RMCG

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# Soil Data Analysis – Reclaimed Water Irrigation Sites

Final Report

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# 1 Introduction

Gippsland Water manages multiple agricultural properties across the central Gippsland region. A key purpose of these sites is sustainable irrigation of reclaimed water from the associated wastewater treatment plants.

RMCG has been engaged to complete analyses of soil data gathered from these agricultural sites. The soil data has already been analysed from an agricultural perspective. This project will focus on analysis in relation to potential for environmental impact.

The objective is to ensure compliance with Gippsland Water's EPA Licence, in particular that *the discharge of wastewater to land must not adversely affect the land*.

The specific sites considered are (from west to east):

- Drouin
- Mirboo North
- Heyfield
- Maffra
- Stratford
- Dutson Downs

All sites are used for beef cattle production, either via direct grazing of stock or production of fodder crops. The irrigation is managed by the Gippsland Water Agribusiness Team.

# 2 Methodology

## 2.1 DATA ANALYSIS

The soils data was provided in an excel format, and all data analyses were completed within excel, including:

- Data cleansing – altering formats and layout within the spreadsheet to enable ease of calculations and trend analysis.
- Calculation of average conditions and identification of outliers in the results. Where required assessment is by paddock or "land management area", to account for varying soil types, irrigation applications and land use.
- Graphing of data trends over time.
- Review of data collection procedures to determine confidence in results.

## 2.2 INTERPRETATION AND REPORTING

Using the outputs of the data analysis, plus supporting site information (e.g. land use, reclaimed water quality, irrigation application rates), consideration is given to potential environmental implications. This is in the form of a risk analysis, through consideration of the likelihood of impact to beneficial uses of the land,

and the consequence if the impact occurs. The risk assessment is guided by the requirements of the Victorian EPA as well as relevant national guidelines.

Key parameters considered are nutrients, salinity, sodicity, pH, organic matter and trace elements. Further discussion is provided below on the risks associated with each.

Recommendations are made as required to respond to the risk levels identified. These include:

- Actions to address the environmental risks identified (e.g. soil amelioration, altered irrigation practices)
- Further analysis required to better understand potential impacts identified
- Actions to improve future soil testing procedures

This project is focused on soil analysis and environmental impact to land. However, soils data can provide indication of potential for impact offsite, e.g. to surface water or groundwater environments. Any issues identified are noted in the following chapters.

A focus on soil data alone, does not necessarily identify all potential environmental hazards. Where we have identified concerns in any particular area, recommendations are given on further analysis that could be undertaken.

Agronomic risk is intricately linked to environmental risk – if the crops don't grow well then they will use less reclaimed water and nutrients leading to increased risk of runoff/leaching to the environment. Agronomic and environmental risk are analysed using very similar soil data, so any agronomic issues identified are noted in the discussions.

## 2.3 PARAMETERS CONSIDERED

### NUTRIENTS

Nutrients are required in soils for healthy plant growth. Australian soils are generally low in nutrients and there is a need to build up nutrient levels to achieve a good level of agricultural production. This can be achieved through application of reclaimed water, compost or other fertilisers.

However, an excess build-up of nutrients can cause toxicity to some plants, leaching to groundwater, or loss to surface waters (via runoff or erosion) leading to eutrophication and algal blooms. There is a need to find a balance between healthy soils for production and low environmental risk.

The risk assessment considers soil nutrient levels combined with nutrient applications (in reclaimed water and compost) and level of nutrient removal (in grain/fodder/beef). Note that phosphorus based fertilizer is not applied to sites where reclaimed water is used[1]. Potassium and nitrogen based fertilisers are only applied in response to soil test results and crop nutrient budgeting. Maintenance nutrient requirements for irrigated beef cattle production are 20 – 40 kg/ha phosphorus (P), 100 – 300 kg/ha nitrogen (N) and 100 – 250 kg/ha potassium (K). The lower end of the range relates to grazing of pastures, while the upper is for fodder cropping.

Soil test results also need to be assessed alongside other site-specific factors such as susceptibility to erosion (slope, soil type), proximity to water bodies and method of nutrient application.

[1] With the exception of Dutson Downs, where irrigation has only recently been developed and the soils need nutrient build up.

Topsoil results are the focus for nutrients, particularly phosphorus as it is readily bound to soil particles. However, subsoil results are also considered to ensure nutrients are not readily leaching through the soil profile (which increases risk to groundwater).

Phosphorus and nitrogen are the most likely nutrients to have potential adverse impacts on the environment. These will be the focus of the assessment.

**Phosphorus**

Several soil extractions are used to determine available soil phosphorus. Common methods are Olsen P and Colwell P and these are part of the suite tested by Gippsland Water, with Colwell P being the extraction common to all sampling undertaken across the years and therefore the focus in this assessment.

These extractions are designed to measure plant available phosphorus (concentration of P in the soil solution). Colwell P is better suited to pH <7.4 (acidic and neutral), while Olsen P is recommended for pH >7.4 (i.e. alkaline). All sites, with the exception of Maffra, have soils in the acidic to neutral range suited to Colwell P testing. Maffra is slightly above this, for the flood irrigated area only, at an average of 7.7 pH.

The Colwell P test extracts more P than the Olsen test – they use the same extraction method, but the Colwell test has extended shake time and an increased soil:solution ratio. However, both tests are not good at picking up organic P forms, which can be at significant levels in reclaimed water and composts. In addition, there is not a well understood link between Colwell/Olsen P levels and risk to the environment. Values for Colwell P also vary depending on soil texture and a soil's Phosphorus Buffering Index (PBI), which is generally not available for sampling undertaken to date[2]. Where the analysis identifies high levels based on the Colwell assessment (refer to Table 2-1), we recommend PBI and Mehlich P testing in future to enhance the accuracy of site management decisions made. Research shows that Mehlich P more accurately predicts risk to the environment (Sims et al, 2002). A discussion paper is provided in Appendix 1 with more information on sampling for phosphorus.

**Table 2-1: Colwell Phosphorus (mg/kg) Availability Ranges (Blaesing, 2006)**

| SOIL TYPE | LOW | MARGINAL | OPTIMAL | HIGH |
|---|---|---|---|---|
| Sand – Sandy Loam | <30 | 30 – 50 | 50 – 100 | >100 |
| Clay – Clay Loam | <30 | 30 – 70 | 70 – 120 | >120 |

**Nitrogen**

Nitrogen is very mobile and nitrogen compounds are constantly cycling within the soil, so soil test results can be a poor indication of the amount of nitrogen in the soil. To achieve the best value, nitrogen tests need to be calibrated for particular crops within a defined area and on a specific soil type. Given the difficulty in achieving this calibration, we instead propose to consider the soil test results in combination with other indicators, including application rates and crop uptake. Where risk is high, we recommend consideration is given to monitoring of groundwater quality and rainfall runoff quality.

The following indicative ranges (Wrigley & Dillon, 2000) are considered in assessment of the sampling results. Both nitrate and ammonium test results are available and considered.

2 Other than for 2008 sampling at Dutson Downs.

- Nitrate values tend to range from 1 – 30 mg/kg and occasionally up to 60 mg/kg with 20 – 30 mg/kg being adequate.
- Ammonium levels are generally lower than nitrate levels and are not considered to be as important as the more available nitrate nitrogen and are therefore relied upon less. Values tend to range from 1 – 20 mg/kg and values >10 mg/kg are considered adequate.

Within the discussion for each site, nutrient inputs and outputs are considered. A summary of this nutrient balance information for all sites is included in Appendix 2.

**Salinity and sodicity**

The main areas of concern in relation to salts are:

- increase in soil root zone salinity – this impacts on a plants ability to extract water from the soil. It also increases risk of salts leaching to groundwater or being carried to surface waters.
- foliar uptake by crops (causing leaf burn) – relevant to spray irrigation only, and more an agronomic issue than environmental.
- soil structure decline (sodicity) – a chemical imbalance caused by sodium replacing other cations on soil materials leading to reduced soil permeability. In regards to environmental risk, the issue is potential for increased site runoff.
- leaching causing rise in groundwater salinity – risk is dependent on soil type (permeability) and soil salinity (see first point above).
- surface run-off from the site carrying salt into creeks and rivers – risk here relates to irrigation application method, site conditions such as slope and soil type, and also soil salinity (as discussed above).

As noted, salts have potential for both environmental and agronomic impacts. The focus here will be on the environmental concerns. However, any agronomic issues noted from the data will be raised for consideration by Gippsland Water.

Soil **salinity** has been measured based on the electrical conductivity of a 1:5 soil:water solution ($EC_{1:5}$). Published data on the salt tolerance of crops refers to the electrical conductivity of a saturation extract ($EC_e$), but the expense involved in testing for this is high. An approximate $EC_e$ value can instead be determined by multiplying the $EC_{1:5}$ result by a soil texture factor as listed in Table 2-2.

**Table 2-2: Soil texture factors for converting $EC_{1:5}$ to $EC_e$**

| SOIL | MULTIPLICATION FACTOR |
|---|---|
| Sands, Loamy sands | 13 |
| Sandy loams, Fine sandy loams | 11 |
| Loams, Silty loams, Sandy clay loams | 10 |
| Clay loams, Silty clay loams, Fine sandy clay loams | 9 |
| Sandy clays, Silty clays, Light clays | 9 |
| Light medium clays | 8 |
| Medium clays | 7 |
| Heavy clays | 6 |

Table 2-3 lists soil salinity classes ranging from very low to extreme, and the corresponding $EC_e$ values. Indicative tolerance for pasture species is also provided.

**Table 2-3: Soil salinity classes**

| CLASS | $EC_e$ (dS/m) | WILL GROW |
|---|---|---|
| A+ Very low | <1.8 | All pasture, white clover |
| A Low | 1.8 – 3.8 | Most pastures, legumes |
| B Moderate | 3.8 – 6.5 | Grass, some legumes |
| C High | 6.5 – 8.6 | Grass but not clover |
| D Extreme | >8.6 | Some barley grass. Salt tolerant plants. |

**Sodicity** is assessed based on a soils Exchangeable Sodium Percentage (ESP), which considers the balance between sodium and the sum of the exchangeable cations (Sodium Na, Magnesium Mg, Calcium Ca and Potassium K). In Australia the demarcation point between non-sodic and sodic soil is at ESP = 6. This differs from US practice where an ESP of 15 divides a non-sodic soil from a sodic soil. In this assessment we consider the risk levels provided in Table 2-4.

**Table 2-4: Soil Sodicity (ESP)**

| ESP | RISK LEVEL | COMMENT |
|---|---|---|
| <6 | Low | Non-sodic. Insufficient proportion of Na to cause dispersion. |
| 6 – 15 | Medium | Potential soil structural problems. |
| >15 | High | Likely soil structural problems (dispersion). |

**Other**

Other parameters to be considered will include soil pH, soil organic matter, structural stability and trace elements.

**Soil pH** indicates soil acidity or alkalinity. Extreme levels can cause nutrient deficiency, toxicity and soil structural problems. Most agricultural plant species prefer a pH range of 5.8 – 7.5, although there is considerable variation with species (Wrigley and Dillon, 2000).

For strongly acidic soils, at pH <5.5, aluminium becomes available and can be toxic to plants. When pH falls below 5.5 (or even 6.0), lime should be applied to reduce acidity.

As soils become alkaline (i.e. pH >8.2), the ESP (sodicity) of the soil can be increased due to the precipitation of calcium and magnesium bicarbonates and carbonates, reducing the permeability and structure of the soil.

**Soil organic matter** can influence a soil's physical behaviour in relation to water (potential for waterlogging and runoff) as well as impacting on plant production levels. This is assessed based on Cation Exchange Capacity (CEC) results. The magnitude of soil CEC depends on clay mineralogy, levels of organic matter, presence of iron and aluminium oxides etc. However, there is an almost direct relationship between the

CEC of a soil and its level of organic matter as shown in Table 2-5. Thus, CEC is an indirect measure of the level of soil organic matter.

**Table 2-5: CEC ratings and organic matter levels**

| CEC (cmol/kg) | RATING |
|---|---|
| <5 | Very Poor, requires organic matter addition |
| 5 – 10 | Poor, organic matter addition recommended |
| 10 – 15 | Marginal (agriculturally), addition of organic matter likely to be beneficial |
| 15 – 20 | Good |
| >20 | Excellent |

The Ca/Mg ratio is an indicator of **structural stability** and results are interpreted as outlined in Table 2-6.

**Table 2-6: Ca/Mg ratio and soil stability**

| Ca/Mg RATIO | INTERPRETATION | COMMENTS |
|---|---|---|
| <1.0 | Very Poor | Large imbalance between Ca/Mg. Definite loss of structure. |
| 1.0 – 1.8 | Poor | Considerable imbalance between Ca/Mg. Probable loss of structure. |
| 1.9 – 2.0 | Marginal | Structural problems may be evident. Balance marginal. |
| 2.1 – 2.5 | Satisfactory | A good balance exists to promote flocculation. |
| >2.5 | Excellent | An abundance of calcium ions to promote flocculation. |

**Trace elements** (e.g. boron, iron, sulfur) can either be deficient for good plant production or toxic to plants, and this can vary according to soil pH. Table 2-7 provides figures for the elements to be considered in this assessment.

**Table 2-7: Trace Element Limits (mg/kg)**

| ELEMENT | DEFICIENT FOR GOOD PRODUCTION | POTENTIALLY TOXIC TO PLANTS | SOIL CONTAMINATION LIMIT[3] |
|---|---|---|---|
| Boron[4] | <0.15 | >2.0 | |
| Copper | | >10 | 100 |
| Iron | <0.03 | | |
| Molybdenum (pH = 5) | <0.2 | >0.8 | |
| Molybdenum (pH 6 – 8) | <0.05 | >0.3 | |
| Selenium | | | 3 |
| Sulfur | <4 | >12 | |
| Zinc | <0.7 | | 200 |

[3] The soil contamination limit is as outlined in the EPA Victoria *Guidelines for Environmental Management - Biosolids Land Application*, Publication 943, 2004. Note that the Health Investigation Levels developed for metals and organic substances are significantly higher that the figures considered here (see National Environment Protection Measures, 2013).

[4] Crop species vary in their tolerance of boron. Where boron is <0.5 mg/kg soils will not be toxic to plants. Between 0.5 and 2.0 mg/kg, sensitivity of crops will need to be considered. At > 2.0 mg/kg only crops tolerant to boron are appropriate. Note that pastures and fodder crops are generally tolerant. Therefore, provided boron levels remain below 2.0 mg/kg, soils are considered suitable.

# 3 Results and Discussion

## 3.1 DROUIN

The Drouin site is irrigated via centre-pivots. There are five in total, covering an area of just over 80 ha. Duplex soils are predominant, with clay loams overlying mottled clays. Permeability of the subsoils is low.

Class C reclaimed water is used, with 325 mg/L salinity (total dissolved solids), 2 mg/L Total P and 12 mg/L Total N.

Topsoil and subsoil testing is available for all pivot areas in 2013 and 2015. In 2016, there were four tests undertaken for the irrigated areas across three of the pivots. Baseline sampling (prior to irrigation) is not available, but results for dryland paddocks provide a reference point. Results are summarized in Table 3-1 and Figure 3-1.

The key issue of concern for Drouin is the very high soil phosphorus levels.

Centre-pivot areas 1 and 2, which cover an area of approximately 35 ha, have had milk waste applied in the past which has substantially increased phosphorus levels. However, test results over the last few years show erratic trends and large changes in results within just a year (refer to Figure 3-1). This could be due to inconsistencies in the testing procedure[5] or the high phosphorus levels may be making accurate testing difficult. There is potential risk to the environment through contamination of rainfall runoff.

Further soil sampling is recommended for phosphorus, including Mehlich P and Phosphorus Buffering Index testing for soil, and monitoring of rainfall runoff quality. Refer to Appendix 1 for further discussion.

Note that the application of phosphorus through irrigation is very low – due to a combination of low phosphorus levels in the reclaimed water and limited volume of irrigation[6]. Phosphorus levels in Pivot areas 1 and 2 are historic (as noted above). However, levels in Pivot areas 3 and 4 have also increased significantly in recent years. This is only partly in response to compost application – in 2012, 3 tonnes per hectare of compost was applied, adding approximately 12 kg/ha phosphorus (and 45 kg/ha nitrogen). The increasing soil levels are not clearly explained by recent reclaimed water and compost applications.

No additional phosphorus fertiliser should be applied to the site. To increase removal of phosphorus, it is recommended that fodder cropping occurs, rather than grazing of the irrigated areas. Particularly for Pivot areas 1 and 2.

Soil nitrogen levels are very low. Application rates from reclaimed water have been <25 kg/ha. This is well below crop uptake rates. Nitrogen fertiliser is likely to be required to maintain good crop production.

Organic matter addition is also recommended as cation exchange capacity is poor. This will help to retain water and nutrients within the plant root zone.

Assessment of trace elements has identified that molybdenum may be toxic to some plants.

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[5] For example, testing may have occurred when it was too wet – it is a high rainfall site, so it can be difficult to find a suitable testing window.

[6] This site receives relatively high rainfall and therefore irrigation demand is low. Reclaimed water is also discharged under licence to Shillinglaw Creek.

**Table 3-1: Summary of Soil Results for Drouin**

| PARAMETER | 2016 MEAN | 2016 RANGE | TREND | RISK LEVEL | COMMENTS |
|---|---|---|---|---|---|
| pH | 6.1 | 5.8 – 6.4 | Slight increase | Low | Slightly acidic, but within preferred range for most plants. |
| Colwell P (mg/kg) | 312 | 111 – 654 | Erratic | High | Levels are high for all test sites in 2016 – particularly Pivot 1. However, trends are erratic (refer to graph below). |
| Nitrate N (mg/kg) | 5.6 | 2.6 – 7.7 | Stable | Very low | |
| Ammonium N (mg/kg) | 6.0 | 1.8 – 13.0 | Stable | Low | |
| Salinity (ECe dS/m) | 1.1 | 0.6 – 2.0 | Stable | Very low | |
| Sodicity (ESP %) | 8.8 | 3.9 – 11.1 | Stable | Low | Technically sodic soils, but risk of dispersion considered low. |
| Ca/Mg Ratio | 3.7 | 1.7 – 5.3 | Stable | Low | Ca/Mg Ratio is excellent. |
| CEC (cmol/kg) | 8.6 | 6.4 – 10.0 | Stable | Medium | CEC is poor, organic matter addition recommended. |
| Boron (mg/kg) | 0.9 | 0.8 – 1.3 | Slight increase | Low | Sufficient for plant growth and non-toxic |
| Copper (mg/kg) | 0.9 | 0.3 – 2.0 | Slight increase | Low | Non-toxic |
| Iron (mg/kg) | 805 | 707 – 871 | Increasing | Low | Sufficient for plant growth |
| Molybdenum (mg/kg) | 0.6 | 0.5 – 0.8 | Stable | Low-medium | May be toxic to some plants |
| Selenium (mg/kg) | <0.5 | N/A | Stable | Low | Non-toxic |
| Sulfur (mg/kg) | 8.9 | 6.2 – 12.1 | Slight increase | Low | Sufficient for plant growth and non-toxic |
| Zinc | 4.5 | 1.7 – 8.9 | Slight increase | Low | Sufficient for plant growth and non-toxic |

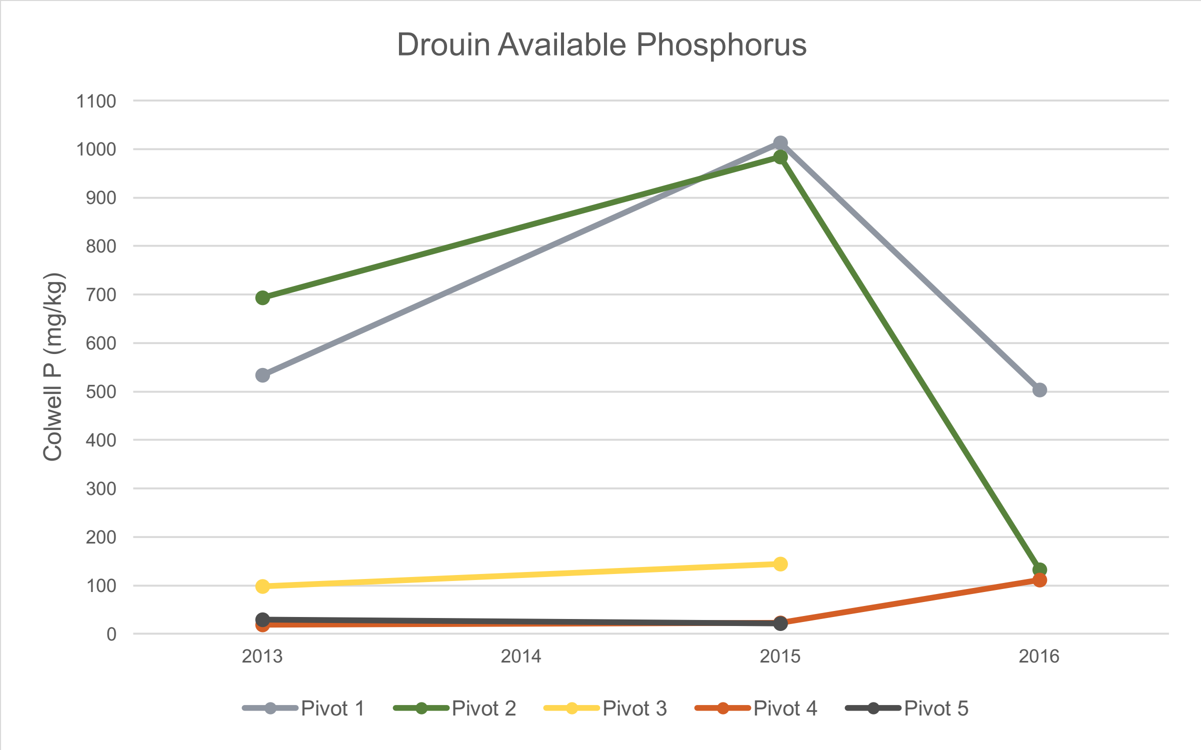


**Figure 3-1: Trend Graph for Drouin**

## 3.2 MIRBOO NORTH

The treatment plant site at Mirboo North includes 17 ha of flood irrigation. This uses the natural slope of land and is, in effect, a wild flood approach. Distribution uniformity[7] will by no means be perfect. However, it is a cost effective, low energy solution. If area available exceeds that required based on water balance modelling (i.e. there is a buffer to allow for potentially poor uniformity), then this irrigation method is considered appropriate for the site.

Class C reclaimed water is used, with 290 mg/L salinity (total dissolved solids), 6 mg/L Total P and 5 mg/L Total N.

Surface soils are typically coarse sandy loam to loamy sand, overlying a bleached similarly textured subsoil[8].

Topsoil sampling is available for the flood irrigated area for 2010, 2012, and 2014. There is also subsoil sampling for 2010 and 2014. Baseline sampling is not available, but there are test results for the dryland paddocks on the site. Refer to Table 3-2 and Figure 3-2 for results summary.

The soils are moderately to strongly acidic (for both irrigated and dryland paddocks). Application of lime is recommended to increase soil pH.

Topsoil phosphorus levels are very high for the irrigated area (they are low to marginal for the dryland paddocks). There is potential for contamination of rainfall runoff from the irrigation area. Subsoil phosphorus levels are also high, indicating potential risk of leaching as well, which is to be expected on sandy soils. Further soil sampling is recommended for phosphorus, including Mehlich P and Phosphorus Buffering Index testing for soil, and monitoring of rainfall runoff quality. Refer to Appendix 1 for further discussion.

Note that the phosphorus applied in reclaimed water ranges from 5 – 12 kg/ha per annum. This is well below maintenance requirements for irrigated beef. If no additional phosphorus fertiliser is applied, soil levels should start to decline. To increase removal of phosphorus, it is recommended that fodder cropping occurs, rather than grazing of the irrigated area.

Soil nitrogen levels are low. Application rates from reclaimed water have been <20 kg/ha and this is well below crop uptake rates. Nitrogen fertiliser is likely to be required to maintain good crop production and assist with phosphorus uptake.

Organic matter addition is recommended as cation exchange capacity is poor and declining. This will help to retain water and nutrients within the plant root zone.

Assessment of trace elements has identified no toxicity issues. However, soils may be slightly deficient in sulfur for good plant production.

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7 Distribution uniformity relates to how even the spread of water is across the area irrigated. Poor uniformity can result in patches of over or under irrigation. This can impact on crop production and also result in patches of waterlogging and/or increased runoff. At Mirboo North, there is a catch drain and runoff return system to manage the latter issue.

8 Sourced from vro.agriculture.vic.gov.au, Soils and Landforms of West Gippsland, Moe 1:100,000 Mapsheet. Site is mapped as Morwell with Boolarra.

**Table 3-2: Summary of Soil Results for Mirboo North**

| PARAMETER | 2014 RESULT | TREND | RISK LEVEL | COMMENTS |
|---|---|---|---|---|
| pH | 5.4 | Stable | Medium | Acidic soils. Lime application recommended. |
| Colwell P (mg/kg) | 208 | Stable | High | Very high phosphorus.<br>Subsoil levels also relatively high.<br>Further investigation required. |
| Nitrate N (mg/kg) | 10.6 | Increasing | Low | |
| Ammonium N (mg/kg) | 3.6 | Slight decline | Low | |
| Salinity (ECe dS/m) | 0.5 | Stable | Very low | |
| Sodicity (ESP %) | 2.5 | Slight decline | Very low | Non-sodic soils. |
| Ca/Mg Ratio | 2.2 | Erratic | Low | Ca/Mg Ratio is satisfactory. |
| CEC (cmol/kg) | 4.9 | Declining | Medium | CEC is poor, organic matter addition recommended. |
| Boron (mg/kg) | 0.65 | Slight increase | Low | Sufficient for plant growth and non-toxic |
| Copper (mg/kg) | 1.9 | Slight decrease | Low | Non-toxic |
| Iron (mg/kg) | 563 | Increasing | Low | Sufficient for plant growth |
| Molybdenum (mg/kg) | 0.4 | N/A | Low | Sufficient for plant growth and non-toxic |
| Selenium (mg/kg) | <0.5 | N/A | Low | Non-toxic |
| Sulfur (mg/kg) | 3.6 | Slight decrease | Low | Non-toxic but potentially deficient for good production |
| Zinc (mg/kg) | 1.7 | Stable | Low | Sufficient for plant growth and non-toxic |

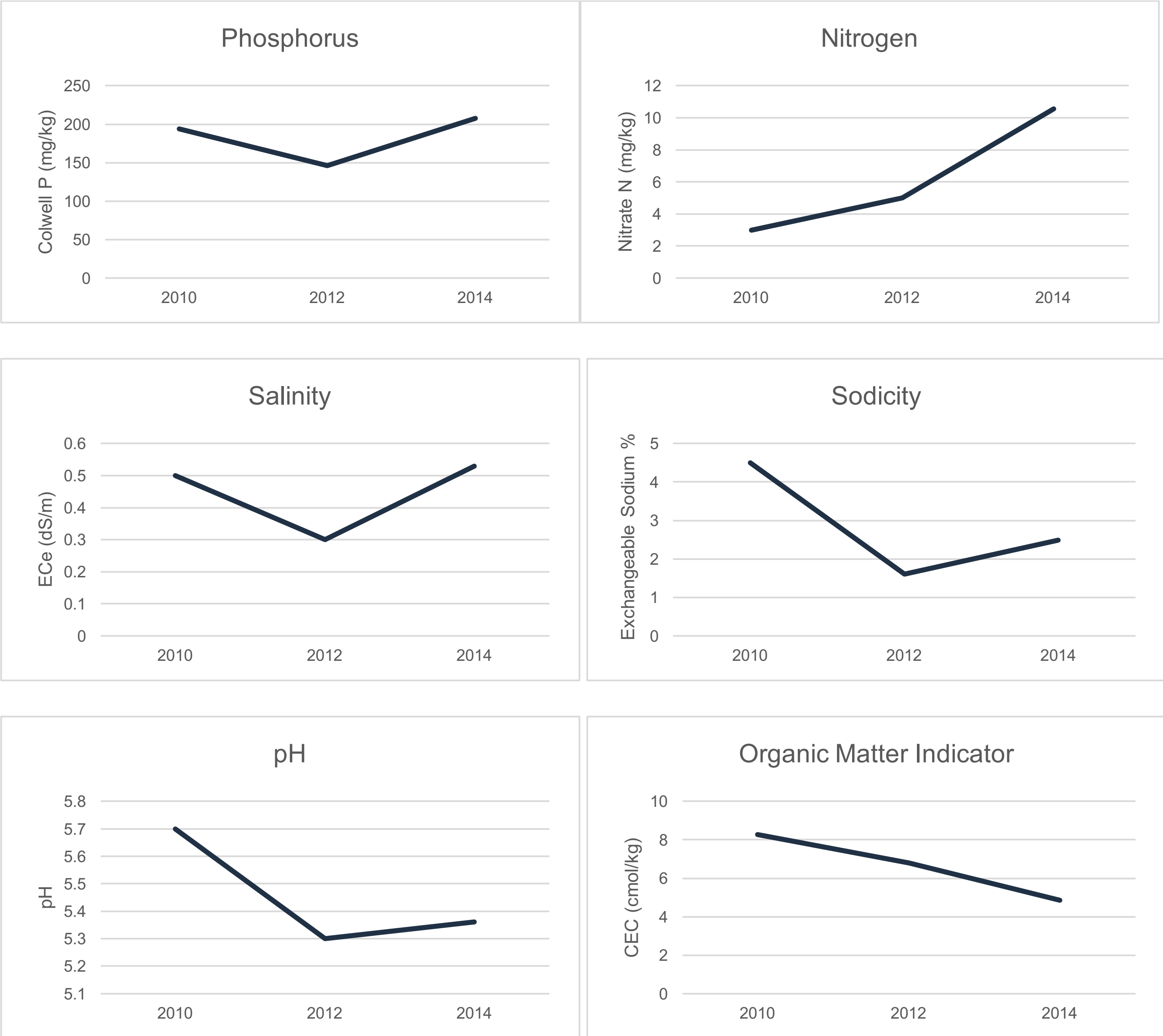


**Figure 3-2: Trend Graphs for Mirboo North**

## 3.3 HEYFIELD

The Heyfield site comprises 2 flood irrigated paddocks covering a total area of 11.6 ha, and two cannon (fixed sprinkler) irrigated areas totaling 26.3 ha. The cannon irrigation area is not intensely irrigated – it is used to manage wetter year flows. Soils are sandy loam and sandy clay loam.

Class C reclaimed water is used, with 460 mg/L salinity (total dissolved solids), 10 mg/L Total P and 6 mg/L Total N.

Topsoil testing is available for all paddocks in 2013 and 2016. Subsoil is available for all paddocks for 2016. Plus there is one sample for topsoil and subsoil from 2009 (for Paddock 4). Baseline sampling is not available for the site, but there are test results for a non-irrigated paddock on the site.

Results indicate that the irrigated area is much higher in phosphorus (particularly the flood irrigation area), and has slightly elevated salinity and sodicity levels, by comparison to the dry paddock.

The higher phosphorus in the irrigation areas is consistent with reclaimed water application. Phosphorus levels in the flood irrigation area are high and increasing. Applications in recent years have been up to 50 kg/ha which exceeds requirements for irrigated beef. Information on phosphorus buffering index (from historic sampling, not recently) suggests that these sandy loam soils are at risk of phosphorus leaching and subsoil levels are increasing beneath the flood irrigation. Additional Mehlich P and PBI testing is recommended to assess environmental risk. Monitoring of rainfall runoff quality from the flood irrigation area should also occur. (Refer to Appendix 1 for further discussion).

The salinity variation between irrigated and dry paddocks is not significant – all areas remain at low to very low salinity levels.

Soils are moderately sodic. Consideration should be given to application of gypsum to the irrigation areas to decrease sodicity.

Soil nitrogen levels are very low. Application rates from reclaimed water have been approximately 20 kg/ha for the flood irrigation area and ranging from 2 – 7 kg/ha for the spray irrigation area. This is well below crop uptake rates. Nitrogen fertiliser is likely to be required to maintain production. Risk to the environment is very low.

Organic matter addition should also be considered as cation exchange capacity is poor. This will help to retain water and nutrients within the plant root zone.

Assessment of trace elements has identified no toxicity issues. However, soils may be slightly deficient in zinc and molybdenum for good plant production.

**Table 3-3: Summary of Soil Results for Heyfield**

| PARAMETER | 2016 MEAN FLOOD | TREND (FLOOD) | 2016 MEAN SPRAY | TREND (SPRAY) | RISK LEVEL | COMMENTS |
|---|---|---|---|---|---|---|
| pH | 7.3 | Slight decrease | 6.6 | Stable | Low | |
| Colwell P (mg/kg) | 156 | Increasing | 74 | Increasing | High (for flood area) | Flood irrigation levels are high. Additional testing is recommended to assess environmental risk. |
| Nitrate N (mg/kg) | 5.0 | Stable | 7.6 | Stable | Very low | Subsoil mean is 1.3. Risk of leaching low. |
| Ammonium N (mg/kg) | 1.9 | Slight decrease | 1.4 | Slight decrease | Very low | |
| Salinity (ECe dS/m) | 1.4 | Stable | 1.0 | Stable | Very low | |
| Sodicity (ESP %) | 13.5 | Slight decrease | 13.8 | Slight increase | Medium | Moderately sodic soils. Consider gypsum application. |
| Ca/Mg Ratio | 2.3 | Increasing | 1.5 | Stable | Low | Ca/Mg Ratio is satisfactory for flood irrigation and marginal for spray. |
| CEC (cmol/kg) | 7.5 | Stable | 6.6 | Stable | Medium | CEC is poor, organic matter addition recommended. |
| Boron (mg/kg) | 1.0 | Slight increase | 0.8 | Slight increase | Low | Sufficient for plant growth and non-toxic. |
| Copper (mg/kg) | 0.2 | | 0.3 | | Low | Non-toxic. |
| Iron (mg/kg) | 126 | | 632 | | Low | Sufficient for plant growth. |
| Molybdenum (mg/kg) | <0.2 | | 0.3 | | Low | May be deficient for good production, but non-toxic. |
| Selenium (mg/kg) | <0.5 | | 0.6 | | Low | Non-toxic. |
| Sulfur (mg/kg) | 8.8 | | 7.0 | | Low | Sufficient for plant growth and non-toxic. |
| Zinc (mg/kg) | 0.6 | | 0.8 | | Low | May be deficient for good production, but non-toxic. |


**Figure 3-3: Trend Graphs for Heyfield**

## 3.4 MAFFRA

Irrigation methods used on the Maffra site include:

- Flood irrigation – 60 ha through the centre of the site
- Centre-pivot – 18.5 ha on the eastern edge of site
- Cannon or fixed sprinkler irrigation – 50 ha in the north and south east corners. This area is not intensely irrigated – it is used for managing wetter year flows.

Class C reclaimed water is used, with 375 mg/L salinity (total dissolved solids), 3 mg/L Total P and 9 mg/L Total N.

There are 9 topsoil samples available for the irrigated areas for 2016, 2013 and 2012, plus 6 from 2010. There are also 9 subsoil samples from 2016, 1 from 2012 and 6 from 2010. Baseline testing is not available for the site, but there is testing from dryland paddocks. Refer to Table 3-4 and Figure 3-4 for a summary of results.

The majority of soil parameters indicate low risk to the environment. The main exception is related to soil phosphorus, which is moderate to high. Note that the non-irrigated paddocks tested have similar moderate to high phosphorus levels (with exception of Paddock 19).

Nutrient applications from the reclaimed water are relatively low, ranging from 5 – 15 kg/ha TP and 25 – 45 kg/ha TN. These rates are for the flood and centre-pivot areas – the cannon irrigation receives a lot less, if any. Nutrients have also been applied in compost, but not since 2013[9]. The overall application rates are less than maintenance requirements for irrigated beef. Additional nitrogen (fertiliser/compost) will help to ensure good crop production.

For phosphorus, the soil levels mean no additional fertiliser should be applied. It would be preferable to allow crops to mine the soil phosphorus in the flood and cannon irrigation areas to below 100 mg/kg Colwell P. This could occur more quickly through fodder cropping, rather than grazing of the site.

Some of the paddocks in the flood irrigation area are in the high category for phosphorus (>120 mg/kg Colwell P) – they range from 55 to 155 mg/kg. As such, it is recommended that additional Mehlich P and PBI testing is undertaken to assess environmental risk. Monitoring of rainfall runoff quality from the flood irrigation area should also occur. (Refer to Appendix 1 for further discussion).

Texture contrast soils are present. This means light textured surface soils (loamy sands to sandy loams) abruptly overlying the clay subsoil. Downward movement of water can be restricted by the subsoil clay[10]. Risk of leaching through the soil profile is relatively low, as indicated by subsoil phosphorus being quite low.

Soil testing also indicates moderately sodic soils, with exception of the centre-pivot area. Application of gypsum should be considered, focusing on Paddocks 7, 8, and 9. This will assist in maintaining soil structure. Organic matter addition is also recommended as cation exchange capacity is poor.

Assessment of trace elements has identified no toxicity issues or deficiencies.

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9 This added approximately 12 kg/ha P and 45 kg/ha N. Some paddocks received a similar amount from compost applied in 2012 as well.
10 Sourced from vro.agriculture.vic.gov.au, Soils and Landforms of Maffra Region (Northern Section). Site is mapped as Briagolong.

**Table 3-4: Summary of Soil Results for Maffra**

| PARAMETER | 2016 MEAN FLOOD | TREND (FLOOD) | 2016 PIVOT | TREND (PIVOT) | 2016 CANNON[11] | TREND (CANNON) | RISK LEVEL | COMMENTS |
|---|---|---|---|---|---|---|---|---|
| pH | 7.7 | Stable | 7.5 | Stable | 6.0 | Stable | Low | |
| Colwell P (mg/kg) | 107 | Slight increase since 2010, but stable since 2013. | 68 | Increasing | 110 | Decreasing | Medium | Flood and spray levels are optimal, but close to high. Pivot area marginal but increasing. Subsoil levels are much lower (<30) so leaching is minimal. |
| Nitrate N (mg/kg) | 6.3 | Decreasing | 17 | Increasing | 4.2 | Stable | Low | Approaching adequate for Pivot area. Otherwise very low. |
| Ammonium N (mg/kg) | 2.4 | Stable | 2.4 | Slight decrease | 3.6 | Slight increase | Very low | |
| Salinity (ECe dS/m) | 1.2 | Slight decrease | 1.2 | Stable | 0.5 | Slight decrease | Very low | |
| Sodicity (ESP %) | 10.2 | Stable | 6.1 | Decreasing | 8.9 | Stable | Low - medium | Moderately sodic soils, with exception of pivot area. Consider gypsum application focussing on Paddocks 7, 8, 9. |
| Ca/Mg Ratio | 2.7 | Stable | 3.5 | Decreasing | 2.3 | Stable | Low | Ca/Mg Ratio is satisfactory to excellent. |
| CEC (cmol/kg) | 11.4 | Slight increase | 9.5 | Stable | 4.3 | Stable | Medium | CEC is poor to marginal. Organic matter addition recommended. |
| Boron (mg/kg) | 1.1 | Slight decrease | 0.8 | Stable | 0.5 | Stable | Low | Sufficient for plant growth and non-toxic |
| Copper (mg/kg) | 0.3 | Stable | 0.4 | Slight increase | 0.3 | Stable | Low | Non-toxic |
| Iron (mg/kg) | 109 | Increased | 166 | Increased | 817 | Increased | Low | Sufficient for plant growth |
| Molybdenum (mg/kg) | 0.4 | | 0.4 | | 0.4 | | Low | Sufficient for plant growth and non-toxic. |
| Selenium (mg/kg) | < 1 | | <1 | | <1 | | Low | Non-toxic |
| Sulfur (mg/kg) | 10.7 | Stable | 7.7 | Decreased | 8.1 | Slight decrease | Low | Sufficient for plant growth and non-toxic. |
| Zinc (mg/kg) | 1.3 | Slight increase | 1.9 | Stable | 1.2 | Slight decrease | Low | Sufficient for plant growth |

[11] Based on test result from Nobles and Hurley paddocks.

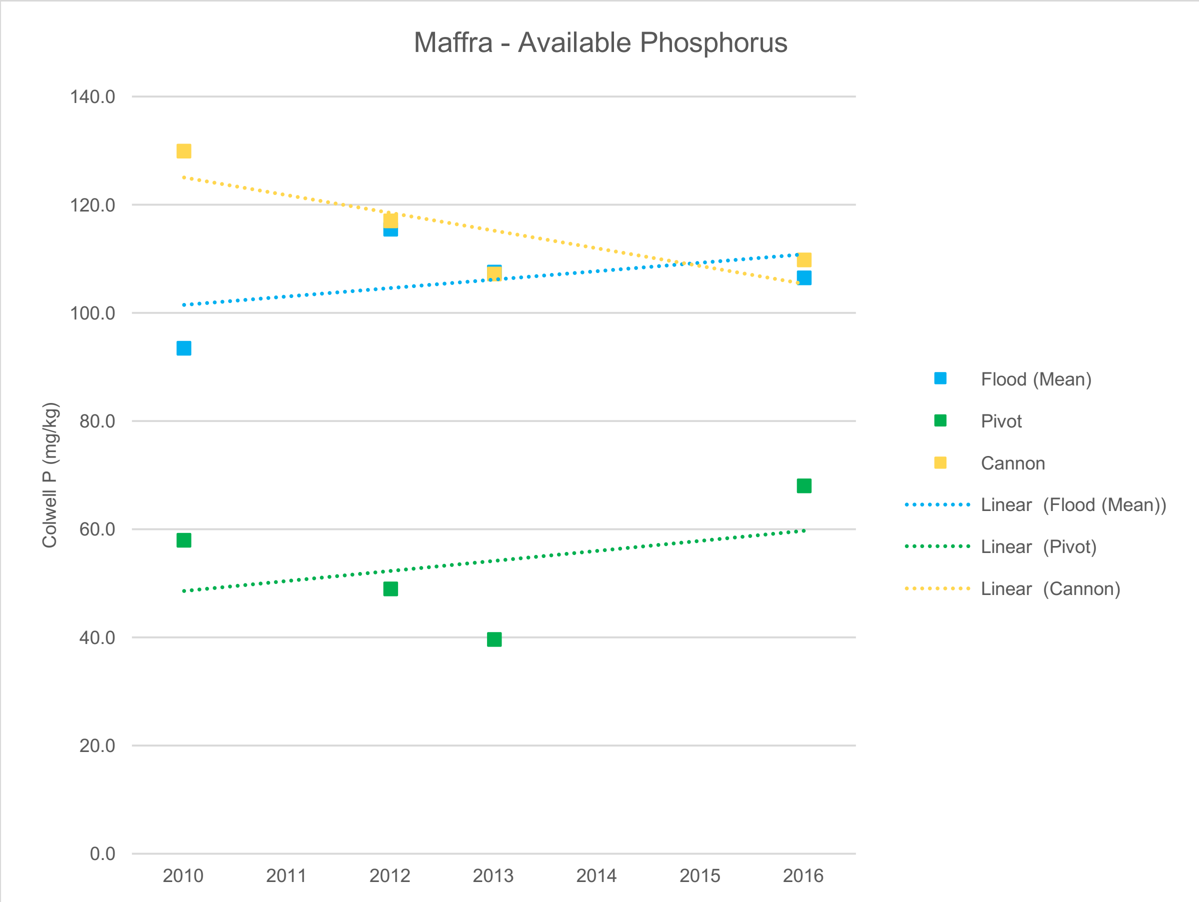



**Figure 3-4: Trend Graph for Maffra**

## 3.5 STRATFORD

The Stratford site comprises 4 flood irrigated paddocks of similar dimension covering a total area of 28 ha. Soils are loam topsoil overlying a heavier clay subsoil.

Class C reclaimed water is used, with 320 mg/L salinity (total dissolved solids), 7 mg/L Total P and 11 mg/L Total N.

Topsoil testing is available for all paddocks in 2013 and 2016. Subsoil is available for all paddocks for 2016. Plus there is one sample for topsoil and subsoil from 2009 (for Paddock 4). Baseline sampling is not available for the site, but there are test results for a non-irrigated paddock. Results are summarised in Table 3-5 and Figure 3-5.

Soil chemistry is relatively stable across the years, other than a beneficial decline in sodicity.

The decline in sodicity may be connected to improved irrigation scheduling in recent years. There has been no recent application of soil ameliorant such as gypsum.

The irrigated area is much higher in phosphorus, and has slightly elevated salinity and sodicity levels, by comparison to the dry paddock. The salinity and sodicity variation is not to levels of concern.

The higher phosphorus levels in the irrigation area are consistent with reclaimed water application. Applications of phosphorus have varied between 30 kg/ha and 40 kg/ha in recent years. This is approximately equivalent to maintenance requirements for irrigated beef (or slightly above). No P fertilizer should be applied to the site. Given soil P levels have been stable over recent years risk to the environment is considered moderate and manageable. There is an irrigation runoff catch and return system in place. This will enable all irrigation runoff and the first flush of rainfall runoff to be contained on site. Rainfall runoff beyond the first flush can continue to be released from the site.

Soil nitrogen levels are very low. Application rates from reclaimed water have been approximately 50 kg/ha. This is below crop uptake rates. Nitrogen fertiliser is likely to be required to maintain production. Risk to the environment is very low.

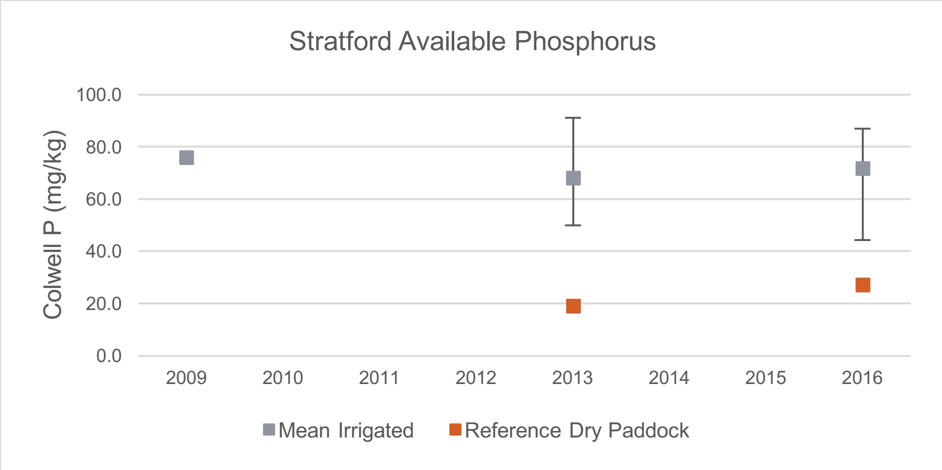
There are no major concerns in relation to environmental risk, particularly if sodicity continues to decline.

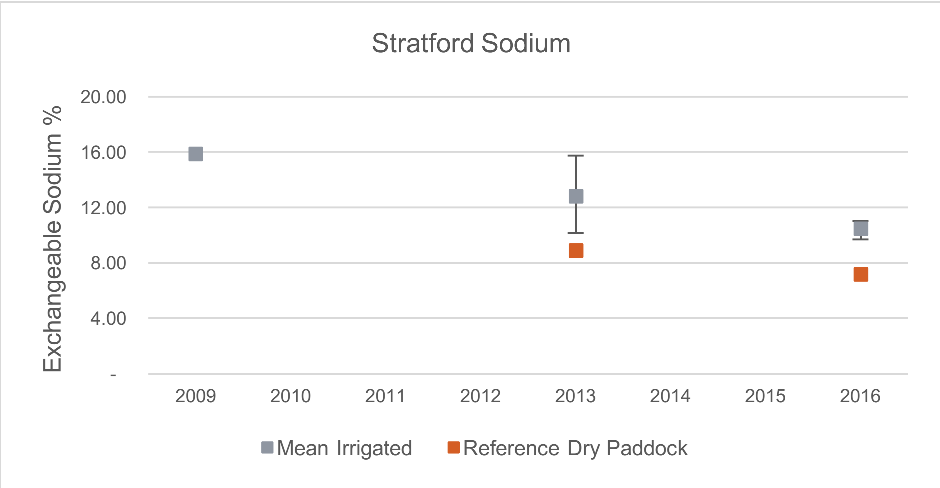
Assessment of trace elements has identified that molybdenum may be toxic to some plants.

**Table 3-5: Summary of Soil Results for Stratford**

| PARAMETER | 2016 MEAN [12] | 2016 RANGE | TREND | RISK LEVEL | COMMENTS |
|---|---|---|---|---|---|
| pH | 6.6 | 6.4 – 6.7 | Slight decline | Low | |
| Colwell P (mg/kg) | 72 | 44 – 87 | Stable | Medium | Optimal levels for crop production.<br>Subsoil levels much lower at mean of 11. So risk of leaching minimal. |
| Nitrate N (mg/kg) | 6.0 | 0.5 – 16.4 | Slight decline | Very low | Subsoil mean is 0.9. Risk of leaching low. |
| Ammonium N (mg/kg) | 4.2 | 1.3 – 8.8 | Slight decline | Low | |
| Salinity (ECe dS/m) | 1.0 | 0.8 – 1.2 | Slight decline | Very low | |
| Sodicity (ESP %) | 10.5 | 9.9 – 11.2 | Declining | Low-medium | Declining trend is positive for soil structure. |
| Ca/Mg Ratio | 2.7 | 2.3 – 3.2 | Declining | Low | Ca/Mg Ratio is excellent. |
| CEC (cmol/kg) | 7.3 | 6.6 – 8.6 | Stable | Medium | CEC is poor, organic matter addition recommended. |
| Boron (mg/kg) | 0.8 | 0.7 – 0.9 | | Low | Sufficient for plant growth and non-toxic. |
| Copper (mg/kg) | 0.4 | 0.4 – 0.5 | | Low | Non-toxic. |
| Iron (mg/kg) | 678 | 305 – 1620 | | Low | Sufficient for plant growth. |
| Molybdenum (mg/kg) | 0.5 | 0.3 – 0.6 | | Low-medium | Potentially toxic to some plants. |
| Selenium (mg/kg) | | <0.5 – 0.64 | | Low | Non-toxic. |
| Sulfur (mg/kg) | 7.5 | 7.2 – 7.9 | | Low | Sufficient for plant growth and non-toxic. |
| Zinc (mg/kg) | 0.9 | 0.5 – 1.4 | | Low | Sufficient for plant growth and non-toxic. |

[12] Considers irrigated paddocks only.



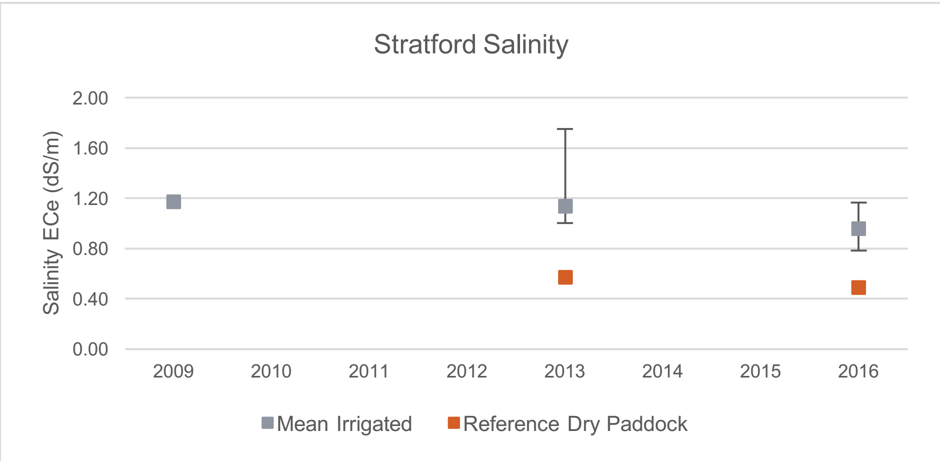




**Figure 3-5: Trend Graphs for Stratford**

## 3.6 DUTSON DOWNS

Centre-pivot irrigation is used at the Dutson Downs site and the majority has only been in operation for 3 years – this includes Pivots 1 through 8 covering a total of 303 ha. Pivot 9 covers another 18 ha and has been irrigated for approximately 12 years.

Class C reclaimed water is used, with 575 mg/L salinity (total dissolved solids), 7 mg/L Total P and 7 mg/L Total N.

Soils for the irrigated areas are sandy and are associated with Aeolian dune deposits. Compost has been applied in recent years, plus other soil ameliorants (e.g. lime), to improve soil organic matter.

Soil testing associated with the irrigation areas includes eight topsoil samples for 2015 and 2016, plus 3 subsoil samples for 2015 and 8 subsoil samples for 2016. Pivot area 9, which has a longer history of irrigation, has been sampled in 2012, 2014 and 2016 for topsoil and subsoil. Baseline samples are available for the recently developed irrigation areas including 7 topsoil samples in both 2012 and 2014, plus 6 subsoil samples in 2014 and 3 in 2012. Results are summarised in Table 3-6 and Figure 3-6.

Nutrients applied in reclaimed water are relatively low for phosphorus (~15 kg/ha) and very low for nitrogen (10 – 15 kg/ha). The compost also provides a supply of nutrients – at approximately 4 kg phosphorus and 15 kg nitrogen per tonne of compost[13]. Fertiliser has also been used on Pivot areas 1 to 8 to build up soil nutrient levels.

Other than the Pivot 9 area, current soil nutrient levels are low to marginal and further build up would be beneficial to crop production.

Note that the sandy soils may mean potential for leaching of nutrients through the soil profile. While some build-up of soil nutrients is recommended, this should be limited to some degree. An upper limit of 70 mg/kg Colwell P is suggested.

Soil organic matter is improving slightly (based on Cation Exchange Capacity or CEC), but remains low. Continued use of compost is recommended. Increasing soil organic matter will help to retain water and nutrients in the plant root zone. From an environmental perspective, this will decrease the risk of leaching through the soil profile, potentially to groundwater.

The Pivot 9 area has very high phosphorus levels. It is recommended that this area is rested from reclaimed water and compost use for a couple of years, to allow the crops grown to mine the soil nutrients. Another option would be reclaimed water use only (no compost or fertilizer) and production of a summer crop to be cut for fodder (not grazed) to increase nutrient use.

Assessment of trace elements has identified that sulfur levels may be toxic to some plants, particularly in the Pivot 9 area.

[13] Approximate average taken from test results over past four years.

**Table 3-6: Summary of Soil Results for Dutson Downs Irrigation**

| PARAMETER | 2016 MEAN[14] | 2016 RANGE | PIVOT 9 RESULT | TREND[15] | RISK LEVEL | COMMENTS |
|---|---|---|---|---|---|---|
| pH | 6.7 | 6.5 – 8.0 | 6.6 | Stable | Low | |
| Colwell P (mg/kg) | 27 | 17 – 61 | 224 | Slight increase | Low for Pivots 1-8<br>High for Pivot 9 | Low to marginal levels for Pivots 1 - 8.<br>Very high for Pivot 9. |
| Nitrate N (mg/kg) | 10 | 6 – 21 | 17 | Stable | Very low | |
| Ammonium N (mg/kg) | 6.9 | 1.1 – 10.6 | 9.1 | Slight increase | Low | |
| Salinity (ECe dS/m) | 1.3 | 0.7 – 2.0 | 2.2 | Slight increase | Very low | |
| Sodicity (ESP %) | 7.5 | 2.7 – 14.6 | 5.6 | Increasing (NB: Pivot 9 has decreased) | Low | Most areas non-sodic. Exceptions are Pivots 5 and 6, although these are still < 15%. and given soils are sandy, dispersion is unlikely to be an issue. |
| Ca/Mg Ratio | 6.2 | 4.8 – 9.0 | 5.0 | Stable | Low | Ca/Mg Ratio is excellent. |
| CEC (cmol/kg) | 7.5 | 5.4 – 12.2 | 8.7 | Slight increase | Medium | CEC is poor, continued compost use is recommended. |
| Boron (mg/kg) | 0.6 | 0.4 – 0.9 | 1.0 | Slight increase | Low | Sufficient for plant growth and non-toxic. |
| Copper (mg/kg) | 0.6 | 0.1 – 0.9 | 1.9 | | Low | Non-toxic. |
| Iron (mg/kg) | 62 | 34 – 83 | 107 | | Low | Sufficient for plant growth. |
| Molybdenum (mg/kg) | | <0.2 – 0.2 | 0.3 | | Low | Sufficient for plant growth and non-toxic. |
| Selenium (mg/kg) | <0.5 | | <0.5 | | Low | Non-toxic. |
| Sulfur (mg/kg) | 14 | 6 – 26 | 72 | | Low-medium | Potentially toxic levels. |
| Zinc (mg/kg) | 2.6 | 0.6 – 4.1 | 11 | | Low | Sufficient for plant growth and non-toxic. |

[14] Considers irrigated paddocks 1 to 8 only.
[15] Focussed on paddocks 1 to 8.

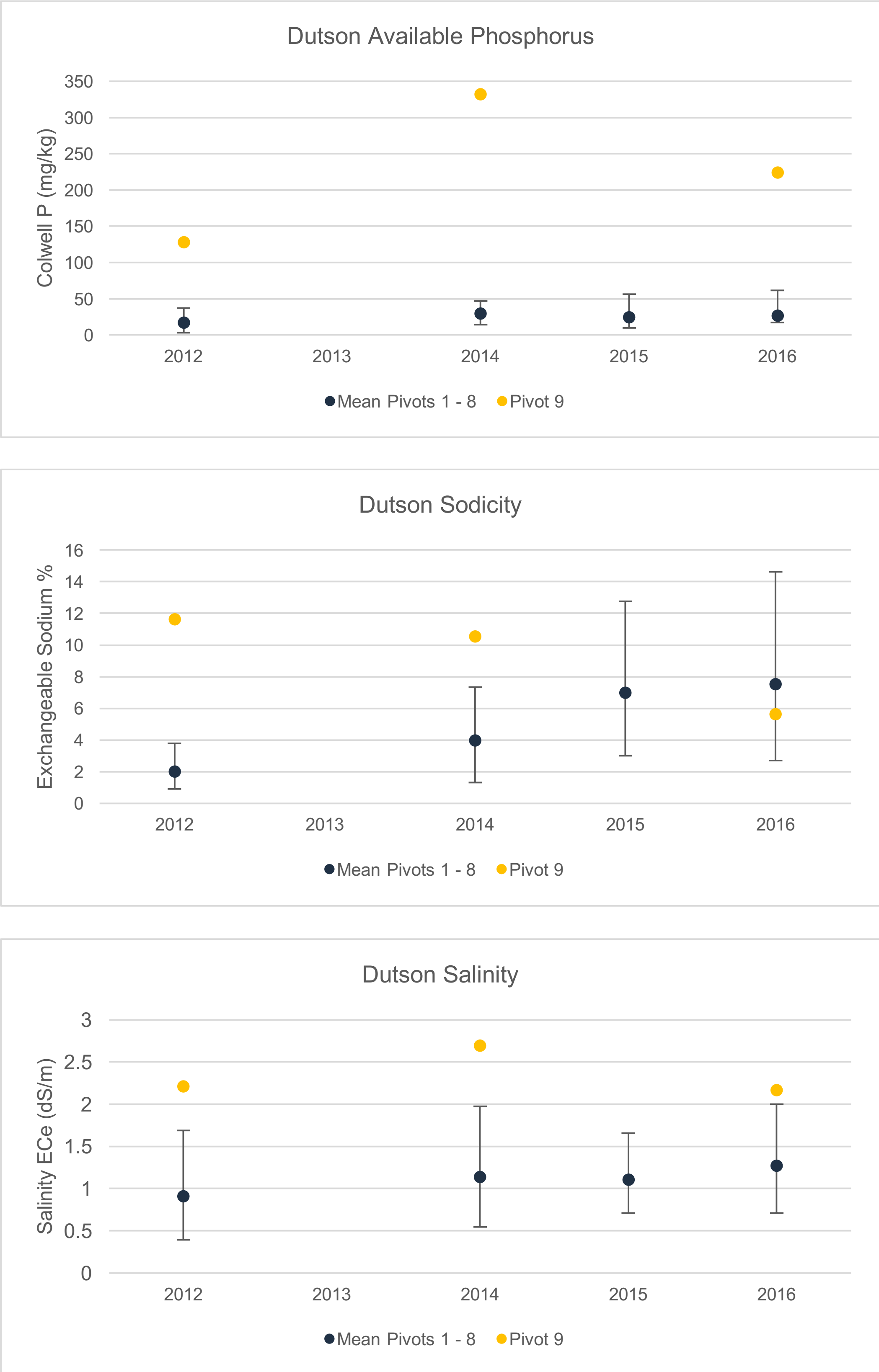



**Figure 3-6: Trend Graphs for Dutson Downs Irrigation**

## 3.7 SOIL TESTING PROCEDURE

A consistent approach to soil sampling is required to ensure repeatability in data and meaningful interpretation of test results (particularly for trends over time). Here, we give consideration to the procedures used to collect samples and comment on the confidence levels in the data being analysed. This includes consideration of methods for sample collection, timing of collection, laboratory used and/or the analytical suite tested in the laboratory.

The frequency of soil testing varies between the sites, but is generally undertaken on a two to three yearly basis. We recommend testing on at least a two-yearly basis for the larger sites (Drouin, Maffra and Dutson Downs). This should be increased to annual testing for Maffra and Drouin until phosphorus levels have reduced. For the smaller sites (Mirboo North, Heyfield and Stratford), frequency could be reduced to every three to four years. Although at present Mirboo North and Heyfield should be assessed at least every two years due to high phosphorus levels.

Timing of sampling within the year varies. The Agribusiness Management Plan refers to testing late in the irrigation season. We would typically recommend testing outside the irrigation season – to reduce the risk of samples containing reclaimed water and to allow for some rainfall leaching to balance soil chemistry. Sampling in 2016 was undertaken in August – it is recommended to aim for a similar time of year in future testing.

The number of samples collected and sample location should be consistent from year to year. At a minimum we recommend:

- Topsoil – one per 20ha, to depth of 10cm, composite of at least 20 sub-samples.
- Subsoil – align with topsoil location, top 100mm of the B-horizon (often a clay layer beneath the topsoil), where B-horizon is not distinguishable use nominal depth of 300 – 400mm, composite of at least 5 subsoil samples.
- Composite samples – sub-samples to be combined and thoroughly mixed and then a representative composite sample collected from the mix. Mix in a clean bucket.
- Sub-samples to be collected by transects (refer to Figure 3-7) with locations recorded using GPS for future reference. Sub-samples spaced evenly along the transect (e.g. one sample every ten steps).
- Avoid sampling areas that are not representative – e.g. obvious manure patches, gateways, stock tracks, channel banks, water troughs. Where there are distinct changes in soil type, ensure transects stick to one soil type only.
- Samples should not be collected when the soil is saturated (i.e. sloppy), or within 4 weeks of fertilizer or compost use, as this can skew analytical results.
- A small diameter auger/corer/probe can be used (for topsoil and subsoil) to ensure minimal damage to crops. Ensure sampler is cleaned between sample transects or between topsoil and subsoil.

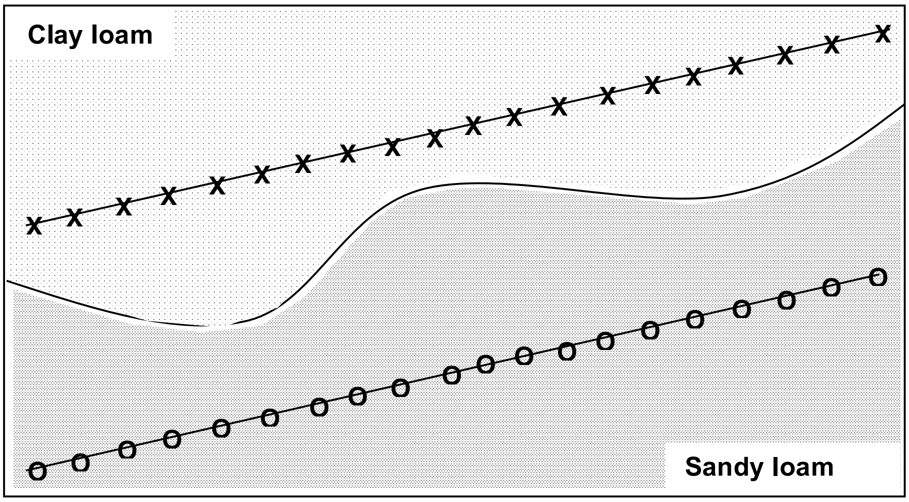



**Figure 3-7: Plan view of example soil transects**

The laboratory used is Environmental Analysis Laboratory (EAL) and this is NATA accredited. Use of this laboratory has occurred since 2013. Previously Farmright provided laboratory services. When the laboratory was changed the analytical suite also changed to align with a standard suite offered by EAL.

It appears that the current analytical suite provides an excess of data. Table 3-7 outlines the standard suite recommended by RMCG for topsoil. A review of the EAL price list suggests that the Mehlich III Standard pack with Colwell P added would be appropriate for topsoils. The suite tested for subsoils can contain fewer parameters. EAL offer the Agricultural Reams Subsoil pack that would be appropriate with Colwell P and Exchangeable Sodium Percentage added.

**Table 3-7: Soil analytical suite - topsoil**

| Soil analytical suite | UOM | Soil analytical suite | UOM |
|---|---|---|---|
| pH ($CaCl_2$) | - | Electrical Conductivity (EC):<br>$EC_{1:5}$<br>$EC_e$ (saturated extract)* | dS/m |
| pH (Water) | - | | |
| Total Nitrogen (N) | % | Organic Carbon (OC) | % |
| Nitrate (NO3) | mg/kg | Available Potassium | mg/kg |
| Ammonium N | mg/kg | Chloride (Cl) | mg/kg |
| Colwell Phosphorus (P) | mg/kg | Cation Exchange Capacity (CEC)* | cmol/kg |
| Mehlich Phosphorus (M3-P) | - | Calcium/Magnesium Ratio* | Ratio |
| M3-P Saturation Ratio (PSR) | Ratio | Exchangeable Sodium Percentage (ESP%)* | % |
| Exchangeable Calcium (Ca) | cmol/kg | Clay dispersion (Emerson)** | - |
| Exchangeable Magnesium (Mg) | cmol/kg | Soil Texture*** | - |
| Exchangeable Sodium (Na) | cmol/kg | | |
| Exchangeable Potassium (K) | cmol/kg | | |

* can be calculated outside of the laboratory
** only required when ESP >10%
*** only required at start-up phase of a reuse scheme

# 4 Summary of Recommendations

The key issue of concern identified from the review of soil sampling data is the high levels of phosphorus in the soils at Drouin, Mirboo North, Heyfield, some of the flood irrigated areas at Maffra and the Pivot 9 area at Dutson Downs. There is potential risk to the environment through contamination of rainfall runoff and potentially leaching to groundwater where soils are sandy (e.g. Heyfield).

For these sites, further soil sampling is recommended for phosphorus, including Mehlich P and Phosphorus Buffering Index. Monitoring of rainfall runoff quality should also be undertaken. Refer to Appendix 1 for further discussion. No additional phosphorus fertiliser should be applied to these high phosphorus sites. To increase removal of phosphorus, it is recommended that fodder cropping occurs, rather than grazing. This has already been implemented for the Pivot 9 area at Dutson Downs, where maize silage is being produced and reclaimed water application has been reduced.

For all sites:

- Organic matter levels are low based on cation exchange capacity results. Addition of organic matter should be considered to improve retention of water and nutrients in the plant root zone.
- Soil nitrogen levels are very low and nitrogen application within the reclaimed water is also low. Application of nitrogen based fertiliser is recommended to ensure crop production is maximised. This is of particular relevance for the sites with high soil phosphorus where production needs to be maximised to ensure phosphorus removal.

The soils at the Mirboo North site are moderately to strongly acidic (for both irrigated and dryland paddocks). Application of lime is recommended to increase soil pH.

At Maffra, soil testing indicates moderately sodic soils, with exception of the centre-pivot area. Application of gypsum should be considered, focusing on Paddocks 7, 8, and 9. This will assist in maintaining soil structure.

Soils are also moderately sodic at Heyfield. Consideration should be given to application of gypsum to the irrigation areas to decrease sodicity.

Soil testing frequency and procedures can be improved to ensure better consistency between years and more accurate trend analysis. Refer to Section 3.7 for further details. In addition, the analytical suite tested can be reduced which should reduce the cost of sampling.

# 5 References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# Appendix 1: Additional Assessment of Soil Phosphorus Risk

Phosphorus (P) is required for healthy plant growth and Australian soils are generally low in this form of nutrient (unless there has been a history of fertiliser use). P in reclaimed water can therefore be beneficial to soil fertility and consequently plant production.

However, an excess build-up of P in soil can cause adverse environmental impacts through surface or ground water contamination, potentially resulting in eutrophication and algal blooms.

A balance needs to be maintained between ensuring adequate plant production (maintaining economically optimum crop yields) and minimising risk to the environment. This discussion paper provides guidelines for maintaining this balance based on soil monitoring information and crop uptake rates.

## Using M3-PSR

The Colwell P test has some limitations in that:

- it mainly measures orthophosphate, the plant available P. It does not pick up all of the organic P forms. This is usually not an issue where fertilisers are used as they generally contain inorganic P. However, reclaimed water can contain significant levels of organic P;
- it does not measure P well where alkaline soils occur;
- it is focussed on understanding availability of P for crops. There is not a clear link to environmental risk.

As such, Mehlich P testing is recommended in addition to Colwell P, where testing to date indicates high soil P levels.

Mehlich P test results can be used to calculate the Mehlich 3 Phosphorus Saturation Ratio (M3-PSR). This ratio is commonly used in the US and other countries, and there is a growing trend for its use in Australia. Research has shown it accurately predicts both agronomic value (profitable crop responses to P inputs) and risk to the environment (Sims et al, 2002). It can therefore be used to enhance the accuracy of decisions made.

## Key trigger points

The key trigger points for soil P in relation to grazing and fodder cropping are summarised in Figure A3-1, and include:

- **<0.06 M3-PSR** – Below Optimum – Soil nutrient status is low and will probably limit crop yield. Can apply P in excess of crop requirements. **Build-up** of soil nutrients will be beneficial in ensuring adequate crop production.
- **0.06 – 0.11 M3-PSR** – Optimum – Soil nutrient status is adequate. Nutrient application recommended to **maintain** soil in optimum range. Apply P to match crop maintenance requirements.

- **0.11 – 0.15 M3-PSR** – Soil nutrient status is above optimum. Of environmental concern if processes exist to transport P to surface or ground waters. **Reduce** P application to less than crop requirements to allow mining of soil nutrients.
- **>0.15 M3-PSR** – Environmental degradation likely. Implementation of improved P management practices should be a high priority. **Stop** P application and focus on maximising crop P removal, until soil nutrient status decreases.

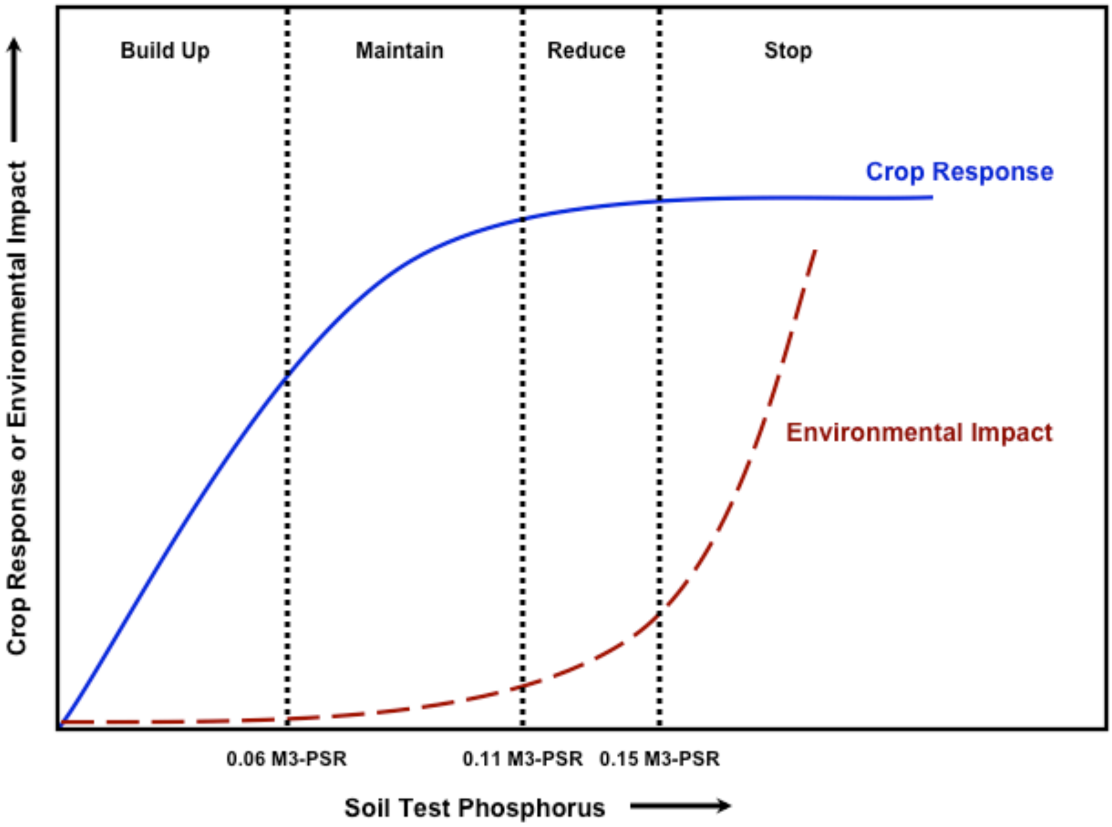


**Figure A1- 1: Soil phosphorus crop response vs. environmental impact**

## Application rates at varying soil P levels

Recommended application rates for M3-PSR are outlined in the table below, for a range of fodder production systems.

**Table A1- 1: Application based on M3-PSR**

| SOIL PHOSPHORUS – M3-P SATURATION RATIO | P STATUS | RECOMMENDED P APPLICATION RATE (KG/HA/ANNUM) | | |
|---|---|---|---|---|
| | | Annual Pasture or Winter Crop | Perennial Pasture or Summer Crop | Double Cropping |
| <0.06 | Below Optimum | 40 | 60 | 80 |
| 0.06 – 0.11 | Optimum | 20 | 40 | 60 |
| 0.11 – 0.15 | Above Optimum | 10 | 20 | 30 |
| >0.15 | Environmental | Nil | Nil | Nil |

## Data trends

If sampling results are available for multiple years, data trends can be used to refine P application rates. This is illustrated through the following examples:

*On cusp of changing category:*

- P levels have been increasing over a few years and now Average Soil P is 0.10 M3-PSR. The production system is summer cropping (e.g. maize). It is recommended to reduce application rates to 20 kg/ha P, as soil nutrient status is otherwise expected to move into Above Optimum range.

*High/low buffering capacity:*

- Soil P levels increase quickly (i.e. >0.03 M3-PSR within two years), even though application rates are in line with maintenance requirements. Consider soil type and P buffering capacity. If, for example, a sandy soil exists, the maintenance requirement may be lower than expected. Note the opposite could occur for soils with high buffering capacity. See below for further details.

## Phosphorus Buffering Capacity

It is also recommended to test a soil's phosphorus buffering capacity. This involves using the P buffering index (PBI) – a laboratory measure used to indicate P sorption capacity.

As the phosphorus buffering capacity of a soil increases, so does the amount of phosphorus application required to raise the soil phosphorus level.

The table below summarises the assessment criteria for buffering.

**Table A1- 2: Phosphorus buffering capacity**

| BUFFERING CAPACITY | PBI | EXAMPLE SOIL TYPE | APPLICATION (kg/Ha) REQUIRED TO RAISE OLSEN P BY 1 mg/kg |
|---|---|---|---|
| Low | <35 | Sand | 5 |
| Medium | 35 – 140 | Sandy Loam | 8 |
| High | 140 – 280 | Clay Loam | 10 |
| Very High | >280 | Clay | 13 |

*Sources: DNRE, 2002 and Melland, Smith and Waller, 2007*

Soils with a high clay or iron content fix P and therefore tend to have a high buffering capacity. The key issue with managing environmental risk due to P is ensuring this soil is not eroded offsite.

In contrast, sandy soil has a low P sorption capacity (and therefore low buffering capacity). As a result, soluble P can readily drain through a sandy soil profile.

Note that the buffering capacity is not static and will change (decrease) with increasing soil P level.

## Assessment of Rainfall Runoff Quality

A key environmental risk relating to high soil phosphorus levels is loss to surface waters through contamination of rainfall[16] runoff or erosion of nutrient rich topsoil.

As such, monitoring of rainfall runoff quality, is recommended for sites with high soil phosphorus levels.

At least three rainfall runoff events should be monitored over the year.

Grab samples should be collected at the point of discharge from the property (e.g. the overflow point from the irrigation reuse sump).

Recommended parameters to be assessed are E.Coli, salinity, total phosphorus and total nitrogen.

For nutrients, the "best estimate" upper limits recommended are 2 mg/L TP and 5 mg/L TN[17].

[16] Note it is assumed that irrigation runoff and first flush rainfall runoff is prevented or captured and reused onsite.

[17] These are based on research projects undertaken at the Institute of Sustainable Irrigated Agriculture in Tatura, including Project I5037 (Nexhip et al) regarding nutrient water quality targets for irrigated pasture and *Towards Environmentally Sound Fertiliser Management on Irrigated Pastures* (Austin, Prendergast & Dick, 1995).

# Appendix 2: Nutrient Balance Assessment

| SITE | APPLICATION RATE[1] | INPUTS | OUTPUTS[2] | BALANCE | SOIL LEVELS | COMMENT |
|---|---|---|---|---|---|---|
| Drouin | 0.9 – 1.5 ML/ha | 1 – 3 kg/ha P[3] | 20 – 40 kg/ha P | Deficit | High | Preference fodder cropping to aid reduction in soil P. |
| | | 11 – 27 kg/ha N | 100 – 300 kg/ha N | Deficit | Very Low | Consider N fertiliser application to maximise production and P removal. |
| Mirboo North | 1.6 – 3.0 ML/ha | 9 – 10 kg/ha P | 20 – 40 kg/ha P | Deficit | High | Preference fodder cropping to aid reduction in soil P. |
| | | 8 – 20 kg/ha N | 100 – 300 kg/ha N | Deficit | Low | Consider N fertiliser application to maximise production and P removal. |
| Heyfield | 2.0 – 4.3 ML/ha[4] | 12 – 50 kg/ha P | 20 – 40 kg/ha P | Excess (some years) | High | Preference fodder cropping to aid reduction in soil P. |
| | | 8 – 20 kg/ha N | 100 – 300 kg/ha N | Deficit | Very Low | Consider N fertiliser application to maximise production and P removal. |
| Maffra | 1.7 – 4.7 ML/ha[5] | 9 – 16 kg/ha P[6] | 20 – 40 kg/ha P | Deficit | Optimal | Maintain current practice. With exception of some flood paddocks where soil P levels could be reduced. |
| | | 17 – 41 kg/ha N | 100 – 300 kg/ha N | Deficit | Low | Consider N fertiliser application to maximise production and P removal. |
| Stratford | 3.3 – 5.5 ML/ha | 28 – 43 kg/ha P | 20 – 40 kg/ha P | Balance to slight excess | Optimal | Maintain current practice |
| | | 37 – 60 kg/ha N | 100 – 300 kg/ha N | Deficit | Very Low | Consider N fertiliser application to maximise production. |
| Dutson Downs | 1.2 – 2.1 ML/ha | 9 – 15 kg/ha P<br>+ 4 kg/ha P from compost | 20 – 40 kg/ha P | Balance to excess with fertiliser[7] | Low[8] | Continued build-up of soil nutrients is appropriate. |
| | | 5 – 15 kg/ha N<br>+ 15 kg/ha N from compost | 100 – 300 kg/ha N | Deficit to balance with fertiliser | Very Low | |

Notes relating to nutrient balance summary:

1. Consideration has been given to the last four years irrigation rates, to account for climatic variation.
2. The lower end of the outputs range relates to grazing of pastures, while the upper is for fodder cropping. All of the sites have the same land use and therefore the same outputs range applies.
3. In 2012, 3 tonnes per hectare of compost was applied to the Drouin site, adding approximately 12 kg/ha phosphorus and 45 kg/ha nitrogen. Outputs still exceeded inputs in that year.
4. Figures for Heyfield relate to the more flood irrigation area. The cannon spray area receives 0.5 – 1.5 ML/ha and soil P levels are correspondingly lower.
5. Figures for Maffra consider the flood and pivot irrigation areas. The cannon spray area receives 0.0 – 1.9 ML/ha – soil P levels in this area are optimal.
6. Nutrients have also been applied in compost at Maffra, but not since 2013. This added approximately 12 kg/ha P and 45 kg/ha N. Some paddocks received a similar amount from compost applied in 2012 as well.
7. Fertiliser has also been used on Pivot areas 1 to 8 at Dutson Downs to build up soil nutrient levels.
8. The Pivot 9 area at Dutson Downs is an exception due to a different history of reclaimed water irrigation. Maize silage is being produced and reclaimed water application has been reduced to allow mining of soil nutrients.

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