Greenhouse gasses and climate change

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Appendix W

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South Metro Connect

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Executive Summary

South Metro Connect is currently in project development phase for the proposed extension of Roe Highway between Kwinana Freeway, Jandakot and Stock Road, Coolbellup. As part of the project development phase, a range of environmental studies have been commissioned by South Metro Connect to enable a comprehensive assessment of the existing environmental condition of the project area and to inform the assessment of potential impacts associated with construction and operation of the road.

In considering the greenhouse gas and climate change implications associated with the development of the Roe Highway Extension, South Metro Connect is able to understand the project both in terms of the net effect of greenhouse emissions and the impact that global increases in greenhouse gases may have as a result of construction of the road. In terms of greenhouse gas emissions, the construction of Roe Highway Extension will result in the emission of greenhouse gases during both the construction and operational phases of the project. These emissions are offset by the considerable emission reductions associated with an improved transport route for both passenger and freight traffic, which are estimated at 59kt $CO_{2\text{-eq}}$ per annum.

When considering the potential impact of climate change on the road and surrounding environment, the available historical evidence suggests that the direct human-induced changes on the Bibra and North Lake system have been substantial and it is likely that these impacts will make discerning climate change impacts difficult. The impact of new developments, including those associated with the proposed Roe Highway Extension, will add to the various selective pressures in and around the wetland systems, as will pressures associated with climate change. However, at least in the near term, impacts of direct human activities are likely to be much more significant than those associated with climate change alone. Therefore, active management and design to maintain ecological integrity will be required (including the management of existing pressures) to improve the adaptive capacity of the system to both a changing climate and urban development.

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1.0 Introduction

South Metro Connect is currently in project development phase for the proposed extension of Roe Highway between the Kwinana Freeway, Jandakot and Stock Road, Coolbellup. As part of the project development phase, a range of environmental studies have been commissioned by South Metro Connect to enable a comprehensive assessment of the existing environmental condition of the project area and to inform the assessment of potential impacts associated with construction and operation of the road.

Greenhouse gases (GHGs) are a group of gases that are known to contribute to an increase in the natural warming of the Earth. Traditionally known as global warming, the term climate change is now used to describe the impacts of the increased greenhouse effect on the Earth as the effects are understood to be more complex than just a change in the average temperature. Whilst carbon dioxide is the most well known greenhouse gas, a range of gases are recognised internationally by the Intergovernmental Panel on Climate Change (IPCC) as GHGs including water vapour, carbon dioxide, methane, nitrous oxide and a number of artificial gases including the Montreal Protocol gases such as hydrofluorocarbons, perfluorocarbonated compounds and fluorinated ethers.

The Intergovernmental Panel on Climate Change (IPCC), in their Fourth Assessment Report, has stated that observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level are indicative of 'warming' of the climate system. Discernible human influences extend also beyond average temperature to other aspects of climate, including temperature extremes and wind patterns (IPCC 2007). As a result, there is a growing consensus within the international scientific and political community of the need to keep the increases in global average temperature to within 2°C, corresponding to a concentration of less than 400 parts per million of carbon dioxide in the atmosphere (IPCC 2007). Progress to establish binding emissions targets in support of reducing the annual growth in global emissions has begun, however regulatory frameworks to support reduced emissions reductions are yet to be fully implemented.

Recent climate change (global warming) has largely been attributed to the increase in atmospheric concentrations of greenhouse gases caused largely by anthropogenic emissions (IPCC 2007). Global atmospheric concentrations of carbon dioxide in 2005 were 379 parts per million, up from 280 parts per million in pre-industrialised times. In particular, increases in carbon dioxide, methane, nitrous oxide and the halocarbons are 'very likely' to be the result of human activities (IPCC 2007). International efforts are underway to regulate greenhouse gas emissions across the Earth, with many developed nations committing to emission reductions as a result of being signatories to the Kyoto Protocol. Adaptation planning associated with communities and infrastructure has already commenced both within Australia and internationally.

The principles and approaches for managing the risk of climate change, including greenhouse gas mitigation, are developing rapidly and there is much debate as to the mechanisms for managing greenhouse gas emissions, including the magnitude and timing of emissions reduction targets. Notwithstanding this, emissions targets are likely be referenced against emissions from a baseline year, potentially either the years 1990 or 2000. Global emissions in 1990, excluding land use changes, were estimated to be 22,530 Mt $CO_{2\text{-eq}}$, with 2000 emissions estimated to be 24,697 Mt $CO_{2\text{-eq}}$ (Boden et al 2009).

An assessment of the greenhouse and climate change aspects associated with the project area has been undertaken and is discussed in this report.

1.1 Regulatory and Policy Frameworks

This summary describes relevant International and Australian domestic regulatory frameworks for both greenhouse gases and climate change. Whilst a causal relationship has been recognised between greenhouse gases and climate change, there are significant differences between them, such that policy and regulatory approaches for these are often considered independently of each other.

1.1.1 Climate Change Mitigation (Greenhouse Gas Management)

The reporting, management and reduction of greenhouse gas emissions is covered by a range of regulatory frameworks.

- United Nations Framework Convention on Climate Change (UNFCCC), including Kyoto Protocol and Copenhagen Accord
- National Greenhouse and Energy Reporting (NGER) Act 2007 and associated legislation and guidelines, administered by the Department of Climate Change and Energy Efficiency
- EPA Guidance Statement Number 12
- ISO 14064-2:2006 Greenhouse gases – Part 2: specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements

1.1.1.1 Framework Convention on Climate Change

Greenhouse gas emissions are addressed internationally through the United Nations Framework Convention on Climate Change. The Convention provides a framework for intergovernmental responses to climate change through the establishment of national emissions inventories, the mitigation of future emissions and assistance for adaptation to the expected impacts resulting from emissions. The development and sharing of new policies to address these issues and the identification of best practice policies and actions is also a key outcome of the UNFCCC. The Convention imposes no obligations on governments as these are addressed in Protocols, such as the Kyoto Protocol.

The UNFCCC and the Kyoto Protocol are the international regulatory frameworks for Australia's international obligations on climate change. The Kyoto Protocol established binding emissions targets for industrialised nations, including Australia. These emission targets are typically reductions compared to the emissions of the baseline year to be achieved by the end 2012 and represent an average emission reduction of 5% of 1990 levels. Australia's emissions target was set under the Kyoto Protocol at 108% of 1990 levels.

In 2007, the Australian Government ratified the Kyoto Protocol, committing Australia to the reporting of emissions utilising a National Inventory and the binding emissions targets set out in the Protocol. Australia had been collating information about Australia's greenhouse emissions as part of the Australian Greenhouse Emissions Information System (AGEIS), well before ratification of the Protocol in Australia and as a result emissions inventories for 1990 to 2007 are available.

1.1.1.2 International Standards

ISO 14064-2:2006 (Part 2) is a project level standard outlining the methodologies for the evaluation, monitoring and reporting of greenhouse emissions. The ISO 14064 family of standards are voluntary standards, although the methodology is frequently used as the basis for project and organisational emissions inventories, including the Australian National Greenhouse and Energy Reporting scheme.

The ISO 14064 family of standards consist of three parts:

- Part 1 - Greenhouse gases: specification for the quantification, monitoring and reporting of organisation emissions and removals;
- Part 2 - Greenhouse gases: specification for the quantification, monitoring and reporting of project emissions and removals; and
- Part 3 - Greenhouse gases: specification and guidance for validation, verification and certification.

1.1.1.3 National Greenhouse and Energy Reporting Act

The focus of regulatory frameworks in Australia has been on the development of greenhouse gas reporting rather than on aspects associated with the identification and management of risks associated with climate change and adaptation options. Additionally, a large number of vulnerability assessments and adaptation planning activities are underway at the local, state and national level.

In 2008, the National Greenhouse and Energy Reporting Act 2007 (NGER Act) was enacted, designed to establish a single framework for the reporting of greenhouse emissions, energy production and energy consumption across all Australian jurisdictions for large organisations with large greenhouse emissions or energy consumption. The NGER Act forms the basis for the reporting elements, including reporting for the CPRS, through the establishment of a national system for reporting greenhouse gas emissions, energy consumption and production by corporations which commenced on 1 July 2008.

NGER and the National Greenhouse Account Factors are consistent with the ISO14064:2006 family of standards.

As a Government Authority, Main Roads WA does not trigger mandatory reporting of greenhouse emissions and energy use under the NGER Act. However, it is possible that construction partners may trigger reporting thresholds depending on the cumulative impact of the emissions and energy use associated with activities and projects they are working on.

1.1.1.4 Western Australian Environmental Protection Agency

The EPA’s Guidance Statement No.12 for Minimising Greenhouse Gas Emissions sets out the EPA’s overarching goal as being to reduce emissions to the lowest possible level. To achieve this the EPA's environmental assessment objective is to ensure that potential greenhouse gas emissions emitted from proposed projects are adequately addressed in the planning/design and operation of projects and that:

- best practice is applied to maximise energy efficiency and minimise emissions;
- comprehensive analysis is undertaken to identify and implement appropriate offsets; and
- proponents undertake an ongoing program to monitor and report emissions and periodically assess opportunities to further reduce greenhouse gas emissions over time.

1.1.2 Climate Change Impact and Adaptation

Adaptation to climate change is not currently mandated by Federal, State or Local government laws or regulations. However, the Commonwealth Department of Climate Change (DCC) has developed an established protocol, based around AS4360-2006. *Climate Change Impacts and Risk Management; A Guide for Business and Governments* (2006) has become the accepted method for undertaking climate change risk and vulnerability assessments within Australia.

Consideration of climate change impacts on drainage and runoff management associated with road design will be included for the first time in the forthcoming release of *Australian Rainfall and Runoff* (AR&R).

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2.0 Greenhouse Gas Emissions

Greenhouse gas emissions can come from a large variety of sources, which may be difficult to delineate and quantify. However, in order to be able to evaluate the degree of impact of a project, it is essential to be able to do so and to have consistent, relevant, accurate and transparent methods for achieving this. The delineation and quantification approach used in Australia in the *National Greenhouse and Energy Reporting Act 2007* (NGER Act) mirrors the approach that has been accepted internationally through ISO14064-2:2006 Greenhouse gases. This approach defines emissions in terms of whether they are considered to be direct or indirect emissions. This assessment uses the terminology and approaches defined by the Australian NGER Act.

2.1 NGER Principles

The NGER Act is based on four key principles of the reporting of greenhouse and energy emissions: the principles of transparency, comparability, accuracy and completeness. Definitions for the NGER Act accounting principles are provided below in Table 1.

Table 1 - Greenhouse gas accounting principles *National Greenhouse and Energy Reporting Guidelines, (DCC 2008)*

Greenhouse gas reporting principle	Explanation
Transparency	Appropriate levels of disclosure in greenhouse gas reporting are essential for report integrity. Justification must be provided for specific data which is included or excluded. A good litmus test is if an external verifier can produce the same assessment as the reporting organisation. Estimates must be documented and verifiable.
Comparability	Emission estimates must be comparable with estimates produced by similar corporations in that industry sector.
Accuracy	Accuracy refers to the correctness of data, that is, calculations should be neither over nor under the actual emissions value. As far as possible, any uncertainty ought to be removed or limited.
Completeness	Completeness refers to the inclusion of all relevant emissions within a chosen inventory boundary such that data used for calculations are 'comprehensive and meaningful'. Where an organisation elects to omit certain emissions, justification needs to be provided to ensure integrity is maintained. Organisations must account for all identifiable emission sources within the energy, industrial process and waste sectors as specified in the *National Greenhouse Accounts*.

2.2 Defining scope 1, 2 and 3 emissions

The NGER Act requires that organisations report scope 1 and scope 2 emissions. A brief summary of the differences between emission scopes is provided below.

Scope 1 – Direct greenhouse gas emissions;

Scope 2 –Indirect greenhouse gas emissions (Purchased Electricity, heat or steam); and

Scope 3 – Other indirect greenhouse gas emissions.

Figure 1 below provides a high level overview of the differences in emissions. Scope 3 emissions are not defined in the NGER Act, as reporting them is not mandatory. Scope 3 emissions are typically included in carbon footprint calculations.

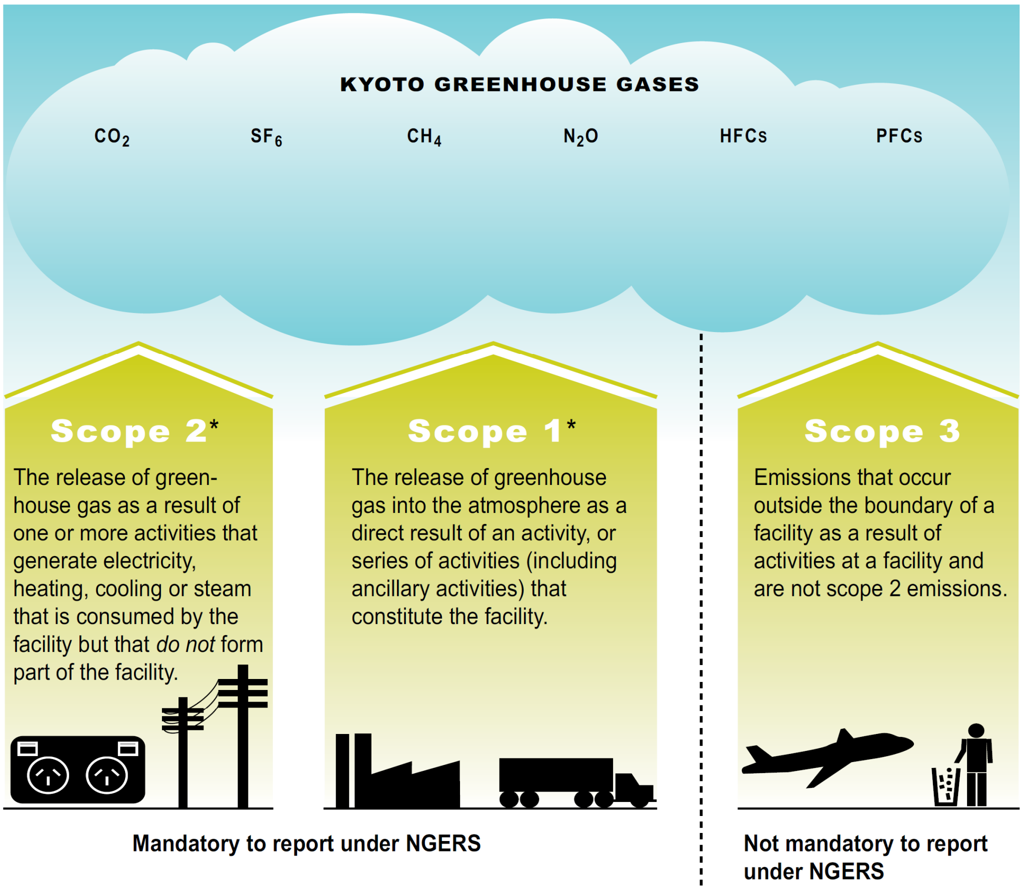

Figure 1 **Emission scopes (NGER Reporting Guidelines, (DCC, 2008)**

Direct emissions are all those emissions from the activity under consideration that are under the direct control of the proponent, in this case Main Roads WA, including those emissions which may result from the activities of the construction partner selected to build the road and supporting infrastructure. The emissions that are directly under the control of the proponent are considered scope 1 emissions using the NGER framework.

Indirect emissions are all those emissions that arise as a consequence of undertaking the activity but which are not under the direct control of the company responsible for the activity. These can be further broken down into scope 2 and 3 emissions. The NGER Act described scope 2 emissions as electricity and any activities that generate heating, cooling or steam, but which are not directly controlled by the organisation responsible for the activity. Scope 3 emissions are all the other indirect emissions occurring as a result of the activity, excluding scope 2 emissions, for example the emissions associated with vehicular movement along the constructed extension.

The purpose of differentiating between the scopes of emissions is to avoid the potential for double counting. This can occur when two or more organisations assume responsibility for the same emissions or reductions in the same category.

2.3 Sources of Greenhouse Gas Emissions

While there are a wide range of gases that can contribute to the greenhouse effect, only six are required to be reported on under the Kyoto Protocol. These are carbon dioxide (CO_2), methane (CH_4), Nitrous Oxide (N_2O), sulphur hexaflouride (SF6), perfluorocarbons, and hydrofluorocarbons. As each of these gases has a different global warming potential, the total emissions are often converted to the equivalent amount of carbon dioxide ($CO_{2\text{-}eq}$) that would result in the same level of climate change. This report will maintain this convention and use the conversion factors described by the Department of Climate Change [and Energy Efficiency] (2009) in the National Greenhouse Accounts Factors.

This assessment will identify the sources and quantities of greenhouse gas emissions associated with the scope 1 and 2 activities from the construction phase and limited scope 2 and 3 emissions from the operational phase. For the purposes of this report, scope 1 emissions will include all direct emissions from construction of the road, although it is likely that these emissions will be under the direct control of the construction partner rather than the asset owner, Main Roads WA.

The emission sources that have been identified are shown in Table 2.

Table 2 Sources, development phase and scopes of carbon emissions

Source of Emissions	Activity / Phase	Scope of Emissions
Vegetation clearing	Construction	1
Pavement (road) construction	Construction	1
Bridge Construction	Construction	1
Construction of supporting infrastructure (Pathways etc)	Construction	1
Site and office electricity consumption	Construction	2
Street lighting	Operation	2
Vehicles using the road after construction	Operation	3
Embodied energy	Construction	3

At this stage of project design, it is not possible to accurately estimate the emissions to within the typical level of accuracy (±10%) usually associated with assessments. An accuracy of ±50% is assumed for the conceptual design phase of the project. This level of uncertainty arises from both the level of detail associated with conceptual design and the inherent uncertainty associated with estimating some emission sources (including vegetation clearing).

Site and office electricity consumption is likely to be insignificant in the context of other emission sources at approximately 1% of project emissions.

2.4 Carbon Emissions from Vegetation Clearing

Vegetation clearing is a key component to many road construction projects, including for the Roe Hwy Extension. Traditionally, most cleared vegetation is used for mulch or compost during roadside revegetation. Onsite mulching is a practical solution, with plant and equipment widely available to mulch the large volumes of vegetation produced on site. Mulch production is energy intensive and the mulch decomposes relatively quickly, releasing the carbon content of the cleared vegetation in a period of two to10 years depending on particle size.

As a result, the clearing of vegetation is a source of greenhouse gas emissions, both through the clearing of land (land use change) and the emission of principally carbon dioxide when the cleared vegetation is burnt or decomposes. Although emissions associated with vegetation are currently not reportable at corporation or facility levels, it is important to understand the magnitude of emissions as part of consideration of the environmental impacts of projects.

2.4.1 Estimating carbon content of heterogeneous communities

There are a number of methods that have been used to estimate the carbon content of above and below ground standing biomass including the collation of vegetative inventories, site specific studies, remote sensing, modelling land cover change, forest type, biomass growth, etc. (Australian Greenhouse Office, 2005; Booth, 2003). Many models used to estimate emissions, including the National Carbon Accounting System (NCAS), quantifies carbon in vegetation based on the Full Carbon Accounting Model (FullCAM), which provides a 25m grid resolution (Australian Greenhouse Office, 2006; Booth, 2003; Richards, 2001) and as a result is best suited to land with some degree of homogeneity of species and quality over this scale.

The determination of the biomass and carbon contents in standing trees is usually accomplished by using calculations that approximate the tree characteristics, such as the total volume of stems, crowns, roots and tops for different sizes, ages and tree spacing (Australian Greenhouse Office, 1999; Bi et al., 2004; Ritzon and Sochacki, 2002). When destructive determination of the carbon contents is not possible or desirable, allometric equations enable the use of basal measurements including tree height, or the stem diameter at breast height (DBH) or diameter at breast height over bark (DBHOB), to be used to approximate carbon content (Brokaw and Thompson, 2000; Eamus et al., 2000; Keith et al., 2000; Snowdon et al., 2002; Zianis and Mancuccini, 2004). It should be noted that there are a number of known issues associated with the use of allometry and the lack of allometric equations to estimate carbon content for all regions. Allometric equations are known to be highly site specific, only applying to the forest stand where they were derived and equations are likely be unsuitable outside of the tree size class and region of which they were obtained when accurate estimation is required (Richards, 2002; Snowdon et al., 2000). However, the main source of error with available biomass estimation equations derives from the regression analysis. Statistical comparisons and combining equations are severely restricted by a lack of standard mathematical form, differences in independent variables, and lack of statistical information and original data (Australian Greenhouse Office, 1999).

2.4.1.1 Biomass Density Estimation

Conversion of measurements to total forest biomass requires wood density measurements and expansion factors that account for the stem as a proportion of the total tree including stem, bark, branches, twigs, leaves and root data (Australian Greenhouse Office, 1999; Keith et al., 2000). For the estimation of carbon content of the proposed vegetation clearing for this project, wood density calculations from the NCAS have been used and are shown in Table 3.

Table 3 Partitioning of biomass and wood density values by major vegetation group (MVG) class. Source: (Australian Greenhouse Office, 2002).

Vegetation	Stem	Branches	Bark	Leaves	Coarse root	Fine roots	Dry wood density (kg/m^2)
Eucalyptus Tall Open Forests	0.67	0.09	0.10	0.02	0.03	0.08	550
Eucalyptus Open Forests	0.65	0.07	0.07	0.01	0.05	0.15	625
Eucalyptus Low Open Forests	0.45	0.12	0.10	0.02	0.05	0.25	550
Eucalyptus Woodland	0.36	0.15	0.10	0.02	0.06	0.31	890
Acacia Forest and Woodland	0.36	0.15	0.10	0.02	0.06	0.31	940
Callitris Forest and Woodland	0.36	0.15	0.10	0.02	0.06	0.31	650
Casuarina Forest and Woodland	0.36	0.15	0.10	0.02	0.06	0.31	860
Melaleuca Forest and Woodland	0.36	0.15	0.10	0.02	0.06	0.31	660
Other Forest and Woodland	0.36	0.15	0.10	0.02	0.06	0.31	800
Tropical Eucalyptus Woodland/Grassland	0.36	0.16	0.10	0.02	0.06	0.30	830
Eucalyptus Open Woodland	0.36	0.15	0.10	0.02	0.06	0.31	890
Acacia Open Woodland	0.22	0.165	0.10	0.025	0.07	0.42	940
Mallee Woodland and Shrubland	0.22	0.165	0.10	0.025	0.07	0.42	1060
Low Closed Forest and closed Shrubland	0.22	0.165	0.10	0.025	0.07	0.42	1000
Acacia Shrubland	0.22	0.165	0.00	0.025	0.07	0.42	940

Vegetation	Stem	Branches	Bark	Leaves	Coarse root	Fine roots	Dry wood density (kg/m^2)
Other Shrubland	0.22	0.165	0.10	0.025	0.07	0.42	940
Heath	0.00	0.30	0.18	0.03	0.07	0.42	900
Chenoped Shrub, Sampire Shrub &Forbland	0.00	0.30	0.18	0.03	0.07	0.42	900
Unclassified Vegetation	0.39	0.14	0.09	0.02	0.06	0.30	780

Biomass estimation through allometric relationships can be complicated by seasonal and annual variability, unique underground vegetative structures, fire, or unusual environmental conditions (Turner et al., 1999). At the landscape scale, soil types, soil texture, local topography, water availability and the condition and exposure of individual trees influence many aspects of the vegetative communities (Kort and Turnok, 1999). Open-spaced trees are subjected to greater mechanical wind stress and respond by increasing the thickness of stems, branches, and particularly the root system (Ritzon and Sochacki, 2002).

The proportion of total tree biomass in roots is generally between 30 - 50% of aboveground biomass (Kort and Turnok, 1999). The amount of aboveground biomass also increases as the trees age relative to the biomass in roots. This is more pronounced with open spaced trees than close-spaced trees (Ritzon and Sochacki, 2002). This assessment has developed underground biomass “root-to-shoot” (RS) estimations based on these percentage proportions, vegetative size and how exposed they are to mechanical wind stress. Root to shoot (RS) ratios are used to estimate belowground biomass from aboveground data (Australian Greenhouse Office, 2006).

2.4.1.2 Carbon Density Estimation

Biomass estimates are converted to carbon by applying carbon factors, which are remarkably consistent between species (Australian Greenhouse Office, 2006). Australian research by Gifford (2000) found that overall carbon contents of all tree tissues and species was 50%, while leaves exhibit slightly higher carbon content of 52.8%, and leaf litter carbon content was 54.3%. Gifford recommended for when a single percentage of carbon value is required to represent all aboveground components of all species, a value of 50±2% be used, including for Australian native species. Gifford (2000a) also obtained an averaged value for the carbon content of coarse root wood of 49±1%, based on an analysis of 23 species. The range of these 23 species was 46.7 to 51.2%. When a single figure is required that represents the carbon content of all woody components above and belowground (including branches and coarse roots), 49±2% is suggested by Gifford. This assessment uses the carbon factor of 49% to approximate carbon density for both above and below ground vegetative biomass carbon density. While carbon factors themselves add little uncertainty to carbon estimates, the errors of biomass calculation carried through assessments remain the greatest source of uncertainty.

2.4.1.3 Estimation of carbon content for the Project Area

In estimating the carbon content of cleared vegetation for the Roe Highway Extension many of the complexities associated with future projections and biomass growth considered as part of other models are unnecessary as the project will not result in wide-scale deforestation. The availability of detailed site data based on flora and vegetation surveys available for the project area has enabled a customised assessment, based on actual vegetative communities at the site, to be developed. This simplified method for determining carbon contents, at a resolution of approximately 10m, is based on a manual count of individual trees from satellite and aerial imagery, in combination with on-site vegetative community assessments and available allometric data which has been developed for a large number of Australian species in specific geographic areas (Australian Greenhouse Office, 1999; Bi et al., 2004; Eamus et al., 2000; Richards, 2002; Specht and West, 2003). Therefore, this estimation of carbon content of cleared vegetation incorporates simple wood biomass and carbon density data to reduce the error of both interpretation, and the lack of statistically useful allometric equations for the particular region surrounding the project area. Whilst this is likely to result in an underestimate of the carbon content of the cleared vegetation, it should be noted that the majority of the carbon content of vegetation is contained within the woody biomass rather than the leaves.

The number and estimated size of trees within each vegetative community type was determined by collating the area, condition, vegetative density, and approximate biomass for each vegetation community. The input data was derived from flora assessments of the sites that are proposed to be cleared for construction. The vegetation communities in the proposed clearing areas were relatively well spread between G (good) and VD (very degraded). As only 2 ha of the vegetation proposed to be cleared was classed as VG (very good), and around 4.5 ha was classed as VG-G (very good to good), the biomass assessment did not include smaller vegetative communities that generally thrive in areas classed as VG and VG-G. This information is presented in Table 4.

Table 4 Vegetation area and condition for each proposed cleared vegetative community type

	Vegetation Area and Condition (ha)							
Vegetation Communities	**VG**	**VG-G**	**G**	**G-D**	**D**	**D-CD**	**CD**	**Total (ha)**
BaNfW			0.02		0.18			0.21
BHhW			2.35	0.72	0.82	4.70	0.04	8.63
BiSiH			0.25		0.03			0.28
BXpW			0.05		0.65			0.70
CcBKgS			0.01	0.24				0.25
CcXpDdS			0.09	0.42	0.39	0.30	0.21	1.41
CcXpMrS			1.07	5.24	2.99	4.07	0.13	13.50
EgXpS			1.42	1.19	3.00	1.27		6.89
EmApS			1.18	0.36		0.37	0.04	1.95
EmKgS						0.70		0.70
EmXpS			0.12	0.23	0.84	1.11	0.48	2.78
ErCtS	0.27							0.27
ErMpAfS		0.08						0.08
ErMpGeS		0.24		0.01				0.25
ErMpH						0.31	0.10	0.40
EtKgS			0.06	0.12				0.18
MpBaS								0
MpKgS			0.26		0.15			0.41
BAhS		1.32	0.74					2.05
JfKgE						0.08	0.13	0.21
EmBaS		0.34	0.25					0.60
BaTS	1.65	2.53	2.53	0.35	0.35	1.69	0.13	9.22

Inclusion of the largest biomass communities (often larger trees) that dominate biomass calculations is consistent with vegetation communities that are not classed VG of VG-G. Therefore, the biomass assessment included an estimate of the total volume of wood of each community per unit area, based upon the height and width of larger trees from satellite imagery. This data is presented in Table 5. The largest potential source of error is likely to originate from this volumetric estimation from the average number and size characteristics of the trees per hectare. While a representative sample was taken for these volumetric estimations, the average condition and the fragmentation of the communities in many areas introduces further uncertainty.

The vegetation community codes were then correlated with major vegetation groups (MVGs) based on the common species of each. This enabled higher resolution biomass estimation by using the wood density values by MVG from Table 5. From the volume estimation, the dry mass can be obtained in kg of wood, as the wood volume is generally independent of whether the wood is dry or wet. The MVG wood densities derived from the Australian Greenhouse Office (2002) data were incorporated with the RS ratio selected according to a representative selection of each vegetative community. This selection was based on the satellite data of how large the vegetation was, which often corresponds to the age of the largest trees that comprise the majority of the biomass in forested areas. The "openness" of each the vegetation community also impacts the RS ratio. Table 5 shows that an RS ratio between 0.3 and 0.5 was selected to represent the belowground biomass according to recommendations of age and exposure to winds (Kort and Turnok, 1999).

After the estimation of the total above and belowground biomass for each vegetation community was determined, a species independent carbon factor of 49% was used to obtain the mass of carbon per hectare a contained in each vegetation community as recommended by Gifford (2000a). Conversion of the mass of carbon (tC) is then made to tonnes of carbon dioxide equivalent ($tCO_{2\text{-}eq}$). The total estimated $tCO_{2\text{-}eq}$ emission estimate from the removal of vegetation (including belowground biomass), is 3478.8 $tCO_{2\text{-}eq}$, assuming that all the carbon is converted to carbon dioxide (Table 5).

Table 5 Carbon estimation for each vegetative community type

Veg. Communities & similar (MVG)	Av. trees per Ha	(Est.) Above-ground av. tree vol. (m^3)	(Est.) RS ratio for below-ground volumes	Sum of total vol. per ha	MVG wood density (kg per m^3)	tC per ha using 49% C density	Ha	(Est.) tC per Class ±50 %	(Est.) $tCO_{2\text{-}eq}$ ±50%
BaNfW MVG10)	35	2.25	0.35	106.3	800	41.7	0.2	8.7	31.8
BHhW (MVG10)	70	0.3	0.4	29.4	800	11.5	8.6	99.5	365.0
BiSiH (MVG10)	80	0.4	0.4	44.8	800	17.6	0.3	5.0	18.2
BXpW (MVG10)	50	1.5	0.4	105.0	800	41.2	0.7	29.2	107.3
CcBKgS (MVG4)	40	1.6	0.35	86.4	550	23.3	0.2	5.7	21.1
CcXpDdS (MVG5)	30	2.4	0.4	100.8	890	44.0	1.4	62.0	227.5
CcXpMrS (MVG4)	40	2	0.4	112.0	550	30.2	13.5	407.5	1495.3
EgXpS (MVG3)	12	2.25	0.35	36.5	625	11.2	6.9	76.9	282.1
EmApS (MVG3)	75	0.5	0.4	52.5	625	16.1	1.9	31.3	115.0
EmKgS (MVG5)	2	3.8	0.35	10.3	890	4.5	0.7	3.1	11.5
EmXpS (MVG4)	20	2.5	0.35	67.5	550	18.2	2.8	50.7	185.9
ErCtS (MVG5)	70	1	0.4	98.0	890	42.7	0.3	11.5	42.4
ErMpAfS (MVG4)	75	0.9	0.4	94.5	550	25.5	0.1	2.0	7.5
ErMpGeS (MVG9)	75	0.75	0.4	78.8	660	25.5	0.3	6.4	23.4
ErMpH (MVG9)	25	0.9	0.4	31.5	890	13.7	0.4	5.6	20.4
EtKgS (MVG5)	50	0.3	0.4	21.0	890	9.2	0.2	1.6	6.0
MpBaS (MVG3)	40	0.8	0.4	44.8	625	13.7	0.0	0.0	0.0
MpKgS (MVG9)	80	0.3	0.4	33.6	660	10.9	0.4	4.4	16.3
BAhS (MVG10)	80	0.3	0.4	33.6	800	13.2	2.1	27.1	99.3
JfKgE (MVG4)	25	1	0.4	35.0	550	9.4	0.2	2.0	7.3
EmBaS (MGV5)	75	0.25	0.35	25.3	890	11.0	0.6	6.6	24.2
BaTS (MGV10)	80	0.25	0.4	28.0	800	11.0	9.2	101.2	371.4
Total								947.9	3478.8

Due to the number of interpretive steps taken to estimate biomass and the carbon content of both the above and belowground biomass, there is a high degree of uncertainty associated with this assessment, with accuracy of ±50%. It should be noted that this estimation of carbon emissions associated with vegetation clearing does not include any loss or gain of soil organic carbon associated with the vegetation clearing.

Whilst an accuracy of ±50% would appear to undermine the reliability of the assessment, it is important to recognise that this estimation provides an indicative and upper limit of carbon emissions associated with the removal of trees (upper limit of 5218.2 tCO_{2-eq}).

2.5 Carbon Emissions from Initial Road Construction

At this conceptual design, accurate quantity estimates used for construction have not been developed. In lieu of this, carbon emissions associated with construction an estimation of these emissions has been developed based on estimated carbon emissions associated with the construction of the Mickleham Road duplication project from Victoria. The Mickleham Road duplication has been used as a reference as there are no comparable estimates for Western Australia. Recent work completed for Main Roads (Access Alliance 2010, AECOM 2010b) has identified that construction emissions are highly site specific, with values of between 92 – 272 tonnes per lane kilometre calculated for regional road upgrade projects in Western Australia. Mickleham Road represents a 2.4km long metropolitan road construction project with bridge components, services, drainage and shared path.

Total carbon footprint of the Mickleham Rd project is 190 tonnes CO_{2-eq} per lane per kilometre, with 75 percent of emissions associated with the embodied energy of materials used in construction. On site emissions associated with construction for Mickleham Rd were 47.5 t CO_{2-eq} per lane per kilometre (Maguire 2009). Embodied emissions associated with materials used in construction on the proposed project are estimated at 142.5 t $CO_{2-eq.}$ per lane kilometre (3468 t $CO_{2-eq.}$ in total). Electricity emissions associated with site office activities are expected to represent approximately 1% of total emissions for the construction.

2.6 Carbon Emissions from Operational Phase

Street lighting associated with illuminating both the vehicle and pedestrian movements at night along Roe Highway and the Principal Shared Path will be the dominant form of direct emissions associated with the construction of the Roe Highway Extension. Whilst final configuration of street lighting has not been determined at this stage, an estimate of the upper limit of annual emissions, based on existing lighting practice on freeways within the Perth Metropolitan area has been made and is illustrated in Table 6. Whilst opportunities for reducing emissions associated with electricity consumption, including energy efficient lighting are being investigated, estimated emissions have been based on the installation of traditional 250W high pressure sodium (orange) lighting as used on major roads within the Main Roads network.

Table 6 Summary of greenhouse gas emissions associated with the operation of Roe Highway extension

Emissions Area/ Source	Direct Annual GHG (t CO_{2-eq})
Street lighting - Road	128
Street lighting - path	64
Total emissions	192

2.7 Vehicle Emissions

The primary purpose of constructing an extension to Roe Highway is to improve vehicle mobility within the region. As a result, it is important to identify the emissions associated with the utilisation of the extension and the net change in emissions associated with the use of the extension as compared to existing vehicle routes when considering the greenhouse gas impact of Roe Highway Extension. This section reports on the assessment of the greenhouse gas emissions resulting from vehicular movements associated with both the no build base case compared with the extension of Roe Highway.

The purpose of the assessment is to provide an understanding of the changes in greenhouse emissions that could be expected to take place under the no build scenario as compared to the situation where the proposed Roe Highway Extension was constructed, assuming that the take up and use of public transport and other sustainable transport methods will be equal in both scenarios.

2.7.1 Standards

This greenhouse gas estimate for emissions associated with the use of Roe Highway Extension by vehicles was based on the following standards and guides:

- Guide to Project Evaluation Part 4. Project Evaluation Data. Austroads 2008;
- ISO14064-2:2006 Greenhouse gases – Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements; and
- National Greenhouse Accounts (NGA) Factors, Australian Department of Climate Change 2009.

2.7.2 Data and assumptions

Data was obtained from Main Roads WA on the projected 2031 vehicle flows (including types and volumes) and speeds on each road for both the base case and construction scenarios. This information was used to calculate fuel consumption based upon the vehicle type, distance travelled and speed, which was then used to estimate vehicular emissions.

The following assumptions were made in this analysis:

- The year 2031 was selected because this is the current planning horizon as considered in Directions 2031 Draft Spatial Framework for Perth and Peel, June 2009. WAPC.
- All light vehicles use petrol (electric vehicles are not accounted for in this model).
- All heavy vehicles use diesel.
- Potential fuel use efficiency improvements have not been included. While inclusion of such a parameter may result in a decrease in the absolute level of fuel consumed and emissions released, it is not expected to impact on the relative amounts as the same percentage reduction would apply to both the no build scenario and Roe Highway Extension construction scenario.
- All light vehicles were assumed to be cars.
- All heavy vehicles were assumed to be articulated vehicles.
- The take up and use of public transport and other sustainable transport methods will be equal in both scenarios.
- Other parameters potentially affecting fuel use including road roughness, gradient and fuel efficiency improvements have not been explicitly included in the calculations. These parameters have been taken to be constant between the models.
- The section of Roe Highway west of the Karel Avenue interchange and east of the Kwinana Freeway interchanges was selected as the origin for the westbound traffic and destination for eastbound traffic. This point was selected as it enabled direct correlation and evaluation of changes from the base case to the upgrade case.
- Identification of the final destinations based on the datasets was provided by Main Roads WA. As it would not be practical to follow all vehicles back to their respective destinations, final destinations were assumed to have been reached in the following circumstances:
    - Annual average daily traffic volume fell below 2000 vehicles per day.
    - At the intersection of Leach Highway and Stock Roads in the northwest.
    - At Stock road in the west.
    - At Anketell Road in the south

2.7.3 Calculation of emissions associated with vehicle travel

Estimates of fuel consumption were based on the model described by Austroads (2008). The basic fuel / speed relationship in this model is:

$$\text{Coefficient} = A + B/V + CV + DV^2$$

Where: Coefficient = Fuel Consumption in L/100km

A, B, C and D are model coefficients

V = All day average speed in km/h

Average annual daily traffic speeds (as opposed to average journey speeds) are used in the equation, and consequently the parameters A, B, C and D have different values based on both vehicle type and the type of road travelled upon, as shown in Table 7 and Table 8. This includes consideration of how travel time may be affected by congested stop-start traffic.

Table 7 Fuel Consumption parameter values on freeways – L/100km

Vehicle Type	A	B	C	D
Cars	-18.433	1306.02	0.15477	0.0003203
Articulated vehicles	-80.0	6342.80	0.48496	0.0020895

Table 8 Fuel Consumption parameter values on other roads – L/100km

Vehicle Type	A	B	C	D
Cars	0.863	542.92	0.01333	0.000585
Articulated vehicles	-14.839	3579.6	0.22244	0.001167

Traffic volumes and speed data across the whole main road network for 2031 was provided by Main Roads WA. This information was used to determine the fuel consumption coefficient. Fuel consumption coefficient was used to determine the fuel consumed on each link within the network. Greenhouse gas emissions from the fuel consumed were calculated based upon the approach specified by the Department of Climate Change (2009). The equation used to convert fuel consumption to greenhouse gas emissions is:

$$E = (Q^* EC^*EF) / 1000$$

Where: E = greenhouse gas emissions (carbon dioxide, methane and nitrous oxide) in tCO2-eq

Q = quantity of fuel (kL)

EC = the energy content of the fuel (GJ / kL)

EF = the emissions factor for the fuel type (in kg $CO_{2\text{-eq}}$ / GJ)

The energy contents of petrol and diesel respectively were 34.2 and 38.6 GJ/kL, while the emissions factors (post 2004 vehicles) were 66.92 and 69.81 kg $CO_{2\text{-eq}}$ /GJ.

2.7.4 Estimation of emissions associated with idle time

In the absence of a defined standard approach for estimating the emissions associated with vehicles that are stationary, the Austroads model was modified to consider a very slow moving vehicle which was used to approximate a stationary vehicle. Although the Austroads model accounts for some idle time in travel, the number of traffic lights on alternate routes is not adequately accounted for. As a result fuel consumption calculations were determined based on the slowest link speed from the network data provided by Main Roads previously. This equated to a speed of 2km/h and an arbitrary link distance of one metre was used to determine fuel consumption. Based on this, estimates of carbon emissions for passenger and freight vehicles was determined to be 2.36 and 2.78 kg $CO_{2\text{-eq}}$ per minute respectively.

Assuming 45,000 vehicles each day per direction, an average of three minutes wait time would be experienced by commuters. This estimate corresponds to a Level of Service 'C' condition with wait time not exceeding 35 seconds at the five sets of traffic lights between Roe Highway at Jandakot and Stock Road, which would not be experienced as a result of construction of the Roe Highway Extension. The net emissions associated with this idle time are 337 tonnes $CO_{2\text{-eq}}$ per day are associated with vehicles under the no build scenario.

2.7.5 Results and Discussion

The construction of the extension is likely to completely change the available travel routes, times and speeds by facilitating a faster, shorter and more direct route from the existing Roe Highway, through to Stock Road and beyond. Without the extension, traffic from the north west of Roe Highway would take alternative routes to reach the Highway. These routes include South Street and Leach Highway which results in regional changes in traffic flows. Similarly, in the no build scenario, traffic heading to, or coming from the, south is forced to take Kwinana Freeway, potentially clogging up that network. Some of this traffic flow may choose to take one of the east-west lateral cross roads such as Russell Road, Anketell Road or Beeliar Road. Again the construction of Roe Highway results in a regional change in travel route options, facilitating an option to use Stock Road / Rockingham Road as a north-south connector for the entirety of the north-south journey.

This regional change in travel route options was reflected in the data set on vehicle flows provided by Main Roads WA. For example, total westbound traffic through the link point on Roe Highway (located to the east of the Kwinana Freeway and west of Karel Avenue) was found to increase by 59% from an annual average of 27,900 vehicles per day to 47,100 vehicles per day. Similarly eastbound traffic at the link point was found to increase by 49% from 22,100 to 45,100. Given that the only change between the models is the inclusion of the Roe Highway Extension, this considerable increase suggests that the extension will enable or facilitate a broader region-wide change in travel routes and times, and consequently a change in the greenhouse gas emission profile for the whole road network.

Whilst the construction of the Roe Highway Extension will have considerable impact on the route selection of passenger and freight vehicles, the net effect on the Main Roads network is negligible as illustrated in

Table 9.

Table 9 Daily Greenhouse Gas Emissions across the Main Roads network

Vehicle	Base Case $tCO_{2\text{-eq}}$	Upgrade $t\ CO_{2\text{-eq}}$	Change $t\ CO_{2\text{-eq}}$	% Change
Light vehicles	10770	10,800	30	0.3%
Heavy Vehicles	26887	27,023	136	0.5%
Total	37,657	37,823	166	0.4%

Indeed, if consideration of the emissions associated with vehicles idling at intersections and traffic lights is considered, the net impact of emissions associated with vehicles using main roads in the metropolitan area will be less as a result of the construction of Roe Highway, due to the reduction in wait times as shown in Table 10.

Table 10 Cumulative Daily Greenhouse Gas Emissions across the Main Roads network

Vehicle	Base Case $t\ CO_{2\text{-eq}}$	Upgrade $t\ CO_{2\text{-eq}}$	Change $t\ CO_{2\text{-eq}}$	% Change
Total	37,994	37,823	-171	-0.4%

Based on these conservative estimates of idle time, the construction of Roe Highway Extension will result in a net saving of 62,415 tonnes $CO_{2\text{-eq}}$ annually across the Main Roads network.

2.8 Summary and Conclusions

The Construction of Roe Highway Extension will result in the emission of greenhouse gases, both during the construction and operational phases of the project. Based on projected traffic movements throughout the Main Roads network, the construction of the Extension will result in savings of 59 kt of $CO_{2\text{-eq}}$ annually by 2031 as compared to the no build scenario as shown in Table 11.

Table 11 Emissions by source

Emissions Area/ Source	Direct GHG ($t\ CO_{2\text{-eq}}$) ±50%	Direct Annual GHG ($t\ CO_{2\text{-eq}}$)	Indirect Annual GHG ($t\ CO_{2\text{-eq}}$)
Vegetation Clearing	3747	-	-
Construction emissions	1140	-	3420
Street lighting - Road	-	~128	-
Street lighting – path	-	~64	-
Operation (additional vehicle movements cf base case)	-	-	-62,415
Total emissions	4887	192	58,995

3.0 Climate Change

Since 1990, the IPCC has provided regular scientific assessments of past, present and future climate for a range of different future emission scenarios. These Special Reference Emission Scenarios (SRES) capture a range of possible population growth and emissions futures. The A1B scenario is a medium emissions scenario, which is commonly used in climate change projections and assumes rapid economic growth. In this scenario, global population peaks around 2050 and then declines. The A1B scenario also includes the rapid introduction of new and efficient technologies across a range of energy sources (fossil fuels and non fossil fuels).

Four scientific assessments have been undertaken to date – in 1990, 1996, 2001 and 2007. In its Fourth Assessment Report, the IPCC concluded that:

- warming of the climate system is unequivocal;
- most of the warming in the past 50 years is very likely (more than 90 percent probability) due to the observed increase in greenhouse gas concentrations from human activities such as the burning of fossil fuels and land use change; and
- it is very likely that changes in the global climate system will continue well into the future, and that they will be larger than those seen in the recent past (IPCC, 2007).

A fifth assessment report is due in 2014.

The principles and approaches for managing the risk of climate change, including greenhouse gas mitigation, are developing rapidly. There is much debate as to the mechanisms for managing greenhouse gas emissions, including the magnitude and timing of reduction targets. Notwithstanding this, emissions targets are likely to be referenced against emissions from a baseline year, potentially either the year 1990 or 2000. Excluding land use changes, global emissions in 1990 were estimated to be 22,530 Mt $CO_{2\text{-eq}}$, with 2000 emissions estimated to be 24,697 Mt $CO_{2\text{-eq}}$ (Boden *et al.,* 2009).

3.1 Historical Climate Observations

This section summarises local meteorological records and trends specific to the Roe Highway Extension project area, for a range of climate variables including: temperature, rainfall, evaporation and evapotranspiration, wind speed, humidity and solar radiation. The closest meteorological recording station to the project area is Jandakot Aero Weather Station, which is maintained by the BOM at the Jandakot Airport (station 009172) and commenced recording rainfall records in 1972. This station is located approximately five kilometres from Bibra Lake. Monitoring for weather statistics (temperature, wind, sunshine, etc) commenced much later in the period 1989 / 1990. As a result, the data set is incomplete, and has not been quality controlled in the same way as official BOM sites.

3.1.1 Temperature

The Australian Bureau of Meteorology (BOM) has approximately 600 weather stations recording temperatures across Australia. BOM has been recording temperatures in the greater Perth Metropolitan region since 1897. The current site for measurements, metropolitan Perth, was established in Mt Lawley in 1994. Other official recording stations in Perth include Perth Gardens and the Regional Office locations in West Perth at the Old Observatory near Kings Park and on Hay St (current location). Some regional temperature variation is experienced between these sites, making robust comparison of ‘Perth’ observations complex.

Mean monthly temperature (measured at 3pm local time) at Jandakot Airport ranges from 16.7ºC in July to 29.7ºC in February. Average minimum temperatures range from 6.9ºC in July and August to 16.8ºC in February. Average maximum temperature varies between 17.8ºC in July to 31.3ºC in February. Winds near the project area primarily originate from the east in the morning, changing to mainly south-westerlies in the afternoon (BOM 2009b).

3.1.2 Rainfall

Jandakot Aero (airport) has been used as a rainfall recording station since 1972 (Figure 2). The mean annual rainfall at Jandakot Airport is approximately 839.5 mm with the majority of rainfall occurring between May and September. Rainfall data for Perth has been recorded since 1897, and the longest continuously recorded site is the Perth Airport (Figure 3), which has recorded a 20% decline in rainfall since 1945 as illustrated by the linear trendline. While the graph shows a strong linear trend downwards, it also shows the annual variability of rainfall represented in the columns.

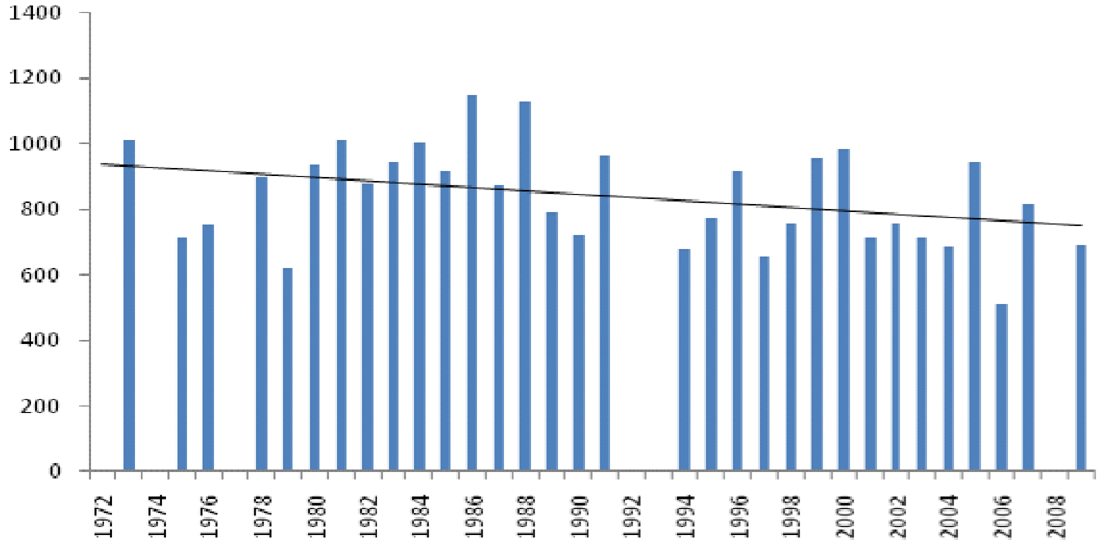

Figure 2 Annual rainfall (in mm) at Jandakot 1972 to 2009 (source: BOM, 2010a).

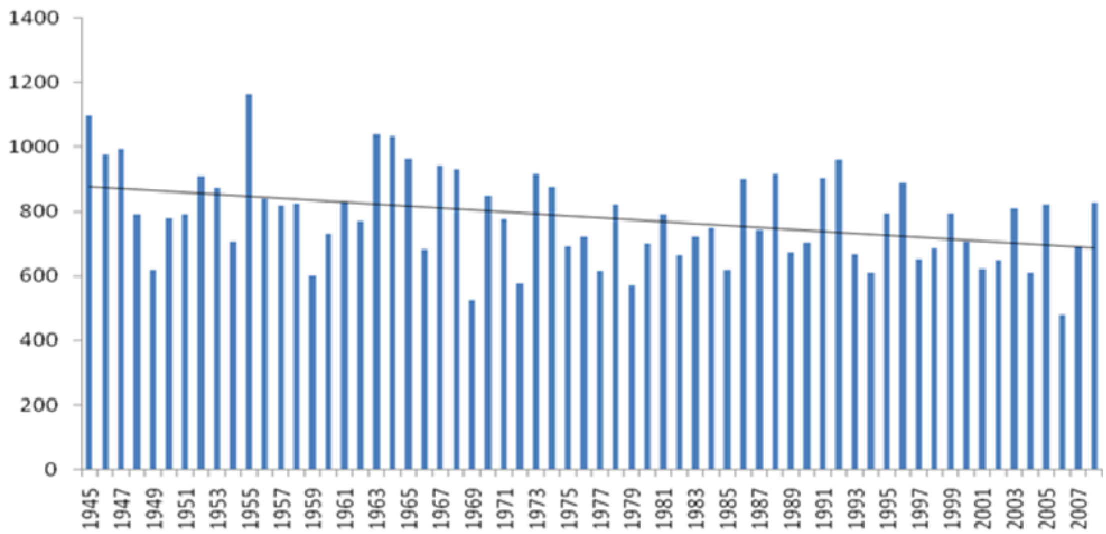

Figure 3 Annual rainfall (in mm) at Perth Airport 1945 to 2008 (source BOM, 2010a)

Whilst the data for Jandakot Aero is likely to closely match the conditions in the wetlands, it is not of a continuous nature, and data has not undergone quality control since 1994. Despite these limitations, the set clearly shows similar annual characteristics to the Perth Airport, and also exhibits the same decline in annual rainfall. Although the distance between the two meteorological stations is only 19 kilometres, there are notable recorded rainfall differences monthly and annually. As shown in Figure 4, the Jandakot Aero weather station (green) receives approximately 15% more rainfall each year than Perth Airport (orange), with the greatest difference in the months of May to July.

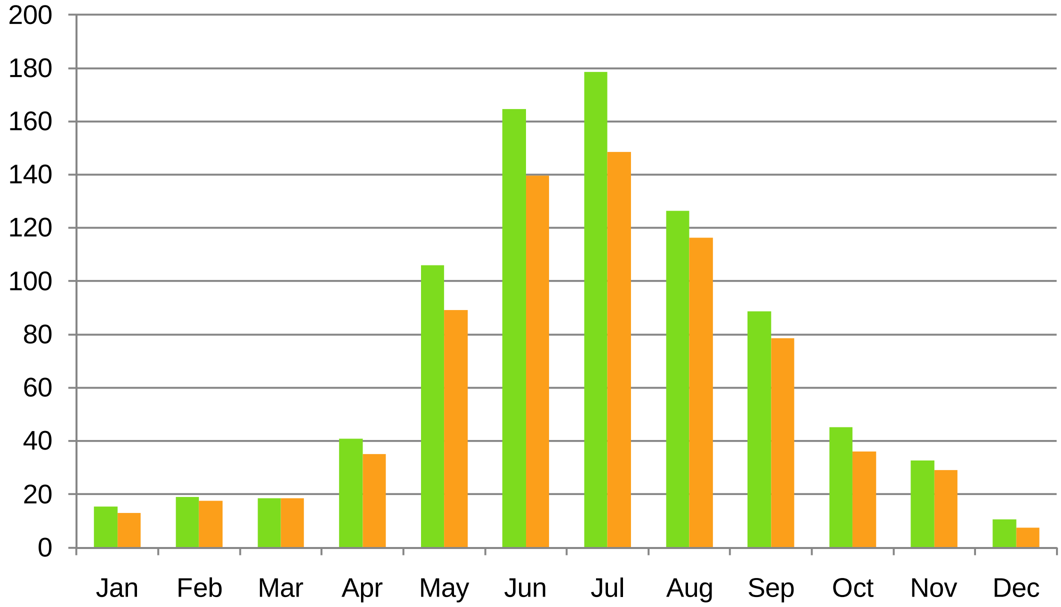

Figure 4 Annual rainfall (in mm) comparison between Jandakot Airport (green) and Perth Airport (orange) for years 1981-2010 (source: BOM, 2010a, 2010b)

Given the general similarity of the two station datasets, the discontinuous and non-quality controlled nature of the Jandakot data, the Perth Airport data has been used in this report. The Perth Airport meteorological station data is used later in this document to compare rainfall with wetland water levels over time.

More broadly, historical changes in summer rainfall per degree of recent historical warming for 1950-2004 shows extensive drying has occurred in the southwest of WA generally (Whetton *et al*., 2005). Around half of the reduction in observed rainfall from 1958-1975 to 1976-2003 was due to a decrease in the number of troughs linked to wet conditions, with the remaining half associated with other synoptic types in the southwest (Hope *et al*., 2006). Winter rainfall in the southwest has decreased substantially since 1950, with the largest decline observed from March to July, while August to October rainfall has slightly increased. In the mid 1970s there was an abrupt increase of between 15-20% in the rate of winter rainfall decline. This sudden reduced rainfall in the southwest is likely a combination of increased greenhouse gas concentrations, natural climate variability and land-use change (Australian Greenhouse Office, 2007). The non-linearity of climate impacts is made clear by the observed approximate 50% decline in water flow into Perth's dams since the mid 1970s from the 1911-1974 long-term average (Power *et al*., 2005). The IPCC's 2007 Fourth Assessment Report (AR4) included a large-scale global projection of relative changes in runoff by the end of the 21st century representing the median values of 12 climate models using the SRES (Special Report on Emission Scenarios) A1B scenario. In this projection, the southwest of WA saw a 90% model agreement on a reduction in runoff, with the median reduction value of between 20 and 40% of 1980-1999 runoff levels (IPCC, 2007).

3.1.3 Evaporation and Evapotranspiration

Pan evaporation records the amount of water evaporated from an exposed pan, taking into account any rainfall whereas evapotranspiration is usually used to describe changes to water release into the atmosphere resulting from land surfaces covered by vegetation. It is the ‘combination of evaporation of water from soil and transpiration from vegetation’ (CSIRO and BOM, 2007). Evaporation across the Perth metropolitan region ranges from 1622.8mm to 2327.8mm per year and very little change to pan evaporation has occurred in the Swan-Avon region of WA in the last 30 years, with annual total pan evaporation decreasing by less than 2.5mm per year. Evapotranspiration in the Perth region is between 800 and 900mm per year, considerably less than the evaporation rate for the same region.

3.1.4 Humidity

Relative humidity is the amount of moisture in air as a percentage of the total amount that the air is capable of holding. Relative humidity varies considerably throughout the day as shown in Figure 5 and Figure 6, as well as seasonally. Humidity data is presented as percentage values (at 9am and 3pm) based on a 30 year period from 1976-2005. Humidity tends to decrease throughout the day, as the annual average 9am daily humidity in the Perth region ranges from 50-70%, whilst the annual average 3pm daily humidity is between 30-50%.

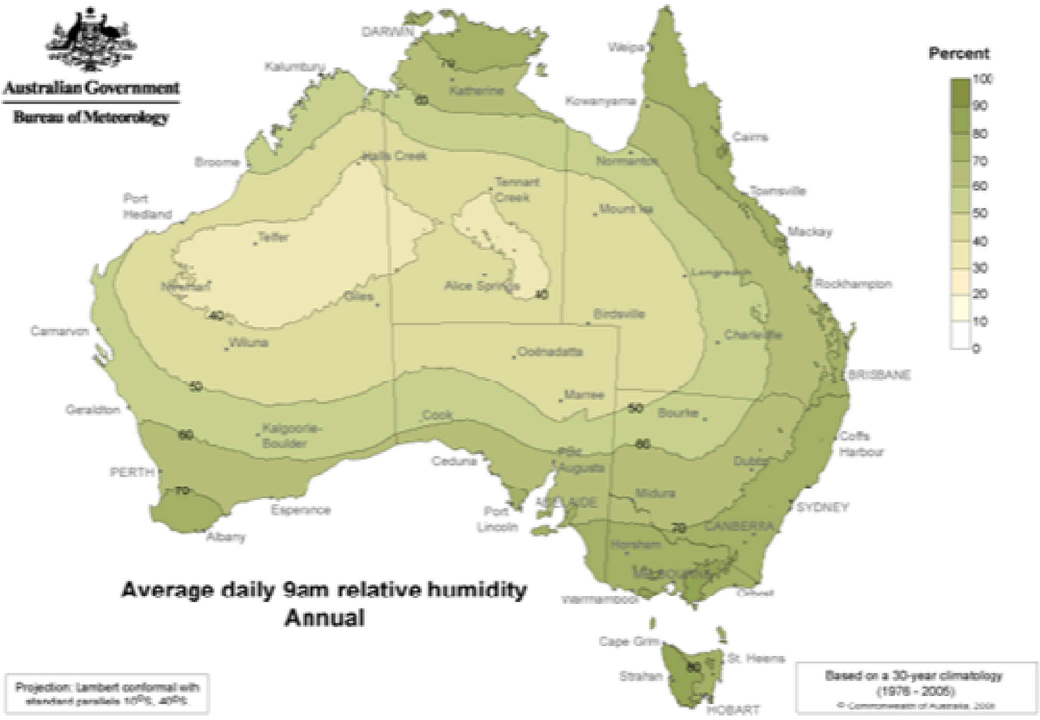

Figure 5 Average relative humidity at 9am (source: BOM, 2009)

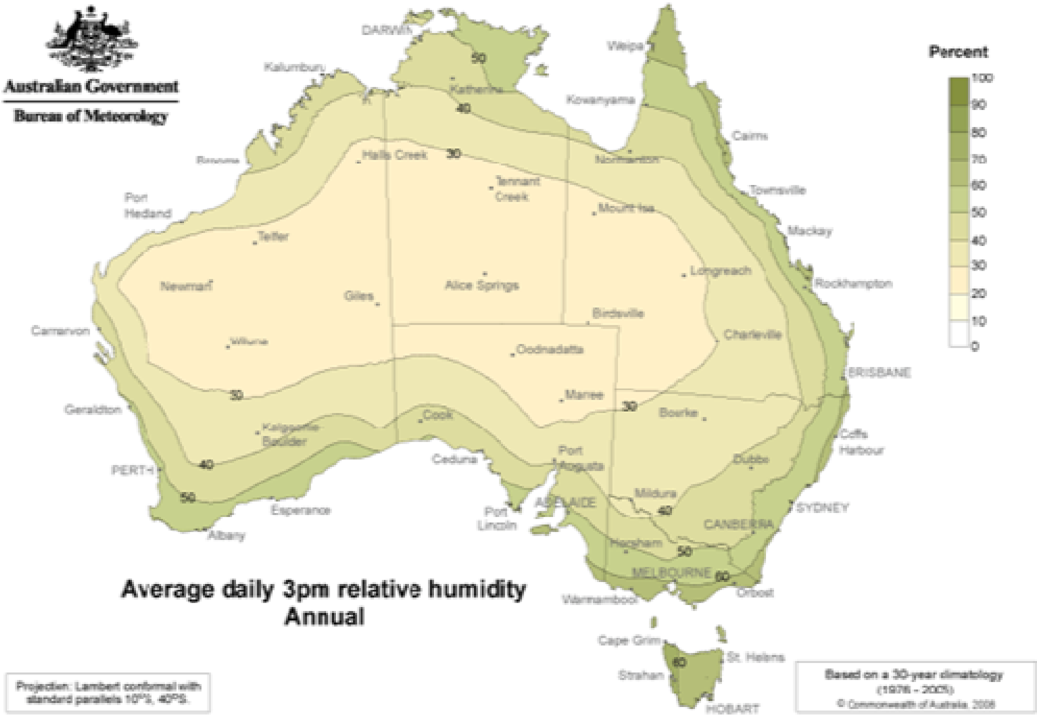

Figure 6 Average relative humidity at 3pm (source: BOM, 2009)

3.2 Observed Changes within the Wetlands

Historical documents can provide a unique view of the often dramatic changes in ecology. These historical land use changes are an important source of initial conditions to assessment of disturbance, resilience and climate change vulnerability. The historical land use changes to the Beeliar wetlands area and its general development have been described by the City of Cockburn in its management plan for Bibra Lake, and the following comments summarise these and other records. In summary, the original Aboriginal inhabitants of the area had semi-permanent settlements on the eastern chain of wetlands in the Cockburn area. However, broad scale landscape level changes only commenced after the arrival of Europeans.

3.2.1 Historical recollections and documentation

As early as 1830, 2,000 acres of land between Hamilton Hill and North Lake was granted to George Robb for pastoral purposes. In 1843, 320 acres of land was obtained by Von Bibra south of Robb's grant, which extended from the southern end of Bibra Lake to almost one mile south of the lake and included most of South Lake. These grazing activities modified the vegetative communities significantly, and further modification followed under horticultural and agricultural related land use changes.

In the 1830-40s, at the time of the European settlers around the Lakes, Bibra Lake was known to be dry in summer except for a small section in the southwest corner. In winter the water depths were generally over 2 metres, and were an excellent source of seasonal game for the Indigenous Beeliar tribe. Early European settlers under the Jandakot Agricultural Scheme (opened on 1 Jan 1890) grew wheat and oats on higher grounds in winter, while maize and vegetables were planted in the summer following the receding lake waters. Later, at the turn of the 19th century, dairy cows and pastures (including lucerne) replaced many cropping activities around the lake districts. At this time, the Fremantle Districts Roads Board opposed all agricultural leases fronting the lakes preferring that the land be reserved for recreational purposes, including tea rooms on the western foreshore (Thomas, 1992). This decision underpinned the strong recreational amenity that the lakes provided, and continue to provide in the area (Hussey, 1987).

Owing to the presence of the fresh water from the lakes and the arable nature of the soil, the land surrounding the wetlands continued to be taken up for agricultural purposes. By 1919, many of the market gardens were replaced with dairy farms. However, as motorised transport became available in the 1920's many of these dairy farmers themselves moved south onto better quality land. After a period of lower usage, urban development then began to progressively encroach on and replace the farming activities, particularly in the latter part of the 20th Century. Each successive land use change removed some of the vegetation around the lake, reducing the woody vegetation in the area.

Oral histories of local residents from the post war era collated by Cathy Drake and Shona Kennealy (1995) note that North Lake did not dry out in that period. North Lake in the 1940s had little of the trees, rushes and reeds in comparison to the larger Bibra Lake, which still has vegetation. Residents recalled that the areas around Bibra Lake were mostly cleared of reeds and paperbark trees by the 1930s by non-Indigenous inhabitants. Additionally during the 1950s and 1960s, there were large amounts of colonisation from introduced bulrushes with a great variation in the levels of infestations over time. In contrast, the smaller native rushes and reed populations remained relatively constant in most areas during the period.

Drake and Kenneally (1995) note that local resident recollections recall a "serious outbreak" of water hyacinth around 1960, which was sprayed, with the result that "99% of the frogs went overnight". However, frog numbers (of at least of one species) had recovered by later in the 1960's according to Packer (1966). Packer collected adult *Heleioporus eyrie* (Gray) from Bibra Lake between April and May in 1960, 1962, and 1964 to study embryo development. The 1966 (p. 92) article states "...*Heleioporus eyrie (Gray) was selected for the study because it was the most easily obtained*." (Packer, 1966).

The sequence of aerial photographs from 1947/48 to the present day (Figure 7) shows how urban development has progressively replaced the agricultural pursuits of the area. Several of the main access routes in use today were evident by 1947/48 including Hope Road, which was bisecting North and Bibra Lakes and Progress Drive to the west of Bibra Lake. Between 1958/59 and 1970, significant urbanisation of the land to the west of the lakes had occurred. This had largely been completed by 1978, by which time the urban development focus had shifted to the eastern side of the lake. Twenty years later, in 1989, most of the regional urban development and land conversion had been completed on all four sides of the wetlands, with further urban development from this point being more due to consolidation. Successive land use change disturbances have led to the progressive increase in vegetative weed species generally known as "*disturbance opportunists*" in the remaining riparian areas (Hussey *et al.*, 2007). Changes to riparian vegetation (by both vegetation removal and altered fire regimes) also altered the nutrient cycle by reducing the capacity of the wetlands to take up the nutrients flowing into Bibra and North Lakes from runoff (Dooley *et al.*, 2006).

Whilst more than 20% of the vegetation surrounding Bibra Lake was described as being in good to very good condition by Bush Forever (DEP, 2000) the remainder (less than 80%) was classified as being degraded. Similar findings were recorded by Bright (2001), who found that most of the vegetation south of Hope Road, was "Poor" or "Very Poor". Weed cover for the former classification was 20 to 60% and 60 to 100% for the latter while native vegetation content was recorded as being 20 to 50% in the former and 0 to 20% in the latter. Past historical vegetation condition reports all demonstrate that significant land use changes in the area have degraded large areas of the wetlands.

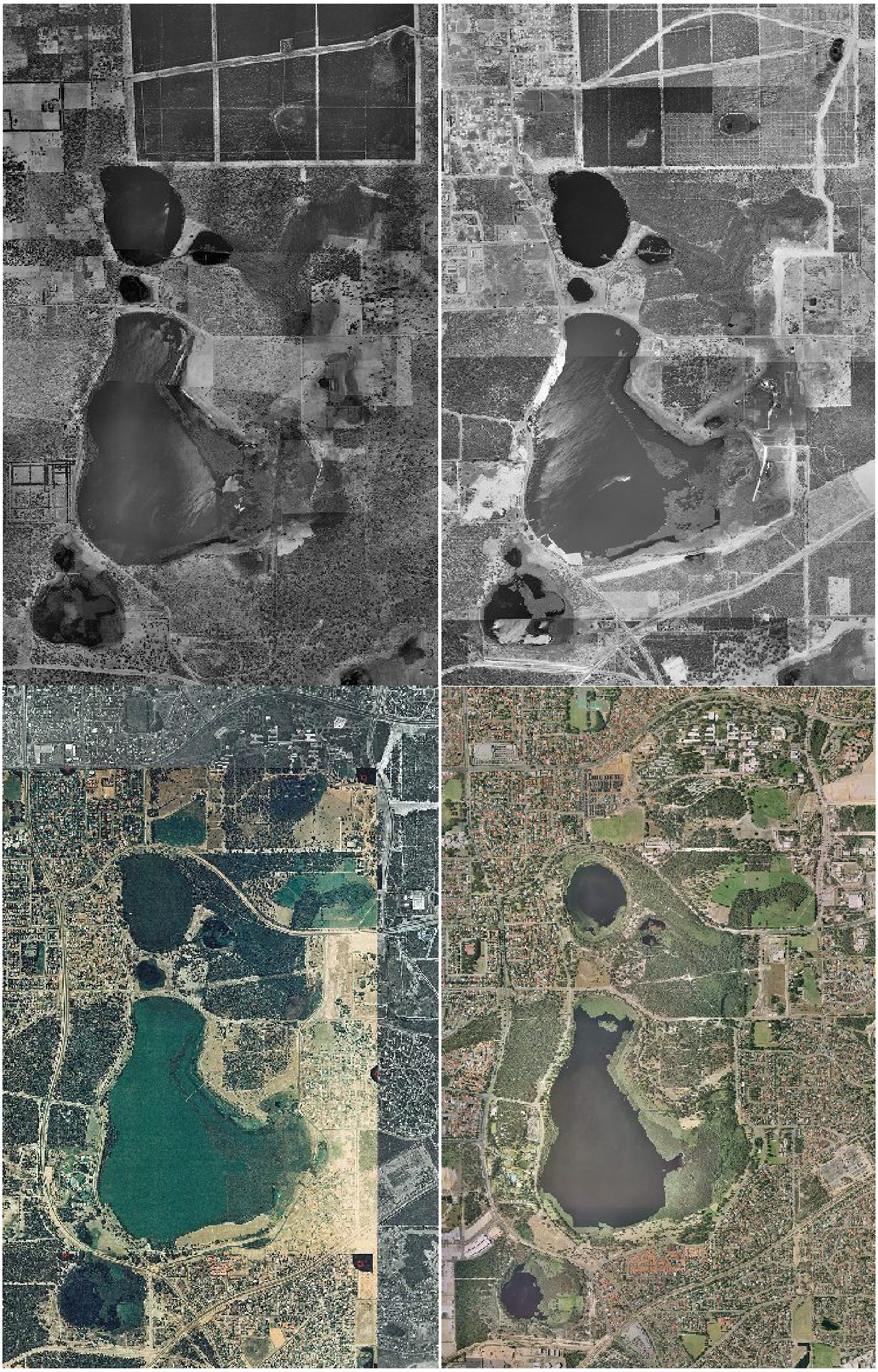

Figure 7 (Top left: 1947/48 mosaic image (dated 02/12/1947 - 05/01/1948). Top right: 1970 mosaic image (dated 19/10/1970). Bottom left: 1989 image (dated 02/1989). Bottom right: 2008 image (dated 03/2008)

3.2.2 Water level changes within the wetlands

North and Bibra Lakes are considered to be hydro-dynamically connected to the unconfined groundwater aquifer, although small winter perched wetlands may exist in the area. They are therefore directly affected by groundwater levels, rainfall and run-off from urban areas and consequently by urban development (AECOM, 2010a). Hydrological changes that have taken place in the area have included (AECOM, 2010a):

- Intersection of overland flows by Hope and Farrington Roads. The natural flow rates and frequencies from the wetlands to the east of North Lake into North Lake are, however, considered likely to have been low owing to the low natural gradient. Direct overland flow from Bibra Lake to North Lake is prevented by the absence of culverts under Hope Road.
- Drainage and nutrient inflow into North Lake. A drain leading from Murdoch University was blocked off in the mid nineteen–nineties to prevent direct flow of nutrient laden waters from entering North Lake. These waters are now pumped north to Murdoch Swamp.
- Construction of drainage networks to divert stormwater from hardstand areas (e.g. roads). The greatest contribution of external surface water to the wetlands comes from stormwater.
- Groundwater abstraction from the Jandakot groundwater mound 3km to the east.

A more detailed discussion on the hydrology of the area can be found in the Hydrology reports commissioned by South Metro Connect.

Water level data of North and Bibra lakes provided by the Department of Water shows that the wetlands exhibit a high degree of variability, both between minima (generally April and May) and maxima (generally September and October) and over longer periods, as shown in Figure 8 and Figure 9 (in blue).

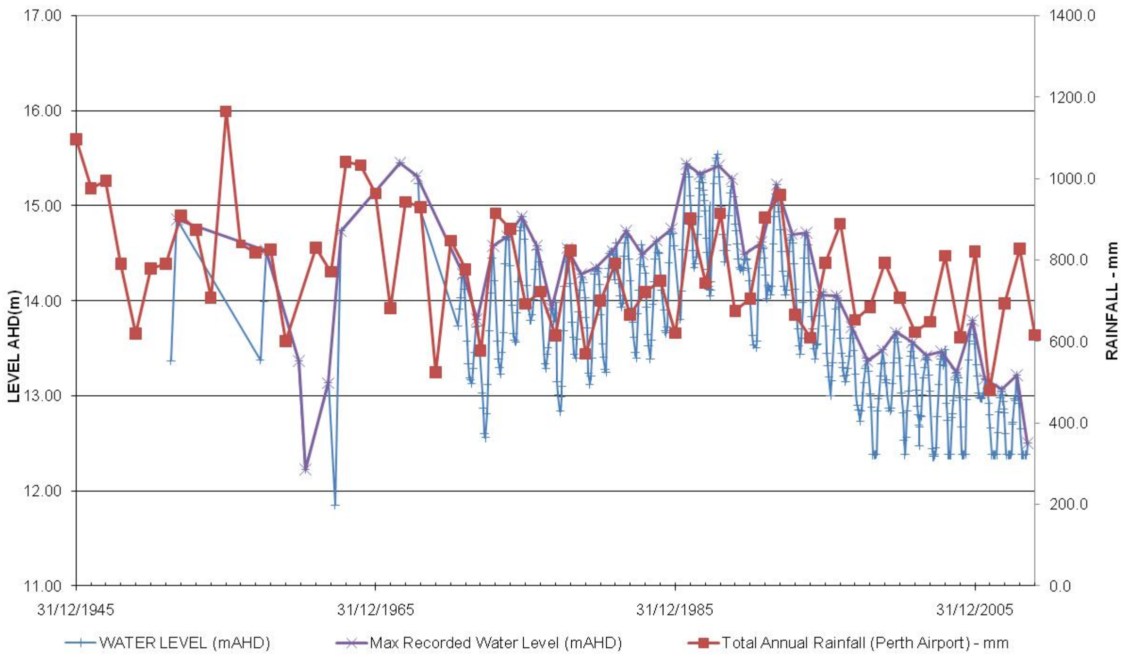

Figure 8 Perth airport annual rainfall (red), North Lake annual maximum water level (purple), and intra-annual variation (blue) (source Department of Water, BOM, 2010a)

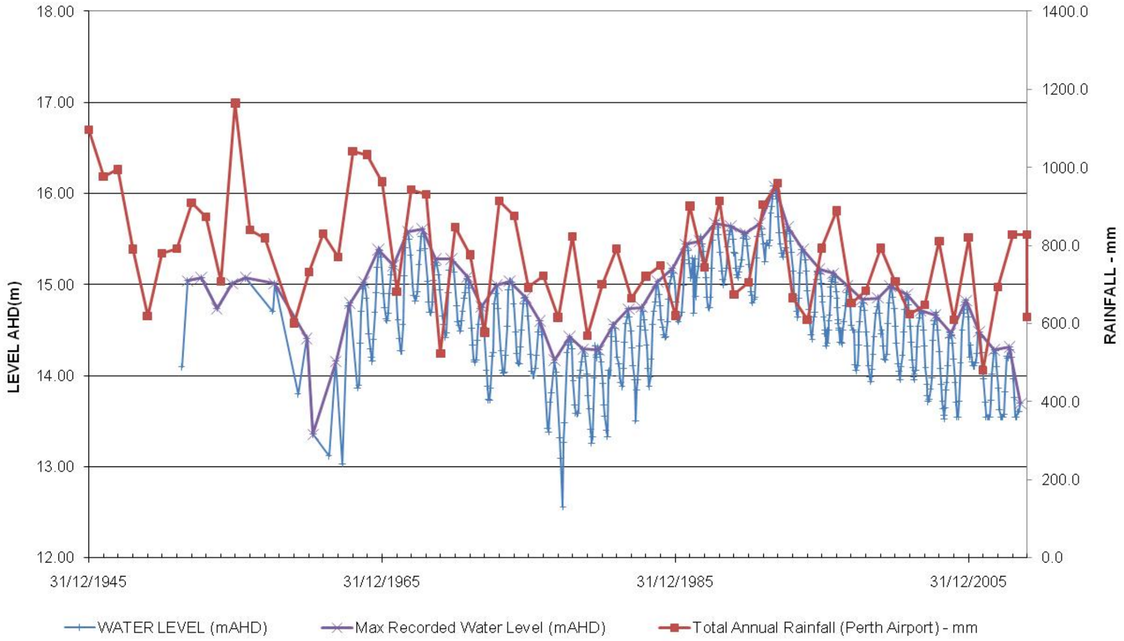

Figure 9 Perth airport annual rainfall (red), Bibra Lake annual maximum water level (purple), and intra-annual variation (blue) (source Department of Water, BOM, 2010a)

The red line in Figure 10 and Figure 11 represents the Perth Airport annual total rainfall, and the purple line is the annual maximum water levels. The graphs clearly show a correlation between rainfall and both North Lake and Bibra Lake wetland maximum water levels, although the same correlation is not seen in minimum water levels.

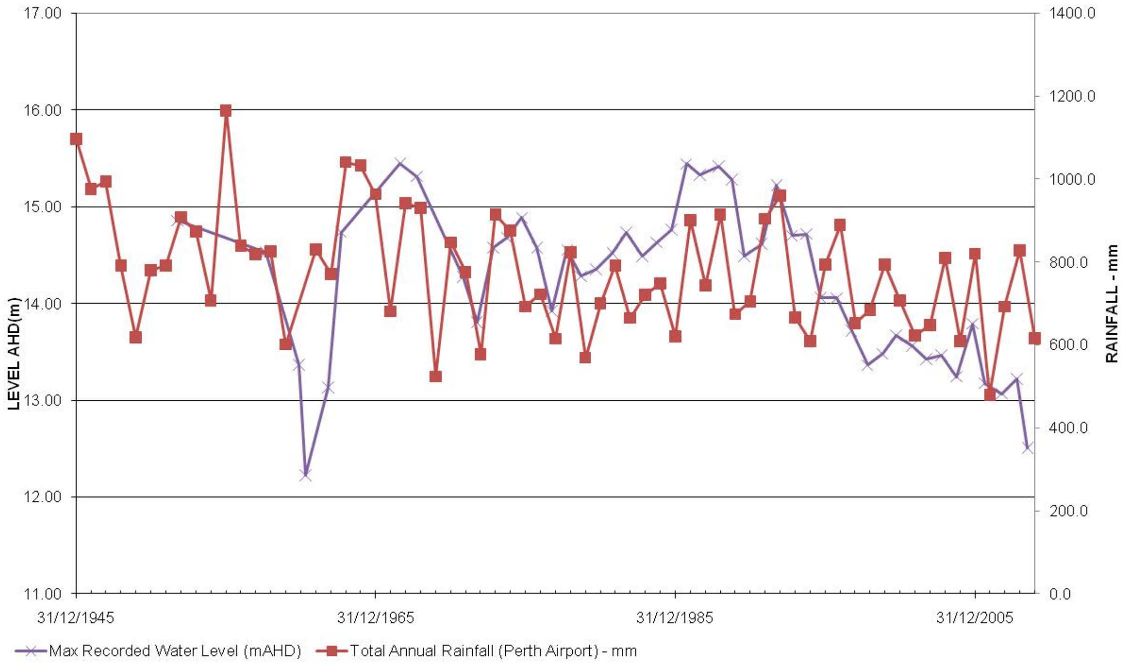

Figure 10 Perth airport annual rainfall (red) and North Lake annual maximum water level (purple) (source Department of Water)

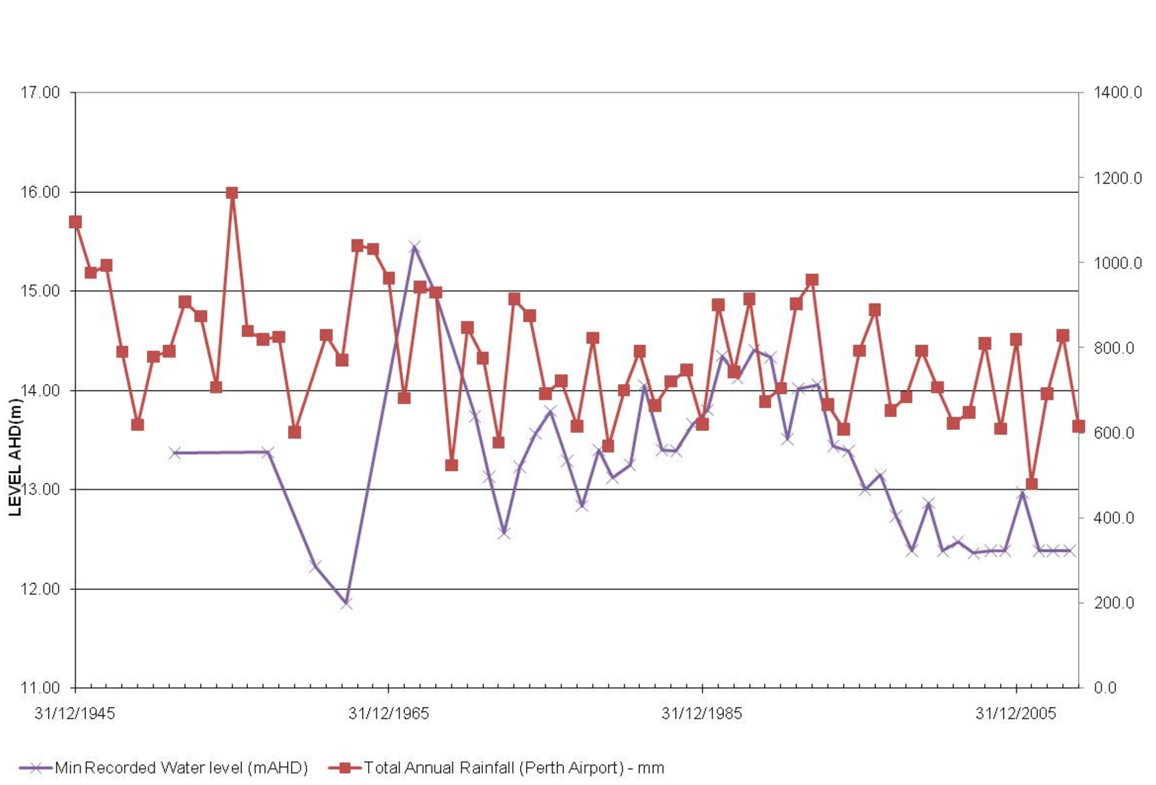

Figure 11 Perth airport annual rainfall (red) and North Lake annual minimum water level (purple) (source Department of Water)

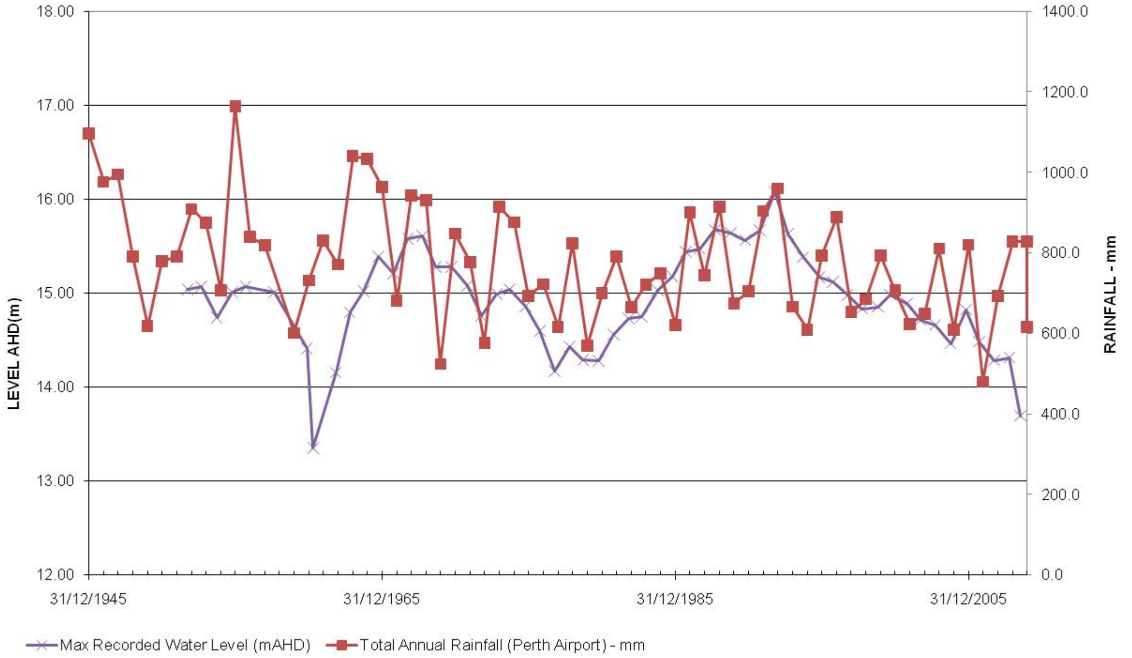

Figure 12 Perth airport annual rainfall (red) and Bibra Lake annual maximum water level (purple) (source Department of Water)

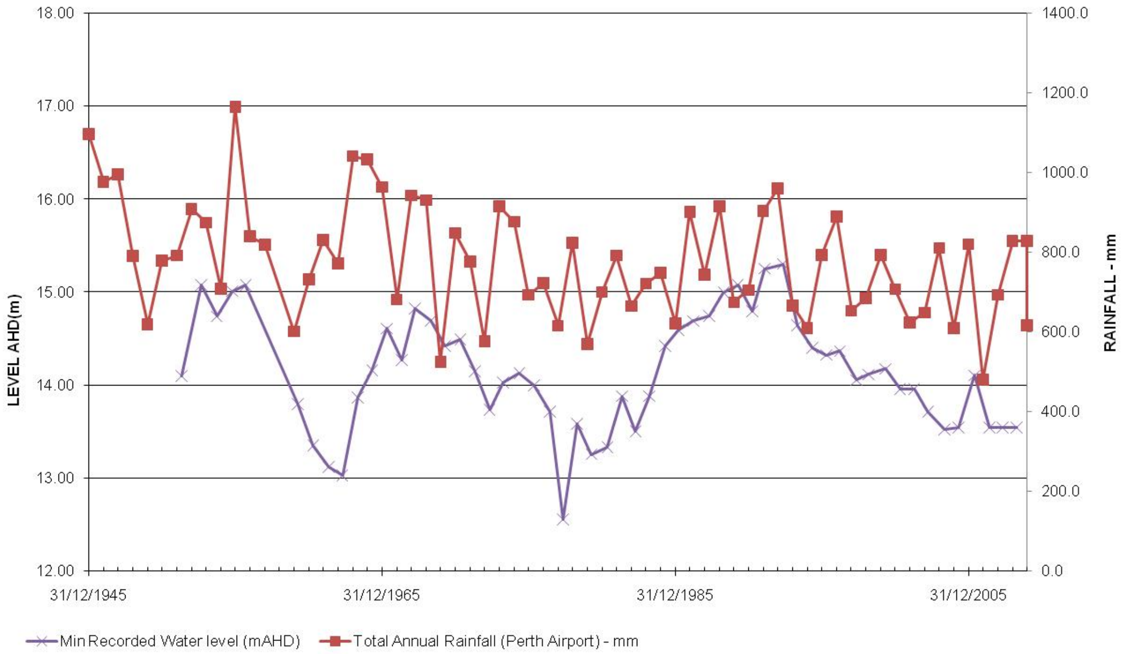

Figure 13 Perth airport annual rainfall (brown) and Bibra Lake annual minimum water level (purple) (source Department of Water)

While the available data indicates that the wetlands have had similar water levels to current recorded levels, a declining trend in both rainfall and water levels is apparent. This drying trend is consistent with what has been observed for the south west as a whole, and what is predicted for the future (IPCC, 2007). When rainfall projections for climate change are considered, it is possible that the maximum water levels in both North and Bibra Lakes will continue to decline as rainfall is reduced.

3.3 Climate Change

In October 2007, the CSIRO and the Australian Bureau of Meteorology (BOM) released *Climate Change in Australia — Technical Report 2007,* which provides the most recent climate change projections for Australia. The report was based upon international climate change research including the latest IPCC conclusions, and built on a large body of climate research for the Australian region. The climate change projections presented in this report are primarily drawn from both these reports and more recent *Science Updates* presented by CSIRO/BOM available through the Climate Change in Australia (http://www.climatechangeinaustralia.gov.au/) and OzClim (http://www.csiro.au/ozclim) websites.

3.3.1 Regional Climate Projections

The projections by CSIRO are at a very coarse level, considerably larger than both the resolution of historical climate observations and the region immediately surrounding the Roe Highway Extension project area as illustrated in Figure 14. The 'mean' values listed in Figure 14 are the 50th percentile. Also shown are the range of possible changes as determined by the 10 and 90th percentile results from CSIRO modelling.

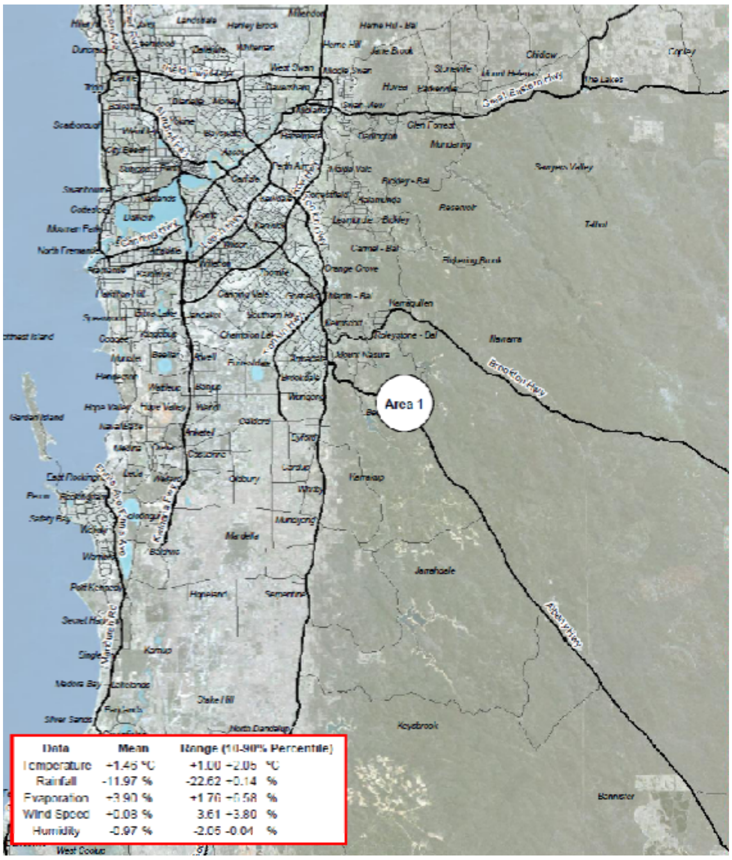

Figure 14 Map representing a single pixel associated with the climate change projections for the Perth Metropolitan area

For the purposes of this study, Special Reference Emission Scenario (SRES) Marker A1B scenarios have been used to identify the projected impacts of climate change for the years 2030, 2050 and 2070. The 50th percentile, also known as best or median estimate, has been used where a range of percentiles are available. The A1B scenario is a medium emissions scenario, which is commonly used in climate change projections and assumes rapid economic growth. In this scenario, global population peaks around 2050 and then declines.

Table 12 Climate Change Projections for Perth for a range of common climatic variables. (source: CSIRO and BOM 2007)

Climate Variable	2030 mean change	2050 mean change	2070 mean change
Temperature	+ 0.9 °C	+ 1.5 °C	+ 2.0 °C
Rainfall	-7%	-12%	-16%
Evaporation	+2.3%	+3.9%	+5.4%
Wind speed	+0.05%	-0.08%	-3.61%
Humidity	-0.6 %	-1.0%	-1.4%

It is important to note that these figures are median increases and do not represent extreme temperature, rainfall and wind events.

3.3.1.1 Temperatures and extreme temperatures

The region is expected to experience an increase in average temperature of 0.87°C by 2030 (with a possible range of 0 to 1.2°C); 1.46°C (range of 1.00 to 2.05°C) by 2050 and 2.0°C (range of 1.39 to 2.85 °C) by 2070. In addition to an increase in the average temperature for Perth, there are significant increases in the projected number of hot days, or days above 35 °C by 2030 and 2070. Perth currently experiences on average of 28 hot days per year. This is projected to increase to 35 hot days by 2030 according to the A1B projections and to between 41 and 54 days by 2070 (B1 and A1FI scenarios).

3.3.1.2 Rainfall

The downward trend in rainfall is expected to continue into the future. Rainfall is projected to decrease by 7.2% by 2030 (range of 14.02% decrease to 0.09% increase); 11.97% (range of 22.62 decrease to increase of 0.11%) by 2050 and 16.3% (range of 30% decrease to 0.2% increase) by 2070. Whilst overall rainfall is projected to change, the mean number of rain days is also expected to decrease resulting in lower total rainfall, but increased in rainfall intensity.

3.3.1.3 Wind Speed

Perth wind speeds are projected to increase by 0.05% (range indicates decrease of 2.12 to increase of 2.23%) for the year 2030. This trend is projected to be the same until 2050 where wind speed is likely to increase by 0.08% (range indicates decrease of 3.51 to increase of 3.80%). However, the longer term projections to 2070 suggest that wind speed for the Swan Catchment area will decrease by about 3.6% (range indicates decreased of 5.02% to increase of 3.60%).

3.3.1.4 Evaporation and Evapotranspiration

Evaporation rates in Perth area are projected to increase by 2.07% to 2.3% to 2030. The projected annual change in evapotranspiration for 2030 is an increase of 2 to 4% annually, with 4 to 8% increases expected in winter. By 2050, the annual evapotranspiration increase remains between 2 to 4%, with increases in autumn of between 4 to 8% and 8 to 12% in winter. By 2070, the annual change is expected to be between 2 to 8% with a winter change of between 8 to 12% for the Perth region.

3.3.1.5 Humidity

Variations in the humidity of -0.5 to 1% are expected for the region by 2030 and 0.97 to 1.35% by 2050 and 2070. While some seasonal variation will be evident, these changes are not expected to change the average humidity ranges historically observed in the region.

3.3.2 Projections Summary

Climate change models approximate geographically-specific processes of longer-term temporal changes (Halsaes *et al*., 2007), and regional models vary in model structure, coverage, analytical approach, and assumptions (Nabuurs *et al*., 2007). Climate change assessments often require input regarding climate, social and economic developments, and other environmental factors that change over time, alongside multiple projections of future developments. These assessment scenarios are often disaggregated down from larger climate models to represent regional or local scales (Parry *et al*., 2007).

The projected impacts of climate change in the area of the proposed Roe Highway Extension are difficult to predict. Actual ecosystem responses to climate variables, such as temperatures, rainfall, sea levels, and storm events are complex and strongly influenced by non climate change factors, including land development. The primary reason for this complexity is insufficient certainty in site-specific historical data as an input for modelling to generate a useful projection for the wetland area. Therefore, this document also includes an overview of primarily qualitative land use changes in the area that have significance for future micro-climatic and climate change-related decision-making.

3.4 Risk Assessment and Vulnerability Study

The impact of climate change on the proposed extension of Roe Highway is likely to express itself in one of four key ways that have been considered in this report:

- Extreme events;
- Degradation of materials;
- Degradation of ecosystems; and
- Long term impacts.

3.4.1 Extreme events

Extreme events are those short lived, intense occurrences that occur as a result of the prevailing weather conditions over a short period of time. Climate change-related extreme events that could affect the road infrastructure and availability of the road include:

- Increased intensity of storms including wind, dust, hail, rain;
- Increased rainfall intensity causing flash flooding;
- Increased number or severity of heatwaves including impacting power supply, particularly signalling and road safety; and
- Increased number or severity of bushfires in the project area.

3.4.2 Degradation of Materials

Changes to the climatic conditions, both in isolation and in combination with other non climatic conditions, are highly likely to impact the rate at which materials degrade. Although degradation changes are usually thought of in terms of increasing the degradation and reducing the durability of materials, the impacts are not as straightforward as this.

- Reduced average rainfall is likely to result in reduced degradation for materials that are degraded by rain.
- Increased mean temperatures are likely to impact materials that are sensitive to temperature, typically living materials such as the vegetation within and around the road reserve, but this is unlikely to impact on construction materials.
- Increases in extreme temperature conditions, such as increases in the length or severity of heatwaves and increases in diurnal temperature conditions, are more likely to affect the degradation and durability of materials.
- Slight increase in solar radiation is unlikely to have an impact on the degradation of materials, although changes in the proportion of UV wavelengths in the spectrum are likely to result in changes to the degradation of materials, such as plastics, that are sensitive to UV radiation.

When combined with geophysical elements, the impact of changes to climatic conditions can be exacerbated. For example reduced average rainfall, particularly where combined with increased groundwater consumption, is likely to change the soil acidity, resulting in increases to the occurrence of active acid sulphate soils. Increased acidity in the soil is likely to increase the degradation of materials, including concrete and metal materials.

3.4.3 Degradation of Ecosystems

Changes to the climate will have an impact on ecosystems as they relate to the road reserve and native bushlands near to Roe Highway. Many of the earliest indicators of climate change are likely to come from observation of these changes, rather than an objective measurement of the change in climate conditions. The impacts on ecosystems, like the impact on materials, are dependent upon the nature of the climate change and the ability for the ecosystem to adapt to the changes. Examples of changes to the ecosystem in and around the Roe Highway project area, supporting infrastructure and managed land are likely to include:

- Changes to the chemical composition of soils and water bodies (acidity and salinity) due to decreases in average rainfall.
- Reduced vegetation cover, changes to wind speed and increased intensity of wind during storms are very likely to result in changes to exposed surfaces, increasing the rate of erosion of these surfaces and the stability of sloped surfaces.

- Changing rainfall patterns, such as more rain in spring with less rain in winter, can increase the amount of vegetation and undergrowth, and combined with increases in maximum temperature and heatwaves can increase the risk of bushfire.
- Changes to water levels in the natural and any engineered wetlands resulting in disruption to wetland ecosystems.

3.4.4 Long Term Impacts

In addition to the long term degradation-related impacts of climate change, long term changes in water levels, for example changes to surface and ground water levels, have the potential to directly impact on infrastructure located within around the wetland area. For example changes to the extent of surface water may result in bridge structures spanning water or swamp areas which reduce in size or dry up as a result of climate change.

3.4.5 Specific Impacts

Three specific impacts were identified during the Environmental Scoping Document for consideration during the Public Environmental Review given the potential for these to negatively impact on existing conservation areas within the project area. These are discussed in the following section.

3.4.5.1 Climate Change and Dieback

Whilst little research has been undertaken in relation to the potential impact of climate change on dieback, a number of studies are able to provide some understanding of the potential effect of climate change on dieback.

P. cinnamomi population fluctuations and recovery have been reported as declining with decreasing rainfall, and that in the dry summer months recovery could reduce to zero in the surface soil of dry upland areas (Shea and Shearer 1987). Future projections of climate for the Perth Metro area are likely to result in warmer and overall drier summer conditions, and as a result potentially lower dieback extent. Rip-lines used in rehabilitation areas to encourage drainage were also observed to increase ponding and it has been hypothesised that such conditions could potentially create favourable conditions for dieback growth.

Summer drought conditions are also thought to increase tolerance to *P. cinnamomi* amongst some species, including Jarrah and *Quercus sp.* (Lucas 2003). Pathogen activity is also reported to substantially increase after extreme summer rainfall events. Whilst climate change projections for cyclonic activity do not suggest a change in the occurrence of cyclones for Perth, and the risk of cyclones remains low, the potential for cyclonic activity in the South West of the state does remain. Similarly, the risk of factors that affect soil moisture content such as the extent of open area, season of disturbance of road cuttings and loss of vegetation have been suggested by Lucas (2003) to have effects on *P. cinnamomi* growth and dieback deaths. In terms of road construction and drainage management, this may imply that higher summer mortality could be expected from dieback where drainage is increased. As a result, control of water and drainage is essential to managing long term impacts of die back associated with road construction.

Hardy (2009) has noted that other *Phytophthora* species exist that have broader potential distributions than *P. cinnamomi*, and that some of these have been associated with the death of Tuarts on calcareous soils. Changes to temperature and rainfall regimes may therefore also create conditions that are more favourable for the growth and lethality of these other *Phytophthora* species should they be introduced into the project area.

Research is currently underway in the 'Fishing for *Phytophthora'* (FFP) programme which aims to sample wetlands across Western Australia as an early detection tool for the presence of *Phytophthora* species, but not *P. cinnamomi*. Data available on the programme's website indicate that several *Phytophthora* species have been detected throughout the Perth Metropolitan area in wetlands, including Bibra Lake, suggesting a broader spread of the genus and a presence in the project area (FFP, 2010). Despite this finding, evidence of *P. cinnamomi* was not detected in a recent survey of the project area (Glevan Consulting, 2009).

3.4.5.2 Climate Change: Weeds and Fire

The relationship between native vegetation, weeds and fire is complex. Australia's native vegetation has developed in response to specific climatic and disturbance regimes, including fire. Changes to these regimes are likely to result in changes in biodiversity including species types, diversity and abundance as the impact of fire on species and communities is not uniform. Potential influencing factors include fuel loads and fire intensity, season of the fire and frequency of fire (Driscoll *et al.,* 2010 and Gill and McCarthy 1998).

A change in fire regime affecting any of these parameters, such as has happened since European settlement, is therefore likely to result in a change in the biodiversity of the community, including facilitating the invasion of weeds. Weeds can also facilitate an increase in fire risk and intensity which may then facilitate further weed invasion or biodiversity changes (WRC, 2000 and Driscoll *et al.,* 2010). Fire related factors affecting vegetation recovery, biodiversity and weed presence or abundance include (Gill and McCarthy 1998, and Driscoll *et al.*, 2010):

- The time between burns enabling or preventing seed set
- Species that require a burn to release canopy stored seed (serotinous seeders)
- The heat intensity and the deaths caused
- Localised loss owing to insufficient fire frequency. This may occur where species that require a fire to produce or germinate seed senesce before doing so
- Presence of unburnt areas for recolonisation of burnt areas and the dispersal capacity of the relevant species.

Fire and weed management have a complex direct and indirect impact on the amount of carbon in an ecosystem over time. While the Bibra and North Lake edges and adjacent lands were burnt periodically by indigenous inhabitants to generate social benefits (Australian Heritage Commission and National Trust of Australia W.A, 2002), the urban development in the area has increased the incidence of unplanned fires other than prescription fires (Dooley *et al*., 2006). Whether this frequency or the effects of the fires would change as a result of the planned Roe Highway Extension is uncertain.

Climate change as a result of anthropogenic activities is expected to result in a hotter, drier climate for the south west (Pitman and Perkins, 2008). However, existing standards or protocols for weed risk assessment and management often lack any specific consideration of climate change (Crossman *et al*., 2008). Whilst this may be an omission, it may also indicate the relative importance between current management issues from direct human activities and those that may occur as a result of climate change. In other words, in this situation, the current known issues and their required management actions and possible system changes may be more significant than uncertain future issues. Despite this, the projected climatic effects are likely to result in a shift towards biota that is more heat, drought and fire resistant, which in the local context may result in denser stands of smaller trees (Pekina *et al*., 2009). However, increasing dryness may diminish fire activity over much of Australia, especially in woodlands, although increases may occur in temperate forests (Bradstock, 2010). Therefore, the future fire regimes in Bibra and North Lakes are uncertain, and will require active management.

Crossman *et al.,* (2008) has noted that the threat posed to biodiversity by invasive plants as a consequence of climate change has seen little attention to date. The Australian Weeds Strategy (NRMMC, 2007) does, however, note that plants (including weeds) are likely to experience a general trend southwards as a consequence of climate change in Australia. This will result in some species extending their potential and actual habitat area, while others will see a contraction. A change in species, abundance and diversity and possibly community type and structure is inevitable as a result of climate change effects.

3.5 Summary

The available historical evidence suggests that the direct human-induced changes on the Bibra and North Lake systems, including land use change, fire, weeds, pollution, and general development and fragmentation, have been substantial. These changes are likely to continue to negatively the impact the wetlands into the future. The impact of new developments, including those associated with the proposed Roe Highway Extension, will add to the various selective pressures in and around the wetland systems, as will pressures associated with climate change. However, at least in the near term, impacts from direct human activities are likely to be much more significant than those associated with climate change alone. Therefore, active management and design to maintain ecological integrity will be required (including the management of existing pressures) to improve the adaptive capacity of the system to both a changing climate and urban development.

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Appendix A

Vegetation Communities in the Project Area

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This summary is presented to assist with the identification of vegetation communities discussed in this report. A full discussion of the flora and vegetation communities identified in the project area can be found in the Flora and Vegetation Report prepared for South Metro Connect.

AfBKgS

Low Woodland of Allocasuarina fraseriana, Banksia menziesii, Banksia attenuata and Banksia ilicifolia over a Low Open Shrubland of Kunzea glabrescens over an Open Herbland of Phlebocarya ciliata, Dasypogon bromeliifolius and Loxocarya cinerea.

This community is represented by quadrat R11 and monitoring quadrats RW15 and RW16.

AfKgS

Low Woodland of Agonis flexuosa over an Open Scrub of Kunzea glabrescens over a Herbland of introduced species.

No representative quadrat was assessed.

BAhS

Low Open Woodland of Banksia attenuata and Banksia menziesii over a Tall Shrubland of Regelia ciliata over a Low Shrubland of Allocasuarina humilis and Hibbertia hypericoides over an Open Sedgeland of Mesomelaena pseudostygia on grey sands.

This community is represented by quadrat R20.

BaNfW

Low Woodland of Banksia attenuata and Nuytsia floribunda with occasional Banksia ilicifolia over a Low Open Shrubland of Xanthorrhoea preissii with emergent Kunzea glabrescens over an Open Herbland of Zantedeschia aethiopica on grey-brown sandy loam.

This community is represented by quadrat R15.

BAtS

Open Woodland of occasional Eucalyptus marginata over a Low Open Woodland of Banksia attenuata and Banksia menziesii with occasional Eucalyptus marginata over an Open-Heath of Allocasuarina humilis, Conostephium minus and Eremaea pauciflora over an Open Grassland/Sedgeland of Amphipogon turbinatus and Mesomelaena pseudostygia on grey sand.

This community is represented by quadrat R13 and monitoring quadrats RW01 and RW04.

BHhW

Low Open Woodland of Banksia attenuata and Banksia menziesii with occasional Eucalyptus marginata and Nuytsia floribunda over a Shrubland of Allocasuarina humilis and Hibbertia hypericoides with occasional Allocasuarina fraseriana and Jacksonia furcellata over a Grassland of Ehrharta calycina and Mesomelaena pseudostygia on pale brown sand.

This community is represented by quadrats R05, R06 and R07 and by monitoring quadrat RW05.

BiSiH

Low Open Woodland of Banksia ilicifolia over a Tall Open Shrubland of Kunzea glabrescens over an Open Herbland of Scholtzia involucrata and Carpobrotus edulis on grey sand.

This community is represented by quadrat R14 and by monitoring quadrats RW20, 21 and 30.

BXpW

Low Open Woodland of Banksia attenuata and Banksia menziesii with occasional Eucalyptus marginata over an Open Heath of Hibbertia hypericoides and Xanthorrhoea preissii over an Open Sedgeland of Mesomelaena pseudostygia.

This community is represented by quadrat R03 and by monitoring quadrats RW12, RW13 and RW17.

CcBKgS

Low Open Forest of Corymbia calophylla, Banksia attenuata and Banksia ilicifolia over a Tall Shrubland of Kunzea glabrescens over a Low Shrubland of Xanthorrhoea preissii with occasional Macrozamia riedlei over a Herbland of Lomandra sp. and Dasypogon bromeliifolius on grey sand.

This community is represented by quadrats R10 and R25 and by monitoring quadrats RW25, RW27 and RW31.

CcXpDdS

Open Woodland of Eucalyptus marginata and Corymbia calophylla over a Low Open Shrubland of Xanthorrhoea preissii, Macrozamia riedlei, Daviesia divaricata and Hibbertia hypericoides over an Open Grassland of Ehrharta calycina on grey sand over yellow sand.

This community is represented by quadrat R12 and monitoring quadrats RW06 and RW07

CcXpMrS

Woodland to Open Woodland of Eucalyptus marginata and Corymbia calophylla over an Open to Low Shrubland of Xanthorrhoea preissii, Macrozamia riedlei and Hibbertia hypericoides. over an Open Herbland of Oxalis pes-caprae and Sowerbaea laxiflora over an Open Grassland of *Briza maxima and Ehrharta calycina on brown sandy loam.

This community is represented by quadrat R02, R04, R17 and by monitoring quadrats, RW08 and RW09.

EgXpS

Open Woodland of Eucalyptus gomphocephala and Eucalyptus marginata over a Low Open Woodland of Banksia attenuata over a Tall Open Shrubland of Xanthorrhoea preissii over an Open Sedgeland of Mesomelaena pseudostygia on yellow sand.

This community is represented by quadrats R18 and by monitoring quadrats RW10 and RW11.

EmApS

Open Woodland to Low Open Woodland of Eucalyptus marginata and Banksia attenuata over Low Shrubland of Acacia pulchella, Hibbertia hypericoides, Macrozamia riedlei and Xanthorrhoea preissii over Briza maxima on yellow sand.

This community is represented by quadrat R19.

EmBaS

Open Woodland of Eucalyptus marginata over a Low Open Woodland of Banksia attenuata and Banksia menziesii over an Low Open Heath of Allocasuarina humilis, Xanthorrhoea preissii and Hibbertia hypericoides over an Open Sedgeland of Mesomelaena pseudostygia in grey-yellow sand.

This community is represented by quadrats R01 and by monitoring quadrats RW02 and RW03.

EmKgS

Low Woodland of Eucalyptus marginata with occasional Corymbia calophylla and Banksia menziesii over a Tall Shrubland of Kunzea glabrescens with occasional Allocasuarina fraseriana over a Closed Herbland of Carpobrotus edulis on grey sand.

This community is represented by quadrat R26.

EmXpS

Low Open Woodland of Eucalyptus marginata, Banksia attenuata and Banksia menziesii over a Low Open Shrubland of Xanthorrhoea preissii with occasional Banksia sessilis in degraded areas, on brown-yellow sand.

This community is represented by quadrat R21 and by monitoring quadrats RW22 and RW23.

ErCtS

Low Woodland to Open Forest of Eucalyptus rudis, Banksia attenuata and Melaleuca preissiana over Low Open Shrubland of Taxandria linearifolia, Gastrolobium ebracteolatum and Pteridium esculentum over Closed Sedgeland of Cyathochaeta teretifolia (P3) on brown sandy loam.

This community is represented by quadrat R29 and monitoring quadrats RW26 and RW29.

ErMpAfS

Low Open Forest of Eucalyptus rudis and Melaleuca preissiana over a Tall Open Shrubland of Astartea fascicularis and Kunzea glabrescens over an Open Shrubland of Pteridium esculentum over a Sedgeland of Lepidosperma angustifolium on brown clayey-loam flats.

This community is represented by quadrat R23 and by monitoring quadrats RW24 and RW28.

ErMpGeS

Low Open Forest of Eucalyptus rudis and Melaleuca preissiana with occasional Banksia attenuata over a Tall Shrubland of Gastrolobium ebracteolatum and Kunzea glabrescens over a Low Open Shrubland of Taxandria linearifolia over a Sedgeland of Baumea preissii ssp. laxa on black clay flats.

This community is represented by quadrat R24.

ErMpH

Open Woodland to Low Open Woodland of Eucalyptus rudis and Melaleuca preissiana over Open Herbland of Carpobrotus edulis, Zantedeschia aethiopica and Oxalis pes-caprae on grey sand.

This community is represented by quadrat R09 and by monitoring quadrat RW18.

EtKgS

Low Open Woodland of Eucalyptus todtiana with occasional Eucalyptus rudis over a Tall Open Shrubland of Kunzea glabrescens over an Open Herbland of Carpobrotus edulis on grey sand.

This community is represented by quadrat R16 and by monitoring quadrat RW19.

MpBaS

Open Forest of Corymbia calophylla, Eucalyptus rudis and Banksia littoralis over a Tall Shrubland of Melaleuca preissiana and Kunzea glabrescens with occasional Melaleuca rhaphiophylla over a Closed Sedgeland of Baumea articulata fringing wetlands.

This community is represented by quadrat R28.

MpKgS

Low Open Woodland of Melaleuca preissiana and occasional Eucalyptus rudis over a Closed Tall Scrub of Kunzea glabrescens over occasional Lepidosperma angustifolium over an Open Herbland of Zantdeschia aethiopica over Aira caryophyllea and Gallium murale on brown sandy-loam flats.

This community is represented by quadrat R22 and monitoring quadrat RW14.

LlHpS

Low Shrubland of Leptospermum laevigatum and Hakea prostrata over a mixed Grassland/Herbland of introduced species associated with disturbed roadside areas.

No representative quadrat was assessed.