Lime Situation Report 2015 South Coast NRM Region

Prepared for South Coast Natural Resource Management Inc.

by Julia Fry

SOUTHCOAST NATURAL RESOURCE MANAGEMENT INC.

Australian Government | National Landcare Programme

1 Acknowledgements

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2 Abbreviations

ABS	Australian Bureau of Statistics
CCL	Cockburn Cement Ltd
DAFWA	Department of Agriculture and Food, Western Australia
DEC	Department of Environment and Conservation
DMP	Department of Mines and Petroleum
DPAW	Department of Parks and Wildlife
EPA	Environmental Protection Authority
GSWA	Geological Survey, Western Australia
NRM	Natural Resource Management

3 Glossary

Buffering capacity (of a soil)	Capacity of a soil to resist changes in pH
Calcrete	Carbonate material deposited in host materials usually in semi-arid areas (also known as kankar)
Dolomite	A sedimentary rock composed primarily of the mineral dolomite $CaMg(CO_3)_2$
Eocene	55.8 to 33.9 million years ago
Limestone	A sedimentary rock composed mainly of calcium carbonate
Lithification (of limestone)	Cementing of sand grains into rock/stone
Neutralise (with lime)	Change pH to 7 by reaction with the carbonate molecules in the lime
pH	Is a measure of hydrogen ion concentration and is therefore a measure of the amount of acidity or alkalinity. A pH of 7 is neutral. Each whole number in the scale represents a 10-fold change in acidity or alkalinity.

Quartenary	The Quaternary period is the current geological time and began 1.8 million years ago. It includes the two most recent geologic epochs, the Pleistocene and the Holocene
Quicklime	Calcium oxide (CaO) produced from calcium carbonate by heating at high temperatures. The process is called calcination or lime burning.

Cover photo

South Coast Limestone by Chris Gazey, DAFWA

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4 Executive Summary

Soil acidification is a major degradation problem in the South Coast Region. A high proportion of soils are either below optimum pH or at high risk of acidity. While topsoil acidity is easy to ameliorate with surface application of lime, sub-soil acidity is a growing problem and it takes much longer for lime to reach deeper soil layers. Acidic soils reduce crop yields by 10-12% and by even more for sensitive crops such as canola. Bulk lime in the form of limesand, crushed limestone or dolomite is currently the cheapest way to ameliorate acid soils.

Lime supplies on the South Coast are limited, more expensive and are often of much lower efficiency at remediating acidic soils, than the limesands of the west coast. Nevertheless the economics of applying more South Coast lime versus transporting lime from the west coast has to be carefully considered, because it will vary with lime pit, efficiency of the lime and distances. This report estimated the agricultural lime required in the South Coast Region over the next 10 years to be approximately 8 million tonnes. If most soils are remediated in the next 5 years, this will require close to a million tonnes per year. To maintain South Coast soils at target pH would require approximately 20 million tonnes over the next 30 years and 30 million tonnes over the next 50 years.

Many of the lime resources in current South Coast lime pits do not have very high carbonate percentages or have large particle sizes and therefore are of relatively low efficiency compared to west coast limesands. Farmers using these resources would often need to apply 2-3 times the amount recommended, which is based on much higher carbonate equivalents. If used at a rate to ameliorate South Coast soils, current pits would only have enough lime resources to last a few more years.

Lime is a non-renewable resource and with the ongoing need to apply lime to Western Australian agricultural soils, the availability and cost of lime into the future is a major concern. This review examines the problem and extent of soil acidity in the South Coast NRM Region, the economics of lime supplies and discusses the advantages and disadvantages of using west coast versus South Coast lime. It also discusses supply and demand and potential future lime supplies. In addition it examines management options to reduce rates of acidification of soils, ways to use lime more effectively and some renewable alternatives for acid soil amelioration including some 'blue sky' ideas.

Other work is progressing but was unavailable at the time of this report. This includes an economic analysis of lime application for the South Coast Region by DAFWA and the GRDC, and a Basic Raw Materials Strategy for the Region by the Department of Mines and Petroleum and Department of Planning.

The two major concerns for the future are whether the South Coast Region is running out of time to lime and whether farmers can access quality lime economically.

This report recommends that South Coast NRM form partnerships with the Department of Mines and Petroleum (Geological Survey of WA), Department of Planning, Great Southern Development Commission, Goldfields Esperance Development Commission and Department of Agriculture and Food WA to:

1. Investigate potential new lime supplies by mapping and tenure analysis

Link Geological Survey of WA mapping of potential deposits and tenure analysis.

Investigate potential deposits of limestone/sand at Torbay, SW of Denmark, Bremer, Hopetoun and Esperance on private land. Pits on Crown land would have to comply with the Mining Act and would be expensive to develop. They are often in areas of high biodiversity value. It is also recommended that South Coast NRM establish a set of site selection considerations based on NRM values.

Sample and analyse potential lime supplies for neutralising value and particle size. Potential deposits will need to be analysed for carbonate content but the potential particle size of the product will also determine efficiency.

2. Support a Basic Raw Materials Strategy for the South Coast

A Basic Raw Materials Strategy for the South Coast (this would include limestone/sand, gravel etc) can guide planning decisions in relation to deposits of limestone/sand and dolomite. These Strategies have been prepared by the Department of Planning for other regions. The GSWA is currently preparing data for this (GSWA 2015).

3. Continue lime extension

Suggested strategies:

- Focus on lime quality and the need for landholders to know the efficiency of the lime they apply. Extension to stress the need to apply more of lower quality lime resources.
- Encourage soil testing, paddock mapping and variable rate technology to use lime more effectively.
- Use the message that lime is only to get more expensive and soils harder to ameliorate.
- Hold workshops with rural real estate agents to include soil pH testing and lime history in farm sales so that it becomes an important part of land value.
- Develop a collaborative project with other NRM regions in the agricultural area on lime supplies for agricultural use.

4. Investigate the economics of further crushing from pits with high NV and large particle size.

Many South Coast lime resources are of low efficiency because of large particle size. Investigate the economics of further crushing of resources, versus freight.

5. Monitor soil acidity trends in the Region

Recommendation 6. Support lime research and demonstration sites on alternative management practices.

Focus on alternative management practices to reduce rates of acidification and more effective use of lime through incorporation and variable rate technology.

7. Investigate Transport Options

Investigate bulk transport options. Although this is unlikely to be feasible because of extra handling costs, it would need economic analysis. Investigate the possibility of transport subsidies.

8. Investigate Nullarbor limestone as an option for the long term

9. Investigate alternative ameliorants

Investigate wood ash as a liming agent. This could be investigated initially in the forestry industry. South Coast could seek funding for a small-scale trial with wood ash on acidic soils, comparing it to lime, and assaying soil and plant chemicals. In the long-term, wood ash as a liming agent, could increase the viability of biomass energy. For example it could be produced as a by-product from a biomass plant in an area close to Ravensthorpe or Jerramungup.

Lime Spreading (Chris Gazey, DAFWA)

5 Soil Acidification

5.1 Introduction

Soil acidification is an insidious process that develops slowly and, if not corrected, can continue until the soil is irreparably damaged (Moody *et al.* 2002 p19).

Soil acidification is a major soil degradation problem in the South Coast Region (DAFWA 2013). Acidification is a natural process but it increases with agriculture and accelerates with higher productivity. The rate of acidification also varies with management, land use and soil type. Although many soils in WA are naturally acidic their acidity has increased, and increased deeper into the soil profile over time since clearance (Dolling and Porter 1994).

Sub-soil acidity inhibits plant growth by increasing the availability of aluminium, which inhibits root growth; decreasing the availability of essential nutrients; and inhibiting nitrogen fixation. Reduced plant growth has off-site impacts by contributing to salinisation, sedimentation and eutrophication because of decreased water and nutrient uptake.

The only way to diagnose soil acidity is to sample and measure pH. Sampling, testing and amelioration with lime should be part of normal farming practice (Gazey and Davies 2009, p4). Without on-going amelioration, agricultural soils can continue to acidify to the point where they become too expensive to recover. If untreated, acidification is likely to affect a larger area of land than any other soil degradation problem (O'Connell *et al.* 1999 p2).

Davies, Gazey and Galloway (2009) estimated that sixty-five percent of the South Coast agricultural area is acidic, with a high risk of sub-surface acidity and therefore aluminium toxicity. Another 8% is at moderate risk (Davies, Gazey and Galloway 2009). Acidification is particularly prevalent on the sandplain soils of the South Coast Region due to their poor buffering capacity. DAFWA (2013) reported that 90% of some sandplain soils in the South Coast Region were acidic. Heavier textured soils acidify more slowly, but will also require more lime and take longer to ameliorate, if they become acidic. There are a few scattered areas of the South Coast where sub-soils are alkaline but where surface acidity may still need amelioration.

Although some management practices can reduce the rate of acidification, the removal of agricultural products as alkaline plant material, will decrease soil pH over time. Applying lime is currently the only way to ameliorate acidic soils. Although lime is a relatively cheap bulk commodity, broadacre farmers often consider it a large expense, particularly if it has to be transported over large distances. Amelioration of acidic soils is going to get more difficult and more expensive as they continue to acidify. The Department of Agriculture and Food (DAFWA) have been conducting liming trials for over twenty years and based on this research, recommend keeping soil pH values at or above a target of 5.5 in the topsoil and 4.8 in the subsurface soil (Gazey and Davies 2009; Gazey *et al*. 2014 a and b). Using all the data from the research trials, yields increased on average by 10%. The yield increase was even greater, if the time for the lime to neutralize soil is taken into account (Gazey *et al.* 2014a). Yield responses to lime for acid sensitive crops such as canola are generally higher.

There is skepticism from some farmers about the benefits of adding lime because of the time it takes to see a yield response. Farmers also find it difficult to attribute a yield response to lime because of large seasonal variations in yield. With the failure to add enough lime, sub-surface acidity is a growing problem. Ameliorating sub-surface acidity can take a long time and so applying lime and raising surface pH may not improve yields for many years. The Department of Agriculture and Food stress the importance of soil testing so that sub-surface acidity isn't allowed to develop in the first place.

DAFWA state that "*if soil surface pH can be raised and maintained above the target this will ensure that management of subsurface acidity will be achieved over time*" (DAFWA 2013 p 30).

To reduce land degradation through soil acidity in Western Australia the last State of Environment Report for WA from the EPA (EPA 2007) recommended the following actions.

- Develop and implement a Soil Acidification Management Strategy as a component of the proposed State Soil Protection Policy, covering all types of acid soils.
- Finalise and implement the draft State Lime Supply Strategy incorporating sustainability principles.
- Develop an agreed baseline of the extent and severity of soil acidification in WA.

The Draft State Lime Supply Strategy was initiated in 1998 to address concerns about lime production and supply in relation to environmental, conservation, urban and heritage issues. The Department of Industry and Resources oversaw development of the strategy, with guidance from other government agencies. The strategy was still in draft form in 2007 as the 'Draft State Lime Strategy 2006'. The State Lime Strategy was still not finalised at the time of writing of this report in 2015. In mid 2015 the State government funded the Shire of Gingin to develop a wheatbelt lime strategy through Royalties for Regions funding.

DAFWA have published baseline data [1] on the extent and severity of soil acidification in WA in the *Report Card on Sustainable Natural Resource Use in Agriculture. Status and trend in the agricultural areas of the South West of WA* (DAFWA, 2013). In this document the sandplain area of the South Coast Region was rated as very poor in resource condition for soil acidity. This is due to the poor ability to resist changes in pH (poor buffering capacity) of many of the soils and inadequate amelioration with lime. Areas of WA with ready access to lime tended to have less acidic soils (DAFWA 2013).

Because of its geological history, the South Coast Region has much fewer and lesser quality lime supplies, than the west coast. The best quality lime supplies on the South Coast occur in coastal outcrops of Tamala and Tamala-like limestone, on coastal reserves and national parks. The cost of freight is a major constraint in farmers purchasing high quality lime from west coast supplies. This is an even greater problem for the eastern South Coast Region. The best option for the future is if good quality lime can be found on private land where extraction is acceptable based on environmental and amenity values.

Use of lime presents a quandary for natural resource management because application of lime is necessary to protect the soil resource but lime itself is a limited resource and often occurs in coastal locations of high biodiversity and amenity value. Lime is extracted from lime sand dunes and limestone and dolomite deposits and this can be detrimental to native

[1] The majority of the data was from the Precision SoilTech Database. Additional data was produced from projects as referenced in the chapter in the report card.

vegetation, landscape values and other natural resources. Lime is a non-renewable resource and with the ongoing need for application of lime to Western Australian agricultural soils, the availability and cost of lime into the future is a major concern. This review examines the problem and extent of soil acidity in the South Coast NRM Region, the economics of lime supplies, potential future lime supplies and discusses renewable alternatives for acid soil amelioration. The two major concerns are whether the South Coast Region is running out of time to lime and whether farmers can access quality lime economically.

5.2 Causes of increased soil acidification with agriculture

The incomplete cycling of N, C and to a lesser extent S is a major cause of the increasing soil acidity with agriculture (Bolan and Hedley 2003, p 51).

The causes of incomplete cycling include:

- the excretion of hydrogen ions from plants due to greater uptake of cations than anions
- use of ammonium-based fertilisers because of nitrification of ammonium and leaching of nitrate
- the accumulation of organic matter as humic acids and mineralization of organic matter in the soil
- removing agricultural products as grain, hay, meat, wool (which results in removal of alkalinity as organic anions) (Helyar and Porter 1989, Tang and Rengel 2003)
- the leaching of nitrogen from the root zone in legume pastures

The two main causes of increased acidification in paddocks that are used solely for cropping, are removal of plant material (pasture and crop), and leakage of nitrogen fertilisers. In paddocks under pasture, legume pastures are also contributing to acidification.

5.3 Rates of acidification

The amount of lime required to counter yearly acidification from agriculture varies with a range of factors including, rainfall, soil type, crop or pasture grown, productivity, fertiliser use and type of fertiliser.

Higher rainfall can increase acidification rate because of increased nitrogen leaching, particularly early in the season in annual winter pastures. There is a spike in nitrate leaching with autumn rains (Anderson *et al.* 1998).

Soils differ in how quickly they change pH, their buffering capacity. This is related to soil texture. Sandy soils are poorly buffered, compared to loams, while soils with high clay content have the most buffering capacity. Acidification rates are four to five times faster on deep sands than on sandy duplex soils (Dolling and Porter 1994).

Pastures with a high legume percentage acidify faster than annual grass pastures because there is more nitrate leaching from legumes. The rate of acidification won't be directly related to annual rainfall, because it is the distribution and intensity of rainfall events that affects mineralisation and leaching of nitrate (Fisher *et al.* 2008). Deep -rooted perennial pastures that use summer and autumn rainfall can reduce early season nitrate leaching.

Dolling and Porter (1994) investigated rates of acidification in deep yellow sands and Dolling *et al.* (1994), in sandy duplex wheatbelt soils under cereal pasture rotations. In deep yellow sands 12-74 years after clearing, Porter and Dolling *et al.* estimated acidification rates to be 0.19-0.23 kmol H+/ha. year, requiring 10-11 kg $CaCO_3$/ha.year to neutralise. The greatest acidification occurred in the 10-20 and 20-30 cm layers, with acidification occurring to a depth of 80 cm. The rate of pH decline for each depth below 10 cm was 0.007 units/year. The surface soil (0-10 cm) did not acidify.

In sandy duplex soils Dolling *et al.* (1994) estimated the rate of acidification from when the land was cleared to be 0.15 kmol H^+/ha.year (in the whole soil profile), requiring 7.7 kg $CaCO_3$/ha to neutralise. They found that most of the acidification could be accounted for by removal of alkaline products through harvest or grazing. Acidification was occurring to a depth of 30 cm, the acidification rate decreasing with depth. In the surface 20 cm the pH decline was 0.005-0.006 pH units/year. Acidification was occurring to 60 cm depth in all rotations, mostly due to nitrate leaching, removal of alkaline products, and build-up of organic matter. Dolling *et al.* (1994) also compared rates of acidification using continuous wheat without fertilizer nitrogen as the control. The rate of acidification relative to the control, ranged from 0.35 kmol H^+/ha .year (17.5 kg $CaCO_3$) for continuous wheat with fertiliser N to 0.92 kmol H^+/ha. year (45.8 kg $CaCO_3$) for continuous pasture (Dolling *et al*. 1994). These experiments give a rough guide to how much lime needs to be used for maintenance on different soil types and rotations. Continuous pasture acidified sandy duplex soils much faster than continuous wheat, probably because of nitrate leaching from the legume content.

Acidification can be slowed by reducing nitrate leaching and using nitrate-based fertilisers rather than ammonium based fertilisers, but soils will still continue to acidify because of the removal of alkaline material. Plants take up nitrogen as positive ammonium ions, and negative nitrate ions. Most ammonium is converted to nitrate (nitrification) in agricultural soils and so most nitrogen is taken up as nitrate. Plants then excrete positive hydrogen ions through their roots and retain hydroxide ions. When the alkaline plant material is removed either by harvesting or grazing, this acidifies the soil.

Plant residues in soil, may raise or lower pH, depending on the soil and soil processes. Xu *et al.* (2006) incubated plant residues in different WA soils and found different effects on pH in different soils at different pHs, depending on whether there was predominantly ammonification or nitrification.

Although acidification rates vary, acidification due to agriculture is a continuing process, which is detrimental to plant growth and is a global problem.

5.4 Effect of soil acidity on plant growth

5.4.1 Aluminium toxicity

Sub-soil acidity inhibits plant growth more than topsoil acidity, because of aluminium toxicity. In the topsoil the aluminium is bound to organic matter and is not available at toxic levels. Aluminium in the subsoil becomes soluble at low pH. As more aluminium becomes available it retards root growth, which reduces water and nutrient uptake. This in turn reduces yields of both pastures and crops. In crops it leads to smaller grain size as a result of inadequate water and nutrition. It can be a particular problem if there is a dry finish to the season. Where topsoil acidity is the only constraint, aluminium toxicity is unlikely to be a problem.

Although aluminium becomes more available at low pH, in some soils it becomes available at much higher pH than others. It is not a simple relationship. Moir and Moote (2014) found that the shape of the response curve between pH and aluminium differed at different lime trial sites. They argued for more research into the soil factors and mechanism leading to aluminium becoming available and leading to toxicity (Moir and Moote 2014, p43). Plants vary in their tolerance to aluminium and the prevalence of acid soils globally has led to a large research effort to identify genes and physiological mechanisms in aluminium tolerant plants.

5.4.2 Plant nutrients

The plant nutrients nitrogen, phosphorus, potassium, sulfur, calcium, magnesium and the trace element molybdemum become less available in acidic soil. Phosphorus becomes less available at pHs greater than 6 so the target is 5.5 for the topsoil, rather than a higher level.

Table 1 Relationship between pH and nutrient availability (pH measured in $CaCl_2$)
Note: availability is also affected by soil properties such as soil organic matter and clay content which bind some nutrients. There are interactions between nutrients. For example iron and aluminum bind phosphorus making it less available. (Based on figures in DAFWA bulletins).

Nutrient	pH $CaCl_2$ at which high level of availability	Acidity
Nitrogen	5.5-7.5	Slightly acid to neutral
Phosphorus	5.5-7	Slightly acid to neutral
Potassium	5.5-9	Slightly acid to alkaline
Sulfur	5.0-9	Slightly acid to alkaline
Calcium	5.5-9	Slightly acid to alkaline
Magnesium	5.5-9	Slightly acid to alkaline
Iron	3-4.5 (high levels bind P)	Acidic
Manganese	3-4.5	Acidic
Boron	3.5-6 and 8-9 Toxic	Acidic or alkaline
Copper and Zinc	3.5-6	Acidic
Molybdenum	5.5-9	Slightly acid to alkaline
Aluminium	3-4.5 Toxic	Acidic

The availability of phosphorus decreases with pH because iron and aluminium become more available and phosphate ions adsorb onto the positively charged metal ions (Hinsinger 2001). (See table 1).

Weaver and Summers (DAFWA 2013) found that phosphorus levels in some south-west agricultural soils, in the higher rainfall areas, were higher than needed for optimal production but because they were acidic, the uptake of phosphorus was restricted. Their data was based on clover requirements rather than crops. Nevertheless, in certain situations applying lime may be able to save on phosphorus inputs, particularly in acidic soils of the high rainfall areas of the South Coast Region. This is particularly important in reducing eutrophication of waterways.

5.4.3 Rhizobia

Acid topsoils reduce microbial activity, including nitrogen-fixing rhizobia bacteria. In pastures this can result in less legume in the pasture and less productive pasture. Evans *et al.* (1988) found increasing soil pH in acidic soils increased both the rate at which sub-clover rhizobium colonized soil and the frequency of nodules. Although the preferred pH range for most rhizobia species is pH 6.0 to 7.5, different legumes and their rhizobia having different tolerances to acid soils. Sub-clover *Rhizobium leguminosarum* bv. *trifolii* will tolerate a lower pH than that of medics, *Sinorhizobium* spp or serradella, (Drew *et al.* 2012). Drew *et al.* (2012) state that sub-clover symbioses are reasonably tolerant of low soil pH, but ideally soil pH should be greater than 5.5 . Drew *et al.* (2012) suggest that background (naturalised) soil rhizobia should not be relied upon in very low pH soils. This would suggest that after correcting topsoil pH farmers should inoculate their sub-clover pastures.

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5.4.4 Pasture and crop tolerances

Soil acidity also restricts which crops and pasture farmers can grow. For example canola is more sensitive than wheat. The range of sensitivities of pastures and crops is shown in figure 1.

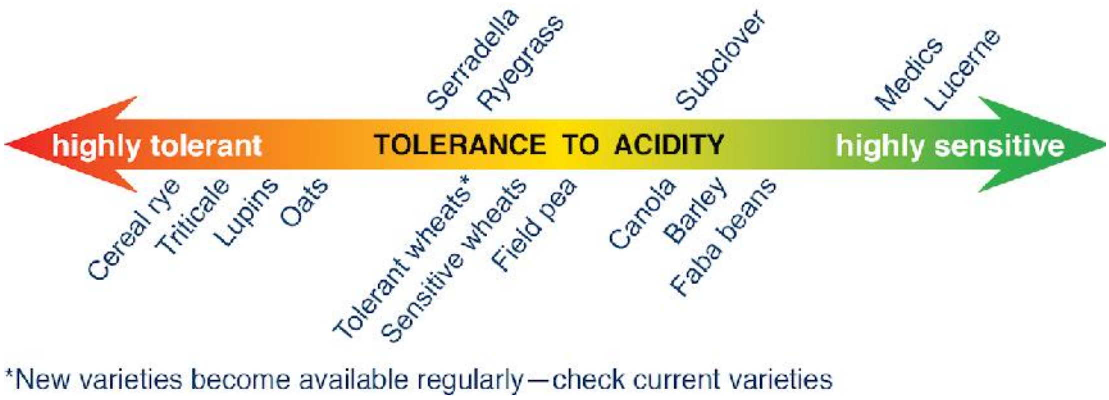


Figure 1 Acid tolerances of crops and pastures Source Gazey *et al*. 2014b (DAFWA)

Medics and lucerne are highly sensitive to acid soils. Most medics are adapted to neutral to alkaline soils but WA breeding has focussed on acid tolerance and Burr medic (*M. polymorpha*), Sphere medic (*M. sphaerocarpos*) and Murex medic (*M. murex*) are more tolerant of acidity than others (Nichols *et al.* 2007). Balansa clover has low tolerance, subclover is moderately tolerant but acidity will decrease nodulation, while kikuyu is much more tolerant. This tolerance of kikuyu masks soil acidity in high rainfall areas of the South Coast, while topsoil acidity may be contributing to sub-clover decline.

Barley and canola are less tolerant than wheat , which is in turn less tolerant than oats, lupins and triticale. Acid tolerant wheats are still a lot less tolerant than crops such as triticale (Gazey and Davies 2009). There has also been an emphasis on breeding legumes suited to deep sandy acid soils, such as improved cultivars of yellow serradella (*Ornithopus compressus*), commercialisation of French serradella (*O. sativus*) and Biserrula (*Biserrula pelecinus*). Biserrula is very hard seeded and suited to 1:1 crop pasture rotations. Cultivars of lucerne are also being developed for more acid (aluminium) tolerance. Lucerne is highly sensitive to acid soils while birdsfoot trefoil (*Lotus corniculatus*) is a perennial legume more tolerant of acid soils (Nicholls *et al*. 2007).

5.5 Measuring soil acidity

The Department of Agriculture and Food recommend using a professional soil sampling service and sending the samples to a laboratory accredited with the Australasian Soil and Plant Analysis Council Inc. (Gazey and Davies 2009). Acidity is measured as pH, which has a logarithmic scale. This means that a soil with a pH of 4.5 is ten times more acidic than one with a pH of 5.5. Accredited laboratories usually measure pH in a solution of calcium chloride because it reduces variations in soil salts that influence the measurement when pH is measured in water. The measurement gives a much more consistent result. Laboratories measure pH in a one-part soil to five parts 0.01 M calcium chloride solution.

For most soils in WA the relationship between the two measurements is a linear regression

pHCa=0.918 pHw-0.3556, r=0.9401. (Brennan and Boland 1998),

The pH measured in water is higher than that measured in calcium chloride and can give a false impression as to whether soils are at target. Gazey and Davies (2009) and Davies *et al.* (2009) recommend a simpler conversion from pH measured in water to pH measured in calcium chloride, is to subtract 0.7 to 0.8. The pH measured in calcium chloride is expressed as pH_{CaCl2} or pH_{Ca}.

Samples for soil pH need to be taken at 0-10, 10-20 and 20-30cm to detect acidity throughout the soil profile, and in various locations across the paddock to detect spatial variability. Samples should be geo-referenced in order to monitor changes.

Geo-referenced monitoring is also important at a broader scale to assess overall soil resource condition.

6 Monitoring at Regional or Sub-regional Level

Moody *et al*. (2002) recommend the main datasets to monitor soil acidity.

- soil pH over time (preferably with pH measured at several depths in the soil profile) from surveillance sites
- pH buffering capacity of each soil layer (ASRIS or from soil data)
- net annual acidification rate (NAAR) of different land management practices. Surveys of land use and land management practices. Estimates of NAAR from permanent monitoring sites and long-term research sites
- critical pH for the nominated crops or land use.

Moody *et al.* (2002) suggested that NRM Regions should set up permanent monitoring sites and surveillance sites. (See table 2). South Coast NRM already has data from a wide range of locations collected in 2012/13 and a continuation of this approach may be more useful to assess trends.

Table 2 Monitoring Indicators for NRM regions for acidity. Source Moody *et al.* (2002)

Indicator	**Method**	**Outputs**
Baseline pH	Collation of commercial and public soil testing data for baseline estimate of pH. Networks of permanent monitoring sites in highest priority regions	Baseline estimates of pH
Change in pH (Δ pH) pH(time1)-pH (time 0)	Collation of commercial and public soil testing data Networks of permanent monitoring sites in highest priority regions $\Delta pH = pH(t_1) - pH(t_0)$	Estimates of pH (t_0, t_1, t_2, …) and ΔpH expressed as summary statistics by region and generalised maps (e.g. Level 3 or 4 in ASRIS)
Net acid addition rate (NAAR) for systems of land management	NAAR based on data from permanent monitoring and research sites. Outputs rely on these data, maps of management practices, and soil data from ASRIS	Regional and national maps of NAAR
Estimated time to critical pH for chosen combinations of land use and soil type	Helyar and Porter models based on ASRIS soil data, land use data and other data	Generalised maps of buffering capacity Generalised maps of time to critical pH based on models
Lime use and other land management practices	ABS statistics of lime use and other land management practices	Tabulations of lime requirements Statistics of lime use and other practices

7 The extent of acidity on the South Coast

7.1 The Department of Agriculture and Food Report Card

In 2013 the Department of Agriculture and Food published a report card on the natural resource condition of agricultural soils, including the extent of acidity.

The overall soil resource condition for acidity for the South Coast NRM region is shown in figure 2.

South Coast NRM has been able to use the data as part of its report card for the South Coast. This data is presented at a broad scale but it gives a good baseline for the Region in measuring whether there is increasing or decreasing soil acidity over time. The report card is not meant to be a tool for farm management but highlights the extent of problem at a regional scale (DAFWA 2013, p30). The DAFWA report card found that:

The majority of agricultural soils are continuing to acidify because the annual use of agricultural lime is 40% of the estimated amount required to treat existing acidity and on-going agricultural soil acidification. (DAFWA 2013 p26)

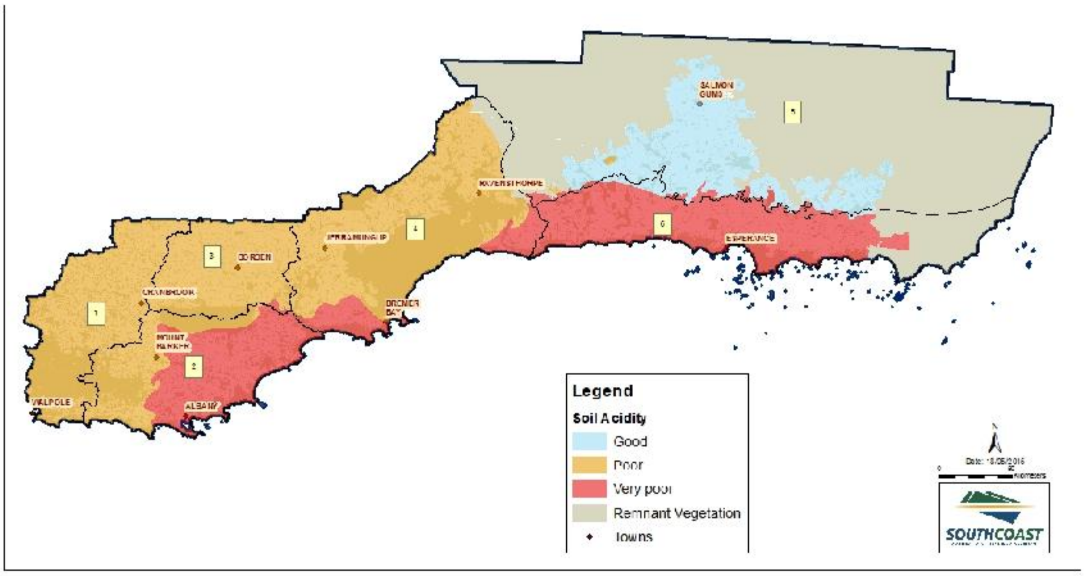


Figure 2 Soil acidity South Coast from the DAFWA (2013) Report Card

A large number of samples were collected and pH determined in calcium chloride solution (pH_{Ca}). The data was used to create a map of the proportion of samples below the targets of pH_{Ca} 5.5 (0–10 cm layer) and pH_{Ca} 4.8 (10–20 and 20–30 cm layers) for each of the major soil types. This information was further allocated to Ag Soil Zones, which are broad spatial areas of grouped soil types (See figure 3). The data on soil zones below target was then mapped at agricultural region scale (DAFWA 2013, p29). Information was provided for those soil types that made up >10% of the Ag Soil Zone.

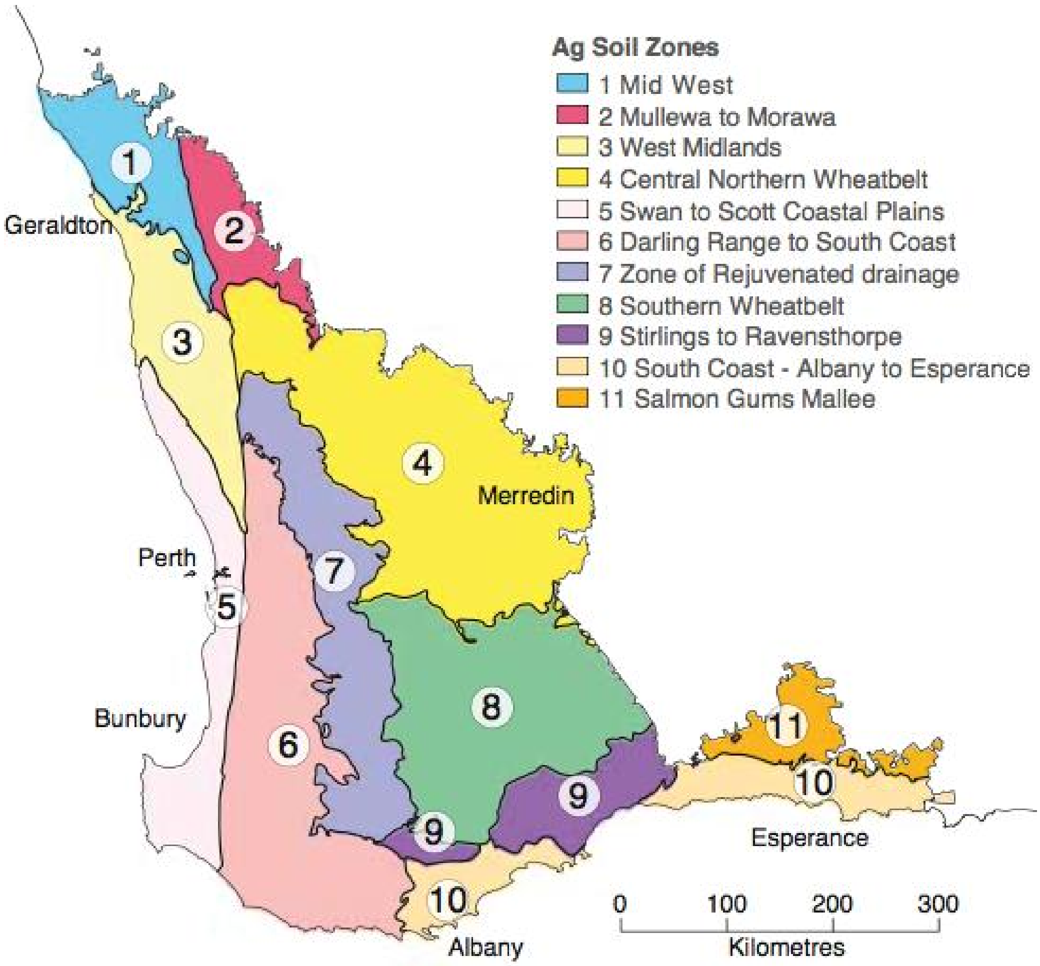
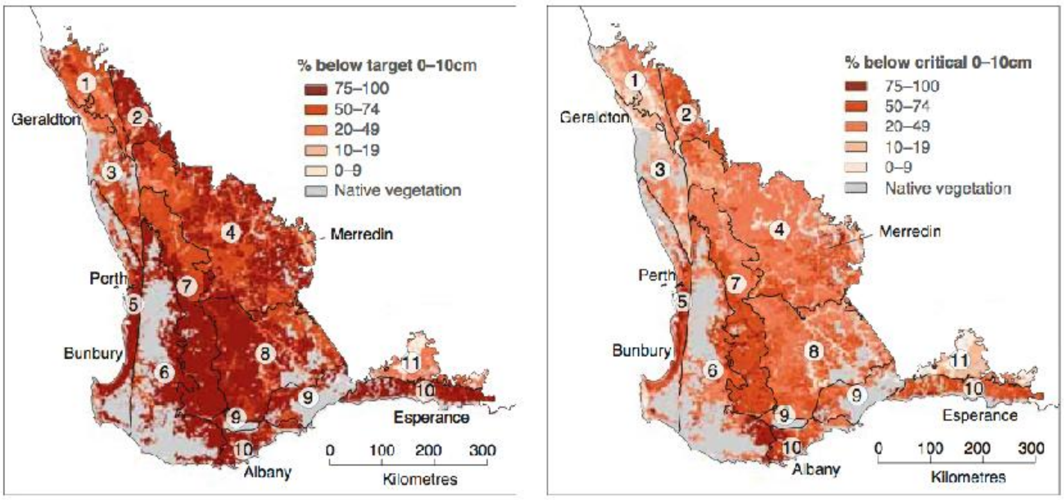


Figure 3 The main Ag Soil Zones in the South Coast Region are: 6 Darling Range to South Coast 9 Stirlings to Ravensthorpe 10 South Coast Albany to Esperance and 11 Salmon Gums Mallee. There are very small amounts of 8 Southern wheatbelt and 7 Rejuvenated drainage. Source DAFWA (2013).



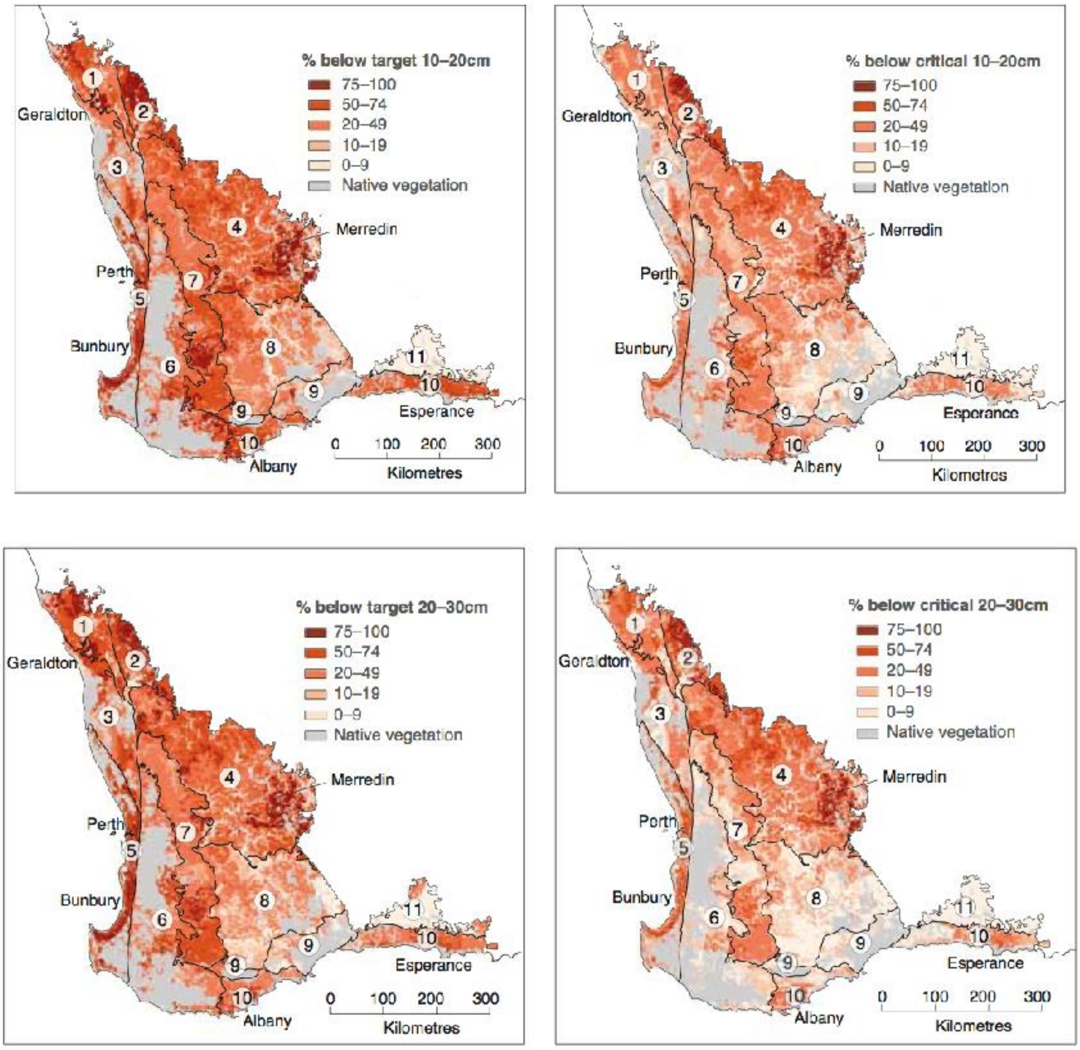


Figure 4 Percentage of sites sampled (2005–12) (2005–12) with soil pH at 0-10, 10-20 and 20–30 cm depth below the DAFWA target of pH_{Ca} 5.5 for 0-10cm and pH_{Ca} 4.8 for 10-20 and 20-30cm (left) and critical pH_{Ca} 5.0 for 0-10cm and pH_{Ca} 4.5 for 10-20 and 20-30cm (right). Source DAFWA 2013.

Figure 4 shows the extent of soil acidity in the agricultural area of WA by Ag Soil Zone

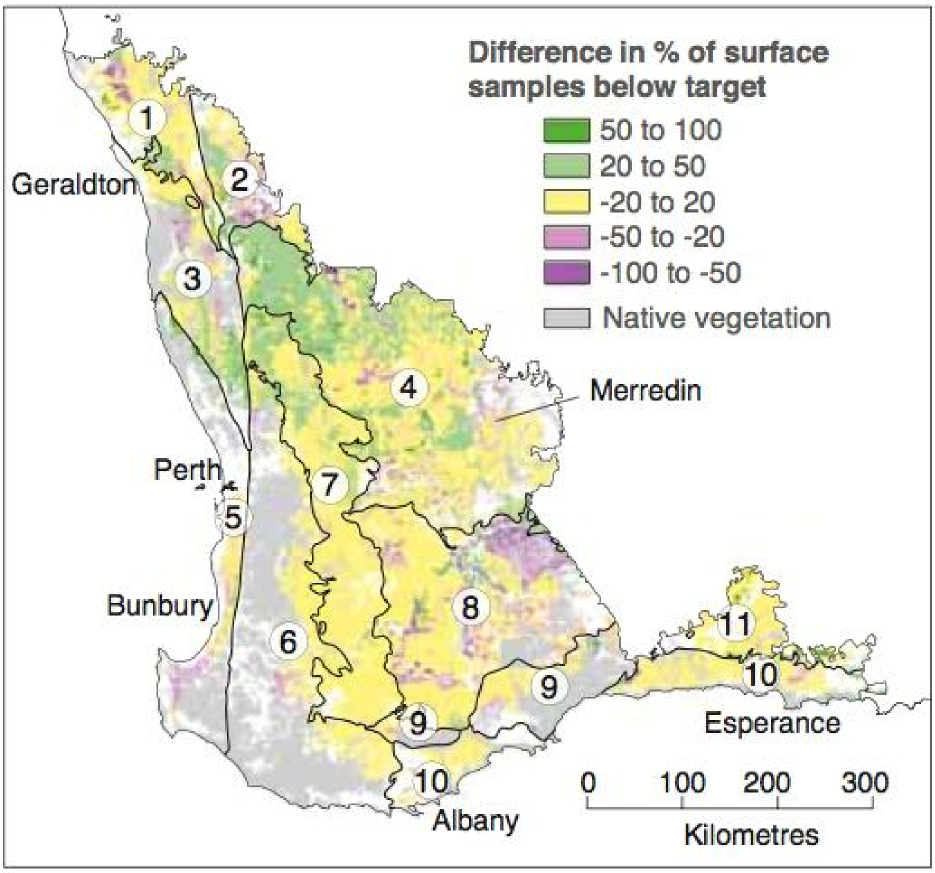


Figure 5 Difference in percentage (%) of surface (0–10 cm) samples below the recommended target of pHCa 5.5. Source DAFWA (2013).
Samples collected in 2010–12 compared to 2004–06. Positive numbers indicate improvement.

Trends in soil acidity over a period of 6 years were also reported. The proportion of samples from the surface 10 cm, below the target of pH_{Ca} 5.5, collected during 2004–06, were compared with those from 2010–12. The changes were recorded on the map to show whether there had been an improvement, no change or a decline in the condition of the soil resource (DAFWA 2013 p 29). Figure 5 shows how surface pH has changed between two sampling times.

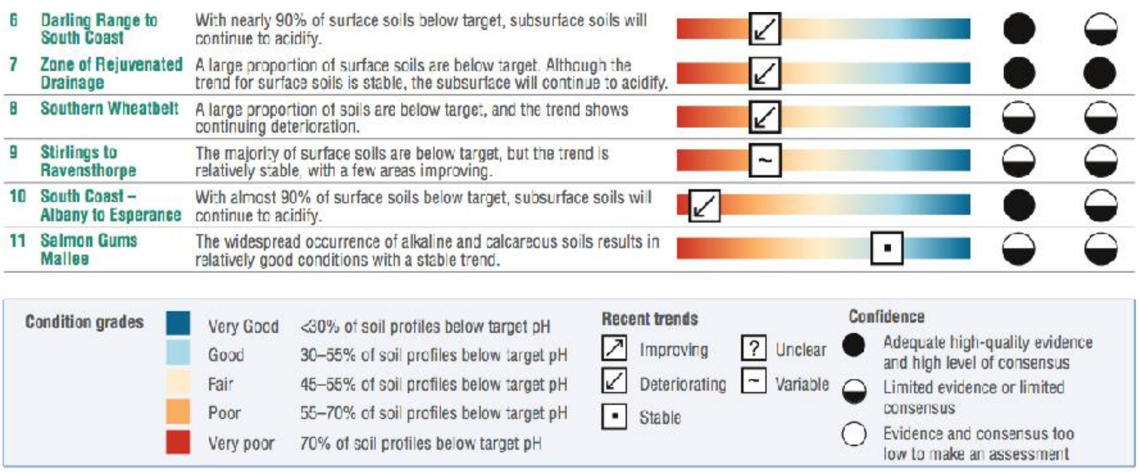


Figure 6 Condition in terms of soil acidity and trend. Source DAFWA (2103)

Figure 6 shows the overall soil condition in terms of acidity and the trend for the Ag Soil Zones in the South Coast NRM Region. Darling Range to South Coast and Albany to Esperance Sandplain are shown as deteriorating.

7.2 Acidity in Ag Soil Zones

7.2.1 Ag Soil Zone 6. Darling Range to South Coast

There is an area of this Ag Soil Zone west of Albany, mainly in the shires of Cranbrook, Denmark and Walpole. It is a high rainfall area dominated by pasture, with mainly beef cattle and some dairying. There are many small rural landholdings in this area. In the 'Gravel' soils of the Darling Range and South Coast Ag Soil Zones, 89% of samples were below the 5.5 target for the surface pH (0–10 cm layer). However, subsurface acidity was less common, with 34% of samples for the 10–20 and 20–30 cm layers, below the target. Many of these high rainfall small farms have kikuyu pasture which is highly tolerant of acid soils which initially conceals that they are degrading through acidification. Legume pastures in this zone is the likely cause of the acidification of the surface soil.

> *the degree of acidification reflects the generally higher production associated with higher rainfall compared to zones further east and the limited capacity of the surface sandy soils to resist change in pH (low buffering capacity). The major impact of soil acidity in this zone is in the surface 10 cm, although half of the 10–20 cm samples from the deep loamy duplexes and earths were below target. The situation improved with depth with around 30% of samples from the 20–30 cm layer having a pH below the subsurface target. This result probably reflects the variable depth of the sandy or loamy textured surface soil, which is more prone to acidification* (DAFWA 2013, p40).

Table 3 shows the soils below target in the main soil groups in the Darling Range to South Coast Ag Soil Zone. In these soils the pH improved with depth.

Table 3 Acidity for soils in the Darling Range Ag Soil Zone

Soil	Soil groups	% below target pH 0-10cm	% below target pH 10-20cm	% below target pH 20-30cm
All soils		86	40	29
Deep loamy duplexes and earths	505, 506, 541, 544	80	50	33
Ironstone gravelly soils	301,302,303	89	38	29
Saline wet		88	46	27

7.2.2 Ag Soil Zone 8. Southern Wheatbelt

There is a small amount of the Southern Wheatbelt Ag Soil Zone in the South Coast mainly in the North Stirlings Pallinup sub-region. (Table 4)

This zone is dominated by duplex soils with deep sandy duplexes and alkaline shallow duplexes. The deep sandy duplexes and gravels are at risk of subsoil acidity. 40 to 50% of the samples collected from the 10–20 cm layer were below the recommended target and around 30% of the samples from the 20–30 cm layer samples below the target. (DAFWA 2013, p41).

Table 4 Soils below target Southern Wheatbelt

Soil	% below target 0-10cm	% below target 10-20cm	% below target 20-30cm
All soils	82	39	25
Deep sandy duplexes	84	41	28
Alkaline shallow duplex	80	28	17
Saline wet	74	19	8
Gravels	88	53	34

7.2.3 Ag Soil Zone 9. Stirlings to Ravensthorpe

This Ag Soil Zone is in the north-western and central part of the South Coast Region and is dominated by broadacre agriculture, a greater proportion of cropping and larger landholdings than in the Darling Range to South Coast zone. The heavier textured soils from the Stirlings to Ravensthorpe were below target but not increasing in acidity and some were found to be improving. (Table 5).

Around 80% of samples collected from the 0-10 cm layer have a pH below the recommended target. From 20 to 30% of the samples from the 10–20 cm layer and 10 to 20% of the samples from the 20–30 cm layer were below the subsurface target, perhaps as a consequence of lower productivity and a greater impact of the duplex subsurface layers (DAFWA 2013, p41).

Table 5 Acidity in soils in Ag Soil Zone Stirlings to Ravensthorpe 2005-2008

Soil	% of Zone	Soil groups	% below target pH 0-10cm	% below target pH 10-20cm	% below target pH 20-30cm
All soils			80	24	15
Clay and shallow loamy duplexes	10	508, 621	77	17	9
Shallow sandy duplexes	21	404,408	82	23	17
Deep sandy duplexes	18	401,403,407,409	81	28	21
Alkaline shallow duplexes. Grey, brown or red sands or loams over alkaline clay at <30 centimetres (cm) depth	23	402,502,503	80	32	9

7.2.4 Ag Soil Zone 10. Albany to Esperance Sandplain (South Coast Sandplain)

This Ag Soil Zone is dominated by broadacre cropping with a trend to more grazing in the higher rainfall, coastal areas near Albany, Bremer and Esperance. This soil zone had the highest percentage of soils below target pH in the South Coast Region, with 90% of surface soil pH below target. Samples collected in 2010–12 compared to 2004–06 showed that much of the Albany and Esperance sandplain had deteriorated (DAFWA, 2013). Sandy soils have poor buffering capacity, which means they acidify more quickly but also need less lime to increase the pH than heavier textured soils.

> *This coastal zone is dominated by duplex soils with deep and shallow sandy duplexes, gravels and pale sands comprising over 80% of the area. Acidity in the surface 0–10 cm is extreme. From 80 to 91% of samples collected had pH below the recommended target for the layer.*
>
> *Over 60% of the subsurface samples collected had pH less than the target. This probably reflects the greater proportion of deeper sandier soils across this zone. Unless surface soil pH is increased the subsurface layers will continue to acidify and restrict productivity. Increased testing and awareness of subsurface soil acidity is recommended as well as consideration of lime quality when calculating appropriate rates as many lime sources from this area tend to be coarser and of lower neutralising value than sources to the north of Perth.* (DAFWA 2013, p42).

Only two or three percent of the soils on the sandplain are estimated to be at target pH (Davies *et al.* 2009). Table 6 shows the extent of acidity.

Table 6 Acidity in the soils of Ag Soil Zone Albany to Esperance Sandplain (South Coast Sandplain)

Soil	**Soil as % of zone**	**Soil groups**	**% below target pH 0-10cm**	**% below target pH 10-20cm**	**% below target 20-30cm**
Pale deep sands	12	442,443,444	85	60	45
Gravels	13	302	86	62	45
Shallow sandy duplexes	14	404	83	63	31
Deep sandy duplexes	42	401, 403, 407	91	55	40

7.2.5 Ag Soil Zone 11. Salmon Gums to Mallee

There is a small amount of this Ag Soil Zone in the north-eastern part of the region. It is has a high proportion of alkaline soils. It is a low rainfall zone dominated by broadacre cropping. Although dominated by alkaline soils this area had some surface soils below target pH. (Table 7). There is also a high proportion of acid groundwater in the zone (DAFWA 2013) so rising water tables could cause further acidification.

> *This zone is dominated by alkaline shallow duplex soils. The numbers of samples from across this zone reflect the distinct change in soil type. Notwithstanding the obvious differences to all the other Ag Soil Zones, the major soil type – alkaline shallow duplex – still has 42% of samples from the surface 0–10 cm below the recommended target pH.*
>
> *Although there is no indication that there is a subsurface acidity risk in this zone, it is still possible that surface acidity could be affecting nutrient availability and nodulation of legumes. The overall numbers of samples for this zone are relatively low, especially for the subsurface layers.*
>
> *Continued expansion of the areas affected by shallow saline watertables is likely over the next 50–100 years, irrespective of rainfall trends. This expansion is likely to result in further increases in discharge of acid, saline groundwater to surface environments,*

particularly in eastern areas where groundwater is more commonly acid. (DAFWA 2013, p166)

Table 7 Acidity in soils Salmon Gums to Mallee Ag Soil Zone

Soil	% zone	Soil group	% below target pH 0-10cm	% below target pH 10-20cm	% below target 20-30cm
Clays and shallow loamy duplexes	7	622	9	n/a	n/a
Calcerous loamy earths	17	542	12	n/a	n/a
Alkaline shallow duplexes	68	402,502,503	42	3	1

It should be noted that even if soil acidity does not appear to be a constraint to production, with the exception of alkaline soils, if top-soils are below target pH, maintenance liming may still be important. Acidification will continue to occur as a result of removal of alkaline product and the use of fertilisers, and once acidity reaches the point where a yield constraint develops it can take a long time to correct it.

The ‘below target pH’ data has been aggregated to soil groups within Ag Soil Zones and shouldn’t be interpreted at smaller scales.

7.3 Enterprises and soil acidity

7.3.1 Intensive agriculture -Viticulture and horticulture

Many of the soils used for horticulture and viticulture in the South Coast Region are poorly buffered. Grape vines are moderately sensitive to acid soils (Thomas and Merry 2007). In field experiments in South Australia, grapevine root growth became depressed at $pH_{Ca} < 5.5$ and was completely retarded at pH_{Ca} 4.5 (Robinson 1993 cited in Merry *et al.* 2004). Although lime is a relatively small input cost for intensive agriculture, such as horticulture and viticulture, soil pH may not always be optimum. High rainfall and high inputs of ammonium based fertilisers acidify soils more rapidly than in broadacre areas. The rate of acidification in viticulture is different with different grape varieties. For example, Thomas and Merry (2007) found more alkalinity is removed for Riesling than Shiraz. Lime is usually incorporated at vineyard establishment but ongoing soil testing is important. The CRC Viticulture (2006) recommends surface application of lime along the vine row and incorporation by tillage in the mid-row. Thomas and Merry (2007) reported soil pHs for some wine regions in Australia but this did not include any South Coast wine areas.

The Australian Bureau of Statistics collected data for horticulture businesses by NRM region as part of Caring for Our Country. The percentage of horticulture businesses soil testing for pH on the South Coast increased from 13% to 40% between 2007-8 and 2009-10 and the percentage applying lime increased from 20% to 30%.(Australian Government, nd). There are currently no updated figures on soil testing specifically for horticulture.

7.4 Livestock

Legumes pastures acidify soils faster than annual grain crops. It has been well established that legumes acidify soils by excreting hydrogen ions (Bolan and Hedley, 2003). High rainfall areas of the South Coast also acidify faster, so livestock enterprises in these areas are likely to need more lime to maintain maximum productivity, than lower rainfall cropping enterprises (Moore 2001). Stock camps and preferred grazing areas add alkalinity and therefore contribute to variability of soil acidity within and between paddocks (Haynes and Williams 1999). Animal dung and urine is also a source of nitrate leaching, where a quantity of N is deposited onto a comparatively small area.

Kikuyu, subclover and annual ryegrasses, the major pasture species in South Coast high rainfall pastures, are all relatively tolerant of aluminium toxicity. Kikuyu can tolerate pHs just below 4. Aluminium toxicity becomes a problem for sub-clover when the soil pH falls below 4.5. As discussed above, a decrease in nodulation and some of the decline in percentage of sub-clover observed by South Coast farmers may be related to low pH. For medics, nodulation and aluminium toxicity generally become a major problem when the soil pH falls below 5.0 but there are some more tolerant varieties.

7.4.1 Cropping

Soil acidification is a major constraint to grain production. It causes decreases in yields and increases the need for other inputs. Crops depend on moisture in the sub-surface and sub-soil (10-30cm) layers at the end of the growing season to fill grain. Acidity increases the amount of toxic unbound aluminium, which in turn restricts root growth and water uptake. There is an increasing proportion of cropping on South Coast sandplain soils and soil acidity, particularly in the subsoil, is one of the major constraints to achieving maximum potential yields (Davies, Gazey and Galloway 2009; Gazey *et al*. 2014b).

Although cropping doesn't appear to acidify soils as rapidly as leguminous pasture most crops are more sensitive to acidity than sub-clover. The increasing cost of inputs to cropping systems increases the importance of maximizing nutrient uptake and achieving yield potentials.

8 Soil amelioration with lime

8.1 Soil sampling and determining lime requirements

While some farmers are not applying lime at all, others are simply applying a blanket 1 tonne/ha lime rather than soil sampling (Fisher 2009; Avon NRM, 2014). DAFWA recommends soil sampling at three layers, 0-10cm, 10-20 and 20-30, every 3-4 years to determine the rate of acidification and where lime is best applied. Fisher (2009) in surveying farmer focus groups found that only 49% were sampling topsoil and subsoil with 44% of respondents only sampling the topsoil. Samples sites should be geo-referenced so the same sites can be sampled and changes in pH monitored.

…pH and Al levels for a particular soil can be extremely variable, both down the soil profile, and between individual sites within the paddock (Whitten and Ritchie 1990 *cited in* O'Connell *et al.* 1999, p2).

South Coast NRM's project (Andrew 2013) illustrated how much variation there was both between and within paddocks. Soil sampling showed differences on the same soil type in topsoils from 4.4 to 6.0. It shows that lime can be used more efficiently if applied only where needed. By using variable rate technology surface soil pH can be mapped quickly and lime applied where needed to keep surface pH at the recommended target.

Table 8 shows some soil results for farms and paddocks in the soil zone Albany to Esperance sandplain, in terms of target pH, and lime recommendations.

Table 8 An example of soil acidity assessment at farm level. (Based on data in Andrew, 2013)

Albany to Esperance sandplain soil	**Top 10cm**	**10-20cm**	**20-30cm**	**Lime recommended 10 year rate**
Farm A				
Paddock 1 Soil type Sand	In this paddock some topsoils and the sub-surface soil is falling below target and will need more lime than other areas.			
Site 1	Below target	Below target	Just at target	4
Site 2	At target	At target	Above target	1
Site 3	At target	Below target	Above target	1
Site 4	Just below target	Below target	Above target	4
Paddock 2	This paddock is more uniform and will just need maintenance liming			
Site 1	At target	At target	Above target	1
Site 2	At target	At target	Above target	1
Site 3	At target	At target	Above target	1
Farm B				
Paddock 1 Sandy loam	In this paddock one site needs less lime than other sites			
Site 1	Below target	Just at target	Just at target	5
Site 2	Well below target	Below target	Below target	5
Site 3	At target	At target	At target	2

A rule of thumb of 5.5 for the topsoil and 4.8 for the sub-soil is necessary because it is not always possible to know how much of a yield loss is likely to occur and there is a time lag between application and response (O'Connell *et al.* 1999,p2; Gazey and Davies 2009). Farmers are uncertain about lime responses and this can be one of the barriers to applying lime. It therefore needs to be considered a routine part of agriculture, and important part of protecting the soil resource, rather than trying to relate liming to a particular response in a particular year. Soil sampling and documented pH levels and lime application history needs to become important attribute when farmers are buying and selling farms. A farm with high levels of sub-soil acidity could take many years and very large applications of lime to reach potential yields.

In 2007-8, the ABS surveyed farm businesses by NRM region on management of soil acidity. Thirty-two percent of farm businesses in the South Coast Region reported activities to manage soil acidity. The ABS also reported the number of farmers who were soil testing for pH, by NRM region. According to the ABS data the number on the South Coast NRM region has remained static between 2007-8 and 2012-13, at about 30%. (Table 9). These figures are unlikely to include the large amount of soil testing done as part of South Coast NRM's lime project in 2013, which carried out soil testing with 148 land managers.

Table 9 Number of South Coast NRM Region farmers soil testing for pH (Source ABS)

Year	No of farmers soil testing for pH	No of agricultural businesses
2007-8	766	2341
2009-10	803	2256
2011-12	713	2088
2012-13	623 *	1967

* This figure does not include the soil tests carried out as part of the South Coast NRM lime project, which involved 148 land managers.

The use of agricultural lime to manage soil acidity needs to increase and be maintained to ensure good condition and productivity of the soil resource (DAFWA 2013 p26).

8.2 Lime use

Lime used on the South Coast includes limestone, limesand (from South Coast Region Tamala like limestone and from west coast Holocene limesands), and dolomite. A small amount of liquid lime is also used.

In 2012/13 the ABS estimated 2.4 million hectares was under agricultural production in the South Coast Region. The ABS statistics show South Coast NRM Region landholders spread lime as limesand, limestone or dolomite to 0.17 million hectares or only 7.2% of the agricultural land in that year. (Table 10). The DAFWA report card data shows that most farm businesses on the sandplain are not applying enough lime for recovery.

Table 10 Area of land on which farmers spread limestone/limesand or dolomite in the South Coast Region between 2009-10 and 2012-13. Source ABS

Year	Amount of land pasture and cropping (ha)				
Land use and source	**Cropping land Limestone/limesand**	**Pasture land Limestone/limesand**	**Cropping Land Dolomite**	**Pasture Land Dolomite**	**Total**
2009-10	114,578	44,175	4,499	8,586	171,838
2011-12	182,073.9	42,770.3	8,608.2	9,714.7	243,167
2012-13	146,750		26,562		173,302

Table 11 Lime applied South Coast NRM region 2012/13 Source ABS

Lime source	Total Tonnes South Coast	No of farm businesses
Limesand and Limestone	170,915	490
Dolomite	14,225	99
Total	**185,140**	**646**

Note: The ABS didn't collect tonnes of lime applied on the South Coast in 2011-12

The tonnage of limestone, limesand or dolomite was collected by the ABS by NRM region in 2007-8 and 2012-13 but tonnage was not collected in other years. The tonnage in the South Coast Region declined from 243, 747 tonnes in 2007-8 to 185,140 tonnes in 2012/13. (Table 11).

In WA just over 1 million tonnes was applied in 2012/13 and 1.6 million tonnes in 2013/14, which was an increase of over 50% on the previous year.

DAFWA estimate that farmers need to apply 2.5 million tonnes per annum for the next decade in WA (Gazey, 2014). Based on the percentage of soils below target in the DAFWA report card, farmers in the South Coast Region need to apply about 1million tonnes per year over the next 5 years to recover soils (see below).

Not enough farmers are applying lime when they need to and also the lime applied is often inefficient. Many farmers are distributing too little lime or lime that is of too poor a quality to be effective enough to maintain surface pH at or above the target. Researchers at DAFWA are increasing their understanding of why farmers don't apply lime, even though it has been shown to provide an economic benefit.

8.3 Barriers to soil amelioration with lime

Gazey *et al.* (2014a) surveyed 539 farmers across the wheatbelt of WA about lime use and intended use. The survey found that the main barriers to applying sufficient lime to reach the target pH in soils, were economic. They included cash flow in poor seasons and the cost of freight.

Fisher (2009) reported on detailed discussions on liming with a small focus group in the wheatbelt. These farmers rated the most important constraints to liming as: the overall cost of lime, returns (return on investment, certainty of return, certainty of response, variability of returns) and cash flow (Fisher 2009, p 11). Some of the other reasons given at Fisher's focus group for not applying lime were: yield variability, timing of liming, which paddocks to treat, prioritizing liming over other inputs, and time constraints. Some farmers even suggested they would wait for acid tolerant varieties.

A major barrier is that farmers have to spend money on an input but don't see a response straight away so it becomes difficult for them to attribute any responses to the lime applied, particularly with the large variability in seasons and yields. Therefore there are farmers who aren't convinced that applying lime has any value and others not convinced about sub-surface acidity (Fisher 2009).

A major problem for farmers has been a short-term view of returns on investment and this can be also determined by the attitude of the banks in extending loans each year. Gazey and Andrew (2010, p232) argued that this short term view is

> *unable to adequately account for either, the long-term losses which accrue from allowing the profile to continue to acidify, the increased costs to ameliorate the degraded soil or, the long-term gains in productivity and other benefits which result from eliminating this economically manageable constraint.*

Nevertheless in general, the increased focus on liming by DAFWA, agronomists, agricultural consultants and NRM groups has increased agricultural lime use in most areas of WA. Lime use has not increased enough on the South Coast, probably because of distance from quality lime.

Table 12 indicates the pH related to of ‘recovery’ and ‘maintenance’ liming requirements.

Table 12 Liming recommendations (Adapted from Precision SoilTech /AgLime)

pH_{Ca}	**Acidity**	**Liming program**
Less than 4.5	Extremely Acid	Very Urgent (recovery)
4.6 to 5.2	Moderately Acid	Urgent – Within the next year or two (recovery)
5.3 – 5.9	Slightly Acid	Maintenance Liming – Within the next few years
Above 6.0	Good	Maintenance Liming – Possibly after 5 to 7 years

9 Lime Requirements South Coast

According to the ABS in 2012/13 the South Coast NRM region had 2,884,635.2 ha under agricultural production.

In 2009 Davies, Gazey and Galloway estimated that sixty-five percent of the agricultural area of the south coast is considered to be acidic or at high risk of developing subsurface acidity with a further 8 per cent at moderate risk if left untreated.

Fifty percent of the Albany sandplain was less than 4.5, with only 2-3% of soils considered to be at target (Davies, Gazey and Galloway 2009).

On the Esperance sandplain 25% of soils had a pH less than 4.5 throughout the topsoil, midsoil and subsoil, and about 15 per cent were considered to have 'good' pH throughout the profile, requiring maintenance liming only (Davies, Gazey and Galloway 2009)

Although there are now data for the proportion of South Coast soils below target, it is difficult to estimate the amount of lime required to ameliorate the soils. Chris Gazey (pers comm) has estimated a preliminary figure for the Ag Soil Zones of Southern Wheatbelt, Stirlings to Ravensthorpe, South Coast Albany to Esperance and Salmon Guns Mallee, over the next ten years of approximately 10-12 million tonnes of lime of a minimum of 90% carbonate. This figure did not include the Darling Range to South Coast Ag Soil Zone. DAFWA will provide more accurate estimates in the future when final results from DAFWA/GRDC projects on sub-soil constraints become available (Gazey, pers com).

There are always a large number of assumptions in developing a figure for lime required for a large geographical area. These include:

- The tonnage required is based on lime of high effective neutralizing value i.e. high percentage carbonate and small particle size.
- The lime required to increase pH in some sub-soils may be higher than estimated. A minimum of 2 tonne/ha for 5 years (possibly even as high as 8t/ha) Gazey (2014).
- Ag Soil Zones are broad zones and may have soils within them that require either more or less lime.
- Soil acidity varies within and between paddocks and with more soil testing and more strategic lime use in the future less lime may be required.

Davies, Gazey and Galloway (2009) developed a rule of thumb guide for correcting soil acidity (Table 13).

Table 13 Approximate amounts of lime to ameliorate soil acidity.
Note: Amounts will vary with rainfall, soil type, farm system (and lime quality). Source: Davies, Gazey and Galloway (2009)

Soil Depth	pH $_{CaCl2}$	Lime amount over 5 years tonne/ha
0-10	<5	2
	<5.5	1
		Plus
10-20	<4.5	2
	<4.8	1
		Plus
20-30	<4.5	1
	<4.8	Measure pH in 3 years

In calculating the lime required for the South Coast Region into the future, a modification of Davies, Gazey and Galloway (2009) rule of thumb (table 13), was used to estimate lime required for soils below target. This was: 1 tonne/ha per 5 years for top soils below target plus 2 tonne/ha for 10-20 cm layers below target plus 1 tonne/ha for 20-30 cm layers below target.

Table 14 estimates lime requirements for the South Coast based on the percentage of soils below target pH in the DAFWA Report Card (DAFWA, 2013). There are some major assumptions behind the data. The problem is the overlap between soils with sub-soil acidity and those with topsoil acidity. In order not to get a gross overestimation of lime required, the sub-surface and sub-soil percentage has been treated as subsets of the topsoil. This is clearly not always the case but at the spatial scale of region and Ag Soil Zone, this approach gives a reasonable estimate of the minimum level of lime required. There are also some small areas of Southern Wheatbelt and Zone of Rejuvenated Drainage in the South Coast Region but these were too small to estimate without more detailed information on the particular soil types in this Zone within the South Coast Region.

The figure of 4.75 million tonnes per 5 years, plus 1 tonne/ha for the following 5 years i.e. 3,000,000 tonnes gives a total for 10 years of 7.75 million tonnes. The amounts will depend on how quickly farmers in the South Coast Region recover soils and also depend on whether soils are sand, clay or loam (1 tonne of high efficiency lime will raise the pH of topsoil by 0.7 units in sandy loam, 0.4 units in loam, 0.2 units in clay (Gazey and Davies 2009).

Table 14 Estimated Lime requirements for each of the main Ag Soil Zones in the South Coast Region.

Ag Soil Zone	Area in Ag Soil Zone (ha)	Area (ha) below target 0-10cm	Area (ha) below target 10-20cm	Area (ha) below target 20-30cm	Lime required per 5 years**
D Ra*	120,000	103200	96000	34800	234000
St-Ra	600054	480043	288026	90008	858077
South coast	1316166	1158226	1553076	552790	3264092
Salmon Gums	848406	322394	50904	25452	398751
	2,884,626	**2,063863**	**1,988,006**	**703050**	**4754920**

*Estimated. The total ha is close to the ABS estimate of 2,884,635 of agricultural land in the South Coast NRM region

** The assumption had to be made that the % subsoil acidity was a subset of the % with topsoil acidity, so that the 0-10cm layer treatment was 2 tonne/ha, the 10-20 cm layer treatment 4 tonne/ha and the 20-30 cm layer treatment 5 tonne/ha, otherwise it would grossly overestimate lime requirements.

A figure of one million tonnes per year for the next five years is probably close to what is required for the South Coast Region to recover acidic soils. After recovery, estimated needs of 1 tonne/ha/5 years or 0.2 tonne/ha per year, over most of the agricultural area of the South Coast Region will depend on:

- whether soils have been ameliorated
- productivity
- more precise fertilizer use
- use of perennial pastures

Therefore the estimates for the South Coast NRM Region based on recovery followed by maintenance, are based on a lot of assumptions. The estimates are:

Over the next 5 years 5 million tonnes (to the nearest 1 million tonnes)

Over the next 10 years, 8 million tonnes (to the nearest 2 million tonnes)

Over the next 30 years, 20 million tonnes (to the nearest 5 million tonnes)

Over the next 50 years, 30 million tonnes (to the nearest 5 million tonnes)

Lime requirement may decline in many areas of the eastern and northern wheatbelt after 2030, due to lower productivity with projected climate change. Productivity is unlikely to decline as rapidly in the South Coast Region.

10 Availability and quality of lime Western Australia

The Department of Mines and Petroleum, Geological Survey, has recently published an evaluation of limesand and limestone resources along the South Coast between Denmark and Point Culver south of Balladonia. The previous overview was by Abeysinghe in 1998.

The report *Limesand and Limestone Resources of southern Western Australia Record 2015/7* collated data from published and unpublished maps and reports on limesand and limestone resources. The review did not involve any field survey work or validation of desktop information. Nevertheless the author stated that

"New interpretations of the available geological mapping highlighted potential resource areas." (GSWA 2015, p4)

While mapping can highlight potential resource areas, information on lime quality, carbonate content, variability and particle size, is important in determining whether a resource is worth exploiting.

10.1 Quality of lime

The ability of lime to increase pH is termed its neutralizing value (NV). The carbonate in calcium and magnesium carbonate, and the oxide in calcium oxide, neutralizes the acid. The NV is calculated by comparing the lime source to pure calcium carbonate, which is given a value of 100. Therefore the NV is the amount of calcium or magnesium as oxides or carbonates, expressed as a percentage.

The effective neutralizing value of a lime source is based on the neutralizing value, the particle size distribution (% by weight) and the solubility of a lime. [2]Fine particles are more effective at neutralizing because they have a greater surface area to react more quickly with the soil to change the pH. Lime particles over 0.5mm are only 50% as effective as smaller lime particles in increasing pH in the short to medium term. Lime particles over 1mm have very little effect. Lime particles down to 0.25mm are even more effective (Cregan *et al*. 1989; Whitten 2002).

The neutralising values (NV) of larger particle sizes are discounted using the values of Cregan *et al.* (1989) to account for the reduced capacity to change soil pH in the short term. The NV are discounted according to particle size:

- under 0.5mm, not discounted
- 0.5–1millimetres (mm), particles discounted by 50%
- greater than 1mm, discounted by 80%

The efficiency increases a lot more for particles around 0.25mm, but this is currently not taken into account in lime calculations. Other factors in determining how quickly lime will reduce acidity in a soil are independent of lime supply and relate to the buffering capacity of

[2] NV is a measure of the purity of the lime source i.e. its capacity to change pH
Particle size determines the speed with which the lime source will change the pH

the soil. A well-buffered soil will acidify more slowly than a weakly buffered soil, but will require more lime to increase the pH value.

Sampling the stockpile. Photo Chris Gazey, DAFWA

The quality of lime used is very important because it can make a big difference to the economics. Fisher (2009, p5) found, from discussion in a focus group of wheatbelt farmers, that participants were aware of the Lime WA Inc. product information specification sheets, although some noted that suppliers did not always provide them unless specifically asked (Fisher 2009, p5).

Limestone and dolomite requires crushing and seiving whereas lime sand does not need much additional processing. Some wheatbelt farmers use dolomite because of the lower transport costs.

10.2 Limestone and Dolomite

Limestone is a sedimentary rock, composed mainly of calcite and aragonite, which are polymorphs (different crystalline forms) of calcium carbonate ($CaCO_{3)}$. Most limestones are generated by the accumulation of fragments of skeletal materials of marine organisms such as molluscs, corals and foraminifera. Limestones can also form by secretion of carbonate by micro-organisms and inorganic chemical precipitation. Most limestone in Western Australia originated from marine carbonate organisms.

The environment of limestone deposition influences the likelihood of developing an economically viable limestone deposit since this factor determines the size, shape, and purity of a deposit. (Abeysinghe 1998, p6)

Although most of Tamala limestone and Holocene limesands in Western Australia contains little magnesium, there are dolomitic limestones in other areas including some inland in the wheatbelt. There is a gradation from limestone to dolomite depending on how much magnesium is present. It varies from high-calcium carbonate with at least 95% calcite ($CaCO_3$) to high dolomitic rock with 90% of the mineral dolomite $CaMg(CO_3)_2$.

Dolomitic rock has the mineral dolomite as the main component although geologists use the term dolomite to refer to the mineral dolomite and the rock. Dolomite is believed to form when magnesium in groundwater replaces the calcite in limestone. Depending on the amount of magnesium present the deposits vary from dolomitic limestone to dolomite. Carbonate rock tends to be classified as limestone if it has up to 10% dolomite, dolomitic limestone with 10-50% dolomite, calcareous dolomite with 50-90% dolomite, and dolomite if it has 90-100% dolomite. Dolomite in WA is mainly found in dry salt lakes. It precipitates out when the lakes become wet and replaces the calcium in the calcite.

The varieties of limestone/limesand, dolomite, magnesite and calcrete are described in Appendix 1 and there is more detailed information in the Geological Survey report (GSWA 2015)

10.3 Main limestone limesand deposits in Western Australia

There is no legislative requirement to report extractive industry tonnage and therefore there is no register of lime supply sites or production figures, apart from those on Crown land. The Department of Minerals and Petroleum holds information on tenements on Crown land (through the Mining Act and royalty collections), but there is no register of sites on freehold land. Local government authorities may have information for their own areas because of their requirements under Town Planning Schemes.

The lack of a single register *"*makes any empirical supply calculations, planning or resource management of the industry difficult" (Western Australian Planning Commission 2012, p21).

In 2001 the EPA when assessing shell dredging in Cockburn Sound referred to the main terrestrial lime extraction areas as:

- *mining is proceeding in the northern Cape Range area near Exmouth with the potential for supply to the south west, a possible pelletising plant at Cape Preston and export markets;*
- *mining is proposed in the Cape Range proposed 5h reserve at Learmonth with similar supply scenarios;*
- *..mining tenements within the proposed Ridges extension to Yanchep National Park. These tenements will continue to stall the park extension;*
- *there is no agreed strategic approach to exploitation and protection of the vast limesand and limestone resource from Guilderton to Geraldton (Central West Coast). Large areas of sensitive vegetated coastal dunes and mobile sand sheets are under mining tenement application;*
- *limesand resources on Legendre Island in the Dampier Archipelago are considered potential resources by resource agencies;*
- *limesand at Boranup within Unallocated Crown Land on the Leeuwin Naturalist Ridge is considered a future source of industrial lime by the* DRD *(now Department of Minerals and Petroleum Resources). However, this should be limited to the supply of local agriculture'; and*
- *State forest previously proposed as a nature reserve at Caraban was changed to a proposed CALM Act 5h reserve (purpose of Limestone and Conservation) for CCL as a*

contingency that the offshore shellsand ceases to remain available. The future status of this area as a conservation reserve may need to be reconsidered if this proposal is approved". (EPA 2001, p32)

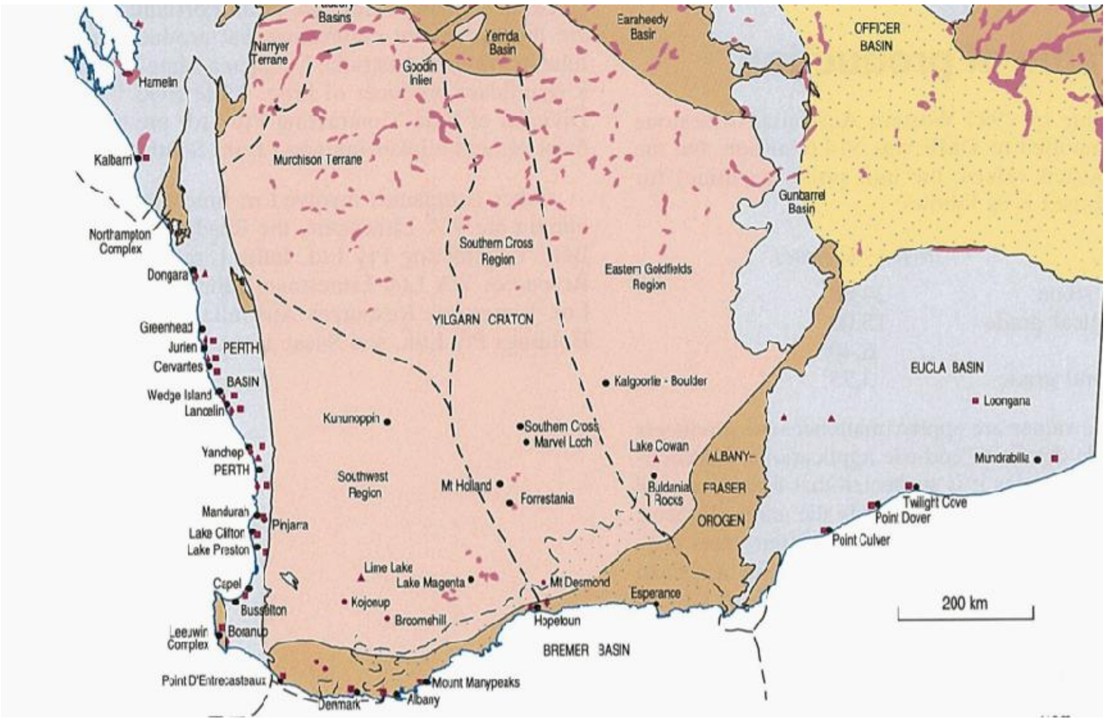


Figure 7 Limestone resources southern and eastern areas (from Abeysinghe, 1998)

Figure 7 shows the southern and eastern part of Abeysinghe's map of limestone resources in WA.

Some of the maps from the Southern part of WA from the GSWA 2015 report are shown in Appendix 3

Most of the lime used for agriculture in Western Australia comes from the sediments in the Perth Basin, which extends 1000 km along the south- western coastal belt of Western Australia from Geraldton to the Capes.

10.3.1 Limesands of the west coast

The limesands of the west coast that extend from Geographe Bay to Geraldton are part of the Quindalup Dune system. They formed in the Holocene, associated with the marine transgression estimated to be 6-7,000 years ago. The conditions during the Last Glacial Maximum were such that the strong westerly winds could rework the unlithified carbonate shelf and coastal sediment into mobile dunes (Brooke *et al.* 2014, p 121). These calcium carbonate rich dune sands don't occur to any great extent on the South Coast. The Quindalup Dunes are characterised by unconsolidated calcareous and quartz sands and are the source of most of the agricultural lime used in the wheatbelt. Many of the Quindalup Dunes are mobile and some threaten infrastructure.

Shellsand Cockburn Sound
The largest volume of lime used in Western Australia comes from shellsand dredged from Cockburn Sound by Cockburn Cement Ltd (CCL). Cockburn Cement has the right to this resource through *The Cement Works (Cockburn Cement Limited) Agreement Act* 1971, as amended in 1986. The scheme of the Agreement Act, effective to 2011, with provision to extend to 2021, entitles CCL to access shells and sediment within a five-mile (8km) radius of a point on Coogee Beach, north of Woodman Point.

Limesand north of Perth
There are high grade, high volume limesand deposits as part of the Quindalup Dune system at Ledge Point, Lancelin and Wedge Island and further north along the coast to Dongara and Port Denison.
Cockburn Cement Ltd holds some of the proven deposits. The company has limesand resource holdings at Ledge Point and large Dongara deposits. AgLime have holdings at Dongara, Jurien and Lancelin. Urban development is infringing on many potential lime sand extraction sites.

Boranup limesand
The Boranup limesand Reserve is located on Caves Road Boranup, 5 km north east from Hamelin Bay, within the boundaries of the Leeuwin-Naturaliste National Park. Samples assayed were about 80% $CaCO_3$ (Abeysinghe, 1998). The tenement is 77 ha, and the pit 2.2ha. It was used by the shire until 2003, with carbonate reported at >90%. (Enmic, 2012). Abeysinghe converted estimates of volumes to tonnage and estimated the two deposits at Boranup to be 108 million tonnes and 13 million tonnes. One limestone sample in the area was assayed at 97.3% (Abeysinghe, 1998 p45). This wider area is of high conservation and amenity value and unlikely to ever be available for excavation. A clearing permit for the current pit was issued in 2014 so the pit is likely to be active in the near future. Freight costs from the current pit to the Denmark/Albany area would be cheaper than from the mid-west coast, but the lime would be in high demand in the lower west coast between Bunbury and the Capes.

West coast limesand. Photo Chris Gazey, DAFWA

10.3.2 Limestones north of Perth

Wanneroo Neerabup/Yanchep

Cockburn Cement Ltd has a tenement of 60 million tonne limestone at Wanneroo on leasehold and freehold titles (EPA 2001).

There is a limestone/sand site in Neerabup designated as a Priority Resource Location within the Basic Raw Materials Statement of Planning Policy 2.4 (Western Australian Planning Commission, 2000).

Several Neerabup limestone-mining tenements on private and Crown land have not yet been approved for extraction. The Neerabup National Park and Nature Reserve of over 1000 ha have no mining tenements but there are a number of approved and pending mining tenements in some of the areas DPAW has proposed for addition to the conservation reserve system (DPAW 2012). In 2001 the EPA recommended that mining tenements held by CCL north of Perth at Caraban and Ridges, be added to the conservation estate (EPA 2001).

DPAW is opposed to extraction of limestone from Ridges because the limestones contain a Threatened Ecological Community (TEC) of limestone vegetation. Community 26a is dominated by chenille honeymyrtle (*Melaleuca huegelii*), coastal honeymyrtle (*Melaleuca systena*) , *Melaleuca* aff. *systena*) and limestone heath species such as parrot bush (*Dryandra sessilis*) and spider net grevillea (*Grevillea preissii*). (Luu, R, and English 2005, cited in DEC, 2012). The Yanchep-Neerubup area also has stygofauna, (aquatic subterranean animals) in the groundwater systems associated with the karst (limestone caves/fissures) (Humphreys 2006).

Toolonga Calcilutite (Toolonga Chalk) and northern Tamala limestone

There is some Toolonga chalk at Kalbarri and futher north in the Carnarvon Basin. There are large deposits of Tamala limestone north of Kalbarri (Abeysinghe 1998).

Limestone and limesand Dampier Archipelago

There are high quality limestone deposits in the Dampier Archipelago, estimated at 190 million tonnes of limesand, and 300 million tonnes of limestone (Biggs and Denman 1978). The authors regarded these as useful to the Pilbara mining area but they are in areas with conservation values.

Limestone Exmouth

There are confirmed deposits of approximately 200 million tonnes of very high grade (97-99% $CaCO_3$) limestone at Cape Range at Exmouth, held by Cockburn Cement. Abeysinghe (1998) suggested there could be as much as 4000 million tonnes of limestone at Cape Range, based on BHP and the Water Authority drilling in the area outside the National Park. Whether these are ever quarried will depend on conservation priorities and transport costs.

10.3.3 Limestones west coast, south of Perth

Myalup and Preston

Limestone is extracted at Myelup and there are potential new limestone pits in the Myelup Pine Plantation area.

Lake Clifton
South of Perth near Lake Clifton is another area of Tamala limestone with limestone vegetation of the Threatened Ecological Community.

Capel
Abeysinghe described limestone 8 km north-west of Capel, as variable, with average of 72.4% $CaCO_3$ (Abeysinghe 1998). Limestone is extracted from a pit at Capel.

Cape Leeuwin to Naturalist
There is both limestone and lime sand in the area between Cape Leeuwin and Cape Naturaliste but most of it is in the National Park. There is a lime pit at Redgate at Witchcliffe.

10.3.4 Goldfields and Nullarbor

Calcrete deposits in the Yilgarn Craton could be explored as a potential lime source for eastern parts of the region (Iain Copp, pers comm).

Lime has been produced in the Goldfields area using limestone quarried east of Kalgoorlie at Rawlinna (and Loongana). The current Nullarbor quarries are quite high in $CaCO_3$ but are likely to be held for gold mining operations rather than for agricultural lime. Nine samples collected from the mine area contained 87.25 to 96.62% $CaCO_3$, (48.86 to 54.11% CaO), with an average of 93.78%. (Abeysinghe, 1998, p75).

Long term, the Nullarbor is a potential area for lime supply but it will be expensive to extract and transport. The Nullarbor is a 240,000 square kilometre carbonate plain formed in the Cenozoic in three main phases (Miller *et al.* 2012). There are vast reserves of limestone containing about 97 per cent calcium carbonate and 1 or 2 per cent magnesium carbonate.

White limestone close to agricultural areas in the east of the South Coast Region is part of the Abracurrie limestone. Most is in the Nuytsland Class A Nature Reserve (GSWA, 2015).

Limestone Resources Nullarbor

Although the quantity and quality is largely unknown samples taken by Abeysinghe *from a number of quarries along the Eyre Highway, and from caves, outcrops, and rockholes in the Eucla Basin, suggest that high-grade limestones are widespread within the Nullarbor, Abracurrie, and Tooliiina units. In many localities, the limestones in these units are fresh and occur beneath a thin soil cover, often less than a metre thick.*

Limestone resources in the Eucla Basin, easily exceeding several billion tonnes of high-grade material, can be considered as the largest in Western Australia. (Abeysinghe 1998, p86)

In 1970 Lowry Director of the Geological Survey wrote: *Large-scale mining of limestone from the Eucla Basin is a possibility, and scattered chemical analyses …indicate that large quantities of limestone are available with about 97 per cent calcium carbonate, and 1 or 2 per cent magnesium carbonate. The Trans-Australian Railway could be used for transport but a quarry situated near the railway would encounter seams of clay and kankar in the top 50 feet of limestone and this could lower the grade. A coastal quarry with sea transport, for example in the Abrakurrie Limestone at Twilight Cove, would probably obtain purer limestone, but the coast is exposed to storms and heavy swell from the south, so that the prospects seem poor for regularly loading ships anywhere along the coast of the Great Australian Bight*. (Lowry 1970, p174).

11 Limestone Limesand and Dolomite in the South Coast Region

11.1 The Geology of the South Coast

The South Coast Region has less agricultural lime supplies than the west coast because of its different geological history. Limestone, as a sedimentary material, varies with a number of factors including: the number and pattern of sea level changes; the biota (carbonate or silica based) in the seas; the proportion of carbonate in the original sediments, the time of deposition and how much dissolution, weathering and lithification has occurred since deposition.

In most areas in the South Coast Region the sediments partly overlie the Mesoproterozoic Albany–Fraser Orogen, which extends along the southern margin of the Archean Yilgarn Craton. Parts of the Albany-Fraser are reworked Yilgarn (Spaggiari *et al.* 2014). The Albany Fraser Orogen basement consists of weathered deformed or highly deformed granite and gneiss rocks and these have been partly overlain by sediments of the Werrilup and Pallinup formations of the Eucla basin (Clarke *et al.* 2003). Most of the dune sediments on the south coast are fine -grained siliceous sands rather than carbonate sands (Sanderson *et al.* 2000). Some of the outcrops of consolidated sediments on the coast around Albany and Denmark are Tamala limestone i.e. cross-bedded calcareous sand in a calcareous matrix with white quartz sand on and adjacent to the limestone. Where there is limesand it is of lower quality than west coast limesand and is probably reworked Tamala limestone.

11.2 The Pallinup Formation (a mixture of sand, mud and fossil sponges but no carbonates)

The Pallinup formation is an upper Eocene, spicule and quartz rich sediment. It consists of claystone, siltstone, sandstone; fossil sponges and molluscs (Clarke *et al.* 2003; Geoscience Australia 2015).

The sediments of the Pallinup Formation were deposited in the Late Eocene during one sea level rise and fall (Gammon and James 2001; Gammon *et al.* 2000 a, b). As the sea regressed the rivers supplied clay sediments to the inshore environment. The sediments consisted of sandstones, conglomerates, mudstones and sponge sediments containing silica (Gammon and James 2001; 2003). In the nearshore environment, the sponges outcompeted the calcium carbonate rich benthos and so the cool water carbonate deposits were offshore in the open shelf. (Gammon and James 2001; 2003).

The Pallinup Formation (revised) consists of five units; 1 and 2 are basal sandstones, 3 and 4 are variably spiculitic mudstones, whilst the uppermost unit is spiculite and spongolite, and formalised as the Fitzgerald Member (new) (Geoscience Australia 2015).

11.3 The Werrilup formation (includes the Nanarup Limestone Member)

The Werrilup formation is dark grey, siltstone, sandstone, claystone, minor brown coal (lignite, carbonaceous siltstone), and limestone (Geoscience Australia 2015). It includes the Nanarup Limestone Member in its upper portion. (It is exposed near Nanarup). The Werrilup formation is partly overlain by the Pallinup formation The Nanarup limestone member is irregularly distributed through the Werrilup formation. Similar limestone occurs in the

Werrilup near Esperance. The GSWA (2015) review found the limestone to be much more extensive than previously thought.

11.4 Coastal limestone

There are coastal deposits of limestone equivalent to the west coast.

..located mainly along the coastal belt extending from Point D'Entrecasteaux to Esperance, and range from calcarenite to pure limestone. They form a complex system of ridges along the coastal region, some of which are associated with extensive deposits of limesand. Major limestone and limesand deposits along the coastal belt are found at Point D'Entrecasteaux, Elleker, Torbay, Herald Point, south of Princess Royal Harbour, on the western side of the mouth of Wilson Inlet, at Parry Inlet, and Hopetoun. (Abeysinghe 1998, p 95)

"Unconsolidated to strongly lithified calcarenite with calcrete/kankar soils; aeolian. Locally quartzose, feldspathic, or heavy-mineral-bearing. (Geoscience Australia, 2014)

The coastal limestone outcrops in the South Coast Region west of Albany are composed of marine aeolian carbonate deposits formed when south-south westerly winds blew sand and shell fragments inland in the Pleistocene. These sediments are classified as Tamala Limestone to the west of Albany. The term Tamala Limestone has been used for limestone in the Perth Basin and is based on lithology rather than origin (Playford *et al*. 1976). It occurs along both the west and western South Coast. It is generally weakly cemented, soft and porous. It formed when sea levels were lower and large areas of the continental shelf were exposed. The climate was arid, and the prevailing south to south-west winds were extremely strong and quartz sand and shell fragments blew inland.

The aeolian sand formed dunes and then they cemented (lithified) in calcium carbonate. The extent of lithification varies within ridges and this determines whether it is used mainly for construction or as agricultural lime. The dune formations are evident in the cross bedding The lithification of the dunes has formed calcarinite (sandy limestone). In many areas the Tamala limestone is weakly calcified and so easily crushed. It is also easily eroded.

The limestone sediments on the South Coast are in environmentally sensitive areas. For example most of the thickest deposits near Albany are where the city borefields are located or are within the Torndirrup National Park. There are broad ridges along the south coast, west of Albany, and one includes the Denmark lime quarry at Ocean Beach. The Tamala limestone is variable in terms of how calcified it is, how much quartz sand was in the original dune and how much carbonate has leached out of over time. The higher the rainfall the more likely it is that the carbonate will have dissolved out leaving a great proportion of quartz or other impurities.

There are also thick shelly limestone coastal deposits just to the west of Esperance , similar to Tamala limestone (Abeysinghe 1998) but these areas are also important for groundwater supply and of high environmental and amenity value. They are scattered and often deeply weathered (Clarke *et al*. 2003).

Off-shore, east of Esperance, is the very large cool water carbonate shelf of the Great Australian Bight. Near Esperance, there is a gradation from quartz sands to carbonate sands offshore. The wave energy tends to transport carbonate sediments offshore (Richardson *et* *al*. 2005). The whole area is an area of important temperate marine biodiversity. It is regarded as marine region of global ecological significance (Rogers *et al*. 2013).

11.5 Dolomite

The GSWA describes the dolomite resources in the west of the Region as dolomitic sand although the samples that have been measured have relatively large particle size. The dolomite is formed in the lake systems possibly as a result of bacterial action (GSWA 2015).

Dolomite rock close to the South Coast Region is in the Cowan Dolomite geological unit north of Norseman. It is thought to have been deposited in a shallow arm of the sea in the Late Eocene (GSWA 2015).

Other lime resources include calcrete and magnesite. These are described in GSWA (2015). The calcrete has not been assayed for carbonate content but may be worth investigating (Copp pers.comm).

11.6 Geological Survey of Western Australia, mapping of Southern WA lime deposits.

The 2015 Geological Survey of WA report produced maps showing the main lime resources for southern WA including the South Coast NRM Region. The author/s found some inconsistencies between the 1:250,000 mapping done in the 1970’s and 1980’s and the more detailed 1:100,000 maps of Norseman and Ravensthorpe and also the 1:50,000 maps of Albany and Torbay produced by Gozzard in 1989 (Gozzard 1989 a and b). Table 15 shows the maps used to compile data and mapping by the GSWA (2015).

Table 15 Maps compiled by GSWA (2015) showing source, date, area covered and information relating to lime resources.

Map	Source	Date	Area	
1:250,000 scale geological maps Primary data set	GSWA	Mainly 1970s	Complete area	Delineation, identification and description of bedrock lithologies and relationships. Primary landform scale. Able to identify limestone and limesand. Boundary mismatches.
1:100, 000 scale geological series maps	GSWA	mid 1990s to mid 2000s	four Norseman, two Ravensthorpe	Focus on mining centres. Able to refine limestone extent and identify valley calcrete and magnesite.
1:50,000 Environmental Geology maps	GSWA (Gozzard, 1989, a and b)	1989	Albany and Torbay	Thematic approach lithology, morphology, slope category, hydrogeology, hydrography and rock and regolith properties.
1:250,000 hydrogeological maps	DoW	Late 1990s	Bremer, Esperance – Mondrain Is, Mt Barker – Albany, Newdegate, Ravensthorpe	Aquifers, groundwater salinity, water bores. Drilling data used to refine limestone.
Soil-landscape maps 1:50,000 to 1:250,000	DAFWA		Limited coverage of study area	Can be used to interpret regolith
Orthophotography	Landgate	2003-9	Complete area	Identification of pits and quarries and spatial extent of limesand and limestone. Derived Digital Elevation Models
Topographic Mapping. Series 3 Geodata Topo 250,000	Geoscience Australia	Current at 2006	Complete area	Themes with 92 data layers. Used by GSWA to identify pits and quarries

The main digital data layers in the digital data package produced by the Geological Survey of WA in 2015 were surficial resources, bedrock resources, quarries, pits and chemical analyses. (GSWA, p16).

Two important points raised in the GSWA review were that the lime resources in the South Coast Region varied significantly in carbonate content within a particular deposit, and that limestone was generally better quality than the limesand. The review did not consider particle size.

11.7 Summary- Why the South Coast has less lime resources than the west coast

In summary lime supplies are limited on the South Coast because there are few young (Holocene), carbonate rich mobile sand dunes and fewer coastal limestone deposits.

In the Holocene the west coast had a 'low-gradient temperate carbonate' continental shelf and probably strong prevailing westerly winds, causing large-scale carbonate dune deposition. There is some evidence for sub-tropical carbonate species, which may also account for differences in the most recent large carbonate deposition between warmer west coast waters and cooler south coast waters.

The sand dunes in the South Coast Region are mainly fine-grained siliceous sands whereas the west coast has more coarse-grained, calcareous sands (Sanderson *et al.* 2000). The Pallinup sediments were not carbonate rich because of the sponge-rich shallow marine environment close to the Southern Coast of Australia in the late Eocene (Gammon and James, 2001, Gammon and James, 2003). The carbonates were deposited as cool water carbonates in the open shelf environment (Gammon and James, 2001). There was little exchange between the shallow embayments and the open shelf and the wind was in the opposing direction.

The Werrilup formation contains limestone, as in the Nanarup member, but it is generally of not very high grade and of large particle size.

Although older dunes of quartz sand and shell fragments have been consolidated and remain in some large Tamala and Tamala-like limestone outcrops along the coast the limestone is variable in composition and occurs mainly in high conservation areas. There is the possibility of higher carbonate limestone in more arid areas east of Esperance where there may have been less weathering, but again they are likely to be in sensitive areas.

12 Lime Pits South Coast Region

The list below is of the lime pits in the South Coast Region surveyed in 2008 and recorded in Gazey and Gartner (2009). The neutralising value and particle distribution calculation gives an indication of their effectiveness in reducing acidity in the paddock (Appendix 2 *not for publication*).

Denmark AgLime is located at Ocean Beach and is operated by the Shire of Denmark. It has a very small output of 15,000 tonnes per year mainly for the use of Denmark shire farmers. The Denmark pit is mainly limesand derived from Tamala limestone.
The Lower Great Southern Strategy of 2007 stated *Although there are other known deposits to the west, these are on private land and scope for mining is regarded as low by the Department of Industry and Resources. Geological interpretation and exploration may locate further sites for agricultural lime extraction similar in geological setting to the Ocean Beach deposit.* (Western Australian Planning Commission 2007, p81)

Bornholm AgLime South Bornholm Road Bornholm
The Bornholm pit is limesand from Tamala limestone. Bornholm Aglime is not a member of Lime WA so the only independent information on NV and effective NV is from the 2008 survey (Gazey and Gartner 2009). Based on that survey farmers would need to use twice as much as that recommended for lime of >90% effective NV.

Manypeaks Homestead Road (Walco).
The limestone in the Manypeaks pit is possibly part of Werrilup formation (Abeysinghe 1998), but has never been characterized. It appears quite different in lithology to the Nanarup formation (Chris Gazey, Tim Overheu, pers com). Large particle size distribution reduces the efficiency of this lime. No figures are available for solubility, which also contributes to effective neutralising value and Walco claim the lime is more soluble. Nevertheless with this lime farmers may need to consider using twice as much as recommended for lime of >90% effective NV.

Nanarup Lime
This pit is now closed. It is limestone from the Nanarup Member of the Werrilup Formation. It could be used for lime rubble and other non-agricultural uses to take the pressure from other pits. The quality is unknown but particle size is likely to be high so it may be useful as agricultural lime with finer crushing.

Windy Harbour
Salmon Beach Road. This pit currently is used mainly for limestone rubble, and construction as reconstituted lime blocks. It is a highly lithified, hard limestone. It has large particle size with over 90% particles greater than 1 mm at the 2008 survey. If the limestone was crushed more finely this pit could yield reasonably high quality lime. The owner is not selling agricultural lime at the moment but plans to sell some in the future (pers comm).

Mason Bay Lime, Springdale Rd Jerdacuttup 50km East of Hopetoun
This Mason Bay lime pit is coastal limestone. The pit is on private property and produces ground agricultural limestone and graded limestone rubble. It has relatively large particle size, so farmers would need to use twice the amount recommended of this lime. This limestone deposit has further reserves that may be able to be extracted and if ground more

finely could be of much higher efficiency.

Krystal Park limestone quarry
This pit is located 5 km north of Hopetoun. This lime was of low quality in the 2008 survey. Farmers would need to use 4-5 times the amount recommended. The existing quarry area is near the Town wellfield and may not be able to expand.

Esperance Dalyup Pit (Triple M transport) 40km west of Esperance
The Dalyup pit is a limesand weathered from a carbonate rich eolianite of Pleistocene age, possibly equivalent to the Tamala Limestone. Similar limestone and limesand occurs between the coastal hills around Esperance (Morgan and Peers 1973; Abeysinghe 1998). The pit has high demand from Esperance farmers. This is relatively high quality lime for the South Coast and would only need a 30% increase in the amount recommended.

Bremer Bay
There is a pit in coastal limestone at Bremer Bay. Nearly 50% of particles were greater than 0.5mm. With further crushing this could be a reasonably high quality lime, requiring just 20-25% more than recommended.

Dolomites
There are dolomite pits at Beaufort River and Kojonup. Based on the 2008 samples farmers would need to use 3-4 times the amounts of these dolomites as recommended.
The GSWA identified limepits and quarries based on orthophotos and Geoscience Australia maps and data from GSWA’s MINEDEX database. Some of this data may be out of date. MINEDEX is increasingly including data from basic raw materials extracted from private land (GSWA 2015). MINEDEX has the potential to be a valuable source of information on lime extraction in the future.

13 Projected lime use in WA to 2030, 2050

13.1 Western Australia

The largest quantity of limestone or limesand excavated in WA is converted to quicklime at Cockburn Cement Ltd(CCL) and used by the mining industry. CCL produces 1 million tonnes of quicklime per year (CCL 2012), from shellsand dredged from Cockburn Sound. CCL now imports clinker rather than producing it in WA, which would reduce its lime use from the Munster limestone pit from 2014.

CCL has been dredging shellsand from Owen Anchorage since 1972. Its long-term (to 2034) proposal is to dredge shellsand from locations on Success Bank, Parmelia Bank and West Success Bank, Owen Anchorage (EPA, 2001). In October 2010, the Western Australian Parliament passed amendments to the *Cement Works (Cockburn Cement Limited) Agreement 1971*, which will enable the Munster plant, sand drenching and washing operations, to continue until 2031, and provide access to 60 million tonnes of shell sands in Owen Anchorage. (DMP 2011)

CCL requires source material with a $CaCO_3$ of minimum of 92% for lime production, although they are investigating beneficiation trials. Land-based feedstock materials sufficient to meet the resource demand are considered by CCL to be unavailable or commercially unviable (EPA 2001). Post 2030, CCL may have to use terrestrial lime resources, so they are unlikely to release any of their holdings.

The amount of limestone and limesand used for quicklime each year varies with commodity prices and construction levels. For example in 2011, during the global financial crisis, there was a fall in the quantity of lime mined from Crown land (Figure 9). Quicklime use will continue to be high providing alumina mining continues in Western Australia and that gold prices are relatively high.

Assuming small fluctuations, and extrapolating from current increases, lime extracted from Crown land in 2030 is likely to be 9-10 million tonnes per year, but will depend on the growth of mining and construction and the use of agricultural lime. The rapid increase in lime from Crown land from 2012 was likely to be because of increased demand for agricultural lime (Gazey pers com).

Lime use by agriculture in Western Australia in the next few years is likely to be at least 2 million tonnes per year. Chris Gazey estimated that WA farmers need to apply 2.5 million tonnes per annum for the next decade, but this figure is currently being revised and may increase, based on recent acidity data. (Gazey pers com).

The Draft Lime Strategy estimated Western Australian demand from 2001-2050 to be close to 500 million tonnes for construction and roads, 300 million tonnes for agriculture [3] and 350 million tonnes for mining. For the South Coast it estimated 10 million tonnes for construction and roads, 53 million tonnes for agriculture and none for mining (Draft Lime Strategy 2006). For the South Coast NRM Region agriculture is likely to use and will continue to use the largest proportion of lime. Local government use is difficult to estimate. Other industry consumption is relatively minor.

[3] Likely to be an overestimate. Gazey pers comm.

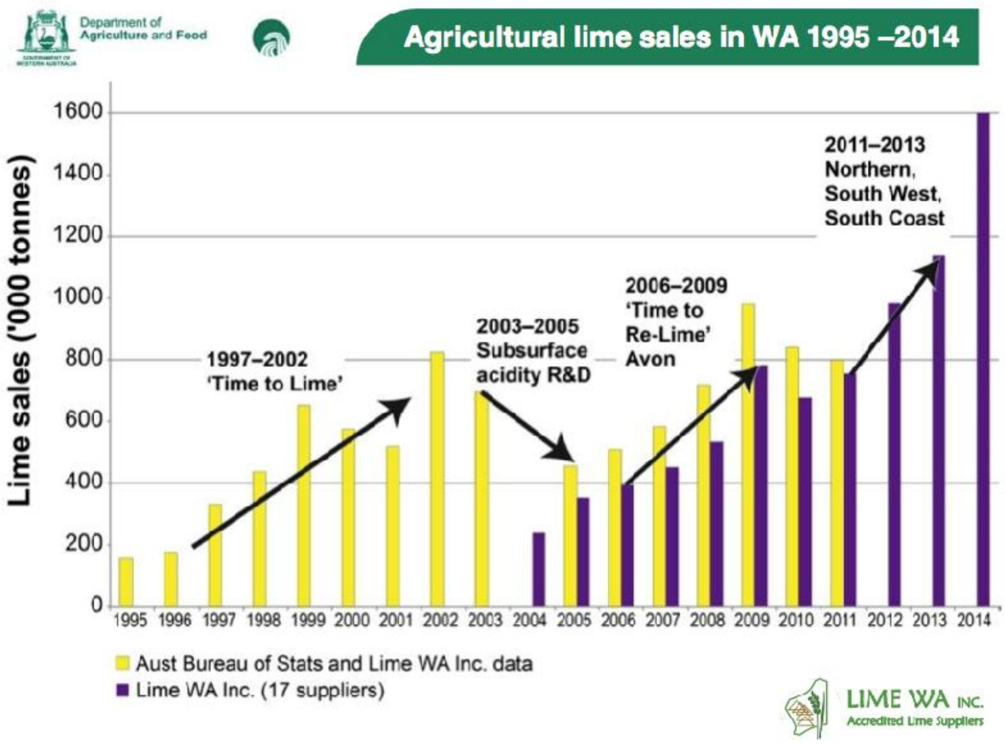


Figure 8 Agricultural Lime Sales from Chris Gazey (2015) graph

Figure 8 shows agricultural lime sales in WA.

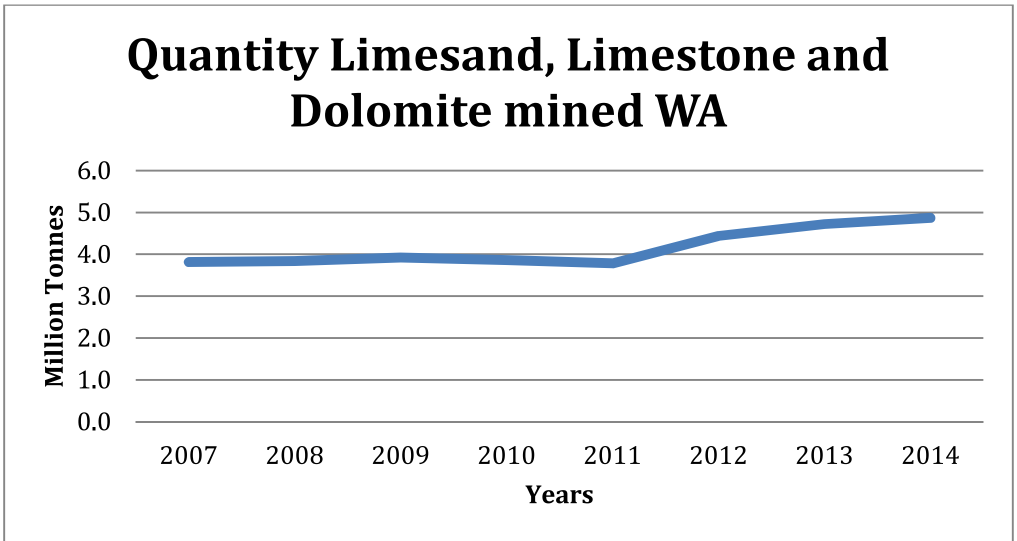


Figure 9 Lime mined (Million Tonnes) in WA on Crown land (royalty based).
Source of Data DMP statistics reports (DMP, 2007-2014 (using corrected tonnages)

Figure 9 shows the limesand, limestone and dolomite mined in WA on Crown land. It does not include lime pits on freehold land, which are currently very difficult to estimate because excavation is not reported.

In 1995, 2.2 million tonnes was mined (Abeysinghe 1998) so in the 20 year period from 1995 to 2015, reported tonnage has more than doubled. Abeysinghe projected limestone use to 2014 to go from 4.5 million tonnes in 1995 to 9.13 million tonnes. The DMP reported the value of lime mined on Crown land to be $17 million dollars in 2009 to $37million in 2012 and to $68 million in 2014 (DMP statistic digests 2009-2014).

13.2 Lime use by other industries in WA

The biggest proportion of quality lime used in WA is used in the mining industry in the form of quicklime (Calcium oxide, CaO). Quicklime is produced by calcination, a process by which limestone or limesand is burnt in a kiln at greater than 825°C which causes decomposition to calcium oxide and carbon dioxide. High quality lime is used for quicklime production.

The chemical process is:
$CaCO_3$ + Heat $\leftrightarrow$ CaO + CO_2

Thus approximately half the weight of $CaCO_3$ is CaO, the other half is CO_2 gas, as a carbon emission. Therefore for every tonne of quicklime, Cockburn Cement produce, twice or more (depending on $CaCO_3$ percentage) the tonnage of lime as limestone or limesand is required. If approximately 1 million tonnes of quicklime are produced each year in WA at approximately 90% lime limestone/sand, over 2 million tonnes of lime are being used in its production. Cockburn Cement's Munster plant produces all of the quicklime used in WA currently in two kilns. It also has a small manufacturing plant close to a lime source at Dongara producing 100,000 tonnes lime per year. Most quicklime is used in alumina refining and gold mining.

Hydrated lime for building is derived from high quality quicklime, via a grinding and slaking process.
CaO + H_20 = $Ca(OH)_2$ + heat

Cockburn cement can also produce a million tonnes of cement a year. Clinker for cement is now imported from the eastern states (CCL, 2014).

Quick lime and hydrated lime are used in the mining industry for:
- alumina refining
- gold extraction
- mineral sand processing
- mine water treatment
- nickel production

The other main uses are in
- flue gas desulfurisation
- construction for brick making and mortars
- low quality lime for roadbase and building blocks
- sewerage treatment
- food processing water treatment
- stockfeed

Limestone and rubble are used as roadbase and in reconstituted limestone blocks and limestone blocks used in retaining walls in land developments. Most of the limestone used for roadbase comes from quarries as close to the road building as possible, often from small local quarries.

As discussed above the main raw material for cement and lime production is shellsand from Owen Anchorage, south-west of Fremantle, under the Cement Works (Cockburn Cement Limited) Agreement Act 1971.

There are many small limestone quarries producing lime of less than 20,000 tonnes for local use. For example a small quarry at Exmouth 10,000 tonnes per year for local users (EPA 2012).

The Chamber of Commerce and Industry WA estimated that the average dwelling and associated infrastructure requires 155 tonnes of limestone including product required for road base, site works and building stone (cited in Department of Planning, 2012), however this doesn't account for limesand for fill on acid sulphate soils in urban areas on coastal plains. Urban demand can be estimated from housing commencements. Housing commencements are reported on Development Commission Regions. For the Great Southern there were 400 commencements in 2013/14. Allowing for another 50 commencements in the South Coast Region, outside the Great Southern this would account for approximately 70,000 tonnes per year. Main roads would also use significant amounts for road base outside urban areas. Calcium carbonate ($CaCO_3$), in the form of finely crushed limestone or 'aglime', is the most commonly used neutralising agent for the treatment of Acid sulphate soils.

The Department of Planning developed a basic raw materials strategy for the shires in the Bunbury region. Estimates from 2009-2030, it would require 372,683 000 cubic metres of limestone whereas the supply (on private land) was estimated at 35,460, 000 cubic metres. This was only 10% of requirements.

13.3 South Coast Region

South Coast lime used by industries, other than agriculture, in the Region is for road base, pure cut limestone blocks, reconstituted limestone blocks (from limestone rubble) for construction, and limesand used for amelioration of acid sulphate soils. There is unlikely to be any quicklime production in the region in the near future. It is difficult to estimate the amount of limestone/sand used by local government. The only limestone used by Main Roads, Great Southern Region (which extends to Munglinup), is from a pit in Albany near the Regional Prison. The area of the pit is vested with Main Roads.

The total South Coast supply from all pits, from pit owner estimates in 1999, was 40 million tonnes (Anderson 1999 p 38). Anderson (1999) estimated this amount of lime would last at least 125 years but noted that if lime was applied at the rate needed, South Coast farmers would require1.3 million tonnes per year. In this case supplies would last less than 30 years. Anderson only used NV in determining lime quality from South Coast pits. On current estimates, if lime was applied at the rate required to ameliorate acidic soils, the remaining lime would last less than 10 years because much of the lime crushed from limestone and dolomite is of low efficiency and needs to be applied at two or three times the recommended rate.

14 Economics of liming

The economic benefit to an individual farmer of applying lime has to be determined based on a whole range of factors such as: soil type, pH variation within paddocks, seasonal variation in rainfall, particular crops or pasture grown, other soil constraints, the cost of transporting lime to a particular property, how the lime is applied (i.e. precision or broadscale, surface or deep application) and grain and livestock market prices. Nevertheless indicative data (Petersen 2015) suggests that for most soil types in the South Coast Region there is a highly positive benefit/cost ratio for grain growers.

The economic analysis released by Petersen in 2015 is version 1 of a report from a DAFWA, GRDC funded project, to estimate the economic impact of four sub-soil constraint on each AgSoil zone in the grain growing areas of south-western Australia. Petersen (2015) points out that the assumptions in the analysis will be updated as new information becomes available from the project including better information on the area of susceptibility to each constraint and penalties in different seasons. A second version of the Peterson economic report will be published in early 2019. The rest of this sub-section presents some of the main data and discusses the Petersen report: *Economic Analysis of the Impacts and Management of Sub-soil Constraints.*

14.1 Optlime Model- Petersen Report

Although Petersen's economic analysis for sub-soil acidity, as a constraint to production, is based on paddock scale and then aggregated to regional level, it cannot provide an accurate estimation of the economics of liming for a particular paddock in a particular year. It can provide a guide to the long-term benefits of liming but individual farmers would need to soil test across paddocks to determine whether sub-soil acidity is likely to be a constraint, where to apply lime and how much to apply.

The Optlime model used for the sub-soil acidity analysis is based on a 20-year stream of benefits. It considers likely impacts of yields and fertilizer on acidification trends in the soil over this time period, and compares the scenario of liming with the scenario of not-liming

As for any model the results are dependent on the assumptions put into the model and Petersen (2015, p5) outlines some of the limitations of the analysis. She points out that the main use for the data generated is in comparing across regions and soil zones. It simulates an average year and doesn't account for seasonal or market variability (Petersen 2015, p14).

The analysis is limited to grain growing areas and sub-soil acidity and therefore doesn't consider high rainfall areas where topsoil acidity may be a constraint for pasture production.

Table 16 shows the average crop and pasture yields in the main AgSoil zones of the South Coast Region with yields under current sub-soil constraints in left hand columns compared to estimates of yields without sub-soil acidity in right hand columns. Lupins are not included in the table as yields do not change when sub-soil acidity is removed as a constraint.

Table 16 Estimated average crop yields and stocking rate for the main AgSoil zones South Coast Region from 2009 to 2013.
Current yields are based on BankWest Planfarm data (2010-2014) and are compared to estimates of yields without sub-soil acidity. (Yields are in tonnes per ha or dry sheep equivalents per winter-grazed ha) Source Petersen (2015, p 12 and 18).

AgSoil Zone	Wheat t/ha	Wheat no ss acidity	Barley t/ha	Barley no ss acidity	Canola t/ha	Canola no ss acidity	Stocking rate DSE/WGha	Stocking rate no ss acidity
Southern Wheatbelt	1.8	2.1	2.1	3.6	0.9	1.6	4.5	6.3
Stirlings to Ravensthorpe	2.3	2.6	2.4	4.1	1.1	2.0	5.3	7.3
South Coast	2.7	3.0	2.8	4.5	1.3	2.1	8.8	11.5
Salmon Gums to Mallee	1.9	2.3	2.1	4.6	1.0	2.1	3.8	5.3

The yield penalties for sub-soil acidity are highest for canola and barley, with yields almost doubling in most soil zones once the sub-soil acidity is ameliorated.

Table 17 shows the estimated production in dollars per ha without sub-soil acidity in each of the main AgSoil Zones of the South Coast Region in the top part of the table and estimated production with no sub-soil acidity in the bottom part of the table.

Table 17 Estimated average production value in dollars per ha of cropping and pasture in the main AgSoil zones of the South Coast Region with and without sub-soil acidity as a constraint (Source Petersen 2015, p13)

Estimated average production in dollars per ha with sub-soil acidity as a constraint						
AgSoil Zone	**Wheat ($/ha)**	**Lupins) ($/ha)**	**Barley ($/ha)**	**Canola ($/ha)**	**Pasture ($/ha)**	**All ($/ha)**
Southern Wheatbelt	496	306	568	433	84	371
Stirlings to Ravensthorpe	618	451	651	521	81	491
South Coast	725	361	766	609	168	543
Salmon Gums to Mallee	521	348	581	442	61	407
Estimated average production in dollars per ha with no sub-soil acidity as a constraint						
AgSoil Zone	**Wheat ($/ha)**	**Lupins) ($/ha)**	**Barley ($/ha)**	**Canola ($/ha)**	**Pasture ($/ha)**	**All ($/ha)**
Southern Wheatbelt	557	306	987	752	116	503
Stirlings to Ravensthorpe	694	451	1131	904	112	703
South Coast	798	361	1225	974	219	738
Salmon Gums to Mallee	608	348	1255	954	86	658

Table 18 Estimated indicative cost of lost production per ha ($ per ha) from sub-soil acidity and estimated total indicative value ($million per year) for the three main AgSoil Zones in the South Coast Region (Source: Petersen 2015, p19)

AgSoil Zone	Wheat ($/ha)	Barley ($/ha)	Canola ($/ha)	Pasture ($/ha)	All ($/ha)	Total in $m per year
Southern Wheatbelt	61	418	319	32	133	258
Stirlings to Ravensthorpe	76	480	383	31	212	76
South Coast	73	459	365	50	195	218
Salmon Gums to Mallee	87	674	513	25	251	27

The estimates of lost production due to sub-soil acidity in dollars per ha per year were $212 for Stirlings to Ravensthorpe, $195 for South Coast and $251 for Salmon Gums to Mallee (Table 18). There is less sub-soil acidity in the Salmon Gums to Mallee Agsoil Zone, but where acidity is present the cost per ha in lost production is higher than in other Agsoil zones. The indicative total cost of lost production due to sub-soil acidity was estimated by multiplying the average indicative cost by the area of land in each AgSoil zone where sub-soil acidity is a constraint. It was AgSoil Zone was $76 million for Stirlings to Ravensthorpe, $218 million for South Coast Sandplain and $27 million for Salmon Gums to Mallee.

Peterson pointed out the analysis should be used to compare across Agsoil zones and soil constraints and used in isolation with caution. There were a number of limitations in the analysis including data in some of the assumptions about area of susceptibility to each constraint in each zone.

Petersen's findings complement Herberts (2009) with Peterson's analysis based on AgSoil zones while Herbert's were based on rainfall zones. Peterson's analysis aligns better with DAFWA's report card where soils below target pH are aggregated to AgSoil zones (see section 8). Herbert's (2009) estimates for the production penalties for the High Rainfall, Medium Rainfall and Low Rainfall South areas, which are zones within the South Coast Region are shown in table 19. Oats were estimated for the whole agricultural area at 30% yield penalty.

Table 19 Current yield Penalty in the rainfall zones of the South Coast Region for different crops from Herbert (2009 p44).

Enterprise	Rainfall Zone and % yield penalty		
	High Rainfall South	**Medium Rainfall South**	**Low Rainfall South**
Wheat	10	12	15
Lupins	0	0	0
Barley	40	45	50
Canola	40	45	50
Pasture	25	30	30

The estimated production penalties for Stirlings to Ravensthorpe, South Coast and Salmon Gums Mallee for wheat to be 12, 10 and 15, for Lupins, 0 for Barley 45, 40 and 55 and for Canola 45, 40 and 55 and for pasture 30, 25 and 30 (Petersen, 2015).
The opportunity costs for the Southern Agricultural Region (which extends beyond the South Coast (to Woodanilling and east of Katanning), were estimated to be $130 million dollars per average year. Herbert points out that this does not include future risk and because soil acidity is increasing this is likely to increase the overall opportunity costs so the figure

underestimates potential cost.

Petersen reported based on Herbert (2009) that soil acidity will have an impact in the Southern Wheatbelt, Stirlings to Ravensthorpe and South Coast Sandplain Ag Soil Zones in 90% of years, and in Salmon Gums Mallee in 95% of years.

The Optlime model was run for different levels of acidity with different lime applications on different soil types within each zone with topdressing and deep banding (Petersen 2015 p 70-76). The annual benefit cost ratio, profit and break even time in years for critical pH from the Optlime model were highest for the soils in the South Coast Sandplain. The figures for moderate pH have a smaller positive benefit cost ratio but break-even time is a lot longer.

Table 20 The Indicative equivalent annual profit and benefit cost ratio (over 20 yearss) of applying lime for the main AgSoil zones in the South Coast Region.

	Liming deep banded with surface applications	
AgSoil Zone	**Indicative equivalent annual profit ($/ha/yr over 20 years)**	**Indicative benefit cost ratio (over 20 years)**
Southern Wheatbelt	41	8
Stirlings to Ravensthorpe	30	9
South Coast	122	13
Salmon Gums to Mallee	37	10

The benefit cost ratio shows that for every dollar spent for the main AgSoil zones in the region the return over 20 years is $10 or more.

The 2015 Petersen report is useful in showing that the South Coast Sandplain Agzone is potentially losing $218 million dollars per year in lost production due to sub-soil acidity. The South Coast Region is going to become an increasingly important agricultural area as projected lower rainfall and higher temperatures reduce yields in other areas. This reinforces the need to ensure there are no yield penalties due to acidic soils when the cost benefit of liming is so far in the direction of benefit with an indicative benefit cost ratio over 20 years of 9 for Stirlings to Ravensthorpe, 13 for the South Coast Sandplain and 10 for Salmon Gums. The analysis also didn’t include the off-site benefits in the benefit cost ratio so the overall benefits are even higher.
The Petersen report provides some useful indicative data that applying lime would provide higher profits for most crops and pastures and increase the value of production on the South Coast. Further work may provide more detailed economic analysis.

14.2 Costs of liming

The Department of Agriculture and Food recommends adding required lime to 25% of the farm each year so costs can be distributed over 4 years (Chris Gazey pers comm).

Soil sampling and pH testing should be an important part of the lime budget. Professional soil sampling of 0-10, 10-20 and 20-30 cm layers, costs approximately $60 per site. The cost of lime has to include:
Cost/tonne ($) lime
Transport (@ c/km/t for x km)
Spreading @ $ per tonne

Percentage Efficiency i.e. the cost of effective lime on paddock

For a lime with 100% efficiency, the effective cost would be the same as the actual cost. For a lime with an efficiency of 50%, the effective cost would be twice the actual cost. The effective cost is (100/Percentage efficiency) multiplied by all other costs.

The short term cost of applying lime does not take account of :

- *the cost of degrading the soil resource*
- *the long term cost of taking (borrowing) alkalinity from the resource by continuing to farm without applying lime*
- *the value of maintaining or recovering a soil pH profile.* (Gazey and Andrew 2010, p234)

For farms close to high quality lime sand in the mid-west, it is possible to purchase, transport and spread 1 t/ha for $25-35 (Gazey pers comm), but on the South Coast it is a much more expensive proposition because of the lower percentage efficiency of South Coast lime or the cost of freight of limesand from the west coast.

14.3 Comparative costs.

A hypothetical comparison of a high quality (>90%) mid-west coast limesand versus lower quality, large particle size (50%) South Coast Region lime is shown below.

South Coast lime (of 50% efficiency)
Lime at pit @ $25 per tonne
Transport @ 10c/km/tonne over 50km =$5 per tonne
Spreading costs $10 per tonne
Total: $40/tonne
Required to spread 1 tonne/ha @ twice amount=$80/ha
High quality mid-west coast lime (>90% efficiency)
Lime at pit $10 per tonne for large tonnages
Freight $50per tonne
Spreading costs $10 per tonne
Total $70 per tonne=$70/ ha

In this hypothetical it would be cheaper to transport lime from the west coast but it could change in the direction of lime from the South Coast Region for west coast lime sands of lesser quality.

An example of costs in one year
A Farmer has 2000 ha of cropping land and aims to treat one-quarter per year. Based on soil tests he needs to treat 250 ha @ 1 tonne per ha and 125 ha at 2 tonne/ha and 125 ha at 4 tonne/ha
He freights 1000 tonnes of >90% lime from Lancelin to Jerramungup
@$50 /tonne transport = $50,000 to transport. Cost of lime and spreading $20,000: Overall cost $70,000 plus initial soil testing.

In general

- For South Coast lime of higher quality than 50% efficiency it may not be economical to transport lime from the west coast.
- For west coast lime of lower quality than 80% efficiency, it may not be economical to transport lime from the west coast if South Coast lime was 40-50% efficiency
- For south coast lime of very poor quality (< 30% efficiency) it would in most cases be more economical to transport high quality lime from the west coast.
- It would be better in terms of carbon emissions to use more of lesser quality south coast lime than to transport lime from the west coast
- The economics of the comparison will vary from lime pit to lime pit and farmers transporting lime from the west coast would need to be assured that the quality justified the extra cost of freight. For example there may need to be certification that the lime transported from the west coast came from a particular pit with recent audit data. This is why it is important for growers to request lime efficiency data such as those available from Lime WA Inc members. DAFWA can only conduct independent audits when funds are available.

o Other factors with the calculations:

- Lime quality is not available from all pits and lime quality can vary significantly within pits.
- Limes can vary slightly in solubility, depending on the amount of aragonite, calcite or magnesium present (Morse and McKenzie 1990; Morse et al. 2006). This is a relatively small factor not used in the lime efficiency calculations.
- Freight costs are likely to increase more rapidly than lime costs

15 Future lime supplies South Coast Region

15.1 Lime Deposits South Coast Region

15.1.1 Tamala and Tamala-like limestone

There are coastal deposits of limesand and limestone in the South Coast Region. The limestones are classified as Tamala or Tamala-like limestones. Tamala limestones vary in in carbonate content, even within a pit, both horizontally and vertically (Playford *et al*. 1976). It is harder to get uniform quality than from Holocene limesands from the west coast. Tamala limestones generally grade above 50% carbonate but rarely as high as 90% (Playford *et al.* 1976: Gozzard 1987)

All along the coast east of Albany there are deposits of shelly coastal limestone and calcareous quartz sand. These are often overlain by dunes of fine grained quartz sand when the limestone has dissolved out (Abeysinghe 1998). The limestone varies it the amount of lithification (cementing). The coastal sediments near Esperance are mainly between Lake Gore and Esperance townsite. These shelly limestone ridges west of Esperance are important groundwater supply and recharge areas. They are also mainly in vegetated areas (Dept of Water 2007).

East of Esperance coastal limestones and calcretes may be in sites where they can be extracted but most are likely to be in vegetated coastal areas with potentially high biodiversity values. Any potential deposits would need to be assayed.

15.1.2 Further Werillup Nanarup Member outcrops

Limestone at the Nanarup quarry (now closed) and possibly that at the Manypeaks quarries are part of the Werrilup formation. (Manypeaks limestone has not been described by a sedimentologist). The Werrilup limestone has been classified as *Nanarup Limestone Member*. It is classified as a friable limestone. It is a yellow and white bryozoan calcarenite that reaches up to 5m in thickness. The most extensive outcrop is in the Nanarup Lime Quarry (Craig 1997, p311). There are likely to be some other Nanarup Limestone Member deposits on private land.

In its 2015 report, the GSWA used stratigraphic logs from the DoW database, combined with remapped surface geology to indicate that the limestone is much more extensive than previously thought. It was originally considered to be 4.6 metres in depth (Abeyshinge 1998) but the GSWA data indicated a maximum thickness of 27 metres (GSWA 2015, p41). Although the GSWA suggests that this is an important resource, unless finely crushed, larger particle size is likely to be a problem in reducing its efficiency.

15.1.3 Dolomite

There are dolomite deposits at Magenta and in the lakes area north of Ravensthorpe (Hill 2001). Ravensthorpe deposits would need to be assayed.

The dolomite based on independent audit data from pits near Kojonup in 2008 is not of very high efficiency with large particle size. The GSWA (2015) referred to the pits in the west as dolomitic sand.

15.2 Other deposits

15.2.1 Limestone Goldfields

Limestone associated with calcrete deposits in the Yilgarn Craton would be worth investigating (Iain Copp, Good Earth Consulting, carbonate sedimentology specialist, pers com). There is limestone near Lake Cowan in the Norseman formation. It is a fossiliferous marine carbonate, formed in the middle Eocene in a drowned estuary, with strong tidal currents (Clarke, Bone and James 1996).

A Basic Raw Materials Strategy for Kalgoorlie is being prepared by Department of Planning which will identify limestone deposits in the vicinity.

15.2.2 Limestone deposits, Nullarbor

The Nullarbor limestone deposits are very large and have the potential to be a resource for the South Coast in the long term, but this will depend on biodiversity values.

"Limestone resources in the Eucla Basin, easily exceeding several billion tonnes of high-grade material, can be considered as the largest in Western Australia." (Abeysinghe 1998, p75)

There is a quarry at Rawlinna (370km from Kalgoorlie) approximately 97% Ca CO_3, and crushing and screening facilities at Parkeston. The facilities are no longer being used for quicklime production, but the quarry is owned by Adelaide Brighton Cement (which also owns Cockburn Cement Ltd).

15.3 Developing new lime resources. Protecting biodiversity and other NRM values.

Developing new lime resources needs to consider NRM values, tenure, amenity values as well as traffic and other factors. The Western Australian Planning Commission has prepared a very detailed booklet. (Western Australian Planning Commission 2009) *Basic Raw Materials Applicants' Manual*

A step-by-step guide for establishing extractive industries in Western Australia

The *Statement of Planning Policy No 2.4 Basic Raw Materials defines Basic raw materials as sand (including silica sand), clay, hard rock, limestone (including metallurgical limestone) and gravel and other construction and road building materials. These materials are produced relatively cheaply, with the major cost being the transport to the construction site (Section 3.1)*

The following is a list of documents to guide site selection:

DER guidelines for clearing appeals
DER A guide to the exemptions and regulations for clearing native vegetation
DMP Mining Environmental Management Guidelines

SAT Information about class 1 and 2 planning applications
State Planning Policy 2.4 Basic Raw Materials
State Planning Policy 4.1 State Industrial Buffer Policy

The Statement of Planning Policy No 2.4 protects some areas close to Perth for limestone extraction specifically so that construction and road building materials are available close to developments in the metropolitan area. It doesn't apply elsewhere in the State at this stage.

Extraction of basic raw materials on Crown Land (but not on private land) is subject to Section 24 of the *Mining Act, 1978.* It is a costly process to get approvals for extraction. The Mining Act 1978, the Mining Regulations 1981 and the Offshore Minerals Act 2003 are located on the State Law Publisher website.
Royalties are paid for extracting lime from Crown land, if the lime is sold.

Limestone quarrying is classified as an extractive industry and it is usually regulated as part of a Local Government Town Planning Scheme. Local governments consider environmental, amenity, traffic and residential concerns.

Any proposal for quarrying that is likely to have a significant impact on the environment may be referred to the Environmental Protection Authority (EPA) for assessment before it is implemented. Any person may refer a proposal to the EPA. In addition, local government or other agencies who are responsible for issuing approvals for the quarry must refer a proposal to the EPA if the proposal is likely to have a significant effect on the environment (EdoWA, 2011).

Extractive industries on private land (freehold) require approval under the *Planning and Development Act 2005* (P & D Act). The P & D Act requires approval from the Western Australian Planning Commission (WAPC) for development in section 162. Both the extraction and building components of an extractive industry application are subject to planning approval. Regardless of the type of land holding, all extractive industry proposals are subject to the provisions of the *Environmental Protection Act 1986* (EP Act) for clearing applications (see part 5). DMP applications are subject to the *Aboriginal Heritage Act 1972*. Local government applications are subject to local laws and the WAPC's state planning policies (WA Planning Commission, 2009). Table 21 outlines some of the site selection considerations.

Table 21 Site selection considerations. Adapted from the Western Australian Planning Commission (2009).

Appropriate site location	Safe access to roads and consideration of traffic
	Not on a ridge or visual from roads
	Not within 500-1000 m of sensitive land uses such as residential development, schools, hospitals.
NRM considerations	Not where it will interfere with a potable water resource
	Not priority agricultural land
	No significant clearance of native vegetation
	Adequate setback from waterways, wetlands
	Not listed as a Bush Forever area
Planning	Consistent with current zoning and proposed zoning
	The time frame considers the long-term impact on the local community

There is concern about the effect of lime quarries on biodiversity and so the focus on finding new lime deposits in the South Coast Region should be on freehold land that has already been cleared. This may conflict with priority agricultural land and these two priorities would need to be assessed. Development may require formation of a farmer cooperative if there is not enough commercial incentive to develop lime resources.

16 Management practices to reduce lime use

There are a number of potential management practices to reduce lime use.

16.1 Fertilisers.

Ammonium fertilisers and urea acidify soils by nitrification. The amount of acidification depends on the amount of nitrate (NO_3^-) taken up by the plant and the amount leached. Bolan and Hedley (2003) give figures of 1.72 and 5.24kg of lime to overcome the acidity produced from 1 kg of nitrogen as urea and 1 kg of nitrogen as ammonium sulfate.

Using a simple mechanistic model and a database of simulated wheat production, Fisher *et al.* (2008) estimated that split fertilizer application would reduce acidification rate by 5-10%, and a later sowing date by 5-10%.

Using less acidifying fertilisers, split fertilizer applications or more targeted applications of fertilizer using variable rate technology, can all reduce rates of acidification.

16.2 Reducing nitrogen leaching

Highest rates of nitrogen leaching are in annual legume pastures, while deep-rooted perennial grass pastures reduce nitrogen leaching. In high rainfall areas in Western Australia kikuyu pastures have been shown to almost eliminate nitrogen leaching (McCascill *et al.* 2003).

Dicyandiamide deactivates ammonium monoxygenase enzyme, the enzyme that causes oxidation of ammonium to nitrate in soil. Its effectiveness depends on a range of factors including soil pH, soil moisture, soil structure, humidity, temperature, organic matter and microbial activity. In New Zealand DCD is being trialled to reduce nitrification, nitrate leaching, and therefore nitrate loss to waterways and nitrous oxide emissions. Its use was stopped because low levels were found in milk (Astley 2013).

Dicyanamide is unlikely to be approved for use on pastures and would only be useful in a small part of the South Coast Region with high rainfall, cool temperatures and intensive animal husbandry such as dairying or intensive free range pig production.

16.3 Incorporation of lime

Incorporation of lime requires deep tillage. The cultivation implement needs to be able to mix the lime to the 20-30 cm depth where sub-soil pH is below target (Scanlan *et al.* 2014). The yield benefit in the first year is mainly driven by the cultivation effect (Davies *et al.* 2015 a). There is most benefit when there is more than one constraint. One-off soil amelioration with mouldboard plough to overcome several constraints at once, such as water repellency, compaction, herbicide resistant weeds and soil acidity, can provide long-term benefits where there is no wind erosion risk (Davies *et al.* 2015b). Deep ripping on deep sands may provide some lime incorporation in seams and overcome other soil constraints benefits but will still leave areas without any lime, and acidity as a constraint (Davies *et al.* 2015a).

Most of the trials on incorporation of lime have been conducted in the northern agricultural area. There are some trials in the South Coast Region at the time of writing this report. Lime incorporation is most effective on deep sandy soils but there is a risk of erosion on light sandy soils. It is also risky on duplex soils, because of inversion of the soil layers.

Scanlan *et al.* (2014) suggest for incorporation to be economical, soil pH_{Ca} in the 0-10 and 10-20 cm soil layer needs to be well below the recommended levels of 5.5 and 4.8 respectively, soil fertility needs to be adequate and the cultivation implement needs to be able to mix to depth. Table 22 gives an indication of depth of various tillage implements and the coast of cultivation.

Table 22 Cultivation depth and cost Source Davies and the Liebe Group (nd)

Tillage Implement	Typical working depth (cm)	Approximate estimated cost ($/ha)
Offset discs	15	35
One-way plough	15-25	35
Rotary spader	30-40	100-150
Mouldboard plough	35-45	100-150
Deep ripper	30-40	30-50

16.4 Variable Rate Technology

Variable rate technology can prevent under and overuse of fertilizer and lime. It may not reduce the overall demand for lime but lime use will be more efficient and result in faster amelioration of acidic soils. The variability of soils within and between paddocks (see table 8) shows that applying lime at a uniform rate across the farm is a very inefficient use of lime.

16.5 Tolerant varieties

Treatment of acidic soils with lime combined with aluminium tolerant crop varieties can reduce the yield penalty of acidic soils (Tang *et al.* 2003). Because sub-surface acidity takes so long to ameliorate, aluminium tolerant crops and pastures may have to be grown, while continuing to treat acidity. It is important to stress, there is a limit to acid tolerance and soils will still need lime treatment to prevent increasing acidity.

There is a major focus globally on understanding acidity tolerance in plants and developing acid and aluminium resistant varieties and there are increasing advances in understanding of the physiology, molecular mechanisms and genes involved (for example Kochian, 2015). Biotechnology and conventional breeding are being used to select acid tolerant varieties.

New perennial legumes to overcome acidity and waterlogging have been developed for southern Australia and include Birdsfoot trefoil (*Lotus corniculatus*), Talish clover (*T. tumens*), and hairy canary clover (*Dorycnium hirsutum*). Stoloniferous red clover cultivars and sulla (*Hedysarum coronarium*) cultivars adapted to southern Australia have also been released, along with a new cultivar of Caucasian clover (*T. ambiguum*) (Nicholls *et al.* 2012).

16.6 Alternative liming agents

Wood Ash

Wood ash is high in pH and has neutralizing capacity. Burning of timber stacks and windrows adds alkali to the soil. Fraser and Scott (2011p223) argued that in the central west of NSW, in a low rainfall environment, the alkali effect would last over a thousand years before returning to pre-burn pH, and that timber burning contributed to the spatial variability of the soil.

Wood ash, as a soil ameliorant, has mostly been used in Europe in forestry applications. Augusto *et al.* (2008) reviewed its use. There are increasing numbers of trials with woodash in Europe because of the use of wood for bioenergy and the need to dispose of the ash. The question is whether some toxic metals may be present in the ash and this varies with wood, temperature of the furnace and component of the ash (Pitman 2006). Patterson *et al*. (2003) found increases in barley and canola yield in Alberta, Canada with wood ash applied to acidic soils, although they used large quantities. It has also been investigated on wheat crops (Huang *et al*. 2008). The use of wood ash on food crops would need thorough investigation.

Water Corporation 'Lime-amended BioClay®,

This product is still being evaluated for agriculture. It requires 30% quicklime to be mixed with the biosolids and then the product is mixed 1:1 with clay. Even if effective it is in very limited quantity and wouldn't reduce overall lime use significantly.

Alcoa

Red Lime™ is a by-product removed during the alumina refining process. It is then washed and dried. It has a high neutralising value and fine particle size. Alcoa are examining the feasibility of producing a Red Limeby-product, with the initial focus on use as an agricultural lime. (Alcoa, nd). In the US red mud was found to contain oxides of iron , aluminium and titanium. Therefore there have been concerns about heavy metal contaminants (Koopman 2006).

Alkaloam ™ another Alcoa by-product was trialled in the Peel-Harvey but there were problems associated with public perception of health risks. "Despite a significant body of research and an extensive monitoring programme, the use of Alkaloam® has been put on hold in Western Australia, due primarily to public perceptions about the long-term environmental and health impacts of the product." (URS 2010 p5).

16.7 Blue Sky - Production of carbonates to sequester carbon dioxide

The urgency to develop carbon capture technology could drive the technology to produce carbonates by biomimicry or geomimicry. Carbonates can be produced from calcium or magnesium ions from sea water or salt lakes, or from silicates in rocks, and at the same time sequester carbon dioxide. For example, carbon dioxide reacting with sodium hydroxide and calcium chloride can produce calcium carbonate, sodium chloride and water. A company in the US (Calera) is investigating the technology (Mathews 2012). Initially this technology could provide carbonates for the use by the mining industry and take pressure from agricultural supplies. Another option is to use biological organisms to produce carbonates.

17 Recommendations to South Coast NRM

In the short term, to 2030, there are two main options for South Coast to increase lime availability for amelioration of agricultural soils.

1. Find and develop more high quality lime supplies on the South Coast at two or three sites, preferably on private land, where extraction will be environmentally acceptable.

2. Transport lime from the west coast. Freight costs are high and transport contributes to carbon emissions, so finding local lime supplies should be a priority.

The overall cost of lime is likely to increase over time so it is more economic for farmers to invest in the higher quantities of lime required to recover soils now.

Recommendation 1. Lime supply investigations

Mapping and tenure analysis

Link the Geological Survey of WA mapping of potential deposits and tenure analysis. Investigate potential deposits of limestone/sand at Torbay, west of Denmark, Bremer, Hopetoun and Esperance on private land. Pits on Crown land would have to comply with the Mining Act and would be expensive to develop. They are also often in areas of high biodiversity value. It is also recommended that South Coast NRM establish a set of site selection considerations based on NRM values such as water and biodiversity.

The initial focus could be in the areas around Torbay, SW of Denmark and near Esperance for limestone/sand on private land. This would highlight areas suitable for further survey. Note that the GSWA (2015) report, in recommending potential deposits, focused on carbonate content and not particle size.

Although the GSWA recommended Nanarup limestone as an important resource, large particle size has been a problem in reducing the efficiency of this lime source in the past. Nevertheless it appears to be a much larger resource than previously thought (GSWA 2015).

In the longer term, investigate calcrete on the Yilgarn. Link with DMP, GSDC and GEDC and the Department of Planning to fund lime supply investigations. Potential funding: Royalties for Regions.

Sample and analyse potential lime supplies for neutralising value and particle size.

Potential deposits will need to be analysed for carbonate content but the potential particle size of the product will also determine efficiency.

Recommendation 2. Support a Basic Raw Materials Strategy for the South Coast.

A Basic Raw Materials Strategy for the South Coast (this would include limestone/sand, gravel etc) would be useful. This document would have the potential to guide planning decisions in relation to deposits of limestone/sand and dolomite. These have been prepared by the Department of Planning for other regions. The GSWA is currently preparing data for this (GSWA 2015).

Recommendation 3. Continue lime extension.

DAFWA's extension on using lime to ameliorate soil acidity has been successful in increasing lime use. It increased 530% from 150 000 tonnes in 1994 to more than 800 000 tonnes in 2002. The number of farmers using lime rose by 240% from 1353 to 3292 over the same period (Department of Agriculture 2003). With ongoing reductions in DAFWA extension staff in the Region it is going to be important for South Coast NRM to increase lime extension.

Suggested strategies:

- Focus on lime quality and the need for landholders to know the efficiency of the lime they apply. Extension to stress the need to apply more of lower quality lime resources.
- Encourage soil testing, paddock mapping and variable rate technology to use lime more effectively.
- Use the message that lime is only to get more expensive and soils harder to ameliorate.
- Hold workshops with rural real estate agents to include soil pH testing and lime history in farm sales so that it becomes an important part of land value.
- Develop a collaborative project with other NRM regions in the agricultural area on lime supplies for agricultural use.

Recommendation 4. Investigate the economics of further crushing from pits with high NV and large particle size.

Many South Coast lime resources are of low efficiency because of large particle size. Investigate the economics of further crushing of resources (multi-stage crushing), versus freight.

Recommendation 5. Monitor soil acidity trends in the Region.

Moody *et al*'s (2002), recommendation to set up permanent sites to monitor soil acidity in the main Ag Soil Zones would be costly but a continuation of the Andrew (2013) project using a large number of sites would provide valuable information on trends.

Recommendation 6. Support lime research and demonstration sites on alternative management practices.

Focus on alternative management practices to reduce rates of acidification and more effective use of lime through incorporation and variable rate technology.

Recommendation 7. Investigate Transport Options

Bulk transport with stockpiling is one option but the extra handling costs would be likely to negate the savings in freight costs. One advantage of bulk stockpiles is that they could be quality assured. Investigate ways to reduce transport costs from west coast to South Coast

Region. Transport of regular amounts of 5-10,000 tonnes per month over the winter months, would be significantly cheaper than farmers individually transporting lime from west coast pit to farm, although it would mean extra handling. The cost of stockpile storage and extra handling would need to be investigated.

Shipping transport from the mid-west to Albany and Esperance is likely to be more expensive. Lime could be transported from Geraldton Port with lime from Dongara pit using options such as Qube half height containers. These reduce handling at loading but they have relatively small capacity (20 tonnes) and are mainly used for transporting high priced minerals. Qube controls all aspects of the transport.

Rail transport from the Nullarbor may be an option for the future but at this stage it is unlikely there would be a commercial pit or that transport from the Nullarbor would be more economic than from west coast supplies.

Pursue the concept of a Commonwealth government transport subsidy per km for lime of >90% efficiency.

Recommendation 8. Investigate Nullarbor limestone as an option for the long term.

Nullarbor limestone is an option for the long term but pit development costs and freight would be too high in the short term. Transport is likely to be more expensive than from the west coast but there are very large quantities of limestone. Abeysinghe (1998) calculated the Nullarbor resource to be 40 Mt/km2.Resources and from the Wilson Bluff Limestone 65 Mt/km2. BHP minerals exploration in found the Nullarbor Limestone is of high grade throughout the area surveyed. Calcrete deposits may be another long term option.

Recommendation 9. Investigate alternative ameliorants.

Investigate wood ash as a liming agent. This could be investigated initially in the forestry industry. South Coast could seek funding for a small-scale trial with wood ash on acidic soils, comparing it to lime, and assaying soil and plant chemicals. In the long-term, wood ash as a liming agent, could increase the viability of biomass energy. For example it could be produced as a by-product from a biomass plant in an area close to Ravenshorpe or Jerramungup.

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19 Appendix 1. Forms of carbonate containing material (e.g. limestone/limesand/dolomite)

There are several forms of carbonate in Western Australia.

Limestone

Geologists classify limestone into several types.

Tamala limestone was first called coastal limestone and the term Tamala was used to refer to its lithology. It is described as "Unconsolidated to strongly lithified calcarenite with calcrete/kankar soils; aeolian. Locally quartzose, feldspathic, or heavy-mineral-bearing." (Geoscience Australia 2015).

The name Tamala Limestone generally refers to Quaternary (Pleistocene) coastal carbonate eolianites in coastal Western Australia, encompassing widespread and voluminous marine and eolian carbonate deposits extending more than 1000 kilometres (km) from Cape Range on the central coast to Albany on the south coast. It is cross-bedded dunes. Sea level rises and falls determined coastal carbonate deposition, with several stages of sedimentation (Brooke, 2001). Higher sea surface temperature probably increased rates of carbonate production off the west coast of WA (James *et al.* 1999).

The Nornalup Limestone Member is in the Werrilup formation on the South Coast. It is a pale brown limestone extending from the eastern side of Albany to Bremer Bay. The GSWA (2015) reports it to be much more extensive than previously thought.

The Nullarbor Limestone unit is a grey limestone of unknown quality. It was probably deposited in the lower Miocene (GSWA 2015).

White limestone is part of the Abrakurrie Limestone. It ranges in thickness from 55 metres to 67 metres at Point Culver and fossils date it to Upper Eocene age (GSWA, 2015). It is almost entirely in an A class nature reserve.

Sandy limestone occurs as part of the Norseman Formation. It was probablt deposited when sea levels extended north in the Upper Eocene.

Gingin chalk limestone is not strictly a chalk. It has a much lower carbonate and much higher silica content than European chalk. Chalk is a soft white limestone from the skeletons of marine plankton " The strict usage of the term chalk is for the very fine grained pure-white limestone found in the Upper Cretaceous of Western Europe". (Abeysinghe, 1998, p7)

Coquina

Coquina consists of shell fragments, usually molluscs, and loosely cemented by calcite. Shell beach at Shark Bay is composed of bivalve shell (*Fragum erugatum*,) fragments. Coquina limestone blocks cut at Denham were used in many of the early buildings. Coquina can now only be excavated to repair existing buildings (EPA, 1992). There are also ooid limesands at Shark Bay.

Tufa
Tufa is usually deposited from solids in groundwater. It forms in ambient temperature fresh water as distinct from Traventine, which forms in hot springs. " It is consolidated to unlithified freshwater secondary limestone deposit that contains biological remains and forms in ambient- to near-ambient-temperature waters in karstic terrains " (Carthew *et al* 2003). In the South West of WA Tufa is classified as a threatened ecological community. Tufa is formed through the acitivity of microbial organisms leading to calcium carbonate precipitation and sedimentary rock. " (Onton, 2009 p2)

Marl
Marl is a lime rich mud, which formed in lakes and swamps in the metropolitan area of Perth. Examples of deposits occur in the Bullsbrook-Muchea area and North Dandalup. They are usually not high in $CaCO_3$ although some small areas were as high as 96% CaCO3 (Abeysinghe, 1998). It has been used as roadbase in the past, but now wetlands are gradually being restored.

Calcrete

Calcrete is a near surface terrestrial carbonate(Chen and Roach, 2002). It differs from other carbonates in that the carbonate minerals, from calcium carbonate saturated groundwater, precipitate within host materials such as soils, sediments or other minerals. This differentiates calcrete from the carbonates which deposit originally from "free water", e.g., from water in springs, caves, rivers, lakes and other water bodies. (Chen and Roach, 2002 p2).

Calcrete varies in calcium carbonate but can have a high carbonate content. Chen and Roach (2002) and Anand and Paine (2002) outline where calcretes occur in WA. Calcretes are common the Yilgarn Craton but are thicker in the northern parts of the Craton. Nodular calcretes occur in the southern Yilgarn to the Nullarbor and to the coast in the winter rainfall areas (Chen and Roach, 2002). There are also tubular and hardpan calcretes in coastal dunes.
Groundwater calcretes are linear, tabular bodies occurring at or close to the surface and forming gentle mounds. They are Ca- and Mg-cemented valley deposits that are up to tens of metres thick. (Anand and Paine, 2002)

Limesand

Limesand is the term used for unlithified CaCO3 i.e. sands rich in calcium carbonate (usually shell fragments). Limesand occurs both along the coast and in near shore environments such as Cockburn Sound. Most limesand is Holocene in origin and has not yet been lithified, but some is weathered limestone.

Magnesite

Magnesite is magnesium carbonate. There are two types in Western Australia. Magnesite in Archean rocks and magnesite in tertiary sedimentary rocks as at Bandalup (30 km east of Ravensthorpe). Magnesite is discussed in detail in a GSWA report by Abeysinghe (1996).

20 Appendix 2. Lime efficiency (2008) South Coast area pits (Not for publication)

Lime efficiency calculated for South Coast Pits based on 2008 samples (Gazey and Gartner, 2009). Variation in efficiency throughout the resource may mean these figures are not representative of the current resource.

Note the comparison with Dongara Limesand at the end of the Table.

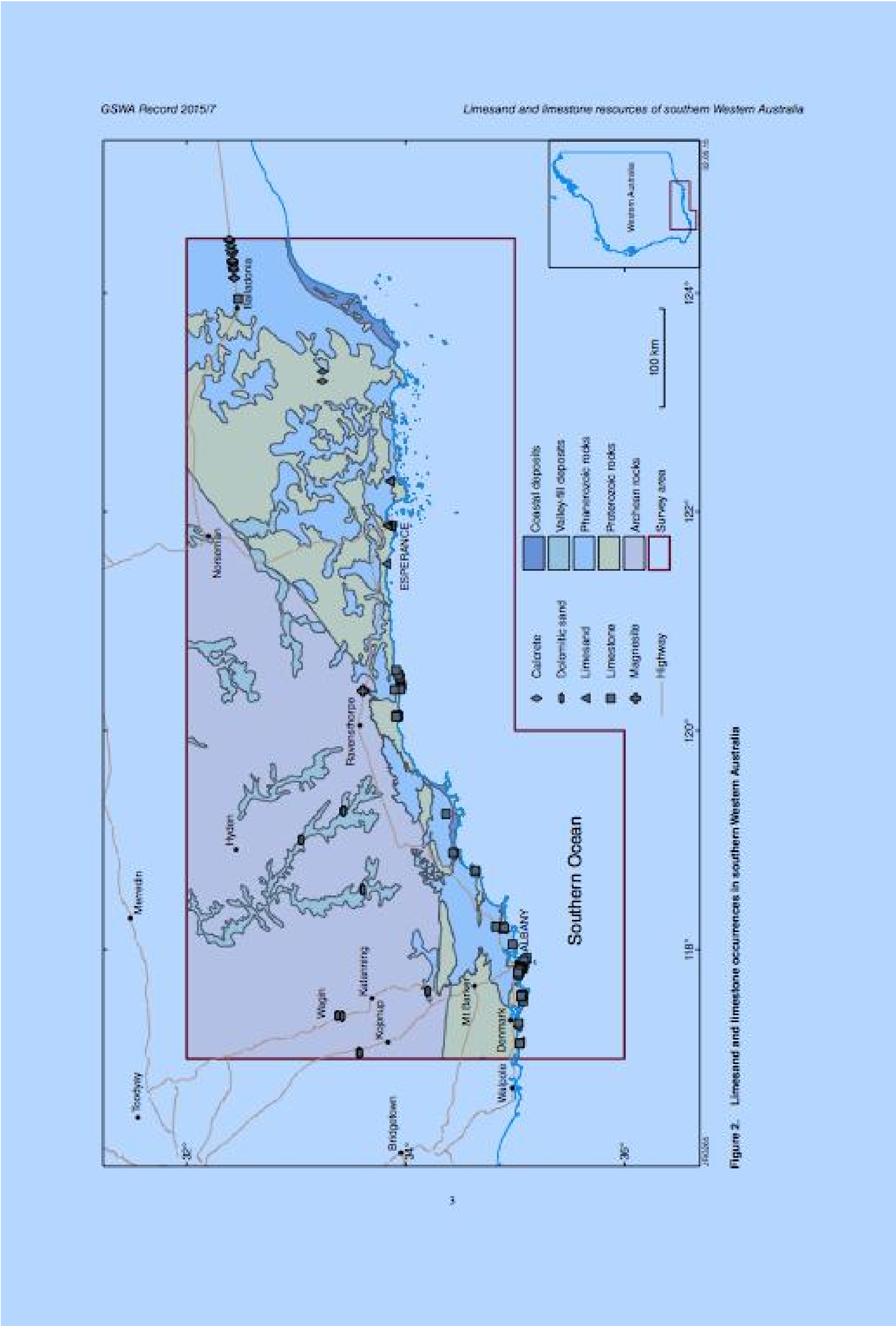
	Sieve range	**% weight**	**NV**	**NV corrected for particle size**
Windy Harbour SCLS 4 *				
	0-0.125	2.3	91.8	2.1114
	0.125-0.25	7.8	74.5	5.811
	0.25-0.5	29.4	82.5	24.255
	0.5-1	35.1	86	15.093
	>1	25.3	91.7	4.64002
	Efficiency		**85.6**	**51.91042**
Ocean Beach Denmark SCLS5				
	0-0.125	2.9	86.4	2.5056
	0.125-0.25	30.3	76.4	23.1492
	0.25-0.5	42.6	78.4	33.3984
	0.5-1	9.9	80	3.96
	>1	14.3	85.7	2.45102
	Efficiency		**79.3**	**65.46422**
Bornholm Ag Lime SCLS 6				
	0-0.125	0.6	81.7	0.4902
	0.125-0.25	24.7	65.3	16.1291
	0.25-0.5	59.6	54.5	32.482
	0.5-1	11.4	58.3	3.3231
	>1	3.5	68.1	0.4767
	Efficiency		**58.1**	**52.9011**
Manypeaks SCLS7				
	0-0.125	7	77	5.39
	0.125-0.25	4.9	75.4	3.6946
	0.25-0.5	11.2	79	8.848
	0.5-1	17.7	77.6	6.8676
	>1	59.1	72.5	8.5695
	Efficiency		**74.5**	**33.3697**
Mason Bay Hopetoun SCLS 8				
	0-0.125	17.8	79.7	14.1866
	0.125-0.25	21.7	67.7	14.6909
	0.25-0.5	22.2	69.2	15.3624

	Sieve range	% weight	NV	NV corrected for particle size
	0.5-1	19.1	72.4	6.9142
	>1	19.2	78.4	3.01056
	Efficiency		**73.1**	**54.16466**
Krystal Park Hopetoun SCLS 9				
	0-0.125	9.2	62.8	5.7776
	0.125-0.25	31.2	23.3	7.2696
	0.25-0.5	20.6	35.9	7.3954
	0.5-1	6.7	49	1.6415
	>1	32.3	53.9	3.48194
	Efficiency		**41.2**	**25.56604**
Dalyup Esperance SCLS 10				
	0-0.125	6.1	59.5	3.6295
	0.125-0.25	72.1	67.8	48.8838
	0.25-0.5	18.7	84.2	15.7454
	0.5-1	0.7	86.5	0.30275
	>1	2.4	78.2	0.37536
	Efficiency		**70.7**	**68.93681**
Bremer Bay SCLS11				
	0-0.125	16.9	74.8	12.6412
	0.125-0.25	14.9	68.3	10.1767
	0.25-0.5	17.6	70.9	12.4784
	0.5-1	17.7	72.4	6.4074
	>1	32.8	79.1	5.18896
	Efficiency		**74**	**46.89266**
Beaufort River Dolomite SCLS12				
	0-0.125	10.7	66.9	7.1583
	0.125-0.25	7.9	65.8	5.1982
	0.25-0.5	11.3	65.3	7.3789
	0.5-1	14.7	64	4.704
	>1	55.5	67.7	7.5147
	Efficiency		**66.7**	**31.9541**
Kojonup Dolomite SCLS13				
	0-0.125	14.5	46.3	6.7135
	0.125-0.25	12.2	63.5	7.747
	0.25-0.5	17.3	65.4	11.3142
	0.5-1	17.8	61.1	5.4379
	>1	38.2	64.3	4.91252
	Efficiency		**61.2**	**36.12512**

	Sieve range	% weight	NV	NV corrected for particle size
Marononi Dolomite SCLS14				
	0-0.125	11.3	54.4	6.1472
	0.125-0.25	9.5	48.7	4.6265
	0.25-0.5	16	43.1	6.896
	0.5-1	20	39.3	3.93
	>1	43.2	48.6	4.19904
	Efficiency		**46.5**	**25.79874**
By Comparison Dongara limesand SCLS21				
	0-0.125	18.7	94.3	17.6341
	0.125-0.25	66.0	93.4	61.644
	0.25-0.5	14.7	94.9	13.9503
	0.5-1	0.4	79.5	0.159
	>1	0.2	93	0.0372
			93.7	**93.4246**
* Code in DAFW (2009)Bulletin				

21 Appendix 3 A selection of GSWA maps

Most relevant GSWA (2015) maps



Limestone Resources South Coast GSWA (2015)

GSWA Record 2015/7 Limesand and limestone resources of southern Western Australia

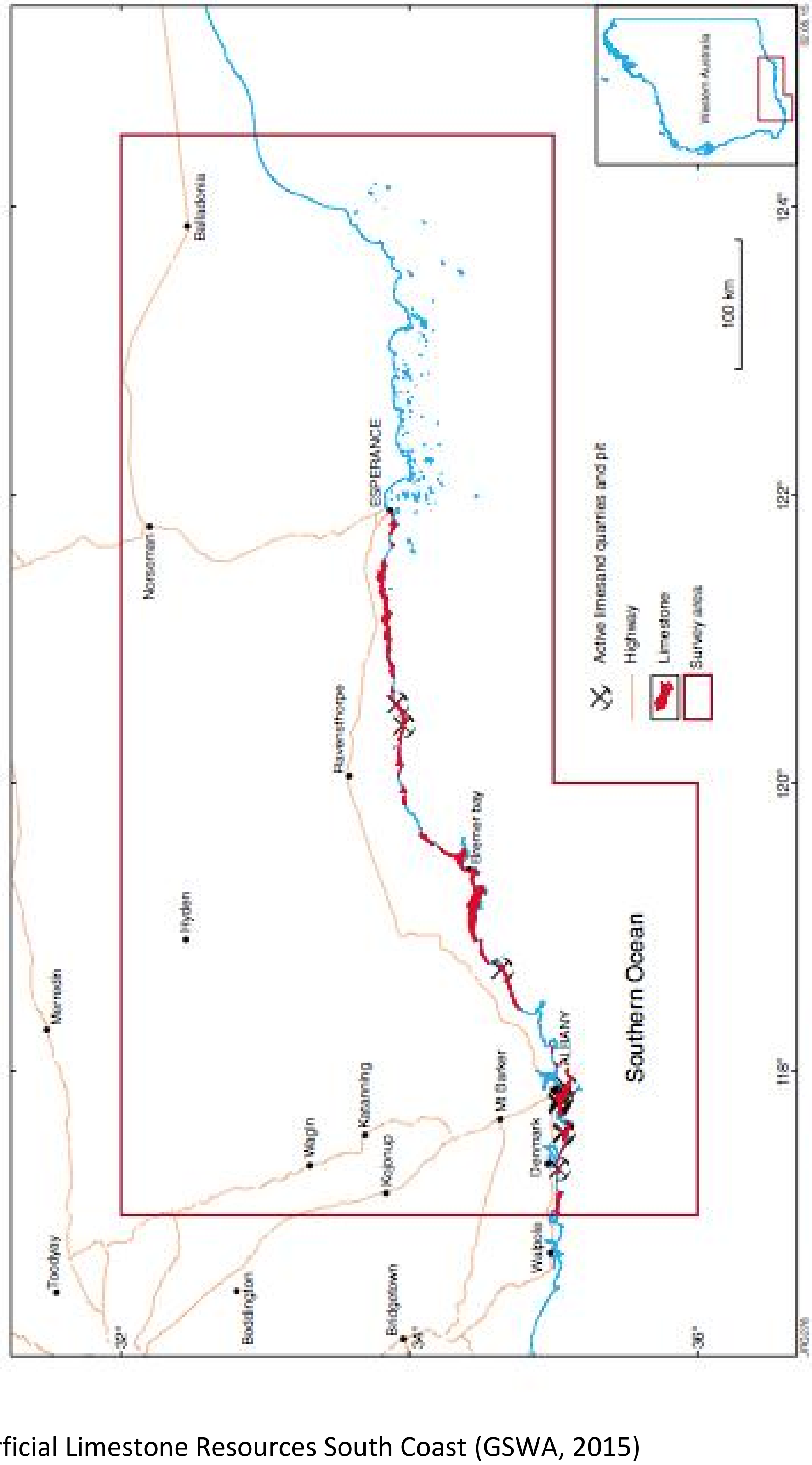
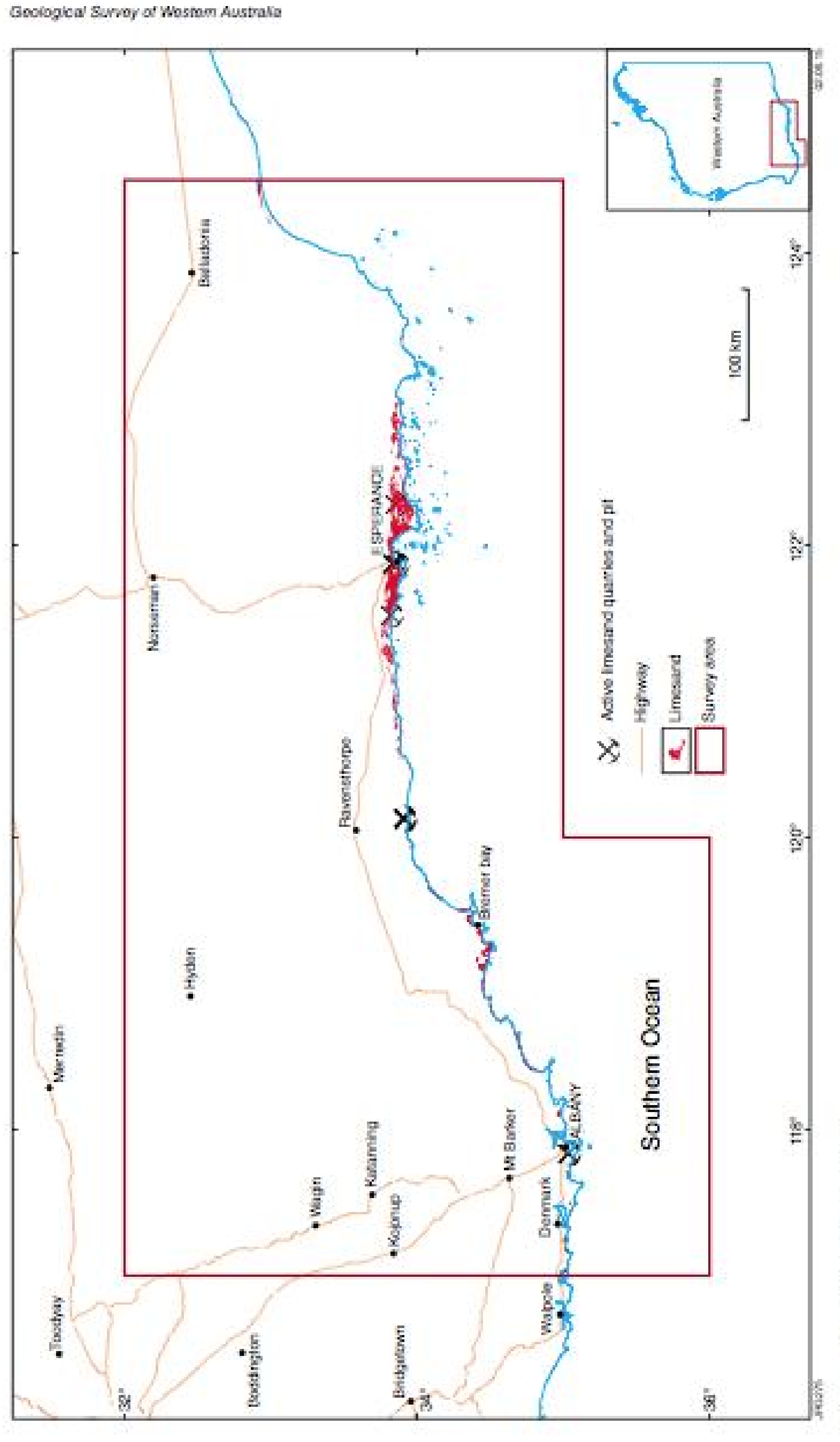
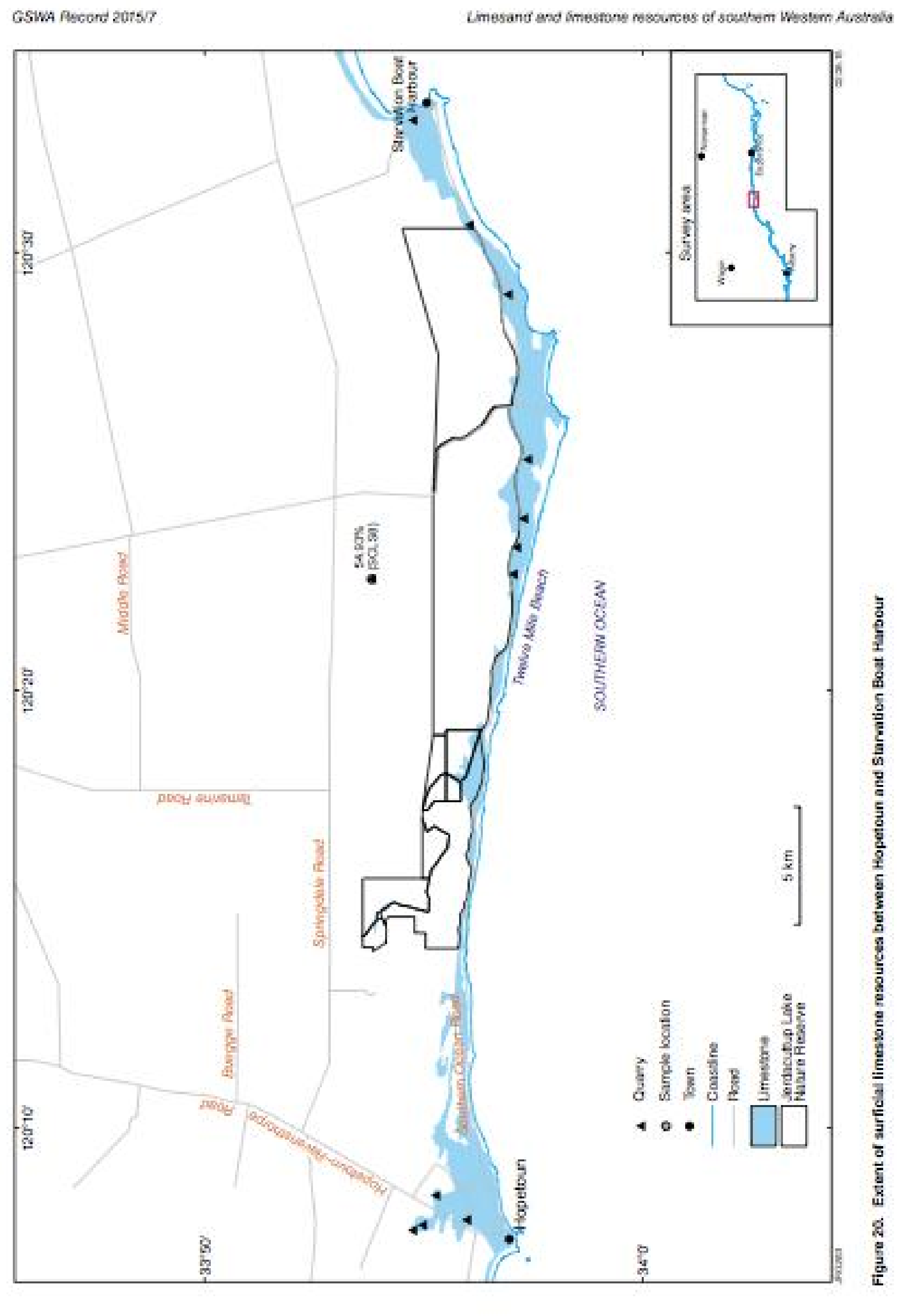


Figure 15. Extent of surficial limestone resources

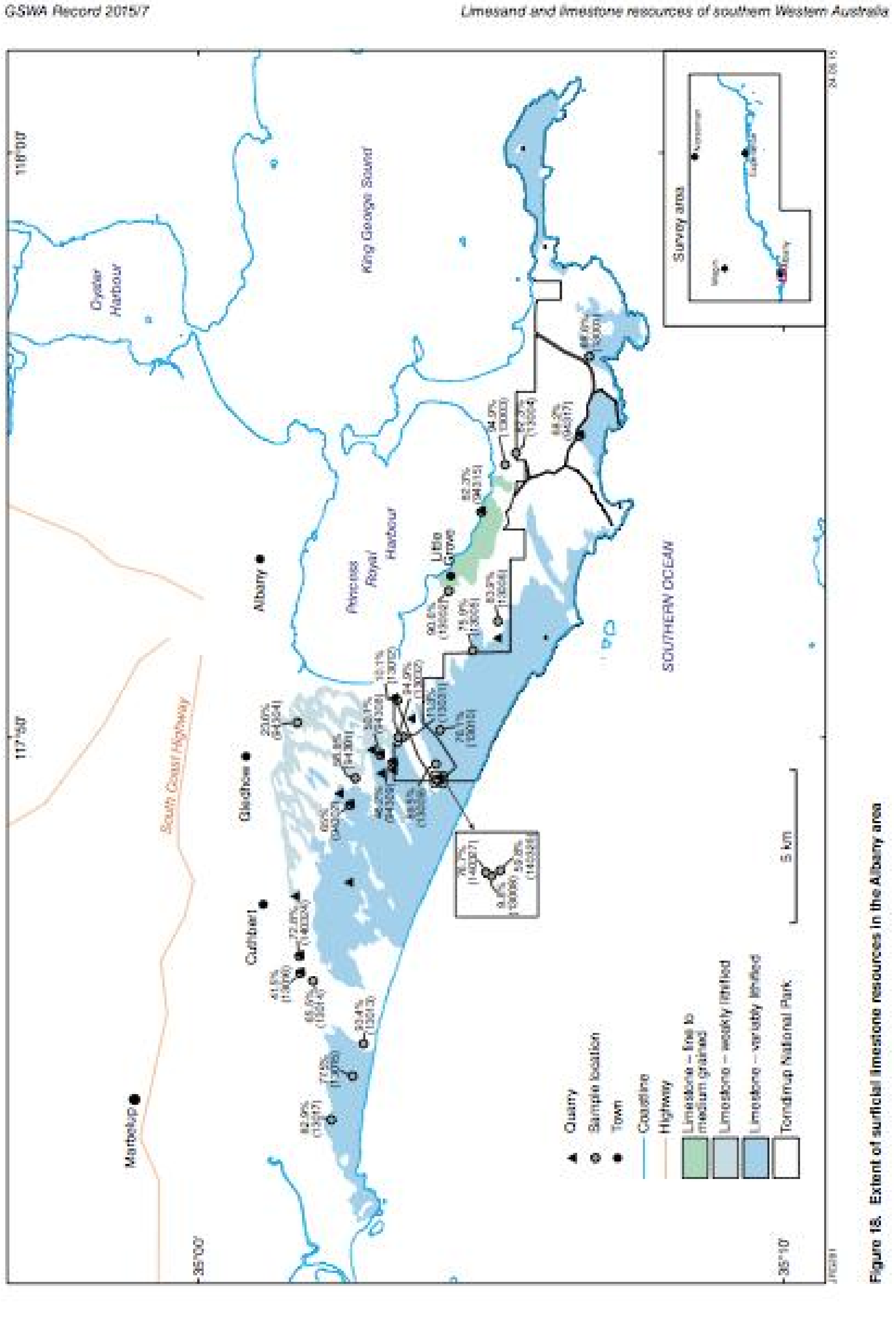
Surficial Limestone Resources South Coast (GSWA, 2015)



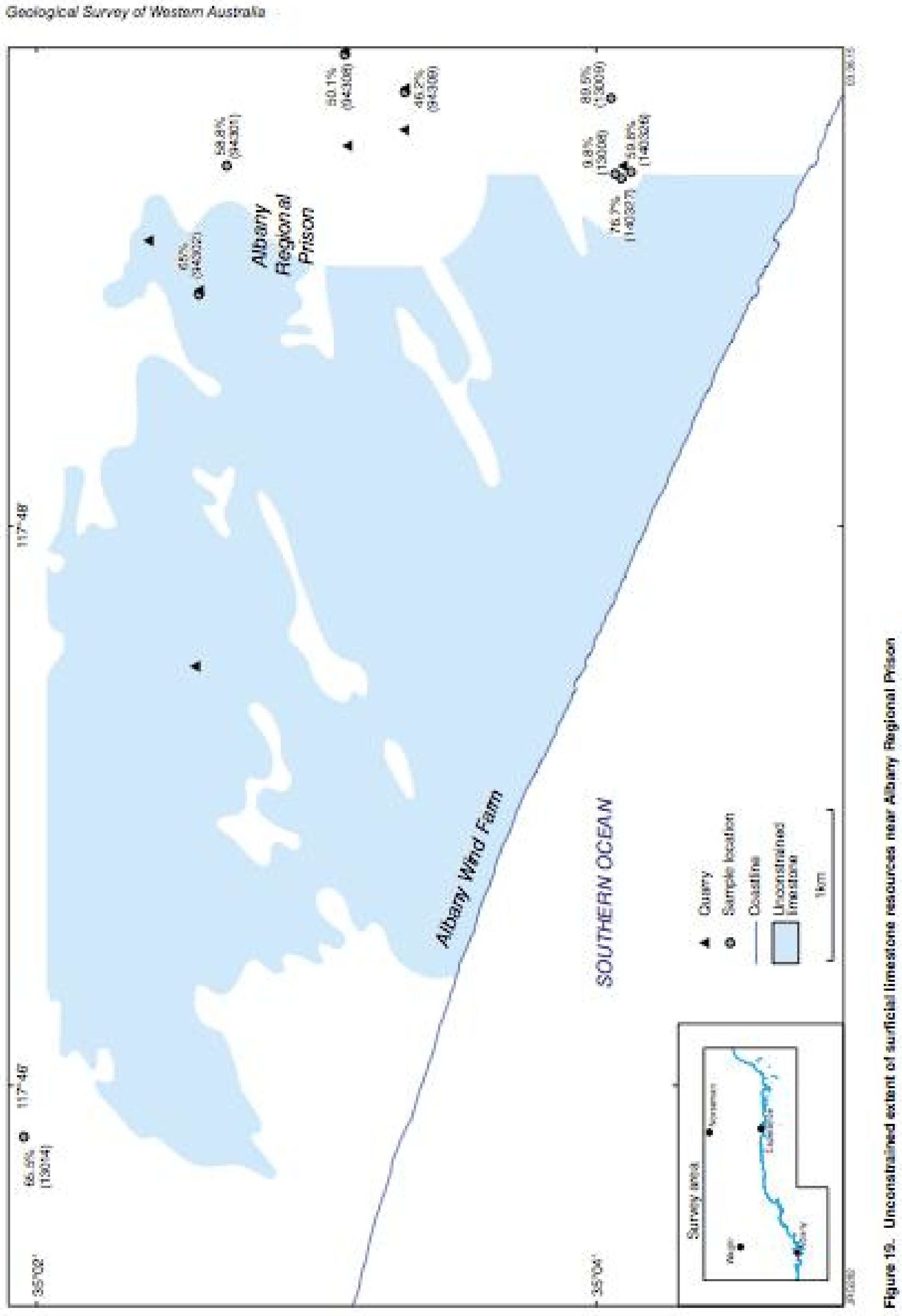
Limesand Resouces South Coast (GSWA, 2015)



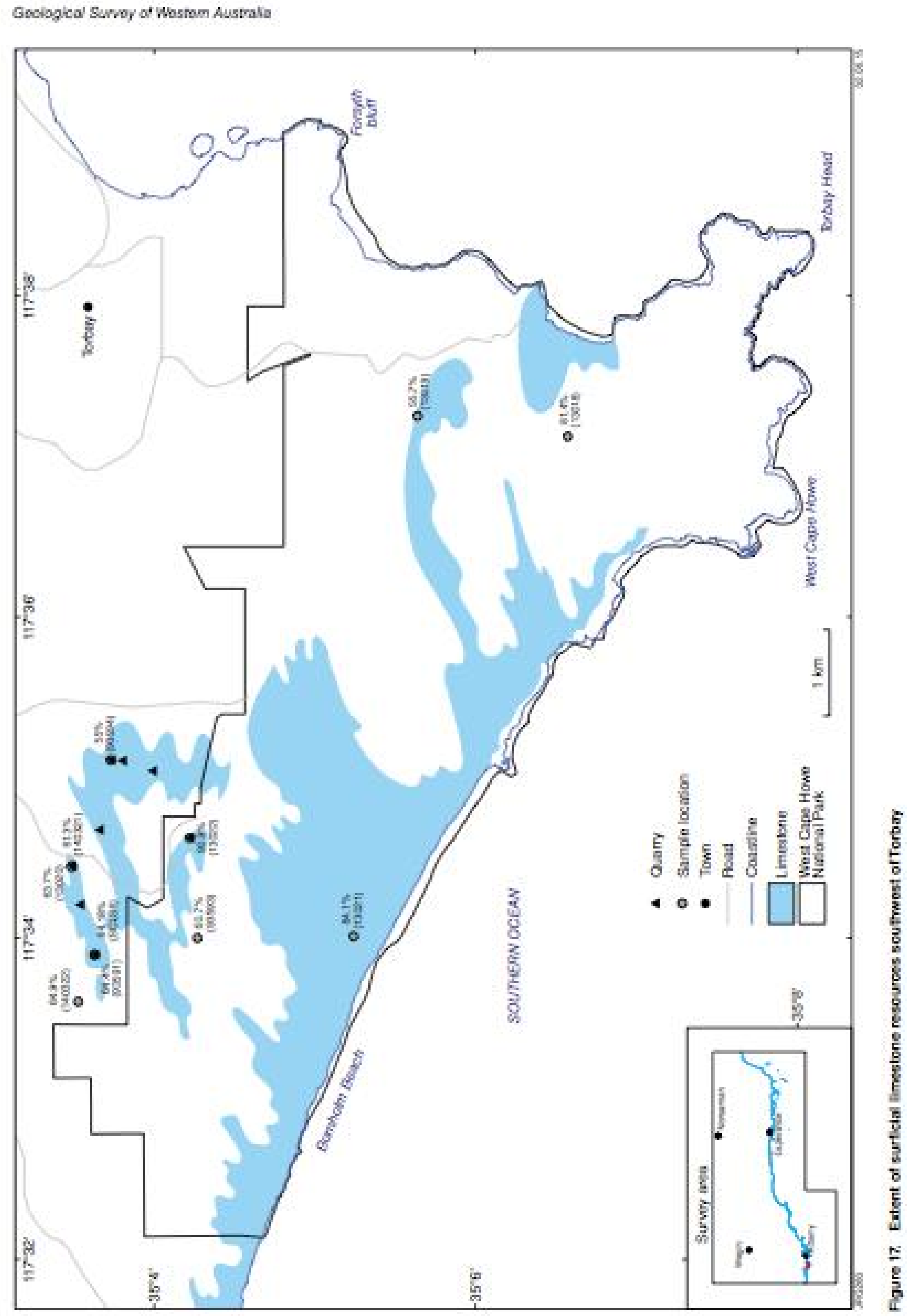
Surficial Limestone Hopetoun to Esperance GSWA (2015)



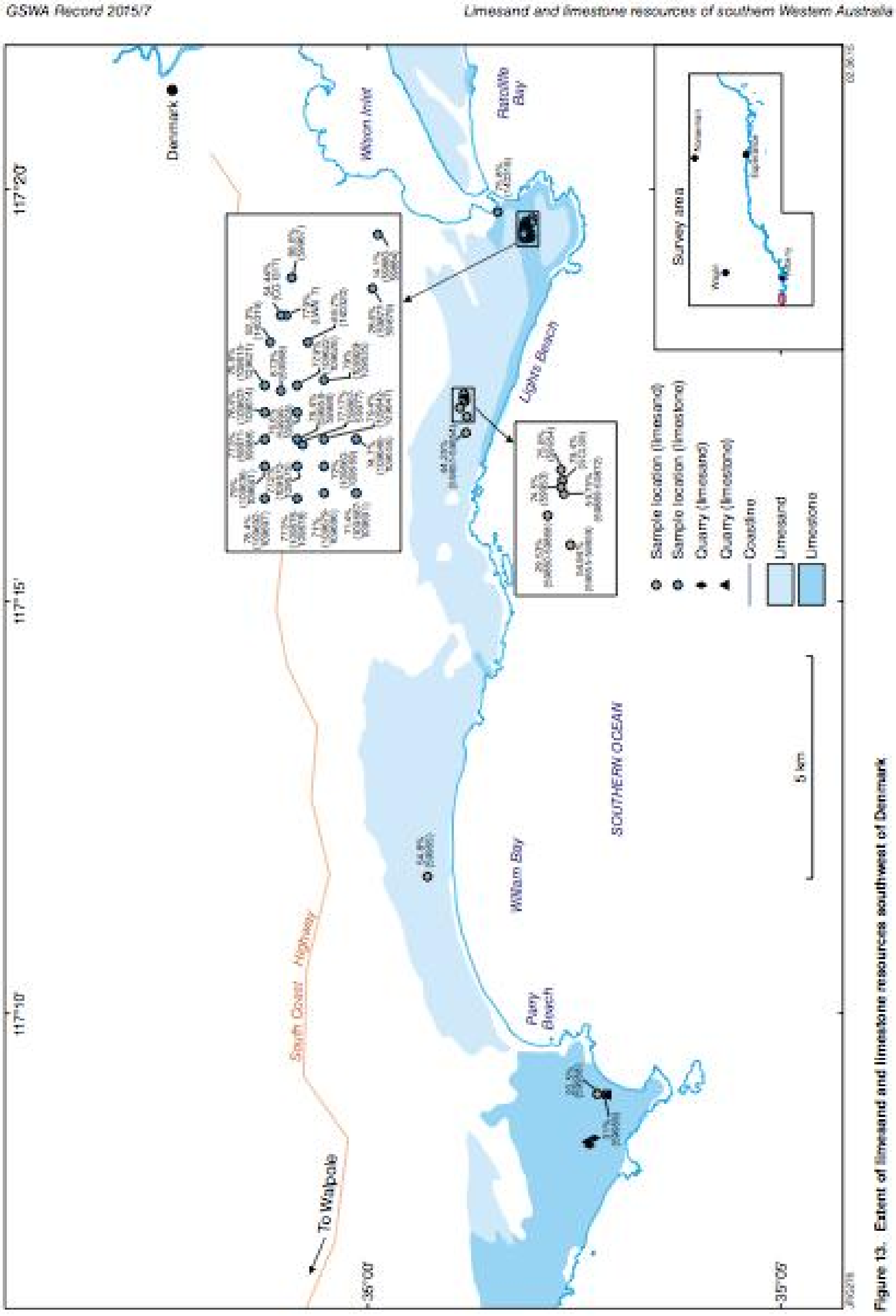
Surficial Limestone Albany area (GSWA, 2015)



Surficial Limestone near Albany Regional Prison (GSWA, 2015)



Surficial limestone near Torbay (GSWA, 2015)



Limesand and Limestone SW of Denmark (GSWA, 2015)

Geological Survey of Western Australia

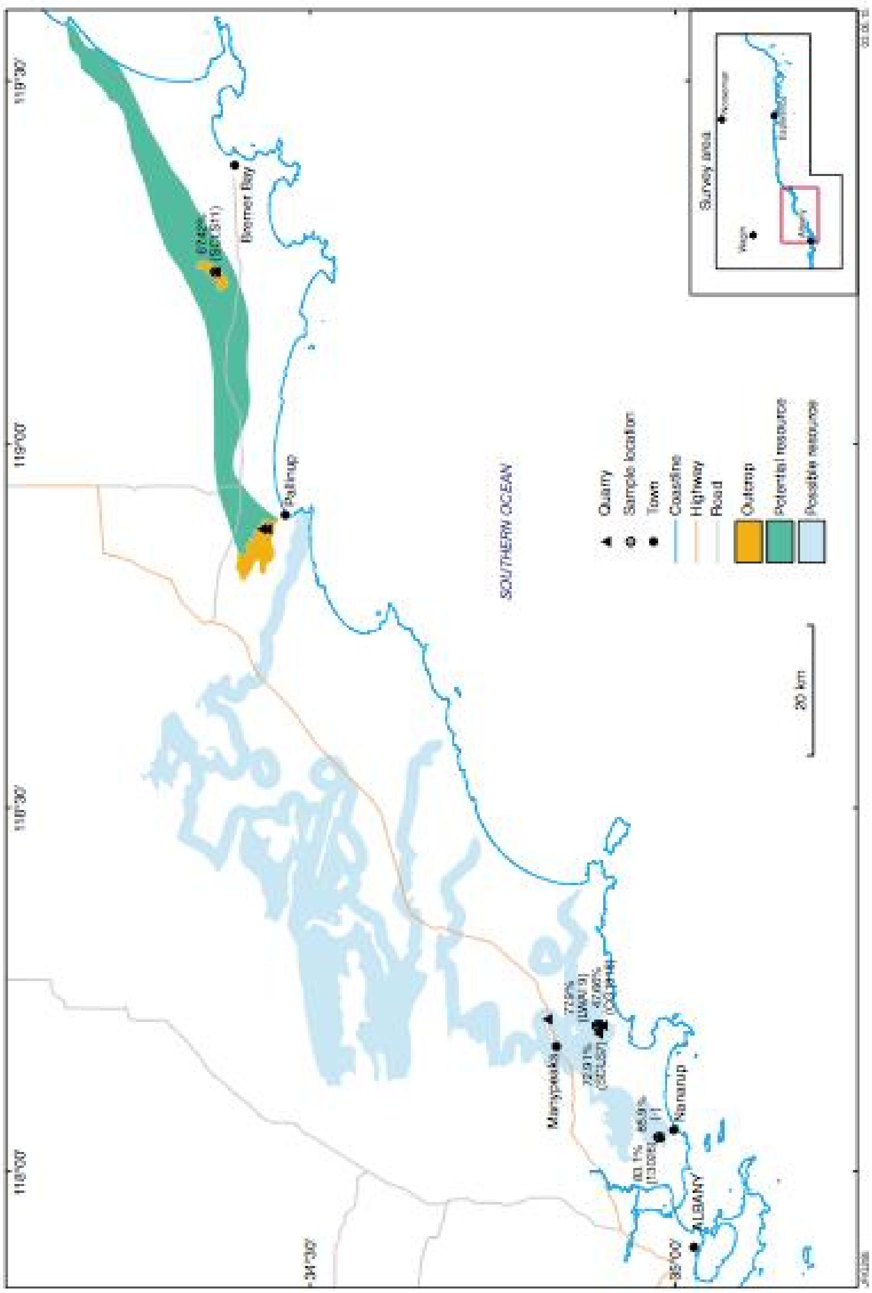
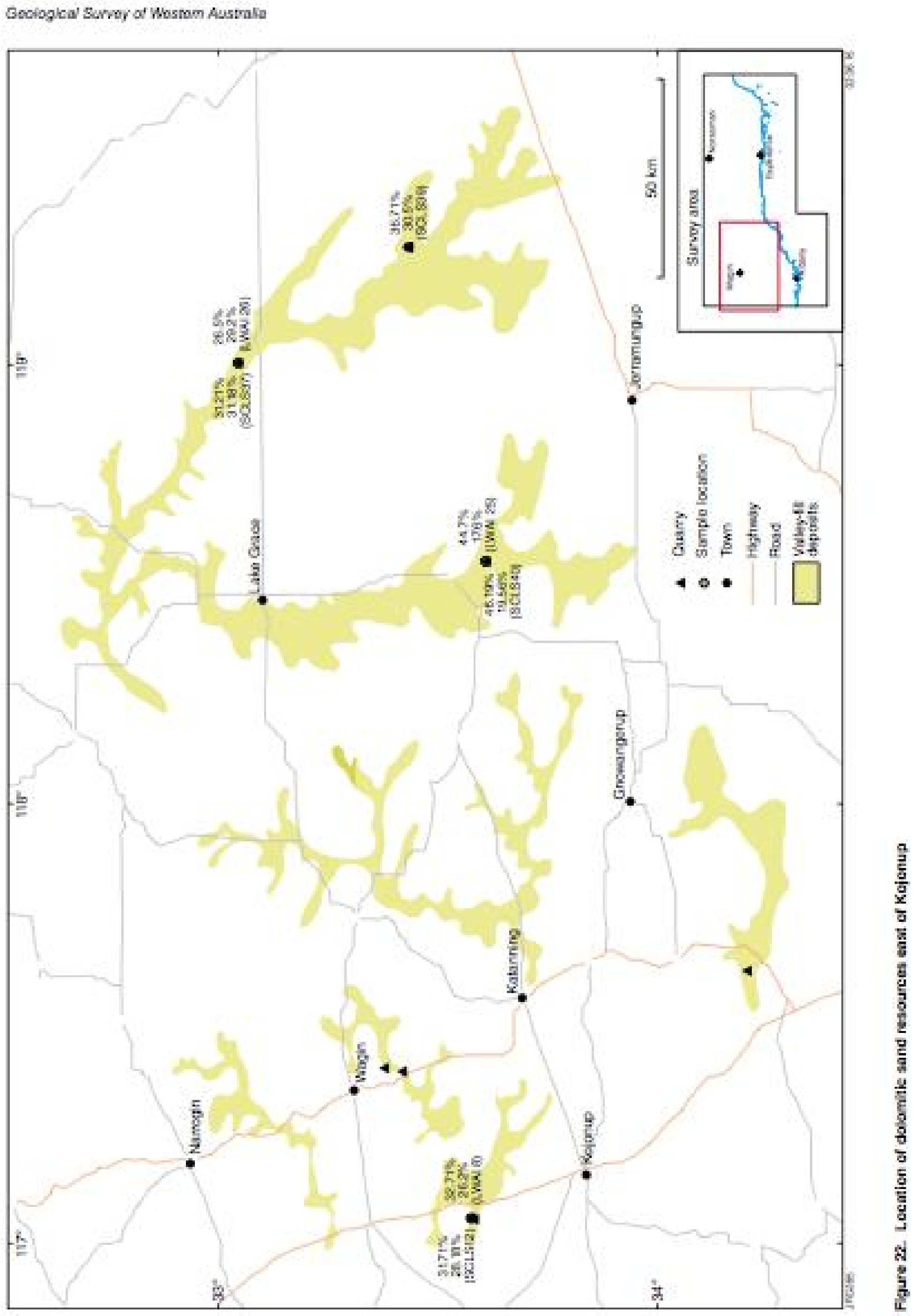


Figure 32. Pale brown limestone resources between Albany and Bremer Bay

Pale Brown Limestone in the Werrilup Formation (Nanarup Limestone Member) (GSWA, 2015)



Dolomite, Southern WA (GSWA, 2015)