Harvey Estuary catchment, but deliver about 90% of the total load to it.

The 1978 studies estimated that the plateau catchment of the Murray River only contributed 10% (17 tonnes) to the input of phosphorus to the estuary. Rainfall and river flow were well below average. Birch estimates this contribution to have been 14 tonnes and 20 tonnes in 1981 and 1982 respectively, both years of below average flow. Management of this source may have to go into the "too hard basket" for the present, but it is clearly an important contributor to Peel Inlet's problems and input from this source cannot be disregarded.

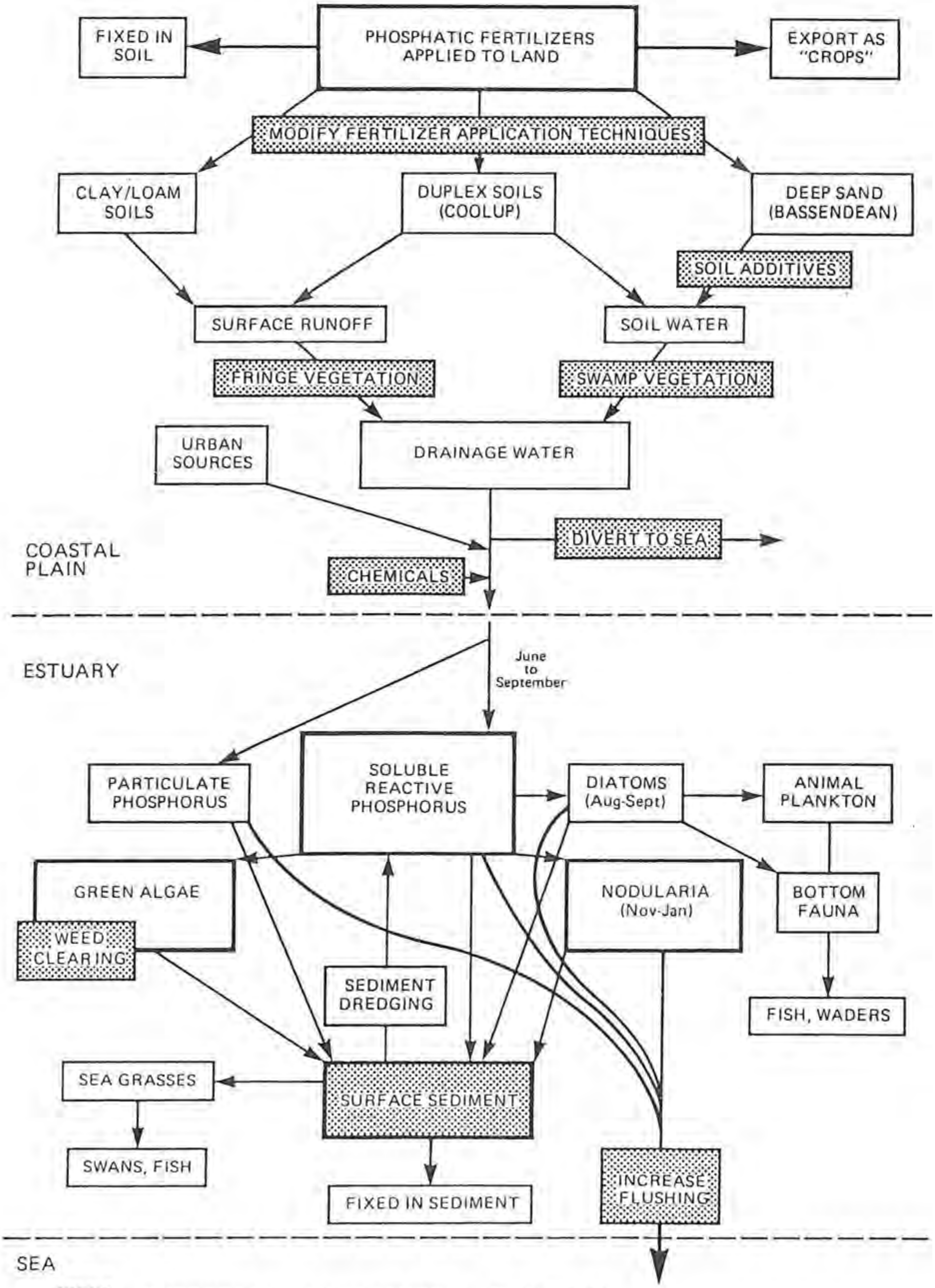
The estuary's response

In 1976 we were asked to investigate the cause of the macroalgal nuisance in Peel Inlet - at that time Cladophora. Subsequently Chaetomorpha and then in 1982-83 Ulva have been the dominant algae. The change cannot be assumed to have been fortuitous and probably represents a further deterioration in the condition of the Inlet. These algae only penetrate the northern 15% of Harvey Estuary. The first Nodularia bloom came in 1978 and since then blooms have extended to Peel Inlet and bloom intensities have been roughly proportional to the input of phosphorus which, in turn, has been roughly proportional to rainfall and river flow. The two years 1973 and 1974 had well above average rainfall. There were almost certainly Nodularia blooms, at least in Harvey Estuary, but there was no public outcry. The blooms cannot have been on the scale of those experienced since 1980.

It is still too early to say what will happen in 1983. The initial bloom in early November was as big as any previously experienced, but since then conditions appear to have been less favourable for Nodularia. However, a disturbing fact of 1983 has been the intensity of the diatom blooms of July to September and the large proportion of phosphorus trapped by them and transferred to the sediments. It is difficult to predict the response of the estuarine biota to this increased load and the potential of greater inputs with any return to above average rainfall. McComb's prediction that Nodularia will be light limited above the 1981 levels is not particularly comforting.

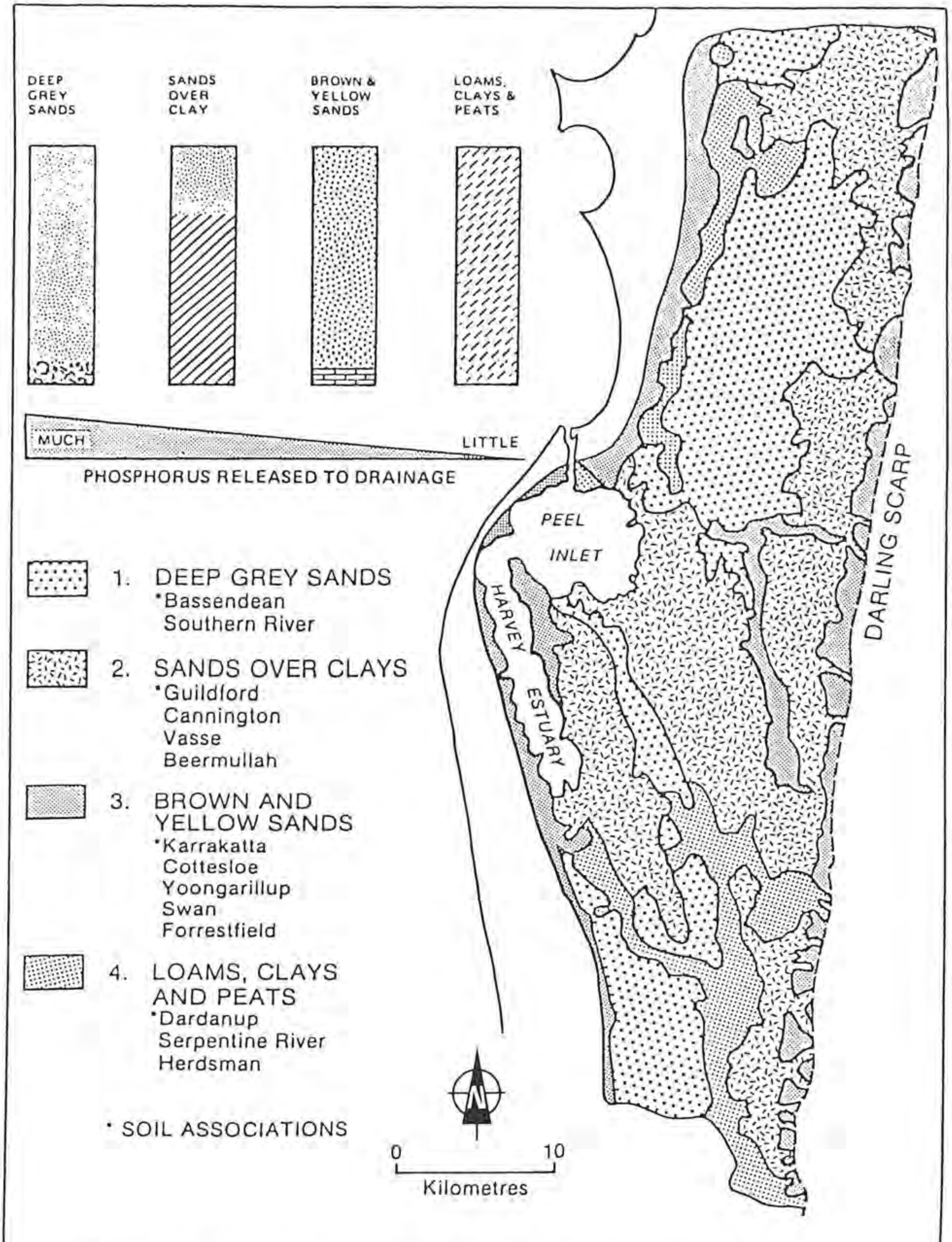
It is probably true that when phosphorus input is reduced below the 1979 level the sediment store will run down rapidly (though that has not always been the experience elsewhere), but that situation is likely to be some years away and in the meantime there is no prospect of the present unhealthy condition of the estuary improving. It is in that context that we need to examine any measures which can be used to ameliorate the present problems, even if they do nothing to reduce the present eutrophic condition of the estuary.

If this is too depressing a note on which to conclude this introduction it will be clear from the papers which follow that the work of the last two years does offer a good basis for management within a time period much shorter than that in which the estuary has been brought to its present unsavoury condition. There will be some hard decisions to be made but the community can be assured that there are ways to reverse the present deterioration in the condition of the estuary, even if they may be expensive and take several years to implement.



POTENTIAL MANAGEMENT MEASURES

Figure 1. Phosphorus flow paths in the coastal plain/estuary ecosystem.



The BASSENDEAN Soil Association includes JOEL sands on the flats with 1 to 2 m of sand over coffee rock and GAVIN dunes with up to 5 m of sand over the coffee rock.

Figure 2. Soil categories on the coastal plain catchment of the Peel-Harvey estuary.

Robinson
(Croft & Humphries)

SEMINAR ON MANAGEMENT OPTIONS FOR THE PEEL-HARVEY SYSTEM

NOVEMBER 28 AND 29, 1983

S J Robinson
Department of Conservation and Environment

18 November, 1983

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SEMINAR ON MANAGEMENT OPTIONS FOR THE PEEL-HARVEY SYSTEM

1. INTRODUCTION

A feasibility study of management options for the Peel-Harvey system has been carried out by R B Humphries and C M Croft at the Centre for Water Research, University of Western Australia.

The study team produced three reports

1. Report 1 (dated August, 1983) - a working document which considered all the management options, rejected those considered to be impractical and made recommendations on areas of additional work required to test further the feasibility of the remaining options

2. Report 2 (dated November, 1983) - considered the more promising options in greater detail

3. Report 3 (dated November, 1983) - contains a summary of the earlier reports and makes recommendations on management packages

The purpose of this summary document is to present in brief all the options, indicate the reasons for rejection at an early stage and to provide a concise account of the modus operandi, advantages and disadvantages of each of the most promising options. The document forms a discussion paper for the seminar to be held on November 28 and 29, 1983.

2. PURPOSE OF THE SEMINAR

It is intended to limit discussion at the seminar strictly to the options believed to be feasible and to give no further consideration to those strategies that were rejected early (a list of these is appended). There is a lot to cover in two days and the time schedule will be rigidly adhered to. If any seminar delegate wishes to make any comment about the rejected options they should consult the full reports which can be seen at the Department of Conservation and Environment (Dr P Birch), Public Works Department and the Centre for Water Research. Any enquiries should be directed to Dr P Birch at DCE or Dr Bob Humphries or Mr Chris Croft at the Centre for Water Research before Friday 25 November, 1983.

3. STATEMENT OF THE PROBLEM AND PROPOSED MANAGEMENT OBJECTIVES

Elevated phosphorus levels in the Peel-Harvey system have been identified as the prime cause of the nuisance algal blooms that frequently occur. Management objectives are aimed particularly at methods of reducing input of nutrients to the estuary from the surrounding catchment. Other problems such as retention of phosphorus in the sediments have also been considered.

Four management mechanisms have been identified:

- reduce phosphorus input to the Peel-Harvey system
- increase phosphorus export from the system
- reduce sediment phosphorus supply within the system
- manage the macroalgal nuisance

A statement of proposed management objectives is given in Table 1.

Table 1 - Statement of Proposed Management Objectives

1. The environmental impact from any strategy adopted should be far less than the existing impact caused by the present nutrient problems.

2. Cyanobacterial blooms are not to occur with a frequency greater than one year in five. A bloom is defined as a peak cyanobacterial $chlorophyll_a$ concentration of 20 $\mu g l^{-1}$ or greater.

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4. SUMMARY OF MANAGEMENT OPTIONS

All the management options considered could be broadly classified into eight groups, these are

(i) modifications to agricultural practices

(ii) wetlands as nutrient traps

(iii) chemical removal or inactivation of phosphorus

(iv) diversion of drainage water to the sea

(v) direct attack on algae

(vi) dredging of the estuary

(vii) increased marine flushing

(viii) miscellaneous options

Of these groups (vi) and (viii) were rejected early (see Appendix). Specific proposals within the other categories were evaluated further and are summarised in the following pages.

4.1 MODIFICATIONS TO AGRICULTURAL PRACTICES

4.1.1 Soil Tests, Types of Fertilisers and Application

Rationale

Soil tests can be used to establish fertiliser requirements and particularly to determine optimum fertiliser application rates and type of fertiliser. New fertilisers are required that will slowly leach from the upper soil horizon yet provide freely available phosphorus to plants and supply adequate annual essential sulphur to the soils. Initial studies indicate that very significant reductions in phosphorus leaching can be achieved.

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Results

According to preliminary estimates, for the partially acidulated rock phosphate fertiliser (AS 3) a reduction in phosphorus application of 69% for deep grey sands and 78% for duplex soils can be achieved while maintaining productivity.

The estimated reduction in loss by leaching was 49% for deep grey sands and 57% for duplex soils.

ACTION

Continue investigations

4.1.2 Changes in Current Land Use

Rationale

Conversion of highly leaching soils from agriculture to land uses requiring low phosphorus fertiliser application rates may be beneficial.

Two possible conversion alternatives have been considered:

(a) total removal of land from production and conversion to parkland which would give no financial return

(b) conversion from agriculture to forestry. This could reduce phosphorus export by reducing the phosphorus requirement in the catchment and by interception of groundwater by the trees. Financial return would be possible from either pine or eucalypt plantings.

Results

The total reduction in phosphorus application to forested areas would be some 45%.

At 1 500 trees ha^{-1} pines will be preventing groundwater recharge after 6-8 years from planting. Assuming that phosphorus input will cease with a reduction in groundwater recharge, a reduction in phosphorus export may be produced in 6 to 8 years.

Costs

Cost of establishing Pinus pinaster on the non-waterlogged Gavin ridges is \$1 500 ha^{-1}.

Cost of establishing eucalypts in the wetter areas is \$425 ha^{-1}.

Pines could give a total rate of return of \$5 600 ha^{-1} (1983 dollars) over a 60 year period, ie \$93 yr^{-1}.

Assuming an initial 15 year (and subsequent 10 year) growth for eucalypts for woodchips, the returns would be \$45 ha^{-1} yr^{-1}.

4.1.3 Amendment of Leaching Soils with Bauxite Residue

Rationale

Bauxite residue has been suggested as a possible soil additive capable of reducing phosphorus leaching losses; it also improves water retention capacity and yield. Application rates of 1 000 to 2 000 t ha^{-1} of red mud have been previously suggested; later work shows that rates as low as 200 t ha^{-1} may reduce phosphorus leaching. Up to a 10-fold increase in pasture productivity may occur on some deep sands.

Results

A reduction in phosphorus in Harvey catchment and drains of about 23% would be possible if the deep grey sands were treated and 57% if the Bassendean sands and Coolup (duplex soils) were both treated.

Costs

For a 40 km cartage distance a cost of \$4 $tonne^{-1}$ to load, cart and spread was obtained.

At a rate of 200 t ha^{-1} this cost is upwards of \$800 t^{-1}.

Transport costs are about 50% of the total cost of the residue and reduction could be achieved by pumping a slurry of approximately 45% solids to holding areas for later redistribution.

4.2 WETLANDS AS NUTRIENT TRAPS

4.2.1 Wetland Filters at Point Sources

Rationale

The treatment of effluent water at point sources eg piggeries, involves the stripping of phosphorus by plant uptake and perhaps by sediment absorption.

This technique could be used for high concentration, low flow sources.

Results

If used at piggeries wetland filters may achieve a reduction of applied phosphorus of 14% in the Serpentine catchment. The amount of this phosphorus that is available for leaching to the estuary is not known. Wetland filters at piggeries could be implemented in about 1 year.

4.3 CHEMICAL REMOVAL OR INACTIVATION OF PHOSPHORUS

4.3.1 Chemical Removal of Phosphorus from Surface Drainage

Rationale

Locally it has been suggested that red mud could be added directly to agricultural drainage water to absorb phosphorus, settle out and thereby reduce the nutrient flux into the Harvey Estuary. Addition of red mud slurry to open drains is not seen as acceptable environmentally. A process has been designed which can treat the Meredith catchment drainage water in a contained system prior to its release back into the Harvey Main Drain. The process uses ferrous sulphate (copperas) waste from the Laporte plant at Australind to neutralise the causticity of the red mud and to increase phosphorus adsorption capacity.

Results

Preliminary results of testing suggest that treatment could remove approximately 40 tonnes of phosphorus or 33% of the total estimated Harvey River inflow.

Costs

Capital cost of this scheme would be $16 million with annual operating costs of $2-5 million.

ACTION

Further work is required to confirm chemical aspects and preliminary engineering design and cost estimates should be carried out.

4.3.2 Chemical Treatment of Sediments

Rationale

Internal phosphorus loading in the sediments may still be an important source of phosphorus even after successful reductions in external phosphorus loadings are achieved. Direct treatment

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of sediments with suitable chemicals (eg alum and nitrate salts) to precipitate and bind the phosphorus could substitute for dredging and would be cheaper and could be applied more rapidly.

Results

Tests using Harvey Estuary water and sediment allowing completely anaerobic conditions and high filterable reactive phosphorus (FRP) concentrations to occur before dosing indicate that alum at 80 g Al m^{-3} or 3 g Al m-2 and nitrate at 90 g NO_3-N m^{-3} or 3.5 g NO_3-N m^{-2} considerably reduced phosphorus release from the sediments.

Costs

Costs of chemicals for treating Harvey Estuary are:

(i) $4-9 million for whole Harvey Estuary volume

(ii) $136 000 - $271 000 for surface treatment

A capital cost of about $1 million would be required for surface injection equipment.

4.4 DIVERSION OF DRAINAGE TO THE OCEAN

4.4.1 Herron Ford Barrages

Rationale

The proposed strategy is to divert to the ocean sufficient inflowing Harvey Main Drain, South Coolup and Mayfields Drain flows to prevent *Nodularia* blooms occurring in 4 out of 5 years. This would prevent all Harvey catchment phosphorus from being bound in either sediments or biomass. Construction of the barrage would alter salinity in the estuary by complete diversion of freshwater inflow.

Results

Modelling studies indicate that maximum summer salinity could reach 55‰ which would not detrimentally affect the primary or secondary production in the system.

Increased winter salinity could restrict a *Nodularia* bloom.

Complete diversion of fresh river inflow and nutrients would probably result in a rapid reduction in nuisance blooms of cyanobacteria which would enhance the estuarine habitat for fish, however diversion of nutrients could lead to a gradual reduction in productivity of the fishery with time.

Construction of the barrage would result in inundation of the Nature Reserve, the extent depending on the height of the barrage. The conservation value of this reserve would need to be assessed.

Costs

For options with a 3 m maximum water level, a land resumption of 1 400 ha would be necessary and for options with a 1.5 m maximum water level land resumption would be 500 ha.

Costs for these schemes in 1983 dollars range from $50-$100 + million (including resumption costs

4.5 DIRECT ATTACK ON ALGAE

4.5.1 Weed Harvesting from Beaches

Rationale

Specially modified Volvo loaders with rakes are used to collect beached algae and stockpile it to allow trapped water to drain away. The combination of rotting beached algae and working heavy machinery reduces the amenity of the populated beaches. Beach clearing only achieves the short-term goal of removal of nuisance algae from public beaches.

Cost

Annual cost is about $70 000.

ACTION

Weed harvesting on beaches should be continued. The need for it should become less as other more successful methods are used to intercept algae before they beach.

4.5.2 Offshore Weed Harvesting

Rationale

Algae, particularly Chaetomorpha, Cladophora, Ulva and Enteromorpha can be intercepted before they beach or can be harvested from growing algal beds. This reduces the requirement for removal of algae from beaches.

The offshore harvesting capacity will be upgraded during 1983 from one unit to two.

Results

Current estimates are that the upgraded offshore harvesting capacity of 3000 wet tonnes yr^{-1} will be sufficient to achieve acceptable control of beach fouling for about 85% of the time.

ACTION

Weed harvesting should be continued.

4.5.3 Algistats (3.5.3 in Report 1)

Rationale

Algistats (growth inhibitors) could be one of the few control options available for single season reduction of both macroalgal and phytoplankton growth and can be applied rapidly.

Results

The most promising substances for further testing are simazine and terbutryn.

Costs

Highly variable depending on whether macroalgae or *Nodularia* are being treated and depending on the area/volume of treatment required.

Maximum cost would be about $1.46 million for treatment of the whole of the Harvey Estuary volume with simazine or $47 000 for treatment with terbutryn (single treatments).

4.6 INCREASED MARINE FLUSHING

4.6.1 Improvements to the Existing Mandurah Channel

Rationale

The objective is to increase the rates of nutrient loss to the sea by increasing marine flushing. Many schemes have been proposed which are variants on four basic components, Channels 1A, 1B, 1C and 1D. (see Report 1)

Two spoil areas would be created, one in the estuary and the other adjacent to a new or existing channel. The dredged southern channel could be located to the east or west of

Channel Island.

Results

Dredging the Mandurah Channel could increase the flushing rate of Peel Inlet by 22-34% depending on which option was adopted. Some long-term harvesting would still be required.

Modelling studies indicate that the extra cost of increasing the width and deepening the ocean entrance ($1.5 million) is not warranted as the increases in water exchange and nutrient loss are small.

The most favourable new channel location could be determined by considerations including public amenity and cost as the differences in flushing are only slight.

Costs

For the most effective option the cost would be about $3.1 million. Dredging to deepen the ocean entrance and increasing the width would be an additional $1.5 million.

4.6.2 Creation of a New Channel Near Dawesville

Rationale

Current research has indicated that *Nodularia* populations stop growing and collapse at salinities of about 31‰ or above. The creation of a new channel near Dawesville would cause the salinity in the estuary to reach 31‰ earlier in the growth season. The channel would also increase flushing of Harvey Estuary and increase loss of nutrients to the ocean.

Results

The channel could produce a 4 fold increase in flushing rate in Harvey Estuary and a 1.5 fold increase in flushing rate in Peel Inlet. These would produce proportional increases in marine losses of nitrogen and phosphorus thereby reducing the level of eutrophication and nuisance phytoplankton growth.

Salinity changes would reduce the period suitable for the growth of *Nodularia*.

Improved water clarity and increased diurnal tide variations would allow macroalgae and seagrasses to extend their distribution south into Harvey Estuary, thus increasing the areas suitable for fish nursery areas.

Costs

For an approximate resumed area of 50 ha for the channel and batters the resumption costs would be about $1-1.5 million.

For a channel depth of about -3.3 m AHD cost would be in the region of $15 million.

For a channel depth of -4.5 m AHD cost would be about $18.5 million.

These costs include dredging ocean and estuary, other excavation, roadworks, training walls at ocean entrance and contingencies.

5. INTERACTIONS AMONG OPTIONS

5.1 REQUIRED PHOSPHORUS REDUCTIONS

Data produced during the study were used to determine the amount of "effective" phosphorus reduction required to reduce the algal problem in the Harvey Estuary. To achieve a frequency of *Nodularia* blooms of less than 1 yr in 5 the "effective phosphorus load to the estuary would have to be reduced by about 70%.

The required phosphorus reduction for the Peel Inlet is more difficult to assess.

5.2 PHOSPHORUS REDUCTION POTENTIAL OF THE OPTIONS

Table 2 shows the conservative effective phosphorus reduction for both Peel Inlet and Harvey Estuary.

Table 2 Effective Phosphorus Reduction Potential of the Options

Option	Effective Reduction Harvey Estuary	Peel Inlet
Modify agricultural practices	40% (from paired catchment studies)	50%
Bauxite residue amendment	15 - 50%-1	35 - 65%-1
Wetland filters	-	10%
Changes in land use	35 - 85%-1	45 - 90%-1
Mandurah Channel dredging	5%	20 - 55%2
New channel near Dawesville	50%	25%
Diversion of drainage	70%	?

Notes: 1. Range of reduction dependent on areas of catchment treated.

2. Range of reduction in nutrient loss over summer and winter based on flushing.

Combining similar strategies will not necessarily have an additive effect eg combining bauxite residue treatments with modifications to agricultural practices. Combining options involving reduction in phosphorus input and increased phosphorus loss by flushing will have an additive component.

6. SUMMARY OF INTERIM AND LONG-TERM MANAGEMENT OPTIONS

Table 3 summarises the nature of the options in terms of time.

Table 3 - Summary of Interim and Long Term Management Options

Interim Management Options

- Use of chemicals to oxidise sediments and/or to precipitate or inactivate sedimentary phosphorus.
- Use of algistats to control cyanobacteria, diatoms or macroalgae.
- In-estuary harvesting and beach clearing of macroalgae.

Long-term Management Options

- Modification of agricultural practices, particularly fertiliser types and application rates/frequencies.
- Bauxite residue for amendment of leaching sands.
- Wetland filters to treat suitable point sources of nutrients.
- Land use changes of highly leaching agricultural soils, for example Bassendean sands to uses such as forests.
- Hydraulic improvements of the Mandurah Channel.
- Construction of a new marine channel near Dawesville.
- Barrage at Herron Ford for diversion of Harvey River flows to sea.

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APPENDIX 1

List of Management Strategies that were Rejected Early

1. Use of Wetlands in Drainage Canals (3.2.2 in Report 1) rejected because length of filter required is excessive and inflow rates are too high to enable phosphorus removal by plant uptake.

2. Nutrient Removal by Swamps and Swamp Margins (3.2.3 in Report 1) rejected because no acceptable open-water plant types were found that would remove significant quantities of phosphorus from the swamps.

3. Artificial Wetlands (3.2.4 in Report 1) rejected because the high winter flows in the Harvey catchment area would greatly exceed the capacity of any artificially constructed swamp and drain outlets to remove phosphorus.

4. In-Channel Limestone Adsorbents (3.3.1 in Report 1) rejected because the adsorbent capacity of limestone is low compared to clays or bauxite residue, the adsorbent capacity was exhausted in about 2 days and the length of wall required for sufficient contact time was excessive.

5. Large-Scale Chemical Removal of Phosphorus from Surface Drainage Using Flyash and other Industrial Waste Products (3.3.2 in Report 1). rejected as too expensive.

6. Diversion of Water Through Coastal Lakes (3.4.1 in Report 1) rejected because the scheme would produce eutrophic conditions in the coastal lakes and Leschenault Inlet. The changed salinity conditions would produce freshwater cyanobacterial blooms which could be toxic to animals.

7. Barrage at Point Grey (3.4.2 in Report 1) rejected because of the severity of the biological consequences of the proposal: conversion of Harvey Estuary into a freshwater lake, loss of fishery, continuation of algal blooms.

8. River Flow Deflectors in Peel Inlet (3.4.4 in Report 1) rejected because a full deflector would restrict water access, a partial deflector may not be sufficiently effective, both would tend to trap algae near Coodanup beaches.

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9. <u>Algicides</u> (3.5.3 in Report 1)
rejected because they contain copper compounds and are more toxic to fish and invertebrates than to algae.

10. <u>Modification of Estuarine Water Quality</u> (3.5.4 in Report 1)
rejected because no current information is available to evaluate either iron chelation or use of dyes.

11. <u>Use of Explosives to Collapse Cyanobacterial Blooms</u> (3.5.5 in Report 1)
rejected because the technique would result in massive fish kills, would be costly, cyanobacteria would rebuild their gas vacuoles within 72 hours.

12. <u>Biological Control</u> (3.5.6 in Report 1)
rejected because no suitable pathogens have been able to control current blooms, <u>Nodularia</u> is generally unpalatable to grazers.

13. <u>Dredging of Estuary Basin and Flats</u> (3.6.1 in Report 1)
rejected because all dredging options would produce severe local impacts, particularly disruption of habitat for juvenile fish. Dredged shallows would act as a pool for decaying algae, dredging to reduce macroalgal growth could increase phytoplanktonic species and disrupt current food chain. Surface sediment skimming was rejected as too expensive.

14. <u>Creation of a New Mandurah Channel</u> (3.7.2 in Report 1)
rejected because of expense: the maximum possible increase in flushing rate of 20% would not greatly increase the loss of nutrients. The scheme would be unlikely to be acceptable to Parry's Esplanade Ltd.

15. <u>Tidal Pumping</u> (3.7.4 in Report 1)
rejected because only small flows can occur in a feasible tunnel because of the low amplitude of the signal available from diurnal tides.

16. <u>Re-route Harvey Diversion Drain Flows</u> (3.8.1 in Report 1)
rejected because the proposed flow re-routing

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would not significantly alter the concentration in or flushing of nutrients from the estuarine system.

17. Introduction of New Plants to the Estuary (3.8.2 in Report 1)
suspended because introduction of an exotic alga would be a protracted affair, even if a suitable species was located.

18. Siting of a Power Station on Harvey Estuary (3.8.3 in Report 1)
rejected because of high cost and the use of power station outflow is not recommended as it could result in increased retention of phosphorus by the sediments or by diatoms.

CATCHMENT MANAGEMENT TO REDUCE PHOSPHORUS DISCHARGE INTO THE ESTUARY - SETTING THE SCENE by Peter Birch

The problems in the Peel-Harvey estuary are caused by an excessive input and subsequent availability of phosphorus for growth of nuisance algae and cyanobacteria. About 90% of this phosphorus is derived from coastal plain catchments where rates of phosphorus loss are greatest.

There are several interacting factors which cause this relatively high loss of phosphorus from the coastal plain. This is because the quantity of phosphorus which is transported into rivers and drains by surface and sub-surface runoff is a complex function of:

soil type
land use
fertilizer application (past and present)
drainage density
rainfall
topography

Of these the major ones contributing to high phosphorus loss from the coastal plain compared to the plateau are -

sandy soils (highly leaching sands are common on the coastal plain)
higher drainage density on coastal plain ($0.64 km/km^2$ compared to $0.13 km/km^2$)
higher rainfall on coastal plain (850-1000mm/yr compared to 450-800mm/yr).

These factors combined with somewhat higher fertilizer use on the coastal plain result in a phosphorus export rate about 30 times higher than that of the plateau. Thus 90% of the phosphorus is derived from 20% of the total catchment for the estuary (see Table 1).

Within the coastal plain there is a two fold difference between the two major catchments, the Serpentine and the Harvey and drains

(Harvey Estuary) catchments. Since the distribution of soils is generally similar between the two it is believed that higher runoff (because of higher drainage density and rainfall) and possibly higher fertilizer applications on the Harvey Estuary catchment are the major reasons for higher P export from this catchment compared to the Serpentine River catchment.

On average about 66% of the total phosphorus load is derived from the Harvey Estuary catchment even though it only represents about 10% of the total catchment for the Peel-Harvey system.

Within the Harvey Estuary catchment the importance of soil type and rate of runoff as influenced by drainage density is emphasized (Table 2). The highest proportion of applied fertilizer was lost from representative sub-catchments with sandy soils (19-33%) compared to 7% from those with clays and loams. Very little phosphorus was exported from the mostly forested, hills catchment of Clark Brook.

Using the data of Table 2 and those of previous years it is estimated that approximately three quarters of the phosphorus entering the Harvey Estuary is derived from sandy soils. Even though there is less runoff from deep sands this is more than compensated by greater leaching losses.

The rate of fertilizer use on the different soils is not simply correlated with P export from the various soils because of differences in sorption capacity, as has been shown in Table 2. However, for each soil a certain portion of the total phosphorus runoff each year is derived from currently applied fertilizer and the balance from the phosphorus bank which has built up in the soil from previous applications. An important question being answered this year is what are these proportions when a maintenance rate of phosphorus application is made on the various soil types? Knowing the answer to this and knowing the best type and amount of fertilizer required for a maintenance dressing tells us the amount by which phosphorus loading to the estuary could be reduced by

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improved fertilizer management without loss of agricultural production.

Yearly Variations in Rainfall and Runoff

The above comments largely relate to what happens in a particular year. Rainfall and runoff and hence P export varies considerably from year to year. Over the duration of the Peel-Harvey study there has been a threefold variation in runoff to the Harvey Estuary although unfortunately this range has been from well below average to about average. At the same time phosphorus load has also varied by almost the same amount, meaning that the flow-weighted concentration of phosphorus in Harvey River water has varied little, averaging about 0.4 mg/L (Figure 1). This implies that there is a relatively large pool of phosphorus in the catchment which is readily leachable.

Where Does All the Phosphorus Go?

Figures 2 and 3 summarize present knowledge with regard to phosphorus fluxes in deep sands and sand over clay soils. The values are estimates only for a hypothetical average situation for non-irrigated pastures for cattle or sheep. For irrigated dairy farms and for hay cut paddocks the agricultural export and fertilizer application would both be greater.

Even though the data in Figures 3 and 4 are only approximate they do serve to indicate that of the fertilizer applied 20-30% is lost in runoff and 20-30% is exported in agricultural produce. Of the remaining 50-70% there is an accumulation of about 20% in the top soil (0-10cm). About 40% is unaccounted for and is presumably accumulating in the sub-soil and deep groundwater.

It must be stressed that in any particular situation these soil fluxes will be different depending on the fertilizer history, even with the same annual application rate. An old paddock, in which a larger bank has built up, will lose more phosphorus in runoff.

The ultimate goal is a maintenance situation where fertilizer applications virtually equal agricultural export with minimal runoff losses and no further accumulation in the soil. Evaluation of fluxes under maintenance is difficult because little is known at present about the fluxes between the various phosphorus pools in the soil (Figures 2 and 3). Also the fluxes and pools may change if the chemical nature of the fertilizer is varied, ie if slow-release fertilizers are used.

Methods of Reducing Phosphorus Input From Catchments

(i) Fertilizer Management

Figure 4 is a simplified version of Figures 2 and 3 on which is indicated the various points at which phosphorus flux can be intercepted or modified.

Firstly the type and amount of fertilizer can be varied as already mentioned and further details of this option will be dealt with by subsequent speakers. Knowing what can be achieved technically is one thing but farmers must adopt these new management strategies either voluntarily or within a legislative framework for anything to be achieved in practice.

(ii) Alternative Land Uses

Other forms of land use such as forestry require much lower phosphorus inputs than the present land use. As a result runoff of phosphorus should be reduced over time. The rate at which this rundown occurs will depend on the uptake rate by the trees and the rate of leaching and runoff from the existing pools of phosphorus. This could take from 5 to 10 years on Bassendean sands.

.. 5

(iii) Biological Filters

Biological filters in the form of wetland vegetation can be effective phosphorus sinks which significantly reduce the phosphorus concentration of water as it passes through the system. They appear most useful in treating rural point sources such as piggeries where the effluent discharge is relatively constant. They are less practical in treating large volumes of water in a short time, as would be required for coastal plain runoff during winter.

(iv) Bauxite Residues

As discussed earlier excessive leaching of phosphorus from sandy soils is a major cause of phosphorus eutrophication in the Peel-Harvey estuary. Incorporation of bauxite residue into topsoil will increase phosphorus adsorption of sandy soils. The residue will also improve water holding capacity of deep sands. Thus yields can be increased and phosphorus runoff reduced, provided treated soils are not excessively fertilized.

(v) Chemical Treatment

Phosphorus concentrations in runoff water can be reduced by treatment with iron, aluminium or calcium ions or with industrial wastes such as bauxite residue. A treatment plant in which phosphorus is precipitated with iron has been successfully employed on the Wahnbach River in Western Germany. Such a scheme could be adopted here but would be very expensive. (ca.$50 million plus running costs).

(vi) Diversion of Drainage

Complete diversion of the Harvey River, Mayfields Drain and South Coolup Drain would solve the eutrophication problem, but the price would be high, and there could be undesirable side-effects on the estuarine ecosystem.

Acknowledgements

Data Sources (i) Flows : R.E. Black and J.E. Rosher
Public Works Dept. (R.Harvey, R.Sheridan)

(ii) Phosphorus analysis : Govt. Chemical Laboratories
Botany Dept. U.W.A.

(iii) Phosphorus flow diagrams : Information supplied by many members of the Catchment Studies Group.

Table 1(a)

Approximate annual flows from the major river systems to the Peel-Harvey Estuary. Means (and standard deviations) for the 5 year period 1978-82

River Systems	Undammed Catchment Area (km^2)	(% of total)	Drainage Density (km/km^2)	Runoff (mm)	($10^6 m^3$)	(% of total)
(i) Coastal Plain*						
Harvey + Drains	990	10.4	0.84	240(76)	210(130)	37.5
Serpentine	910	9.6	0.42	120(47)	110(43)	19.6
Total	1900	20	0.64		320	57.1
(ii) Plateau*						
Murray	7600	80	0.13	28(17)	240(75)	42.9
Total to Estuary	9500	100		59(24)	560(230)	100

Table 1(b)

Approximate annual export of phosphorus from the major river systems to the Peel-Harvey Estuary. Means (and standard deviations) for the 5 year period 1978-82.

River Systems	P. Conc (mg/L)	P Exported (Tonnes)	(% of total)	(kg/ha)	P Applied (kg/ha)	P Exp./P Appl. (%)
(i) Coastal Plain*						
Harvey + Drains	0.38	89(29)	61	0.90	8	11
Serpentine	0.36	39(18)	27	0.43	4.1	10
Total	0.37	128(47)	88	0.67	6.1	11
(ii) Plateau*						
Murray	0.09	18(12)	12	0.024	3.7	0.7
Total to Estuary	0.26	146(54)	100	0.15	4.3	3.5

* About 6800 km^2 of the Murray catchment is east of the Darling Scarp. Most of the drainage from the Harvey and Serpentine is from the Coastal plain.

TABLE 2 PHOSPHORUS EXPORT FROM VARIOUS CATCHMENTS OF THE HARVEY ESTUARY. RUNOFF DATA ARE PRELIMINARY ESTIMATES FOR 1983 WINTER (JUNE - SEPT)

Catchment	Area (km^2)	Runoff (m^3/ha)	Drainage Density (km/km^2)	P Conc (mg/L)	P exported (kg/ha)	P applied 1 (kg/ha)	P exp / P appl	Fertilizer History (years)	Dominant Soil Type	Land Use
Meredith Dr.	52	1100	0.55	1.2	1.3(4.0)	4(12)	33%	10-15	Deep Sands	1
Mayfield G Dr.	10	3800	1.51	0.61	2.3(2.3)	12(12)	19%	30-50	Sand over Clay	1
Samson Br.N.Dr.	18	3300	1.58	0.3	1.0(1.0)	16(16)	6%	30-50	Clays and Loams	1+2
Clark Br. (Hills)		4000		0.05	0.20(-)	little		-	Lateritic	3

1. Values in brackets are estimates for cleared area of the catchments.

2. Land Use Categories
   1. Non-irrigated pastures for beef and sheep
   2. Irrigated pastures for beef and dairying
   3. Mostly forest

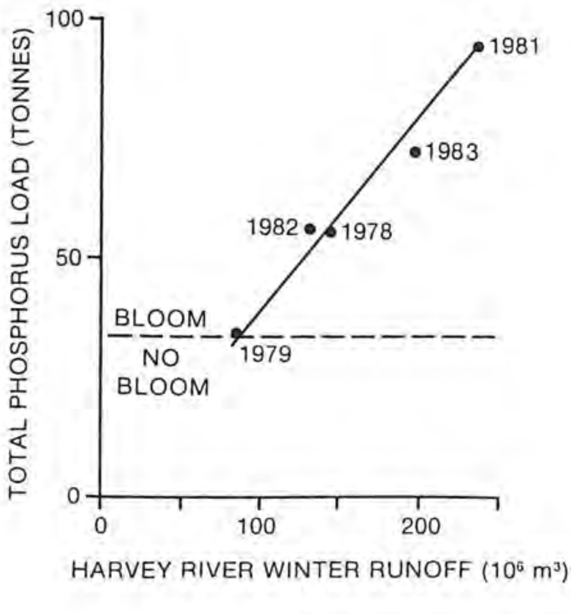
100
50
0
TOTAL PHOSPHORUS LOAD (TONNES)
1981
1983
1982
1978
BLOOM
NO
BLOOM
1979
0
100
200
HARVEY RIVER WINTER RUNOFF (10⁶ m³)

Figure 1

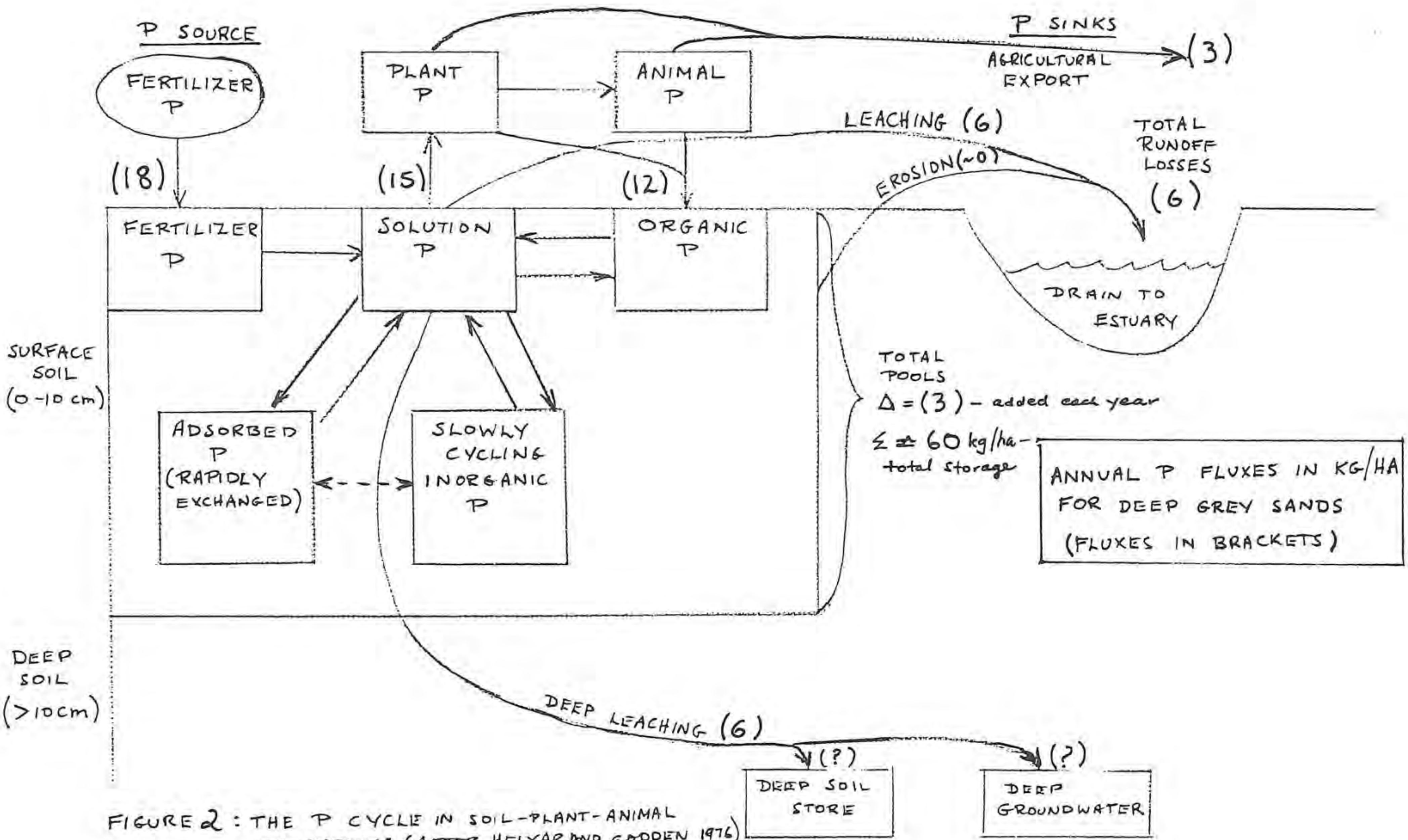

FIGURE 2: THE P CYCLE IN SOIL-PLANT-ANIMAL ECOSYSTEMS (AFTER HELYAR AND GODDEN, 1976)

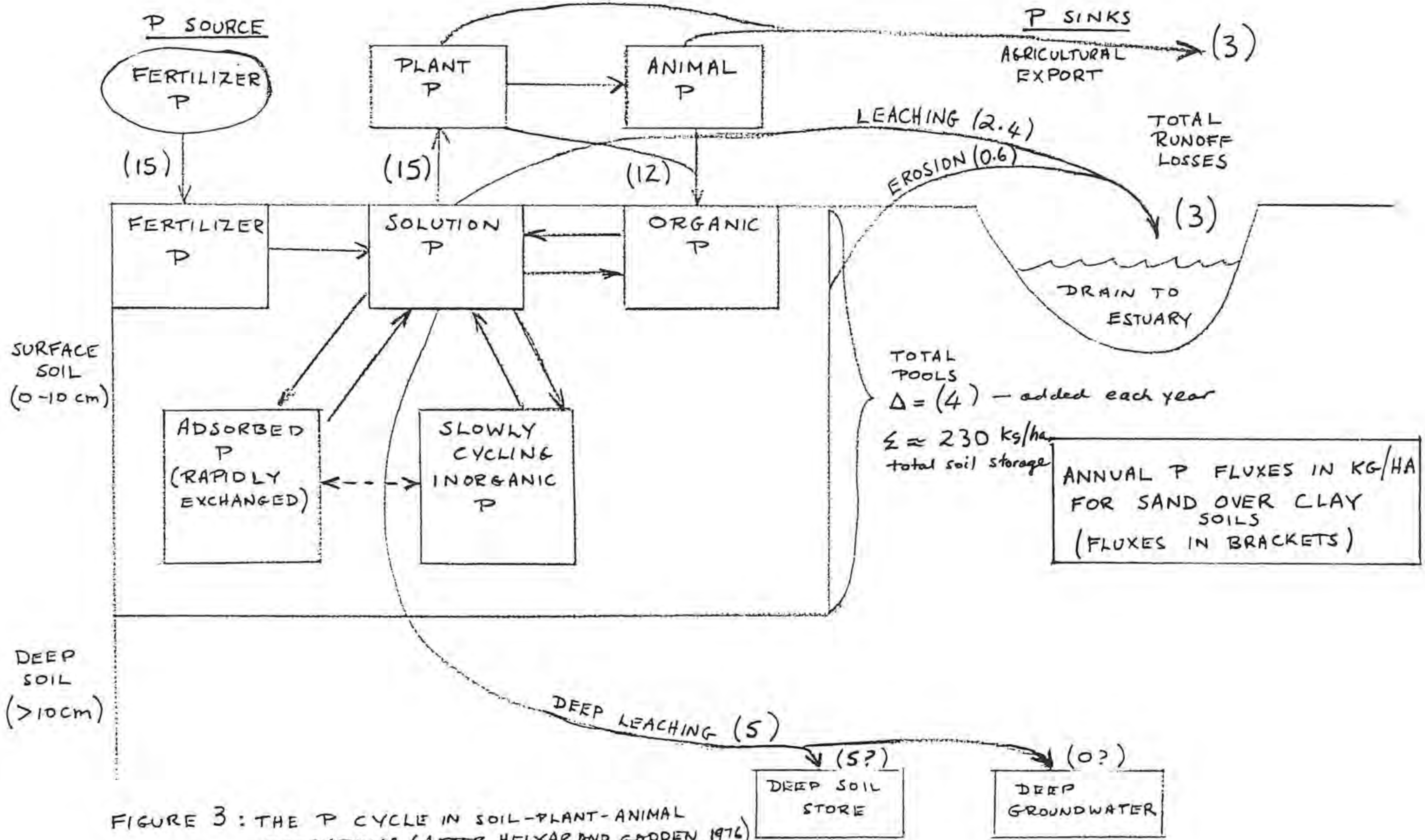

FIGURE 3: THE P CYCLE IN SOIL-PLANT-ANIMAL ECOSYSTEMS (AFTER HELYAR AND GODDEN, 1976)

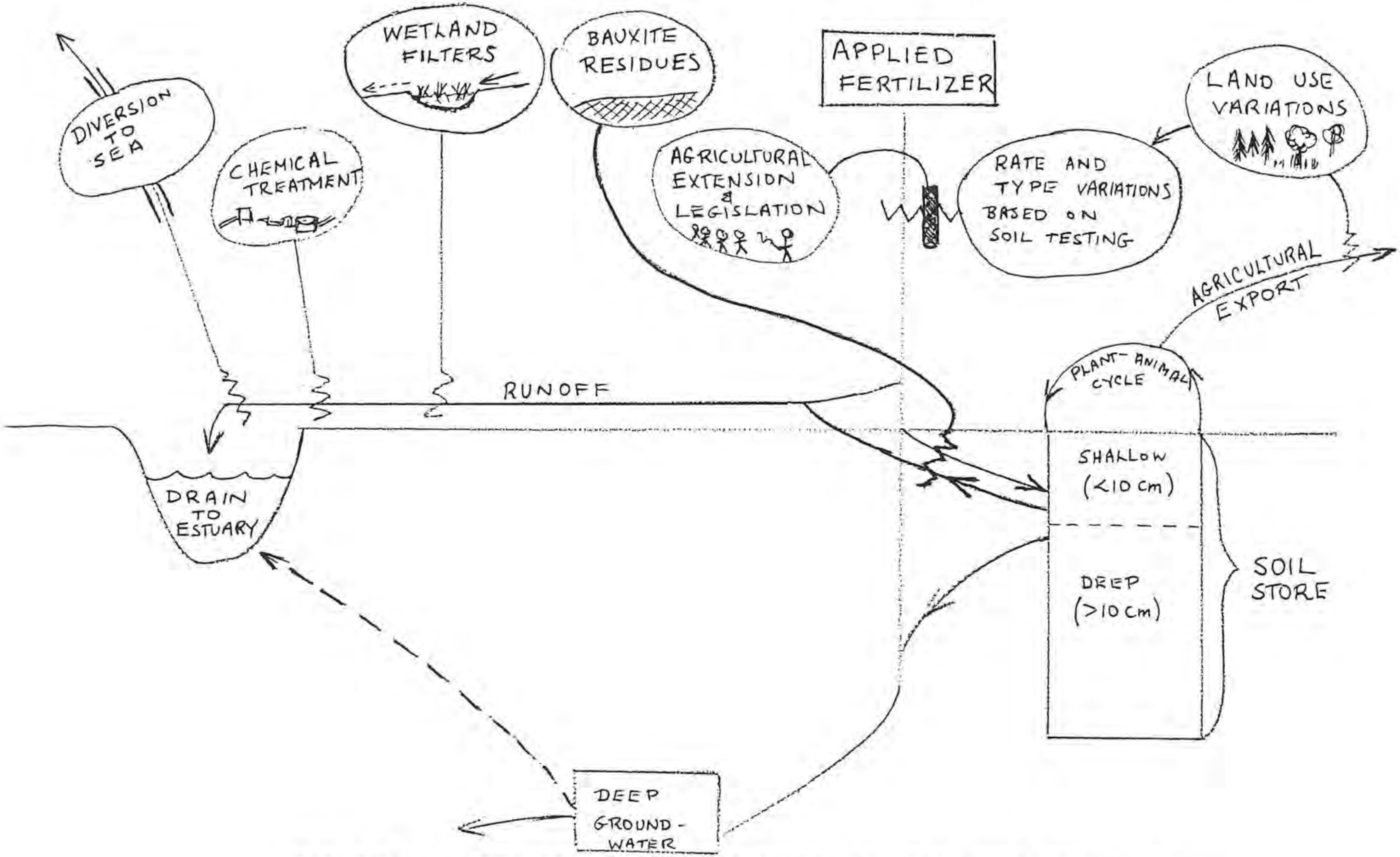

FIGURE 4. METHODS OF INTERCEPTING OR REDUCING PHOSPHORUS FLUXES FROM THE COASTAL PLAIN INTO THE ESTUARY.

PEEL-HARVEY ESTUARINE SYSTEM STUDY SYMPOSIUM

November 28-29, 1983

FERTILIZER MANAGEMENT - AGRONOMIC ASPECTS

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Two major fertilizer practice modifications with potential to reduce leaching losses of phosphorus applied to pastures of the sandy soils have been identified. Both are within the initially specified constraints of maintaining the current type and level of agricultural production of the soils without incurring additional production costs. Two related areas, the use of 'red mud' to increase P retention of the sands, and alternative agricultural or semi-agricultural land uses are to be covered in other papers in this symposium.

FERTILIZER PRACTICE MODIFICATIONS

1. Accurate definition of phosphorus requirements for the sandy soils

To accurately define P requirements the parameters of response curves for currently applied P and the residual value of past P applications (as whatever source) need to be established. From these, a prediction of P rate needed to achieve a nominated level of production in year 1, and the rate necessary to return to that level in year 2, 3, 4 etc. can be made. Residual value of past fertilizer applications can be estimated either from a previously defined residual value function (RVF), or by use of soil tests calibrated to growth potential in the subsequent season.

The ultimate aim of accurate prediction of P requirement is to determine the maintenance application rate for any desired level of production (i.e. the optimum economic rate, determined by the cost/price ratio applicable). The maintenance rate is the minimum required to maintain growth which does not increase soil P storage, and this rate will determine the magnitude of long term leaching losses as, at true equilibrium (assuming asymptotic soil P 'pools'), P applied = P lost in product + P lost as leachate.

Both the shape of response curves for currently applied P, and the residual value of P applied to the sandy soils are variable and are still ill defined because of seasonal influences on plant growth, fertilizer dissolution and leaching characteristics, and possibly soil age and small differences in soil type. That residual value of super (as measured by bic. P) is affected by field conditions (site and year) is evidenced by the data in Table 1 for two trials at Albany on deep grey sands which received applications of P as superphosphate

..../2

TABLE 1

Site and seasonal effects on bicarbonate extractable residual P one year after application of superphosphate (0-10 cm)

P rate (kg/ha)	TRIAL 80AL2 Applied 1980 Sampled 1980/81	Applied 1981 Sampled 1981/82	Applied 1982 Sampled 1982/83	TRIAL 80AL5 Applied 1980 Sampled 1980/81	Applied 1981 Sampled 1981/82	Applied 1982 Sampled 1982/83
0	10	8	8	6	6	5
10	10	13	11	9	5	10
30	10	11	14	6	6	8
90	25	30	28	9	7	18
180	36	26	26	9	11	25

Current work has, however, established a soil test calibration curve for the Bassendean sands (Fig 1) which, with an estimated Mitscherlich 'C' coefficient for the response curve for currently applied P, results in recommendations for reduced P applications compared to previous recommendations and rates in common usuage.

Predictions for Coolup sands are hampered by the lack of a well defined soil test calibration curve (due to a dearth of responsive sites for experimental work). Available data (Fig 1) suggest that 25 ppm is probably adequate as a cut off point, and as a gradation in P sorption (and soil test curve Mitscherlich 'C' coefficients) will occur between 'Bassendean' and 'Coolup' sands, a scaling between cut off points of 10 ppm and 25 ppm is probably appropriate for individual paddocks. **Hopefully**, scaling can be achieved by using an objectively measured criterion related to P responsiveness, such as reactive iron, rather than by further experimental work.

Soil test survey work (Russell) and calibration curve data indicate that a short term reduction in average P application rates of 60% (compared to 1982) on the Bassendean and Coolup sands would not reduce pasture yields.

Using an estimated RVF ($\frac{1}{T+1}$), and a Mitscherlich 'C' coefficient of 0.10 for currently applied P, a long term reduction of 40% in annual P application rate (as superphosphate, compared to a current rate of 18 kg/ha) is at lower production predicted to be achievable while still maintaining maximum growth levels, appropriate on some soils, greater reductions would be achieved. Changes in long term leaching losses will equal changes in P application rates once the soil P cycling system has reached an equilibrium state.

While the above provides useful first order estimates of possible reduction in P losses with more efficient use of currently available fertilizers, the sensitivity of the estimates to poorly defined parameters obviously means that such estimates should be treated with extreme caution. Further definition of both the residual value function for P applied to the sandy soils, and the appropriate P response curve (and/or definition of factors affecting both) are required before more reliable estimates can be made. This work is currently in progress.

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Despite the relatively well defined soil test calibration curve for Bassendean sands (Fig 1) some problems remain in this area. Bic P underestimates the residual value of past applications on organic sands (Joel), but tends to overestimate the value of recent very high P rate applications (relative to the established curve). This is interpreted as an indication of the relative availability of different soil 'pools' Plant availability of total soil P is similarly related to P history. Recent work (Allen, Government Chemical Laboratories) has shown that on old land Joel sands 60-70% of total P is in an organic form, and similar proportions may be present in the bic P extract (normally only analysed for inorganic P). Sands with lower organic matter levels have lesser proportionate levels of organic P. Apart from implications for the relevance of various soil analytical procedures, these findings have important implications for understanding the soil P cycles on the sands. As inputs of P in organic matter may reach 40 kg/ha/annum, and total soil organic P levels appear to rarely exceed 60 kg/ha (0-10cm), organic matter will play a large role in the P nutrition of pastures, and in determining the fate (including 'leachability') of applied P. This is particularly evident when compared to experimental data which shows that 50 kg/ha total P (0-10 cm) is adequate to produce maximum pasture growth on these soils.

Other problems occur with soil testing after applications of various 'slow release' fertilizer sources. Bic P greatly underestimates the value of rock phosphate residues, and other extractants or additional calibration curves may be necessary if use of these sources (e.g. 'AS3') becomes widespread.

Other methods of establishing maintenance P application rates include wholly empirical repeated rate experimental data and the use of a balance approach to P losses (replacement of P losses by fertilizer application, with assumptions about the asymptotic nature of soil P 'pools'.) However, as estimates of losses from total P monitoring of field plots are extremely variable (Table 2) the latter approach cannot currently be used unless more accurate measurements of these losses are obtained, and necessary assumptions shown to be valid.

TABLE 2

Estimated losses of phosphorus from unfertilized plots over one year periods on deep grey sands. Losses were estimated from changes in total P content (0-10 cm)

	At 1981/82	At 1982/83	ΔP	P removed as pasture	Nett P loss
Site 1	150	115	35	10	25
Site 2	110	85	15	5	10
Site 3	35	30	5	0	5
Site 4	150	75	75	20	55
Site 5	145	110	35	10	25
Site 6	75	55	20	5	15

2. Fertilizers of reduced water solubility
('slow release' fertilizers)

The initial premise for the development of slow release fertilizers was that losses of water soluble P in the year of application accounted for the major P leaching losses from the sandy soils. Recent data from various sections of the catchment studies group suggest that in fact major losses occur from previously fertilized soils without current P applications - that is from residual soil P 'pools', indicating that modification of source of P may achieve only relatively small changes in P losses as direct losses from fertilizer account for only a part of the total.

The pattern and rate of fertilizer dissolution will affect P leaching losses, the rate of incorporation into the various 'pools', and plant uptake. Use of slow release fertilizers aims to maximize transfer of applied P into plant and soil 'pools' which retain P against leaching. Dissolution rate must be fast enough to match plant requirements (as effectively as superphosphate, or with other relevant economic constraints) but slow enough to minimize leaching losses. Once incorporated into the soil P 'pools' leaching losses will be independent of initial source of P, unless the relative size of the 'pools', or the 'leachability' is also affected by the source.

Prediction of the fate of applied P is vital to an understanding of the long term implications of the use of 'slow release' fertilizers. Ideally, a plant uptake model should be used to match plant requirements and P release patterns, and work is current in this area. Data from new land experimental sites (nil growth on nil P plots) shows that <20% of P applied as any source is actually plant utilized in the year of P application, indicating large leaching losses, incomplete fertilizer dissolution, and/or the relative capacity of the competing processes to immobilize P. Much lower apparent uptakes (of % P applied) are evident on old land, though substitution of fertilizer and residual P in plant uptake may distort apparent uptakes.

Initial data from the study of dissolution rates and processes of different P sources (Deeley) has shown large differences in leaching losses from the various sources during intense leaching in sand filled laboratory columns (Fig 2). Loss rates were higher from CSBP coastal super than from AFL lime super or 'AS3', though less than from ordinary superphosphate, confirming field data. The effects of incubation time and other factors affecting dissolution and leaching rates are under further investigation.

Field work data are comprehensively presented in Tables 3 to 5. As measured by agronomic effectiveness, AS1/AS3 and the lime supers were approximately equivalent to superphosphate in the year of application,* and had a higher residual value in subsequent years (Table 4). Other sources were generally less effective. These results mean that less phosphorus can be applied to achieve the same level of growth, but exactly how much less depends on the shape of the current response curve, and the residual function for each source, as previously discussed.

Estimated leaching loss data is difficult to interpret, and very variable. Apparent losses of super varied between 0% and almost 100% in year 1 (depending on site, and depth of sampling) but were greater than from the less soluble sources. Problems are obvious with some of the data (e.g. recoveries >200%). On some sites (81AL6, 1981; 82AL10, 1982) sources

* including 1983 trials 83HA26 and 27 on Coolup sands

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TABLE 3

Sources of phosphorus used in experimental work.

<u>Note</u>: Source followed by year in Tables 4 & 5 refers to year of application

Abbreviation	Source	% of P as water soluble	% of P as citrate soluble	% of P as citrate insoluble	Total P content (%)
Super*	superphosphate)	84	9	7	10.0
	triple superphosphate)				19.7
LS*	lime reverted superphosphate (AFL)	9	50	41	5.4
LS2*)	lime reverted superphosphate (CSBP)	32	55	12	8.3
LS3*)	)				7.6
CS	coastal superphosphate)	17	71	12	7.2
AS1*)	partly acidulated rock	22	15	65	9.6
AS2)	phosphate (GRP(1)) +				13.1
AS3*)	elemental sulphur	20	13	66	9.8
GRP(1)*	island A grade rock)	<1	10	90	16.0
GRP(2)*	phosphate)				
GRP(3)*	Duchess rock phosphate	<1	8	92	13.7
RR	'reactive' North Carolina rock phosphate				13.5
C-500*	calcined Christmas Island C grade rock phosphate	<1	66	33	14.0
C-ORE	Christmas Island C grade rock P.	0	0	100	11.2

* as analysed

Particle sizes	>20 µm	>106 µm
GRP(1)	77%	31%
GRP(2)	67%	13%
GRP(3)	73%	18%
C-500	79%	28%

<u>N.B.</u>:

Clay	< 2 µm
Silt	2-20 µm
Fine sand	20-200 µm

TABLE 4

Effectiveness of various P sources relative to superphosphate applied in the year of trial establishment. RE was calculated from % P in tops where trials were non-yield responsive

P source*	83HA27 **	83HA26 **	82HA32		82HA31		82AL10		81AL6			81AL5			81KE2			81MA4			80AL2				80AL5			
	1983	1983	82	83	82	83	82	83	81	82	83	81	82	83	81	82	83	81	82	83	80	81	82	83	80	81	82	83
Super 1980																					1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Super 1981									1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0			1.1				1.6	
Super 1982			1.0	1.0		1.0	1.0	1.0		2.8	3.2		4.1	1.2		1.9			2.6	1.7			1.4				5.4	
Super 1983	1.0	1.0		1.6				-			6.3			6.3						6.6								
LS 1980																					0.8	1.1	0.8		1.3	1.1	2.1	
LS 1981									-	1.8	1.4	1.7	1.4	1.5	1.2	1.2		1.0	1.5	1.8								
LS 1982							1.1	1.1																				
LS2 1982			1.1	1.5																								
LS3 1982			1.3	1.8																								
CS 1983	0.9	0.6		2.1																								
AS1 1981									-	3.4	2.7	1.1	2.1	2.2	0.7	1.2		1.0	1.3	3.4								
AS1 1982							0.8	1.4																				
AS2 1981									-	0.9	-	0.3	0.7	0.4	0.6	0.5		0.6	0.5	1.0								
AS3 1983	0.8	0.8		1.5				-			1.2			5.5						3.2								
GRP(1) 1980																					1.1	0.8	1.1		1.3	1.4	2.2	
GRP(1) 1981									-	1.6	2.4	0.7	1.3	1.8	0.4	0.4		0.4	0.9	1.7								
GRP(1) 1982			0.8	1.3			1.3	1.0																				
GRP(2) 1981									-	1.9	2.1	0.8	1.3	1.5	0.5	0.5		0.6	0.7	2.0								
GRP(3) 1981									-	1.2	2.7	0.6	1.3	1.2	0.3	0.4		0.3	-	1.8								
RR 1982			0.5	1.3																								
C-500 1980																					-	-	0.8		1.2	1.5	1.7	
C-500 1981									-	2.1	3.2	1.2	1.1	1.5	1.0	0.7		0.6	1.1	1.0								
C-500 1982			0.5	1.3			0.7	0.7																				
C-ORE 1981									-	0.6	0.7	0.2	0.1	0.1	0.1	0.1		0.3	0.1	0.1								

** Coolup sands. All other trials are on deep grey sands.

TABLE 5

Estimated % of applied P recovered from the soil

	83HA27		83HA26		82HA32			82HA31	82AL10		
	6/1983		6/1983		1/83	6/83		1/83	12/82		
	0-5	0-10	0-5	0-10	0-10	0-5	0-10	0-10	0-5	0-10	0-25
Super 1980											
Super 1981											
Super 1982					17			6	38	36	68
Super 1983	63	60	34	44		20	22				
LS 1980											
LS 1981											
LS 1982									49	95	94
LS2 1982					33			15			
LS3 1982					34			23			
CS 1983	80	60	32	48		32	31				
AS1 1981											
AS1 1982									66	101	89
AS2 1981											
AS3 1983	75	61	67	56		64	46				
GRP(1) 1980											
GRP(1) 1981											
GRP(1) 1982					71			57	84	79	147
GRP(2) 1981											
GRP(3) 1981											
RR 1982					101			51			
C-500 1980											
C-500 1981											
C-500 1982					110			64	88	89	112
C-ORE 1981											

	81AL6						81AL5						
	1/82			12/82			6/81	1/82			12/82		
	0-5	0-10	0-25	0-5	0-10	0-25	0-10	0-5	0-10	0-25	0-5	0-10	0-25
Super 1980													
Super 1981	27	41	77	10	30	72	65	30	62	111	23	59	98
Super 1982				39	39	49					28	55	93
Super 1983													
LS 1980													
LS 1981	74	127	155	38	38	70	130	50	78	141	34	61	54
LS 1982													
LS2 1982													
LS3 1982													
CS 1983													
AS1 1981	107	133	206	46	90	107	71	30	58	121	23	34	54
AS1 1982													
AS2 1981	59	154	224	49	58	25	-	38	80	109	56	52	67
AS3 1983													
GRP(1) 1980													
GRP(1) 1981	111	157	234	95	125	102	102	71	97	121	27	40	37
GRP(1) 1982													
GRP(2) 1981	51	77	138	31	67	128	83	41	92	117	35	37	61
GRP(3) 1981	74	113	184	32	121	175	99	51	82	134	40	61	56
RR 1982													
C-500 1980													
C-500 1981	83	124	185	63	79	133	72	54	98	113	25	36	41
C-500 1982													
C-ORE 1981	77	114	173	76	55	61	105	72	119	182	54	72	103

	81KE2						81MA4					
	1/82			12/82			1/82			12/82		
	0-5	0-10	0-25	0-5	0-10	0-25	0-5	0-10	0-25	0-5	0-10	0-25
Super 1980												
Super 1981	31	58	117	11	21	65	43	80	91	32	50	29
Super 1982				26	45	65				39	39	53
Super 1983												
LS 1980												
LS 1981	39	74	144	59	45	69	66	115	130	44	44	34
LS 1982												
LS2 1982												
LS3 1982												
CS 1983												
AS1 1981	54	99	168	55	46	57	73	165	190	90	55	30
AS1 1982												
AS2 1981	21	70	126	55	24	69	96	171	146	29	41	22
AS3 1983												
GRP(1) 1980												
GRP(1) 1981	54	103	173	78	48	98	119	212	213	72	77	76
GRP(1) 1982												
GRP(2) 1981	68	131	233	68	85	57	64	96	78	90	49	33
GRP(3) 1981	44	117	152	35	11	48	86	177	179	38	33	31
RR 1982												
C-500 1980												
C-500 1981	68	127	213	56	73	75	96	157	153	46	52	76
C-500 1982												
C-ORE 1981	66	121	169	49	39	87	96	160	145	47	58	17

	80AL2					80AL5				
	1/81	1/82	12/82			1/81	1/82	12/82		
	0-10	0-10	0-5	0-10	0-25	0-10	0-10	0-5	0-10	0-25
Super 1980	47	38	9	39	66	31	0		3	0
Super 1981		11	19	31	70		17	0	7	3
Super 1982			21	40	83			36	44	39
Super 1983										
LS 1980	78	50	26	52	65	72	102	31	90	41
LS 1981										
LS 1982										
LS2 1982										
LS3 1982										
CS 1983										
AS1 1981										
AS1 1982										
AS2 1981										
AS3 1983										
GRP(1) 1980	71	60	84	73	110	49	66	38	93	42
GRP(1) 1981										
GRP(1) 1982										
GRP(2) 1981										
GRP(3) 1981										
RR 1982										
C-500 1980	66	64	60	71	113	69	53	34	31	42
C-500 1981										
C-500 1982										
C-ORE 1981										

with agronomic effectiveness equal to super had greatly reduced leaching losses from the top 25 cm of soil, but at others (81AL5) all recoveries were about 100%. On some sites losses from all sources were high (82HA31).

Data for years following the year of application shows extreme variation. At some sites (81AL6, 81MA4) C-ORE, a source of extremely low water solubility and agronomic effectiveness, showed large apparent losses. As the rock phosphate sources are predominantly in the particle size range of fine sand (> 90% of particles >20 µm) vertical particulate losses are unlikely. Re-analysis of some samples has shown consistent results. Generally, the data indicates that in year 2, differences in recovery of applied P between the various sources is relatively small, consistent with complete dissolution and incorporation into the various soil 'pools' in year 1, and losses in year 2 as a function of the size of these 'pools'. However, this hypothesis is difficult to reconcile with big differences in residual value of the sources as measured by bic P (data not presented) and with the agronomic data in Table 4. Until a better understanding is reached of the soil chemical behaviour of P from the various sources, prediction of long term leaching losses will remain difficult.

Theoretical estimates of losses are extremely sensitive to the actual size of leaching losses from soil P 'pools'. The results of calculated reductions in P losses from maintenance pastures using a P balance approach, assuming that all losses from the dissolving fertilizer occur in the year of application and all residual P subsequently enters soil 'pools', are presented in Table 6 for two fertilizers of differing dissolution characteristics. Changing from a fertilizer with 40% loss in the year of application to one with a 10% loss, reduction in total soil losses range with product removal from 27% to 41% at constant 'pool' losses of 5 kg/ha/annum, and from 33% to 53% at 'pool' losses of 2 kg/ha/annum. If 'pool' losses are lower, or are reduced with change in fertilizer type, greater reductions can be achieved, but hard data on which to test any of these calculations is unavailable.

TABLE 6

Changes in projected leaching losses with a change in P source from super (40% loss from the fertilizer) to a slow release source (10% loss)

Losses are expressed as % reduction of maintenance super losses.

(SIMULATION ONLY)

Product Residual (kg/ha/annum)	SOIL P 'POOL' LEACHING LOSSES (kg/ha/annum)					
	Constant				Changing with P source	
	0	2	5	10	5 → 2	2 → 1
2	75	33	27	24	69	64
5	75	44	34	28	70	67
10	75	53	41	33	71	69

The provision of sulphur in a P fertilizer designed to replace superphosphate for maintenance dressings has previously been identified as a vital factor in farmer acceptance of modified fertilizer strategies (Yeates, Russell). Though of reduced P solubility, coastal super does not contain elemental sulphur, believed to be an appropriate source of S. 'AS3' has been developed specifically as a P and S source for maintenance pastures and 1983 field data has confirmed its effectiveness as an S source (data not presented). Effectiveness as a P source should be very similar to 'AS1', which has been experimented with in the field since 1981. The degree of improvement of 'AS3' over coastal superphosphate as a P and S source for pastures should become more evident with time (from field and laboratory work). Major improvements over 'AS3' are not expected within the initially specified constraints of the study, but work will continue in this area.

SUMMARY AND CONCLUSIONS

Scope exists for phosphorus drainage losses from the sandy soils of the Peel Harvey catchment to be reduced without reducing agricultural production on the soils, but the exact magnitude of the reductions cannot currently be estimated with certainty. With farmer cooperation, and use of an objectively based P recommendation system, fertilizer application rates may be considerably reduced to those necessary to just maintain production on a long term basis, resulting in a minimization of P leaching losses from any phosphorus fertilizer source. An improved recommendation system based on soil testing has been developed to help achieve this aim, but recommendations can be further refined with better definition of phosphorus response curves and residual value functions on the sands. Further reductions in P losses appear possible with the use of P fertilizers of lower water solubility than superphosphate, but many unknowns are still associated with the long term effectiveness of these sources in achieving reductions. Farmer acceptance of new fertilizers will depend on attractive pricing, availability and physical properties, and, as with reduced P applications, on the provision of sulphur in a suitable form to replace S in superphosphate.

Crude estimates of potential reductions in P losses which may be achieved are sensitive to many factors. However, from data available a 40% reduction in losses appears possible with the use of appropriately reduced application rates of superphosphate, with a further potential reduction of up to 20% with the use of 'slow release fertilizers' (i.e. maximum of 60%). However, both error associated in these estimates and the uncertainty of the level of adoption of changed practices makes this maximum figure unlikely to be achieved, and actual reductions may be considerably less. How long it will take for these estimated reductions to have an impact on the estuary algal problem, and how big the impact is likely to be will be addressed by other speakers.

FIG 1. SOIL TEST CALIBRATION DATA. YIELDS REFER TO THE GROWING SEASON FOLLOWING SUMMER SOIL SAMPLING.

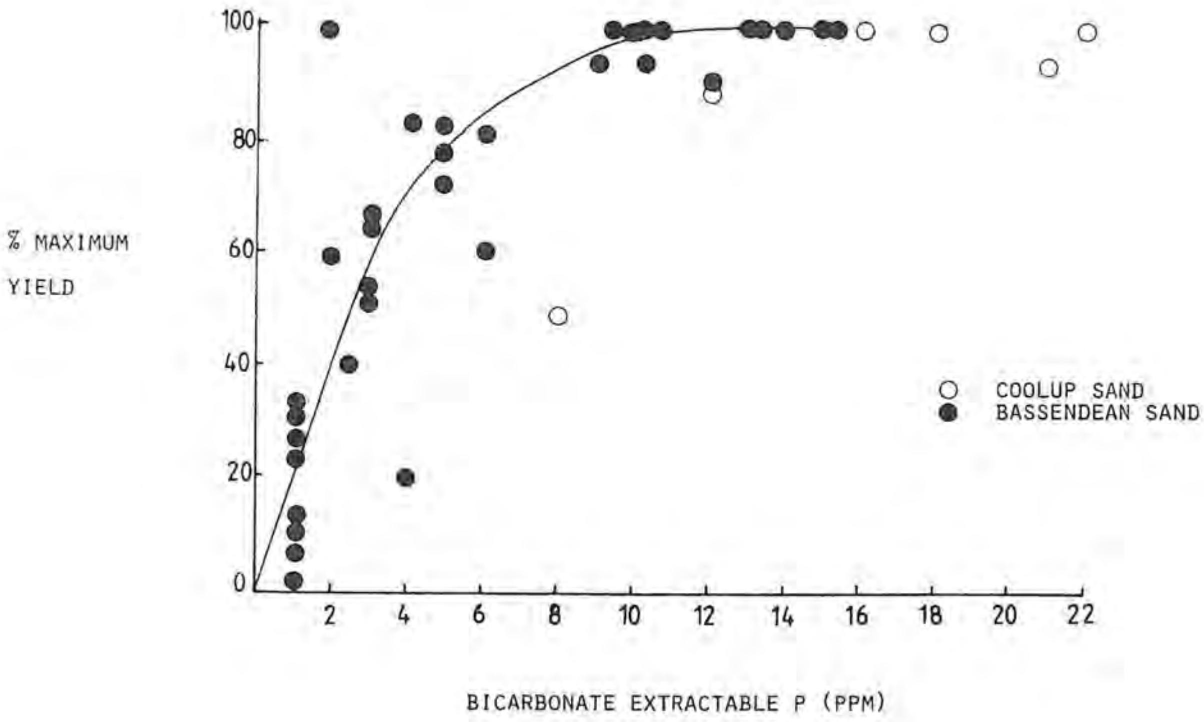
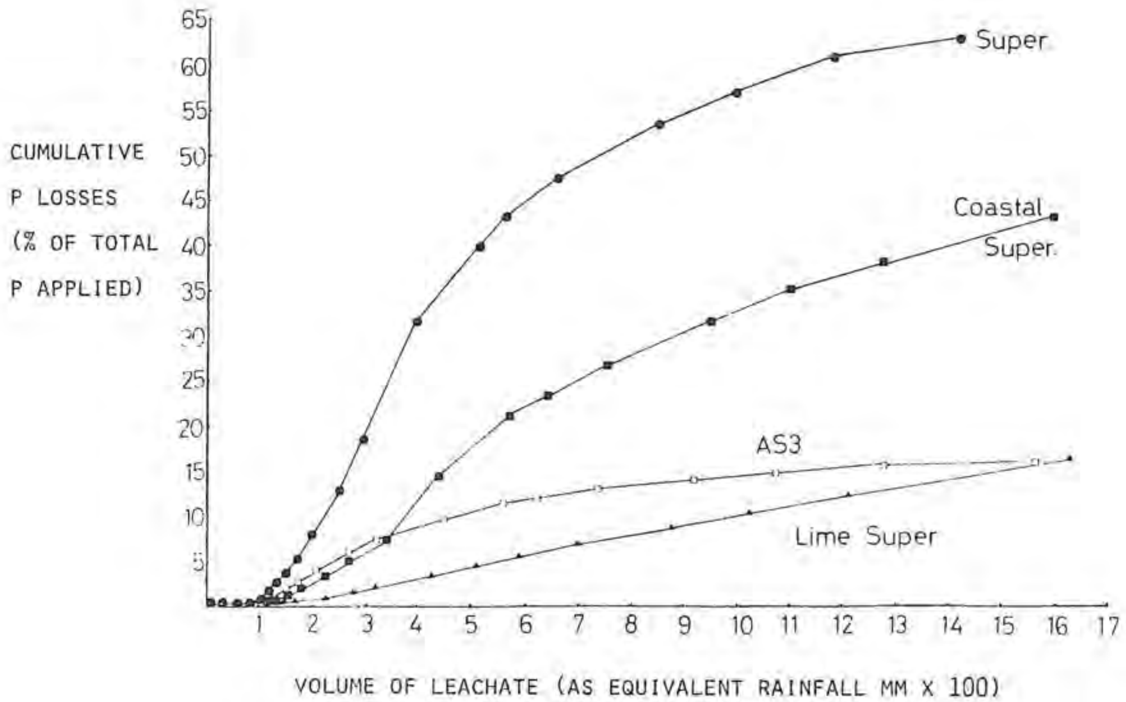


FIG 2. SAND LEACHING COLUMN EXPERIMENT



PEEL-HARVEY ESTUARY STUDY

SYMPOSIUM 28-29 NOVEMBER 1983

PHOSPHORUS LOSSES FROM SANDY SOILS

G.S.P. Ritchie, D.M. Weaver and D. Deeley

The effect of soil properties, environmental conditions and management practices on soil phosphorus losses are being investigated to ascertain whether leaching losses can be reduced sufficiently to prevent algal blooms and still maintain plant production. The effects of the factors in Table 1 are being combined in a predictive model. The model has evolved by constructing a base from consideration of soil properties and adding environmental and management factors as optional variables. There are two important aspects to predicting losses:

1) Short and long term consequences: factors can affect not only concurrent losses but also future losses in subsequent seasons.

2) The effect of factors on the initial amount of P desorbed from the soil and intermittent effects during the wet season.

The model will be used to illustrate the implications of our findings for management prospects (Figs. 1-3).

Soil	Environmental	Management
hydrous oxides	rainfall	fertilizer type
organic matter	storm interval	fertilizer application rate
clay fraction	flooding	fertilizer application method
soil solution properties	seasonal patterns	plant growth
P content	temperature	
Non-wetting properties		

Table 1: Factors affecting phosphorus losses from soils

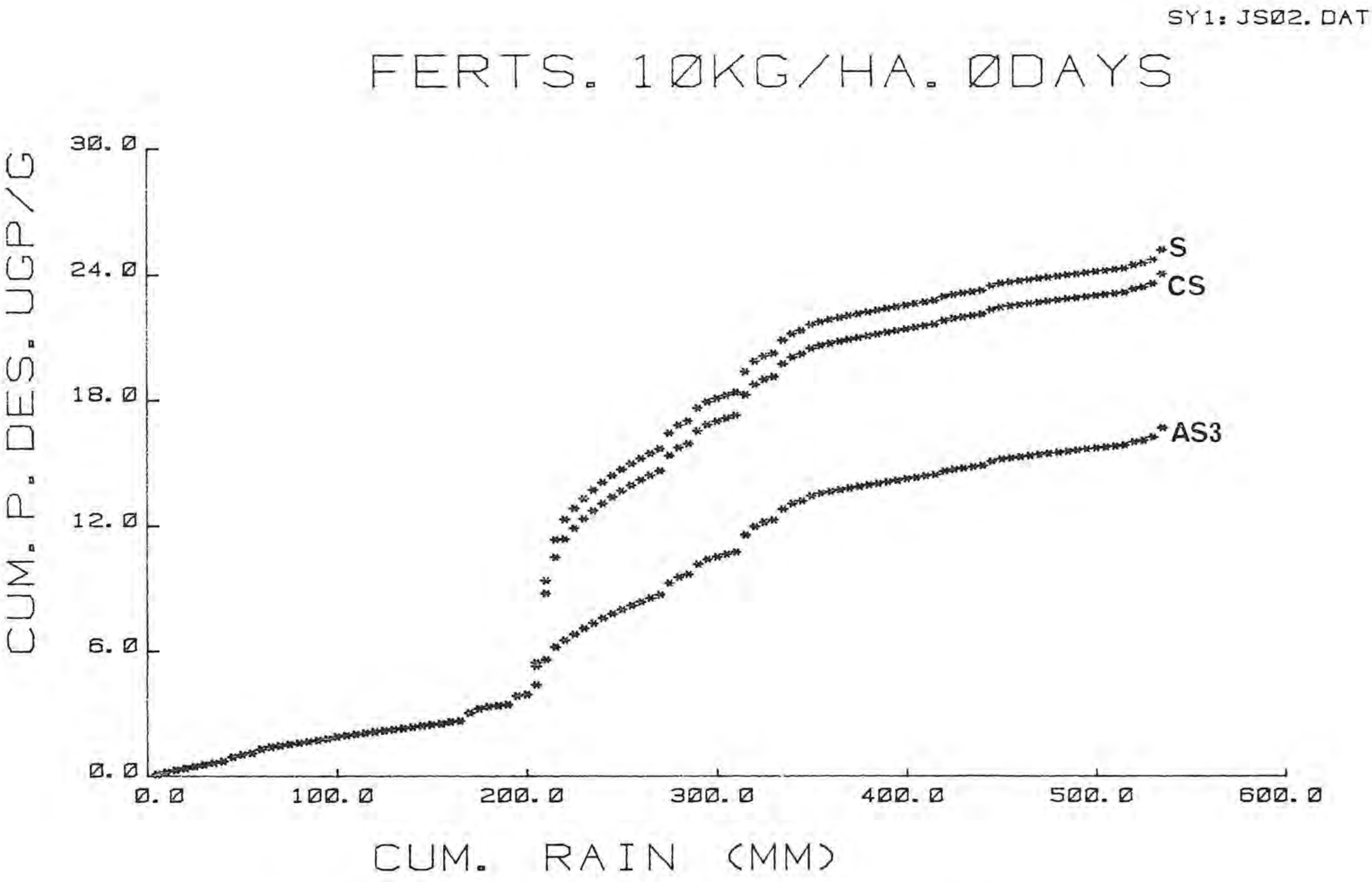


Fig 1. Phosphorus lost after application of 3 different fertilizers during continued rain.

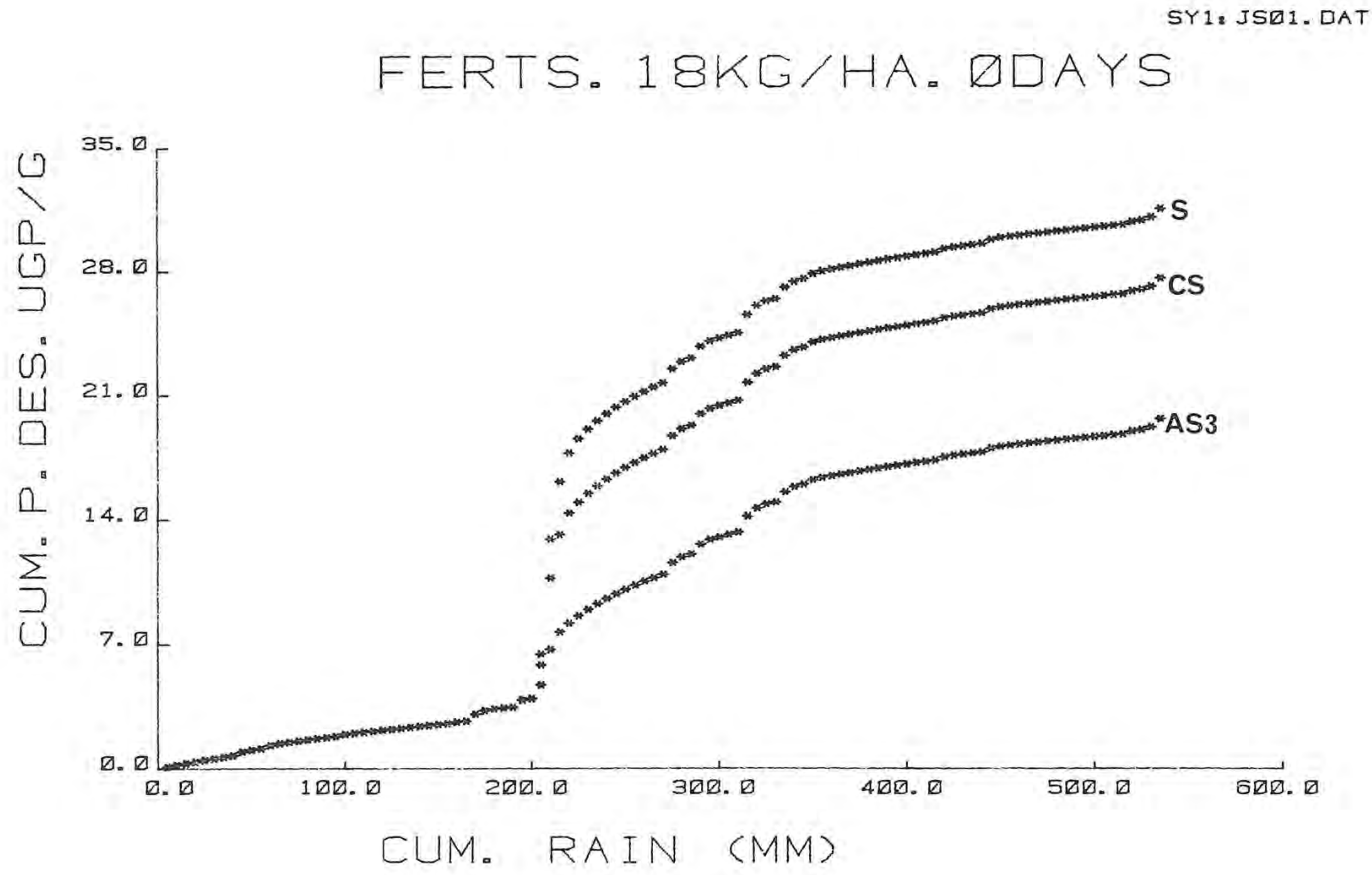


Fig 2. As for Fig 1 except higher application rate.

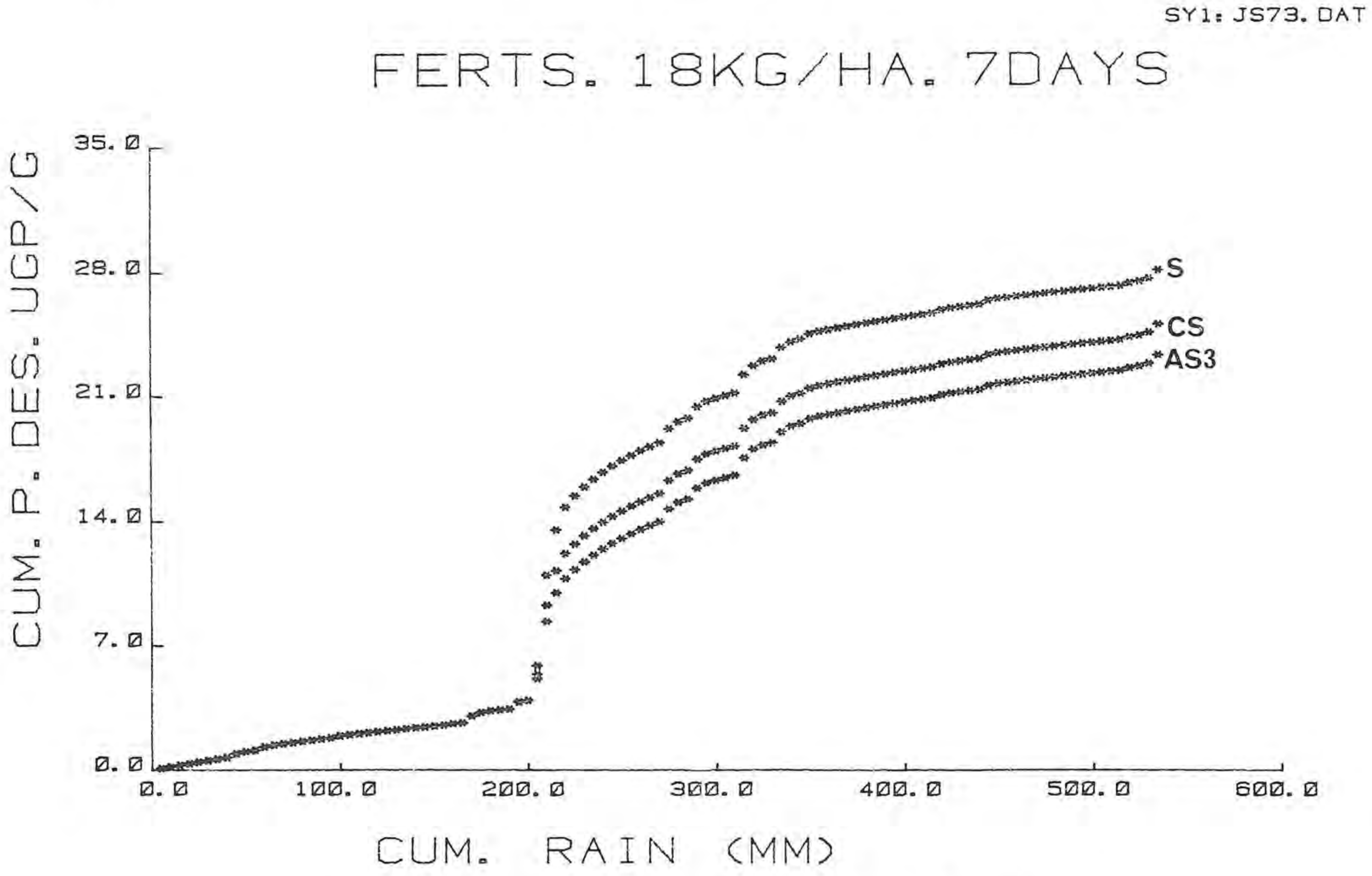


Fig 3. Phosphorus lost after fertilizer application. 7 day pause in rainfall after application.

Determining phosphorus losses to drainage from currently applied superphosphate and coastal superphosphate fertilisers and from soil storage for different soil types in the Peel-Harvey catchment.

N.J. Schofield, P.B. Birch, G.G. Forbes, K.W. McAlpine, G.M. Bott

1. INTRODUCTION

The quantity of phosphorus leached from the landscape into drainage channels is likely to be a complex function of several factors, some of which are listed below:

- rainfall characteristics
- runoff characteristics
- runoff components (flow paths)
- drainage characteristics (e.g. density)
- topography
- land-use
- applied fertilisers
- fertiliser history (soil phosphorus storage)
- time of fertiliser application and subsequent rainfall
- soil physical and chemical properties

The single factor being considered here as a means of reducing phosphorus leaching is applied fertiliser. Both the reduction of applied superphosphate and the introduction of a newly-developed slow-release fertiliser (coastal superphosphate) have been investigated. The other factor considered in the study is soil type as this is a major determinant of the phosphorus leaching rate. Climatical variables, especially rainfall, will always strongly influence the actual amount of phosphorus leached from the landscape. Finally, an understanding of the mechanisms of phosphorus movement and the quantification of individual transport components is an important part of developing a successful management plan.

2. PREDICTING PHOSPHORUS LOSSES TO DRAINAGE FROM DIFFERENT SOIL TYPES

Theoretically, if one could specify loss rates from particular soil groups, for given fertiliser application, soil phosphorus storage and runoff, it would be a simple matter to scale-up the results of small plot experiments to the management scale. This possibility, however, is made less attractive by the great variability of soils on the coastal plain and by complicating influences of the other factors listed above. Nevertheless, the soils of the coastal plain can be grouped into broadly differing soil types and this has formed the basis of the field experimental programme.

The major soil classifications are:

Soil Type	Extent in Harvey Estuary catchment*		Properties
	ha	%	- deep sand profile up to ∿30m
deep grey sands	14 300	22	- hard-pan (coffee-rock) often present near summer low watertable. - characterised by dunes (Gavin sands) and flats (Joel Sands) and interspersed by swamps (outcropping groundwater). - unconfined watertable close to surface. - sand has v. low P-adsorption capacity. Most P-storage in organic A. horizon (~10 cms) and on surface of coffee rock. - partly cleared for agriculture.
duplex soils of sands to sandy loams overlying clay	16 700	26	- surface soil 0-150 cm averaging ∿30 cm, usually with dark organic A, horizon. - B horizon of low permeability clay. - very flat topographically (<1%) - moderate P-adsorption capacity. - virtually entirely cleared for agriculture.
ridgehill shelf soils - yellow and brown sands	4 650	7	
loams and clays	14 300	22	- heavy soils with v. high P-adsorption capacity. - embodies much of the irrigation district.
Hills	13 900	22	- mostly uncleared - steep gradients - lateritic soils

* Harvey River plus Mayfields Drain catchments

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Three catchments were established in 1982 to compare phosphorus leaching from the three main soil types of the coastal plain (deep sands, sand over clay, loams and clays). The locations of the catchments are shown in figure 1 and their properties are listed in Table 1.

Table 1: Some Properties of the Soil Study Catchments

	Meredith	Mayfield (sub-G)	Samson Brook N. Drain
Soil type	deep sands	sand/clay	loams and clays
Area (km^2)	52	10.65	18.0
% cleared	33%	∿100%	∿100%
Max.distance from outlet (km)	11.2	8.2	9.8
Max. width along long axis (km)	5.5	2.0	3.6
Drainage length (km)	27.3	16.1	28.4
Drainage density (km/km^2)	0.55	1.51	1.58

To date only winter 1982 data are fully analysed for all three catchments and these will be used as a basis for discussion. The 1982 results (6/82 - 10/82) are summarised in Table 2.

Table 2: Summary of 1982 winter streamflow and phosphorus drainage loss (/6/82 - /10/82)

	Meredith	Mayfield (sub-G)	Samson Brook N. drain	Harvey River (mouth)
Streamflow ($10^6 m^3$)	4.6	1.97	4.0	130
Surface runoff (%)	41%	77%		
Subsurface runoff (%)	59%	23%	?	?
Rainfall at Waroona/mm)	707	707	707	707
Runoff/Rainfall	0.13	0.26	0.31	
Phosphorus load (tonne)	7.9	1.01	1.4	57
P-Flow-weighted mean conc. (mg/L)	1.7	0.52	0.36	0.44
P load/ha (kg/ha)	1.5(4.5)*	1.1	0.8	1.1

* P load/ha cleared

The results of the individual catchments may be multiplied to the coastal plain scale to determine the relative proportions of phosphorus contribution to the Harvey Estuary (Table 3). The total amount of phosphorus predicted corresponds

Table 3: Contributions of phosphorus from the major coastal plain soil types to the Peel-Harvey Estuary

Soil type	% of Harvey estuary catchment	P drainage 1982 kg/ha	P contribution (tonne)	(%) of total P
deep sands	22	1.5	21.5	36
duplex soils	34	1.1	23.5	40
loams and clays	22	0.8	11.4	19
hills	22	0.2	3	5
		TOTAL	59.4	

quite well with that of the measured Harvey drain input for the same period (57 tonnes) which accounts for about 85% of the Harvey estuary input.

3. THE POTENTIAL FOR REDUCING PHOSPHORUS LOSSES TO DRAINAGE BY CHANGING FERTILISER PRACTICE: EVALUATION OF SUPERPHOSPHATE, COASTAL SUPERPHOSPHATE AND NIL TREATMENTS

During the winter of 1983, experiments on deep sands and duplex soils have been conducted to evaluate the potential for reducing phosphorus losses to drainage by changing fertiliser practice, while at the same time maintaining pasture yield.

Deep Sands (Talbot's property)

A paired catchment study was undertaken to determine the effect of not applying phosphatic fertiliser to a deep (Bassendean) sand whose soil test indicates adequate phosphorus for maximum yield. The site chosen is shown in figure 2 and the catchment parameters are listed in table 4. Both catchments are seen to be similar with respect

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Table 4: Comparison of paired-catchment parameters (Talbots)

	North drain		South drain	
total area (ha)	22.2		38	
area cleared (ha)	19		27.2	
area of swamp	2.8 ha	(12.6%)	6.4 ha	(16.8%)
gavin dunes	8.5 ha	(38%)	13.1 ha	(34%)
joel flats	13.7 ha	(62%)	23.0 ha	(61%)
mean slope	0.515°		0.383°	
drainage length (km)	0.6		1.05	
drainage density (km/km^2)	2.7		2.8	
	total P	bicarb.P	total P	bicarb.P
soil phosphorus tests (ppm)	71	10.5	59	8.5 - 9.5
(kg/ha/10cm depth)	106.5	15.8	88.5	12.8 - 14.3
fertiliser history	> 20 years		> 20 years	
Land-use	sheep grazing pasture		sheep grazing pasture	

to these parameters.

Due to the urgency of obtaining results, only a limited period of pre-treatment monitoring was possible. On July 21 superphosphate was applied to the most of the South drain (see Table 6 for application rates). Substantial rains occurred a week later and a high concentration 'spike' (∿15 mg/L) was observed on the fertilised plot. The cumulative load-runoff graphs are shown in figure 3. Prior to applying fertiliser, the P-losses from the two catchments are very similar (2.6 mg/L), indicating that a good pair had been chosen. After applying superphosphate, the loss rate from the South drain increased from 2.6 to 8.3 mg/L and then gradually declined to a value similar to the unfertilised North drain by the end of the winter. A summary of the results for the two catchments is given in table 5. The runoff coefficients for the two drains are very similar, again indicating the similarity of the two catchments. Consequently, the flow-weighted mean concentration is a good indicator of the reduction in phosphorus leaching to drainage when no fertiliser is applied, this value being 30%.

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Table 5: Paired-catchment results summary (deep sands: Talbots)

		North drain	South drain
pre-treatment	total rainfall (mm)	218	218
	total runoff (10^6L)	8.2	15.8
	runoff/rainfall	0.17	0.19
	P load (kg)	20.8	41.6
	P conc (flow-weighted mean) mg/L	2.54	2.63
	treatment	nil	5.4 ha at 20.7 kg P/ha 25.2 ha at 18.2 kg P/ha
post-treatment	total rainfall (mm)	357	357
	total runoff (10^6L)	50.3	82.1
	runoff/rainfall	0.64	0.61
	P load (kg)	89.1	219
	P conc (flow-weighted mean) mg/L	1.77	2.67
total period	total rainfall (mm)	575	575
	total runoff (10^6L)	58.5	97.9
	runoff/rainfall	0.46	0.45
	P load (kg)	109.9	260.6
	P conc (flow-weighted mean) mg/L	1.86	2.67
	P drainage/P applied	-	0.38
	P drainage/P storage (bic P)	0.32	0.51
	Yield (tonnes/ha) of pasture	5.72	5.12
	Yield/Yield (nil treatment)	1	0.90
	Plant uptake (kg P/ha)	15.6	16.7

Duplex Soils

Three hillslope plots of 120m x 35m dimensions (figure 4) were established on duplex sandy-loam/clay soils. In addition to the nil and superphosphate treatments, a newly-developed slow-release coastal superphosphate from CSBP was evaluated. Some of the properties of the individual plots are listed in Table 6.

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Table 6: Properties of hillslope plots on duplex soils (Stacey)

	Plot 1		Plot 2		Plot 3	
area (ha)	0.42		0.42		0.42	
mean depth of soil horizons A1 (cm)	9.2		12.2		10.8	
A2 (cm)	18.4		16.9		38.3	
B_1 (cm)	0.3		–		5.3	
Slope (%)	$.428^{o}$		$.438^{o}$		$.465^{o}$	
	total P	bicarb P	total P	bicarb P	total P	bicarb P
Soil phosphorus tests (ppm)	150	38	140	36	130	34
kg/ha/10 cm)	225	57	210	54	195	51
fertiliser history	> 30 yrs		> 30 yrs		> 30 yrs	
land-use	sheep grazing pasture		sheep grazing pasture		sheep grazing pasture	

Cumulative graphs of phosphorus load v runoff for the two fertiliser treatments compared with the nil treatment are given in figures 5 and 6. In the case of coastal superphosphate the graph has been adjusted so that the pre-treatment section of the graphs coincide. In both cases the effect of adding fertiliser is apparent but the increased concentrations are comparatively short-lived as compared to the deep sands. The main results of the experiment are summarised in Table 7. The effect of no fertiliser was to reduce phosphorus leaching to drainage by 37% over the winter. The use of coastal superphosphate brought about a 28% reduction, but this value is quite uncertain owing to the need to compensate for the higher release rate from soil storage exhibited by this plot. Another problem with the experiment was the significantly lower runoff from plot 1.

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Table 7: Hillslope plot results summary (duplex soils, Stacey)

		Plot 1	Plot 2	Plot 2 (adjusted)	Plot 3
pre-treatment	total rainfall (mm)	325	325	325	325
	total runoff (10^3L)	332	420	420	467
	runoff/rainfall	0.24	0.31	0.31	0.34
	P load (kg)	0.167	0.280	0.212	0.213
	P conc (flow-weighted mean) mg/L	0.50	0.67	0.50	0.46
post-treatment	treatment	super-phosphate 18.2 kg P/ha	Coastal superphosphate 18.2 kg P/ha		nil
	total rainfall (mm)	388	388	388	388
	total runoff (10^3L)	832	1403	1403	1490
	runoff/rainfall	0.51	0.86	0.86	0.91
	P load (kg)	0.53	0.76	0.58	0.53
	P conc (flow-weighted mean) mg/L	0.64	0.54	0.41	0.36
whole period	total rainfall (mm)	713	713	713	713
	total runoff (10^3L)	1164	1823	1823	1957
	runoff/rainfall	0.39	0.61	0.61	0.65
	P load kg	0.70	1.04	0.79	0.74
	P load kg/ha	1.67	2.48	1.88	1.76
	P conc (flow-weighted mean) mg/L	0.60	0.57	0.43	0.38
	P drainage/P applied	0.09	0.14	0.10	–
	P drainage/P storage (bic P)	0.029	0.046	0.035	0.035
	Yield (tonnes/ha) pasture	3.8	3.5	3.5	3.35
	Plant uptake (kg P/ha)	12.4	13.1	13.1	11.1
	Yield/Yield (nil treatment)	1.13	1.04	1.04	1.0

4. COMPARISON OF PLOT RESULTS TO CATCHMENT RESULTS

The question of scaling-up small-scale plot experimental results to large areas is an important issue from the management point of view. Since data have been collected at three different scales (plot, micro-catchment, sub-catchment) this enables us to make direct comparisons for each soil type. Table 8 lists some of the pertinent parameters and results at the different scales. For the micro-catchments on the deep sands the

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Table 8: Scaling comparisons for deep sands and duplex soils

		Microcatchments (Talbots)	Subcatchment (Meredith)
DEEP SANDS	Area (ha)	38	5 200
	Drainage density (km/km^2)	2.8	0.55
	Runoff coeff.	0.45	0.17
	P conc (flow-weighted mean) from superphosphate applic'n (mg/L)	2.7	1.2
	P export (kg/Ha)	6.9	1.3 (4)*
		Plots (Stacey)	Subcatchment (Mayfield sub-G)
DUPLEX SOILS	Area (ha)	.42	1 065
	Drainage density (km/km^2)	8.3	1.51
	Runoff coeff.	0.54	0.50
	P conc (flow-weighted mean) from superphosphate applic'n (mg/L)	0.6	0.61
	P export (kg/ha)	1.7	2.3

* From cleared area

drainage density and runoff coefficients are somewhat higher than for the Meredith subcatchment. These factors will contribute to the higher phosphorus loss rates observed. Additionally, the high proportional of uncleared land on the Meredith subcatchment substantially reduces the net catchment phosphorus loss rates.

On the duplex soils there appears to be fairly close agreement between the plot phosphorus loss values and those of the Mayfields catchment, despite differences in drainage density. This may indicate that the drainage density of the catchment is sufficiently high to effectively remove the high proportion of surface runoff. Also, many of the farmer-made field drains were not included in the Mayfield sub-G drainage density calculation.

5. ESTIMATING POTENTIAL PHOSPHORUS DRAINAGE LOSS REDUCTION IN THE PEEL-HARVEY CATCHMENT

A gross estimate of the potential reduction in load to the Harvey Estuary can be made by extrapolating the paddock scale results to the whole catchment and by assuming that phosphorus runoff from the control areas is indicative of runoff from paddocks receiving a maintenance dressing of slow-release fertiliser. The latter assumption may not be unrealistic since both control areas were at or above non-responsive soil test levels (confirmed by plant yield data) and could be rundown somewhat before a maintenance dressing would need to be applied.

Using these assumptions a long term potential reduction of 25% is calculated (Table 9) if no reduction is achieved on the clays, loams and hills soils. These soils are at present fertilised at about twice the rate needed to maintain production. Therefore, some reduction in runoff of phosphorus will be achieved if these soils are fertilised according to soil tests. Even if the rate of reduction achieved is only about 50-60% of that achieved for the duplex soils then a further 5% overall reduction will be achieved, giving a total of 30%. This figure could be further improved on if the chemical nature of the phosphorus bank in the soil is altered by the long term use of slow-release fertilisers.

Since there are general similarities between the Harvey Estuary Catchment and the Serpentine River catchment similar fertiliser management and similar reductions in phosphorus runoff should be achievable there.

Table 9: Potential longterm reduction of phosphorus inputs to the Harvey Estuary

Soil type	% P input	% reduction in field expts	% reduction for soil type area	% catchment P reduction
Deep sands	36	30	30	11
Duplex (sand/clay)	40	37	37	15
Clay and Loams	24	?	15*	4
			TOTAL	30

* estimated

6. EVIDENCE OF CATCHMENT-SCALE REDUCTIONS IN PHOSPHORUS DRAINAGE LOSS FOLLOWING DECREASED SUPERPHOSPHATE APPLICATION AND THE USE OF COASTAL SUPERPHOSPHATE

In 1983 a significant change in fertiliser practice on the Meredith catchment (5 200 ha) took place. In 1982, which may be considered typical of previous years' fertiliser practice, 24 tonnes of phosphorus, almost entirely in the form of superphosphate, was applied to the catchment. In 1983, 6.2 tonnes of phosphorus as superphosphate and 10.2 tonnes as coastal superphosphate were applied. This change in fertiliser use corresponded to a reduction in the flow-weighted mean concentration of phosphorus in runoff from 1.7 mg/L to 1.2 mg/L. Thus, a 32% decrease in phosphorus application saw a 29% reduction in concentration in runoff. However, such a direct correlation between phosphorus application and runoff mean concentration must be considered against the background of other influencing factors and variability from year to year.

.../11

The 1983 reduction in flow-weighted mean phosphorus concentration in the Meredith catchment was also observed in the Harvey River, which decreased by 20% over 1982 and by 12% over the four year mean 1978-82 (Table 10).

Table 10. Flow-weighted mean phosphorus concentrations for Harvey River

Year	Flow-weighted mean phosphorus concentration (mg/L)
1978	0.38
1979	.39
1980	?
1981	.39
1982	.44
1983	.35

7. IMPLICATIONS

1. Predicting phosphorus losses to drainage on the basis of soil types

On the basis of the 1982 data, the concept of scaling-up results from medium-sized experimental catchments (1000 - 5000 ha) to predict phosphorus losses to drainage from different soil types appears to be a useful management tool.

2. Reducing phosphorus losses to drainage from deep sands by modifying fertiliser application

Reducing fertiliser application to zero on deep (Bassendean) sands which have adequate bicarbonate extractable phosphorus for maximum yield, has the potential to reduce phosphorus leaching to drainage by about 30% in one year, without affecting pasture yield.

The high proportion of phosphorus drainage loss to soil bicarbonate extractable phosphorus (0.32) indicates that significant reductions in further years of no fertiliser application may be possible, but this could be at the expense of pasture production.

3. Reducing phosphorus losses to drainage from duplex soils by modifying fertiliser application

Reducing fertiliser application to zero on sandy-loam duplex soils with adequate bicarbonate extractable soil phosphorus for maximum yield has the potential to reduce phosphorus leaching to drainage by about 37% in one year, without significantly affecting pasture yield. The use of coastal superphosphate in the same situation could effect a reduction of 28%. However, these figures are subject to uncertainty due to natural differences in runoff characteristics and phosphorus leaching rates on the experimental plots.

.../12

4. Estimating catchment reduction in phosphorus drainage loss

On the basis of scaling-up small experimental site results, a net reduction of phosphorus drainage loss (in terms of flow-weighted mean concentration) of about 30% could be achieved in the long-term whilst maintaining agricultural production.

A substantial decrease in superphosphate application and its replacement by coastal superphosphate in the Meredith catchment in 1983 reduced flow-weighted mean phosphorus concentration by 29% compared to 1982. A 20% reduction was also observed for the Harvey River but these figures are subject to other influencing factors and variability.

Figure 1: Experimental subcatchments in relation to soil type and drainage in the Harvey Estuary Catchment

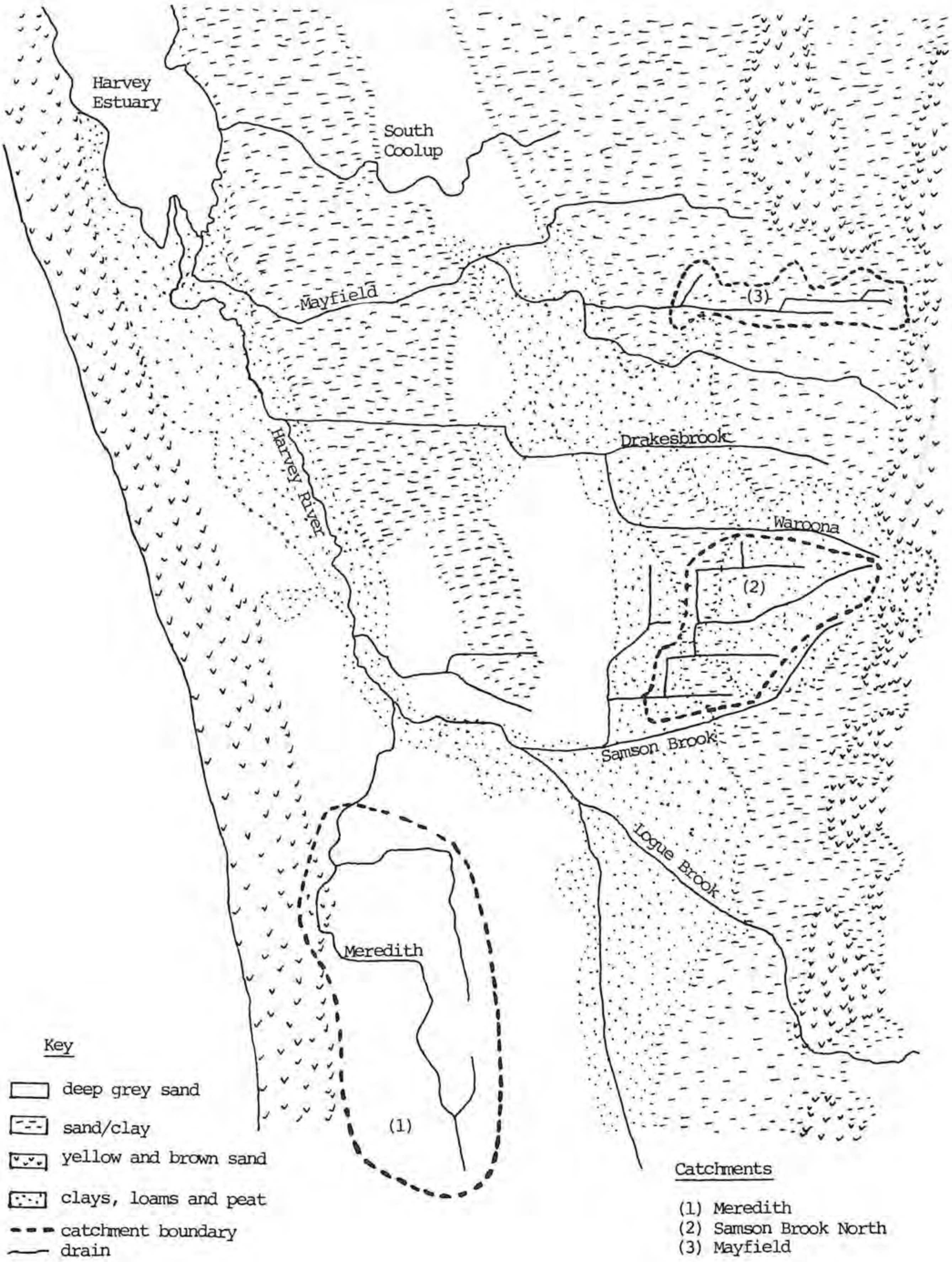


Figure 2: Deep sands Paired-catchment study (Talbots)

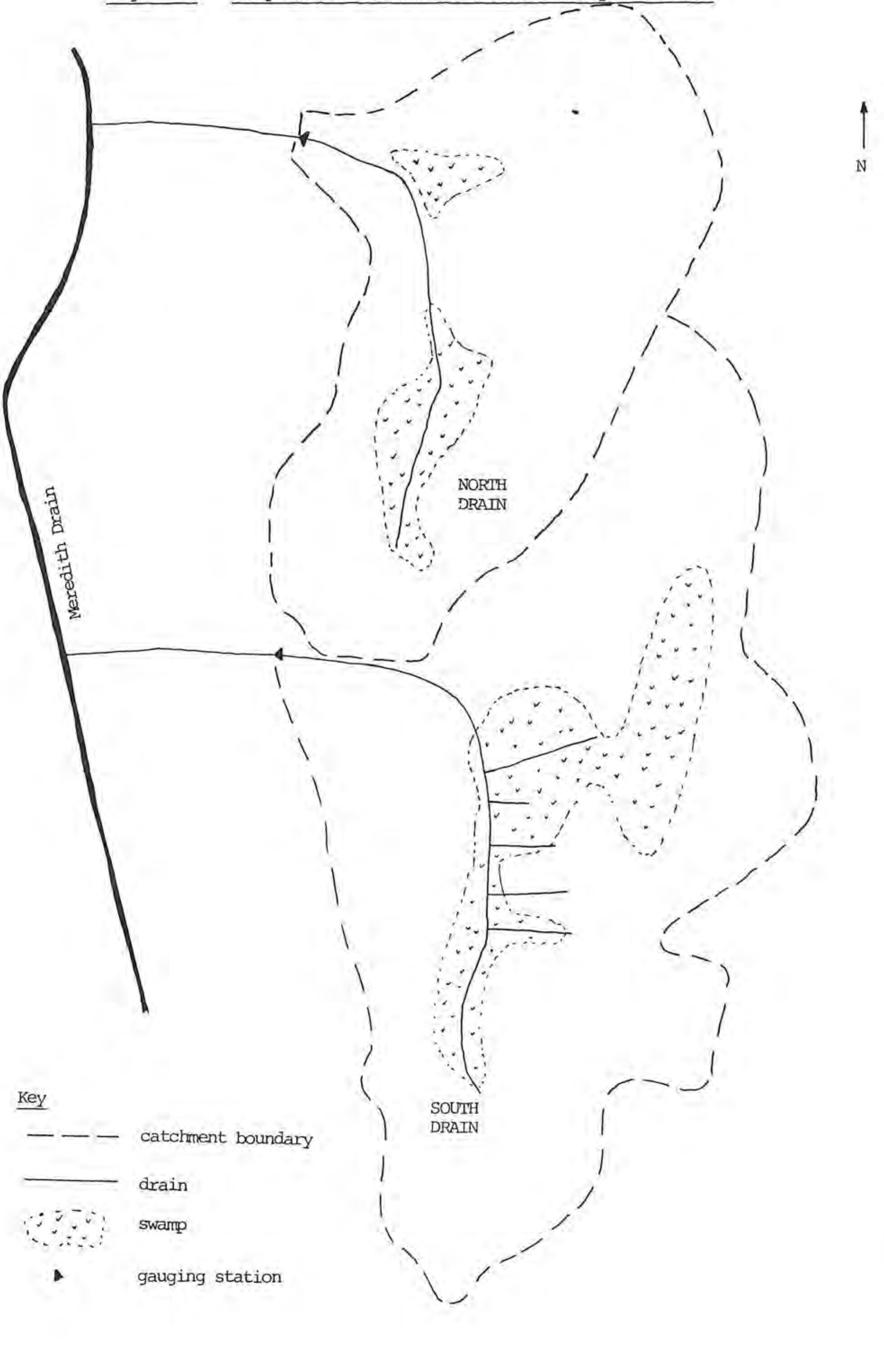


Figure 3: Cumulative phosphorus load v flow from superphosphate and nil treatments on deep sands (Talbot)

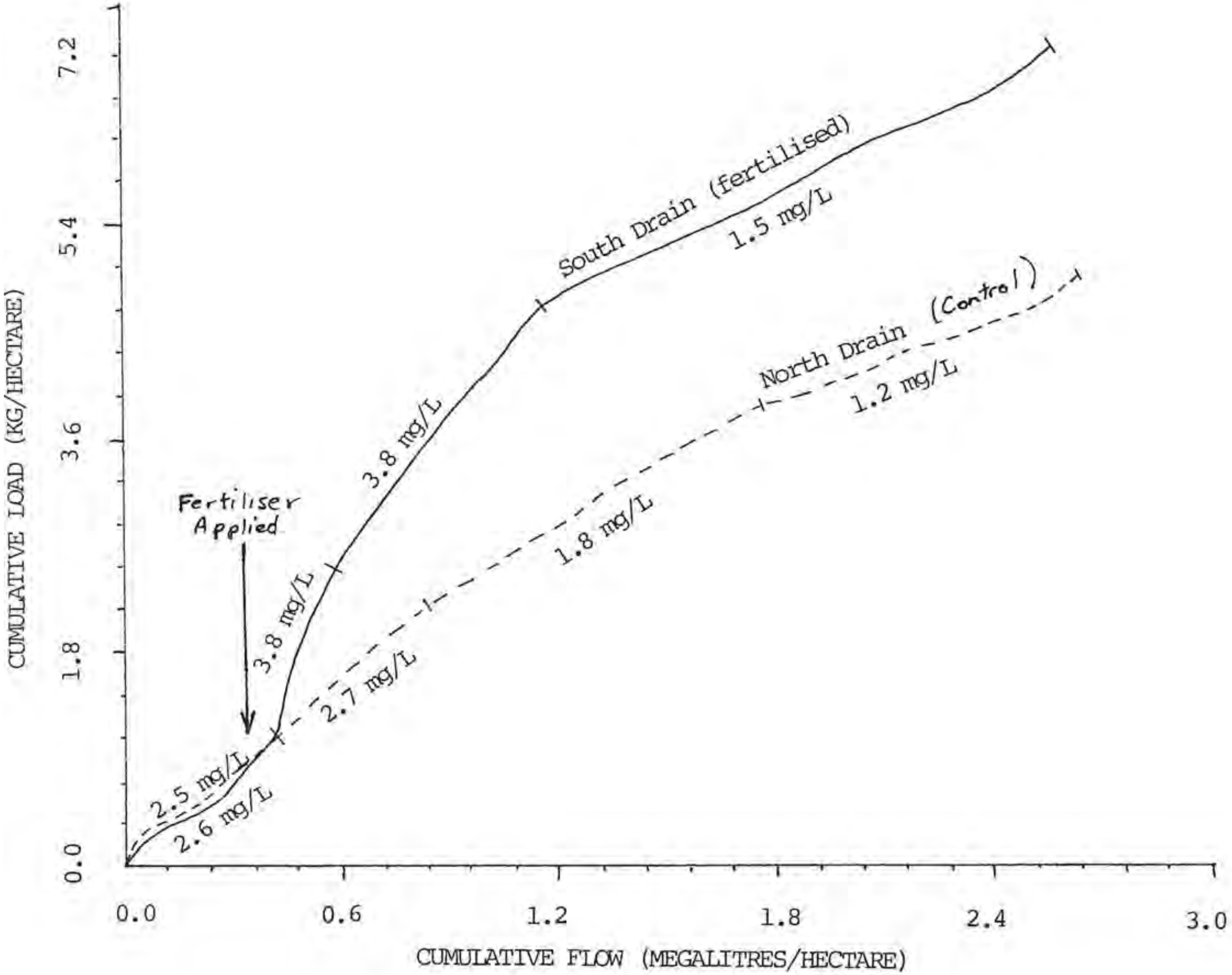


Figure 4: Hillslope plots on duplex soils: layout and fertiliser application (Stacey)

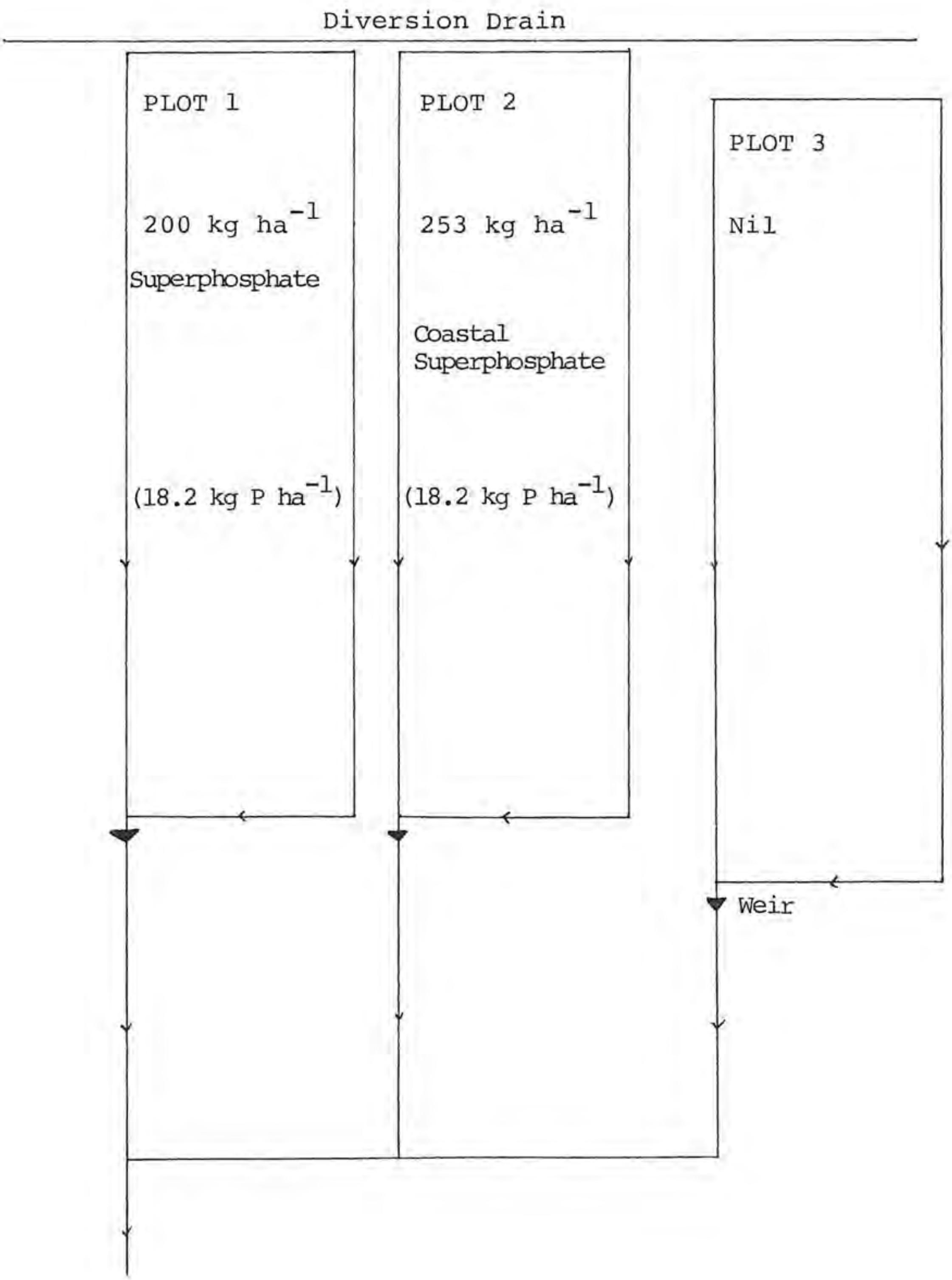


Figure 5: Cumulative phosphorus load v flow for superphosphate and nil treatments on duplex soils (Stacey)

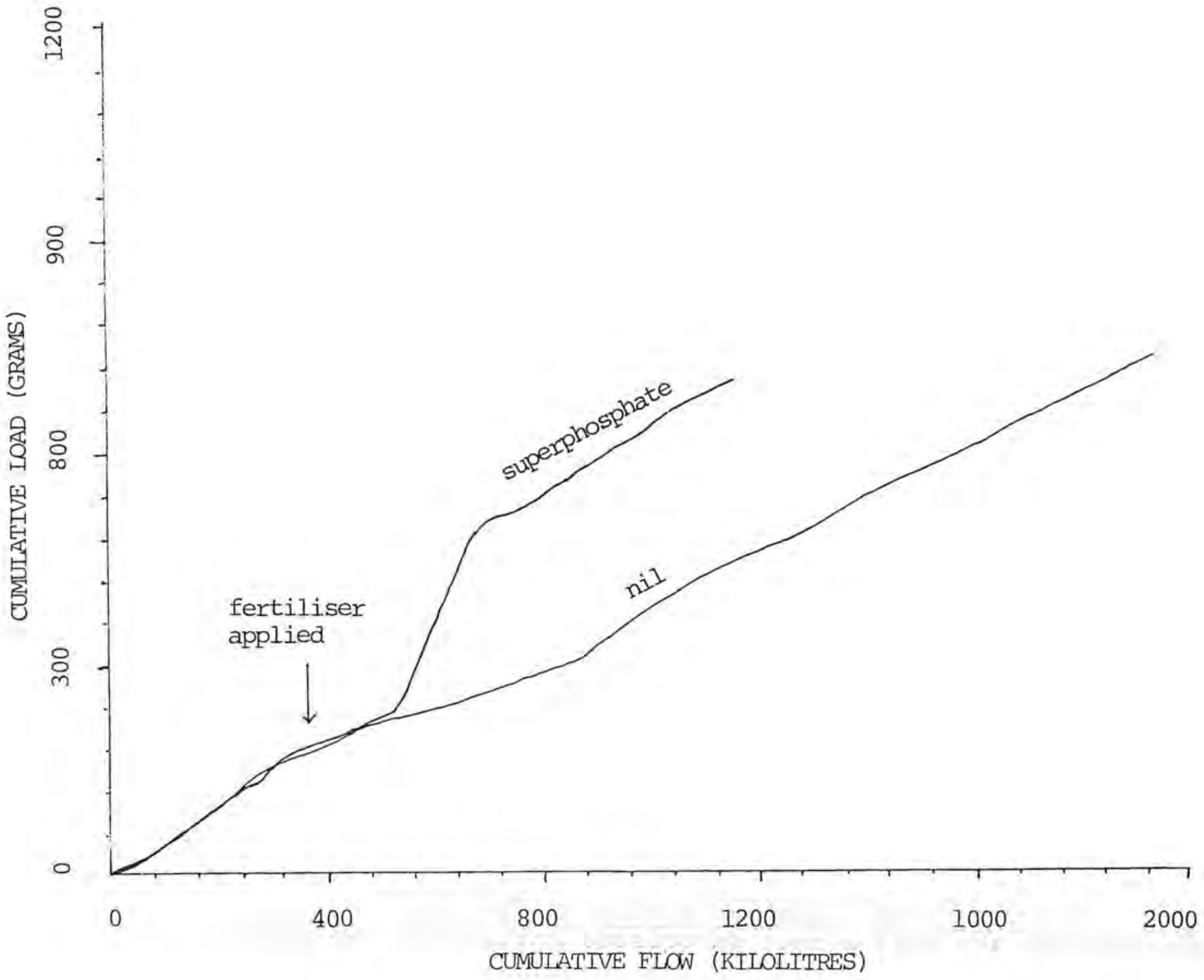
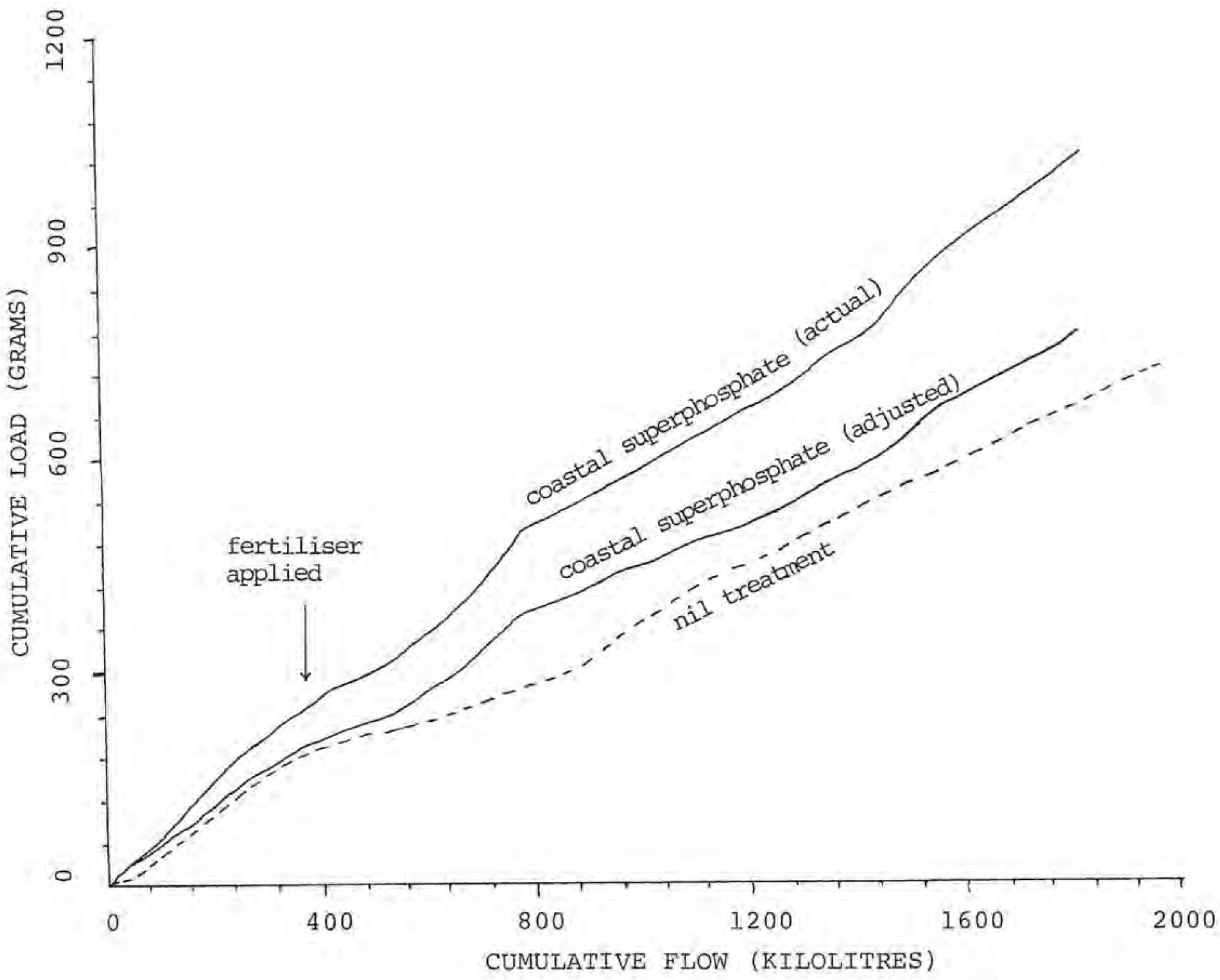


Figure 6: Cumulative phosphorus load v flow for coastal superphosphate and nil treatments on duplex soils (Stacey)



PEEL HARVEY ESTUARY STUDY

GROUNDWATER SURVEY - DRAINAGE RESPONSE

ERIC BETTENAY*, MAURICE HEIGHT* and DENIS HURLE+

*CSIRO Division of Groundwater Research

+Denis Hurle and Associates

INTRODUCTION

Movement of phosphorus to the Peel-Harvey system via regional groundwater flow and via base of flow to drains is one part of a story. It needs to be integrated with surface, and near-surface, flows (Nick Schofield), and storage and release of P from surface and subsurface soil horizons (Gerry Ritchie).

In this paper we attempt to summarise the current state of knowledge on the importance of groundwaters. Both published and unpublished works have been drawn on, and we are grateful to those who have allowed us to quote their as yet, unpublished data. Much data has been collected from recently installed wells. This data, which generally covers a period of less than one year is provisional, and has not been rigorously checked or subject to detailed examination.

REGIONAL GROUNDWATER

1. Water Movement

. Black and Rosher (1980) looked at an area to the east and north-east of the Peel-Harvey system. Gradients are similar to surface gradients, and flatten towards the estuaries. Gradients average about 1:1000 with a saturated hydraulic conductivity K_s of $5m^3/day/m^2$ (5 m day^{-1}) estimated. They estimated flows direct to the estuary and showed that about 1% of P input may come from groundwaters.

- Alan Deeney (GSWA; private communication) indicates an overall groundwater slope of 1:800, and a K_s of 5-10 m day^{-1} for aquifers in this area generally. Movement is to the west to Peel Inlet, and to the north-west towards Harvey Estuary.
- Ian Cameron (Murdoch University; private communication) has measured K_s in packed laboratory columns, for two deep sand profiles of the Bassendean Association, and finds:

  Jandakot sand, 0-20 cm, K_s = 9.6 m day^{-1} rising to 24.4 m day^{-1} by 50 cm.

  Gavin sand 0.20 cm, K_s 7.8 m day^{-1} rising to 33.3 m day^{-1} by 50 cm.
- For Merredith drain catchment in the Bassendean Association (see Fig 1), groundwater gradients, based on swamp heights which are an expression of the groundwater surface, are about 1:1500 with a fall to the north-west to the Harvey Estuary. Again the groundwater surface approximates the ground surface. Using a K_s of 50 m day^{-1} (Unpublished CSIRO data for similar sands in the Gnangara Mound), the calculated general flow rate is 0.1 m day^{-1}. It would thus take 250-300 years for groundwaters to move from near the divide south of Riverdale Road to the Merredith drain gauge site at Johnston Road (approximately 10 km).

2. P levels

- Black and Rosher used an average figure for total P of 0.48 mgL^{-1} for groundwater in bores east and north-east of the estuary.

- Deeney more recently estimates an average figure of about 0.1 mgL^{-1} for the Peel-Harvey area.
- In waters from a grid of bores, from the scarp near Cookernup to the Harvey River Drain, CSIRO has measured ortho-P levels from 0.0-0.27 mgL^{-1}. These are within the range generally encountered in surface soil (Coolup, Dardanup, Wellesley).
- Near the groundwater surface in Bassendean sands, P levels as high as 26 mgL^{-1} have been encountered, but at depth levels fall to very much lower values (see later).

3. Conclusions

- It would seem that the Black and Rosher estimates for total P inputs to the estuaries via groundwater are of the right order. Their estimates of P concentrations may be generally high. Both P concentrations and K_s may be higher for Bassendean sands, but in the Merredith drain area gradients are not as steep.
- By contrast surface flow, or flow via open drains may be very rapid. It would take about 0.2 days for water to travel the 10 km, from near the Merredith drain divide to the Johnston Road gauge site, in a straight drain (say 0.5 days via the present Merredith drain).
- Merredith drain has a permanent flow fed by groundwater base flows. Flow rates, both as groundwater or surface flow, will be faster adjacent to sinks - particularly drains - due to the steeper gradients developed.
- Losses from Coolup types will be largely via surface or near surface flows (see Nick Schofield).

DETAILED GROUNDWATER STUDIES

Detailed groundwater studies are being carried out at Eastcotts (80 m grid of wells) remote from a major drain, and at Talbots (100 m grid of wells) adjacent to Merredith drain (see Fig 1). Both sites are within the Bassendean association. Only the Talbots data has been analysed to date.

1. Water Movement

- A grid of fully slotted wells was inserted into the top ± 1 m of the watertable at the end of autumn. Groundwater contours have been generated from periodic water table measurements.
- There is a general flow direction from the south-east to the north-west. This is the same direction as the regional flow, but flow rates to drains are faster due to greater gradients (up to 4 m day^{-1} compared to 0.1 m day^{-1} for regional flow).
- Ground surface contours are shown in Figure 2, while Figure 3 shows groundwater contours prior to the winter rains (25 May 1983), and Figure 4 shows groundwater contours at a maximum after rains (7 September 1983).
- There is a close correlation between surface contours and groundwater contours.
- Groundwater levels rise between approximately 1 to 2 m with winter rains. The greatest rises are under the small dunes, which are also the areas remote from drains.
- Water levels rise to above the surface in some low lying areas, when water would move to the drains via surface flow.
- There is no apparent difference in groundwater response to rain between areas adjacent to either the north or south paddock drains.
- Perennial flows in Merredith drain indicate a groundwater input. The north and south paddock drains are seasonal. Surface flows contribute at times although the drain hydrographs are not as peaked (spikey) as those for drains in Coolup type soils (see Nick Schofield).

2. P levels

- P concentrations are measured in water entering recently pumped wells and so are considered to be a composite of water to the slotted depth.
- Concentrations rise in some wells as water levels rise. Those wells which rise to, or near the surface in winter generally have higher P concentrations than those in which the water table is deeper (see Fig 5).
- Increased P concentrations with time does not necessarily mean that concentrations at the surface are the highest. There may be a bulge profile as reported last year in Joel tube wells (see Fig 6).
- P concentrations in, on and under the coffee rock are low.
- Visual inspection of contour data (see Fig 7, end autumn, and 8, end winter, P contours) shows that obvious hot spots stay pretty much in place. It is unlikely that P applications to the south paddock drain have affected the north drain.

3. Conclusions

- Water levels rise to, or above, the surface in winter thus generating surface flow. There are large spatial differences in P concentrations, both between sites and with depth.
- Hot spots stay in place, and areas remote from drains are not much affected.
- The area adjacent to Merredith drain has low P concentrations, but there are swamp soils with a higher clay content near the surface.
- Drains may have an effect, in removing P, of up to 25 m on either side. This would not show up well on the current grid.
- Increased concentrations in groundwaters as wells rise may result from waters rising into zones where larger amounts of P are stored as organic P, or as mineral P in the unsaturated zone.

- If P additions are reduced then areas close to drains should be depleted of P. Removal of P from hot spots remote from drains will take much longer. This should mean that drains will flow at a reduced P level once the excess soil store is removed from near drains.

MODELLING

The groundwater levels at Talbots will be modelled numerically to match the observed levels so that groundwater flow rates can be calculated for use in a solute transport model. An additional component needed for a solute transport model is the sorption characteristics of the soils.

FUTURE REQUIREMENTS

- Better characterisation of aquifer materials - since we are using Gnangara K_s - by means of pump tests with nests of observation wells.
- Determine influence of coffee rock hard pan on water movement and P movement.
- Install further wells to determine total P storage in groundwater at depth.
- Install further tube wells to determine shape of P profile above hardpan (? Bulge profile).
- Obtain better idea of movement of groundwater to drains by means of more detailed grids of wells.
- Determine flow rates in drains.
- Further analysis of existing data, and testing model against data.
- Correlate with other groundwater models, and integrate with P adsorption - desorption models.

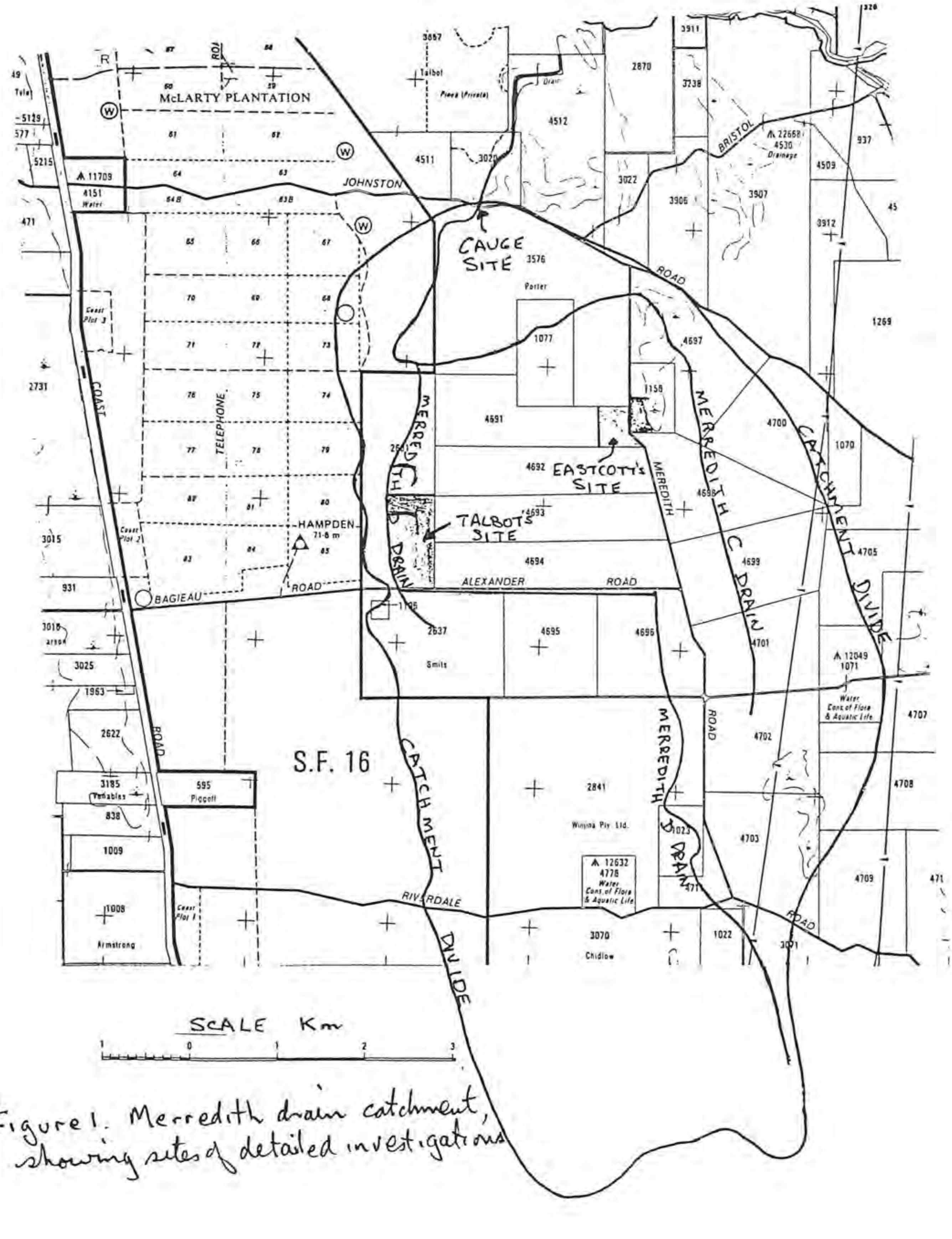


Figure 1. Merredith drain catchment, showing sites of detailed investigations

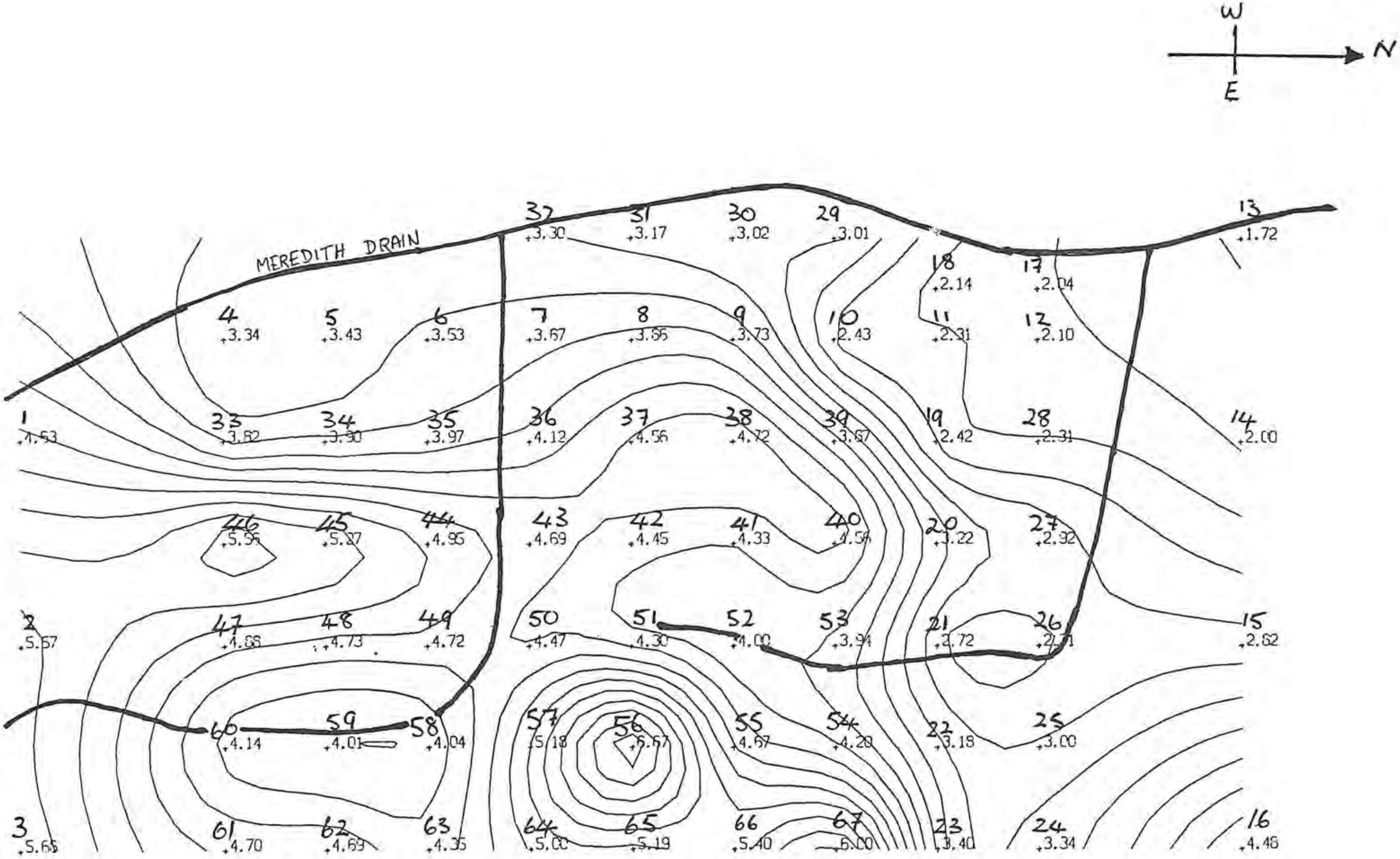


Figure 2
GRØUND LEVELS - TALBØTS 0.25M CØNTØURS

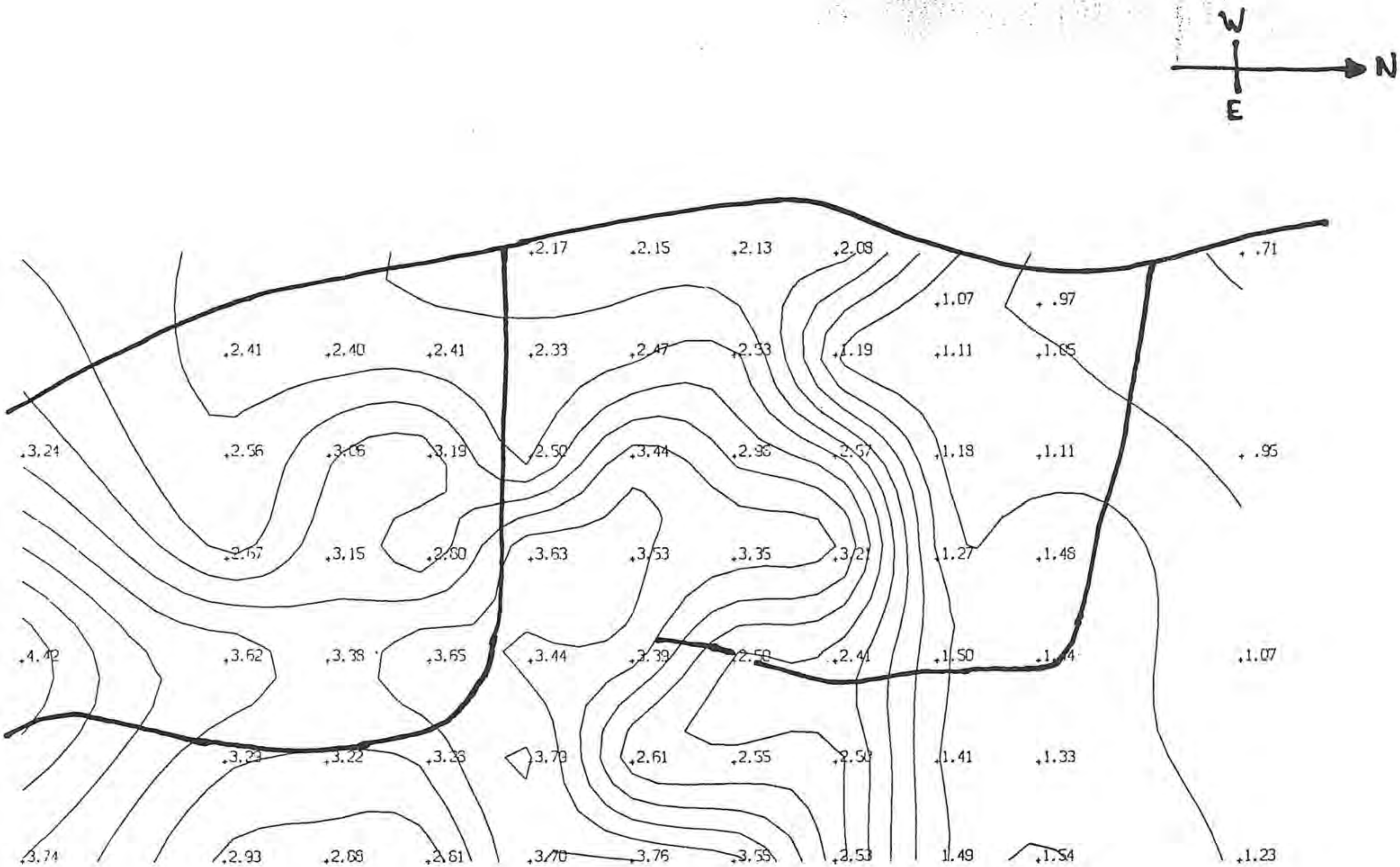


Figure 3

RELATIVE LEVELS ØF GRØUNDWATER - TALBØTS 25/05/63 0.25M CØNTØURS

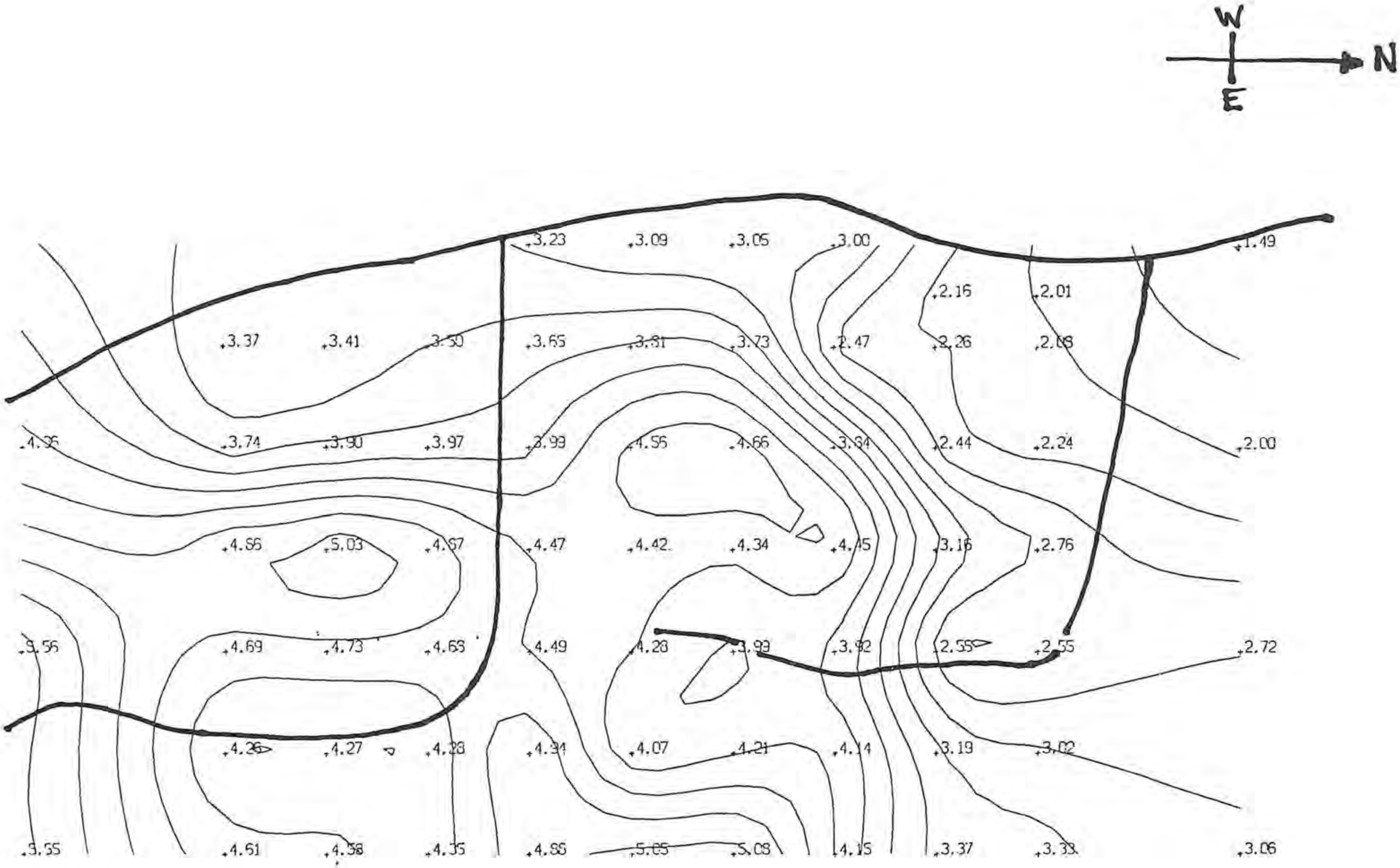


Figure 4

RELATIVE LEVELS ØF GRØUNDWATER - TALBØTS 07/09/83 0.25M CØNTØURS

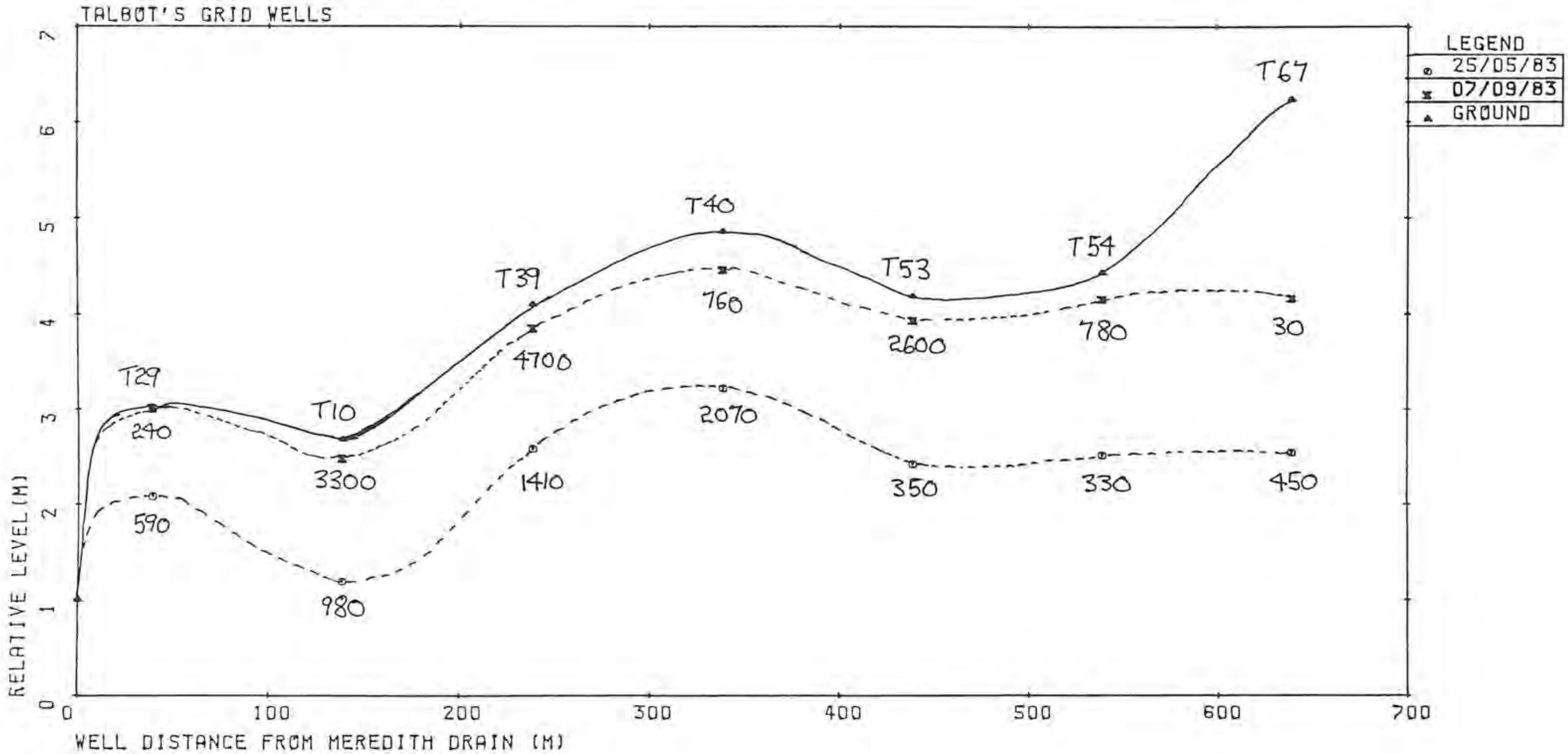

TALBOT'S GRID WELLS
LEGEND
25/05/83
07/09/83
GROUND
T29
T10
T39
T40
T53
T54
T67
240
590
3300
980
4700
1410
760
2070
2600
350
780
330
30
450
RELATIVE LEVEL (M)
WELL DISTANCE FROM MEREDITH DRAIN (M)
0
1
2
3
4
5
6
7
100
200
300
400
500
600
700

Figure 5.

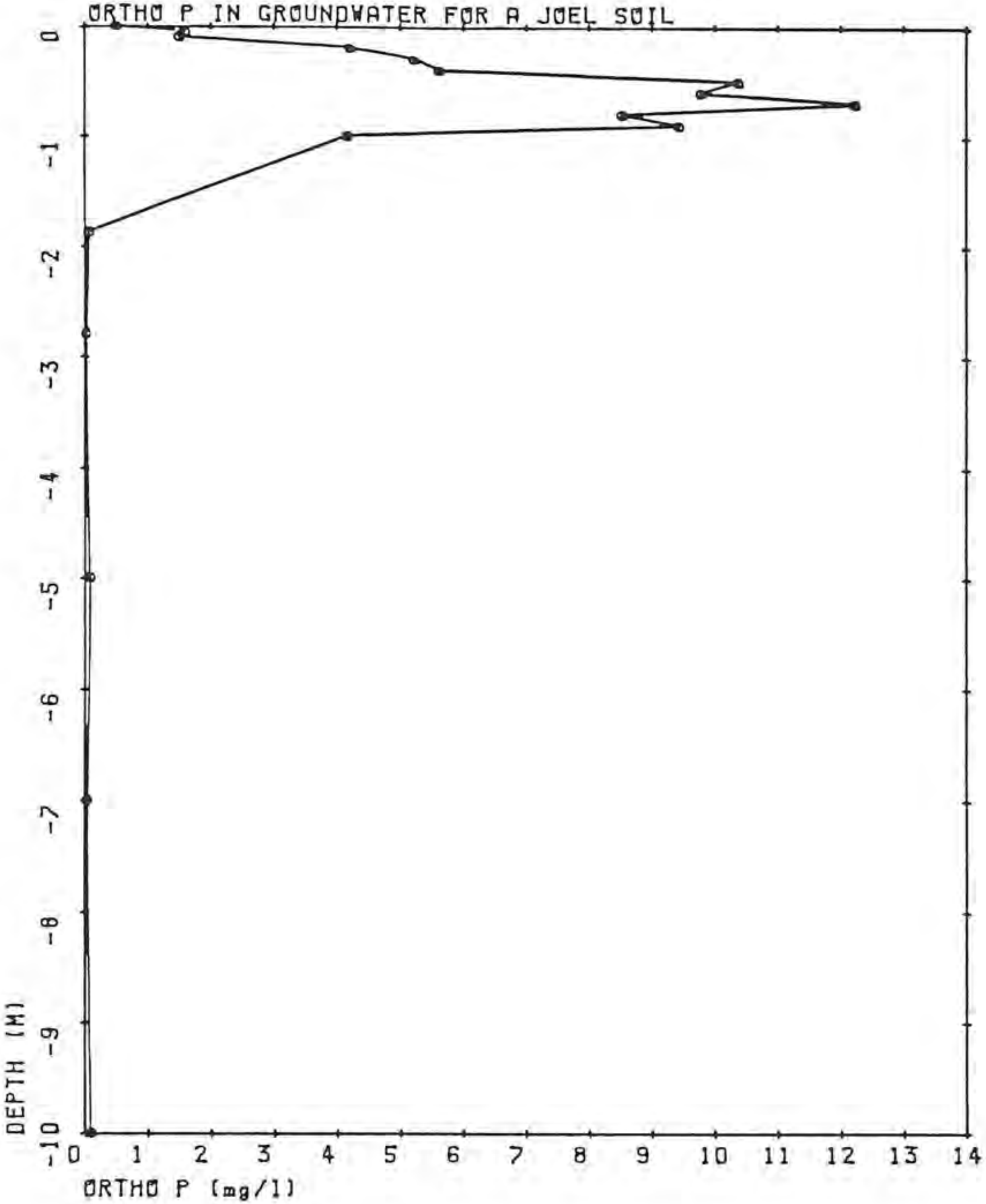

ORTHO P IN GROUNDWATER FOR A JOEL SOIL
DEPTH (M)
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
ORTHO P (mg/l)

Figure. 6.

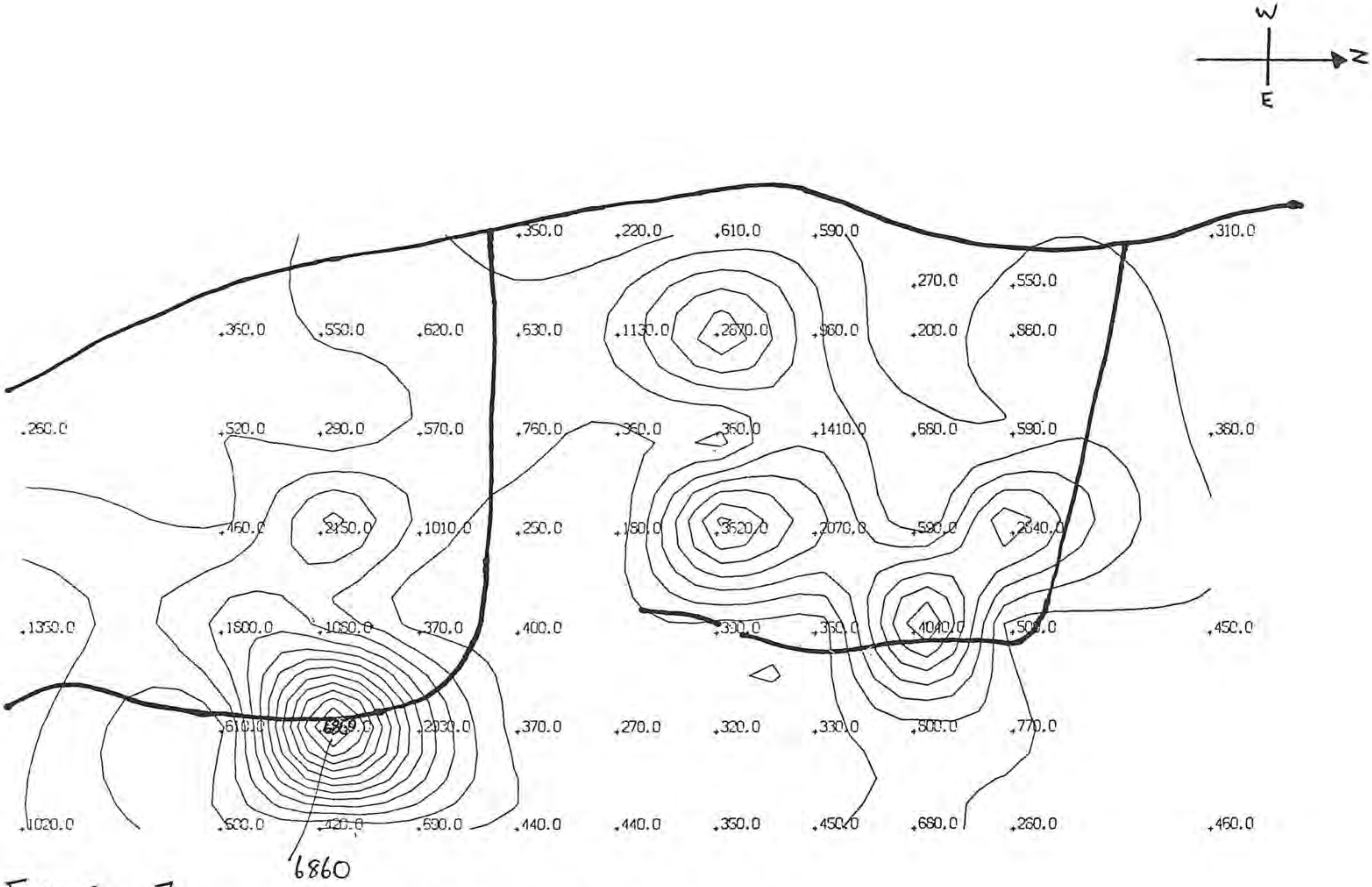


Figure 7

P CONCENTRATIONS OF GROUNDWATER - TALBOTS 25/05/83 500UG/L CONTOURS

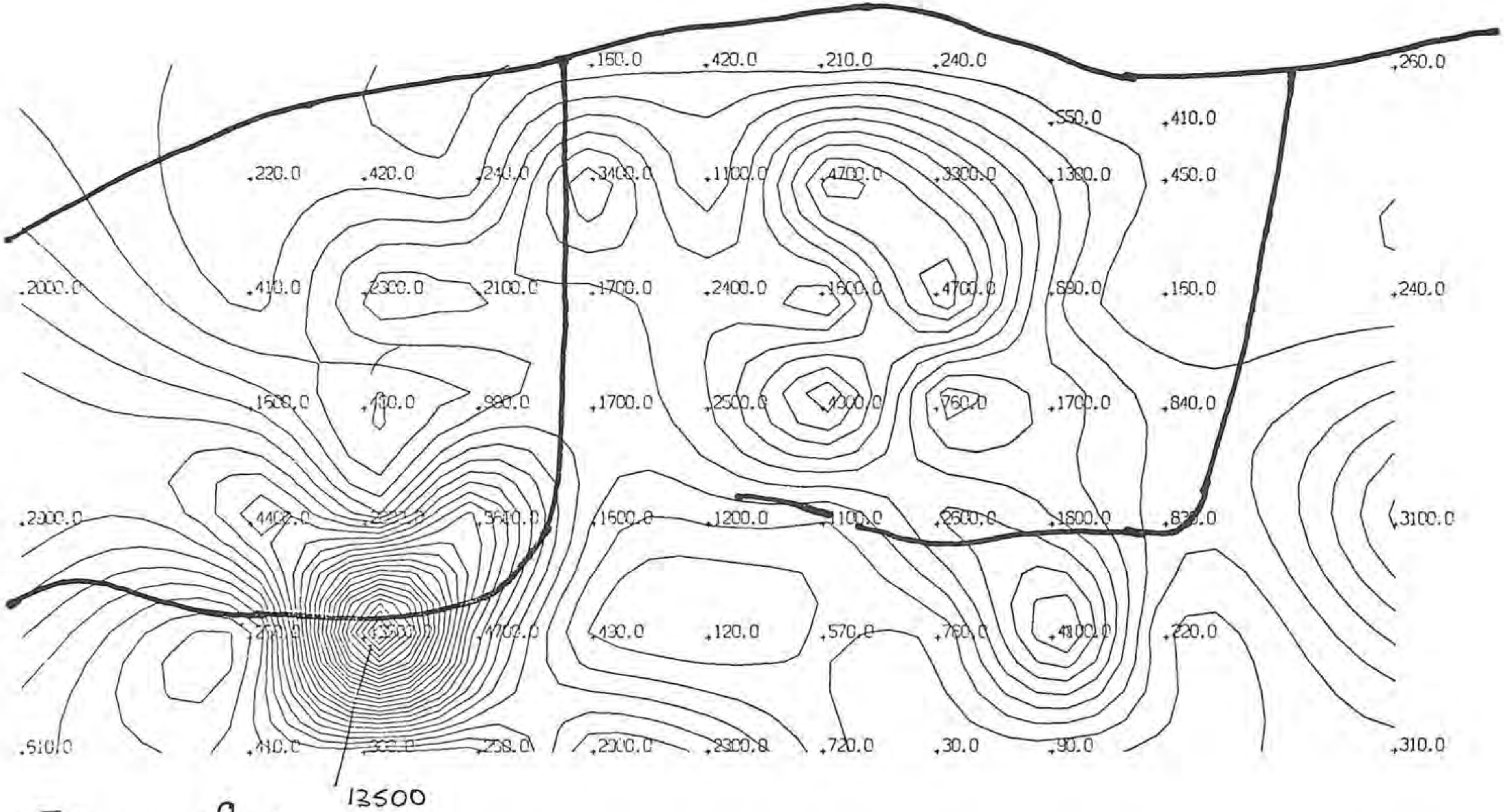


Figure 8.

P CONCENTRATIONS OF GROUNDWATER - TALBOTS 07/09/83 500UG/L CONTOURS

PHOSPHORUS MOVEMENT THROUGH SANDY SOILS AND GROUNDWATER IN THE PEEL HARVEY CATCHMENT AREA.

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Goen E Ho

School of Environmental & Life Sciences
Murdoch University

Paper submitted to the Department of Conservation & Environment as a contribution to the Symposium on the Peel Harvey Estuary Study, 28-29 November 1983.

N.B. Full report will be available on request from this Department, or at the Symposium.

ABSTRACT

The movement of soluble phosphorus through soil and groundwater is investigated employing a model incorporating phosphorus movement by convection and dispersion, and its removal by soil adsorption. Laboratory experimental work using soils from the Peel Harvey catchment area has shown that the soils have widely varying properties which affect phosphorus transport. Hydraulic conductivity varies from 0.2 md^{-} to 33 md^{-1}, dispersion coefficient from 6 x 10^{-7}m^{2}s^{-1} to 8 x 10^{-6} m^{2}s^{-1} and soil adsorption capacity from 1 mg P/kg soil to 100 mg P/kg soil.

Preliminary results of a one dimensional modelling work and the corresponding soil column experiments are reported in this paper. Phosphorus breakthrough curves through soil columns obtained experimentally reflect the varying soil properties noted above. In addition the breakthrough curves are also affected by the time dependent nature of phosphorus adsorption by soil.

Future work will be directed at developing the model further, obtaining its parameters, their variation more precisely using batch and column tests and comparing model prediction with field results.
The results obtained so far indicate the possibility of utilizing the capacity of soils for phosphorus adsorption in the field for P storage by modifying the water flow regime in the catchment area.

CHANGING FARMER'S ATTITUDES AND PRACTICES

Bill Russell
Officer-In-Charge
Department of Agriculture, Harvey.

Over the past twelve months, farmers in southern catchment areas have been subjected to an almost barrage of information on what has gone wrong with the estuary and what probably has to be done to correct it. It has been made clear that farmer practices are the major cause of the problem, even if the farmers are not being blamed for the state of the estuary. The majority of farmers accept this but a few are still disputing the facts as presented by the study group.

There is a general recognition that part of the solution will be for farmers to alter their fertiliser practices, but there is as yet little sign of a large scale change in attitude. It is possible that the non-farming community has been led to expect a more rapid improvement in the condition of the estuary as a result of changes in farmer fertiliser practices than will in fact be possible.

Three reasons for slow adoption of new fertiliser practices by farmers are:

1. It is unusual for a large number of farmers to make major changes in long standing practices in a short time, even when the change can be demonstrated to be beneficial. It is more likely that they would try the new recommendations on part of the farm for a year or two before adopting them for the rest of the farm.

2. For many farmers, the changes proposed were not physically possible in that the alternative fertilisers suggested had to be applied by special machines at an extremely difficult time of the year.

3. Continuing media reports about farmers needing to change fertiliser practices to solve the problems of the estuary, the inference being that farmers will have to change to help solve somebody else's problem and that the recommendations being made are at least partially politically influenced.

Adoption of Recommendations

Farmers whose properties were soil sampled last summer were surveyed for their response to the recommendations made on the basis of the soil test. Of the 40 who wrote a comment to the question 'did you follow the recommendation completely?', 11 did not follow the recommendations because they were inconvenient or impractical and 8 because they didn't believe the recommendation. 15 farmers applied less than the recommendation for a variety of reasons - usually because of lack of finance.

The results simply reinforce what we already knew - until we get a sulphur fertiliser which can be applied before mid winter, there is little chance of getting a substantial reduction in the amount of phosphorus applied. Existing fertilisers are an extremely convenient way of applying three essential plant nutrients - phosphorus, potassium and sulphur. Until the alternatives can be demonstrated to be at least as convenient, and no more expensive, there is little incentive for farmers to change.

The newly developed fertiliser AS3 looks promising but there is still no announcement that it will be commercially available next year, it will probably cost a lot more per tonne than existing fertilisers and it doesn't contain any potassium. As with Coastal Super this year, the questions are:

- will there be sufficient demand for AS3 to justify producing the full range of mixes which farmers have become accustomed to?
- will they be available from Picton as well as Kwinana?

These are questions only the companies can answer but they have a bearing on the likely farmer acceptance of a new fertiliser. There could be a case for some Government assistance to reduce the on-farm cost of AS3 to a more attractive level.

An alternative would be to supply gypsum in a more attractive form so that it could be spread with existing machinery at a more convenient time of year. There appear to be substantial technical problems to overcome before this option becomes feasible.

A 'spreadable' gypsum is a very attractive proposition; 34 out of 53 farmers indicated that they would use it as a source of sulphur if the cost could be held down to about $4.50/ha. This is about three times the current cost of Kwinana gypsum and compares with $22.00/ha to use superphosphate as a source of sulphur.

The problem we have is that we are dealing with a relatively small market. We really cannot justify producing a big range of fertilisers and still expect the cost to be réasonable. It may be that we should settle on a fertiliser which supplies P, K and S and accept that one or more of the nutrients will be oversupplied on some farms in some years.

Carrot or Stick

The issue of legislation to force farmers to adopt 'better' fertiliser practices has been raised and has to be faced.

Farmers, like any other group in the community, do not like the idea of being forced to change established practices - especially to solve somebody else's problem. The carrot is much better than the stick.

Hopefully, we can convince the majority of farmers that it is in their own best financial interests to adopt the new fertilisers being produced. Coastal Super was quite widely used on the Bassendean Sands this year, in spite of the higher cost and reported handling problems.

Until we have settled on a 'best bet' P and S fertiliser for catchment soils, have demonstrated that its use will reduce P run-off while maintaining production and have given farmers the opportunity to use it voluntarily, I don't believe that it would be fair to consider the use of legislation to enforce its adoption. The cost of legislation to enforce the use of soil testing and new fertilisers would be high, both in severely damaging relations with farmers and in the financial cost of collecting and analysing the samples and getting the recommendations back to farmers.

To ensure that the soil samples were collected properly, they would have to be collected by the Government and arrangements made to have them analysed. Even allowing for the fact that an area probably only has to be sampled every 2 or 3 years, there are a lot of farms in the Peel Inlet - Harvey Estuary catchment and only a few months of the year in which the samples can be collected. If farmers collect the samples themselves, there is the risk that the most infertile area on the farm - or on somebody else's farm - will be sampled. A recommendation made on the basis of this type of sample would be meaningless.

I hope that we are a long way off even thinking about the use of legislation.

THE POTENTIAL OF NATURAL AND ARTIFICIAL WETLANDS FOR PHOSPHORUS REMOVAL IN THE HARVEY CATCHMENT. Jane Chambers.

In this study an assessment was made of the potential for using various management options, involving wetland filters, to reduce phosphorus loadings into Harvey Estuary. These included:

(i) fringing agricultural drains with wetland plants;
(ii) the diversion of runoff through existing wetlands;
(iii) the use of artificial wetlands at the outlet of swamps and major drains;
(iv) the use of artificial wetlands at point sources.

The study involved experimental work on phosphorus uptake by aquatic plants and substrates found in the catchment and study of the natural wetlands in the area. Up to 90% reduction in phosphorus was achieved in experimental wetlands, at high input concentrations (20 mg l^{-1}) and low flow rates (2.4 l m^{-2} day^{-1}). However, the use of artificial wetlands along the borders or outlets of drains was not considered feasible, as high rates of water movement into the drainage system (several orders of magnitude greater than the experimental rate) would preclude efficient phosphorus retention by the filter. The use of artifical wetlands at the outlet of certain point sources, e.g. piggeries, is likely to be effective, although further work on design and efficiency of the wetland filter would be required before implementation.

Diversion of agricultural runoff into existing natural wetlands was not recommended as the majority of wetlands in the catchment have higher phosphorus concentrations than the runoff, due to removal of fringing vegetation from swamps in farmland. Overflow from these swamps due to high rainfall during winter, into drainage canals, may provide a signif-cant source of phosphorus to the estuary. The quantity of phosphorus released by swamps, on a catchment basis, is not known, but values of 15 kg over 28 days was recorded for one wetland. There appears to be no practicable way of reducing the amount of phosphorus contributed in this overflowing water, which would be effective in the short term. In the long term, reintroduction of fringing vegetation (including sedges and trees) sited around wetlands and at areas of overflow, may be profitable.

Tacey

PROSPECTS FOR REDUCING PHOSPHATE LOSS AND IMPROVING PRODUCTIVITY ON SANDY FARMLAND USING NEUTRALISED BAUXITE RESIDUE

W.H. Tacey
Alcoa of Australia Limited

ABSTRACT

Retention of phosphate on the farm is a potentially attractive solution to the problem of excessive nutrient loss to the Peel-Harvey Estuary. Neutralised bauxite residue fines have a higher phosphate adsorption capacity than sands.

Residue neutralised with gypsum was mixed with coarse Gavin and Joel sands at between 200 and 4000 t/ha in lysimeter and field experiments. Loss of applied phosphate was 55% on Gavin sand alone but only 4% from sand amended with 1000 t/ha of bauxite residue. The amount of phosphate leached from amended sand is similar to that of clay/loam soils. Amendment of the sandy soils could thus achieve 80% of the required reduction in phosphate loss to Harvey Estuary.

Significant increases in pasture production occur in the first year on amended sands. Improved re-establishment will occur on treated soil because water repellance is lowered. This will avoid the rapid pasture failure normally occurring on sands.

From 7 to 14 years would be required to treat all sandy agricultural soils in the Harvey catchment. Residue supply could commence in 1987. Total costs are dependent on residue application rate. Rates between 200 and 1000t/ha were considered here. Over 14 years, the costs would range from \$3.2 m to \$4.7 m/annum for production and amendment. Transport would cost between \$0.9m and \$4.5m/annum. These costs might reasonably be shared between residue producers, the State and Farmers. Higher productivity would lead to increased returns of \$2.3 m/annum.

During the period of soil amendment 50% of the required reduction in phosphate input to the Estuary could be achieved by a treatment plant designed to mix phosphate rich waters with residue. A capital cost of $16m is estimated with annual operating costs of $2.5m.

Bauxite residue could significantly reduce the inflow of phosphate to Harvey Estuary. This option would be cost effective due in part to the increased productivity of amended dry sands. Neutralisation of the residue could utilise waste gypsum from the superphosphate industry or the strong copperas effluent from the titanium dioxide industry.

Testing at the operational scale will confirm the effectiveness of residue in the field. Resources from both industry and government are required to achieve this.

LAND USE VARIATION IN THE HARVEY ESTUARY CATCHMENT

Findings from a Preliminary Cost Benefit Analysis

D. MORRISON WADA, NOVEMBER, 1983

Assistance from Dr G. Malaczuk and Mr M. Rayner
from Forests Department is gratefully acknowledged

INTRODUCTION

At the present stage of investigation the worthwhileness of pollution control is not questioned; it is implicitly assumed that the cost of environmental damage exceeds the least cost method of pollution control. It follows that the question is not whether to control pollution or not, but which is the best method for the task?

This study focuses on one method of pollution control - changing to non-phosphate exporting land use in the critical Bassendean Sands of the Harvey River catchment. It has only recently commenced: we are in the process of estimating benefits and costs of the present land use and a non-phosphate exporting alternative, forestry. From this the cost of a change in land use is being estimated for comparison with the cost of other pollution control methods. This paper is a summary of preliminary findings from the study.

METHOD

The analytical method adopted for comparison of alternative land uses is standard cost benefit analysis. In view of the widely held misconceptions of non-economists, a brief background description of this method of analysis is warranted.

Cost Benefit Analysis: *Alternative strategies generate different streams of benefits and costs over time. The purpose of cost benefit analysis is to compare these streams. The major conceptual difficulty is in comparing alternatives for which the timing of costs and benefits is very different. This is well illustrated in this case of the comparison between agriculture and forestry: agriculture provides a relatively small but positive income every year, whereas forestry incurs costs in early years but provides a relatively large income in the distant future. All other things being equal, sooner returns are preferable to later returns even after allowing for inflation. For this reason all returns and costs are discounted back to the present and alternatives are compared on the basis of their discounted present value (DPV).*

$$DPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+r)^t}$$

where B_t *is the return generated in year* t

C_t *is the cost incurred in year* t

r *is the rate of discount*

Considerable economic debate centres on selection of an appropriate discount rate (Mishan, 1976). Two related approaches are used in its estimation, the social rate of time preference and the social opportunity cost of capital.[1] *The former is difficult to estimate, requiring measurement*

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1. *The relationship is that in the ideal state of a competitive market economy, the real opportunity cost of capital is equal to the social rate of time preference.*

of Society's willingness to trade off present and future consumption. The latter is simpler to estimate, being based on the notion of what could be earned in an alternative investment. \$1 return in year one is to be preferred to \$1 return in year two because the former will be worth \$(1 + r) in year two (where r is the opportunity cost of capital and thus also an estimate of the appropriate real discount rate.)

It follows that \$1 in year two is worth $\frac{\$1}{(1 + r)}$ *in year one.*

A review of the literature provides support for a real rate of discount in the range 3% to 5% (Gregory and Duncan, 1979; Porter, 1979 and Hastings and Taplin, 1978). However, State Treasury argues for a real discount rate of 7.5% while a U.S. study by Randall (1981) suggests that a rate as low as 2.5% to 3% could be appropriate. Because of the wide range of suggested discount rates, the effect of a number of different rates in the range of 0% to 7% is examined in this study. However, higher creditibility is attached to $r = 3\%$*, 4% and 5%, with the most credible DPV being derived using* $r = 4\%$*.*

Procedure: The study is under way, but far from complete, although it is sufficiently advanced for the presentation of some preliminary results. The following stages of the study have commenced:

1 *Landowner survey. So far only 8 landowners have been surveyed. It is intended to survey 25 landowners which will provide a sample of about 50% of the population. Results from this survey provide data for the estimation of the profitability of present land use and its DPV.*

2 *Data provided by Forests Department is used to estimate the DPV of the most profitable forestry alternative.*

3 *The DPV of farmers converting from agriculture to forestry is derived from 1 and 2.*

4 *The DPV of Government land purchase and Government pine growing is derived from 2.*

5 *The cost of land use change and land use purchase is compared with the cost of other strategies for pollution control.*

RESULTS AND DISCUSSION

The study is far from complete so that precise interpretation of results is not yet warranted. Nevertheless, some findings are already clearly apparent.

1 *Profitability of present land use: there is a widely held view that soils of the Bassendean Association are of low productivity and scarcely profitable in their present use. This view is held by some (a small minority) land holders.*[1] *However, it is simplistic and at best, partly true: within the Bassendean Association there are soils of low and extremely low agricultural productivity. Transition sand and Gavin Sand respectively, but there is also the highly productive Joel sand which is able to sustain profitable agriculture. Because developed land is predominantly Joel (80%) the average developed hectare has a productivity and a profitability closest to Joel*[2].

TABLE 1: Productivity and Profitability of Soils of the Bassendean Association.

	Joel	Transition	Gavin	Weighted Average
Area (% of total)	78.4	8.8	12.7	100
Productivity (DSE/ha/yr)	9	3.6	.9	7.49
Profitability[3] ($/ha/yr)	72.83	22.20	10.21	60.39

2 *Profitability of Farmer Conversion to Forestry: the forestry alternative, a pine plantation, is a considerably less profitable land use than agriculture. This is shown in Table 2 where it can be seen that pines have a higher DPV than agriculture only for discount rates below 1%, by 3% its DPV is only half agriculture's, by 4% (the most credible discount value) it is a quarter and by 6% pines have a negative DPV.*

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1. *At this stage of the survey, one farmer has claimed that Bassendean Association soils are very poor agriculturally, another has not developed the land although he has had it for more than a decade. However, another 6 farmers viewed it as productive land.*

2 *Although profitable, the average project per hectare is almost certainly below the profitability of the region's best dryland soils due to:*

   i *The distance of these blocks from home bases causing less intensive management and the absence of incentive wholemilk production.*

   ii *The effect of Gavin and Transition sands.*

3 *Profit is defined as income above costs where costs include labour, plant replacement and repairs and maintenance in addition to operating costs.*

2 *continued*

The poorer performance of pines at higher discount rates simply reflects that pines incur costs from the first year but do not provide any income until well into the future (years 11, 19 and 45) whereas the present agricultural enterprise generates income above costs in each year. However, the generally poor performances of pines over all discount rates is a function of the nature of Bassendean Association soils in particular:

i The necessity of using a species of low productivity, Pinus Pinaster, on these soils.

ii The cautions limit set on phosphate application for these soils.[1]

Table 2 shows that the DPV of a farmer converting from agriculture to pines is negative for all discount rates greater than or equal to 1. At a discount rate of 4% (assumed to be the most credible rate) the DPV of conversion to pines is $946.79/ha or an annual equivalent of $45.70/ha/yr. It follows that in order to compensate a farmer for converting to pines or to offer him sufficient incentive to change, he would have to be paid at least $45.70/ha/yr.

TABLE 2: Discounted Present Values for Present and Alternative Land Uses.

Discount Factor	Agricultural Land Use	Private Pines Plantation	Conversion Agriculture to Pines	Annual Payment for Conversion Equivalent to DPV
0	2717.55	3362.22	644.67	
1	2179.54	2114.09	-65.45	
2	1769.73	1230.20	-539.53	
3	1480.40	676.87	-803.53	
4	1251.22	304.43	-946.79	-45.70
5	1073.25	63.38	-1009.28	-56.82
6	901.56	-100.72	-1002.28	-56.82
7	821.55	-214.62	-1036.17	

1. The issue of the appropriate limit has not been resolved by Forests Department researchers. Some claim that because of their efficient utilisation of phosphate, pines would not allow phosphate export even if it were put on at a much higher rate. The issue is important because of the sensitivity of pine yield to phosphate. Completion of this study will include investigation of a pine option with a higher rate of phosphate.

2 continued

Although on a whole block basis farmers would lose substantially from converting to pines, disaggregation shows that farmers would benefit from this change on their Gavin sands and lose little in converting Transition sands. The DPV (at a 4% discount rate) of changing the land use is $92.89/ha for the Gavin sands (an annual equivalent of $4.48/ha) and - $155.53/ha (an annual equivalent of -$7.51/ha for Transition sands. The reason for this is simply that, in contrast to agriculture, pines are as productive on Gavin and Transition sands as they are on the Joel sands.

This finding implies that it would be easy to demonstrate to farmers profitability of replacing agriculture with pines on the Gavin sands and that a relatively small incentive would be required for farmers to change over on their Transition sands. However, it is unlikely to be a very effective pollution control measure: only a small part of phosphate export from the Bassendean Association is from Gavin sands, survey results showing that they are fertilised at a low rate and they are a small part of the total area. Moreover, it may prove impracticable to run small pine plantations confined to the relatively small area of Gavin sands.

3 *Profitability of Land Use Change through Government Purchase: the option of Government run pine plantations has a low DPV which diminishes rapidly with increases in the discount rate (Table 5). Reasons for this are the same as for private pine plantations plus the additional expense of Government operation of pine plantations. (Government Pine plantations involve considerably higher overhead costs). With the cost of land purchase included in the DPV calculation, it can be seen that (when considered in isolation) Government purchase of land and planting to pines is an unprofitable use of the Government's resources. The pines would do very little to recoup the expense of land purchase. For discount rates of 4% and above, results in Table 3 show surprisingly, that the Government would be better off purchasing the land and doing nothing with it.*

TABLE 3 Discounted Present Values for Government Pine Plantations.

Discount Factor	Private Pine Plantation	Government Pine Plantation	Government Pine Plantation Including Land Purchase	Government Purchase only
0	3362.22	2375.55	1275.55	-1100
1	2114.09	1438.02	338.02	-1100
2	1230.20	680.47	-419.53	-1100
3	676.87	174.36	-825.64	-1100
4	304.43	-160.26	-1260.26	-1100
5	63.38	-365.89	-1465.89	-1100
6	-100.72	-506.82	-1602.82	-1100
7	-214.62	-593.20	-1693.20	-1100

4 *Change in Land Use Versus other Pollution Control Strategies:* For policy purposes the important issue is not the expense of changing land use per se, but how this compares with other strategies for pollution control. The comparison shown in Table 4, puts the cost of land use change in perspective although it should be interpreted in the light of the following deficiencies:

i It is not yet known exactly what pollution control effect the various strategies would have, however, it is unlikely that the effect of changing land use would be exactly the same as for engineering strategies.

ii These strategies are not simply competitive, the best practice may be a combination of strategies.

iii Engineering strategies involve additional environmental disruption and this has not been included as a cost.

iv Some costs are only rough approximations.

Table 4 shows that an effective fertiliser modification programme is considerably less costly[1] than options involving land use change or land purchase, but the latter are in turn considerably less expensive than those involving an engineering solution. In spite of deficiencies in this comparison, an effective fertiliser modification programme would obviously be at least part of the best strategy for pollution control. If this strategy could not be implemented then changing land use may be the next best option because it is far less expensive than engineering strategies. Offering farmers sufficient financial incentives to change their land use is less expense than changing land use through Government land purchase. However continued private ownership would mean less certainty of pollution control.

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1. It has been assumed to cost nothing although it may in fact prove profitable.

TABLE 4 Cost Comparison of Various Strategies for Pollution Control.

	Option 1 Fertiliser Modification	Option 2 Farmer Conversion	Option 3 Government Conversion	Option 4 Land Purchase	Option 5 Barrage	Option 6 Channel
DPV/ha (4% discount)	negligible	\$947	\$1260.	\$1100	-	-
DPV Total	negligible	\$9.1m[1]	\$11.6m[1]	\$10.3m[1]	\$53m to \$11m	\$17m to \$21m

1. *Total land is defined as all privately owned land in the Bassendean Association of the Harvey River catchment. It is an area of 99km^2 of which 80 km^2 is cleared and another 19 km^2 is undeveloped. For each of the three options involving a change in land use it is assumed that the Government purchases all undeveloped land at \$800/ha while developed land is purchased at \$1100/ha in options 3 and 4.*

SUMMARY AND CONCLUSIONS

1 *Agriculture on the cleared land of the Bassendean Association is reasonably profitable returning a profit of around $60/ha/yr although this ranges widely from about $10/ha/yr on the Gavin sands to $73/ha/yr on the Joel sands.*

2 *Pine production, the most profitable forestry alternative, has a considerably lower DPV than agriculture because:*

i *The discounting procedure severely penalises the delayed income from forestry.*

ii *A low productivity species (Pinus Pinaster) has to be used on Bassendean Association soils.*

iii *A cautious limit placed on phosphate application causes low yields corresponding to sub-optimal rates of phosphate.*

3 *Except on the Gavin sands, farmers cannot be expected to convert from agriculture to forestry without a substantial financial incentive. It follows from the DPV of -$947/ha that farmers would require an initial payment of $947/per cleared hectare or an equivalent annual payment of $46/per cleared hectare to break even in converting to pines over all Bassendean soils. The conversion would be slightly profitable on Gavin soils although by itself this is likely to contribute little to pollution control.*

4 *If the Government were to purchase the land from farmers it could not recoup the cost of purchase through pine production. Furthermore, if discount rates of 4% or above are accepted, the Government is better off doing nothing with the land.*

5 *Without information on the effectiveness of different strategies, no conclusion can be drawn as to which strategy of pollution control is best. Nevertheless, comparison of costs puts the strategy of alternative land use in perspective with other strategies: pine production or Government purchase of soils of the Bassendean Association is a relatively inexpensive method of control of pollution ($9.1m to $11.6m) when compared with engineering options such as a barrage at Herron Ford ($53m to $110m) or a channel from Dawesville ($17m to $21m). However, it is considerably more expensive than a fertiliser modification programme (negligible cost).*

NEED FOR FURTHER WORK

1 *Refinement of cost benefit findings in the light of further information collected on the economics of changing land use.*

2 *Expansion of the cost benefit study to include:*

i *Sensitivity analysis, looking at less cautious assumptions about pine production.*

ii *Investigation of other alternative land use options.*

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Peel Harvey Estuarine System

Management Symposium

Drainage Diversion Options

Author: D. Vodanovic (Public Works Department)

ABSTRACT

The drainage diversion options investigated principally involved techniques to divert the phosphorus rich waters coming off the Harvey and Waroona Irrigation Areas from the Harvey Estuary. The original sizing of the engineering components of the diversion options was based on the flow data for the winter of 1982 alone in the belief that it would be representative of the size of the works required. When over-spill criteria was considered that did not permit spill greater than 100 x 10^6 m^3 more frequently than 1 in 5 years, it was necessary to increase the size of the diversion system. The least cost system with an estimated total cost of $52 million is described. The implications for management of adopting the concept are outlined. The least cost option is a 6.5 metre high barrage with a low lift pumping capacity through a combination of pipes and tunnels to the ocean.

Phytoplankton, algae and nutrients

R.J. Lukatelich

Summary

Macroalgae

The massive blooms of Cladophora which first became obvious in the mid -60's were the first symptom of the eutrophication of the Peel-Harvey system. The Peel-Harvey study was initiated to investigate the cause of these blooms. Phase - 1 of the Peel-Harvey study concluded that the macroalgal blooms were the result of increased nutrient loading to the system. With the appearance of Nodularia in 1978 the main emphasis of Phase- 2 studies has been to reduce the blue-green algal problem in the Harvey Estuary.

The macroalgae still present an ongoing management problem in Peel Inlet, although biomass has dropped dramatically since early 1979. Two possible reasons for the decline in macroalgal biomass are below average riverflow since the mid-70's and increased turbidity due to the increase in phytoplankton since 1978, both in terms of biomass and the duration of the blooms.

The ability of the macroalgae to increase rapidly has been seen in recent years with blooms of Chaetomorpha in 1980 and Ulva sp in 1983 from trace amounts in previous years. A reduction in turbidity may lead to a rapid increase in macroalgal biomass. The macroalgae need to be considered in any overall management strategy for the Peel-Harvey system.

Phytoplankton

Diatom blooms occur most winters following river-flow. The diatom blooms are replaced by massive Nodularia blooms in spring, and in later years progressively greater diatom blooms have followed the collapse of the Nodularia blooms. In 1978 there was no diatom bloom following the Nodularia bloom. In 1980 there was a short-lived bloom, a somewhat larger bloom in 1982, and this year there has been a persistent bloom following the collapse of the Nodularia bloom up until the onset of riverflow in late June.

In 1982 and again this year, following the collapse of the Nodularia blooms there have also been blooms of a benthic species of Oscillatoria. The Oscillatoria bloom was much worse this year than the previous year.

These long term data suggest that the phosphorus store in the sediments and the recycling of phosphorus has progressively increased since 1978.

The available data suggest that the development of the winter diatom blooms, and the following Nodularia bloom, depends upon phosphorus from the current year's riverine input rather than from phosphorus release from the sediment phosphorus store.

The magnitude of the Nodularia bloom is limited by phosphorus, but in winter, the period of major phosphorus input to the system, its growth is limited by temperature.

Nodularia, therefore, relies on recycled phosphorus from the current year's riverine input. The winter diatom blooms which immediately follow river input offer a mechanism by which phosphorus is trapped, sediments out, and becomes available for *Nodularia* growth when conditions are more favourable. The sediment supply of available phosphorus at the present time is not large enough to support a *Nodularia* bloom unless it is supplemented and enhanced by the collapse of the winter diatom bloom. However this may not continue to be the case in the future if the sediment store and supply of available phosphorus continues to increase.

Phosphorus retention in Harvey Estuary

A study was carried out in July-August this year to determine the major mechanisms by which phosphorus is trapped and the proportion that is trapped in the Harvey Estuary. To date only a very preliminary analysis of the data has been carried out.

The results clearly show that the phytoplankton (diatoms and dinoflagellates) were the major mechanism by which phosphorus was trapped in the Harvey Estuary during the study.

A preliminary phosphate phosphorus budget has shown that almost all of the phosphate phosphorus (the major form in which phosphorus enters the estuary via riverflow) which entered during the study was trapped in the Harvey Estuary. Similar data collected in 1980 show a different picture.

IN-ESTUARY STUDIES AND THEIR RELEVANCE TO MANAGEMENT: THE SEDIMENTS AND THE MOVEMENT OF PHOSPHORUS.

by Denis Kidby, John Gabrielson, Christina Huse.

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IN-ESTUARY STUDIES AND THEIR RELEVANCE TO MANAGEMENT: THE SEDIMENTS AND THE MOVEMENT OF PHOSPHORUS

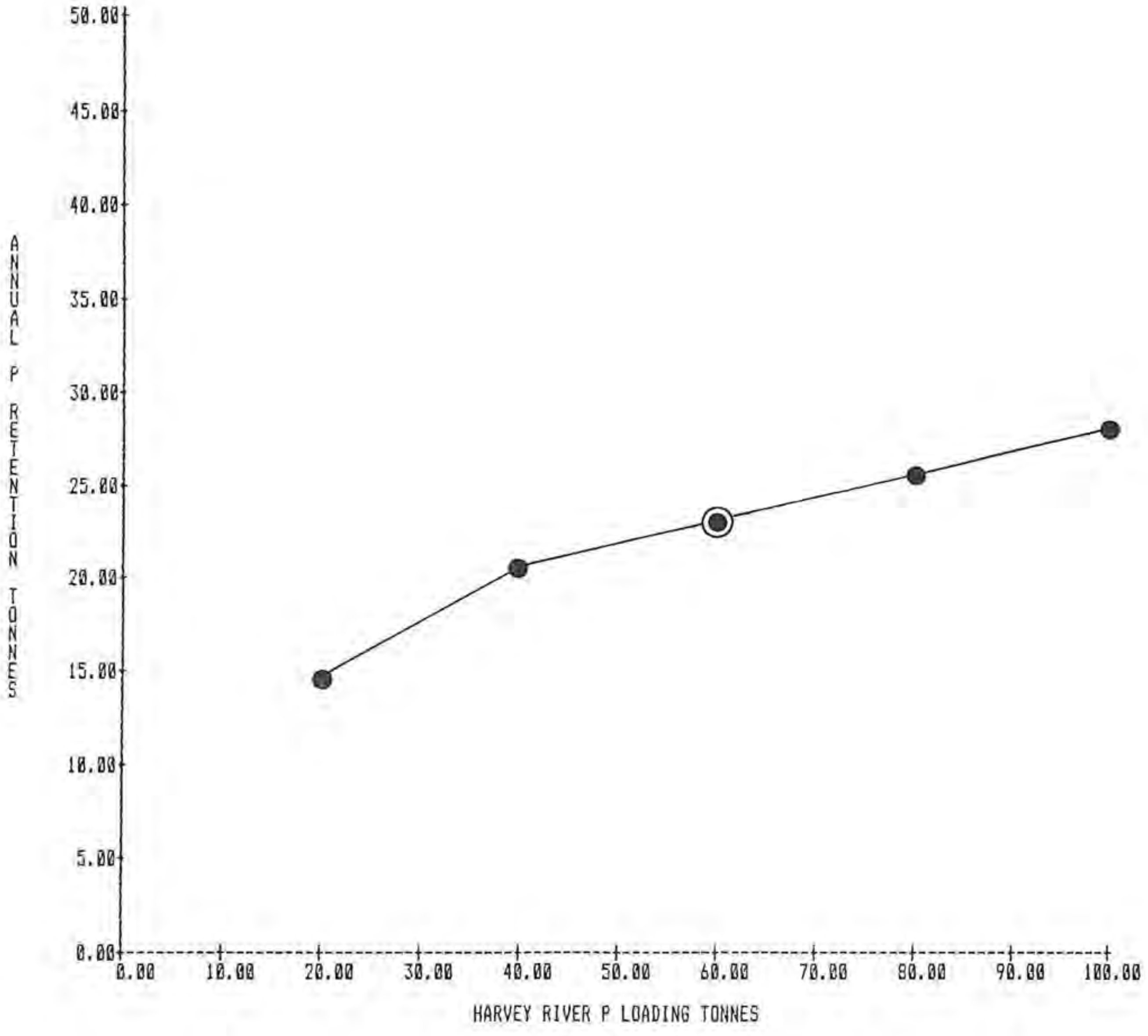
By Denis Kidby, John Gabrielson, and Christina Huse

SUMMARY: The movement of phosphorus is discussed in terms of transfer between the sediments and the water column. An analysis of mechanisms is performed in terms of the forms of phosphorus present, primary and secondary mechanisms of transfer either to or from the sediments, and the conditions which are conducive to the various transfer mechanisms.

The Gabrielson model for phosphorus transfer from the Peel/Harvey system is explained in terms of its parameters and the application of the model. The model examines the influence of riverine phosphorus loading and variation in flushing rates on the net movement of phosphorus to the ocean. The model indicates the extent to which the net transfer of phosphorus is driven by biological assimilation. The model predictions are relatable to recent studies on sediment phosphorus depletion by biological assimilation.

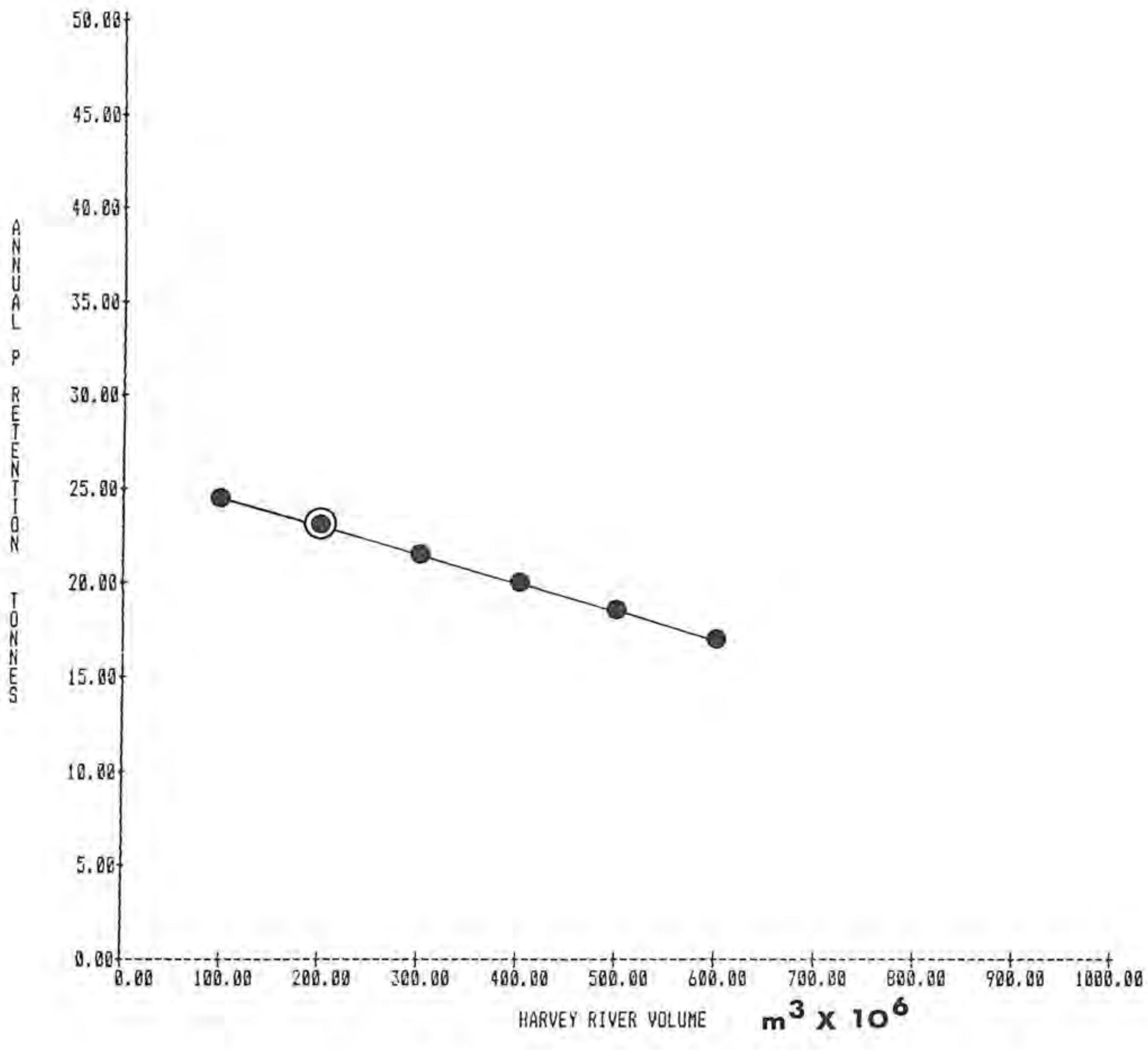
2

HARVEY RIVER P LOADING VS. P RETENTION



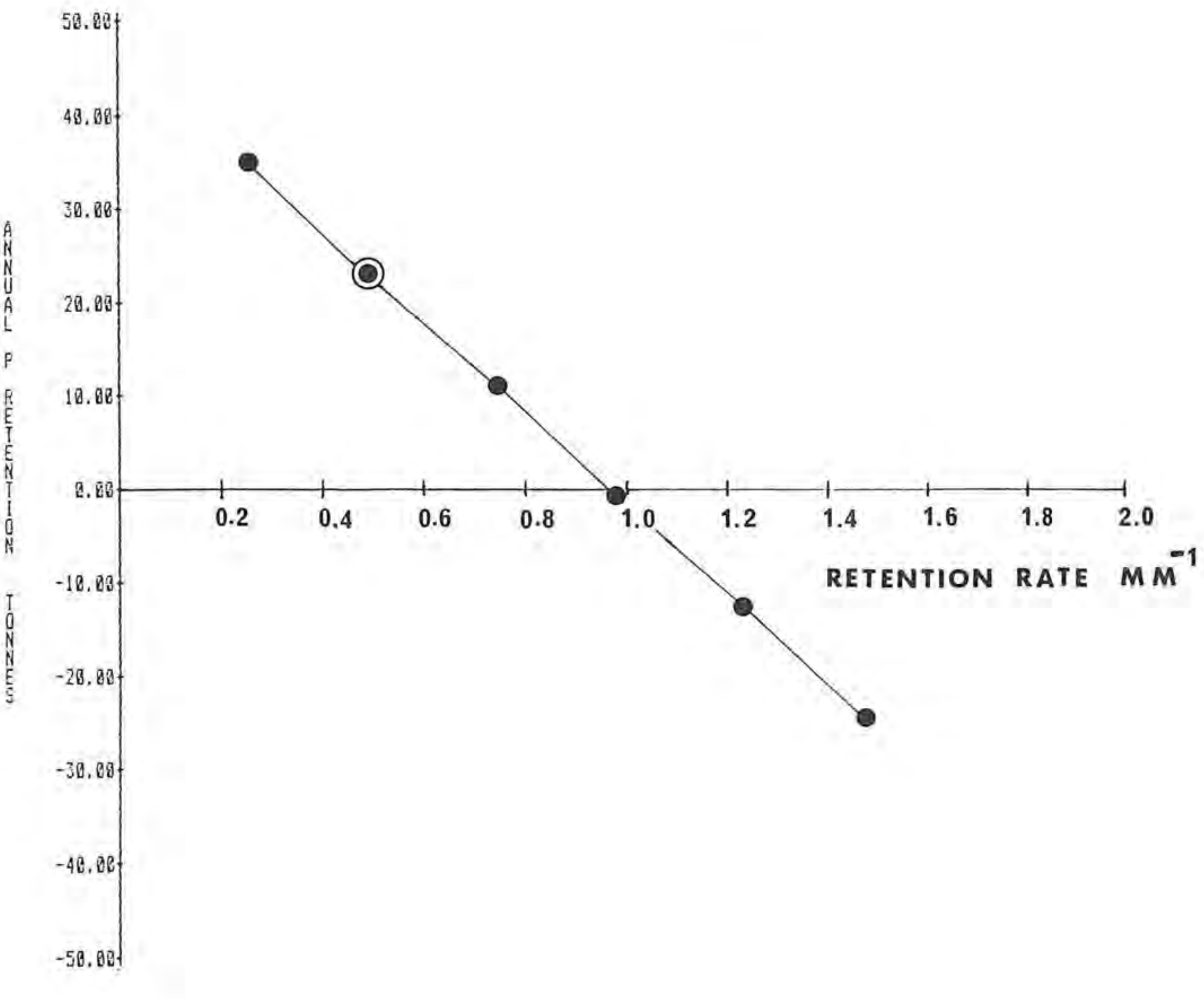
X 100 80 60 40 20
Y 28.21 25.66 23.1 20.55 14.26

HARVEY RIVER VOLUME VS. P RETENTION

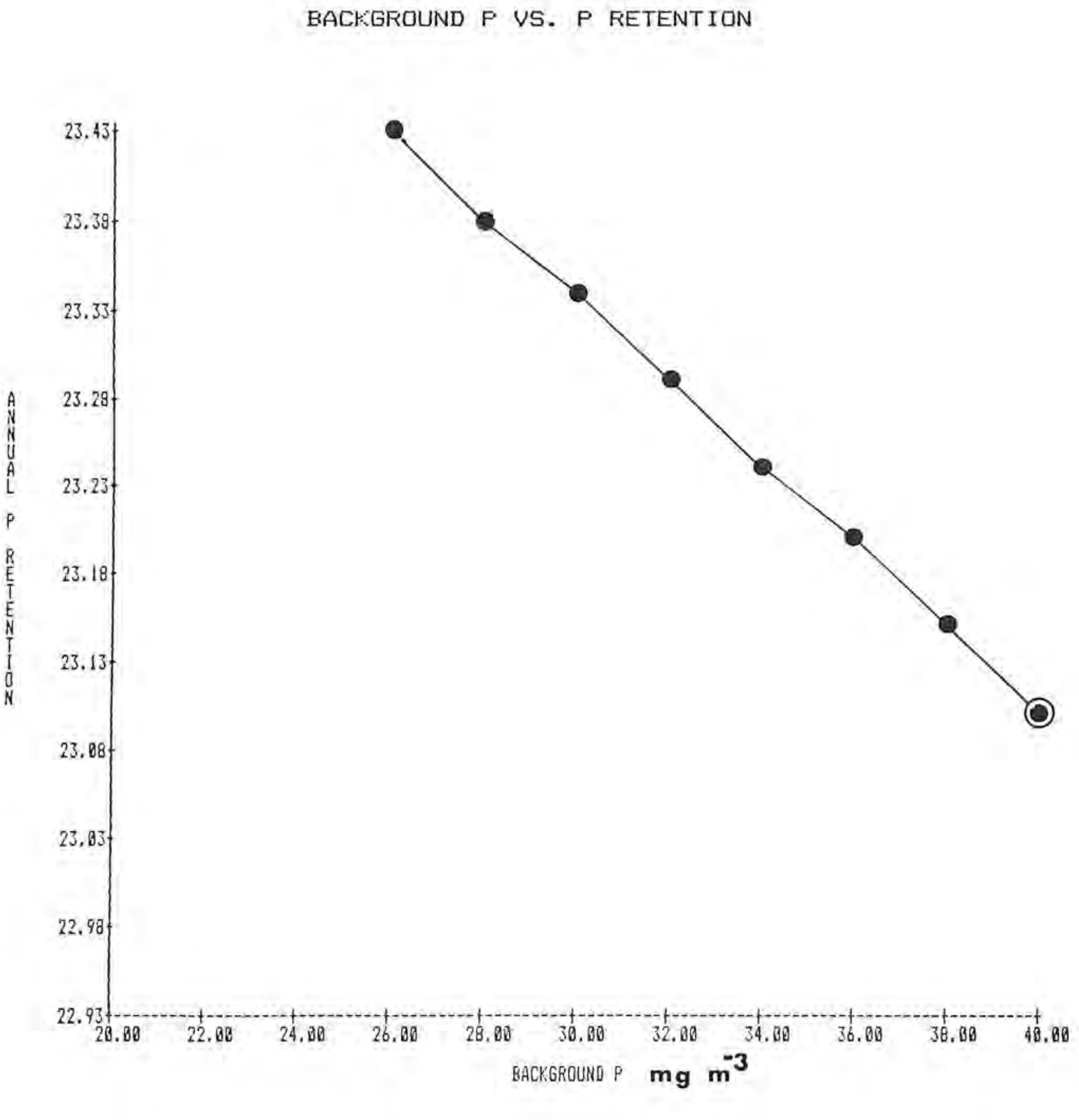


X 600 500 400 300 200 100
Y 17.04 18.56 20.07 21.59 23.1 24.62

RETENTION RATE VS. P RETENTION

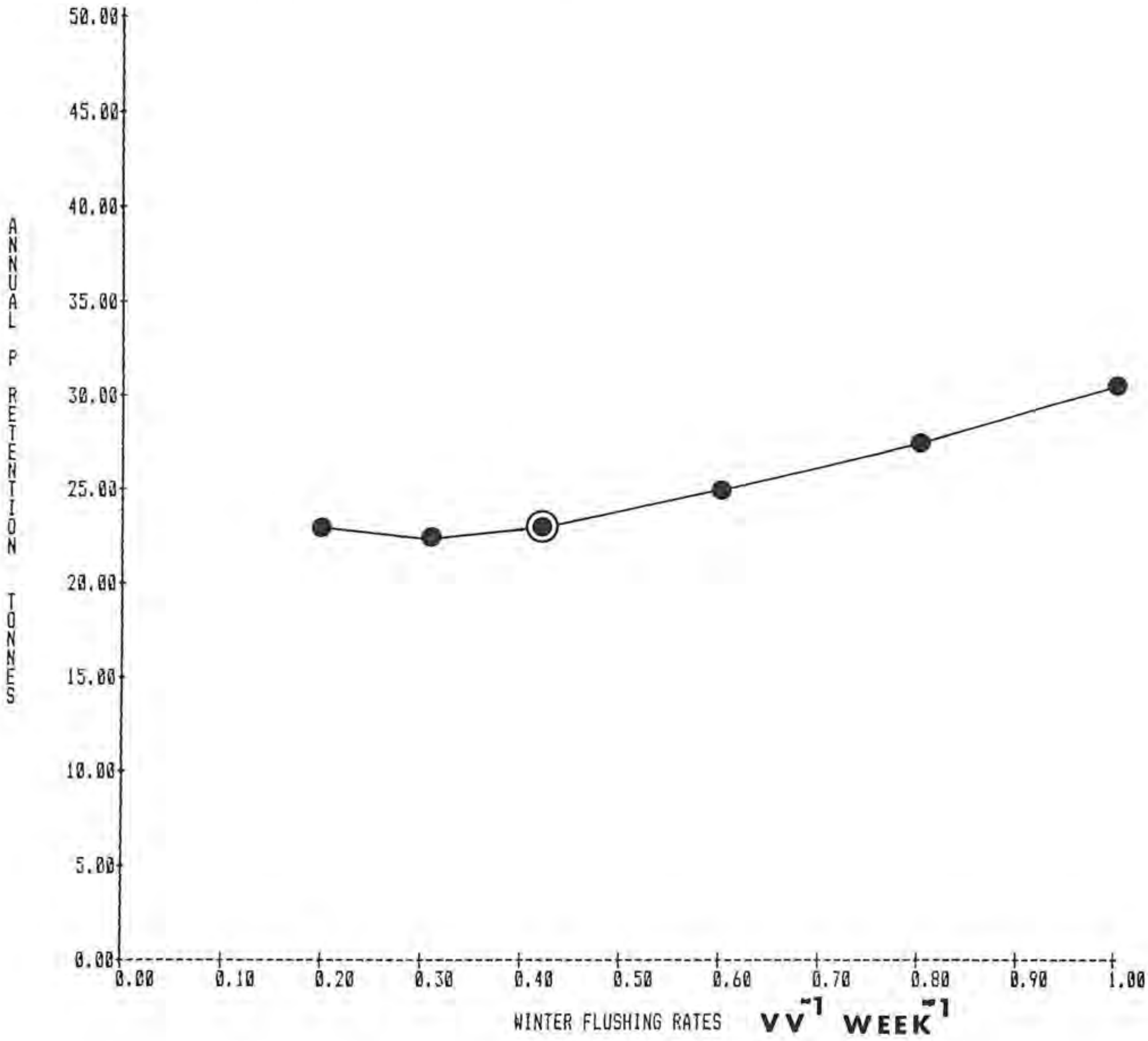


X 1.5 1.25 1 .75 .5 .25
Y-24.6 -12.68 -.75 11.18 23.1 35.03



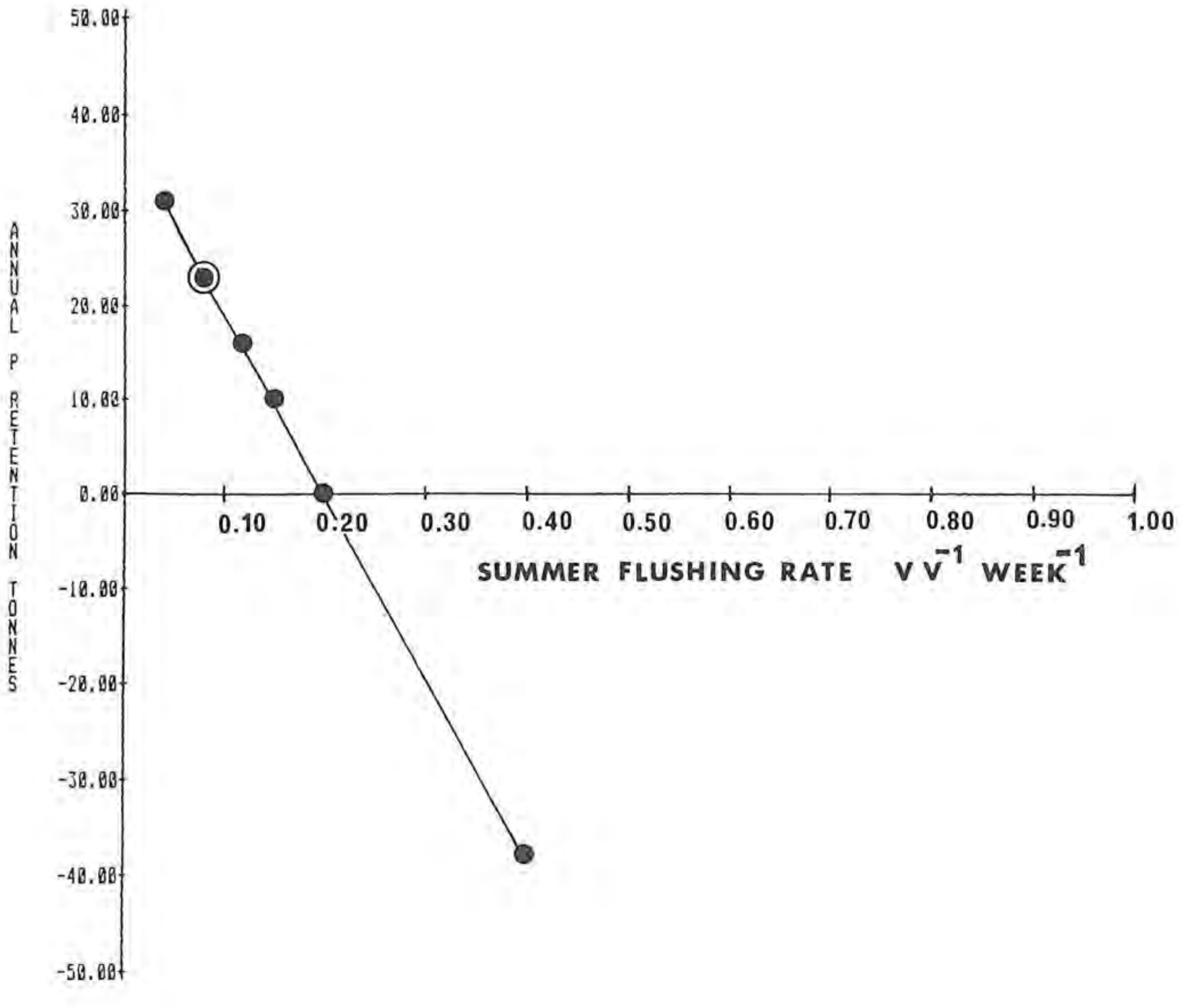
X 40 38 36 34 32 30 28 26
Y 23.1 23.15 23.2 23.24 23.29 23.34 23.38 23.43

WINTER FLUSHING RATE VS. P RETENTION



X 1 .8 .6 .42 .31 .2
Y 30.62 27.65 24.98 23.1 22.52 22.96

SUMMER FLUSHING RATE VS. P RETENTION



X .4 .2 .12 .15 .08 .04
Y -37.62 .33 15.51 9.82 23.1 30.69

Huber

CYANOBACTERIA

A.L. Huber, Dept. of Soil Science and Plant Nutrition, University of Western Ausralia.

Summary

The aspects of cyanobacteria, and in particular Nodularia, which are of most significance in assessing the management options for the Peel-Harvey Estuary will be discussed.

There are three stages in the Nodularia life cycle which must be considered separately with respect to possible control mechanisms: 1. bloom initiation involving akinete germination, 2. the bloom, including initial rapid growth and stationary phases, and 3. bloom decline.

The effects of light, temperature, salinity, phosphorus, nitrogen and iron on akinete germination have been determined. It is considered that massive germination of akinetes in the surface sediments requires a significant exposure to light, $>16^{o}C$, <20 ppt salinity, > 10 ug PO_4-P/1, and <500 ug NH_4-N/1. Within these bounds, the timing and distribution of Nodularia blooms has been very consistent (Tables 1,2).

Once a Nodularia bloom is established, it remains at a more or less constant standing biomass. However, in situ studies indicate that Nodularia maintains a growth rate in the estuary which is similar to that obtained in P-enriched laboratory cultures (Fig 1). The biomass losses from the bloom, and the minimum amount of phosphorus which must be given up by the sediments in order to maintain the standing biomass can be estimated. During a bloom, the sediments are continually being depleted of phosphorus, with the most rapid depletion occurring early in the bloom (Fig 2). Recycled phosphorus becomes more significant as the bloom progresses. The current phosphorus status of the Harvey Estuary sediments appear to be such that they could support blooms without any further phosphorus inputs. Furthermore, the condition of the Peel Inlet with respect to phytoplankton also appears to have deteriorated in the recent years (Figs.3,4).

The factors which could affect the decline of Nodularia blooms are salinity, light, temperature, carbon dioxide, and pathogens, grazing, or competition. In the field, the declines of blooms have been very well correlated with salinities at or about 30%. Under laboratory conditions, however, Nodularia grows above 30%, albeit at a reduced rate. It is likely that high salinities, in combination with high light and temperatures, and CO_2 depletion in surface "scums" leads to the rapid declines observed. At 30 ppt salinity, no akinete germination can occur to "re-seed" the bloom.

The implications of the above findings for management will be discussed.

TABLE 1: Conditions for germination of akinetes.

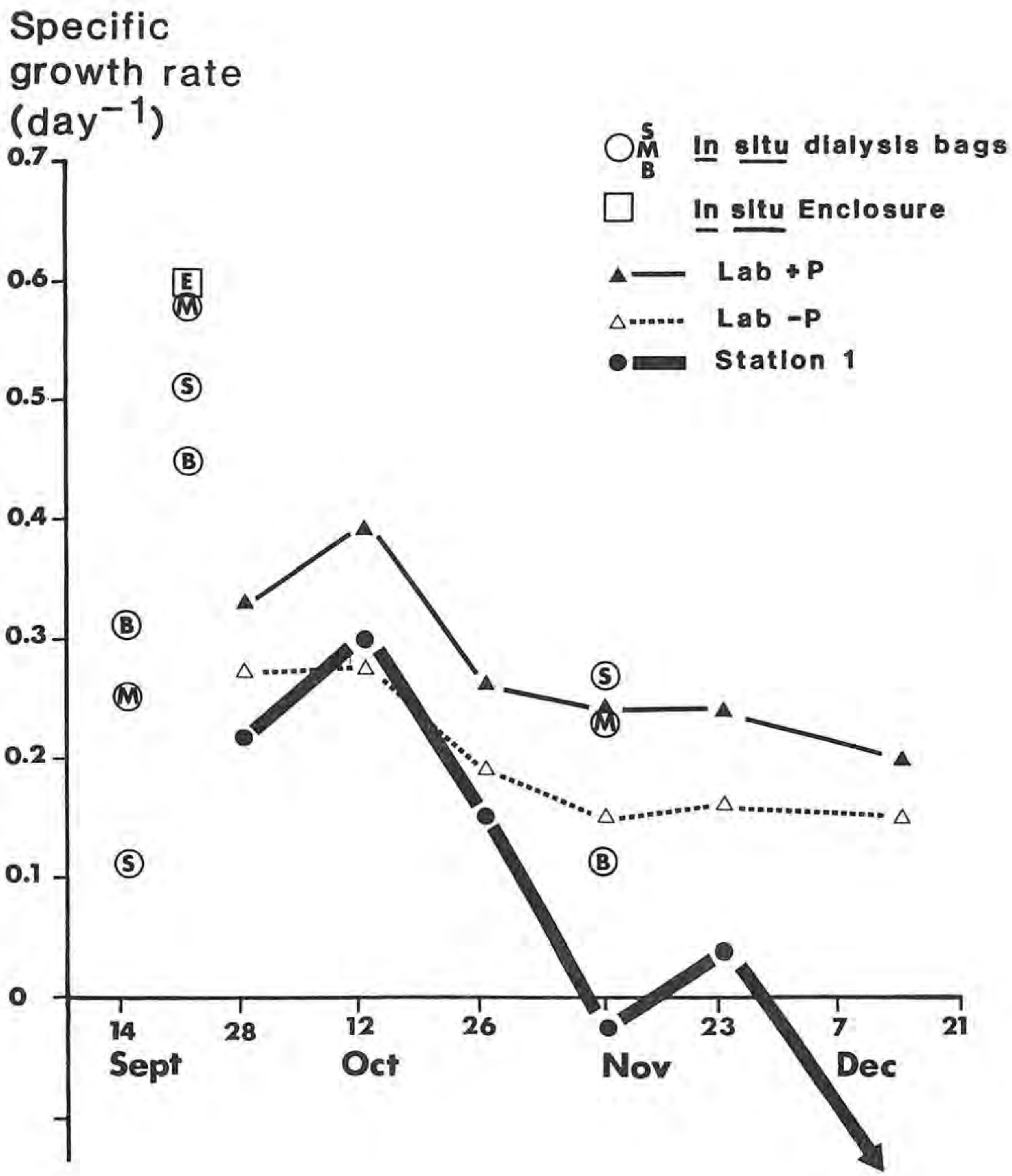
Parameter	No Germination	Maximum Germination
Orthophosphate-P (uM)	0	1 (31mg/l)
Nitrate-N (uM)	–	0->720 (10mg/l)
Ammonia-N (uM)	>70 (980ug/l)	<40 (560ug/l)
Iron (uM)	?	>30 (5mg/l)
Temperature (°C)	12-15	20-25
Light (uE/m²/sec)	0	>9
Light exposure time (h)	<12	>50

TABLE 2: Dates when bottom water conditions were appropriate for akinete germination, 1978-1983.

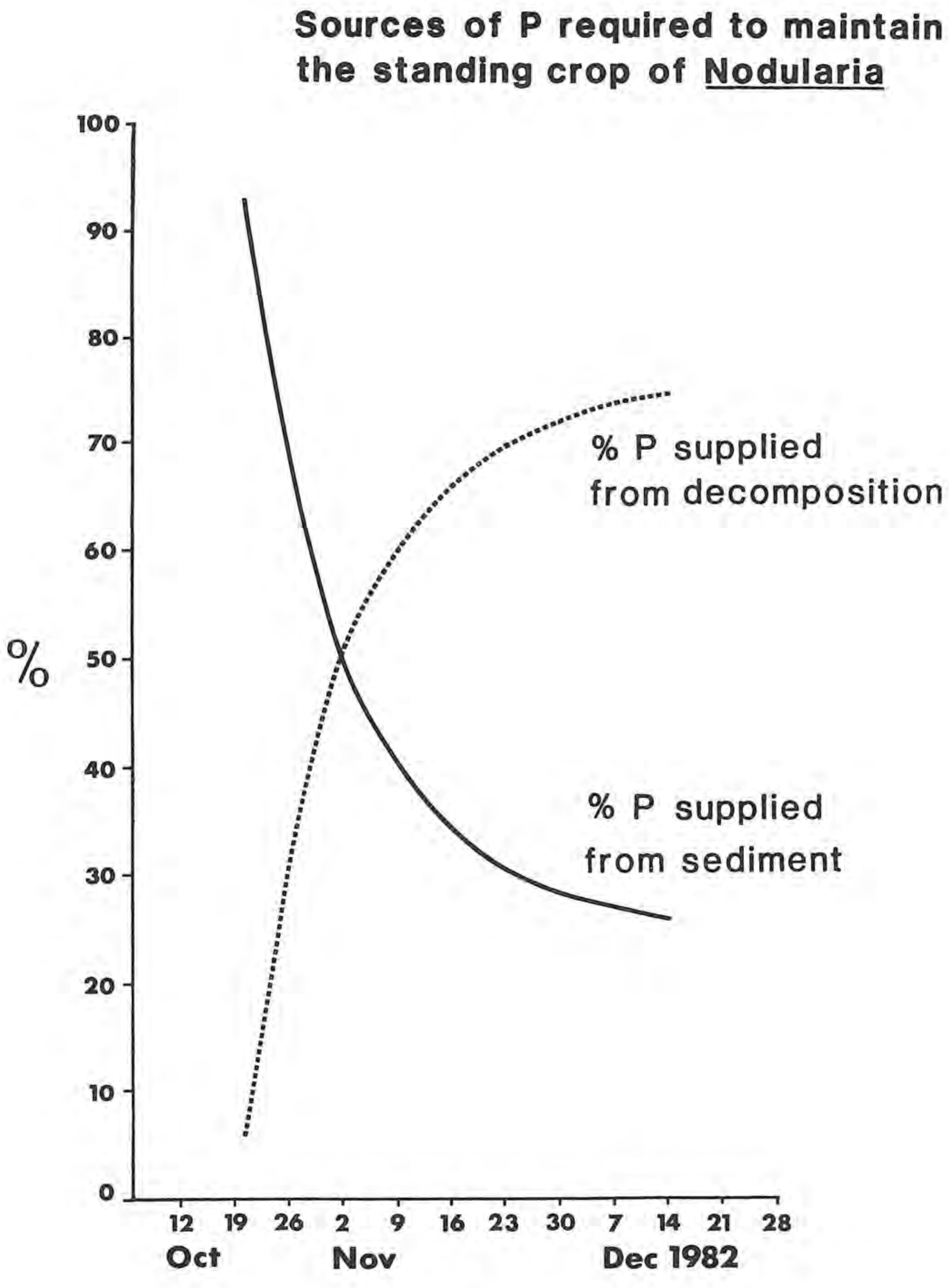
Station	31	1	58	2	7	4
Year						
1978	ND	O10,24	ND	O10	–	O10,24
1979	S25	–	–	–	–	–
1980	O10 – N1	S23 O22	–	–	–	–
1981	A25 S15-O27 F2-9/82	A25 S22 O13-27 F2,9/82	A25 S22 F9/82	S22- O13	A25	A25 S15
1982	A31 S21-12 N16-23	A31 S21-05 O26-N2	A17,31 S28 O12	S21-28	S21-28	A31 S28
1983	S13-27 O4-11	S13-27 O4	S13-27 O4-11	S20-27 O4	S20-27	S13-27 O1

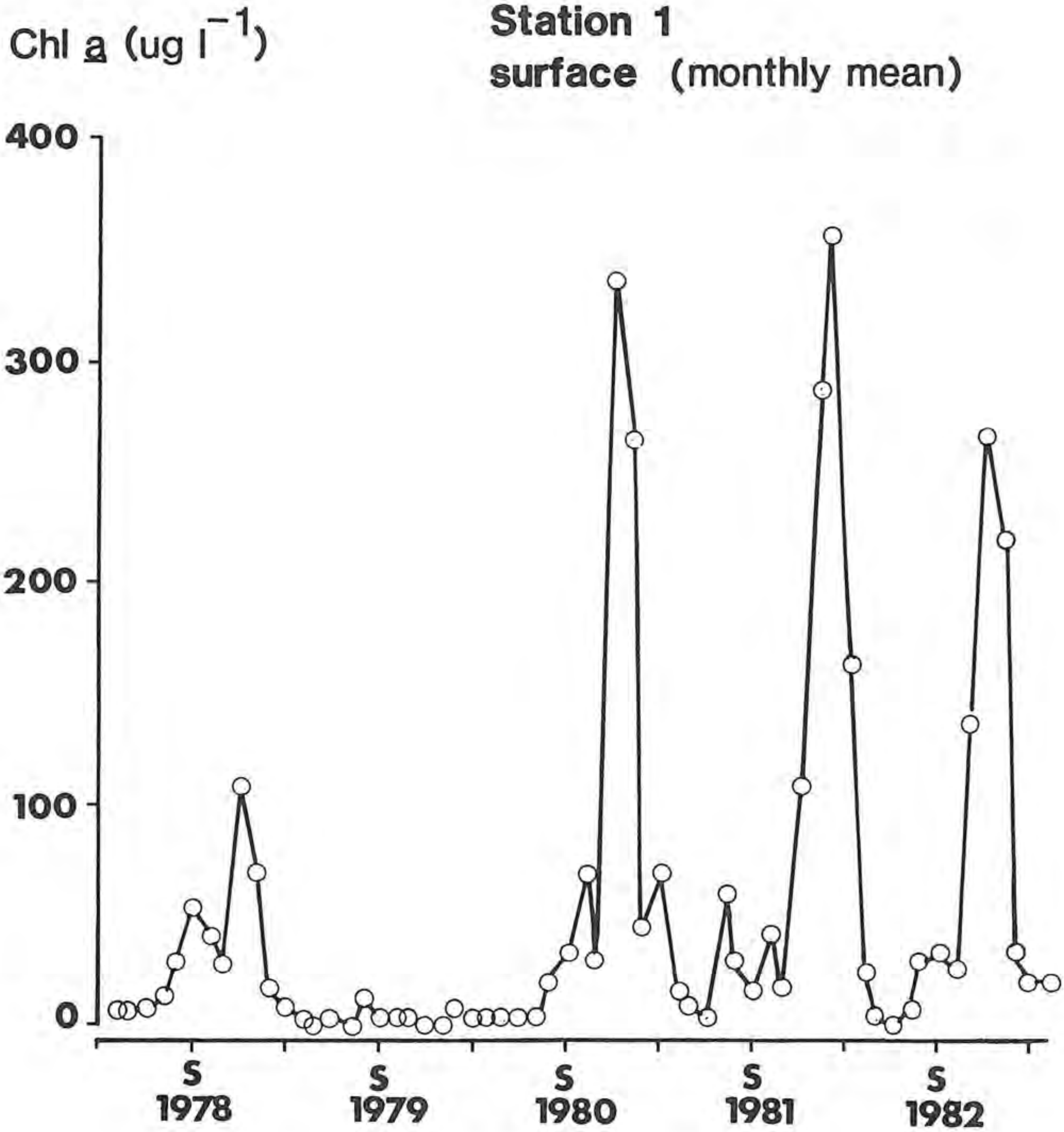
A=August S=September O=October N=November F=February

*Blooms reported: 15/11/78, 23,29/10/80, 27/10/81, 1,7/09/82, 4/10/82.

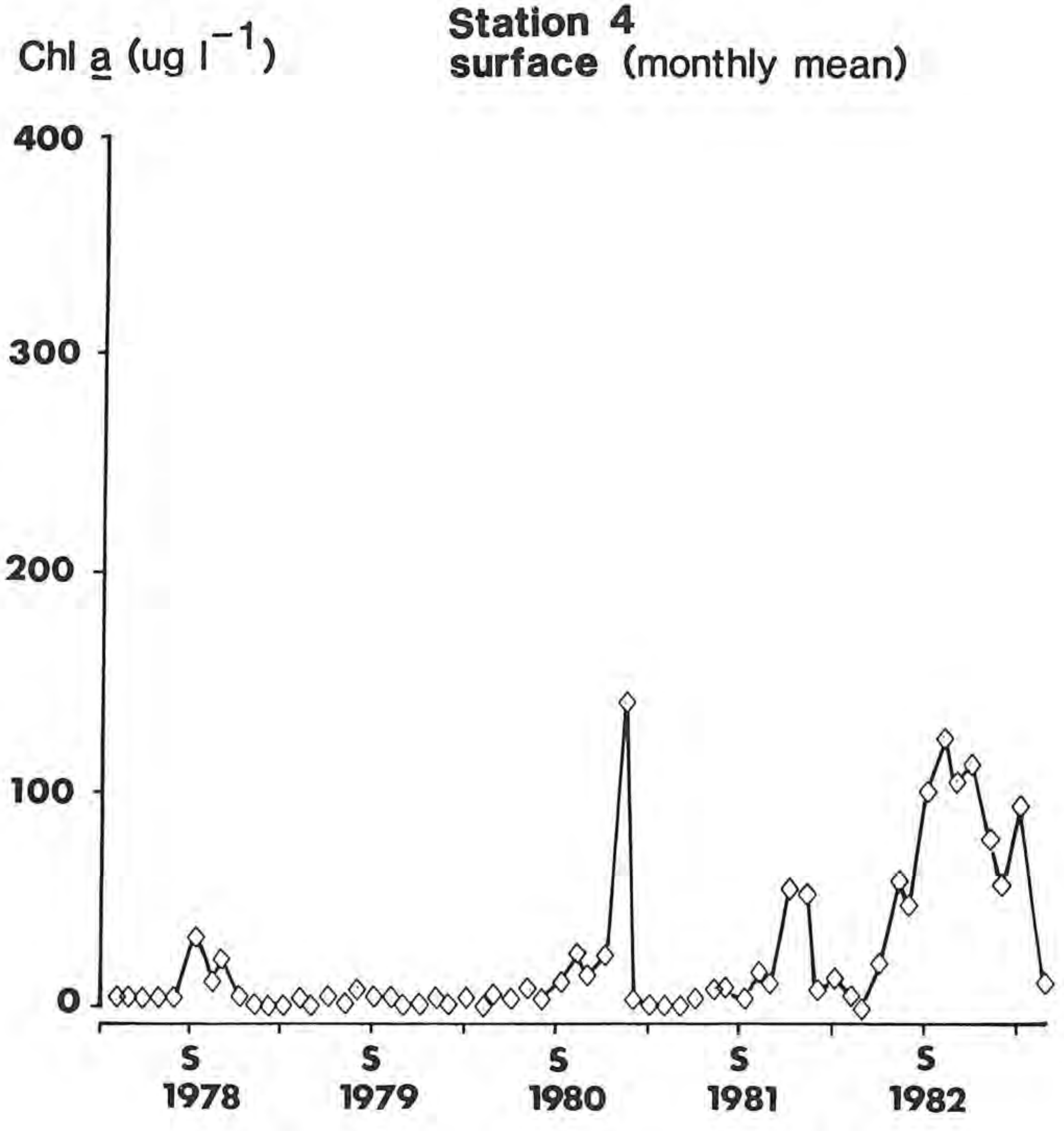


Specific growth rate (day^{-1})
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
S M B In situ dialysis bags
In situ Enclosure
Lab +P
Lab -P
Station 1
E
M
S
B
14 Sept
28
12 Oct
26
Nov
23
7 Dec
21


Sources of P required to maintain the standing crop of Nodularia
%
100
90
80
70
60
50
40
30
20
10
0
12
19
26
2
9
16
23
30
7
14
21
28
Oct
Nov
Dec 1982
% P supplied from decomposition
% P supplied from sediment



Data from Waterways Commission and Botany Department, U. of W.A.



Data from Waterways Commission and Botany Department, U. of W.A.

Potter

Fish and the Fishery

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Introduction

The initial work on the fish fauna and the blue manna crab in the Peel-Harvey estuarine system, which commenced in April 1979, was aimed at elucidating the patterns of distribution, abundance and growth of the different species (Potter *et al.*, 1983a, in press). At the same time, the data on the commercial fish catches for the last 40 years were subjected to detailed analysis to ascertain whether any changes in catch during the 1970s could be related to the increased growth of macroalgae (Lenanton *et al.*, in press). More recent work has focussed on determining whether *Nodularia* has an effect on the fish fauna either through inducing changes in behaviour or by causing mortality.

The Fish Fauna

Beach seines, gill nets and otter trawls were used during 1979-81 to sample extensively the fish fauna of the Peel-Harvey estuarine system. Approximately 145,000 individuals were caught, representing 29 families and 55 species. The Clupeidae, Teraponidae, Mugilidae, Apogonidae, Atherinidae and Gerreidae were the dominant families, each contributing more than 8% to the total catch (total 86.2%). Seasonal catch data and length-frequency distributions were used to help clarify the way in which the estuary was utilised by fish. Nine of the fifteen most abundant fish species were marine species which entered the estuary for variable periods, while the other six were represented by populations in which the individuals were capable of passing through the whole of their life cycle within the estuary. In order of abundance, the nine marine species were the sandy sprat or whitebait (*Hyperlophus vittatus*), six-lined trumpeter (*Pelates sexlineatus*), yellow-eye mullet (*Aldrichetta forsteri*), sea mullet (*Mugil cephalus*), common blowfish (*Torquigener pleurogramma*), long-finned goby (*Favonigobius lateralis*), Ogilby's hardyhead (Pranesus ogilbyi), devil fish (Gymnapistes marmoratus) and western sand whiting (Sillago schomburgkii), while the six species with estuarine populations were the gobbleguts (Apogon rueppellii), elongate hardyhead (Atherinosoma elongata), Wallace's hardyhead (Atherinosoma wallacei), cobbler (Cnidoglanis macrocephalus), Perth herring (Nematalosa vlaminghi) and yellow-tailed trumpeter (Amniataba caudavittatus). The extent and seasonality of the distribution of the species within the estuary and associated river systems varied considerably. Our data also showed that marine species were represented predominantly by individuals in their first or second year of life and that in general fish tended to move further away from the shallow banks near the shore with increasing age and size. Comparisons of the fish fauna of the Peel-Harvey were made with those of Cockburn Sound and the estuary of the Swan-Avon in Western Australia and with Botany Bay in eastern Australia. These comparisons showed that the incidence of large piscivorous fish was lowest in the Peel-Harvey system.

The blue manna crab

Various aspects of the biology of the blue manna crab, Portunus pelagicus, were investigated using samples collected regularly by beach seine, gill net and otter trawl. Whereas crabs were widely dispersed throughout Peel Inlet, Harvey Estuary and the saline regions of tributary rivers during the summer and autumn, they were found mainly near the estuary mouth in the winter and spring. Since our data suggest that P. pelagicus prefers salinities of 30-40‰, the above changes in distribution are apparently related to the marked seasonal variation in salinity which results from the very seasonal pattern of rainfall. The number of ovigerous crabs in the estuary were greatest in January and February. The mean carapace length and number of eggs of ovigerous females were 110 mm (range 85-157 mm) and 509,433 (range 270,183 - 847,980) respectively. P. pelagicus started to reach the minimum legal size for capture (carapace width 127 mm) in the summer when they were approximately one year old and left the system in large numbers in the following winter when they were 15-20 months old. These features explain why the fishery for P. pelagicus is highly seasonal, with the vast majority of crabs being taken between January and May. As crabs approached the end of their first year of life, the ratio of females began to exceed that of males, apparently as a result of the movement of males out of the system and the legislation against the capture of ovigerous females.

The fishery

Comparisons were made between the catch statistics for the commercial gill and haul net fisheries of the Peel-Harvey system and that of the large neighbouring Swan-Avon estuary. The results indicate that during the 1970s the abundance of fish in the Peel-Harvey system rose as a result of the effects of nutrient enrichment, which included a massive increase in macroalgae (Cladophora sp. and Chaetomorpha spp.). In terms of mean monthly catch per boat per annum, which is shown to be a good reflection of the annual catch per unit effort, the total fishery increased by 1.8 times from 738 kg in the ten years prior to 1969 to 1,327 kg between 1970 and 1979. The comparable values for the three most important commercial species, i.e. the yellow-eye mullet (Aldrichetta fosteri), sea mullet (Mugil cephalus) and cobbler (Cnidoglanis macrocephalus), increased by 1.9, 2.1 and 3.3 times respectively. This contrasts with the situation in the nearby large Swan-Avon estuary which has not seen prolific macroalgal growth but whose fishery uses the same techniques and is exposed to similar market demands. Thus, in the Swan-Avon the mean monthly catch per boat for the total fishery increased in the 1970s by only 1.2 times and no significant change occurred in this parameter for the important sea mullet and cobbler. Length-frequency data showed that all three species grew rapidly in the Peel-Harvey estuary, with the result that most individuals had reached the minimum legal length for capture within two years. In the case of the sea mullet, this length was sometimes achieved by the end of the first year of life. Since growth rates of the main fish species in the Peel-Harvey were similar to those in the Swan-Avon, the increase in weight of fish caught is probably attributable to a rise in fish abundance rather than a faster growth rate. While the rise in abundance may reflect a greater food availability, it could also represent a decline in predation from the large, local, piscivorous bird populations as a result of the development of extensive macrophyte cover.

Effects of *Nodularia*

Our data indicate that dense blooms of the blue-green alga *Nodularia spumigena* affect fish and crab populations in the Peel-Harvey system. For example, the numbers of fish were generally very low at sites in which chlorophyll *a* level, an excellent indicator of *Nodularia* density during the late spring and summer, was above 100 $\mu l\ l^{-1}$. Moreover, commercial fishermen have recorded greatly reduced catches in *Nodularia*-affected areas and dead fish and crabs were found in regions where *Nodularia* was very dense. While the effects of this blue-green alga apparently led to death in the case of some bottom-living species in the most affected parts of the system, more active species moved into regions where *Nodularia* was virtually absent.

Current work is examining the relationship between *Nodularia* blooms and the commercial catch. This study involves an analysis of the fishermen's commercial log books which have been designed to distinguish catches taken in different parts of the system. It also involves the chartering of two fishermen to determine the areas in which commercial sized cobbler and yellow-eye and sea mullet are found in the Peel Inlet and Harvey Estuary during *Nodularia* blooms.

Conclusions

For the following reasons, the introduction of the Dawesville cut with no plug between the Peel Inlet and Harvey Estuary is likely to have beneficial effects for the fishery.

1. It adds an additional entry point to the Peel-Harvey system for the juvenile stages of marine teleosts and crustaceans which form the basis of the commercial and recreational fisheries.
2. The reduction in *Nodularia* in the Harvey Estuary will remove the major reason for the decline in crab numbers and fish catches in this part of the Peel-Harvey system during those periods when the cyanobacterium reaches high levels.
3. The reduced period of very low salinities in the Harvey Estuary will mean that large crabs remain far longer in this part of the Peel-Harvey system.

In contrast to the above beneficial effects, a reduction in macroalgae in Peel Inlet as a result of reduced phosphorus input may lead to a slight reduction in fish catches. However, it is relevant to note that a very viable commercial fishery operated in the Peel-Harvey prior to the massive outbreak in macroalgal growth.

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Paul

DISCHARGE TO THE OCEAN

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Over the past year, the Public Works Department has investigated various engineering concepts which, if implemented, would increase the discharge of nutrients to the Ocean and thereby improve water quality within the Peel-Harvey Estuarine System.

These investigations have included an examination of cost effectiveness for the following dredging and flow training options:

i) widening and/or deepening of the existing Mandurah Ocean Entrance Channel (several different alternatives),

ii) a combination of dredging and flow training works between the Murray River mouth and the Mandurah Ocean Entrance Channel,

iii) dredging works to create a new channel between Harvey Estuary and the Ocean at Caddadup, both with and without complete separation of the Peel and Harvey estuarine basins by reclamation to 'plug' the existing flow channel between Point Grey and Ward Point.

Detailed conceptualisation of the various schemes, probable construction techniques and estimated costs were determined by officers of the Harbours and Rivers Branch (ref. 1). The water quality and hydraulic effects were determined from mathematical model studies carried out by the Centre for Water Research, University of Western Australia, as part of a core project sponsored by the Public Works Department (refs. 2 to 11).

The mathematical models adopted for purposes of these investigations include:

i) the one dimensional DWOPER flood routing model - used to simulate water levels and flow velocities between the Murray River mouth and the Ocean,

ii) the two dimensional RAND water quality model - used to simulate water circulation and exchange within the Estuarine System, under the influence of defined tide and wind conditions.

The DWOPER model was used to examine the effects of dredging works on discharge of a 100 year Murray River flood. The RAND Model was used to calculate the concentration of Peel, Harvey and Ocean water at points throughout the Estuarine System after 14 days of water circulation under "normal summer" and "normal winter" patterns of wind and tide. The results were presented in the form of concentration maps. Also, rates of water transport calculated over a 14 day period were used to determine estimated flushing times, or the time over which all estuary water would be replaced if the replacement rate continued at a similar rate to that existing over the first 14 days of water circulation.

Estimated costs for the alternative Mandurah Ocean Entrance Channel dredging options are summarised in Table 1, whilst estimated flushing times and the corresponding Improvement Factors (relative to existing conditions) are shown in Table 2 for both "normal summer" and "normal winter" conditions. These indicate that the largest proposed Mandurah Channel improvements (i.e. dredging option F at an estimated cost of $8 700 000) would result in a Flushing Time Improvement Factor of the order 1.54 to 1.66 for the Harvey Estuary.

The proposed combination of dredging and flow training works between the Murray River mouth and the Mandurah Ocean Entrance Channel were shown to be relatively ineffective.

Estimated flushing times and corresponding Improvement Factors for the proposed new channel between Harvey Estuary and the Ocean are included in Table 2 for comparison with results on the Mandurah Channel improvements. These indicate that the largest proposed Harvey Estuary to Ocean Channel (i.e. 1.5 km long x 200 m wide and excavated to a depth of 4.5 m below AHD, at an estimated cost of $25 000 000) would result in a Flushing Time Improvement Factor of the order 2.59 to 3.50 for the Harvey Estuary when the 'plug' is in place. Of the engineering concepts investigated, the proposed new Harvey Estuary to Ocean Channel is best able to improve water quality within the Peel-Harvey Estuarine System.

TABLE 1

MANDURAH OCEAN ENTRANCE CHANNEL
SUMMARY OF CHANNEL IMPROVEMENTS BY DREDGING
JULY 1983 COSTS

Dredging Option	Channel 1A Depth m AHD	Channel 1A Width m	Channel 1B Depth m AHD	Channel 1B Width m	Channel 1C Depth m AHD	Channel 1C Width m	Channel 1D Depth m AHD	Channel 1D Width m	Project Duration one dredge only months	Total Cost
A	-2.45	200	-1.95	200					17	$2 300 000
B							-2.75	up to 200 m	6	$1 100 000
A + B	-2.45	200	-1.95	200			-2.75	up to 200 m	23	$3 400 000
C	-2.45	200	-1.95	200			-2.75	200	24	$3 900 000
D (East)	-2.45	200	-1.95	200			-3.75	200	29	$5 200 000
D (West)	-2.45	200			-1.95	200	-3.75	200	25	$4 600 000
F	-2.45	200	-2.95	400			-3.75	200	54	$8 700 000

TABLE 2

PEEL/HARVEY ESTUARINE SYSTEM - CHANNEL IMPROVEMENTS BY DREDGING
COMPARISON OF ESTIMATED ESTUARY FLUSHING TIMES

Forcing Conditions	Location of Channel Improvements	Dredging Option	Flushing Time (days)		Flushing Time Improvement Factor	
			Harvey	Peel-Harvey	Harvey	Peel-Harvey
"Normal Summer"	Mandurah	Existing	128	103	1.00	1.00
Tide and Wind	Ocean Entrance	D (East)	85	69	1.51	1.49
		D (West)	84	62	1.52	1.66
		F	80	47	1.60	2.19
	New Harvey to	without 'Plug'	46	38	2.78	2.71
	Ocean Channel	with 'Plug'	38	43	3.37	2.40
"Normal Winter"	Mandurah	Existing	84	47	1.00	1.00
Tide and Wind	Ocean Entrance	D (East)	59	38	1.42	1.24
		D (West)	59	35	1.42	1.34
		F	57	33	1.47	1.42
	New Harvey to	without 'Plug'	42	29	2.00	1.62
	Ocean Channel	with 'Plug'	34	31	2.47	1.52

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