9-2006

Current status and 25 year trends for soil acidity, fertility and salinity in the coastal catchments of the Peel-Harvey

Robert Summers
Department of Agriculture and Food, Western Australia, robert.summers@dpird.wa.gov.au

David Weaver
Department of Agriculture and Food, Western Australia, david.weaver@agric.wa.gov.au

Recommended Citation

Summers RN and Weaver DM 2006, 'Current status and 25 year trends for soil acidity, fertility and salinity in the coastal catchments of the Peel-Harvey', Final Report to South West Catchment Council, Project L7-03.

Current status and 25 year trends for soil acidity, fertility and salinity in the coastal catchments of the Peel-Harvey

Robert Summers and David Weaver
SWCC Project L7-03 (3PE)
September 2006

Natural Heritage Trust
Helping Communities
Helping Australia
An Australian Government Initiative

SOUTH WEST CATCHMENTS COUNCIL

GOVERNMENT OF WESTERN AUSTRALIA

Acknowledgements

The large body of information about soil testing that was collected in the 1980's was carried out, amongst others, by staff still at the Department of Agriculture and Food who were able to give valuable advice about the dataset. These included Bill Russell, Caroline Peek, Deb Tyler and Tony Allen. The reviewed soil sampling was carried out by Kuswardiyanto and Simon Vivian with data entry carried out by Martin Clarke, Gina Fiorenza, Carole Rivers and Tegan Archibald. Cooperation from a large number of landholders over many years is gratefully acknowledged.

Summary

The current status and trends of soil analyses in the coastal catchment of the Peel Harvey estuary were developed from historical soil data (1982 to 1991) combined with a renewed sampling to greater depth (1 m). This report encompasses the data collected from the first year of the project.

Soil phosphorus content was found to be high but has dropped slightly since 1991. Soil pH is very low and is likely to be limiting production but have risen slightly since 1991. Soil potassium content is generally so low that it may be limiting production especially to the west of the south west highway. Correcting these deficiencies would reduce the rate of increase in soil phosphorus and reduce the hazard of phosphorus loss. These findings show some improvement but much greater effort is required to develop better nutrient management for both production and the environment.

The sandy soils have not retained phosphorus and the heavier, clay soils have accumulated very large stores of phosphorus. Much of the soil has become saturated with phosphorus with the lighter textured soils being completely saturated and the heavier textured soils also showing signs of phosphorus saturation in the topsoil. The soils with the least stores of phosphorus appear to retain little of the applied phosphorus and are unfortunately very close to the estuary and major drainage lines.

The sandy soils do not build up phosphorus stores and the phosphorus that is applied leaches, the heavy textured soils have built up phosphorus to the point that up to 77% do not need more phosphorus to be applied.

Total Phosphorus
The soils of the Peel-Harvey have become greatly enriched by the application of phosphorus since clearing. The farmed soils have 1020 kg/ha/m stored in them compared with 180 kg/ha/m in the uncleared sites This is equivalent to about 10 tonnes of superphosphate added to the top metre of soil profile over each hectare or about 50 years of 200 kg of superphosphate per hectare. The greatest absolute enrichment has occurred in the top 5 cm as would be expected for surface applied fertiliser, but enrichment continues deep into the soil profile indicating leaching and incorporation of phosphorus in all soil types.

Phosphorus status
The phosphorus status of the soil is a measure of how well a pasture will respond to applications of phosphorus. The phosphorus status of the soils, as a group, have dropped shown by the low phosphorus status (those likely to benefit from additions of phosphorus) having risen from 28 to 33% and those in a high phosphorus status (those unlikely to benefit from additions of phosphorus) having dropped from 58 to 42%. When the soils are grouped into their different categories of phosphorus retention the sandier soils have the greatest proportion of low phosphorus status samples (70 to 80% of samples) while the heavier, higher phosphorus retentive soils, have a greater proportion of high phosphorus status (45 to 77%).

Phosphorus retention
The phosphorus retention mapping has been included into the DoW Modelling project which is renewing the modelling of the nutrient flows in the catchment and the chemical analyses are being included into reviewed soil information held by the Department of Agriculture and Food, WA. The mapping of phosphorus accurate to the high levels achieved here enables a clear understanding of the location and mechanism of phosphorus movement which can be used when targeting extension or planning works as it allows the mechanism of leaching or sediment bound nutrient runoff to be identified.

pH

The pH of the soils of the catchment are mostly acidic (below 4.5) and most require lime to minimise productivity loss. There was a small increase in pH over the soil sampling period.

EC

The was no overall trend in the electrical conductivity of the soils of the Peel-Harvey. As would be expected the soils with the higher iron content (heavier clay soils) had higher electrical conductivity and localised drainage conditions are likely to be having the greatest influence on salinity levels.

Potassium status

Overall, the potassium status of the soils are low and the lowest levels correspond to the phosphorus retention. Although there is a similar distribution of potassium and phosphorus the magnitude is much lower with few sites having built up high enough potassium to effectively utilise other nutrients. The potassium levels have not changed with time.

Management implications

There are a number of relationships in the soil analyses that have been described that are useful in modelling and for conveying risk as an adjunct to agronomic recommendations when considering the results of soil testing.

This is a preliminary report that encompasses the data compiled to date and is not considered complete or final.

Introduction

Eutrophication of the Peel Inlet and Harvey Estuary is driven to a large extent by nutrient surpluses from inputs to agricultural and other land uses, leading to nutrient build up in soils and consequent reductions in a soils capacity to retain further inputs. Equally soil acidity and salinity changes occur because of inherent soil characteristics and the nature of land uses applied to them.

This project combined a large historical database about soils and land management with data from revisiting old sites in the catchment of the Peel-Inlet and Harvey estuary.

In order to sustainably manage soil resources subject to these chemical changes it is necessary to understand their current status, and to estimate the rates of change and trends in condition to better predict the impact of proposed actions. Current status, rates of change and the direction of trends can be compared to desired conditions (standards) to identify the level and nature of change or remediation required to achieve a desired condition. There is a wide range of soils in our region, each exhibiting different critical points at which they become saturated by nutrients and rapidly lose nutrients to regional surface and ground water resources. Soils vary in their capacity to retain nutrients and buffer against changes in acidity, salinity and nutrient retention, and there has been little assessment of the degree or rate of change. It is important to assess soil nutrient status in the context of soil acidity and salinity as these latter resource condition measures, if left unmanaged can adversely impact on eutrophication. The purpose of this project was to review data from a large, historical soil dataset and acquire new data on current status to assess trends and rates of change. The data will also be useful as an indicator of soil health and catchment risk- a resource condition target and assessment. This information feeds into the base data for such products as AgMaps, soil classification and models used in decision support systems.

This project is targeted at the protective and productive capacity of the land asset of the Peel-Harvey while at the same time as developing an understanding of the degradation of buffering capacity of the soil and the risk to regional assets (which are the waterways of the Peel-Harvey) that this degradation represents. This project has implications for all coastal catchments in the South West at risk of eutrophication. There is also the improvement of the regional asset of the knowledge base and understanding of degradation status and processes. This is often overlooked as an asset.

Methods

Peel-Harvey 1982 to 1991 soil testing

Existing hard copy data of soil test analyses and land management information was entered into a database which included a unique identifier for each sample and each property had a group of these unique samples over the period from 1982 to 1991. There were 15,334 samples of the 0-10 cm of topsoil. Included amongst a large number of the original files were maps indicating where samples were taken and these sites were entered onto a geographical information system. Sites were given a code indicating the confidence in assigning their location either at the paddock scale or the farm scale. The data included in this was a standard set of agronomic soil tests such as pH, phosphorus, potassium, electrical conductivity as well as information relating to the management practices such as amount and type of fertiliser applied and the land use that was carried out on the property.

Peel-Harvey 2006 soil testing

314 of the original sites were revisited using both the same soil sampling equipment used in the capture of the historical dataset (0 to 10 cm hand sampler) and also a mechanised direct-push soil sampler, where samples were taken to 100 cm in increments of 0 to 5, 5 to 10, 10 to 20, 20 to 40 and 40 to 100 cm. The analysis of the new samples was expanded to include the PRI (phosphorus retention index) and organic carbon.

Table 1. The number of sites sampled in each year and the proportion of the total in each sampling year.

Year	Count	%
1982	15	0.096
1983	1514	9.70
1984	3821	24.5
1985	2925	18.7
1986	1715	11.0
1987	1703	10.9
1988	1172	7.51
1989	1111	7.12
1990	738	4.73
1991	581	3.72
2006	314	2.01

Albany soil testing

The analysis of the data here is from the above two datasets and a third dataset from Albany. The dataset from Albany was derived over the same period as the Peel-Harvey database and included the same agronomic analyses of the top 10 cm of soil. Similarly it includes an analysis of a subset of samples to 100 cm but this was carried out in 1992.

Chemical analyses

Sample preparation consisted of oven drying at less than 40° C, sieving < 2mm, mixing and splitting of samples into duplicates before analysis. Bicarbonate extractable phosphorus and potassium were determined after extracting soil with 0.5 M Na HCO_3 at pH 8.5 for 16 hours at 25° C in a soil solution ratio of 1:100 (Colwell, 1965). Extracted P was determined using the colorimetric procedure of Murphy and Riley (1962) and K by atomic adsorption spectroscopy (Jeffery, 1982). Ammonium oxalate extractable iron (Amox Fe, reactive iron or simply Fe) was determined by absorption spectrophotometry after extracting soil for 1 h at a soil solution ration of 1:33 with Tamm's reagent (Tamm 1922; Blackemore et al, 1977). Electrical conductivity (EC) and pH(H_2O) were determined after extracting soil for 1 h with deionised water at a soil solution ration of 1:5, pH ($CaCl_2$) was determined using the same method but using a 0.01 M calcium chloride solution (Schofield and Taylor, 1955; Rayment and Higgison, 1992). Soil organic carbon was estimated using the heat of dilution method of Walkley and Black (1934). Phosphorus retention index (PRI) of Allen and Jeffery (1990), which is the ratio of the P sorbed by the soil from a 10 µg P/mL solution after incubation with 1 : 20 soil:solution for 16 h.

The reactive iron (ammonium oxalate extractable iron) had been used in the 1982 to 1991 sampling as a simplified measure of phosphorus retention and the validity of this was measured here when comparison was made with the phosphorus retention index (PRI). It also enabled the same soil type groupings to be used between the two different sampling periods. The use of reactive iron also has the advantage of being a measure of the total phosphorus binding capacity of the soil which does not decline with applications of phosphorus as opposed to the PRI which does decline. Both techniques are useful together.

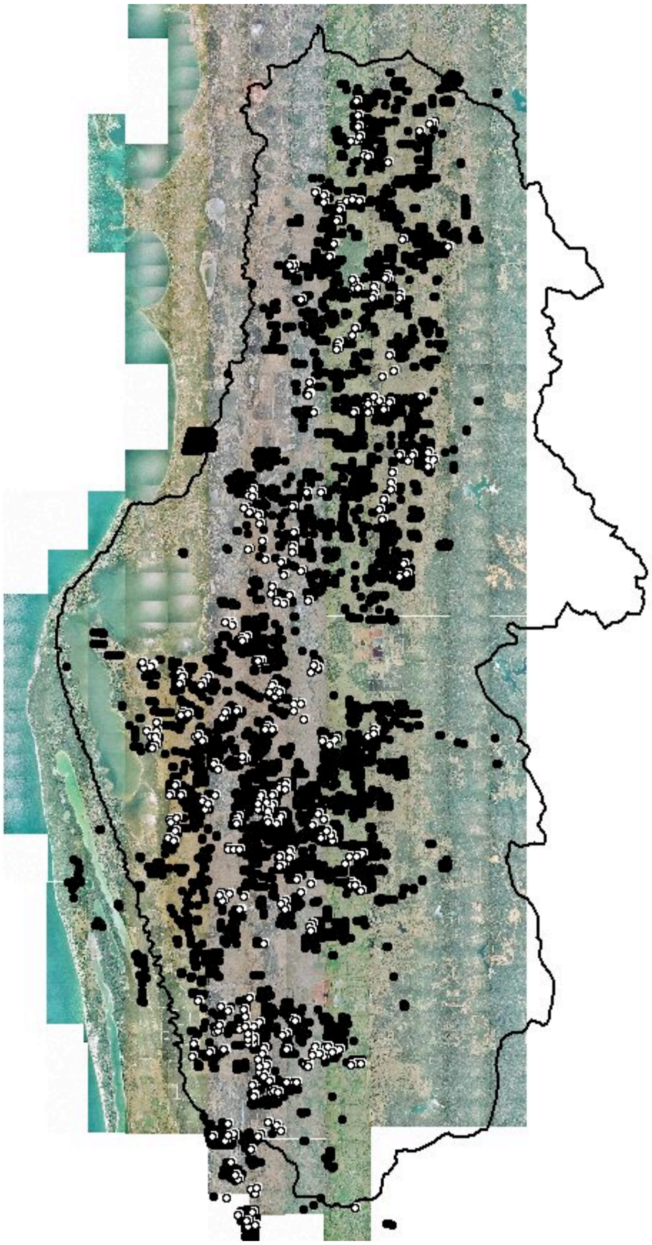
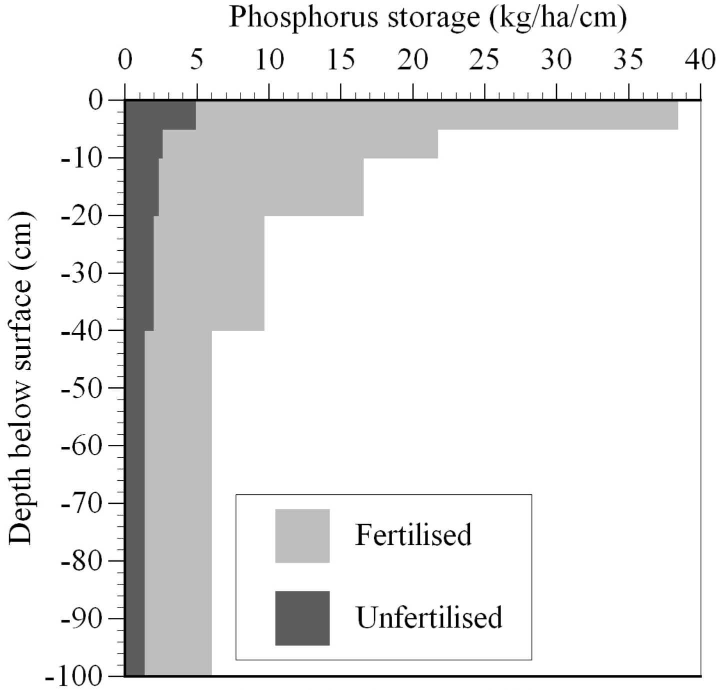


Figure 1. The 1982-1991 sampling sites (●) and the 2006 sampling sites (○), superimposed on the aerial photography. The outline of the Peel-Harvey Coastal Catchment is shown in black.

Results and Discussion

Total phosphorus



Fertilised: Mean P stored = 1020 kg/ha/m
Unfertilised: Mean P stored = 180kg/ha/m

Figure 2. Total phosphorus in the soil profile from fertilised and uncleared remnant vegetation.

The soils of the Peel-Harvey have become greatly enriched by the application of phosphorus. The farmed soils have 1020 kg/ha/m stored in them compared with 180 kg/ha/m in the uncleared sites (Figure 2). This is equivalent to about 10 tonnes of superphosphate added to the top metre of soil profile over each hectare or about 50 years of 200 kg of superphosphate per hectare. The greatest absolute enrichment has occurred in the top 5 cm as would be expected for surface applied fertiliser, but enrichment continues deep into the soil profile indicating leaching of phosphorus in all soil types. The store of phosphorus in the landscape was estimated by comparing the cleared soils with the uncleared soils in the 2005/2006 sampling.

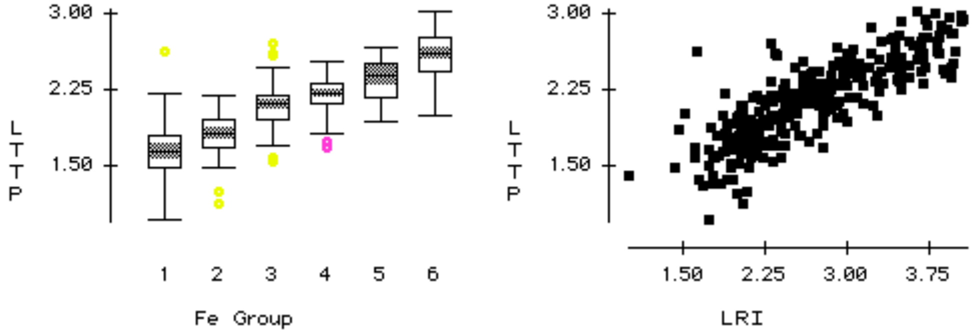


Figure 3. Log Total phosphorus (LTTP) as a function of Fe group (1=0-100, 2=100-200, 3=200-400, 4=400-800, 5=800-1600, 6=>1600), Log total phosphorus as a function of Log Fe (LRI, log reactive iron).

The total amount of phosphorus stored in the soil is directly related to the reactive iron, a surrogate for phosphorus retention index (Figure 3). Each of the reactive iron groupings are different. This relationship exists because of the binding capacity of the soil (measured as reactive iron) increasing with the iron content of the soil making more binding sites available.

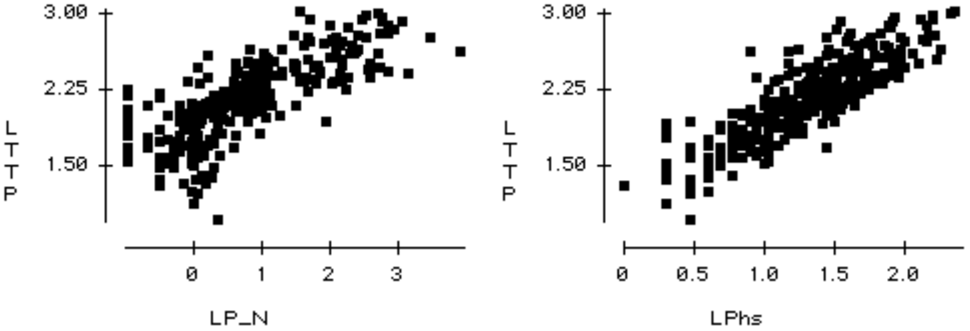


Figure 4. Log total phosphorus as a function of Log PRI (phosphorus retention index LP_N), Log Total phosphorus (LTTP) as a function of Log Bicarbonate extractable phosphorus (LPhS).

The same relationship between the total amount of phosphorus retained and PRI (Figure 4) is the same as the relationship with reactive iron (Figure 3). Similarly the bicarbonate extractable phosphorus has a similar relationship (Figure 4). The more iron in the soil the more phosphorus is retained and the more that is dissolved in the bicarbonate solution as a measure of the plant available phosphorus.

2006 Soils data used in Figures 3 and 4.

```
Summary of      TOTALP
No Selector
15648 total cases of which 15334 are missing

Count   314
Mean    204.701
Median  142.5
StdDev  195.318
Min     9
Max     1048
Range   1039
```

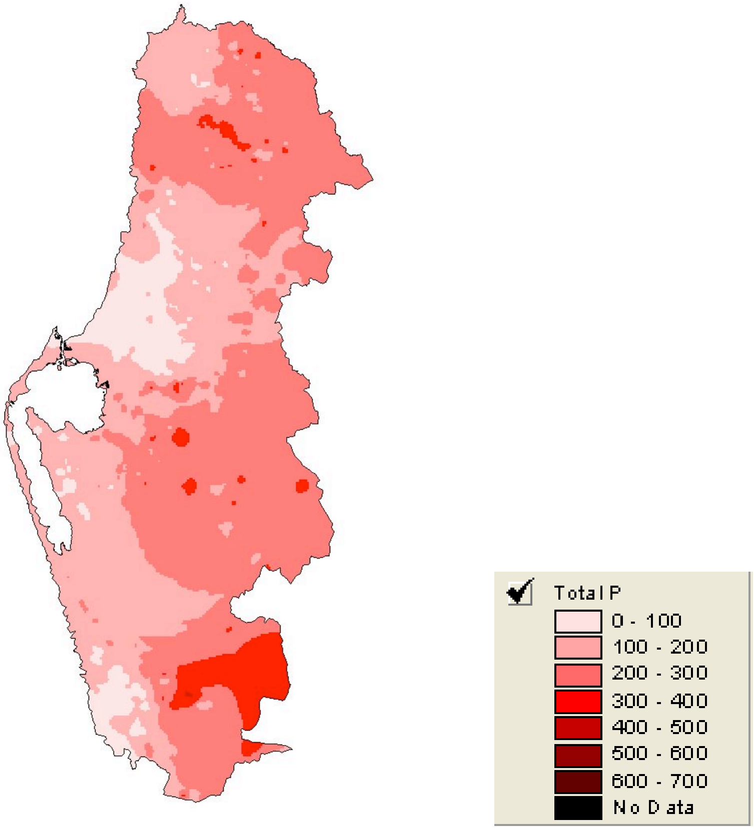


Figure 5. The distribution of phosphorus concentration in the top 10 of soil (mg/kg) in the coastal catchment of the Peel-Harvey.

The phosphorus occurs in highest concentrations closest to the scarp where heavier, clay soils predominate. The sandy soils, adjacent to the estuary and major drainage channels, have retained the least phosphorus (Figure 5).

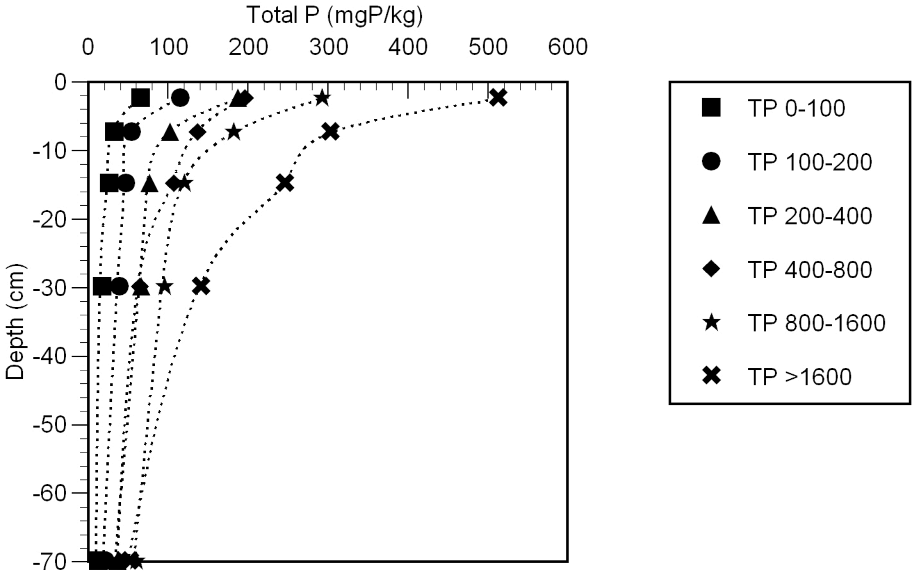


Figure 6. The phosphorus levels in the soil profile of the different reactive iron groups.

Phosphorus accumulates in the topsoil at greater levels in soils with higher phosphorus retention capacity (shown as reactive iron groups in Figure 6). It should also be noted that these soils also show enrichment of P to depth indicating some level of mixing and leaching. This has implications for the mode of risk for highly leaching soils (the lowest groups) which leach phosphorus rather than accumulate and the much higher levels that accumulate in the surface of soils which are at risk of phosphorus loss from runoff rather from leaching. High levels of phosphorus in the topsoil represents a greater risk or loss of phosphorus from erosion of the clay particles which act to carry the phosphorus into the waterways and may accumulate in the sediment and be available for later release, however, when phosphorus accumulates to very high levels desorption can occur where the phosphorus dissolves into the water running off these clay soils. All three mechanisms act in the transfer of phosphorus into waterways.

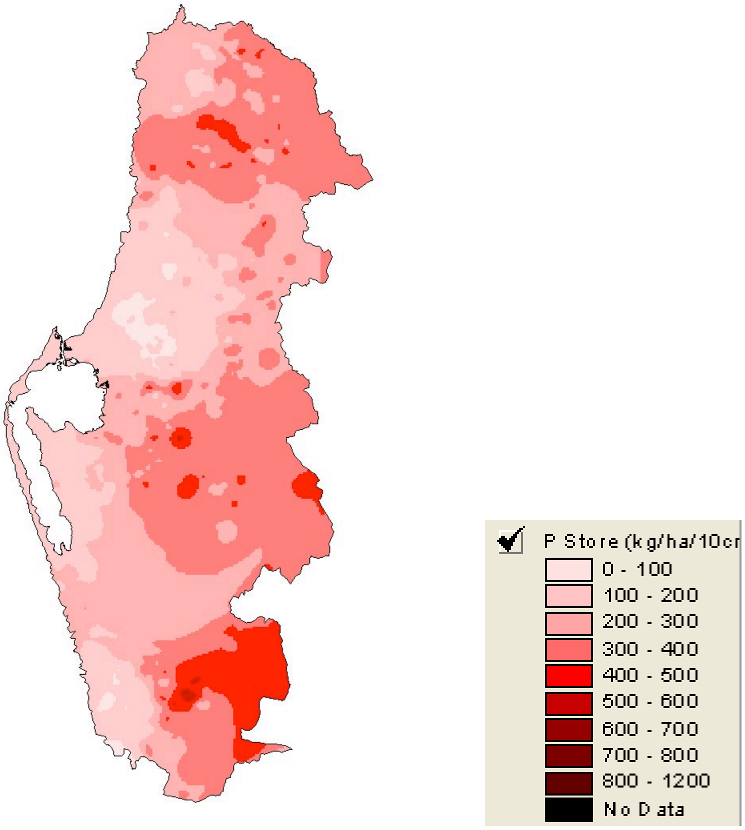


Figure 7. Soil phosphorus store – kg of phosphorus stored per ha in the 0-10 cm layer

The store of phosphorus in the top 10 cm (Figure 7) is related to the capacity of the soil to retain phosphorus. Each year that phosphorus is applied it either leaches in the low PRI soils, no phosphorus build-up, or contributes to the phosphorus build up in high PRI soils.

The majority of the phosphorus build up is along the scarp where the soils higher in iron and aluminium have formed from the erosion of the scarp itself. The sandier soils predominate on the western side of the catchment closer to the river systems and the estuary where the phosphorus that is applied cannot be retained.

Bicarbonate P

Bicarbonate extractable or plant available phosphorus

Table 2. The plant available phosphorus (bicarbonate extractable P) in the top 10 cm of soil compared between the 1982 to 1991 (legacy) group and the 2006 (SWCC) group.

Sample period	Median P	Count	Min	Max
1982 to 2006	29	15373	1	536
1982 to 1991	29.2	15059	1	536
2006	21	314	1	233

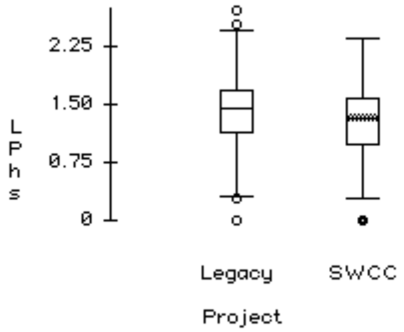


Figure 8. Plant available phosphorus (bicarbonate extractable P) in the top 10 cm of soil compared between the 1982 to 1991 (legacy) group and the 2006 (SWCC) group shown using a box and whisker plot.

Log bicarbonate extractable P between two projects

An analysis of variance (ANOVA) on log transformed data suggests a significant decrease in Bic P over the two sampling perios. When un-logged, the data suggests a change from 25ppm to 19ppm (Table 2, Figure 8), medians go from 29 down to 21. The data is transformed by taking the log of each value to give a more normal distribution of results, this enables a valid statistical comparison of the data. Note, however, that this is from all samples combined from all soil types and may represent a slight skew between the two sampling periods where slightly less sandy soils were sampled. To more accurately assess the changes with time, the soils need to be compared for each soil type to get a clearer picture (following).

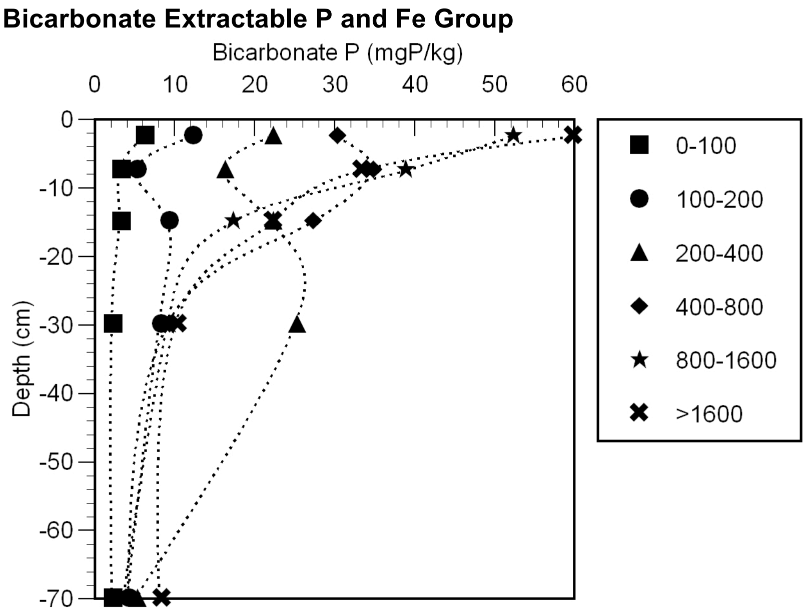


Figure 9. The plant available phosphorus (bicarbonate extractable P) in the top 100 cm of soil (2006 data). The soils have been grouped by reactive iron soil test (legend).

The plant available phosphorus (bicarbonate extractable P) is highest in the soil of higher reactive iron groups and highest in the topsoil (Figure 9). The lower reactive iron groups have much lower P and relatively lower P in the topsoil, i.e. the phosphorus does not build up in the sandiest of soils at any depth.

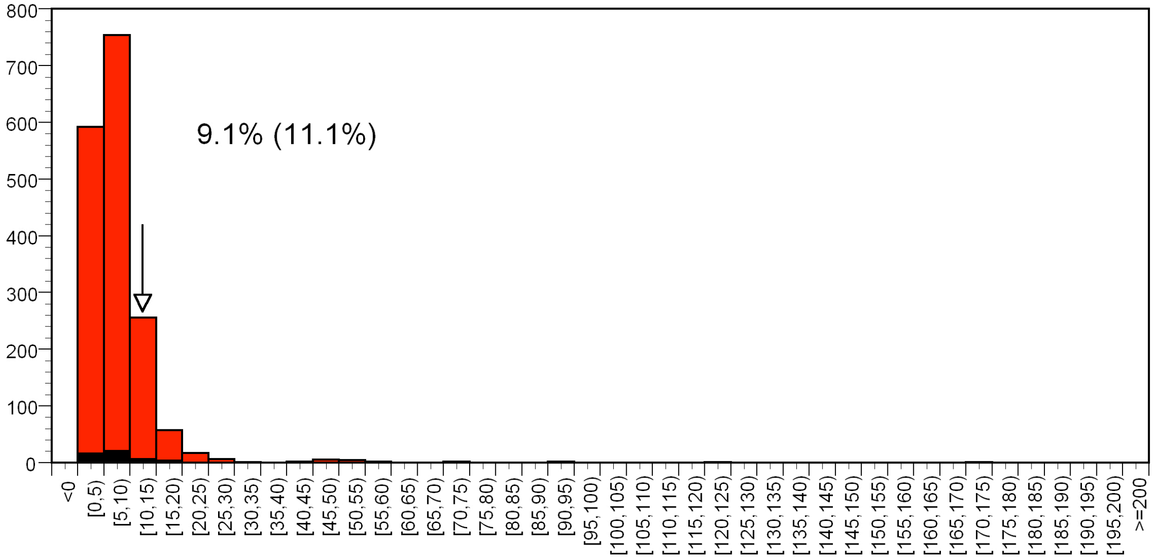


Figure 10. Frequency histogram of the 1 to 100 ppm reactive iron group (the sandiest soil). The soils are grouped by bicarbonate extractable P. 9.1% are above the maximum production P level (arrow) in the 1982-1991group and 11.1% are above the maximum production for the 2006 group (in brackets).

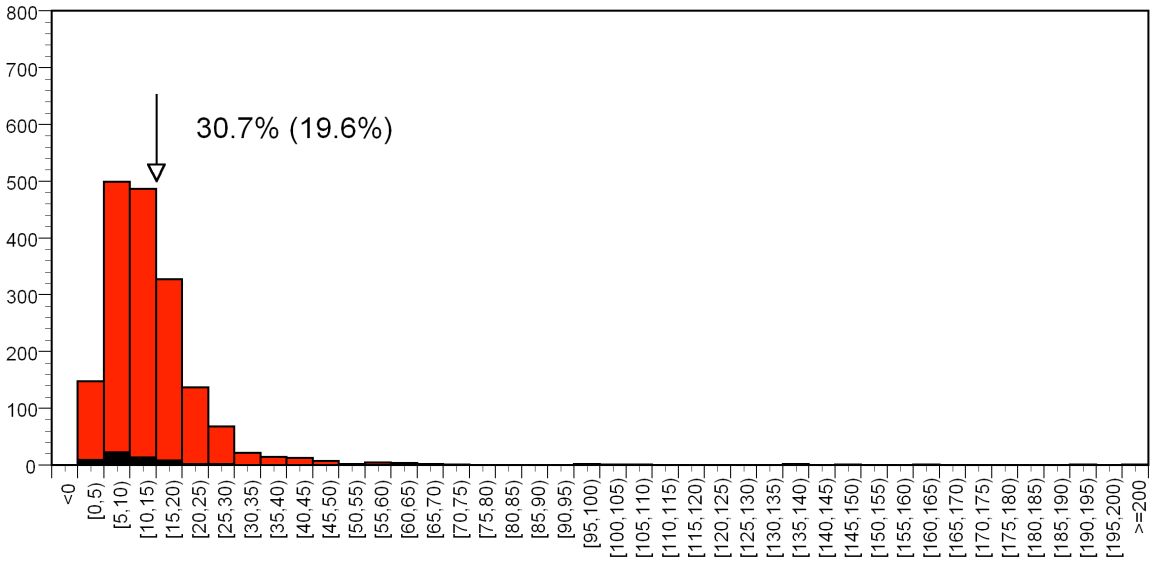


Figure 11. Frequency histogram of the 100 to 200 ppm reactive iron group (the next sandiest soil). The soils are grouped by bicarbonate extractable P. 30.7% are above the maximum production P level (arrow) in the 1982-1991group and 19.6% are above the maximum production for the 2006 group (in brackets).

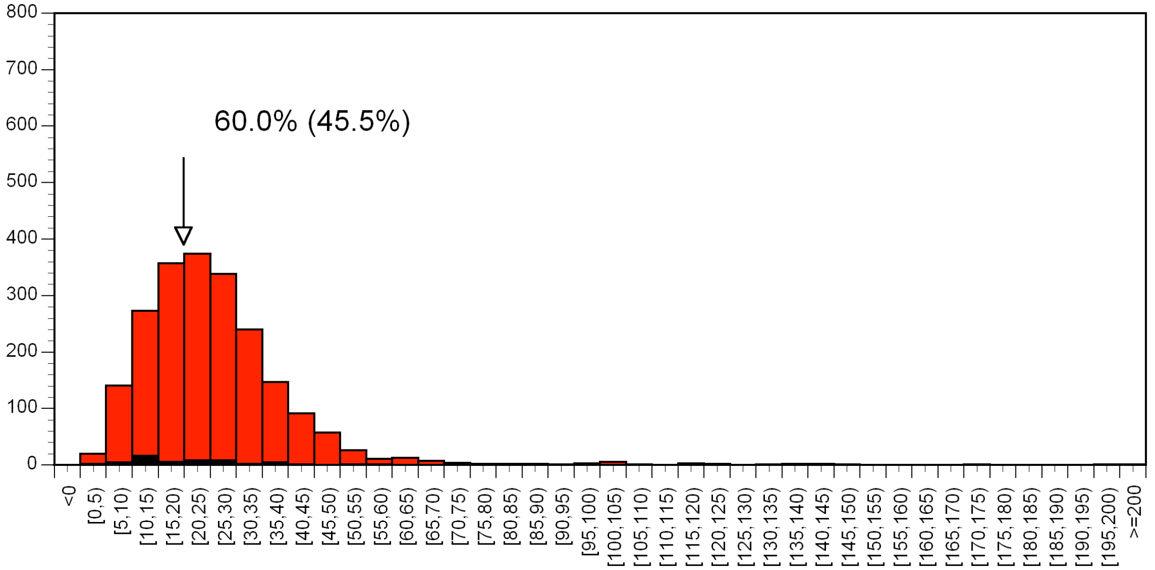


Figure 12. Frequency histogram of the 200 to 400 ppm reactive iron group. The soils are grouped by bicarbonate extractable P. 60.0% are above the maximum production P level (arrow) in the 1982-1991group and 45.5% are above the maximum production for the 2006 group (in brackets).

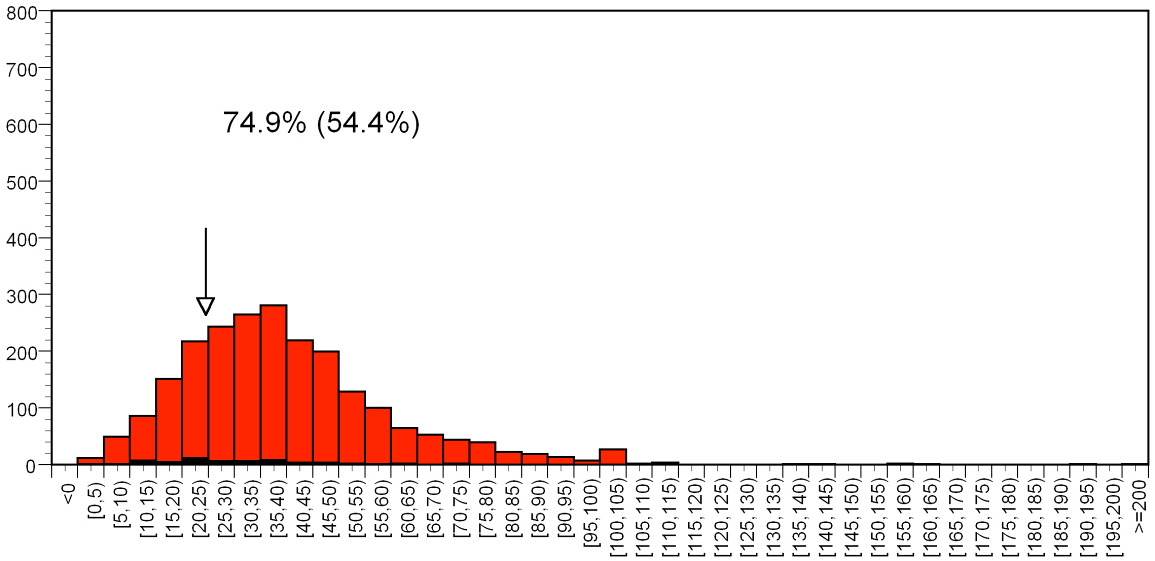


Figure 13. Frequency histogram of the 400 to 800 ppm reactive iron group. The soils are grouped by bicarbonate extractable P. 74.9% are above the maximum production P level (arrow) in the 1982-1991group and 54.4% are above the maximum production for the 2006 group (in brackets).

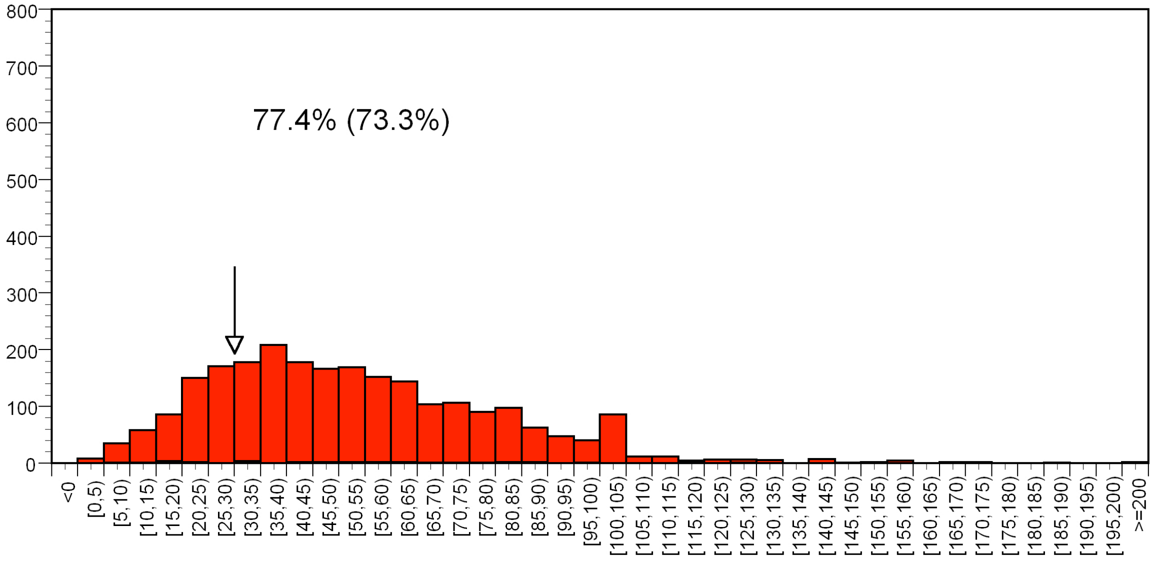


Figure 14. Frequency histogram of the 800 to 1600 ppm reactive iron group. The soils are grouped by bicarbonate extractable P. 77.9% are above the maximum production P level (arrow) in the 1982-1991group and 73.3% are above the maximum production for the 2006 group (in brackets).

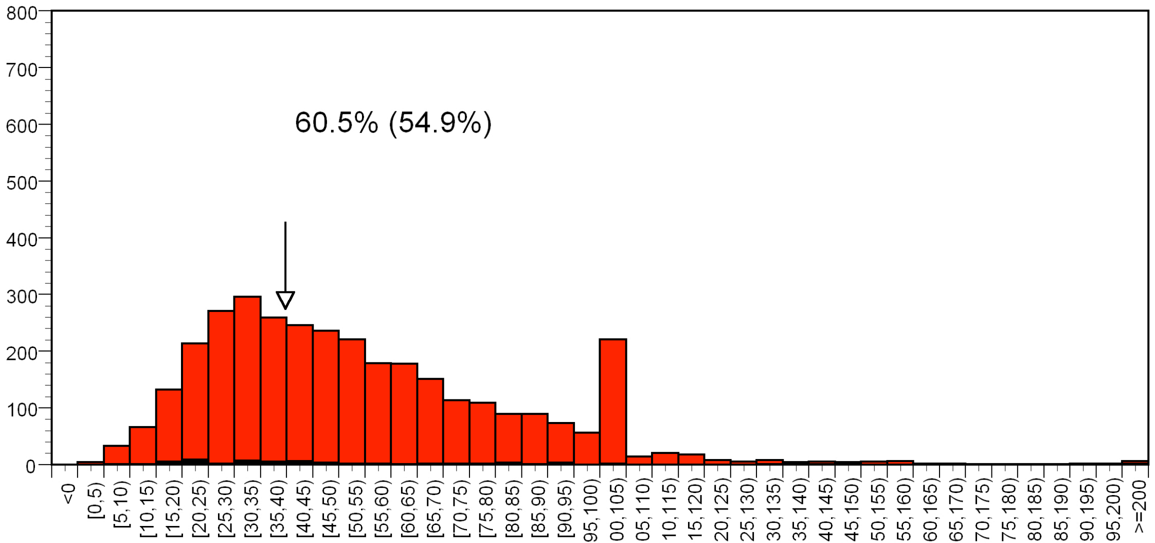


Figure 15. Frequency histogram of the > 1600 ppm reactive iron group (the highest clay group). The soils are grouped by bicarbonate extractable P. 60.5% are above the maximum production P level (arrow) in the 1982-1991group and 54.9% are above the maximum production for the 2006 group (in brackets).

The bicarbonate extractable P in the lower reactive iron groups (the sandiest) have not changed from the 1982-1991 to the 2006 sampling. Most samples were below the optimum production and this has not changed. In contrast, the higher the reactive iron (the heavier soils) the higher the bicarbonate extractable P and the higher the proportion is above the optimum level for production (Figures 10 to 16, table 3). There has been a reduction in bicarbonate extractable P between the two sampling times for some of the soils.

There is an anomaly of samples in the 100 to 105 ppm bicarbonate extractable P caused by a laboratory maximum for part of the sampling period.

Table 3. The number of samples in each of the soil groups and the bicarbonate extractable P.

Fe Group				Bicarbonate extractable P					
		Count		Median		Min		Max	
		2006	82-91	2006	82-91	2006	82-91	2006	82-91
1-100	1	45	1702	6	6	1	1	19	171
100-200	2	56	1740	9	12	2	1	28	269
200-400	3	55	2130	18	23	2	2	57	281
400-800	4	57	2250	28	36	3	1	73	300
800-1600	5	30	2399	52	48	8	1	127	345
>1600	6	71	3351	44	48	9	2	233	536

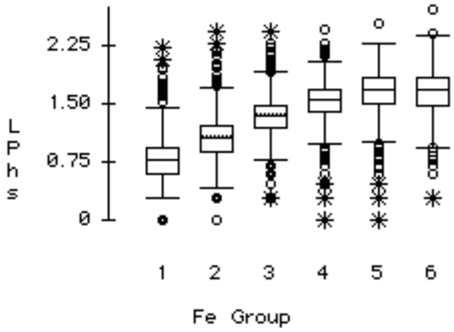


Figure 16. Log Bic P as a function of Fe groups.

Bicarbonate extractable P variation in space

Table 4. Analysis of the spatial variation of the 2006 soils using a Spearman Rank Correlation, no selector.

	Phosphorus	Northing	Easting
Phosphorus	1.000		
Northing	-0.019	1.000	
Easting	0.243	0.452	1.000

http://faculty.vassar.edu/lowry/VassarStats.html
Using this online facility, there is a significant increase (<0.0001) of Bic P with increasing easting, but no relationship with northing (table 4).

Table 5. Analysis of the 1982-1991 soils using a Spearman Rank Correlation, no selector.

	Easting	Northing	Phosphorus
Easting	1.000		
Northing	0.508	1.000	
Phosphorus	0.275	-0.036	1.000

There is a significant increase (<0.0001) of Bic P with increasing easting, and a possibility that P decreases with northing (table 5).

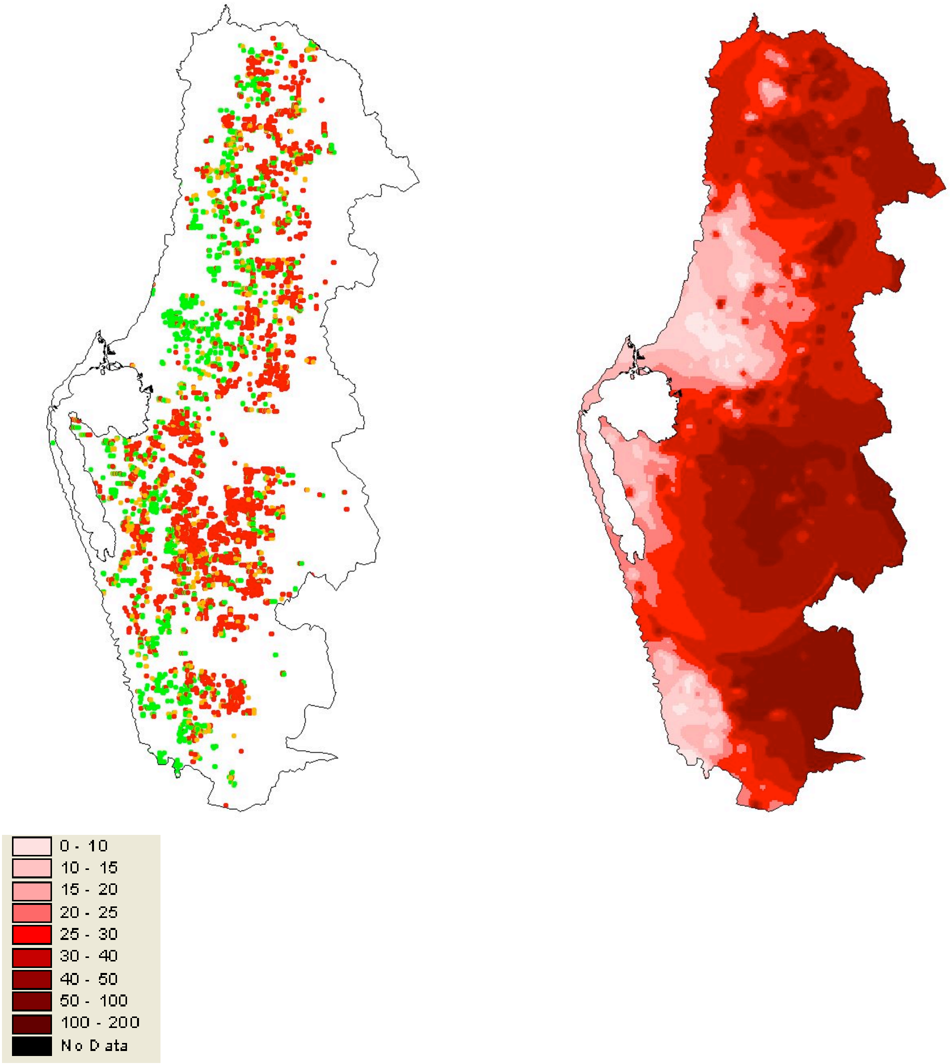


Figure 17. Lower P status samples (green) in the west and high P status (red) in the east (left). Soil Bic P shown as shaded contours (right).

The higher bicarbonate extractable P is to the east along the scarp (Figure 17) coinciding with the higher total P (Figure 5) and P store in the soil (Figure 7).

Bic P changes with time

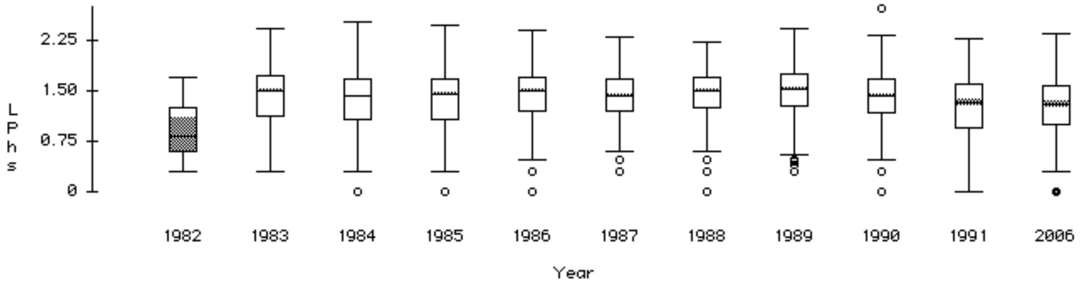


Figure 18. Log of bicarbonate extractable P with all soil types grouped for each year of sampling.

ANOVA suggests that for log bicarbonate extractable P values, 2006 sampled soils are significantly lower than those sampled in 1990, 1989, 1988, 1987, 1986 and 1983. 1982 can be discounted because of low sample numbers. Despite that, a regression of Log bicarbonate extractable P levels vs Year overall shows no trend, and no significant slope (Figure 18). Grouping by Fe shows some differences. See log bicarbonate extractable P vs Year for different Fe groups below.

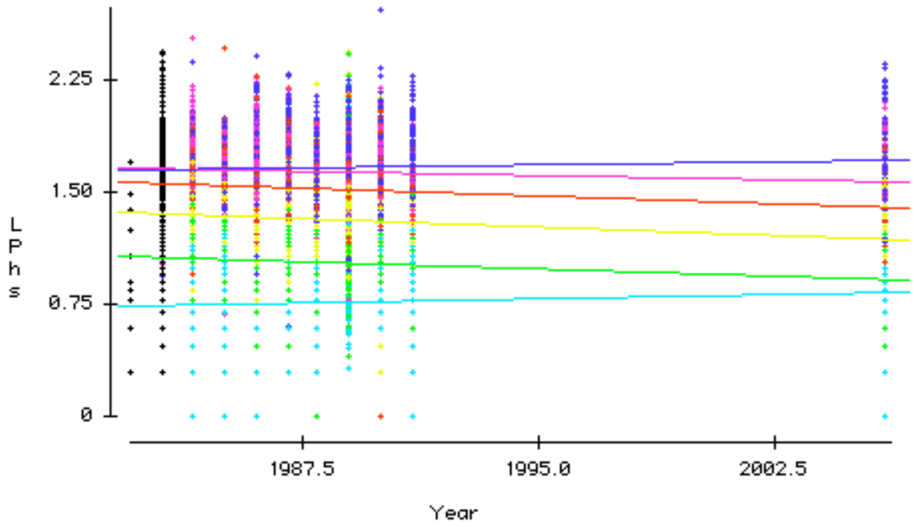


Figure 19. Slope of log bicarbonate extractable P for different soil Fe groups.

When slopes are analysed through time for each Fe Group we find poor regression coefficients (<2%), but the slopes are significantly different from zero (Figure 19, table 5). This may be an artefact of the most recent sampling being time distant from the earlier samples, that is the statistical analysis may be distorted by having a point such a long way from the main group of points.

Table 5. The slope of the regression line for each reactive iron group of soil.

Reactive Iron Group	P Trend with time
1-100	Up
100-200	Down
200-400	Down
400-800	Down
800-1600	Down
>1600	Up

Table 6. Spearman Rank correlation of time trends.

Group	P Trend with time	R	significance
1-100	Up	0.062	<0.05
100-200	Down	-0.142	<0.0001
200-400	Down	-0.146	<0.0001
400-800	Down	-0.127	<0.0001
800-1600	Down	-0.073	<0.001
>1600	Up	0.028	<0.1

Analysis of the slope of bicarbonate extractable P with a Spearman Rank correlation (table 6, medians in table 7), this helps overcome the time distant nature of the 2006 data. 0.062 is the critical value when N >=1000 for significance of monotonic trend @0.05. All N's for this are greater than 1700, so all but the >1600 Fe range has a significant time trend.

Table 7 Median bicarbonate extractable P in different Fe groups through time.

Group	Median 0-100	Median 100-200	Median 200-400	Median 400-800	Median 800-1600	Median >1600
1982	•	•	•	•	•	•
1983	9	16	23.85	25.6	53	35
1984	6	14	26	39	51	48
1985	5	11	24	39	50	47
1986	5	7	19	34	47	44
1987	7	11	20	33	43	49
1988	6	9	22	35	48	49
1989	7.7	12.5	24.6	37.65	53.4	50.8
1990	7	12	22	31	48	47
1991	6	9	19	29	34	53
2006	6	9	18	28	51.5	44

P status

The phosphorus status of the soil is impacted upon by the phosphorus retention capacity of the soil (measured as PRI and an estimate of this is Fe). Each level of Fe has a low, medium and high status as defined by the (table 9). The soil is broken into these groups assigned to the particular status and then grouped together to give the following table (table 8).

Table 8. The phosphorus status of each sampling group.

	2006		1982-1991		1982-2006	
Group	Count	%	Count	%	Count	%
Low	136	43.3	4194	27.8	4330	28.2
Medium	45	14.3	2128	14.1	2173	14.1
High	133	42.3	8737	58.0	8870	57.7

High P status has decreased from 58% to 42%, and low increased from 28% to 43% between the 1982-1991 sampling and the 2006 sampling.

Table 9. The phosphorus status of the different reactive iron groups.

Ammonium oxalate extractable Fe (mg kg^{-1})	Low P status (Bicarbonate P (mg kg^{-1}))		
	Low	Medium	High
1-100	<10	10-12	>12
101-200	<12	12-15	>15
201-400	<15	15-20	>20
401-800	<20	20-25	>25
801-1600	<25	25-30	>30
>1600	<30	30-40	>40

Table 10. The proportion of each phosphorus status of the different reactive iron groups with all of the data from 1982 to 2006 combined.

Group	0-100	100-200	200-400	400-800	800-1600	>1600
Low	79.1	48.8	20.2	13.3	14.1	21.3
Medium	11.7	19.9	19.3	11.6	8.5	18
High	9.2	31.2	60.5	75.1	77.4	60.7

The phosphorus status of the low Fe groups which are sandy, is generally low (79.1% and 48.8%) and reflects the poor ability or these soils to retain phosphorus that is applied. Above a reactive iron level of 200 mg/kg this reverses and the proportion of soil with a high phosphorus status and does not need further fertiliser is in the majority (tables 11 to 17).

Table 11. The proportion of each phosphorus status for each year with all reactive iron groups combined.

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	2006	total
Low	66.7	16.4	29.8	31.3	30.5	26.6	25.8	22.7	24.9	40.3	43.3	28.2
Medium	6.67	7.12	14.2	13.2	13.2	18.4	16	13.3	20.5	16.6	14.3	14.1
High	26.7	76.4	56	55.5	56.3	55	58.3	64.1	54.6	43.1	42.4	57.7
total	100	100	100	100	100	100	100	100	100	100	100	100

Table 12. The proportion of each phosphorus status for each year for the 0-100 reactive iron group.

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	2006	total
Low	•	66.7	78.9	83.5	87.5	71.1	80.8	74.6	56	77.9	80	79.1
Medium	•	0	13.9	8.96	4.17	11.3	13.7	6.35	22.7	12.5	8.89	11.7
High	•	33.3	7.17	7.5	8.33	17.5	5.48	19	21.3	9.62	11.1	9.16
total	100	100	100	100	100	100	100	100	100	100	100	100

Table 13. The proportion of each phosphorus status for each year for the 100-200 reactive iron group.

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	2006	total
Low	•	0	33.3	49.4	72.7	53.6	59.4	44.2	42.3	63.5	69.6	48.8
Medium	•	50	23.5	19.4	11.2	20	18.8	17.4	35.6	12.5	10.7	20
High	•	50	43.2	31.3	16.1	26.4	21.8	38.4	22.1	24	19.6	31.2
total	100	100	100	100	100	100	100	100	100	100	100	100

Table 14. The proportion of each phosphorus status for each year for the 200-400 reactive iron group.

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	2006	total
Low	•	0	13.7	16.5	34.2	23.8	20.8	13.4	18.7	34.8	41.8	20.2
Medium	•	50	16.1	16.9	19.5	28.1	17.9	21.5	22.8	18.5	12.7	19.3
High	•	50	70.2	66.6	46.3	48	61.3	65.1	58.5	46.7	45.5	60.5
total	100	100	100	100	100	100	100	100	100	100	100	100

Table 15. The proportion of each phosphorus status each year for the 400-800 reactive iron group.

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	2006	total
Low	•	0	10.8	9.46	16.2	18.6	11.2	13	14.2	20.3	22.8	13.3
Medium	•	42.9	8.33	7.33	12	15.7	14	9.5	16.7	21.7	22.8	11.6
High	•	57.1	80.9	83.2	71.9	65.7	74.9	77.5	69.2	58	54.4	75.1
total	100	100	100	100	100	100	100	100	100	100	100	100

Table 16. The proportion of each phosphorus status for each year for the 800-1600 reactive iron group.

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	2006	total
Low	•	14.3	12.8	12	13.7	14.7	16	12.6	15.6	28.2	23.3	14.1
Medium	•	14.3	8.07	7.08	8.35	11.3	6.86	5.8	9.84	17.6	3.33	8.48
High	•	71.4	79.1	80.9	78	74	77.1	81.6	74.6	54.1	73.3	77.4
total	100	100	100	100	100	100	100	100	100	100	100	100

Table 17. The proportion of each phosphorus status for each year for the >1600 Fe reactive iron group.

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	2006	total
Low	•	41.7	23.4	20.1	26.1	18.8	18.6	20.7	20.1	16.4	25.4	21.3
Medium	•	41.7	16.7	17.6	18.5	19.8	19.8	15.5	19.1	17.9	19.7	18
High	•	16.7	59.9	62.3	55.3	61.4	61.6	63.7	60.8	65.7	54.9	60.6
total	100	100	100	100	100	100	100	100	100	100	100	100

Phosphorus Retention Index PRI

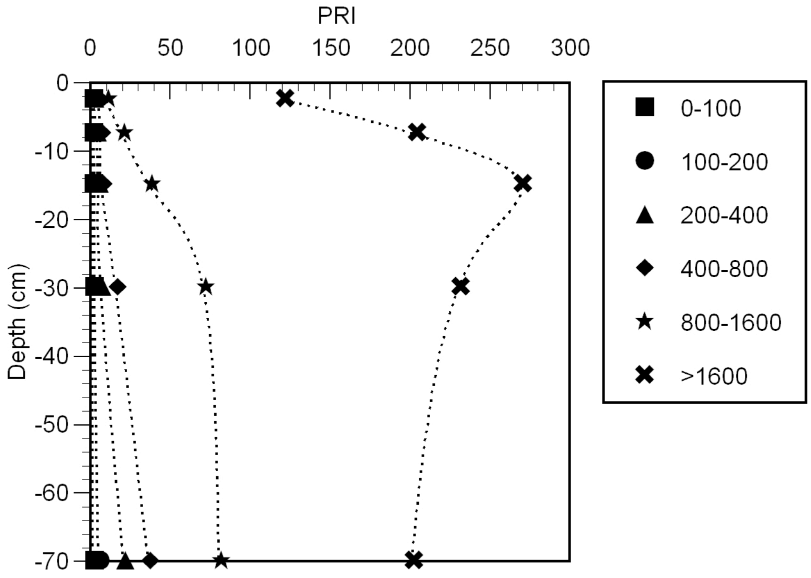


Figure 20. The phosphorus retention index of the soil profile in reactive iron groups.

The phosphorus retention index of each soil group is lower in the topsoil than in the subsoil for all but the lowest PRI soils (Figure 20). This opposes the phosphorus levels in the soil where the topsoil has the highest phosphorus levels that have accumulated in them (Figures 6 and 9) and is likely to be the result of repeated applications of P reducing the PRI and accumulating P in the surface.

Summary of PRI for the 2006 soil sampling
No Selector
15648 total cases of which 15334 are missing

Count	314
Mean	93.9443
Median	4.25
StdDev	520.751
Min	0
Max	8300
Range	8300

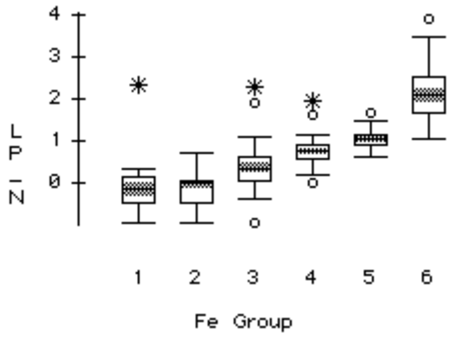


Figure 21. Log PRI as a function of Fe group

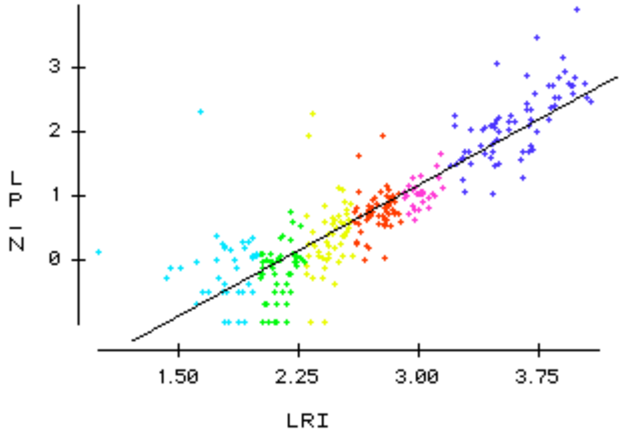
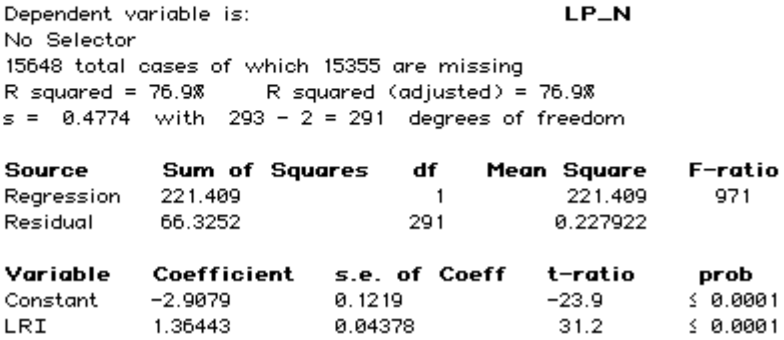


Figure 22. Log PRI as a function of Log Fe for 0-10 cm soils in the 2006 sampling – coloured by Fe group (low Fe to the left and high Fe to the right).


```
Dependent variable is:                    LP_N
No Selector
15648 total cases of which 15355 are missing
R squared = 76.9%     R squared (adjusted) = 76.9%
s =  0.4774  with  293 - 2 = 291  degrees of freedom

Source      Sum of Squares    df   Mean Square   F-ratio
Regression  221.409            1       221.409     971
Residual    66.3252          291      0.227922

Variable    Coefficient   s.e. of Coeff   t-ratio    prob
Constant    -2.9079       0.1219          -23.9      ≤ 0.0001
LRI         1.36443       0.04378          31.2      ≤ 0.0001
```

There is a strong relationship between the reactive iron level and the PRI (Figure 21 and 22).

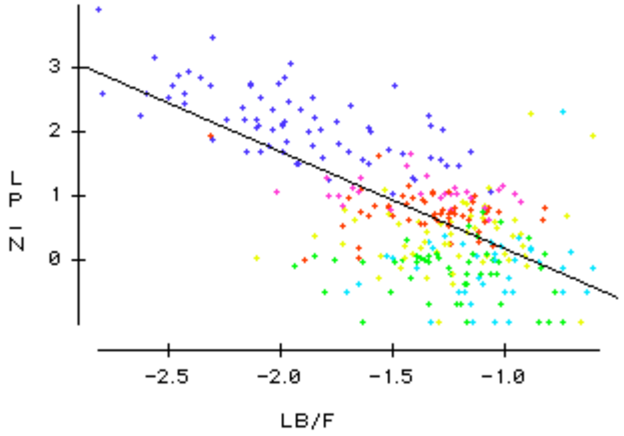


Figure 23. Log PRI as a function of Log BicP/Fe

As a general rule, the more P saturated soils have lower PRI

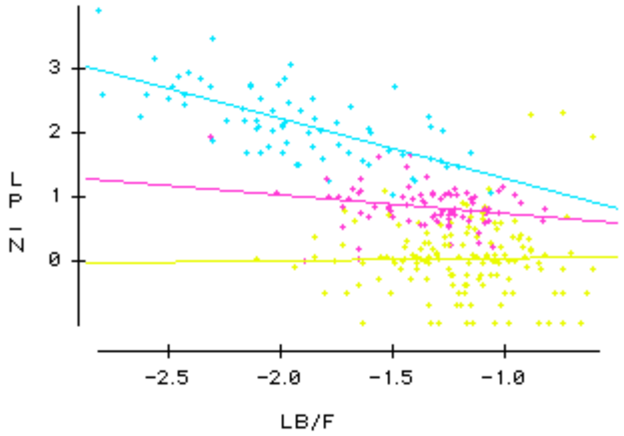


Figure 24. Log PRI as a function of Log BicP/Fe and grouped by reactive iron.

If we classify soils according to Fe, but fewer groups than the standard Fe groups, into P sorption classes such that 0-400=Low, 400-1600=Moderate, and >1600=High (Table 1 Weaver and Reed, 1998) we see the above responses of LogPRI as a function of LogBicP/Fe (Figure 24). The soils with high P sorption show the greatest change in P sorption because they have some capacity to diminish whereas the Low P sorbing soils have none to diminish.

Equations

Low	LogPRI = 0.1157+0.0603*LogBicP/Fe
Moderate	LogPRI = 0.4854-02801*LogBicP/Fe
High	LogPRI = 0.3711-0.9283*LogBicP/Fe

Based on these equations we can derive a PRI map for the catchment.

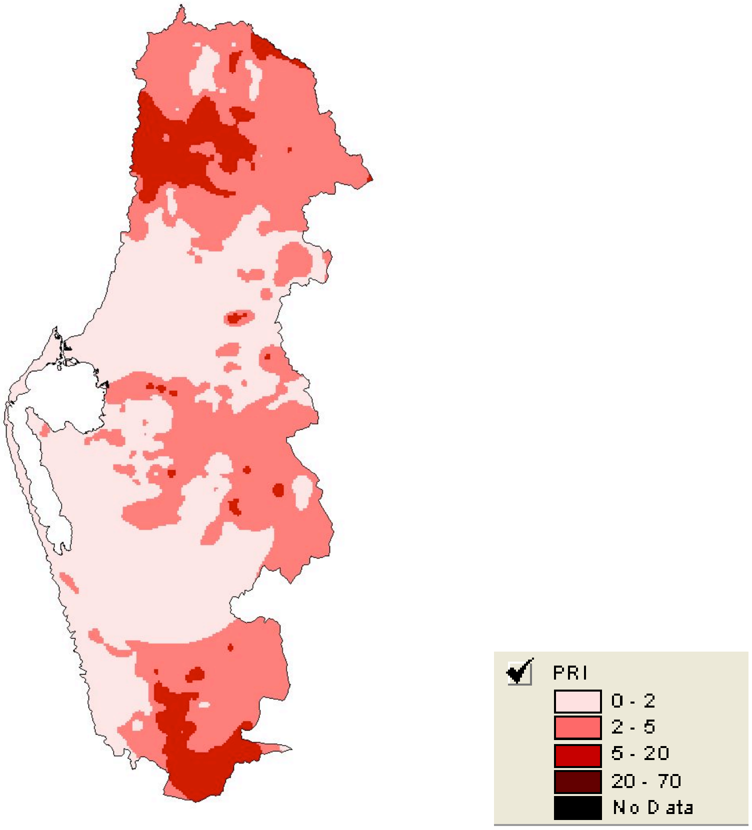


Figure 25. PRI in the catchment according to the classification of Allen and Jeffery (1990) based on the reactive iron from the 1982 to 1991 data and the actual PRI from the 2006 data.

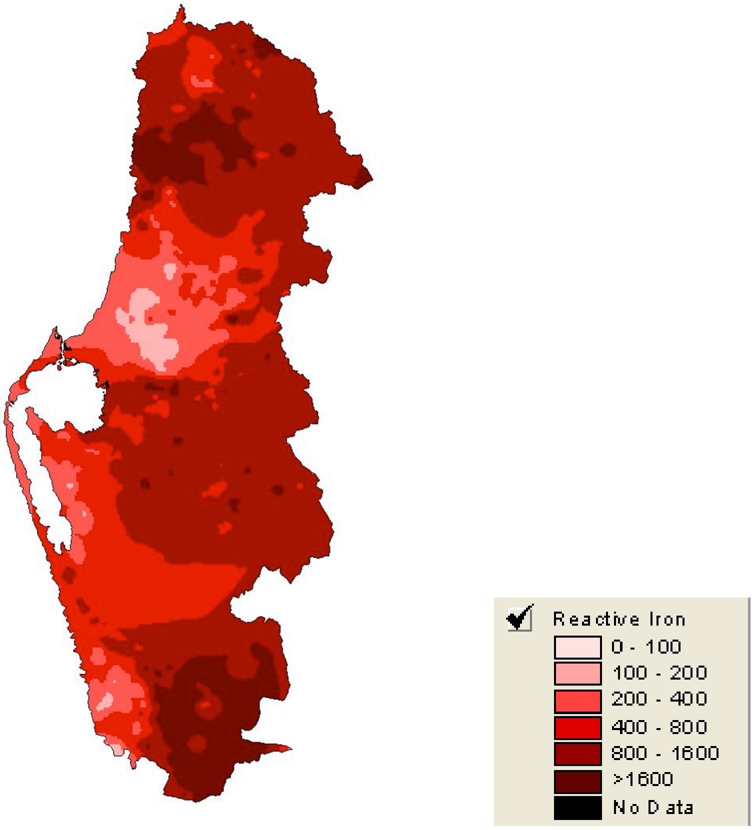


Figure 26. Reactive iron in the catchment based on the reactive iron from the 1982 to 1991 data and the 2006 data.

Soil Fe across the catchment – correlates well with PRI (Figure 25 and 26).

Table 23. Number by Reactive Iron (Fe) Breakdown

	2006		1982 to 1991		1982 to 2006	
Fe Group	Count	%	Count	%	Count	%
1-100	45	14.3	1702	12.5	1747	12.6
100-200	56	17.8	1740	12.8	1796	12.9
200-400	55	17.5	2130	15.9	2185	15.7
400-800	57	18.1	2250	16.6	2307	16.6
800-1600	30	9.6	2399	17.7	2429	17.5
>1600	71	22.	3351	24.7	3422	24.6

The sample distributions between the 1982-1991 and the 2006 sampling are similar in terms of Fe (table 23).

Phosphorus saturation

The use of the bicarbonate extractable P divided by the reactive iron is as a surrogate for P saturation and this approach is discussed in a number of papers included in an annotated bibliography of references to phosphorus saturation at the end of this report.

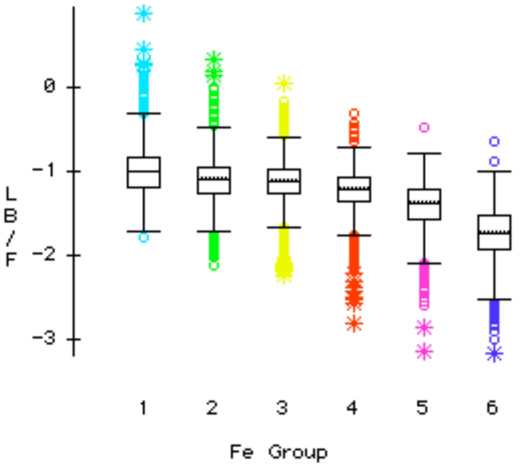


Figure 27. Log of (BicP/Fe) as a function of different Fe Groups (1=0-100…6=>1600) all soil samples combined.

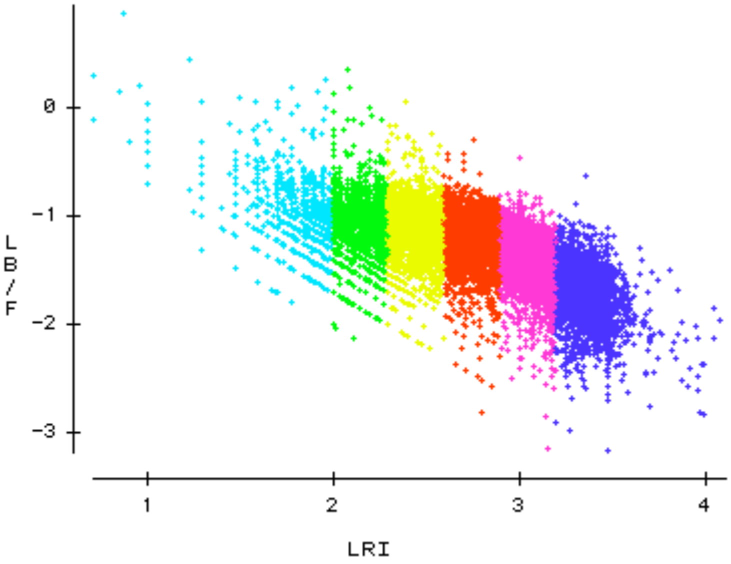


Figure 28. Log of (BicP/Fe) as a function of logFe. Different Fe groups are coloured. Shows same as boxplot above.

Figures 27 and 28 shows more P per unit of Fe for low Fe than for high Fe. This shows that low Fe soils (sandy soils) are more saturated.

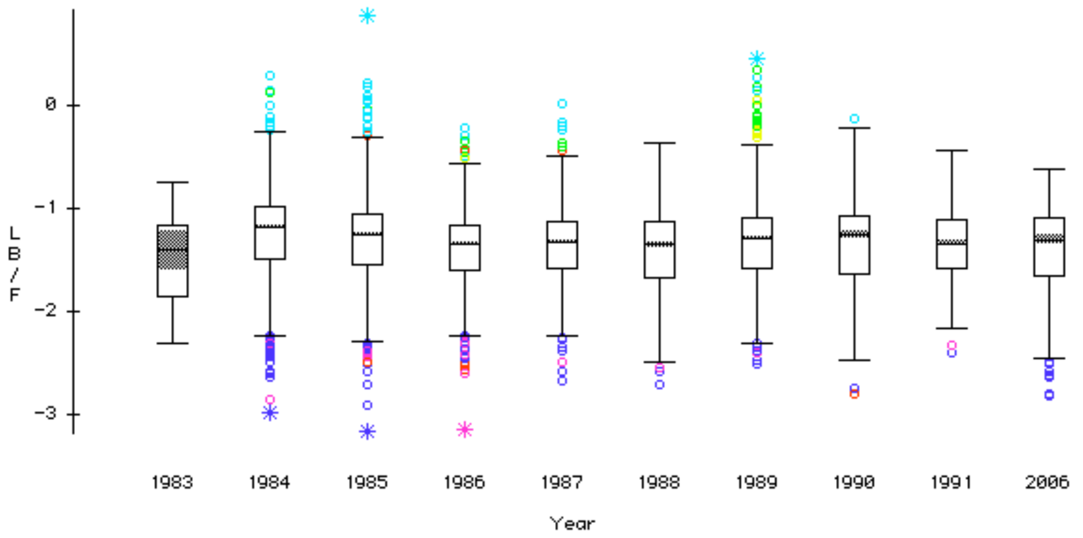


Figure 29. Log BicP/Fe as a function of year.

There is no trend in the saturation through time, although some years are different than others (Figure 29).

ANOVA of LogBicP/Fe as influenced by Fe Group and year shows there are significant effects of both as well as significant interactions.

```
Analysis of Variance For                    LB/F
No Selector
15648 total cases of which 1765 are missing

Source      df       Sums of Squares      Mean Square    F-ratio     Prob
Const       1        24013.4              24013.4        349.83e3    ≤ 0.0001
FG          5          181.141              36.2282      527.78      ≤ 0.0001
Yr          9           18.0384              2.00427      29.198     ≤ 0.0001
FG*Yr       45          25.2926              0.562057      8.1881    ≤ 0.0001
Error       13823      948.853               0.0686431
Total       13882     1984.94
```

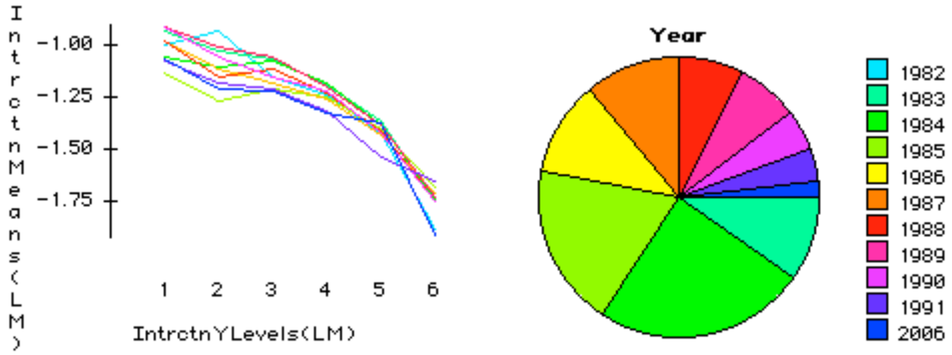


Figure 30. An interaction plot of mean LogBic/Fe (y axis) and the Fe group (x-axis).

The interaction plot (Figure 30) shows how the mean LogBic/Fe (y axis) varies for both Fe group (x-axis) and year (different colours). It appears that the Fe trend is much stronger than the Year trend and the significance of the interaction is due to year variations in LogBicP/Fe for low Fe groups. This is not a surprise given that P will be more weakly bound for low Fe soils than high Fe soils, and hence P measures are likely to be more variable (but within a narrow range) over time due to seasonal effects for low Fe than high Fe. Year colours are shown but difficult to untangle.

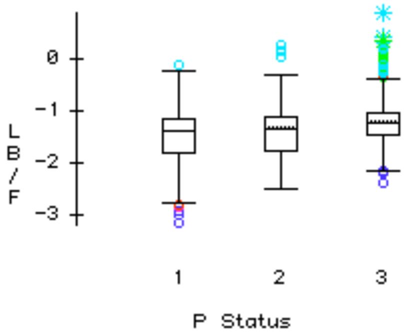


Figure 31. Log BicP/Fe as a function of P status (table 9, 1=low, 2 =med, 3=high).

The higher saturation is found in the higher P status soils (Figure 31).

Table 19. Mean Log BicP/Fe in each P status by Fe Group.

Fe Group	P status (Low)	P status (medium)	P status (high)
0-100	-1.067	-0.768	-0.546
100-200	-1.263	-1.028	-0.829
200-400	-1.411	-1.199	-0.979
400-800	-1.576	-1.381	-1.117
800-1600	-1.800	-1.609	-1.284
>1600	-2.079	-1.867	-1.569

Table 19 shows the mean Log BicP/Fe in each P status by Fe Group where arbitrary shading according to the ratio shows where the nutrient leaching risks are. These are shown graphically (Figures 32 and 33) where the location of the greatest saturation occurs.

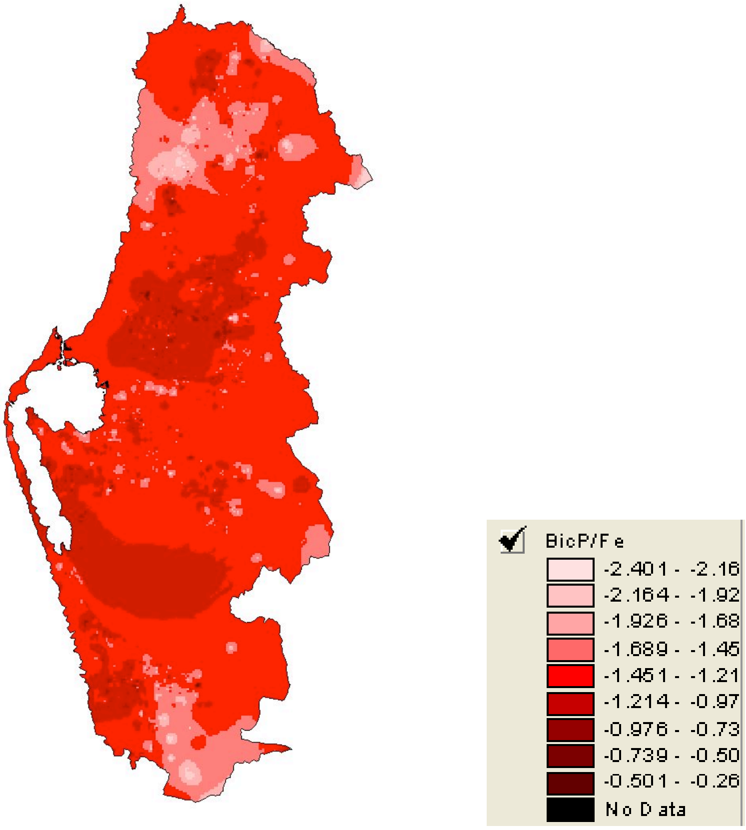


Figure 32. P saturation where darker shades = higher P saturation.

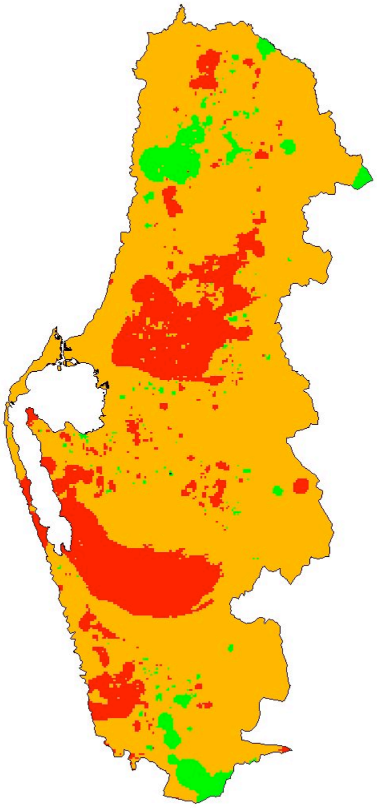


Figure 33. Green = low P saturation, Orange = medium P saturation, red = high P saturation. Based approximately on scales set in coloured table above.

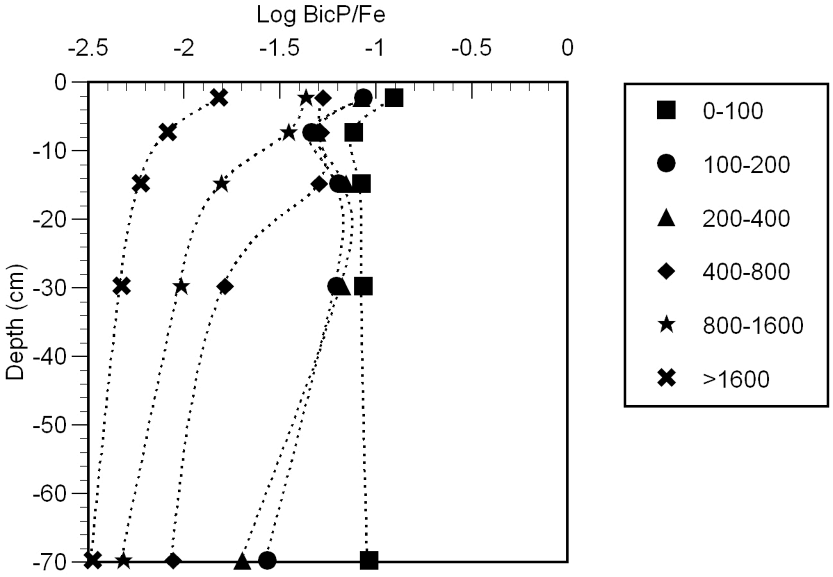


Figure 34. The log BicP/Fe (phosphorus saturation of the soil) over the depth of the soil profile.

The soil surface and sandier soils (lower reactive iron) are saturated (Figure 34) in a manner similar to the reduction of the PRI in Figure 20 (although mirrored through logging).

pH CaCl2

pH has increased between the 1982-1991 sample period and 2006 by 0.2 pH units (P<0.01). However a closer examination of the individual years reveals more variation between years than between the two sample periods (Figures 35, 36). The acidic soils are widely distributed in the catchment (Figure 38).

Table 20. pH of the sample periods.

Sample period	Mean pH	Median pH	Count	Std Dev	Min	Max
1982 to 2006	4.4	4.3	10012	0.53	3.1	8
1982 to 1991	4.4	4.3	9698	0.53	3.1	8
2006	4.6	4.5	314	0.61	3.1	7.1

Untransformed pHCaCl2 has significantly (P<0.01) increased from the 1982 to 1991 data set to the 2006 data set by around 0.2 pH units (table 20, Figure 35).

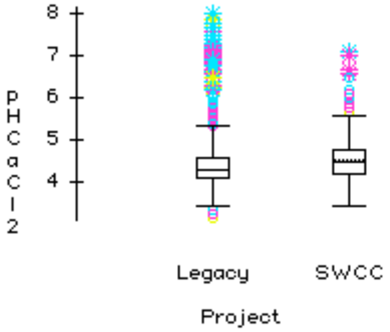


Figure 35. pH of all samples in the 1982 to 1991 group (Legacy) and the 2006 group (SWCC).

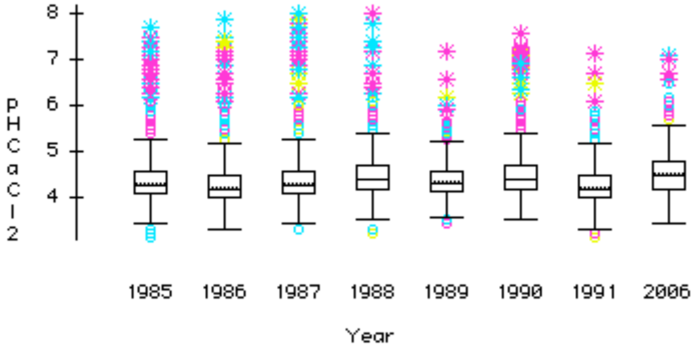


Figure 36. pH of the samples by year.

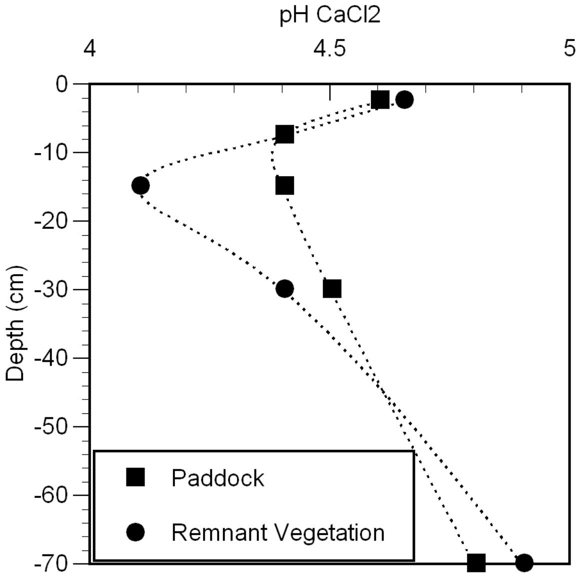


Figure 37. The pH of the soil profile in the 2006 sampling from paddock samples and remnant vegetation.

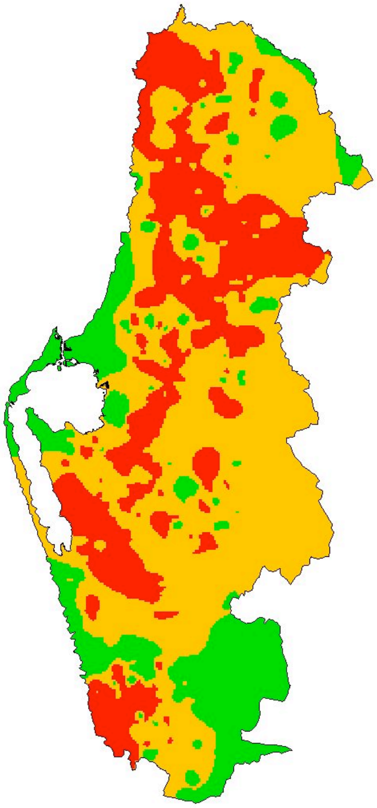


Figure 38. Surface soil pH (red <4.3, orange 4.3-4.5, green >4.5)

Potassium

Potassium status and distribution is similar to that of phosphorus and follows the reactive iron content, where the greater the reactive iron the greater the potassium concentration (Figures 41, 42, 43). However, the potassium status is generally low for most of the soils especially to the west of the south west highway (Figure 39). There is no trend of potassium concentration or status through time (Figure 40 and table 21), 1982 is considered anomalous due to low sample numbers.

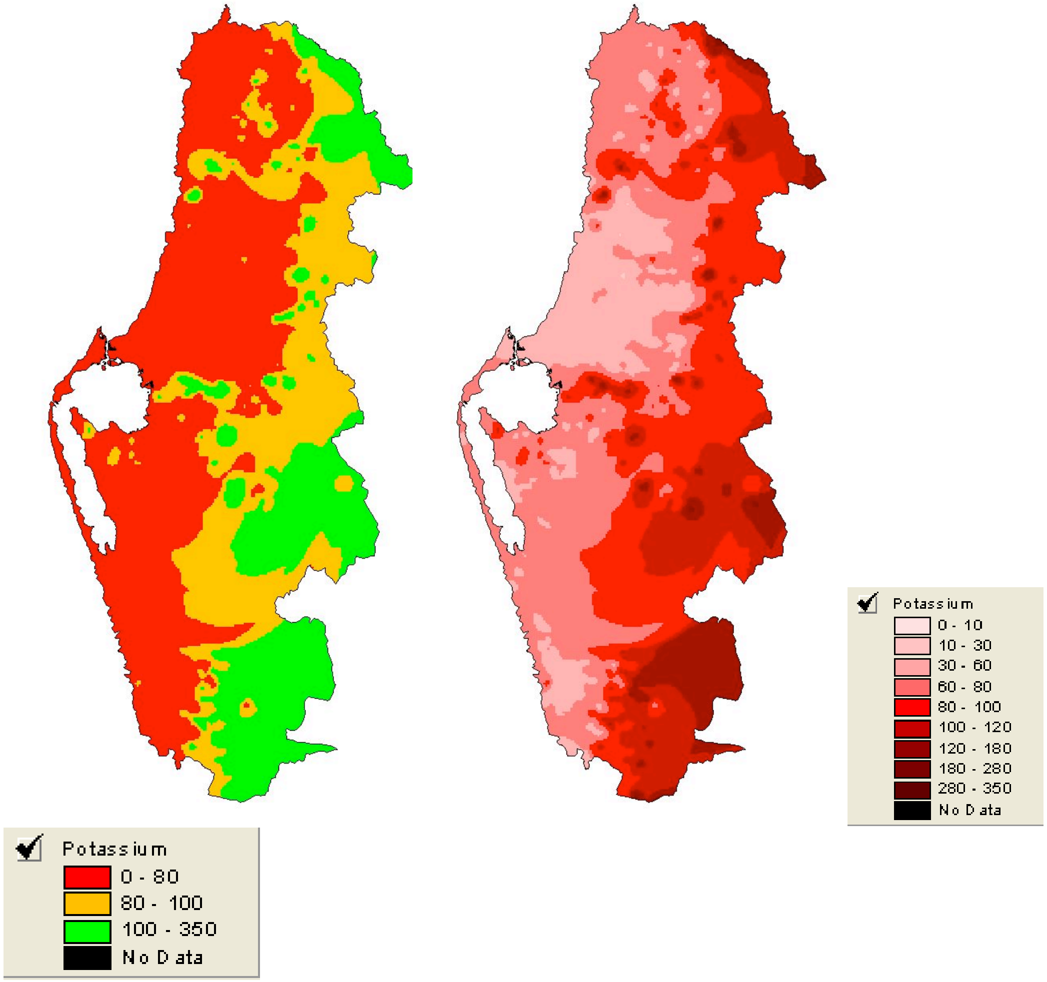


Figure 39. Potassium distribution maps showing the potassium status (left) and the actual potassium levels (right).

All Soils
Summary of POTASSIUM
No Selector
15648 total cases of which 275 are missing

Count	15373
Mean	84.1064
Median	67
StdDev	66.0387
Min	2
Max	1857
Range	1855

1982 to 1991

```
Summary of      POTASSIUM
15648 total cases of which 589 are missing

Count     15059
Mean      83.9989
Median    67
StdDev    65.7748
Min       2
Max       1857
Range     1855
```

2006

```
Summary of      POTASSIUM
15648 total cases of which 15334 are missing

Count     314
Mean      89.258
Median    66
StdDev    77.5989
Min       14
Max       745
Range     731
```

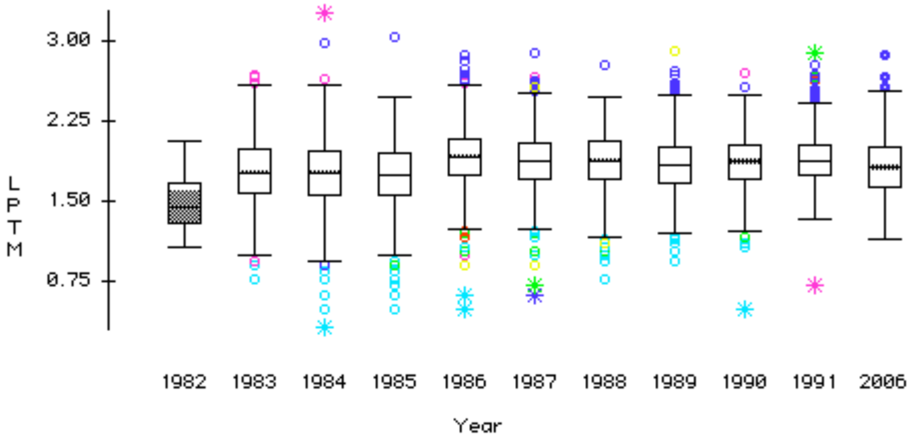


Figure 40. Log potassium through time

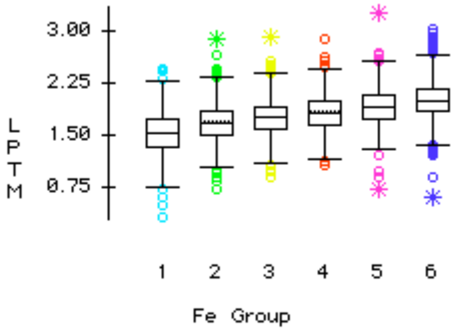


Figure 41. Log K as a function of Fe group

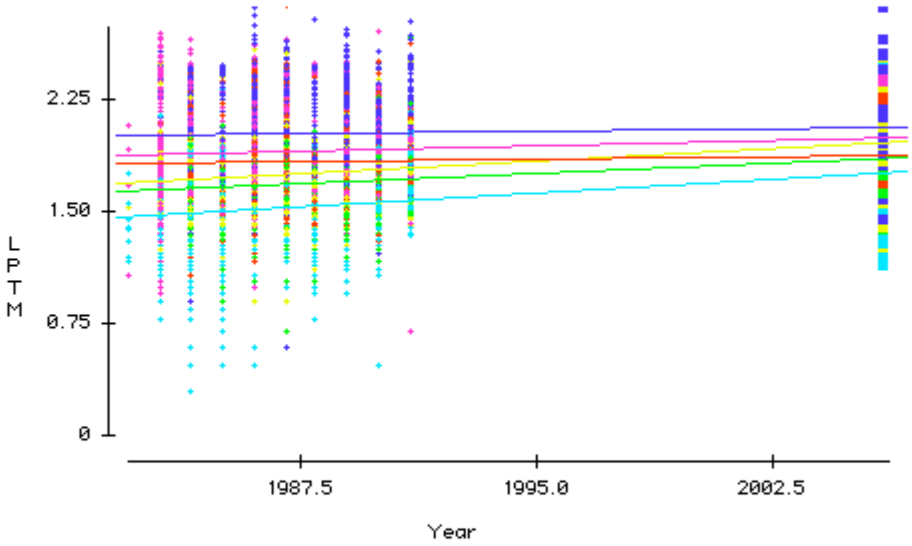


Figure 42. Log Potassium through time in different Fe groups

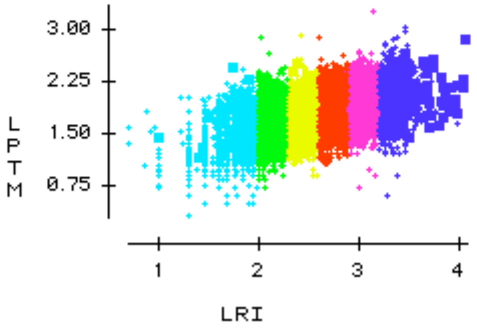


Figure 43. Log K as a function of Log Fe

Table 21. Potassium status through time

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	2006	total
Low	86.7	65.5	65.5	69.1	47.1	53.4	50.7	61.3	53.5	55.5	61.5	60.5
Medium	6.67	12.1	11.4	12.2	16.3	15.4	15.9	12.5	15.9	16	11.5	13.4
High	6.67	22.4	23	18.6	36.7	31.3	33.4	26.2	30.6	28.4	27.1	26.1
total	100	100	100	100	100	100	100	100	100	100	100	100

Conductivity

There is no trend in electrical conductivity (EC) throughout the entire sampling period and no difference between years (Figure 43). The 1982 and 1983 datasets appear to be anomalous, but this is very likely to be because of different undocumented units being used when the project first started. The EC increases with increasing reactive iron (Figure 44). The distribution of EC over the catchment appears to be the result of heavier soils and poor drainage (Figure 45).
really needs to be converted to ECe using soil texture so that classes can be identified. This will be possible when the points are tagged based on a coarse scale soils map.

All Soils

```
Summary of      NewEC
No Selector
15648 total cases of which 301 are missing

Count   15347
Mean    33.8032
Median  13.7
StdDev  95.964
Min     0.01
Max     4127.27
Range   4127.26
```

Legacy

```
Summary of      NewEC
cases selected according to         Selected [Untitled.xls]Sheet1
15648 total cases of which 617 are missing

Count   15031
Mean    33.7663
Median  13.7
StdDev  90.7648
Min     0.01
Max     4090.91
Range   4090.9
```

SWCC soils

```
Summary of      NewEC
cases selected according to         Selected [Untitled.xls]Sheet1
15648 total cases of which 15334 are missing

Count   314
Mean    20.5201
Median  12.45
StdDev  30.4921
Min     1.9
Max     346.2
Range   344.3
```

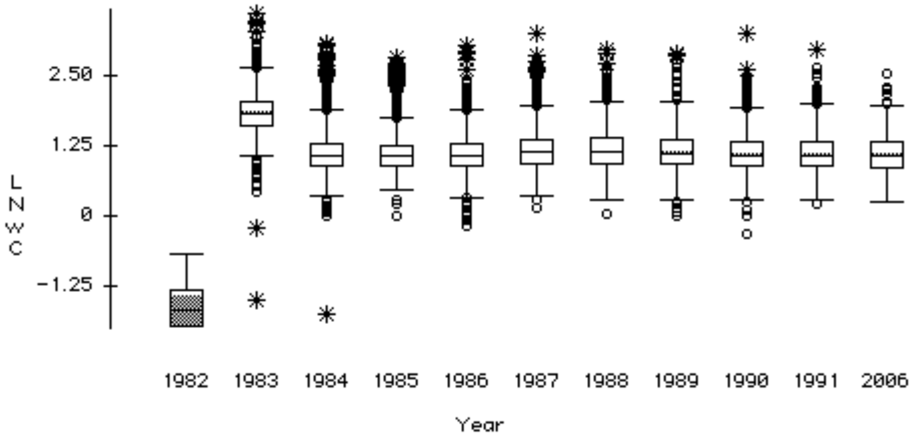


Figure 43. Log EC through time

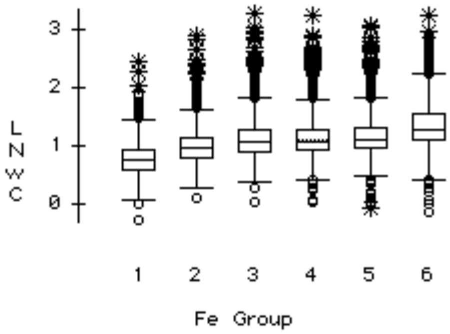


Figure 44. LogEC as a function of Fe group

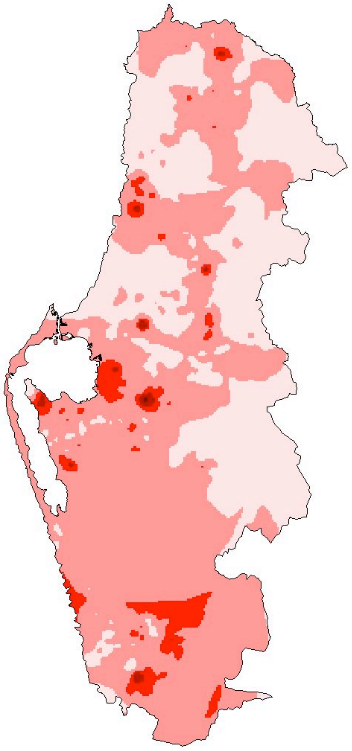


Figure 45. Soil EC surface – darker shades = higher EC.

Organic Carbon

Organic carbon analysis was only carried out on the 2006 samples. The organic carbon was greater in the higher reactive iron soils throughout the depth of the soil profile (Figure 46) and is higher in the topsoil. The organic carbon has increased slightly since clearing (Figure 47).

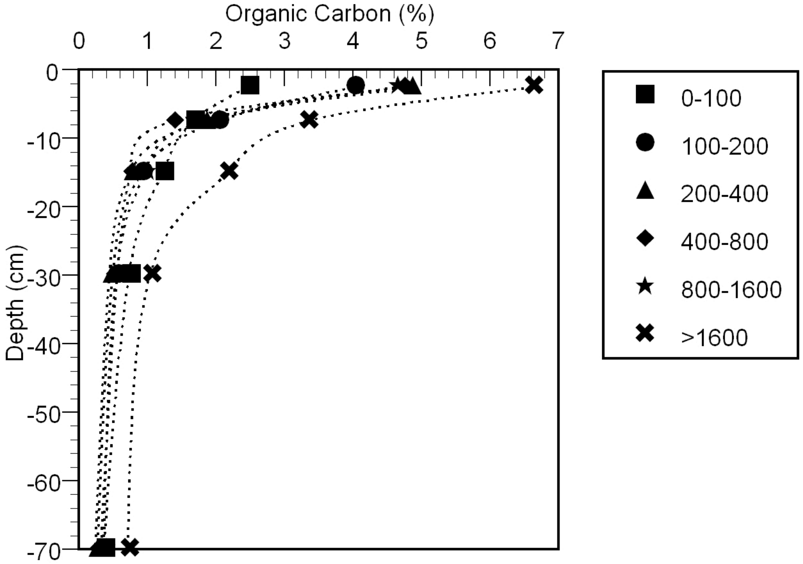


Figure 46. Organic carbon in the soil profile by reactive iron groups.

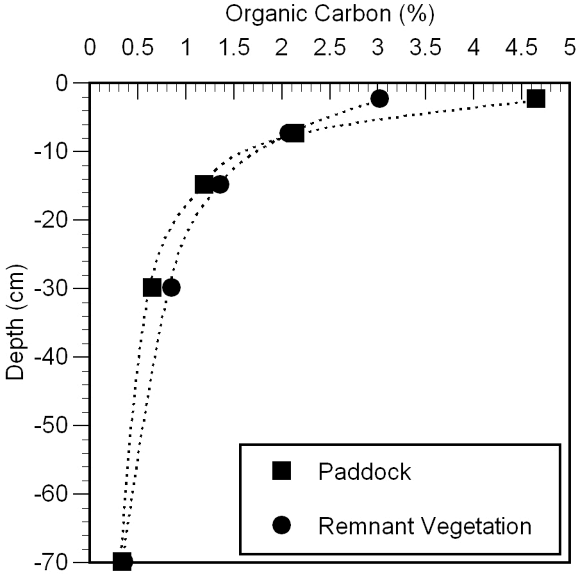


Figure 47. Organic carbon in the soil profile.

Soil data overview

Increasing OC increases BicP, BicK, TP, PRI but decreasing pH.

Higher PRI results in higher BicP, TP, BicK

Saltier soils have higher PRI, TP, BicP, Bic K. When combined with an eastward increase in PRI, TP, BicP and BicK. This makes sense as the better soils are further away from the coast, and probably have poorer drainage which would increase the salinity risk. BicP/Fe also decreases in an easterly direction suggesting better soils are inland. This is supported by an increase in Fe in an easterly direction.

BicP, BicK, pH have been increasing through time although some of these may not be significant – eg P.

BicP, TP, PRI and Fe are all correlated well.

Table 22. Spearman Rank multiple correlation

	BicP	BicK	ORGC…	Fe	EC	pHCaCl	PH_H2O	PRI	TP	Year	easting	northing
Phosphorus	1.000											
POTASSIUM	0.505	1.000										
ORGCARBON	0.268	0.455	1.000									
Reactive Ir…	0.708	0.540	0.310	1.000								
CONDUCTY	0.338	0.272	0.393	0.467	1.000							
pHCaCl2	0.234	0.295	-0.144	0.300	0.223	1.000						
PH_H2O	-0.131	0.091	-0.261	-0.139	-0.220	0.702	1.000					
PHOS_RET…	0.634	0.236	0.184	0.863	0.504	0.286	-0.013	1.000				
TOTALP	0.853	0.473	0.430	0.838	0.621	0.303	0.017	0.782	1.000			
Year	0.017	0.145	•	0.094	-0.225	0.086	0.026	•	•	1.000		
NewEasting	0.274	0.173	-0.073	0.232	0.017	0.025	-0.089	0.347	0.333	0.050	1.000	
NewNorthing	-0.039	-0.106	-0.288	-0.012	-0.083	-0.055	-0.046	0.075	0.012	0.041	0.507	1.000

Table 23. Spearman Rank Correlation

	Phosph…	POTA…	ORGC…	Reacti…	EC	pHCaC…	PH_H2O	PHOS_…	TOTA…	Year	NewEa…	NewN…	BicP/Fe
Phosphorus	1.000												
POTASSIUM	0.505	1.000											
ORGCARBON	0.268	0.455	1.000										
Reactive Ir…	0.708	0.540	0.310	1.000									
EC	0.338	0.272	0.393	0.467	1.000								
pHCaCl2	0.234	0.295	-0.144	0.300	0.223	1.000							
PH_H2O	-0.131	0.091	-0.261	-0.139	-0.220	0.702	1.000						
PHOS_RET…	0.634	0.236	0.184	0.863	0.504	0.286	-0.013	1.000					
TOTALP	0.853	0.473	0.430	0.838	0.621	0.303	0.017	0.782	1.000				
Year	0.017	0.145	•	0.094	-0.225	0.086	0.026	•	•	1.000			
NewEasting	0.274	0.173	-0.073	0.232	0.017	0.025	-0.089	0.347	0.333	0.050	1.000		
NewNorthing	-0.039	-0.106	-0.288	-0.012	-0.083	-0.055	-0.046	0.075	0.012	0.041	0.507	1.000	
BicP/Fe	-0.075	-0.249	-0.165	-0.710	-0.275	-0.166	0.095	-0.572	-0.274	-0.124	-0.054	-0.012	1.000

Appendices

Modelling information

To construct models and allow the capacity for risk of nutrient loss to be quantified, it is important to have a measure of total phosphorus in the soil. This is a relatively expensive analysis and is seldom part of an agronomic soil test, however there appears to be a strong relationship with several parameters commonly used in the soil test which is discussed below. This allows a surrogate assessment of total phosphorus to be made for input into an evaluation of risk factors either provided with the soil test or in conjunction with a soil test when considering both agronomic and environmental factors.

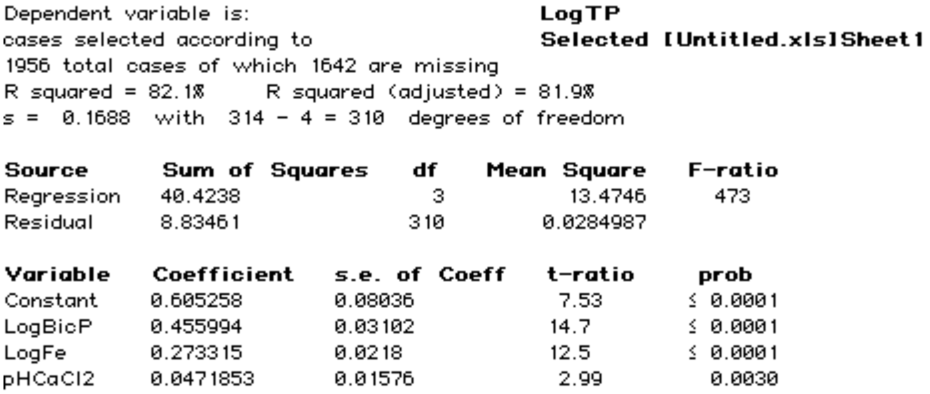
Management implications of the relationship between total P and other agronomic data:

Of interest is the relationship between total phosphorus and ph ($CaCl_2$), organic matter and content as there is some control over these. Liming the soil can be seen to increase the retention of phosphorus

The association between total phosphorus and reactive iron or phosphorus retention index is expected and could also be under the control of the landholder through soil amendment of sandy soils.

An analysis of the data from the soils sampled in 2006 SWCC sampling in the Peel-Harvey shows a strong relationship that can be used to derive the total phosphorus level with a high degree of confidence from the standard agronomic tests (Figure 48).

For 0-10 cm paddock soils in Peel Harvey: New ones with total P (326 samples)



```
Dependent variable is:                    LogTP
cases selected according to               Selected [Untitled.xls]Sheet1
1956 total cases of which 1642 are missing
R squared = 82.1%     R squared (adjusted) = 81.9%
s =  0.1688  with  314 - 4 = 310  degrees of freedom

Source       Sum of Squares    df    Mean Square    F-ratio
Regression    40.4238            3       13.4746      473
Residual      8.83461          310      0.0284987

Variable     Coefficient    s.e. of Coeff    t-ratio     prob
Constant     0.605258       0.08036           7.53       ≤ 0.0001
LogBicP      0.455994       0.03102          14.7        ≤ 0.0001
LogFe        0.273315       0.0218           12.5        ≤ 0.0001
pHCaCl2      0.0471853      0.01576           2.99         0.0030
```

logTP=0.605+0.455*logBicP +0.273*logFe+ 0.047*pHCaCl2

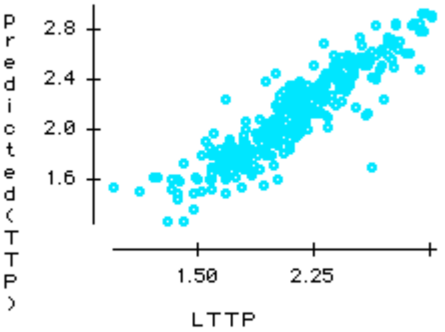


Figure 48. Predicted total phosphorus and actual phosphorus using the above regression equation from the Peel-Harvey.

For 0-10 cm paddock soils in Albany:

```
Dependent variable is:                        LogTP
No Selector
919 total cases of which 497 are missing
R squared = 74.9%     R squared (adjusted) = 74.7%
s =  0.1335  with  422 - 4 = 418  degrees of freedom

Source       Sum of Squares    df     Mean Square    F-ratio
Regression   22.2447            3          7.4149     416
Residual     7.44634          418       0.0178142

Variable     Coefficient     s.e. of Coeff    t-ratio      prob
Constant     0.463223        0.05947            7.79       ≤ 0.0001
LogBicP      0.586508        0.02698           21.7        ≤ 0.0001
LogFe        0.186714        0.01856           10.1        ≤ 0.0001
PHCACL2      0.112785        0.01256            8.98       ≤ 0.0001
```

logTP=0.463+0.586*logBicP +0.187*logFe+ 0.112*pHCaCl2

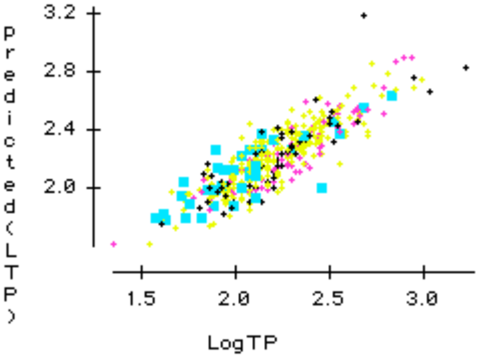


Figure 49. Predicted versus actual using the above regression.

The subset of samples from Albany from 1992 were also analysed for total phosphorus and the same predictions from the agronomic analyses can be made and the correlations

Using the Albany equation the Total P for the 0-10 cm of the paddock soils in the Peel Harvey was then predicted. The following shows how well the Albany equation predicts the Peel Harvey Total P, and the graph shows the actual TPs for Peel Harvey 0-10 cm soils as a function of what the Albany equation predicts.

```
Dependent variable is:                          LogTP
cases selected according to                     Selected [Untitled.xls]Sheet1
1956 total cases of which 1642 are missing
R squared = 80.0%     R squared (adjusted) = 80.0%
s =  0.1775  with  314 - 2 = 312  degrees of freedom

Source        Sum of Squares    df     Mean Square    F-ratio
Regression    39.4264            1        39.4264      1.25e3
Residual      9.83196          312       0.0315127

Variable      Coefficient     s.e. of Coeff     t-ratio      prob
Constant      0.045035        0.06007            0.75         0.4540
AlbPredict    0.938343        0.02653           35.4        ≤ 0.0001
```

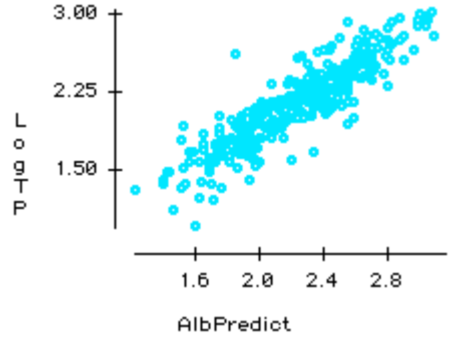


Figure 50. Predicted total phosphorus and actual phosphorus using the above regression equation from Albany

Both sets of data together

```
Dependent variable is:                     LogTP
No Selector
790 total cases of which 54 are missing
R squared = 77.2%     R squared (adjusted) = 77.1%
s =  0.1578  with  736 - 4 = 732  degrees of freedom

Source        Sum of Squares    df     Mean Square    F-ratio
Regression    61.8746            3        20.6249       828
Residual      18.2308          732       0.0249055

Variable      Coefficient     s.e. of Coeff     t-ratio      prob
Constant      0.633723        0.04871           13          ≤ 0.0001
LogFe         0.224546        0.01452           15.5        ≤ 0.0001
LogBicP       0.534916        0.02076           25.8        ≤ 0.0001
PHCACL2       0.057948        0.01001            5.79       ≤ 0.0001
```

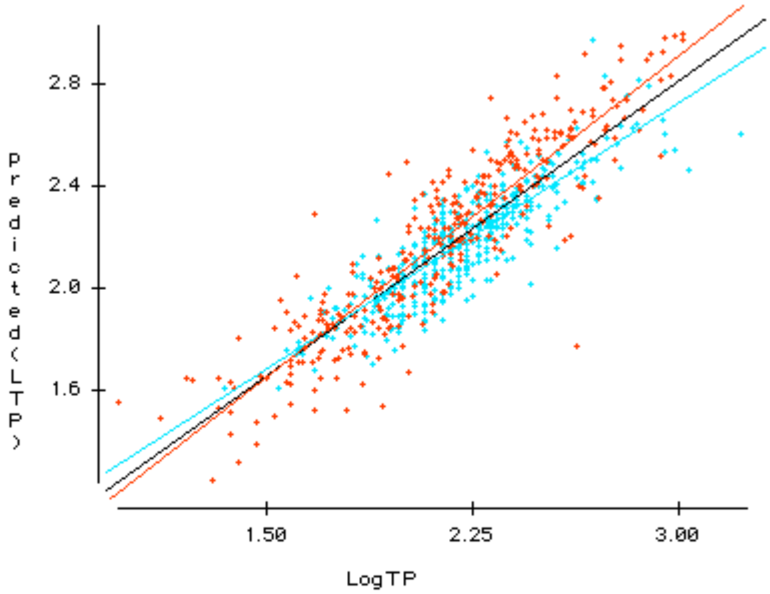


Figure 51. Predicted total phosphorus and actual phosphorus using the above regression equation from Albany and Peel-Harvey. Blue points = Albany; Red points = Peel; Black line is regression through both data sets.

When both sets of data are combined the datasets can be seen to be very closely related and they can be considered to have the same relationship for the purposes of prediction.

References:

Allen DG, Jeffery RC (1990) Methods of analysis of P in Western Australian Soils. Report of Investigation No. 37, Chemistry Centre of Western Australia, East Perth.

Blackemore, L. C., Searle, P.L. and Daly, B.K. (1977). Methods of analysis of soils. N.Z. Bur. Sci. Rep 10A.

Colwell, J. D. (1965). An automatic procedure for the determination of phosphorus in sodium hydrogen carbonate extracts of soil. Chem. Ind. Pp 983-895.

Jeffery, R. (1982). Annual technical report No. 2. Agricultural Chemistry Laboratory, Government Chemical Laboratories, Perth Western Australia, 11pp.

Murphy, J., and Riley, J.P. (1962). A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta. 27, 31-36.
Rayment, G.E. and Higgison, F.R. (1992) Australian Laboratory Handbook of soil and Water Chemical Methods. Inkata Press, Melbourne.

Schofield, R. K. and Taylor, A. W. (1955). The measurement of soil pH Soil Sci. Soc. Am. J. Proc. 19, 164-167.

Tamm, O. (1922). Eine Methode zur Bestimrnung de der anorganischen Komponente des Bodens. Meddelanden fran Statens skogsoksanstalt Stockholm 19, 387-404.

Walkley, A. and Black, I. (1934). An examination of the Degtejareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci. 37, 29-38.

Annotated bibliography of references to phosphorus saturation

Kleinman-PJA, Bryant-RB, Reid-WS (1999) Development of pedotransfer functions to quantify phosphorus saturation of agricultural soils. Journal of Environmental Quality, 28, 2026-2030
Soil P saturation affects the risk of P loss to surface and ground water and is therefore a critical environmental indicator in regions where eutrophication is a concern. In the USA, most soil testing laboratories do not include environmental indicators such as son P saturation as standard soil test options. Development of pedotransfer functions that relate soil test data to soil P saturation, however, would enable soil testing laboratories to estimate soil P saturation as part of soil test results without significant additional expenditures. This study examines associations between readily-available soil test data (pH, soil organic matter, and extractable P, Al, Fe, and Ca) and soil P saturation as estimated by add ammonium oxalate extraction. Fifty-nine soil samples were collected from the Delaware River Watershed in New York State (42 degrees 21'N, 74 degrees 52'W) and subjected to standard soil test analyses as well as to acid ammonium oxalate extraction. Some soil test variables were well correlated with soil P saturation. As a single predictor, soil test P was most highly correlated to soil P saturation (r = 0.88). This association supports the use of soil test P as an environmental indicator. Soil test Al also was well: correlated with soil P saturation following logarithmic transformation (r = 0.73). Multivariate pedotransfer functions containing soil test P, Al, Fe, soil organic matter, and pH did not significantly improve estimation of soil P saturation (R = 0.91) above soil test P alone. [References: 22]

Behrendt-H, Boekhold-A (1994) Phosphorus saturation in soils and groundwaters. Land Degradation and Rehabilitation, 4, 233-243

Beauchemin-S, Simard-RR (1999) Soil phosphorus saturation degree: Review of some indices and their suitability for P management in Quebec, Canada. Canadian Journal of Soil Science, 79, 615-625
Many agricultural fields contain excessive labile soil P in regard to crop needs. Its environmental fate must be assessed. The concept of P saturation degree is meaningful as it describes the portion of the soil binding sites already covered with P, and indicates the potential desorbability of soil P. The first objective of this study was to review different indices that have been proposed to estimate the degree of soil P saturation and the relationships between soil P saturation degree and P solubility. The second objective is to discuss their suitability as environmental indicators for P management in the province of Quebec, Canada. In the Netherlands, the P saturation index is defined as the ratio of P to Al + Fe contents extracted by ammonium oxalate [P-ox/(Al-ox + Fe-ox) or (P-ox/0.5(Al-ox + Fe-ox)]. This approach has been mainly used with non-calcareous soils. In Quebec, the ratio of Mehlich-III extractable P to Al (M3P/AlM3) is proposed as an alternative, which relies on routine laboratory test. However, the suitability of the M3P/AlM3 ratio has yet to be determined for some specific soil groups (e.g. gleyed soils, soils with Al-ox content >6 g kg(-1)) and for Subsoil horizons. Regardless of the chosen index, it is suggested that the best way to manage the risk of water contamination by P in Quebec (namely, defining critical levels of soil P saturation) may be to form homogeneous soil groups to account for their distinctive behaviour and characteristics. [References: 63]

Pautler-MC, Sims-JT (2000) Relationships between soil test phosphorus, soluble phosphorus, and phosphorus saturation in Delaware soils. Soil Science Society of America Journal, 64, 765-773
Methods to identify agricultural soils that contribute to nonpoint-source pollution of surface waters by P are of increasing importance, particularly in areas with high animal densities (animal units per hectare of cropland). Our objective was to determine the relationship between agronomic: soil test P (STP = Mehlich 1) and other soil P tests proposed to measure the potential for P loss by erosion, runoff, and leaching. We compared STP with soluble P, P in the "fast desorbing pool" (strip P), and soil P saturation for 127 soils (122 from Delaware and five from the Netherlands). Soil test P was significantly correlated with total P (r = 0.57***, significant at the 0.001 level), soluble P (r = 0.71***), strip P (r = 0.84***), and oxalate-extractable P (P-ox; r = 0.84***). Strip P was a better predictor of soluble P than STP (r(2) = 0.76***). The ratio of strip P/P-ox (the percentage of reversibly sorbed P in the fast desorbing pool) increased as P sorption capacity,

estimated from oxalate-extractable Al and Fe (Al-ox + Fe-ox), decreased. We also determined the degree of P saturation (DPS) using three methods: Langmuir P sorption isotherms; oxalate extractions of P, Al, and Fe; and STP plus a single-point P sorption index (PSI). Soluble P, STP, and desorbable P increased for DPS values >30%, similar to upper DPS limits in the Netherlands and Belgium. Soils rated agronomically excessive in STP (>50 mg kg(-1)) had higher ratios of soluble P, strip P, and P-ox to total P than those in agronomically optimum or lower categories. [References: 50]

Hughes-S, Reynolds-B, Bell-SA, Gardner-C (2000) Simple phosphorus saturation index to estimate risk of dissolved P in runoff from arable soils. Soil Use and Management, 16, 206-210
There is increasing evidence that phosphorus has been accumulating in the surface horizons of agricultural soils to the extent that some soils represent a potential diffuse source of pollution to surface waters. The relationships between equilibrium phosphorus concentration at zero sorption (EPCo) of soil and a number of soil physicochemical variables were investigated in the surface layers of arable and grassland agricultural soils sampled from the Thame catchment, England. Soil EPCo could be predicted from an equation including soil test (Olsen) P, soil phosphate sorption index (PSI) and organic matter content (OM) (R-2 = 0.88; P<0.001) across a range of soil types and land use. The simple index Olsen P/PSI was found to be a good predictor of EPCo (R-2 = 0.77; P<0.001) and readily desorbable (0.02 M KCl extractable) P (R2 = 0.73; P<0.001) across a range of soil types under arable having soil organic matter contents of <10%. [References: 30]

Nair-VD, Graetz-DA (2002) Phosphorus saturation in spodosols impacted by manure. Journal of Environmental Quality, 31, 1279-1285
Significant amounts of phosphorus (P) accumulate in soils receiving animal manures that could eventually result in unacceptable concentrations of dissolved P loss through surface runoff or subsurface leaching. The degree of phosphorus saturation (DPS) relates a soil's extractable P to its P sorbing capacity, and is reportedly a predictor of the P likely to be mobilized from a system. A DPS value (DPS-1) was derived that expressed the percentage of Mehlich I-extractable P to the sorbing capacity of a Spodosol (expressed as the sum of oxalate-extractable Fe and At). Values of DPS-1 were determined in various horizons of soil in current and abandoned dairy systems in South Florida's Lake Okeechobee watershed to assess P release potential. Land use within the dairies was classified as highly impacted by cattle (intensive and holding), and minimally impacted by cattle (pasture, forage, or native) areas. The A and E horizon of soils in heavily manure-impacted intensive and holding areas for both active and abandoned dairies generally had higher DPS-1 values than the pasture, forage, and native area soils, which were minimally impacted by manure. Degree of P saturation was also calculated as a percentage of Mehlich 1-extractable P to the sum of Mehlich I-extractable Fe and Al (DPS-2). Both DPS-1 and DPS-2 were shown to be significantly (P = 0.0001) related to water-extractable P for all soil horizons, suggesting that either index can be used as an indicator for P loss potential from a soil. [References: 30]

Nair VD. Portier KM. Graetz DA. Walker ML. (2004) An environmental threshold for degree of phosphorus saturation in sandy soils. Journal of Environmental Quality, 33, 107-113
There is critical need for a practical indicator to assess the potential for phosphorus (P) movement from a given site to surface waters, either via surface runoff or subsurface drainage. The degree of phosphorus saturation (DPS), which relates a measure of P already adsorbed by a soil to its P adsorption capacity, could be a good indicator of that soil's P release capability. Our primary objective was to rind a suitable analytical protocol for determining DPS and to examine the possibility of defining a threshold DPS value for Florida's sandy soils. Four farmer-owned dairy sprayfields were selected within the Suwannee River basin and soil profiles were randomly obtained from each site, as well as from adjacent unimpacted sites. The soil samples were divided either by horizon or depth, and DPS was determined for each soil sample using ammonium-oxalate (DPSOx), Mehlich-1 (DPSM1), and Mehlich-3 (DPSM3) extracts. All methods of DPS calculations were linearly related to one another (r(2) > 0.94). Relationships between water-soluble P and DPS indicate that the respective change points are: DPSOx = 20%, DPSM1

= 20%, and DPSM3 = 16%. These relationships include samples from Ap, E, and Bt horizons, and various combinations thereof, suggesting that DPS values can be used as predictors of P loss from a soil irrespective of the depth of the soil within a profile. Taking into consideration the change points, confidence intervals, agronomic soil test values, and DPS values from other studies, we suggest replacing Mehlich-1 P values in the Florida P Index with the three DPS categories (DPSM1 = <30, 30-60, and >60%) to assign different P loss ratings in the P Index. [References: 32] Publication Type Article

Tarkalson DD. Mikkelsen RL. (2004) Runoff phosphorus losses as related to soil test phosphorus and degree of phosphorus saturation on piedmont soils under conventional and no-tillage. Communications in Soil Science and Plant Analysis, 35, 2987-3007
Elevated soil phosphorus (P) concentrations on agricultural land from the application of P in fertilizers and animal manures have increased the potential for excessive P losses in runoff to nutrient-sensitive waters. This study was conducted to determine P losses in runoff from agricultural land in the Piedmont region of the southeastern U.S. with varying soil P levels resulting from past applications of broiler litter and inorganic P fertilizers. The correlations between soil P content and P in runoff can be used to validate and develop P loss-assessment tools for Piedmont soils of the southeastern US. Rainfall simulation at rates of 6.35 cm hr(-1) were utilized to collect runoff samples from cropland under conventional tillage (CT) and no tillage (NT) with a range of initial P concentrations. Runoff samples were collected at 5-min intervals for 30 min and analyzed for reactive P (RP), algal-available P (AAP), and total P (TP). Concentration of RP in runoff from CT and NT plots was positively correlated with Mehlich-3 extractable P (M3 STP) (r(2) = 0.70 and 0.67, respectively) and oxalate extractable degree of P saturation (DPS) (r(2) = 0.62 and 0.57, respectively). A Mehlich-3 extractable P concentration of 294 mg P kg(-1) and a DPS of 65% corresponded to I mg RP L-1 in runoff from NT plots. There was a significant linear relationship between M3 STP concentration and DPS on CT and NT plots. Results of this study indicate that both M3 STP concentration and DPS can be used to help predict P losses from a typical Piedmont soil managed with CT and NT cultivation. Overall, these soil tests predicted P concentration in runoff more effectively than P mass losses in runoff. [References: 36] Publication Type Article