"Investigations of environmental regeneration at the Penrith Lakes Scheme, Sydney, Australia"

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Acronyms

AGB	Above Ground Biomass
AGO	Australian Greenhouse Office
BGB	Below Ground Biomass
CBD	Central Business District
CCE	Chicago Climate Exchange
CPRS	Carbon Pollution Reduction Scheme
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DBH	Diameter at Breast Height
EEX	European Emission Exchange
ETS	Emissions Trading Scheme
EU	European Union
EUA	EU Allowances
EU Carbix	European Carbon Index
GBH	Girt at Breast Height
GGAS	Greenhouse Gas Abatement Scheme
GIS	Geographic Information System
GPS	Global Positioning System
GPRS	Greenhouse Pollution Reduction Scheme
HNR	Hawkesbury Nepean River
IPCC	Intergovernmental Panel on Climate Change
LGA	Local Government Area
NHBMP	Natural Heritage and Biodiversity Master Plan
NPK	National Park
NPWS	National Parks and Wildlife Service
NSW	New South Wales
OECD	Organisation for Economic Co-operation and Development
PCC	Penrith City Council
PGP	Permanent Growth Plots
PIA	Planning Institute Australia
PLS	Penrith Lakes Scheme
PLDC	Penrith Lakes Development Corporation
SEE	Species Specific Equations
SREP	Sydney Regional Environmental Plan
SoE	State of the Environment
UNSW	University of New South Wales
UWS	University of Western Sydney

Acknowledgements

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All the above mentioned people and organisations as well as not closer mentioned contributors, have made my time in Australia an unforgettable and highly successful trip of a lifetime. Twenty months ago I could never have imagined writing about a thesis in English and in Australia.

Certification of Authenticity

This document has been produced by a student of the University of Applied Sciences Neubrandenburg, Germany to satisfy the learning requirements of a Diplom Ingenieur (FH) in Landscape Architecture and Environmental Planning. Except where specifically referenced all work in this Diplomarbeit is the original work of the author.

Peter Struck.

AIM

Permanent growth plots were established in the area known as the Penrith Lakes Scheme between 31^{st} of March and the 5^{th} of May 2009. The main objective was to determine the above and below ground biomass currently present in tree plantation in this area and initially assess its potential future value in emission trading.

Abstract

Scientific research has outlined the significant negative impacts of greenhouse gas emissions on the earth's climate and their possible mitigation through forest management and reforestation projects. Established Emission Trading Schemes (ETS) indicate the possibilities for financing such projects, while at the same time mitigating the release of greenhouse gas emissions.

For the Penrith Lakes Scheme (PLS), as a major ecological rehabilitation project in Western Sydney, Australia, these possibilities have been explored during this project undertaken to fullfil the requirements of a Diplom Ingenieur (FH) degree at the University of Applied Science Neubrandenburg in Germany.

On the 1935 ha PLS site, some 490 trees in 8 representative areas were measured during field investigations. Allometric equations developed by the Australian Greenhouse Office and other scientists, were used to calculate above ground and below ground biomass and subsequently stored carbon dioxide.

The study revealed high differences in total biomass stored per hectare due to varying stand ages, historic land use patterns and applied management strategies. Furthermore it revealed that financial benefits under current market conditions and political uncertainties remain marginal.

However the registration of only small areas might be valuable to gain experience while markets still evolving. The study supports the development of markets that will allow carbon banking or carbon renting as a more appropriate tool for forestry and rehabilitation projects to reduce the substantial risks on future carbon pool at the PLS that where identified during this work.

Recommendations are made on further studies that will help clarify the market potential and risks involved.

Keywords: Penrith Lakes Scheme, Rehabilitation, Climate Change, Emission Trading Schemes

1 Introduction

1.1 Industrial Revolution and its impacts

Economic and technological changes of the last 250 years have lead to a globally connected world with high speed communication systems, mass transportations and global markets.

Such achievements are the results of a process that started in the middle of the 18th century and is known today as the industrial revolution. It was marked by a change of industries, production patterns and societies. The invention of steam engine and the use of coal as a primary energy source, assisting and partly replacing human work force elevated efficiency and productivity. Simultaneously changes in society were leading to freedom of trade and constitutional legality, enshrining property rights and enhancing wealth. The conflict between bourgeoisie and nobility was a defining element of this time.

With the end of the 19th century, the substitution of coal by oil and subsequently nuclear power in the middle of the 20th century, marked a new phase of industrial achievements that is often referred as the second industrial revolution (Jänicke & Jacob, 2008, Mensch, 1975, Wallerstein, 1983 and Greenwood, 1999). Inventions like electricity, new chemical processes, synthetics and combustion engines further defined this period leading to mass production, mass societies and mass mobility.

The high demand for energy together with low resource prices, and an ever accelerating use of fossil fuels provided the basis of this growth (Jänicke & Jacob, 2008).

The last third of the 20th century and the beginning of the new millennium marked the beginning of a new era of thinking within industrialised societies driven by a growing awareness of resource use and limitations.

The first concerns about accelerating industrialization, rapid population growth, widespread malnutrition, depletion of non renewable resources and a deteriorating environment were expressed by the Club of Rome as early as 1972 with their publication on 'The Limits of Growth'.

Since then, the still growing demand for energy, rising resource prices (as seen in 2008) and environmental problems including rising CO_2 levels and global climate all have indicated that such resource intensive growth cannot be maintained.

Notwithstanding this, some traditional industries (e.g. nuclear power) are indicating their ability to solve these problems. However such an approach is highly risky, and may only postpone the problems. A change in industries and innovations are needed to solve this crisis and a new deal is proposed by a growing number of scientists and statesmen (Jänicke & Jacob, 2008).

A statement made by EU Commission President Barosso during a speech on the 1. October 2007 expressed this so called "new deal":

"*I believe we are now standing on the brink of a Third Industrial Revolution: the Low Carbon Age […] Like the previous industrial revolutions, this will be driven by technology and new forms of energy. It will also transform our societies."*

Unlike former industrial revolutions global governance today offers a great chance to control these society transformations and to create a change on broad society bases and throughout all layers of the global system.

Today's changes in legislation that supports renewable energy enhance environmental and social awareness and regulations to cap pollution are first steps in a change of the political system. But it is also evident that the degree of challenges and the resistance of traditional industries (as evidenced by lobbying) are limiting the effectiveness of political instruments. Actions are therefore often limited to Win-Win situations. As such international, federal and state governments remain key players as it is their duty to sustain long term interests of their citizens. They have the ability through legislation to enforce changes and ensure long term public interests are met by internalising external environmental and social costs (Jänicke & Jacob, 2008).

A review of the last 200 years shows that the rise and fall of nations and world regions has been was highly dependent on the movement of innovative changes into new markets.
An example of such a movement is given by Garnaut et al. (2008) who indicates that the middle of the 20th century (often referred as the Golden Age) has seen an immense growth in countries in Western Europe, North America, Oceania and Japan. With the beginning of the 21st century this growth, supported by changes in regimes and personal freedom had started to spread into population rich countries in South, South East Asia and Central Asia.

Australia as a resource rich country was, is and will remain a major beneficiary of these developments. Consequently Garnaut et al. (2008), p. xxi states that

"For Australia, the commitment to the mitigation of climate change can be seen as the reinvestment of a part of the immense gains that have come from accelerating Asian economic growth, in contributing to reduction of an adverse side effect of that growth".

Australia has therefore the chance to take a similar leadership role in environmental friendly and low carbon economics in the South East Asia region as the EU in Europe. Furthermore the development and adoption of innovative technologies will ensure a long term economic viability of Australia.

1.1.1 Global Climate Change

The development of today's atmosphere composition began around 3.5 billion years ago when algae-like organisms began to convert carbon dioxide from the air into carbohydrates through the use of sunlight and with oxygen as a by product.
Today the lower atmosphere (troposphere) comprises 21% oxygen and 78% nitrogen. All the major greenhouse gases make up less the 0.1% of the atmosphere. Despite these small volumes of greenhouse gases, their impact on the earth's climate is significant. Garnaut et al. (2008) stated that:

"Their presence means that the earth has an average global surface temperature of about 14 degrees Celsius – about 33 degrees Celsius warmer than if there were no greenhouse gases at all."

Fluctuations in CO_2 concentrations in the last 2.5 million years have been in a range of 180 to 280 parts per million (ppm) (Garnaut et al., 2008). Today's concentrations of CO_2 exceed the natural range by 25%, methane by 120% and nitrous oxide by 9% (IPCC 2007a).

A stylised model of the natural greenhouse effect on earth has been adapted from Garnaut et al. 2008, p 28 and is presented in Figure 1.

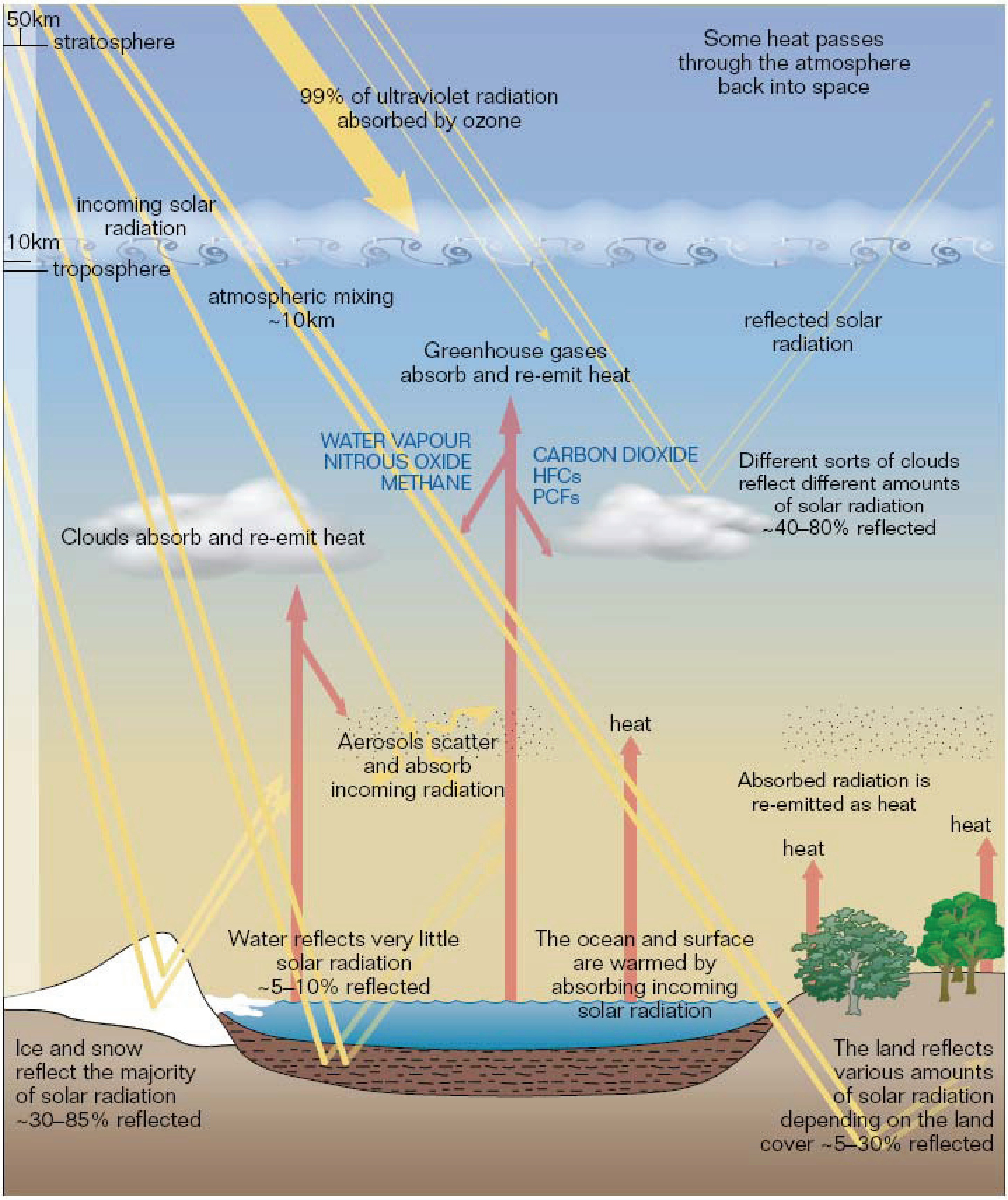


Figure 1: stylised model of the natural greenhouse effect and other influences on the energy balance of the climate system

The majority opinion of the international scientific community towards human induced climate change is that it is happening and that it will intensify as greenhouse gas emissions increase and that this could impose large cost on human civilisation (Garnaut et al., 2008).

For CO_2 levels, where this project mainly concentrates, it is evident that the industrial revolution some 250 years ago marked the starting point for this accelerating rise.

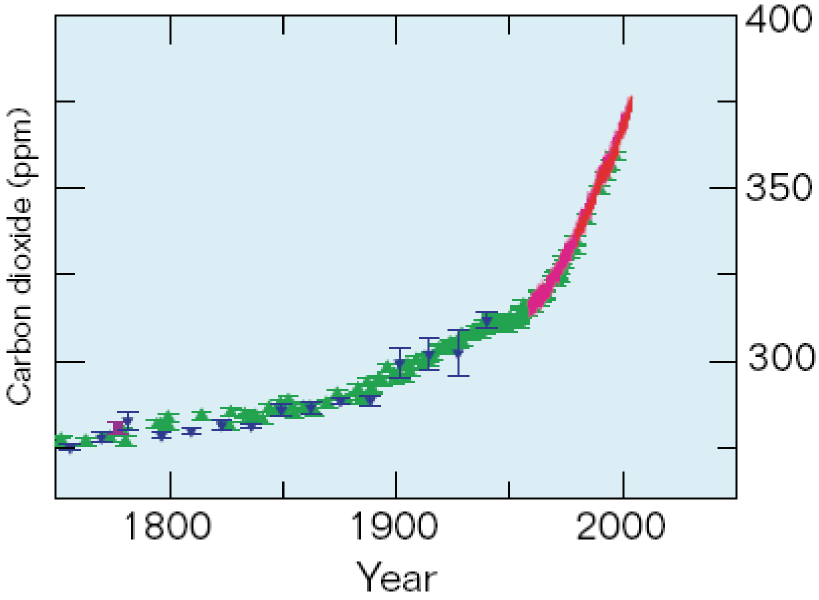


Figure 2: Trend in atmospheric concentrations of carbon dioxide adapt from Garnaut et al.2008 p.26)

Today's CO_2 level at 383ppm (2007) well exceeds the historical ranges that lay between 180 and 280 ppm (Steffent et al., 2004 and Garnaut et al., 2008)

Even if fluctuations in temperatures and atmosphere composition are occurring normally, today's warming rate and rising CO_2 levels are unusual and the global average net effect of human activities since 1750 has been warming (IPCC, 2007a, p.3).

1.1.2 Loss of Biodiversity

As the world enters the 21st century more and more people choose to live in urban cities (Planning Institute Australia Report, 2003). This urbanisation has lead to an expansion of cities beyond their historical range resulting in the loss of habitats, fragmentation of the landscape and finally the loss of biodiversity. Newman et al. (2001) has identified that over 40% of nationally listed threatened ecological communities in Australia occurred on the fringe of cities.

The Sydney area and especially the Western Suburbs of Sydney are no exception to this. Since early settlement at the beginning of the 19th century the area in the west of the Sydney Basin, known as the Cumberland Plain, has experienced major clearing and loss of habitats. The floodplain of the Hawkesbury-Nepean River System has been used to support the needs of Sydney (Bridgman et al., 1995). These needs have shifted from the supply of agricultural goods in earlier days, to the current growing demand for residential areas.

In addition to this current growth, another 45,000 people need to be accommodated in the Penrith Local Government Area alone. Other major development proposals including the South West and North West Growth Sectors of Sydney also need to be taken into consideration, as they will increase the pressure on threatened ecosystems and biodiversity. Beeton et al. (2006) have identified this problem and state in the Australian State of Environmental Report 2006 that;

"Of continuing concern for Australia's immediate future is continued population growth along the coastline. The formation of mega-metropolitan centers with increasing population density on Australia's coasts has the potential to displace much valuable biodiversity and 'high-value' agricultural land."

2 Emission Trading and BioBanking – supportive elements of rehabilitation

Australia is recognising its responsibilities to protect, rehabilitate and restore its unique ecosystems (from which human society's goods and services are drawn) for current and future generations and to act against global climate change. Recent research has been focused on topics including the loss of biodiversity, nature degradation and climate change. The Australian Government and the New South Wales State Government, in particular, have signed international agreements including the Kyoto Protocol and introduced new legislation such as the Threatened Species Conservation Act in 2003 and the Native Vegetation Act in 2006. Furthermore the proposed national Greenhouse Pollution Reduction Scheme (GPRS) as well as the Biodiversity Banking (BioBanking) Scheme in NSW will both act to broaden this approach and strengthen the position of nature conservation and sustainability.

2.1 Emission Trading

2.1.1 Global Emission Trading Schemes (ETS) and the EU - ETS

The trading of carbon dioxide emissions as a mitigation tool for global climate change is a reasonable new approach. It first gained global attention with the agreement reached at the conference of parties in Kyoto in 1997. This agreement is known today as the Kyoto protocol. Up to this point attention was minor and Russel et al. (2006) stated that:

"… during the earth summit in 1992 emissions trading was presented as a side show in a tent … while concerns over climate change were limited."

Today as the knowledge bases on the greenhouse effect, carbon emissions and global climate change are broadening, the perspectives are changing. With human induced climate change now widely accepted and scientifically proven, concerns about its impacts are growing and so is the interest in appropriate adaptation and mitigation tools.

The establishment of a so called Emissions Trading Schemes (ETS) has been undertaken by many member states of the OECD to meet their emission targets agreed under the Kyoto protocol. The majority of these countries, mentioned in

Annex I, are intending to use ETSs to meet their agreed emission targets. This flexible mechanism allows countries to trade emission allowances between each other in order to meet their goal of capturing or reducing their GHG emissions (Klaasen et al., 2002).

Today's modern ETSs are based on the model of the United States chemistry industry which reduced its sulfur dioxide (SO_2) with the help of specifically designed ETS in the 1970s.

With the exception of the European Union ETS(EU ETS) emission trading has only been established on a national level. These national ETS's are driven by the domestic political economy and differ in monitoring, reporting and verification designs making it difficult to establish a global carbon trade market and to compare prices. However, as markets are still developing different approaches present different opportunities to build knowledge and experience (Egenhofer, 2007).

As shown in Table 1 the global carbon markets have more then doubled from US$31 billion in 2006 to US$64 billion in 2007. The EU ETS launched in 2005 is with 69% of the total volume and 78% of the value of trades is the dominant market.

Table 1: Carbon market size and value adapt from J. Peace & T. Juliani/ Policy and Society 27 (2009)

	2006		2007	
	Volume ($MtCO_2e$)	Value (US$ million)	Volume ($MtCO_2e$)	Value (US$ million)
Voluntary markets				
Voluntary OTC	14.3	58.5	42.1	258.4
Chicago climate exchange	10.3	38.3	22.9	72.4
Subtotal	24.6	96.7	65	330.8
Regulated markets				
EU ETS (phase I)	1,044	24,436	2,061	50,097
New South Wales (Australia)	20	225	25	224
Primary CDM	537	5,804	551	7,426
Secondary CDM	25	445	240	5,451
JI	16	141	41	499
Subtotal	1,642	31,051	2,918	63,697
Total	1,667	31,148	2,983	64,028

Source: EMNCF (2008). Totals are rounded numbers.

As the first cross-border ETS, it has adopted the literature preferred cap and trade model for both, efficiency and effectiveness reasons. It is also split into three periods providing research and learning opportunities. The base level for emission targets are provided by the emission levels from 1990.

During the first period (from 2005 to 2007) the cap was placed at a 95% emissions level with fines for exceeding these level put at 40 Euros per tonne CO_2 equivalent (CO_2 –e). The current second phase (running from 2008 to 2012) has increased fines to 100 Euros and emissions are a capped at a 90% level.

The allowances allocated by the member states, a procedure necessary to get member states and industry support for the scheme, caused major delays during phase one but were improved in the second phase. In addition teething problems were experienced from the high volatility and the guidance of trading by expectations rather then reliable information (Egenhofer, 2007).

The high volatility lead to a peak in carbon prices of 30 € in April 2006, before it was reduced to a penny stock by the end of the trading period in December 2007 (Figure 3). This price development was explored by Jaehn et al. (2009) who found that no computer model was able to predict or forecast these price curves. The reason identified for this was the allowance for "grandfathering" energy producing companies. This allowed companies to raise their product prices in accordance with the price allowances, profiting from the ETS at the expense of smaller emitters and electricity consumers. Therefore the strategic behaviour of some market players acted to harm other participants.

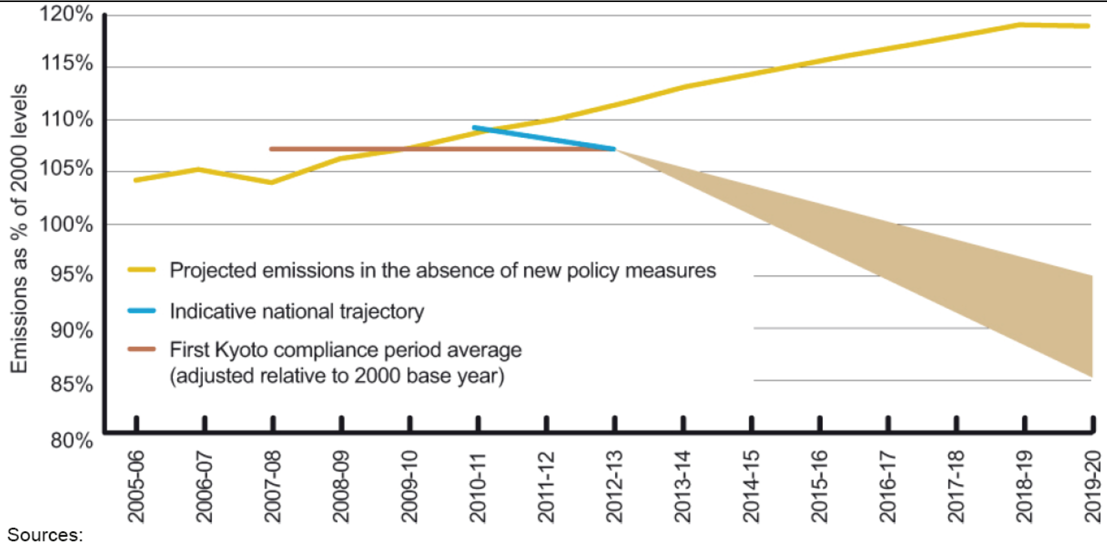
Figure 3: Prize development EU ETS 2005 to date (source www.eex.com)

Spot trading of EU Allowances (EUA) for the second trading period started on 16 January 2009 and todate the Carbix (Carbon Index) prize has ranged between 10.55 Euro/EUA and 15.10 Euro/EUA as shown in Figure 3 (EEX Press Release 0001A, 02. Feb. 2009).

2.1.2 Australia and the proposed Greenhouse Pollution Reduction Scheme (GPRS)

Australia as a member state of the OECD is committed to restrain its emissions to an average of 108% of the 1990 levels across the period 2008-2012. Future targets include the mid-term target of reducing Australia's emissions between 5 and 15% of the 2000 levels by 2020 (see Figure 4) and have a long term target of reducing emission by 60% below 2000 levels by 2050 (CPRS White Paper Version, 1 Dec. 2008).

The initiation of the Australian ETS was proposed to commence in 2009, but lobbying by industries and a negative vote by the Opposition in parliament deferred the start of the Scheme. Currently political discussions indicate a changed Scheme might start as early as 2010.
The GPRS will incorporate currently operating ETSs including the NSW GGAS introduced in 2003 and initial emission prices are expected to be around A$23/t CO_2-e.



Sources:
2005–06 data published in the National Greenhouse Gas inventory, relative to a 2000 base year.
2006–07 and 2007–08 data from Tables 4.1 and 4.2, relative to a 2000 base year.
All other data based on projections published in *Tracking to the Kyoto target*, relative to a 2000 base year.

Figure 4: CPRS White Paper Version 1 Dec. 2008, p. 4-23

2.1.3 The New South Wales Greenhouse Gas Abatement Scheme

Introduced in 2003 the NSW GGAS presented a market volume of 25 Million tonnes CO_2 Equivalent ($MtCO_2$-e) in 2007. It was the smallest existing regulated market but the first ETS that included forest and forestry projects (Peace and Juliani, 2009).

Major Participants under the NSW GGAS are electricity retailers and certain other parties. The 2003 per capita emissions of 8.65 tonnes CO_2-e have been established as a bench mark. The goal was to reduce emissions on a 7.27 per capita level by 2007 and to stabilise emissions on this level for the following years (Figure 5). The 2007 goal represents a level that is 5% below the 1990 bench mark outline in the Kyoto protocol.

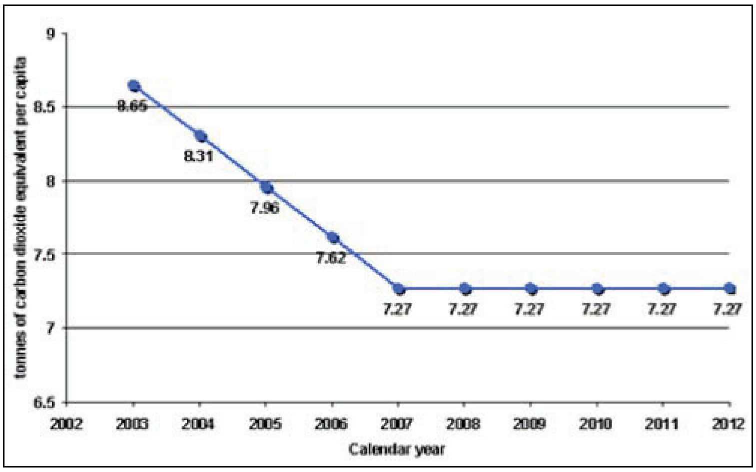
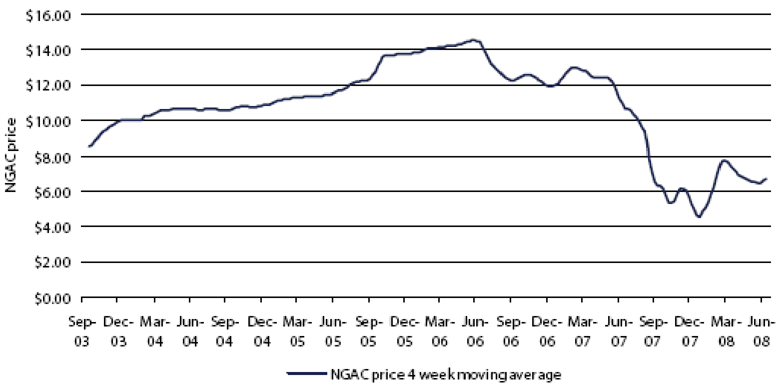


Figure 5: Emission targets NSW GGAS

Penalties for exceeding the pollution allowances are set at $12 AUD per tonne CO_2-e with current prices alternate between $6 and $8 AUD (Figure 6).



Note: This figure shows a 4-week rolling average of the last market spot price. This data accounts only for NGACs traded through NGES and may not reflect the price paid by NGAC buyers at the times shown. The Scheme Administrator recommends that persons seek independent advice before buying or selling NGACs; and cautions against making decisions based solely on this chart.

Data source: The Green Room, published by NGES (see www.nges.com.au)

Figure 6: Prize development NSW GGAS

The Scheme provides the opportunity for some large electricity consumers and persons carrying out projects that are designated as being of State significant to be elected as benchmark participants.

In addition forest owners can apply to be a certified provider if the following requirements (as outlined in the GGAS regulations) are met (http://www.greenhousegas.nsw.gov.au/documents/FS-CS-Certs-01.pdf).

The forest owner must:

- own or control the Carbon Sequestration Rights registered on the title to the land on which the eligible forest is planted
- be able to demonstrate that the carbon sequestration achieved by the forest project will be maintained for 100 years
- have appropriate procedures in place to manage risks such as fire, disease or climate variability, and
- maintain adequate records.

If the forest owner is eligible to enter the ETS then further land and forest requirement must be met.

Land must be consistent with Article 3.3 of the Kyoto Protocol which outlines the following criteria:

- was cleared at some time prior to 1 Jan 1990
- was planted on or after that date, and
- can have Carbon Sequestration Rights registered over its title.

The characteristics of forests under the NSW ETS are the following:

- to be a minimum of 0.2 hectares
- to have at least 20% crown cover at maturity, and
- to consist of trees with the potential to reach a height of 2 metres at maturity.

If the above outlined requirements of the land owner, land and forest are met then credits can be generated and sold on the market. However the following limitation on credits and carbon sequestration applies:

- carbon sequestration has taken place after 31 December 2002, and
- credits have not been used or traded for any other purpose.

2.1.4 The future of Emissions Trading

There are long term possibilities to establish a global carbon trade market by linking different regional and national ETS. Therefore various ETSs worldwide can provide experience and expertise but a final indication of possible prices to estimate a value for carbon captured in biomass remains difficult. Furthermore, political obstacles can be expected while linking two ETS as it will present winners (low price ETS) and losers (high price ETS) when prices are combined in one market (Egenhofer, 2007). However these challenges have to be subjected to further discussions and negotiations for post Kyoto agreements. The acceptance of the 2 degrees Celsius target by the G8 and emerging countries including India and China at the G8 summit in July 2009 was a significant step towards this long term goal. Further discussions during the Copenhagen summit in December 2009 may act to clarify future steps and the actions to be undertaken.

2.2 The NSW Biodiversity Banking and Offset (BioBanking) Scheme

The degradation of native vegetation and loss of habitat is continuing to threaten Australia's biodiversity and presents the greatest challenge in conservation and protection of unique ecosystems, flora and fauna, for future generations.

The state of NSW is acknowledging these threats and its responsibility by establishing new legislation that will support conservation efforts and prevent further degradation of habitat especially through ongoing urban development. In December 2006 the NSW Government passed an amendment to the Threatened Species Conservation Act by inserting a new Part 7A (Eco Logical Australia, 2008).

This new legislation provides the opportunity to preserve and regenerate native Cumberland Plain vegetation from which only 12% of the former 260,000 hectares remain. This wide variety of habitat types and vegetation communities are under constant pressure from the needs of a growing population and new developments (NSW Department of Environment and Conservation, 2005).

The BioBanking Scheme is operating with two types of credits to be generated by landholders who commit to enhance and protect biodiversity on their lands. Credits can be generated for an endangered vegetation type or for a threatened species occurring on the site. These credits can then be sold to developers to offset their impacts on biodiversity or to those seeking to invest in conservation outcomes (www.environment.nsw.gov.au)

The rehabilitation process on the Penrith Lakes Scheme in likely to generate both vegetation type and species credits that will be in high demand by developers. The NSW Biodiversity Banking and Offset Scheme can therefore provide an appropriate tool to further support the remediation efforts on site.

3 The Penrith Lakes Scheme – a best practice example

Located in the Penrith Local Government Area 3 kilometres north of the Penrith City CBD and approximately 60 kilometres west of the Sydney CBD the PLS provides a best practice example for the remediation of a sand and gravel extraction site of its kind.

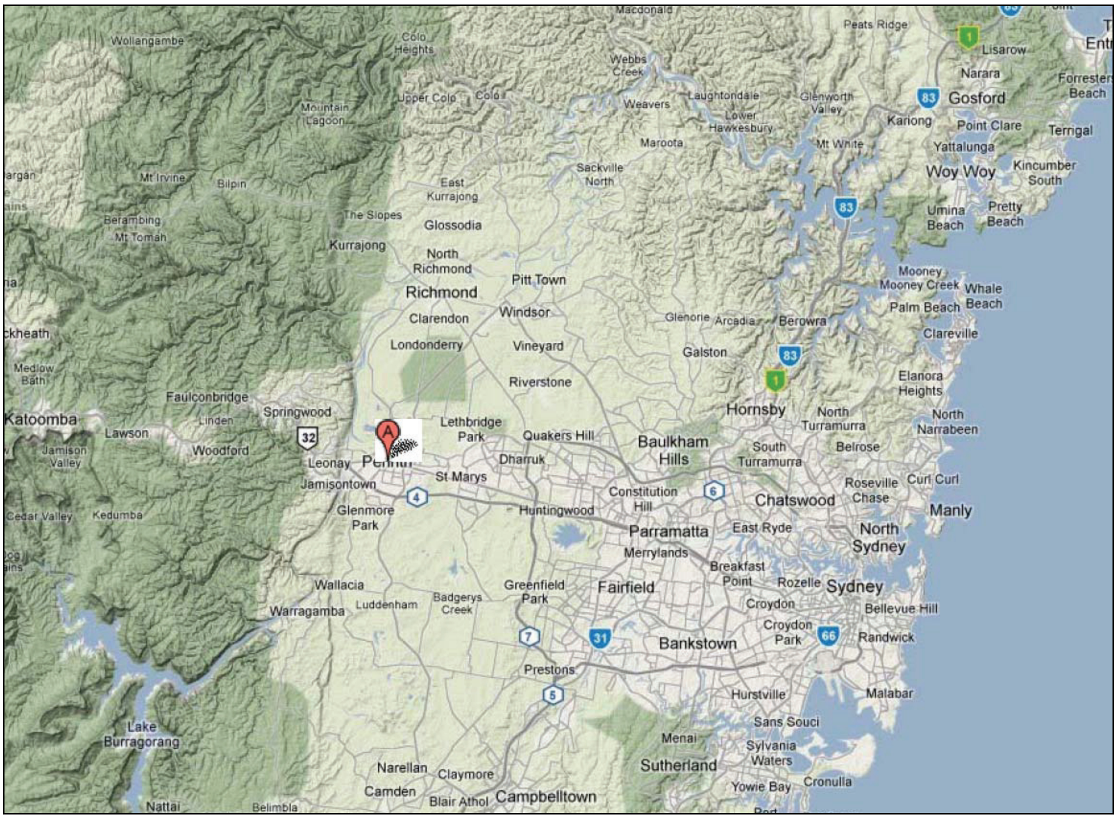


Figure 7: Overview map Sydney (source www.google.com)

The Penrith Lakes Scheme covers an area of 1935 ha and is located on the floodplain of the Nepean River. It reaches from the Cranebrook Escarpment north of Penrith to the Nepean River which run adjacent to the lower slopes of the Blue Mountains in the west.

Figure 8: The Penrith Lakes Scheme (source: Penrith Lakes Development Corporation)

3.1 Its History

Before the area today known as the PLS was altered by European settlement patterns, a rich flora and fauna would have been present on the floodplain of the Nepean River. Frequent flooding naturally changed the morphology of the river, its floodplain and lower terraces permanently.

As a result alluvial deposits provided fertile soils that supported a wide range of ecosystems and the area was occupied by a wide range of plant communities found on the Cumberland Plain. Cumberland Plain Woodland and Sydney Riverflat Forest would have been found on the generally richer soils on the floodplain. On higher grounds the poorer sandstone influenced soils would have been occupied by Shale Sandstone Transition Forests, with some remnants still remaining today. An abundant wildlife inhabited these ecosystems and reports by Trench from the early years of settlement, listed possums, platypus, fish freshwater mussels, lizards, quail, wild yams and edible tubers as primary food sources for Aboriginals who occupied the area (Clouston Associates, 2009, Mitchell, 2008, Comber, 2008 and Kohen, 1981).

3.1.5 Aboriginal and European Settlement History

(a) Aboriginal/ Indigenous Settlement

Before European settlement started during the early 19th century the area was inhabited by the Mulgoa clan of the Darug for more then 14,000 years. Their presence was first recorded by Watkin Trench in 1791 (Comber, 2008 and Kohen, 1981).

The area was regarded as a significant meeting place and an archaeological survey has revealed a high intensity of artefacts on the northern end of the Scheme.

Hunting techniques including regular low intensity burns to flush out small game are thought to have aided and improved plant regeneration and acted to maintain the open character of the floodplain (Clouston Associates, 2009).

(b) European Settlement

European settlement commenced officially in 1803 with the awarding of some of the earliest grants in the colony. The land muster of 1806/1807 provides evidence that the area of the PLS had been cleared for pasture and that small quantities of wheat maize, potatoes and barley had been cultivated (Clouston Associates, 2009).

However the varying terrain and low river floodplain which was subject to regular floods caused a movement of settlers to the higher elevations of the Cranebrook escarpment. The failure of wheat crops in the 1850s and 1860s triggered a shift to more disease resistance crops like oats and latter fruit orchards, market gardening and diary farming at the end of the 19th century (Clouston Associates, 2009).

3.1.6 Quarry History and Future

The farms in the Castlereagh area helped to support the growth of the Sydney metropolitan region until the development of sand and gravel extraction activities, which first emerged in 1880's and began to compete with the agricultural use of the area.

Early gravel extraction activities were undertaken by Emu Gravel and Road Metal Company the two main companies operating, with other numerous small land owners quarrying along the riverbank.

In the 1940s and 1950s large diesel machinery was employed to extract raw material from the river.

Quarry operations further expanded in the following years and decades and started to spread onto floodplain, away from the river. The expansion of quarry operations and the resulting alteration of the landscape started to raise concerns by Penrith City Council (PCC) in the late 1960s who agreed that no further developments consents would be issued until environmental impacts were addressed (Clouston Associates, 2009).

The Penrith Lakes Scheme Working Party was established to address these concerns and in 1976 it prepared an interim report directing the rehabilitation of the area. In addition the need to coordinate operations on site was identified as a result of subsequent technical, environmental and financial studies.

As a direct consequence, the Penrith Lakes Development Corporation Ltd. (PLDC) was formed and commenced the management of operations within the 1935 hectare quarry in 1979 (Tinson, 2008).

In 1984 the Penrith Lakes Regional Environmental Study recommended to the Corporation the development of a large Main Lake to provide recreational facilities and an urban development after the quarrying operations were finished (RES 1984). These ideas, together with the intention to design different lakes for water recreation activities and wildlife conservation, were incorporated into the Sydney Regional Environmental Plan No. 11 – Penrith Lakes Scheme.

In 1987 the Penrith Lakes a Deed of Agreement between PLDC and the Department of Planning (DoP) addressed principal commercial issues and gave PLDC the responsibility for the development and maintenance of the lakes system until the quarrying and land rehabilitation was completed. After this anticipated 30 year time period the ownership and responsibility is to be transferred to the State Government (Sydney Regional Environmental Plan No.11, 1986).

Todate the quarry has provided sand and gravel for the building industry and the growth of Sydney for the last 30 years. It is anticipated that quarry activities will end within the next six to seven years.
Rehabilitation works are well underway and are focusing on the long term vision of transforming the site into the Penrith Lakes Scheme; providing a world class tourism destination, recreational facilities for Western Sydney and Core Conservation areas with habitat for native wildlife.

Parts of the Scheme, including the Sydney International Regatta Centre (SIRC) and some small lakes and basins in the east and the relocated Castlereagh Road have already been completed.

The future Penrith Lake Scheme as outlined in Figure 9 is proposed to contain three lakes namely:

- Quarantine Lake, located in the south east corner of the Scheme and will mainly be used for creating a habitat for native flora and fauna

- Main Lake which is centrally located and will be mainly used for active recreation such as boating

- Wildlife Lake located in the north of the scheme that will provide habitat for native flora and fauna and passive recreational opportunities

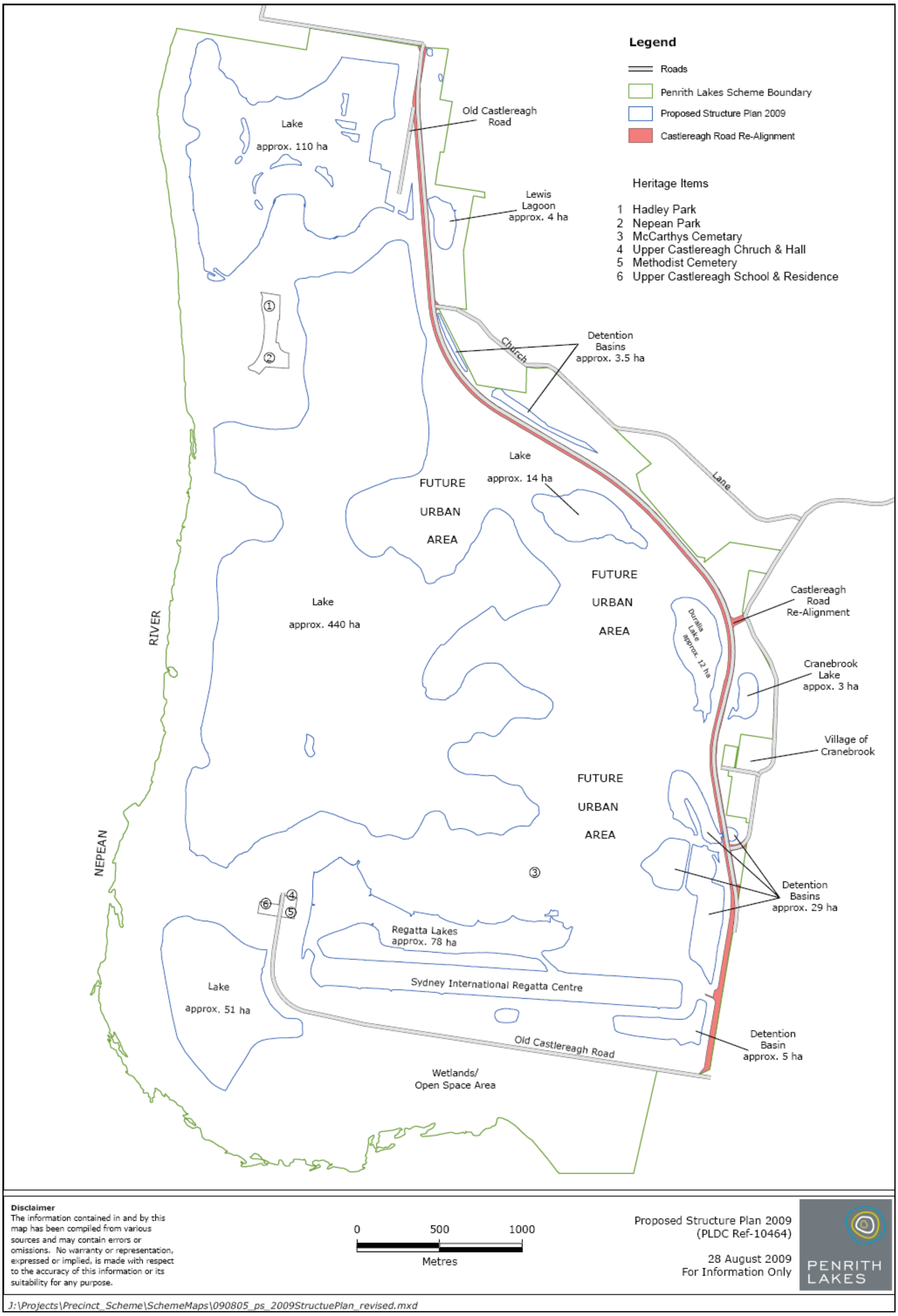


Figure 9: Proposed Structure Plan outlining future shape of the Scheme

The development of soil conditions capable of supporting fully structured ecosystems including soils fabric and flora and fauna, remains one of the key challenges in the rehabilitation process. Investigations have been undertaken to support the process and key steps to be undertaken have been outlined. Soils already developed east of the relocated Castlereagh Road are highly dispersive during irrigations and high rainfall. They also contain high levels of soluble salts that will reduce the water availability to plants. Additional studies on the soil have shown a slightly increased acidity and treatments are necessary to improve the cation exchange capacity. Additional application of fertilizer also needs to be conducted to improve functional soil properties like the ability to retain moisture and nutrients, translocates nutrients and support soil biology. Rehabilitation work undertaken in an area known as Core 4 has provided highly desirable results (see Figure 10) and should guide the rehabilitation of other areas (Aitken, 2007 and Mitchell, 2008).

Figure 10: Good soil rehabilitation in Core 4

Figure 11: Poor soil rehabilitation

3.2 The Natural Heritage and Biodiversity Master Plan

The Natural Heritage and Biodiversity Master Plan (NHBMP) is building upon achievements in Natural and Cultural Heritage conservation in the PLS area during the last 20 years. It has recognised the ecological, social and economic significance of the area to the traditional Aboriginal people of the region, the Darug. The report recommended the ongoing application of ecological sustainable design principles to maintain and enhance the current best practice approach.

The developed key principles reflect PLDC's obligation under the Deed of Agreement as well as incorporating the PLDC vision for the Castlereagh area that will support high quality, urban, rural residential, employment and recreational lands.

Figure 12 presents a possible practical application of these principles which result in a number of different zones. However, changing quarry operations and development plans driven by the overall global economic climate are impacting on the rehabilitation of the Scheme and consequently the NHBMP is under ongoing review and adjustment (TCM Services, 2008).

In addition to recommendations made to re-establish and strengthening the cultural significance, the report extensively focuses on the practical and most efficient re-establishment of effectively functioning and sustainable soils as well as natural plant communities reflecting former Cumberland Plain vegetation and their associated fauna at Castlereagh. Furthermore, the report outlines the key challenges being faced and recommends management approaches to guide ensuring processes.

The recent decision of PLDC to concentrate on the finalisation of the most northern section of the Scheme, known as the Wildlife Lake Precinct has resulted in the productions of the report Ecological Consideration for the Wildlife Lake Precinct (TCM Services, 2009), that focuses specifically on this area and updates the NHBMP.

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Figure 12: Proposed natural heritage/ biodiversity Zones adapted from TCM Services (2008), p.18

4 Carbon Sequestration in Biomass

This chapter applies individual tree data obtained during field surveys to general equations to make estimations on above ground biomass (AGB) and below ground biomass (BGB)for the PLS.

4.1 Literature Review of Methodologies

With growing concerns about climate change it is widely accepted that terrestrial ecosystems and forests, in particular, have a key role in mitigating global climate change. Their ability to sequester carbon dioxide by the use of chloroplasts through the process of photosynthesis is expressed through the simplified chemical formula below

$6CO_2 + 6H_2O \rightarrow \text{Chloroplasts} \rightarrow C_6H_{12}O_6 + 6O_2$ Eq (1)

Photosynthesis and its fundamental role in supporting life on Earth is well known and understood.

Traditional forestry used to ensure correct planning and sustained harvesting of resources are currently widely used to estimate tree AGB and subsequently sequestered carbon dioxide stored in forest ecosystems.

There are three broad approaches to measure biomass within trees in a terrestrial forest ecosystem. The destructive harvest method is the most accurate and preferred method to determine AGB. However felling of trees is not always possible due to restricted access (e.g. gorges or steep slopes) or restricted permission to fell trees (e.g. core conservation zones and rehabilitation sites). If destructive sampling is not possible, then the second method known as the partial harvest method needs to be applied Snowdon et al.(2002).
The partial harvest method involves the felling and sampling of key parameter from a small number of individual trees, representative for the overall stand. A general assumption from these results is then been made for the whole stand. Formulas developed with the total harvest as well as with the partial harvest method are often used in the following described third method.

This method is the most efficient one and involves the measurement of tree parameters and the use of formulas that express their relationship to above ground biomass (AGB) and below ground biomass (BGB). This is generally known as Allometry.

Allometry involves the relationship between tree AGB and easily measured variable parameters such as tree diameter at breast height (DBH) or the height of trees (Keith et al., 2000).

Allometric equations have been developed using the total harvest method to relate the tree parameter to biomass.

The importance of these allometric equations is growing as they present a rapid and easily implemented method to asses standing biomass as a basis for estimating sequestered carbon (Zianis & Mencuccini, 2002).

Extensive databases have been established for coniferous and deciduous broad leafed forestry in the northern hemisphere. However these ecosystems differ significantly in structure, species composition and growth pattern from ecosystems in Australia. Australian native forest ecosystems are mainly dominated by *Eucalypt* species. Their distinguishing attributes include leaf turnover rates of less than 2 years and hence year round photosynthesis and growth, broadleaf and evergreen foliage and differences in bark types between species and within trees. Furthermore soil nutrient status is low in many Australian regions and soil water availability is a major determinant of the magnitude and timing of growth. Major survival strategies of tree species within these ecosystems include the ability of their canopies to re-sprout and re-development of canopies after damage from fire or insect herbivore (Keith et al., 2008).

Notwithstanding the understandings that have evolved from forestry research in Australia, Baldocchi and Valentinie (2004) mentioned that these *Eucalypt* forest have been studied far less than northern hemisphere broad-leafed forests and rainforests. Additional regional data is needed to broaden the understanding of biological processes and enhance the data base for these *Eucalypt* forest ecosystems. Furthermore elevation in precision of biomass and carbon sequestration estimations that are subsequently used for the inclusion of terrestrial sinks in national greenhouse inventories for future ETS are other beneficial outcomes (Keith et al., 2000).

To address this need for a broader data base, extensive work on Australian forest ecosystems has been undertaken. Keith et al. (2000) and Snowdon et al. (2000) have prepared substantial work for the Australian Greenhouse Office (AGO) which focuses on the development of general equations for major Australian ecosystems. Based on extensive research and literature reviews it comprises a large number of different approaches for Australian ecosystems and plantations undertaken in the second half of the 20th century Keith et al. (2000). Furthermore research undertaken by Specht & West (2002), Bi et al (2004), Birk et al. (1994), Montagu et al. (2004) and Forrester et al. (2006) focused mainly on regional native *Eucalyptus* and *Acacia* plantation within or close to the Sydney Basin area. Plantations age ranged between 2 and 11 years.
For example Specht & West (2002) conducted a research program to develop allometric equations to investigate the biomass sequestration on small estates in central NSW, Australia. The estates were up to 170 ha in size and were located around the city of Singleton.
Where as Ravindranath & Ostwald (2008) focused on the global perspective and delivered a handbook to assist in conducting research projects that aim to establish an carbon inventory or estimate carbon stored in AGB and BGB.

The relationship between AGB and BGB was further investigated by Brown (2001), Lal (2005) and Shrestha and Lal (2006). They found that the most practical way of estimating root biomass was to relate it to AGB (Brown 2001). In addition, Snowdon et al. (2000) concluded that the mean BGB and root biomass estimation in particular for Australian vegetation is broadly comparable with estimations for major global vegetation types.

Additional work related to the PLS project was undertaken by Lal (2005) who concluded that soils in equilibrium with a natural forest ecosystem have a high carbon density. However, Shrestha and Lal (2006) reported that it may require a long period of 30 years or more until this equilibrium is attained on disturbed mine soils.

Also of potential relevance to the site is research investigating forest management techniques. The application of different management techniques, including pruning or thinning and effects of fertiliser application were the core of works done by Muñoz et al. (2005), Birk et al. (1995) and Stape et al. (2007).

Research undertaken by Almeida et al. (2004) and Landsberg et al. (2003) aimed to predict stable carbon equilibrium under varying growth conditions and impacts of natural disaster including fire, droughts or heavy rainfalls using the 3-PG (Physiological Principles Predicting Growth) computer model.

The AGO Technical Reports number 5b, 17 and 31 provide results of additional research undertaken to ensure statistical reliability and correctness. These reports have been substantially drawn upon to provide the foundation for the project on the PLS. The work of Keith et al. (2000) and Snowdon et al. (2000) for the AGO was chosen to calculate the AGB on the study areas. In addition work done by Specht & West (2002) and Birk et al. (1994) were used to compare results with similar research and to seek to improve the research outcomes of the project. Research of Ravindranath & Ostwald (2008) was used to define and establish the Permanent Growth Plots (PGP) and as a step by step guide to conduct the research proposal.

This broad based literature review has assisted in defining the limitations of this project, including time and resources. They also helped to identify impacts of previously applied and future management strategies that may be subject to further research studies.

4.1.5 Method selected and rationale

(a) Site Selection and Description

Air photo interpretation was initially used to determine suitable areas for investigation.

Eight different investigation areas were identified on the PLS to conduct measurements of AGB. These eight areas were selected on the basis of their ability to best represent rehabilitation works on reclaimed soils as well as natural regeneration on former, partly cleared, grazing areas.
Site locations were also influenced by previous impacts on current vegetation structure and vitality that could subsequently influence vegetation growth and hence carbon sequestration. Therefore past and current disturbances (e.g. mining and clearing) and management activities (mowing, mulching, irrigation) were ascertained from records and used to further determine the location of PGPs.

Table 2 presents a summary on the history and nature of each selected site. The sites included 28 PGP. Plot locations and sizes were determined within selected sites to best represent the overall area and so stand structure.

Table 2: Overview PGP history and data

Investigation Area (IA)	Area Name	Plot size Range	Planting Established	History	Landform build	proposed future Vegetation Community
1	Riverbank North	49m²	2005	cleared for grazing	n/a	Shale Sandstone Transition Forest
2	Smith Road	49 - 150 m²	2006	Cleared for Grazing	n/a	Shale Sandstone Transition Forest
3	Swan Lake	625 m²	1980's	quarried	1980s	Alluvial Woodland
4	Vincents Creek	625 - 750 m²	regrowth since 2002	cleared understorey for grazing	n/a	Western Sydney Dry Rainforest & Shale Plain Woodland
5	Cranebrook and Duralia Lake	49 m²	2003	quarried	2002	Alluvial Woodland
6	North Basin	600 m²	1998	quarried	1997	Alluvial Woodland
7	Castlereagh School	49m²	2002	quarried	2001	Alluvial Woodland
8	Riverbank South	625m²	1994	cleared	n/a	Castlereagh Riverflat Forest

Square PGPs were laid out and plot sizes were based on DBH using suggestions made by Pearson et al. (2005) who related plot sizes to the DBH range (see Table 3). Hence PGPs covered an area ranging between 49 m^2 and 750m^2 .

Table 3: Suggestions for plot shapes and sizes

Stem diameter (DBH, cm)	Circular plot (radius, m)	Square plot (m)
< 5	1	2 × 2
5–20	4	7 × 7
21–50	14	25 × 25
> 50	20	35 × 35

Field measurements were undertaken in Autumn 2009 between 31st of April and the 5th of May 2009.

Tree planting within selected PGPs ranged from recently established, aged three years, to rehabilitations works undertaken decades ago. Natural regeneration in IA 4 was aged up to 25 years with mature canopy trees aging around 50 years (Muru Mittigar, 2008).

All trees in each PGP were numbered and tagged, using aluminium tags and stainless screws as fixation, to ensure later identification and monitoring of individual plants.

A descriptive summary of the vegetation present in each PGP can be found under section 4.1.2.

(b) Site Measurements

The literature review under 4.1 showed that the DBH (over bark), where breast height is measured at 1.3 m above ground level, is the most widely used parameter to estimate AGB of trees and forest ecosystems (Montagu et al., 2004, Specht & West 2002, Zianis & Mencuccini, 2002). Ground level was defined as the ground at a tree base if ground was level, or on the higher side of the tree base if the ground was sloping Carron (1968).

The standing woody biomass in each plot (all trees and shrubs) had DBH measurements taken. In plot 4.1, due to the structure of the stands, extensive natural regeneration was present, only trees higher than 1.5 m in height and with a DBH greater than 5 cm (15 cm GBH –girt at breast height) as outlined by Ravindranath & Ostwald (2008) were included in the field sampling.

The parameters outlined in Table 4 derived from Ravindranath & Ostwald (2008) were measured and recorded for each tree. Examples of field data sheets can be found in Chapter 10.

Table 4: Parameters used to estimate above ground biomass

Carbon pool	Parameters to be recorded
Above-ground biomass of trees and shrubs	Name of the species
	DBH (cm)
	Height (m)
	Origin: regenerated or planted
	Extent of crown: full crown or percent
	Status: dead or living

The following formula derived from Zianis & Mencuccini (2002) is a result of long term research and used in forestry worldwide for studies on forest productivity, nutrient cycle and for calculating AGB, carbon storage and sequestration Bi et al. (2004).

$$M = aD^b \qquad \text{Eq (2)}$$

where a and b are parameter, the total above ground dry tree biomass is presented by *M* or sometimes by *W* see Specht & West (2002) and *D* is the diameter at breast height.

The linear function of the allometric model can be expressed as

$\ln(M) = \ln a + b\ln(D)$ Eq (3)

where ln is the natural logarithm to the base of 10.

The linear function Eq (3) was mainly used in the technical reports prepared for the AGO and was hence used during this project. Zianis & Mencuccini (2002) pointed out that the linear relation of Eq (3) is mathematical, but not in a statistical sense, identical to Eq (2). This inconsistency has long been recognised with concern about that emerging only recently. In addition it is also recognised that the translation of Eq (2) into Eq (3) is appropriate when standard deviation of *M* to any *D* increases in proportion to the value of *D*. Even though this relationship will not be tested during this project it implies that *M* can be measured more precisely at a low value than at a high value of *D* in a linear function. Consequently as the tree stands investigated during this project present mainly plantations of younger aged trees, the linear function has been selected for use on the PLS.

The obtaining of the parameter *a* and *b* is well explained by Zianis & Mencuccini (2002) as a laborious and time consuming approach where estimates for the coefficients *a* and *b* are obtained by the least-square regression of log-transformed data for *D* and *M* measured from destructively sampled trees that represent the diameter range within the stands under investigation.

To estimate the biomass in each of the PGP allometric equations developed by Keith et al. (2000) and Snowdon et al. (2000) for Australian ecosystems were used as they present the best data for Australian trees (Joe Landsberg pers. comm.).

Due to the structure and age of stands two equations from these reports were chosen as baseline estimations. Equation 4 presented by the following formula Eq (4) was developed by Keith et al. 2000 and Snowdon et al. (2000) for Natural Sclerophyll Forest was only used in Area 4 (Vincent's Creek).

$\ln(M) = -1{,}9335 + 2{,}3501(\ln(DBH))$ Eq (4)

Eq (5) was developed for native plantations and is presented below.

$$\ln(M) = -2{,}2450 + 2{,}3582(\ln(DBH)) \quad \text{Eq (5)}$$

As PGPs in IAs 1, 2, 5, 6 and 7 are young plantings aged between 3 and 10 years Eq (5) was used to estimate the AGB as it best represents the current structure of stands.
IA 3 and IA 8 are approx. 25 and 15 years in age but planting rows are still visual and no substantial understory has evolved leaving the stand in a plantation-like structure. On this basis, Eq (5) was again used as a best fit to estimate AGB.

If suitable Species Specific Equations (SSE) were available they were tested against the general equation (Eq 5).

Estimations of BGB were undertaken using ratios relating AGB to BGB Snowdon et al. (2000). The factor of 0.41 for Woodlands is used in IA 4 and the factor 0.22 for Hardwood Plantations was used in the remaining IAs.

$$AGB*rt \quad \text{Eq (6)}$$

Where AGB is the above ground biomass and *rt* is the ration factor relating AGB to BGB for Woodland and Hardwood Plantations.

Basal area in m² per was calculated for each tree in a plot using formula Eq (7).

$$BA_{tree} = \pi\,(DBH/200)^2 \quad \text{Eq (7)}$$

Where BA_{tree} is total basal area per tree in m², division factor 200 was used to convert DBH measurements from cm² to m². Individual tree data was then summed and formula Eq (8) was used to calculated total basal area per hectare.

$$BA_{hectare} = BA*(10000/AS) \quad \text{Eq (8)}$$

Where $BA_{hectare}$ is summarized basal area for all plots in one IA and AS is presenting the total area under investigation, covered by plots sum of plot sizes resulting in the total investigated area of tree stands in the same area.

The multiplier of 0.5 is widely used and suggested by the Intergovernmental Panel on Climate Change (IPCC) to reduce costs of carbon inventory investigations.

4.1.6 Plot Vegetation summaries

This section represents a small summary about the structure of stands in each area and Table 5 gives an overview about the species composition present.

Table 5: Species summary per area

Species No.	Species Key	Investigation Area Number								Total species Individuals
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
1	*Acacia binervia*							5		**5**
2	*Acacia decurrens*	5	1					1		**7**
3	*Acacia flacata*		1							**1**
4	*Acacia Implexa*					1		9		**10**
5	*Acacia paramettensis*		9	2	1	16				**28**
6	*Acer negondo*								9	**9**
7	*Angophora floribunda*	2								**2**
8	*Angophora subvelutina*	1			3					**4**
9	*Backhousia myrtyfolia*				52					**52**
10	*Brenia obgligifolia*				1					**1**
11	*Casuarina cunninghamiana*	10	5	9		2	39	3	86	**154**
12	*Casuarina glauca*			4						**4**
13	*Dead Tree*			10	9	1			8	**28**
14	*Eucalyptus amplifolia*		2	13		6		4		**25**
15	*Eucalyptus baueriana*			2		2				**4**
16	*Eucalyptus botryoides*				1					**1**
17	*Eucalyptus crebra*		5			3				**8**
18	*Eucalyptus euginoides*					3				**3**
19	*Eucalyptus mollucana*			5	15					**20**
20	*Eucalyptus ssp. 1*			3						**3**
21	*Eucalyptus ssp. 2*			2						**2**
22	*Eucalyptus ssp. 3*			1						**1**
23	*Eucalyptus tereticornis*	3	1	16	5	6	21	16		**68**
24	*Exocarpus cypressiformis*				2					**2**
25	*Lingustrum simensis*								3	**3**
26	*Melaleuca decora*				12					**12**
27	*Melaleuce lariniifolia*			5				2		**7**
28	*Poplar spp.*								3	**3**
29	*Rapanea variabilis*				3					**3**
30	*Salix hybrida*								12	**12**
31	*Solanum aviculare*		1							**1**
32	*Synnearpia glomulifera*		1		6					**7**
	Total tree number	**21**	**26**	**72**	**110**	**40**	**60**	**40**	**121**	**490**

(a) Investigation Area 1 – Riverbank North

Three PGPs were established on top of the river bank. Ongoing regeneration on this site over the last five years has improved species diversity and eased the pressure from weed infestation. The stand is reasonable young, trees of different ages, mainly around four years, occur and maintenance works resulted in a high survival rate (Muru Mittigar, 2008). No woody understorey and a grassy ground layer were present (see Figure 13 and 14).

Figure 13: Stand structure in Plot 1.1 and 1.3

Figure 14: Stand structure in plot 1.2

(b) Investigation Area 2 - Smith Road

A range of native tree and shrub species occur on this site. It planted in 2003 as an addition to an old stand of *Eucalypt* trees (see Figure 15). Some *Acacia* species are naturally regrowing and the ground stratum is dominated by *Kikuyu* (Muru Mittigar, 2008).

Figure 15: Mature Eucalypt individual and additional planting Plot 2.1

(c) Investigation Area 3 - Swan Lake

Early attempts of regeneration on this site date back into the 1980's and consist of evenly spaced *Casuarina, Eucalypt* and *Melaleuca* species (see Figure 16). Some *Eucalypt* seedlings that appear to be about three years old occur on the site and vegetative regrowth of *Casuarina*, through possibly suckering or seedlings have begun to form an understorey and expanding the original tree stand.

Figure 16: Stand structure in area 3

The ground stratum consists predominantly of grasses that are mainly non native including *Kikuyu* and *Eagrostis curvula* with some patches of native *Microlina* sited. The site may be affected by variations in the watertable due to pumping and releasing of water in the near by Main Lake water (see Chapter 10).

(d) Investigation Area 4 - Vincents Creek

The area was formerly used for grazing and was cleared for this purpose. Purchased by PLDC around 2002 as part of the quarrying process the area is now supporting regrowth aged between 25 and 50 years of three endangered vegetation communities; Western Sydney Dry Rainforest; Shale Plain Woodland and Alluvial Woodland. A previously conducted survey in this area found 120 different plant species in ratio of 80 native and 40 exotic species (Muru Mittgar, 2007).

Figure 17: Stand structure area 4.1

Figure 18: Stand structure area 4.2

Figure 19: Stand structure area 4.2

PGP 4.1 is located in the Western Sydney Dry Rainforest patch where an intensive understorey regrowth of *Backhousia myrtyfolia* occurs (see Figure 17). Shale Plain Woodland is
the dominating vegetation community in and around PGP 4.2. This area shows characteristics of open woodland with sparse understorey and mature *Eucalyptus mollucana* stands up to 25 metres in height forming the canopy layer. A grassy ground stratum is present with a native and introduced species mix (see Figure 18 and 19).

(e) Investigation Area 5 - Cranebrook and Duralia Lake

Tree plantings surrounding the water bodies of Cranebrook Lake and Duralia Lake undertaken in form of 'tree cells' with high densities. The stands are between four and five years old. Unequal soil improvement techniques and management have resulted in varying soil conditions in the area and may also explain variations in tree stands health (see Figure 20 to 24). Regrowth of *Acacia parramettensis* is appearing amongst the tree cells, expanding them. Currently no significant understorey and ground stratum has emerged in these tree plots. The area was formerly quarried and is amongst the first completely remediated landforms on site.

Figure 20: Stand structure Plot 5.1 (1)

Figure 21: Stand structure Plot 5.2 (2)

Figure 22: Stand structure Plot 5.2 (1)

Figure 23: Stand structure Plot 5.2 (2)

Figure 24: Stand structure north of Duralia Lake – low soil conditions

(f) Investigation Area 6 - North Basin

Plantings in IA 6 occurred between 1997 and 1998. The stands investigated consist of evenly space individuals of *Eucalypt tereticornis* and *Casuarinacunninghamiana* species currently aged between 11 to 12 years. Soil conditions remain poor as no work was undertaken to improve structure or nutrient content (Muru Mittigar, 2007).

Management activities involving crown lifting and regular mowing resulted in the development of an open stand with no understorey and a cultivated grass layer present (see Figure 25).

Figure 25: Stand structure area 6

(g) Investigation Area 7 - Upper Castlereagh School

Mixed stands of C*asuarina, Eucalypt* and *Acacia* species are present in IA 7 with no shrub layer currently present. Planting was undertaken in 2002, the site is well established tree stands are between five and seven meters in height (see Figure 26). The ground stratum is dominated by *Eragrostis curvula* and *Pennisetum clandestinum* with some patches of *Themeda australis*.

Figure 26: Stand structure area 7

(h) Investigation Area 8 - Riverbank South

The site was formerly cleared and used as a picnic area before replanting took place approximately 15 to 20 years ago (D. Drewry pers. comm.). The canopy trees are mainly *Casuarina cunninghamiana,* and a shrub stratum is only partly present. The ground stratum consists of *Lomandra* and a range of exotic species (see Figure 27). During field measurements alluvial deposited materials on the lower branches of some trees indicated the presents of recent floods of 1 to 1.5 metre above the ground surface (see Figure 28). These events and sparse sunlight are limiting the growth of an understorey layer leaving the area open at ground level.

Figure 27: Stand structure area 8

Figure 28: Alluvial deposits indicating flood level

4.1.7 Measurement of Parameters

During field investigations on the PLS the following outlined techniques were used to investigate parameters presented in chapter 4.1.1.

The Girt at Breast High (GBH) was taken at a height of 130 cm using a tape measure of 150 cm in length and a 50m fibreglass tape measure for larger trees. The GBH was subsequently converted to the DBH high using Eq (9) :

$$D = GBH/\pi \qquad \text{Eq(9)}$$

Where D is the diameter at breast height, GBH is the girt at breast height and π is the mathematical constant of 3.142.

If a multiple trunk was present each trunk was measured and the gained data was summed and converted into the DBH using the above described method. The summarised data was then treated as one stem.

Tree height was measured using a straight ledge for trees up to 7 meters tall. Medium sized trees represented by a stand height of between 7 and 15 meters were estimated using single tree measurements from a clinometer to improve estimation precision. The 20 meter direct reading scale was used for measuring tree height and instructions given were followed. Twenty meter distance from the base of the tree was determined using a fibreglass measure tape. Large trees represented by stand heights over 15 meters were all measured using the above described equipment and methods.

Additional parameters that were recorded on site included an estimation of canopy cover after Figure 29 developed by McDonald et al. (1984), the history of the plants (whether they were planted or natural regeneration) and the status of the plants (alive or dead) plant health, the success or failure of applied management strategies and the progress of ecosystem development.

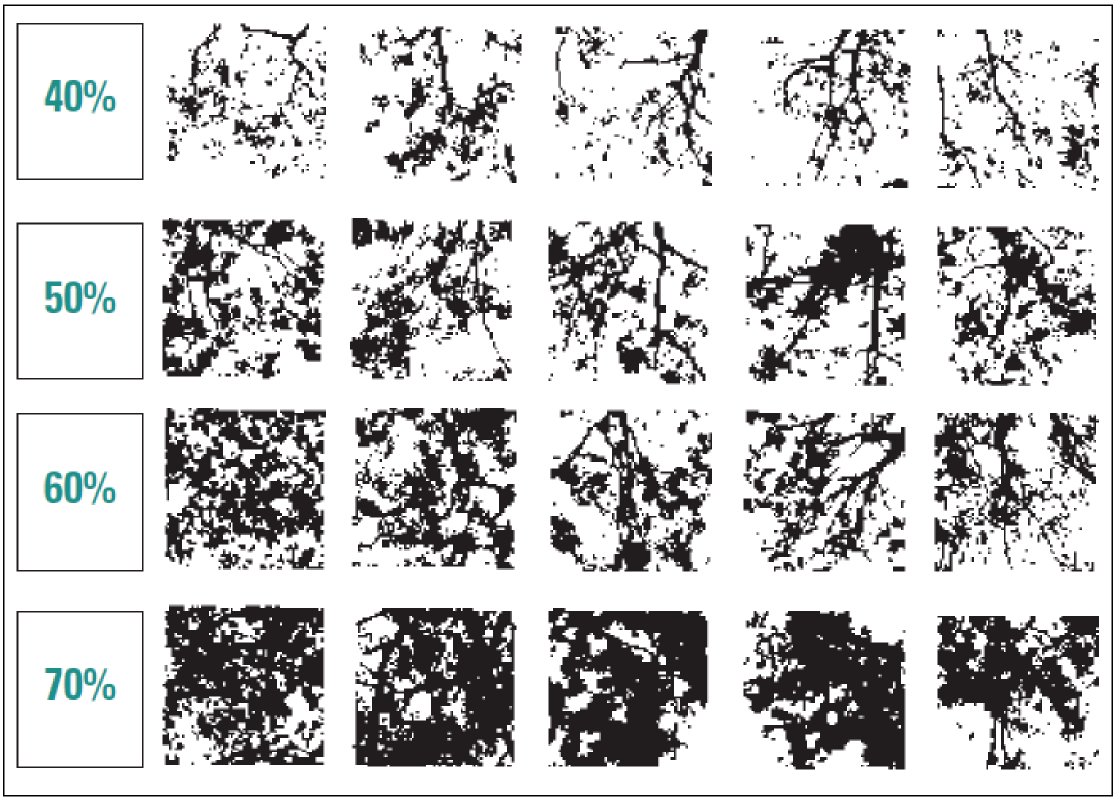

Figure 29: Foliage cover at various percentages (McDonald et al. 1984)

4.2 Results

4.2.5 Biomass and supportive results

(a) Results per Area

To estimate the biomass for each investigation area, a total of 490 individual trees and shrubs, representing 33 species were assessed during the field studies. Species diversity across the sites ranged from two species in IA6 to up to twelve species in IA4 (Table 5). General equations described under Section 4.1.1 were used to estimate the AGB. Ratios relating BGB to AGB were used to obtain total biomass estimation for each individual area. The results of each plot were extrapolated to tonnes per hectare and plot results were averaged for each area (Figure 30).

Stocking density in stems per hectare was also calculated based on the number of trees present in all permanent growth plots in each area. Results are shown in Figure 31.

The investigation showed that area 4 and 8 have the highest amount of biomass which can mainly be explained with stand age and structure, good soil conditions and water availability. Both stands comprise of mature trees and natural regeneration.

Mean diameter recorded was 14.16cm for IA 4 and 18.71cm for IA 8. Stocking density is low with 800 and 968 stems per hectare, respectively. Natural competition occurs in early stages of growth leaving the survival rate of saplings low and ensuring mature trees are healthy and well established.

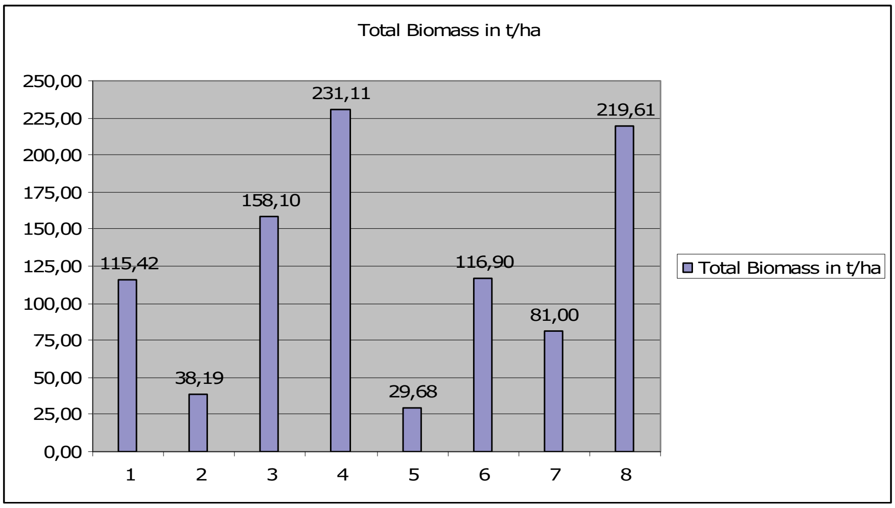

Figure 30: Mean biomass estimations for investigated Areas on the PLS

Surprisingly the oldest stand of trees among plantations in IA 3 didn't show the highest amount of biomass 158.19 t/ha (Figure 30). Even stock density was with 576 stems/ ha the second lowest. Poor soil conditions and heavy wind impacts (most of the trees showed heavy crown damage and wind fall) may explain these findings.

Quite similar results in biomass were obtained for the IA 1 and 6 even though the stand characters were significantly different. While stands in IA 1 showed an average stocking density of 1429 stems per hectare, area 6 had only 500 stems per hectare present

The remaining IAs 2 and 5 can be grouped as they all show a reasonable low biomass component. The IA 2 planting is established on natural soils while planting in IA 5 are established on rehabilitated landforms and soil profiles. Nevertheless IA 2 showed a high die back rate and represents the lowest stocking density (1048 stems/ha) among the young plantings.

The opposite was observed in the remaining two areas were the stocking density was with 2721 stems/ha the highest within investigated areas.
Although stocking density in IA 2 was low and plantings were two and three years younger (compared to IA 5 and IA 7) the biomass was slightly higher then in area 5 and more then double of the biomass present in area 7. However these results are likely to be biased by a high number of fast growing and short living *Acacias* present in PGP 2.3. In addition explanations could be the quarrying history and soil disturbance that may have impacted the plant growth. Also the higher stocking density and hence inter plant competition for water and nutrients (already low due to history) could have had further impacts.

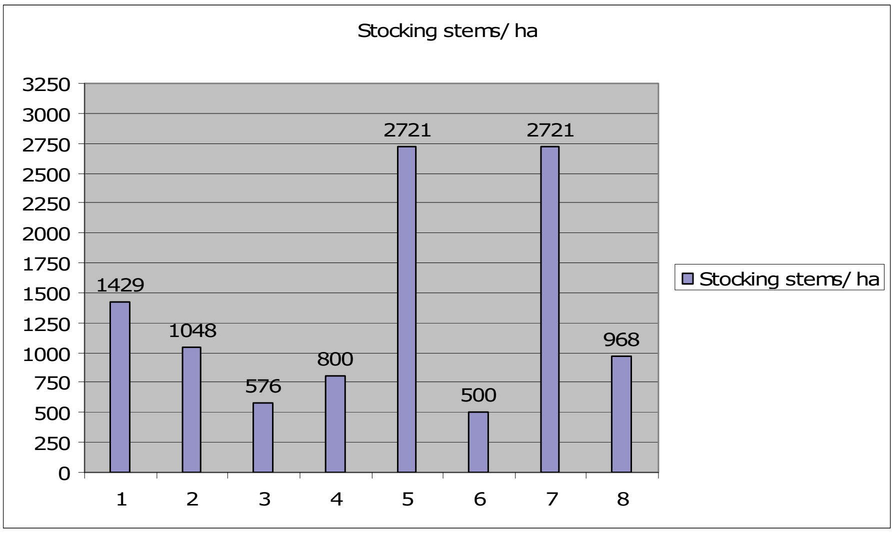

Figure 31: Mean Stocking density for investigated areas on the PLS

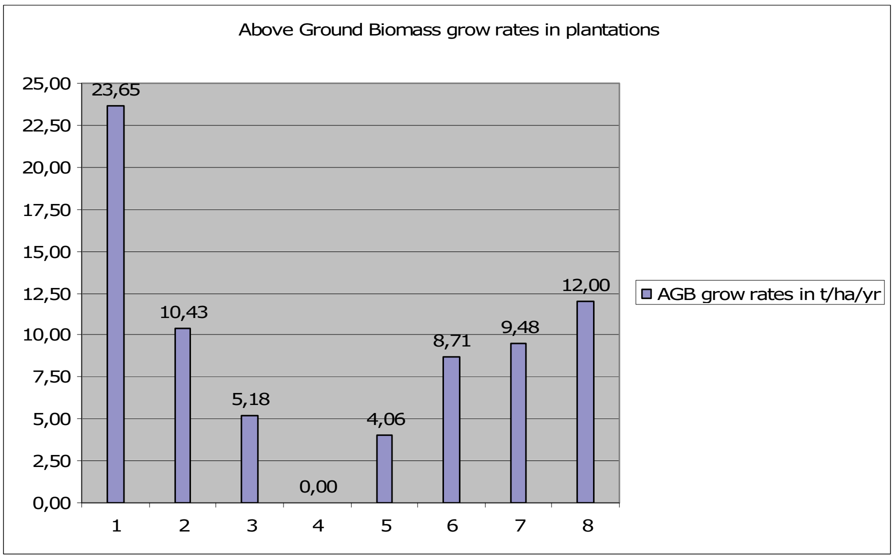

Figure 32: Above Ground Biomass Growth Rates in Plantations on the PLS

A calculation of biomass growth rates for plantation areas, area 4 was excluded, it is mainly contains natural re-growth, showed an exceptionally high annual growth rate in biomass in IA 1, followed by IAs 2 and 8 where growth rates laid above or close by the average of 10.50 t/ha/yr^{-1}. IA 6 and 7 showed little variations in yearly growth rates of AGB were as IA 3 and 5 showed only growth rates that reached with 5.18 t/ha/yr^{-1} respectively 4.06 t/ha/yr^{-1} not even 50% of the recorded average for plantations on the PLS (see Figure 32).

Mixed average results were obtained for DBH and height of trees. In general both parameters increased with stand maturity and decreasing stands stocking density. Furthermore it is evident that sites 2, 5 and 7 on reclaimed soils with poor soil conditions and minor management applications represented stands with low DBH and height.

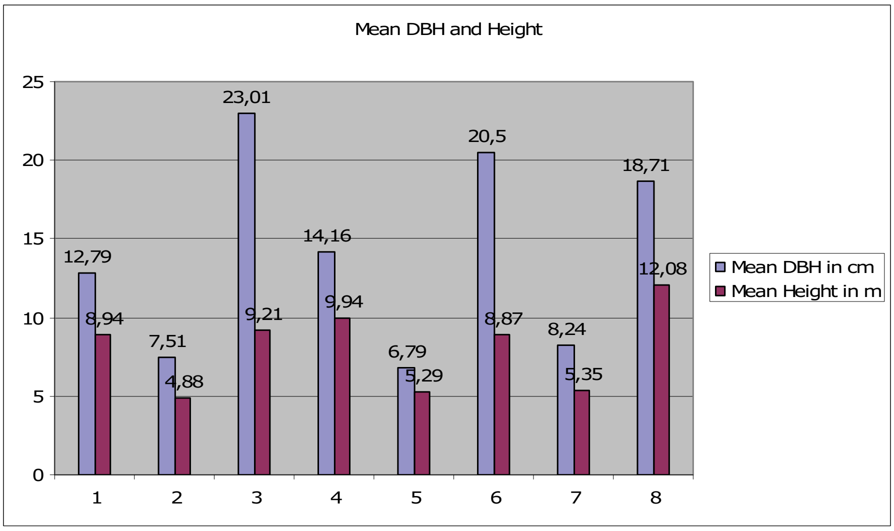

Figure 33: Mean DBH in each Area

In addition to biomass estimations basal area was calculated for each tree in each area (Figure 34). Calculation of basal area rather aimed to establish an evaluation tool for applied management strategies. Basal area increments obtained in future years can be used as part an integrated monitoring program. They are easily measured and a good indicator of productivity and over- or under stocking of an area Birk et al. (1995).

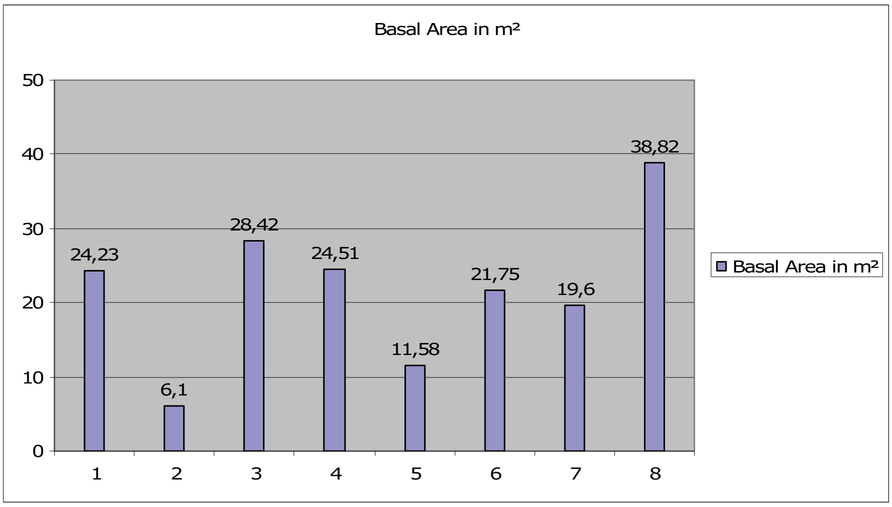

Figure 34: Basal area per hectare

(b) Application of species specific equations (SSE)

If sufficient data and equations were available, AGB estimations obtained from general equations were tested against species specific equations (SSE) developed by Birk et al. (1995). This approach was undertaken in IAs 1, 6 and 8.

A comparison between the use of general equations developed by Snowdon et al. (2000) for Native Plantations and SSE for PGPs in IAs 1 and 8 revealed a difference in AGB of 3.9% in IA 1 and 8.5% in IA 8.
Both investigations also showed large differences among individuals of *Casuarina cunninghamiana*. Overestimations of biomass peaked at 485% at a DBH of 2.55 cm and underestimations peaked at -42% at a DBH of 54.59cm. Trees with a DBH of approximately 23 cm showed nearly no differences.

In IA 1 SSE for *Eucalyptus tereticornis*, *Casuarina cunninghamiana* and *Acacia decurrens* were applied. These three species accounted for 85.72% of all species present in the area. For remaining species present in the area the results gained from the application of general equations were used to calculate total biomass.

Even stronger correlations were obtained for IA 6 and the IA 8. In IA 6 only two species *Eucalyptus tereticornis* and *Casuarina cunninghamiana* were present with a correlation of $R^2 = 0.97$. *Casuarina cunninghamiana* was the dominant species in IA 8 and despite the above outlined variations the application of SSE showed a strong correlation of $R^2 = 0.98$ to General Equations.

As presented in Figures 35, 36 and 37 in all three areas showed a positive correlation between the application of general equations for native plantations and SSE was obtained.

The positive correlation between general equations and SSE all three areas underlined the use of general equations developed for Native Plantations as baseline for this work.

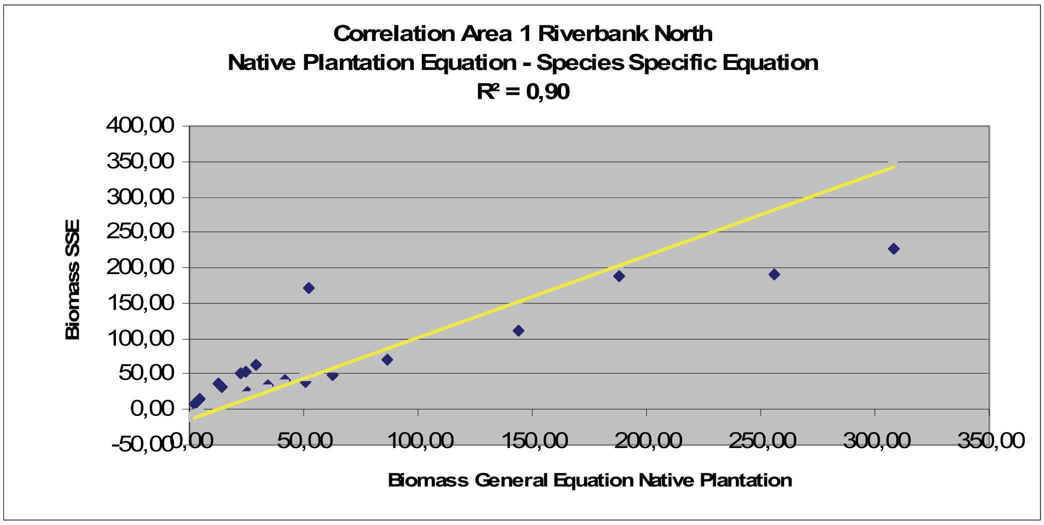

Figure 35: IA 1 Correlation Biomass estimation General Equation – Species Specific Equation

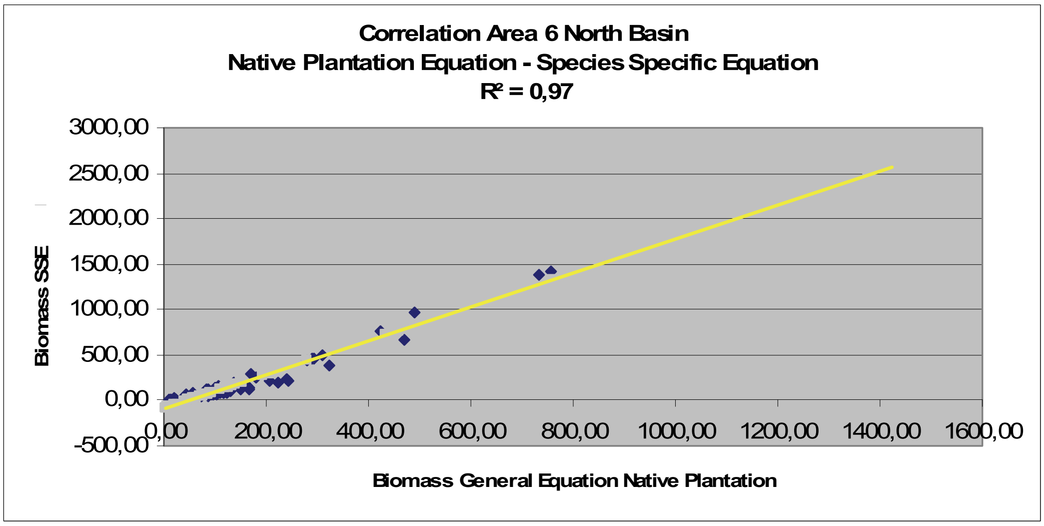

Figure 36: IA 6 Correlation Biomass estimation General Equation – Species Specific Equation

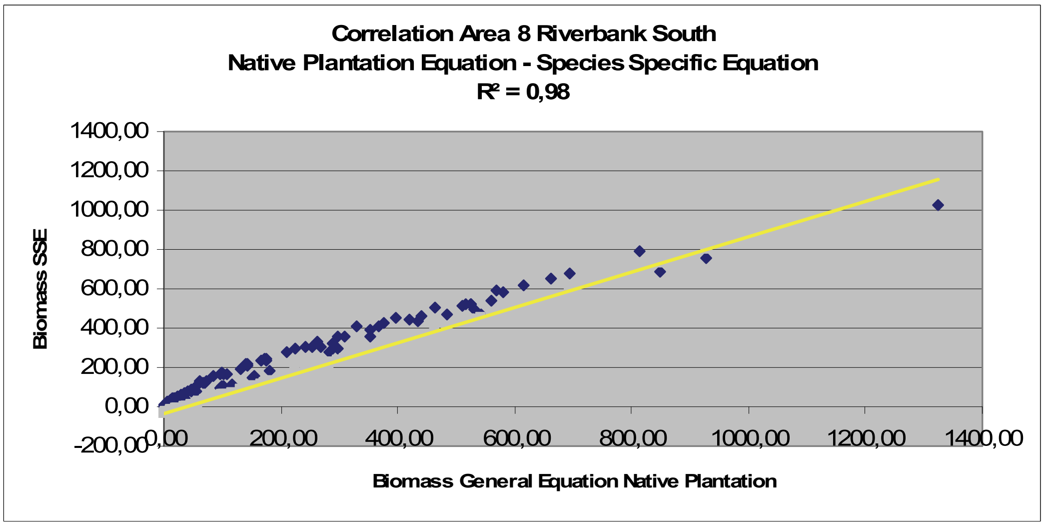

Figure 37: IA 8 Correlation Biomass estimation General Equation – Species Specific Equation

Unfortunately such an approach was not possible for general equations developed for natural sclerophyll forests as no SSE have been available. However a comparison for *E. mollucana* and *E. tereticornis* for Plot 4.2 showed only minor differences of 8.5% in total above ground biomass that are well within the range of -56% to +57% reported by Keith et al. (2000).

(c) Site wide combination of results

If area results were combined and averaged the 490 tree measurements represented an approximately 12 year old stand with a stocking density of 1345 stems per hectare. Biomass would be estimated at 123.75 tonnes per hectare, while mean DBH would be 13.96 cm, average stand height of 8.07 meter (Tab.6). However uncertainties remain since for IAs 3, 4 and 8 no data was available about how plantings were established and what management strategies were applied.

Table 6: Average results of key stand parameter obtained for the PLS and plantations

	Total Biomass in t/ha	Basal Area in m²/ ha	Stocking density stems/ ha	Total No. of trees measured	Mean DBH in cm	Mean Height in m	Stand Age
Average Plantation	76.24	16.65	1683.80	187	11.17	6.67	6.20
Average PLS	123.75	21.88	1345.37	490	13.96	8.07	12

A more precise overview about recent plantings and areas were data availability and certainty was better was applied for the 5 remaining areas.

If results for IAs 1, 2, 5, 6 and 7 are combined and averaged, they represent a planting aged just over six years. While results for biomass, stocking density and basal area ranged widely between the single areas the average plantation results should give an indication on how plantations could develop on site.
The combination of single results represent a biomass of 76.24 tonnes per hectare, a stocking density of just under 1684 stems per hectare and mean height of 6.67 meters. The average DBH is 11.17 cm while average basal area is 16.65 square metres per hectare (Tab. 6).

A comparison between the plantation average and data averaged for the whole PLS including natural grown forest and older plantations showed an high increase in total AGB per hectare while stand age nearly doubled.
At the same time mean DBH and mean height of tree is just slightly increasing. An observation by Snowdon et al. (2000) who mentioned that younger trees have a lower biomass for a given DBH then older, is confirming these observations.

Differences in total number of trees are a result of the relation between plot size and DBH. As IAs 3, 4, 8 were more mature tree stands with greater DBHs plots size increased and covered a higher number of individuals.

The increase in basal area per hectare is possible to be biased by the change in stocking density which declined be nearly one fifth. Therefore more trees in the younger plantation contributed to this result. Often crown closure and natural thinning of stand, due to die backs of individual tree as a result of competition in water and nutrient availability hasn't occurred yet in these stands. The existence of short living coloniser species including *Acacias* is also likely to influence the different results in basal area. Their short life span will contribute to a natural thinning of stands when exceeding this time frame. Additional Birk et al. (1995) reported that basal area contribution of *Acacia* species was slightly over estimated relative to single stemmed species.

(d) Conversion of biomass to carbon

The conversion from biomass results to carbon was done using a simple generic multiplier of 0.5. Hence it follows that 50% of the total biomass results for each tree combining AGB and BGB representing the amount of carbon stored.

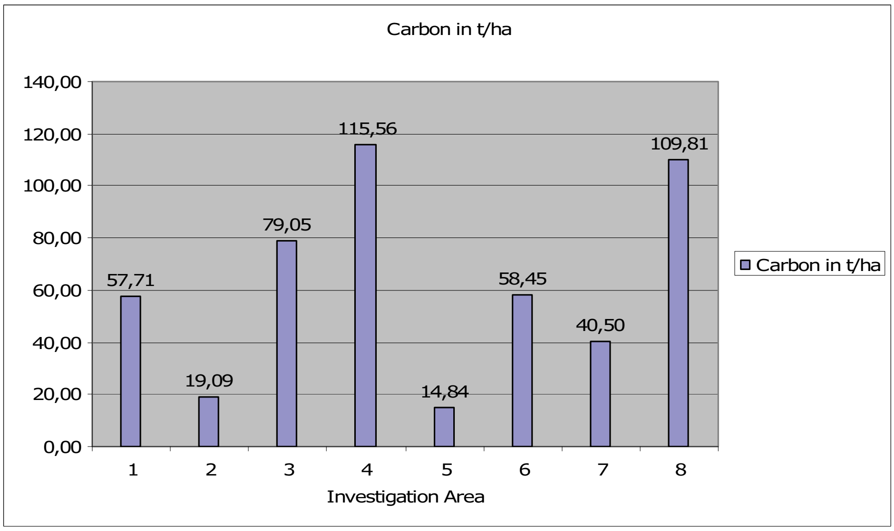

Figure 38: Basal area per hectare

The multiplier of 0.5 is widely used and suggested by the IPCC. Furthermore Snowdon et al. (2002) state that the application of such a multiplier will reduce the costs associated with carbon inventory investigations.

Regional more precise data is available for some regional *Eucalypt* species developed by Convey (2007). However more precise data if not available should be subject to further research.

(e) Converting carbon to carbon equivalents

Emission trading schemes either domestic or international are operating on the bases of carbon dioxide equivalents (CO_2-e). Therefore the results obtained for carbon during fieldwork on the PLS site need to be converted.

The conversion of biomass and carbon into CO_2-e is directly related to the ratio of the atomic mass of a carbon dioxide molecule and the atomic mass of a carbon atom. The ratio is 44:12 or one tonne of carbon in forest biomass requires sequestrations of 3.667 tonnes of carbon dioxide. An application of this ratio to carbon results outlined presented the following CO_2-e estimates (Fig. 39).

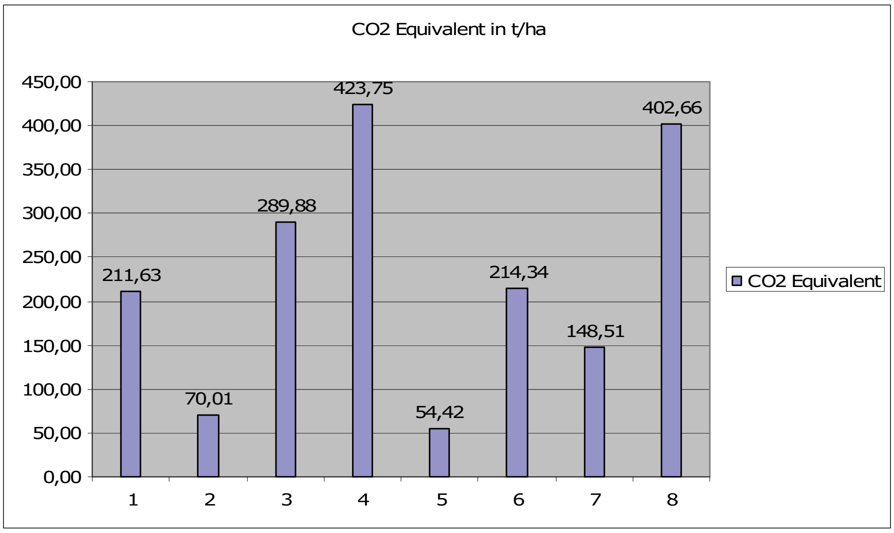

Figure 39: Basal area per hectare

5 Estimation of Carbon Equilibriums for future vegetation communities

The estimation of a Carbon Equilibrium is based on the assumption that mature Australian forest ecosystems reach a state were the carbon sequestration through photosynthesis is offset by the release of CO_2 due to soil respiration, decay processes in a functional ecosystem and plant respiration during night times.
A final estimation of a Carbon Equilibriums remains difficult and will be further complicated under predicted changing climate conditions. Increasing temperatures and atmospheric CO_2 levels might have possible positive effects on carbon sequestration, soil respiration and water use efficiency. These positive effects may be offset by carbon releases due through increased disturbance frequencies and intensities (Galik and Jackson, 2009).

As outlined in chapter 4.2.1 (d) carbon in forest ecosystems can directly be linked to forest biomass. Therefore estimations of mean above ground biomass for Australian forest ecosystems outlined in Table 7 prepared by the AGO can give an indication of possible biomass equilibriums on the PLS.

Depending on site conditions mature forest types that are likely to occur on site could reach a biomass density ranging between 100 tonnes per hectare for Low woodlands (L2) to 279 tonnes per hectare for Tall open forest (T3) (see Table7). An average of these six vegetation types resulted in an expected total above ground biomass density of approximately 200 tonnes per hectare.
Previous work done by Eco Logical Australia in 2008 was based on Wall, (2001) who related soil fertility and average annual temperatures to biomass growth rates. Estimations on AGB in this work for the PLS area were also based around 200 t/ha after 100 years (Humphries & Wall,2008).

Table 7: Estimation of mean above ground biomass for various Australian forest ecosystems adapted from Snowdon et al. 2000, p. 15

Forest type	Structural class	Biomass density (t/ha)	Source
Tall closed forest	T4	450	Gifford *et al.* 1992
Medium closed forest	M4	356	Gifford *et al.* 1992
Low closed forest	L4	300	Gifford *et al.* 1992
Tall open forest	T3	279	Gifford *et al.* 1992
Medium open forest	M3	272	Gifford *et al.* 1992
Low open forest	L3	200	Gifford *et al.* 1992
Tall woodland	T2	200	-
Medium woodland	M2	150	Gifford *et al.* 1992
Low woodland	L2	100	Grierson *et al.* 1992
Mallee	M3m, L3m, M2m, L2m	39	Grierson *et al.* 1992
Shrubland	S2	22	Gifford *et al.* 1992
Plantations		244	NFI 1997, NGGIC 1996

An application of a mean shoot ration of 0.40 also used by Snowdon et al. (2000) for M3 (Open Forest), M2 (Woodlands) and L2 (Low woodlands) resulted in an additional 80 tonnes of below ground biomass per hectare bringing the total forecasted carbon biomass equilibrium to about 280 tonnes per hectare.

A conversion of the biomass equilibrium into CO_2-e as outlined in section 4.2.5 (d) will result in a predicted equilibrium of approximately 500 CO_2-e/ ha for the PLS.

Field investigations in this work revealed annual average AGB increments of 10.50 tonnes per hectare which is significantly higher then results reported by Eco Logical Australia in 2008. However as this work included a wide range of plantations on site this result is like to be biased by the application of irrigation techniques and the use of fertiliser.

In Addition area 1, 2 and 8 are located on insitiu soils or close to the Nepean River with additional benefits to soil fertility and water availability.

Therefore the remaining four areas 3,5,6 and 7 could be used to get an indication of AGB growth on reclaimed mine soils on the PLS. Were as area 6 and 7 showed results closely related to the estimations made by Eco Logical Australia area 3 and 5 are well below these estimations indicating possible difficulties in tree establishment (Table 8).

Trees in area 3 are not known to have received any assistance during their early years of establishment that may have biased annual AGB increments. Hence this approx. 25 year old stand can give a good indication of likely AGB growth rates on reclaimed mine soils in the Scheme area. However minor uncertainties remain as a small proportion of trees in the stand are non native to the Castlereagh area.

Table 8: Comparison between Eco Logical Report and this Project

Area	Annual AGB growth in t/ha	Wall 2001 site quality classes	
		This work	Eco Logical Australia estimation
1	23.65	1	7-8
2	10.43	5	
3	5.18	8	
5	4.06	9	
6	8.71	6	
7	9.48	6	
8	12.00	4	
Average	**10.50**	**5**	

1.	**growth rate**	**≥ 17.0 t.ha^{-1}.yr^{-1}**	or	20 yr standing biomass	**≥ 400 t.ha^{-1}**
2.	**growth rate**	**15.0 – 16.9 t.ha^{-1}.yr^{-1}**	or	20 yr standing biomass	**300 - 399 t.ha^{-1}**
3.	**growth rate**	**13.0 – 14.9 t.ha^{-1}.yr^{-1}**	or	20 yr standing biomass	**250 - 299 t.ha^{-1}**
4.	**growth rate**	**11.0 – 12.9 t.ha^{-1}.yr^{-1}**	or	20 yr standing biomass	**200 – 249 t.ha^{-1}**
5.	**growth rate**	**9.5 – 10.9 t.ha^{-1}.yr^{-1}**	or	20 yr standing biomass	**150 – 199 t.ha^{-1}**
6.	**growth rate**	**8.0 – 9.4 t.ha^{-1}.yr^{-1}**	or	20 yr standing biomass	**125 – 149 t.ha^{-1}**
7.	**growth rate**	**6.5 – 7.9 t.ha^{-1}.yr^{-1}**	or	20 yr standing biomass	**100 – 124 t.ha^{-1}**
8.	**growth rate**	**5.0 – 6.4 t.ha^{-1}.yr^{-1}**	or	20 yr standing biomass	**75 - 99 t.ha^{-1}**
9.	**growth rate**	**3.5 – 4.9 t.ha^{-1}.yr^{-1}**	or	20 yr standing biomass	**50 – 74 t.ha^{-1}**
10.	**growth rate**	**2.0 – 3.4 t.ha^{-1}.yr^{-1}**	or	20 yr standing biomass	**0 – 49 t.ha^{-1}**

An application of these results to site quality classes developed by Wall 2001 indicates a site quality class of 9 rather than 5 as an overall average result of this work (see Table 8). This would result in an average standing biomass of 62 tonnes per hectare with CO_2-e results of just over 110 per hectare after a 20 year period. Bases on the above outlined results it is most likely that previous reports would have overestimated possible carbon trading revenues for the PLS on a 20 year base scenario.

It is therefore evident that more research is necessary to further define estimations for the PLS. Furthermore timeframes remain uncertain weather or not these equilibriums may be reached. Possible impacts and climate variation to be discussed under section 5.1 may cause an intentional or unintentional release of carbon back to the atmosphere.

5.1 Possible impacts and climate variations

5.1.1 Long term and short term weather variations

High variability on a regional as well as a seasonal scale is characteristic for Australia's climate. Main long term weather pattern are temporarily disrupted by short term constellations like the El Nino – Southern Oscillation or the La Nina weather pattern.

El Nino is a naturally occurring phenomenon in many countries in the Asia Pacific region (Garnaut et al., 2008). It is coupled with fluctuations in the atmosphere and the equatorial Pacific Ocean and leads to changed conditions in surface temperature across the central equatorial Pacific Ocean. El Nino southern

Oscillation is thought to be once every three to seven years and leads to changes in rainfall, floods and droughts (Garnaut et al., 2008).
For Australia El Niño periods are usually (but not always) associated with below normal rainfall in the second half of the year across large parts of southern and inland eastern Australia. Oppositional weather conditions can be expected during a La Nina event (www.bom.gov.au).

In Addition major work has been undertaken by CSIRO and the Australian Bureau of Metrology (BoM) in projecting the impacts of climate change on Australia. Analysis of weather pattern from 1910 to date showed a nation wide increase of average temperatures by 0.9 C. Drought conditions observed in east and south-east Australia have been marked by a decrease in rainfall and increased average maximum temperature and heatwaves have been affecting evaporation and reducing stream flows (Garnaut et al., 2008).

5.1.2 Fire

Investigations on bushfires undertaken for the period from 1973 to 2007 showed a general increase in the forest fire danger index for the east and south east of Australia with statistically significant probability level for inland locations (Garnaut et al., 2008).
A study conducted by Lukas et al. (2007) suggests that the fire season will start earlier, end slightly later and generally be more intense with two new fire categories 'very extreme' and 'catastrophic' identified.
The Victorian bushfires experienced in February 2009 could fall into these categories.
Surrounding landscapes especially the National Parks on the western border of the PLS, the proposed rehabilitation with intensive tree planting makes the area viable to severe fires. Frequently occurring fire events (Figure 40), mainly trough fire management underline the need to develop a fire management plan to take such risk into consideration.

Figure 40: Controlled burns on the 19th September 2009 in Yellowmundi National Park just northwest of the Scheme

5.1.3 Droughts, heavy Rainfall and Floods

Temporal variations in rainfall project that annual rainfall may remain the same with an increase in intensive rainfalls while at the same time decrease in a number of days with rainfall (Garnaut et al., 2008). This could limit average water availability and hence increase stress levels on ecosystems. Furthermore a higher erosion potential and floods at times may have further negative impacts on the health and recovery potential of ecosystems and will place a constant risk on evolving ecosystems on the PLS.

5.1.4 Wind

Notwithstanding annual strong wind events occur in the area on a regular bases, these storms are not as severe as similar events in western and central Europe nor is the areas influenced by tropical storms. Hence wind damage in the area is likely to be of small scale and of low impact for the entire site if forest stands are developed properly and fully structured to withstand such impacts.
However predictions on climate change impacts are still broad based and should be monitored on a local base to be able to apply appropriate responsive management actions.

5.1.5 Rising CO_2 Levels and higher temperatures

Various research approaches undertaken to investigate the influence of rising CO_2 levels revealed likely increasing forest productivity in the next century. However research also indicates that warmer temperatures, likely to occur with rising CO_2 levels may not only increase carbon fluxes into the forest but also increase carbon fluxes back out. Higher temperatures may increase the uptake in boreal forest but potentially reduce photosynthesis activity if temperature stress occurs in warmer climates, like Australia. Furthermore rising temperatures are likely to increase soil respiration, particularly of soil organic matter and could result in a higher abundance of herbivores and insects that are able to complete there lifecycles more quickly and overwinter more readily (Galik and Jackson, 2009). As a result additional benefits in forest productivity that go along with rising CO_2 levels are likely to offset by arising natural impacts.

5.1.6 Impacts of further developments

Further development upstream of the Nepean River might lead to increased flash flooding potential with adverse effects on the PLS. In addition a decrease in air quality as a result of development and industrial activities may further limiting plant growth and hence carbon sequestration

5.1.7 Mitigation of Impacts trough forest and fire management

(a) Management Techniques to minimise disturbances

Traditional forest management plays a key role in determining the potential for carbon sequestration and susceptibility to reversal. However for the PLS traditional forest management techniques that can reduce moderate risk are not applicable for all areas.

Site preparation techniques that will lay the foundation for a healthy and well developing forest ecosystem can be applied through out the entire site.

Ploughing is known to allow deeper rooting, draining to reduce soil saturation and can be used to minimise wind vulnerability Furthermore wind impacts can be reduced if no thinning is applied.

An application of fertiliser and water crystals is a widely used technique to reduce die back rates and enhance stand development. Despite additional benefits for stand health and thus decreased susceptibility to insect and herbivore attacks, the application of fertiliser might not be possible under some ETS. Furthermore emissions produced with tied during energy intensive production processes of synthetic fertiliser are potentially lowering the net GHG benefit (Galik and Jackson, 2009).

(b) Management Techniques to maximise carbon sequestration

General management techniques that are applied to improve tree health and stand resilience against disturbances are also known to improve carbon sequestration. However rules and regulations established under the ETS may limit their use and so a general strategy for an optimal management to enhance carbon sequestration in trees remains difficult. The development of heterogenic stands with high biodiversity and various stand ages have the greatest potential to increase carbon sequestration Complementary benefits includes the full utilisation of limited site resources and the supportive growth of another provides facilitative benefits (Galik and Jackson, 2009).

Thinning as reported by Muñoz F. et al. (2005) increased the average stem, crown and total biomass of individual trees. However he also reported that there were no differences in AGB in stands ranging between 800 and 1000 stems/ha stocking density. In addition information on pruning was lacking an understanding on how early or late such an application would negatively affect biomass growth but did not have an affect on AGB during this investigation.

Notwithstanding it is obvious that the thinning of stands could positively effect biomass growth and hence carbon sequestration such management approaches should generally be excluded as the maximum of carbon sequestration is achieved under a no-thin management regime (Garcia-Gonzalo et al., 2007). Thinning and pruning of natural stands may not be possible in the Core Conservation area, but will occur naturally during succession processes.

6 Implications for the PLS

The aim of this work was to develop an understanding and application of biomass and carbon sequestration measurements to be applied to some established tree stands at the PLS. Furthermore, the work aimed to present an overview of current and developing national and international emission trading schemes and additional offset schemes. Indications of potential revenues for current and future owners of the lands within the PLS were proposed. While the first aim has been achieved, political and legislative uncertainties made it difficult to present indications on future revenues through biological asset trading.
However some implications for the PLS have been made as a result of this work.

(a) Carbon trading and current site values

The rehabilitated sites on the PLS have already sequestered carbon dioxide. As shown in Table 9, potential revenues on the current market of the NSW GGAS remain minor and the sites might not be competitive enough to enter the market. Due to restrictions of the NSW GGAS IA 6 is not applicable as sites were established prior to 2003.
Also shown are the predicted value under the proposed GPRS and the current value under the EU ETS. The area of the PLS is not eligible to participate in the European market, but it might be an indication of future global markets to be established in the long term.
A computer model based study conducted by Klaassen et al. (2002) revealed high potential cost savings between 88% and 98.5% in international carbon trading and could give further indications on possible price developments. He investigated the bilateral trading and the single bid auction approach on an experimental base. The experiment showed price equilibrium of 38.7 Euros (respectively 38 Euros) after the 17th trade.
High volatility under the bilateral trade option was present and also unpredictability as outlined for the EU ETS under section 2.1.1 remains.

Table 9: Estimated market values in established state and international markets as well as proposed future national Australian market

IA	Area Size in hectare	CO_2-e present in tonnes/ hectare	Market value under the NSW GGAS ($7/ CO_2-e)	Predicted market value under the GPRS ($25/ CO_2-e)	Current market value under the EU ETS (14€/ CO_2-e)
1	1.07	211.63	$1,585.11	$5,661.10	3,170.22 €
2	1.54	70.01	$754.71	$2,695.39	1,509.42 €
5	3.17	54.42	$1,207.58	$4,312.79	2,415.16 €
6	3.35	214.34	N/A	$17,950.98	10,052.55 €
7	4.09	148.51	$4,251.84	$15,185.15	8,503.68 €
Estimated Value of sites			$7,799.24	$45,805.40	25,651.02 €

Figure 41: Overview market estimated market values of plantations on the PLS

Bigsby (2008) outlined that international carbon trades at the Chicago Climate Exchange are undertaken with contracts built around 100 tonnes CO_2-e and that the project-based approach of carbon trading requires or assumes that sequestered carbon is stored for a long term in perpetuity. These long term commitments can also be found under the NSW GGAS and the NSW BioBanking Scheme as outlined in Chapter 2.

Entities of sufficient size are needed to provide a stable carbon reservoir and the optimal market participant is a large-scale forest owner with a constant annual harvest or an owner who is never harvesting. While this is presenting some challenges for small forest owners, Specht & West (2002) proposed a combination of several small estates to one large carbon provider on the market providing combined market power, a reduction of risks towards natural disaster and a reduction of assessment cost for each single forest owner.

In regards to the PLS, the non-harvest owner approach would mainly apply for proposed Core Conservation areas within the Scheme leaving the question of maintaining these areas over a period of 100 years with possible changing land ownership open. However a registration of these areas could provide a possible conservation tool as a change in land-use would involve additional cost for development.

The registration of urban parkland areas could also be possible depending on entry regulations to be set up under the ETS legislation (Eco Logical Australia, 2008).

Cooperation with NPWS or Forestry Australia presents some opportunities for a combined approach at the PLS area and may even apply once such a state agency takes over the responsibility of the entire area or specific land titles.

There are conclusively potential benefits of using carbon credit trading to support the development of native ecosystems on the PLS. However long-term commitments and agreements made to enable participation in a carbon market, will involve risks and uncertainties that need to be taken into consideration.

Figure 41 shows the location of areas listed in Table 9 with in the PLS.

(b) Impact of climate variations

As outlined in Chapter 5, the trade of a biological asset like forest ecosystems involves numerous risks and uncertainties. Natural disturbances that have appeared in the past such as bushfires, droughts and heavy rainfalls with flooding are expected to occur more frequently with higher intensities in the future (Garnaut et al., 2008).

For the PLS the risk of potential fires under the local summer climate conditions is always a given possibility and past records show regular and recurring fires events within or at close by areas (www.rfs.nsw.gov.au).

The risk of severe droughts threatening the established forest ecosystems on site may be slightly decreased due to the water storage capacity of the PLS. Further research might be under taken to investigate the availability of the lake water for adjoining vegetation involving a risk (floods) – benefit (water table) analysis with increasing water distance.

While the risk of drought might be reduced, the risk from floods could potentially be higher for the PLS due to its location on the Nepean floodplain. However proposed vegetation communities are highly resistant to floods and high water tables. Increased velocity and severe damage on trees during a major flood could have negative adverse effects on forests and existing carbon pools. Occurring natural re-growth may be offsetting carbon losses of decomposing trees and dead wood due to higher sequestration in younger stands (Eco Logical Australia, 2008). Further research may be under taken to investigate this hypothesis.

(c) Beneficial market developments

The new and evolving carbon markets and market structure are presenting additional risks and uncertainties for participants and forest owners in particular. The development and inclusion of new legislation, sequestration techniques and climate change science is making it difficult to predict a true carbon price. This currently evolving market contains the risk that the current price of CO_2-e may not reflect its true value with resulting uncertainties for sellers when to sell and buyer when to buy Bigsby (2008).

Different suggestions for the development of additional tools suitable for trading biological assets like forests including carbon rental and carbon banking can be found in scientific literature Bigsby (2008). These different approaches which are outlined below might reduce risks and uncertainties as well as increase trading volumes, making the market more compatible.
Bigsby (2008) points out that no market has been developed yet that can facilitate carbon rental. Carbon banking on the other hand would be able to

incorporate carbon renting. As sown in Fig. 42 such a market has three main players. The Carbon depositor presented by forest owner or low emission industries, the Banker responsible for managing the Carbon pool and the Carbon Borrowers that seek for carbon credits to offset their emissions avoiding heavy fines.

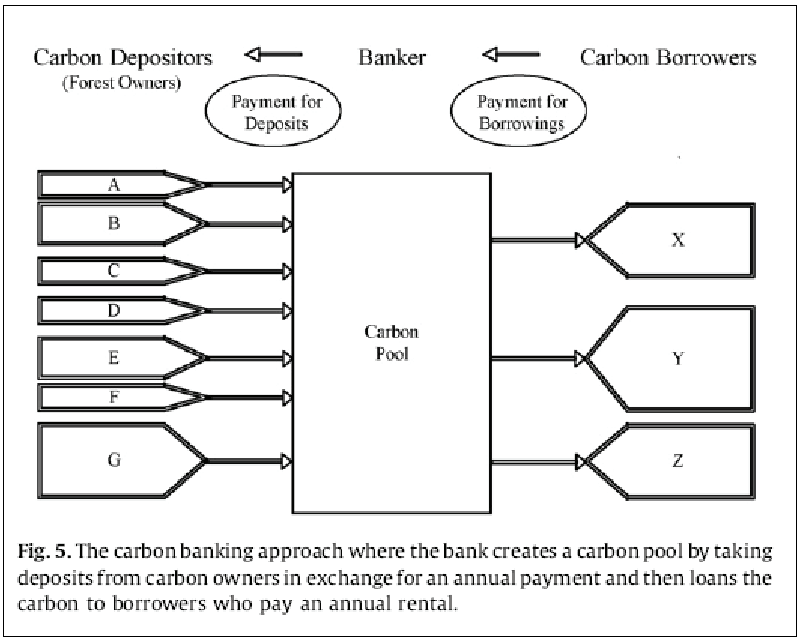

Figure 42: Carbon Banking approach adopted from Bigsby 2008, p. 381

Time scales of five years (Table 10) are proposed and favoured by Bigsby (2008) and Maréchal and Hecq (2006).

After this time the Carbon depositor is granted the credits back that can subsequently be used to re-enter the market or to offset past impacts on carbon pools caused by natural disaster. Additional to the re-granted carbon credits, the sequestration increment in individual carbon pools can be deposited to the market carbon pool.

Table 10: Five year accounting scenario adopted from K. Maréchal, W. Hecq (2006), p. 708

Number of tCER5 generated according to the "5 years accounting" scenario

Year	Sequestrated tons/year/ha	Number of TCER5
1	21	0
2	21	0
3	21	0
4	21	0
5	21	105
6	21	0
7	21	0
8	21	0
9	21	0
10	21	210
11	21	0
12	21	0
13	21	0
14	21	0
15	21	315
16	21	0
17	21	0
18	21	0
19	21	0
20	21	420

To reduce the risks, different carbon pools should be installed for the PLS. Galik and Jackson (2009) suggests the development of a 'live tree' and 'dead wood' carbon pool. In the event of a major disturbance of the registered forest, the dead wood could be transferred to dead wood pool that will over time re-emit to the atmosphere at a yearly rate. This will reduce the amount of carbon immediately lost and only parts of the sold credits have to be brought back from the market immediately. This will allow the time and flexibility to wait for more convenient carbon prices on the market or offsets by the growing forests on site.
Conclusively the participation of forest owners in a carbon trading can provide short term incomes, but future liabilities inherent with long term commitments and agreements for forest losses might be higher than what the carbon was sold for. Above outlined natural disaster and events change the amount of carbon stored on site, forcing the forest owner to compensate with credits purchased elsewhere for potentially increased prices Bigsby (2008).

The creation of carbon buffer withheld or a flat contribution to a pooled buffer as required under some ETS is another approach to reduce risks Galik and Jackson (2009).

7 Limitations

The focus of this work was to investigate the above and below ground biomass currently present in plantation and rehabilitated site on the PLS and relate this to potential revenues to be generated in future ETS. This aim was achieved and an overview of sites that could potentially enter the NSW GGAS revealed only marginal revenue opportunities.

Time limitations of the work and the fact that the Penrith Lakes Scheme is a rehabilitated site made it impossible to use the more precise sampling methods to estimate biomass.

Further research should focus on soil carbon, and the potential of native grass areas and wetlands and other water bodies on site for carbon sequestration potential. In addition a modelling approach using adequate computer models like the 3PG – model would further improve estimations and risk benefit analyses for the site.

Inter-species relationships including competition and symbiotic effects should also be investigated to possibly improve and accelerate rehabilitation effort and processes.

8 Recommendations

1. The conduct of more sophisticated studies to develop site specific equations for the PLS should be considered by PLDC.
2. Ongoing use of the established permanent growth plots should be considered, and at least an annual measurement should be undertaken to determine site-specific biomass and carbon increments.
3. Increments in basal area and biomass could be used as indicators for ecosystem development and evaluation of applied management strategies.
4. Based on revegetation experiences, the development of a data base (under the 3-PG Computer Model Program) would be capable of predicting and forecasting carbon sequestration onsite and taking possible risks (e.g. drought, fire and flooding) into consideration. This data base could also be used to run a risk benefit analysis.
5. The registration of a small single area (up to 5 ha) under the NSW GGAS should be considered to gain valuable experience while risks are low. Possible future losses could be offset through ongoing rehabilitation on site.
6. To enter the NSW GGAS for the trial sites, already registered companies might be consulted to minimise registration fees and time involved. Shareholders of the PLS might have an interest in sequestered CO_2-e themselves to offset emissions or to use it for CSR purposes (e.g. Sustainability Report)
7. Studies should be conducted to investigate the carbon offset potential of wetlands across the site that can subsequently be used as risk management tool for possible carbon losses due to wild fires. However, the impact of fires on wetlands and reductions of carbon pools in these areas needs to be investigated as well.
8. The preparation of fire management strategies will be necessary for the completed scheme and urban development. If the decision is made to enter the carbon trading market these strategies should also include risk mitigation strategies for carbon pools on site.

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10 Appendices

I. GIS Maps of Plot Location within the Penrith Lakes Scheme

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Riverbank South 1

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Riverbank South 2

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II. Tree Plot Data Sheet

<table>
<tr><td colspan="3">Name of the Area (Ref. no):
Regeneration Riverbank North (1)</td><td colspan="5">Tree
plot no: **1**</td><td>Plot size:
625 m²</td><td colspan="3">Investigator:
Date:</td></tr>
<tr><td rowspan="4">Location:</td><td>1st corner</td><td colspan="6">Easting:</td><td colspan="4">Northing:</td></tr>
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<tr><td>4th corner</td><td colspan="6">Easting:</td><td colspan="4">Northing:</td></tr>
<tr><td>Species no:</td><td>Species name</td><td>Tree number</td><td colspan="5">GBH of stem (cm)
1 2 3 4 5</td><td>Planted or regenerated</td><td>Height (m)</td><td>Status of Crown (% cover)</td></tr>
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