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Ecological Footprint accounting for Western Australia



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1. Introduction

The latest cycle of State of the Environment (SoE) reporting in Western Australia (WA) commenced in 2003. The Environmental Protection Authority (EPA), on behalf of the State Government, is responsible for overseeing production of the SoE Report, which is due for release in early 2007. The EPA is an independent environmental advisory body and has welcomed the responsibility of coordinating the 2007 State of the Environment Report. Over the past few years, the EPA has sought to engage the community to provide input on various aspects of this report. To this end, the SoE reporting series of technical and discussion papers has been produced for community and stakeholder input to influence the next report.

State of the Environment reports are designed to communicate credible, timely and accessible information about the condition of the environment to decision makers and the community. The EPA has identified that the scope of the 2007 State of the Environment Report should address population and consumption patterns as these are fundamental pressures that cause human impacts on the environment.

This technical paper provides information on a key indicator of demand on the environment from consumption, the ecological footprint. Ecological footprint accounts document the area of land and water ecosystems required to produce the resources consumed by a given population and assimilate the wastes that the population produces (Rees, 2000). The aim of this paper is to outline a methodology for applying the ecological footprint to WA and establishing baseline measures against which to compare future analyses.

The ecological footprint was identified as an indicator in the 1998 SoE report; however, at that time no analysis had been undertaken for WA. Subsequently, the State Government has established a target in the *State sustainability strategy* (Government of Western Australia, 2003) to halve the ecological footprint of the WA economy by 2020.

There is currently no ecological footprint account for WA. The need to establish a methodology and regular accounting has been identified by the State Government. This will provide a measure of progress against goals in the *State sustainability strategy*. The results of this analysis will be reported in the 2007 SoE Report and it is intended that regular reporting of the WA ecological footprint will occur through the State of the Environment reporting process.

This report has been prepared in collaboration with Dr Peter Johnson of Prime Research Pty Ltd.

2. Overview of the ecological footprint and input-output analysis

2.1 Ecological footprint accounting

The ecological footprint is a form of natural resource accounting, which measures the ecological demand of human populations. It accounts for the direct land required by households for housing, roads etc. It also accounts for the indirect land embodied in the inputs to goods and services that people consume, such as agricultural land, land for manufacturing, land for waste disposal etc. It can be seen as an indicator of sustainability because it measures the total ecological cost (in area of biologically productive land) required to supply all the goods and services to a human population (McDonald & Patterson, 2003).

The ecological footprint is closely related to the concept of carrying capacity which, in ecological terms, is the maximum number of a given species that can be supported indefinitely in a defined habitat without permanently damaging the ecosystem on which it depends (Bicknell et al., 1998). While carrying capacity is generally expressed as number of individuals per hectare, the ecological footprint is essentially the inverse of this and is expressed as number of hectares per person. In this sense it is also considered a sustainability indicator as it relates to an underlying principle for sustainability - the requirement for maintenance of natural capital on which humanity depends. From this perspective, if the ecological

footprint of a defined population exceeds the biological carrying capacity of the population, then the population is considered to be in ecological deficit, or a net debtor of ecological capacity.

Unlike carrying capacity, ecological footprint accounts include the land embodied in trade and therefore measure the ecological demand of a population regardless of where the resources originated. Ecological footprint accounts enable distinction between the portion supplied domestically and the portion embodied in imports. They also provide a framework to compare resources embodied in trade flows, i.e., the resource demand to supply economic production versus that required to supply final consumption (Wackernagel et al., 2004).

It is important to note that ecological footprint accounts do not capture of the environmental impacts of human consumption. For example, they do not include emissions to land, water or air (other than greenhouse gases). Also, using area of land use as a metric for measuring sustainability has limitations. Firstly, because not all types of consumption can readily be converted to land area, such as water use, and secondly because ecological footprints are typically presented as an aggregate value. This approach has been criticised (see for example Van den Bergh and Verbruggen, 1999 and Lenzen and Murray, 2001) as the intensity of land use and the impact of different human activities on land varies considerably. For example, a hectare of land covered by buildings is treated as equivalent in terms of ‘impact’ to a hectare of land used for extensive livestock grazing in ecological footprint accounts. In reality, land used for buildings is considerably more impacted (altered from its natural state) than land used for extensive grazing. Ecological footprints therefore do not reflect the relative level of environmental impact of different land uses.

2.2 The evolution of ecological footprint accounting

The ecological footprint methodology has been subject to continual review and refinement since its inception. There is currently no general consensus on a standard methodology for calculating ecological footprints and to date, a number of approaches have been developed and applied at the national and regional (e.g. state) scale. In some instances, this has led to large variances in results between analyses and confusion in the interpretation of results. For example, past analyses of Australia’s ecological footprint have ranged from 6 ha per person to 13.6 ha (Simpson et al, 2000; Lenzen & Murray, 2001). Determining and documenting an appropriate methodology for Western Australia is an important component of this report so that the results can be used in the 2007 SoE report and future comparisons can be clearly made.

Probably the most widely used method to date is ‘compound’ footprinting. This approach is based on national economic and biophysical data on production, trade and consumption. In this approach, regional analyses are derived from national accounts.

To address the inconsistency in footprinting methodologies, the Global Footprint Network has initiated a committee-based process for the development of standards governing footprint applications, and for an ongoing scientific review of the methodology based on the compound approach (Global Footprint Network, 2006). However, criticisms have been raised of the applicability and policy relevance of this approach for regional EF accounting.

For example, the results are expressed in standardised units (global hectares) of world-average productivity. Incorporating global productivity into the calculation provides a common standard for comparison of national footprints and highlights the global sustainability issue of the inequity in the distribution and consumption of resources. It has relevance to the *State sustainability strategy*, which, in its principles, recognises the responsibility of the State to contribute to global sustainability issues (Government of Western Australia, 2003). However, as Lenzen & Murray (2001) note, much regional detail is lost in this approach, as the results no longer reflect actual areas of land used. Lenzen and Murray argue that methods that focus on regional problems are more useful for policy application as most policies are developed and implemented at a regional level.

To overcome some of the drawbacks associated with application of the compound method at a regional level, this method has been modified by a number of practitioners using input-output analysis.

2.3 Input-output analysis

At the heart of input-output analysis is the input-output table, which provides a summary, or a “snapshot”, of the transactions occurring within a defined economy over a selected period of time. The Australian Bureau of Statistics (ABS) produces input-output tables at the national level. These tables show, in a tabular or matrix format, the consumption and sales patterns of over 100 industries. In simple terms they show, for a given industry, which other industries it purchases from and to which other industries it sells. The national (Australian) input-output tables also show the use of industry production in private and government consumption, the use in public and private investment and export sales.

While the ABS produces national input-output tables, they do not produce state or regional tables. An input-output table for Western Australia for the year 2001-02 was made available by Prime Research Pty Ltd for the purpose of this study. The table was derived by the following process.

1. An input-output table for Australia for 1996-97 was updated to 2001-02 using a procedure known as RAS (or biproportional matrix adjustment). (The 1996-97 Australian input-output table was used as the basis for this approach rather than the 1998-99 table so as to make use of the 1996 census data.)
2. An input-output table for Western Australia was generated using a modified cross-industry quotient method (Johnson, 2003).

The Western Australian input-output table contains the 74 industries shown in Table 1.

Table 1: Western Australian input-output industries

Industry	Industry
1 Sheep	38 Other chemical products
2 Grains	39 Rubber products
3 Beef cattle	40 Plastic products
4 Dairy cattle	41 Glass, glass products and ceramic products
5 Pigs	42 Other non-metallic mineral products
6 Poultry	43 Iron and steel
7 Hay	44 Basic non-ferrous metal and products
8 Other agriculture	45 Structural, sheet and fabricated metal products
9 Services to agriculture; hunting and trapping	46 Transport equipment and machinery
10 Forestry and logging	47 Electronic, household and electrical equipment
11 Commercial fishing	48 Prefabricated buildings
12 Coal	49 Furniture
13 Oil & gas	50 Other manufacturing
14 Iron ores	51 Electricity supply
15 Non-ferrous metal ores	52 Gas supply
16 Other mining	53 Water supply; sewerage and drainage services
17 Services to mining	54 Construction
18 Meat and meat products	55 Trade and repairs
19 Dairy products	56 Accommodation, cafes and restaurants
20 Fruit and vegetable products	57 Road transport
21 Oils and fats	58 Rail, pipeline and other transport
22 Flour mill prods, cereal foods and bakery prods	59 Water transport
23 Confectionery, other food prods and soft drinks etc	60 Air and space transport
24 Beer and malt	61 Services to transport; storage
25 Wine and spirits	62 Communication services

26	Tobacco products	63	Finance and insurance
27	Textiles	64	Ownership of dwellings
28	Knitting mill products	65	Other property services
29	Clothing, footwear and leather	66	Business services
30	Sawmill products	67	Government administration
31	Other wood products	68	Defence
32	Pulp, paper and paperboard	69	Education
33	Paper containers and products	70	Health services
34	Printing and publishing	71	Community services
35	Petroleum and coal products	72	Entertainment and the arts
36	Basic chemicals and paints	73	Sport, gambling and recreational services
37	Medicinal, pharmaceutical, pesticides, soap, cosmetics	74	Personal and other services

2.4 Input-output multipliers

Input-output tables provide a snapshot of the economy of a given region. They are therefore very useful in a descriptive sense, and they allow for a detailed analysis of a regional economy to be performed. However, input-output tables are most frequently used to generate input-output multipliers, which are used to conduct economic impact analysis.

Input-output multipliers capture the direct and indirect effects of an economic stimulus on a region. For example, if demand for transport services from Western Australia were to increase, input-output multipliers can be used to estimate the total impact of this increased demand on various economic attributes of Western Australia, such as output, income, employment, and value-added.

The total economic impact identified by use of input-output multipliers includes the direct effect of the initial increase in demand and the indirect (or “flow-on”) effects. The flow-on effects result from the linkages between industries in the economy. For example, transport service providers in Western Australia purchase inputs from other local industries. When demand for their output increases, the transport companies will increase their purchases from other local businesses, who themselves must increase their consumption, some of which will be from other local firms, and so on.

2.5 Input-output and ecological footprints

Incorporating input-output analysis into the calculation of ecological footprints was first undertaken by Bicknell *et al.* (1998). The technique has since been refined by Ferng (2001), Lenzen and Murray (2001), McDonald and Patterson (2003) and others.

Input-output tables represent the payments, in dollars, made for purchases of goods and services by different sectors of an economy in a reference year. Associated with this financial flow is the actual flow of goods and services in the economy. If the price of each purchase is known, the input-output table can be adjusted to represent the physical flow of goods and services between sectors. However, the price of each transaction represented in any input-output table is rarely known. By assuming a constant price across purchasers for each good and service, the input-output table can be taken to represent the relative share of sales of all goods and services between purchasing industries and final consumers. With this constant price assumption, the input-output table can be used to trace physical flows in the economy.

One of the physical inputs to all of the industries in an input-output table is land. Land is an obvious input into certain industries, such as agricultural industries. Land is a less obvious, and less important input into other industries, particularly service industries such as insurance and banking. Some sectors, such as food processing, do not have a large direct usage of land; however, since they depend upon agricultural products as their main process input, they have a large indirect dependence upon land. Input-output tables, which cover all of the economic activities in a given economy, provide a rigorous framework for capturing all of the land usages, direct and indirect, in an economy.

2.6 Advantages and disadvantages of the input-output approach

McDonald and Patterson (2003) list four main advantages of using input-output tables for determining ecological footprints:

- 1) **Comprehensiveness:** previous methods for determining the ecological footprint lacked a consistent framework. These approaches typically neglected service sectors, a major part of all modern economies, although not large direct users of land. Input-output analysis, by being a comprehensive representation of the economy, ensures no industries are left out of the ecological footprint calculations.
- 2) **Systematic approach:** input-output tables are balanced so that inputs equal outputs ensuring that all aspects of the economy are covered. Their complete listing of economic activities provides a convenient checklist when determining land use by industry.
- 3) **Avoids double-counting:** input-output accounting eliminates the problem of double-counting encountered in some methods.
- 4) **Mathematically rigorous:** input-output matrices are balanced and complete representations of a given economy. Manipulation of these matrices using matrix algebra is a well-established and well-documented procedure.

McDonald and Patterson (2003) also list disadvantages of the use of input-output tables in ecological footprint analysis:

- 1) **Industry definition:** input-output industries are frequently broadly defined, leading to loss of detail and, potentially, to inaccuracies in the analysis.
- 2) **Accuracy and currency:** accurate and up-to-date input-output tables are not always available for the region to be analysed. In periods of rapid technological change, using dated input-output tables can distort inter-industry relationships and introduce inaccuracies into the analysis.
- 3) **Physical versus financial flows:** input-output tables are presented in monetary terms, which represent the price and quantity of goods and services transferred in an economy. If prices are constant for each product sold, then this does not represent a problem, as physical flows move proportionally to financial flows. If, however, prices differ across users, then physical relationships in the table are distorted with a corresponding loss of accuracy in the analysis.

3. Methodology

3.1 Deriving a multi-regional input-output table

In the analysis of Western Australia's ecological footprint, it is necessary to estimate the component of the footprint that is due to the consumption of goods and services from beyond the state's borders. McDonald and Patterson (2003), in their analysis of regional (councils) ecological footprints in New Zealand, made use of multiregional input-output tables for New Zealand to determine the full New Zealand component of each region's footprint. Multiregional tables include trade between each region by supplying and consuming industry and by final demand sector. The process of developing the Western Australian input-output table included the development of an input-output table for the rest of Australia (ROA) and included the estimation of detailed trade data between these two regions. In effect, a bi-regional input-output table (a special case of a multiregional table where there are only two regions) was developed. From this bi-regional Australian table it is possible to derive estimates for the full Australian component of the Western Australian ecological footprint.

The ecological footprint of Western Australian consumption also includes a value for the use of goods and services supplied from outside of Australia. McDonald and Patterson (2003) estimate land embodied in foreign imports by assuming similar production technologies overseas as apply in New Zealand. Therefore, the land embodied in imports is calculated by multiplying final demand for imports by the appropriate domestic land use multiplier.

In this work we use similar assumptions to McDonald and Patterson, but apply a more comprehensive analytical approach by deriving an input-output table for the suppliers of these imports. By assuming that Western Australia's industries and consumers purchase imported goods and services at the same rate as the national average, the Western Australian input-output table includes detailed data on imports from the rest of the world. Similarly, foreign imports to the ROA are also included in the ROA input-output table.

The rest of the world is a very large economy to characterise in an input-output table, and no attempt was made to do so. Instead, an abstract region, referred to as the import producing world (IPW), was developed. The IPW is defined as a region of the world that produces all of Australia's foreign imports while taking none of Australia's exports. While it is clearly the case that some Australian exports do return to the state as components of imported goods, this simplifying assumption is not expected to significantly alter the results of the analysis.

An input-output table for the IPW was developed based upon the Australian input-output table. The IPW table retains the same input cost structure as shown in the Australian table for 2001-02. This is in effect the same assumption made by McDonald and Patterson: that similar production technologies apply in domestic and foreign production. Each industry in the IPW table is required to produce, at a minimum, sufficient production to meet the import demands of Western Australia and the ROA, and sufficient production to meet the needs of the "local" IPW economy. To derive an input-output table for the IPW that meets the needs of local industry, private and government consumers and the needs of the Western Australian and ROA economies is an iterative process, the details of which are not provided here. However, the key criteria upon which to judge the success of the process are that:

1. a balanced input-output table is produced: industry production equals industry sales;
2. the technical coefficients¹ derived from the table (which are a representation of the cost structure of each industry) are identical to the technical coefficients for the Australian input-output table; and
3. sufficient exports are produced to meet the needs of all Australian consumers.

The final IPW input-output table met each of these criteria.

With the estimation of the IPW's input-output table, it was then possible to develop a multi-regional input-output table covering Western Australia, the ROA and the IPW. Figure 1 is a schematic representation of this table.

¹ Technical coefficients are calculated as the cost of each input used by an industry divided by total costs (where total costs include labour payments and payments to the owners of capital).

Figure 1: Schematic representation of multi-regional input-output table for Western Australia, the ROA and the IPW

	Region	Use						Total sales
		Intermediate usage			Final demand			
		WA	ROA	IPW	WA	ROA	IPW	
Supply	WA	Q1	Q2	Q3	Q4	Q5	Q6	
	ROA	Q7	Q8	Q9	Q10	Q11	Q12	
	IPW	Q13	Q14	Q15	Q16	Q17	Q18	
	Primary factors	Q19	Q20	Q21	Q22	Q23	Q24	
	Total costs							

Figure 1 shows 24 separate quadrants (Q1 to Q24) in the multiregional table. Consider quadrant 1 (Q1). Q1 contains 74 rows and 74 columns corresponding to the 74 industries in the Western Australian input-output table - these are not shown so as to simplify the figure. The rows in Q1 show the sales of the output of Western Australian industries to other Western Australian industries. An alternative, and equally valid interpretation is that the columns of Q1 show the purchases of Western Australian industries from other local industries. Similarly Q8 shows sales and purchases of ROA industries while Q21 shows the sales and purchases of IPW industries. So in summary, Q1, Q8 and Q15 show the domestic inter-industry transactions in each region.

Quadrant 2 (Q2) shows sales of Western Australian output to industries in the ROA, while Q3 shows sales of Western Australian output to IPW (which, for simplicity, we have assumed are zero). Q2 and Q3 also have alternative representations. From the point of view of industries in the ROA, Q2 represents the consumption of Western Australian production by ROA industries. From the point of view of IPW, Q3 represents consumption of Western Australian production by IPW industries.

Quadrants 19, 20 and 21 represent the payments made to primary factors by industries in, respectively, Western Australia, the ROA and the IPW. Where primary factors represent labour, land, capital and natural resources.

With purchases from all three regions and payments to factors of production represented in the multiregional table, the shaded areas at the bottom of Figure 1 contain the Western Australian, ROA and IPW total costs for Western Australian, ROA and IPW industries.

While we have described total costs, we are yet to describe all sales from the industries in the multiregional table. Tracing across the rows that represents the Western Australian input-output relationships, quadrant 4 (Q4) in Figure 1 shows the final demand purchases (private consumption, government consumption and investment) of Western Australian consumers of Western Australian production. Q5 shows the final demand purchases of ROA consumers of Western Australian production; while Q6 shows the final demand purchases of IPW consumers of Western Australian production. Summing across the each of the 74 rows of Western Australia production gives total sales from Western Australian industries, which since industry definitions in rows and columns are the same, equals the total costs of Western Australian industries.

3.2 Creating land use multipliers

Figure 1 represents the multi-regional input-output table used in the analysis of Western Australia's ecological footprint. If the elements of each column of the input-output table are divided by the column sum (the shaded area at the bottom of each column in Figure 1) then the input-output coefficients are determined. These coefficients, which sum to a value of one, show the inputs, by source, used to produce \$1 worth of output from each industry.

The elements of the coefficients table that cover usage of inputs from all industries in all locations can be placed into a square matrix **A**. From **A** the Leontief inverse matrix $(\mathbf{I}-\mathbf{A})^{-1}$ can be derived. It is from this inverse matrix that all input-output multipliers are calculated.

The Leontief inverse matrix captures the linkages between different sectors of an economy. From the Leontief inverse the impact of an increase in demand for the output of one sector, on production from all sectors in the economy, can be determined.

To calculate the land required to increase output from an industry by one dollar it is first necessary to calculate land coefficients. The land coefficient is the quantity of land used to produce \$1 of output from an industry. This is calculated as the area of land used in production divided by the total value of production. From this procedure a coefficient L_i (where i represents industry) for each industry can be determined. Forming the L_i coefficients into a diagonal matrix $\hat{\mathbf{L}}_i$, and using this matrix to pre-multiply the Leontief inverse matrix calculates **C**, the matrix of embodied land requirements for each industry. The columns in this matrix represent the direct and indirect land needed to produce a dollars worth of output from each industry. By summing down the column a total land use multiplier, m^T , is derived. This multiplier shows the land required from all sources - domestic and foreign - and from all industries to produce one dollar of output from each industry. By summing over only those industries located in Western Australia (Q1, Q2 and Q3 in Figure 1) the WA multiplier, m^{WA} , is calculated. This multiplier is concerned with land that is located within Western Australia, and does not include land located in other states or in other countries.

Actual land and total land (including energy land) multipliers were calculated for this analysis. The difference between these two land types is described in later sections.

3.3 Data sources for area of land used by each industry

The area of land used by each industry in WA and the ROA were obtained from several sources (Appendix B). The area of land used for ROA industries was calculated as the balance between national and WA statistics on each industry. However, land use data for many industries were not available at the national level and for these industries WA land coefficients were used for the ROA. A summary of land area

Agricultural industries

The areas of land used by agricultural industries were largely derived from the ABS 2001 agricultural census (ABS, 2002; 2003). The agricultural census collects information on area of most agricultural crops. This information was aggregated to determine the total area used for 'grains', 'crops and pastures for hay', 'other agriculture' and 'wine and spirits'.

Data were not available on the actual land grazed by 'sheep' and 'beef cattle'. However, the agricultural census collects information on the area of sown pasture, native pasture and other grazing land (e.g. saltbush and brigalow scrub), as well as the number of each livestock type in each local government area (LGA). Since stocking rates and productivities of land used for grazing in Australia are highly variable, the amount of land included in the calculations for these industries can substantially modify the result of the analysis. For example, Simpson et al. (1998) estimate that 7.58 ha/person is required to sustain the consumption of meat and dairy products for a typical Australian if all pastures are included, but only 1.08 ha/person is required if sown pastures only were included in the calculations.

In this analysis the ABS classification 'all pastures' (natural pastures plus sown pastures) was used as the basis of land grazed by beef cattle and sheep after subtracting the area used for dairy cattle. This excludes 'other grazing' land, such as saltbush and brigalow scrub, which in WA amounts to an additional 21.8 million ha. It is arguable whether this land should be included in the calculations for beef and sheep cattle. Using only pastures is consistent with the approach used by the Global Footprint Network (2006),

which produces the national ecological footprint accounts. In addition, 'other grazing' land is typically subject to very low grazing densities due to very low productivities and if included, would considerably increase the WA ecological footprint. However, Lenzen and Murray (2001) argue that all land should be included in ecological footprint assessments for the direct and indirect value to humans. They employ weightings to different land uses to reflect the varying level of disturbance of different land use types, which counteracts the effect of vast grazing areas of Australia's ecological footprint. However, this approach introduces another problem into the accounts – the no longer represent actual land area, but are converted to arbitrary values based on the weighting factors applied. Incorporating disturbance weightings into ecological footprint analysis introduces additional assumptions and uncertainties into an already uncertain model. Nevertheless, this component of the methodology should be subject to further review for future analyses.

As data were not available on the area grazed by beef cattle and sheep, an average grazing ratio of eight sheep to one beef cattle (Division of National Mapping, 1982), was applied to the number of beef cattle and sheep to determine relative areas grazed by each. This ratio is general as ratios can vary between regions. For example, the Department of Agriculture Western Australia uses the standard livestock ratio of one cattle unit to seven dry sheep equivalents for the pastoral areas of WA. As grazing densities vary greatly within WA, the areas grazed by beef cattle and sheep were calculated for each local LGA and then aggregated to determine totals for the State.

For the ROA, the grazing ratio (sheep to beef cattle) was applied directly to the total numbers of beef cattle and sheep in the ROA as data on the number of beef cattle and sheep at the LGA level were not obtained for this analysis.

Additional sources of data for land use by animal industries were the Australian Dairy Corporation (2000) and the National Land and Water Resources Audit (2001).

Mining and forestry

The area of land used by mining industries in WA was based on data collected by the Department of Industry and Resources (unpublished) on the area disturbed by mining activity. The area of land use for each mining industry was calculated as the cumulative area of disturbance minus the area that has been rehabilitated. As data for mining industries was not available for the ROA, WA coefficients were used.

The area of land used for forestry for WA and ROA was obtained from the Department of Conservation and Land Management (2004), National Forest Inventory (2003) and Department of Agriculture, Fisheries and Forestry (2002). Both plantation and native forest areas available for harvest were included.

Urban land uses

The area of land used by industries in urban areas was determined through geo-spatial analysis using detailed survey information on urban land use, town planning scheme zoning data and ABS census data. Comprehensive survey information on land use (floor space and activity) in commercial, industrial and recreational areas were obtained from the Department for Planning and Infrastructure (2003). The surveyed areas included all commercial, industrial and recreational zoned areas in the Perth metropolitan region and several regional and rural towns throughout WA.

Each activity, which is based on the Western Australian Standard Land Use Classification Scheme, (Western Australian Land Information System, 2006) was concorded to the input-output industries. Within the surveyed areas of each settlement, the total area required to support each industry was determined as a proportional scaling of known floor space to zoned area. This scaling accounted for shared facilities (such as car park space) and multilevel buildings. Average floorspace areas were applied to the small number of responses where no floorspace figure was returned.

The information on surveyed areas was then used to extrapolate out to the balance of urban areas in WA. To do this the results from the surveyed settlements were aggregated into 'settlement profiles' representing different types of settlements in WA (metropolitan, regional centre, urban centre, locality). The average per capita area of land required for each industry within each settlement profile was derived from the known survey data, LGA boundaries (Department of Land Information, 1998), town planning schemes (Department for Planning and Infrastructure, 2005) and census information (Australian Bureau of Statistics, 2001).

The total area used by each industry in Western Australia was calculated by scaling the known areas by population. All unsurveyed local government authorities were characterised as 'metropolitan', 'regional centre', 'urban centre' or 'locality' and the population of each LGA multiplied by the per capita breakdown of the respective settlement profile. This approach accounts for the differing industry structures in different settlements in WA. The known and derived areas for each industry were then aggregated to determine the total area of land use for each industry in WA.

The area of land used for residential purposes was derived from town planning scheme data (Department Planning and Infrastructure, 2005) for each LGA.

The area for roads was determined by multiplying all road lengths in WA by standard widths for each road type using geo-spatial analysis. The road centreline dataset (Main Roads, 2005) was classified to correspond with average widths for standard road types. The area for rail was obtained by multiplying the total length of railways in WA (Auslig, 1995) by the average width for rail (including shoulders) which is 20m. The area for gas transmission pipelines was obtained from Alinta Gas and the WA Office of Gas Access Regulation. Urban supply gas networks were excluded as these are all underground and covered by other land uses that would be captured elsewhere in the analysis.

Fisheries

Consumption of seafood products is a controversial component of ecological footprint accounts as area is not a very useful metric for estimating human demand on marine ecosystems. However, seafood forms a significant part of the Australian diet and therefore an attempt was made to capture the demand on nature from seafood consumption in WA's ecological footprint account. The 'area' for fisheries in this analysis is hypothetical. It is based on the area of land that would be required to produce the equivalent protein content in seafood products consumed by growing a land-based alternative. Wheat was used as it is the main crop grown in WA and data on the average protein content of wheat and yield were readily available. A meat substitute, such as beef, would probably be more suitable; however, information on the average protein yield from beef cattle was not readily available.

Land use in the import producing world

Land use, production and trade data for the IPW were obtained from the United Nations Food and Agriculture Organisation statistical databases (2005). Reliable data was only available for forestry and some agricultural industries at the international level (Appendix B). For the remainder, national or WA coefficients were applied to the IPW.

3.4 Calculations for 'actual land'

'Actual land' is that component of the ecological footprint that accounts for land used to produce goods and services consumed. It is based on all available data on area of land use by each industry and the input-output framework.

In calculating actual land multipliers the actual land use data described above was divided by industry production to determine actual land use coefficients. These actual land use coefficients were then used in the derivation of the actual land use multipliers.

3.5 Methodology for 'energy land'

The 'energy land' component of the ecological footprint accounts for the need to manage the greenhouse gas emissions from the combustion of fossil fuels for energy supply and other activities. Nearly all carbon dioxide (CO₂) emissions in WA are from energy use and these constitute nearly 65% of total greenhouse gas emissions for the State (Australian Greenhouse Office, 2005). The 'energy land' footprint is an estimate of the area required to sequester atmospheric CO₂ emissions through sequestration by forests. Only CO₂ has been included in this analysis as it is the only greenhouse gas removed from the atmosphere through biosequestration. This is consistent with the approach used by the Global Footprint Network and in McDonald and Patterson's New Zealand study (McDonald and Patterson, 2003) on which this analysis has been based. Other studies (eg Lenzen and Murray, 2001) have included all greenhouse gases (by converting to CO₂ equivalent) on the basis that removal of CO₂ from the atmosphere could compensate for emissions of other greenhouse gases.

The average sequestration rate of the WA forest stock of 5.5 tonnes CO₂/hectare/year was determined from average carbon uptake rate of all forest types (based on data from the Australian Greenhouse Office, 1998).

Data on carbon dioxide emissions for 2002 were obtained from the WA Greenhouse Gas Inventory (Australian Greenhouse Office, 2005). Where available, emissions were identified for each industry. Where data was not available at the industry level, aggregated emissions data was allocated across industries on the basis of fuel use.

In calculating total land multipliers the actual land use data and the energy land use data described above were summed and the total divided by industry production to determine the total land use coefficients. These total land use coefficients were then used in the derivation of the total land use multipliers.

3.6 Assumptions and limitations

The input-output analysis technique is based on certain restrictive assumptions, including:

- constant prices
- fixed technology
- fixed import shares
- unlimited supplies of all resources, including labour and capital
- a fixed relationship between income and private consumption.

As a result of these assumptions, there is no substitution between goods and services or between capital and labour in the production process and no substitution between goods and services in consumption. Also, there are no limitations on the supply of labour or capital to industry, and so no supply-side limits on growth.

Additional assumptions, specific to this analysis, include:

- The cost structure of the import producing world can be approximated by the cost structure demonstrated in the Australian input-output table.
- As data on land used by many industries for ROA and the IPW were not readily available, it was assumed that the land required to produce a given value of output for these industries in these regions was equivalent to the land required to produce the same value of output by those industries in WA (or ROA for the IPW where this data was available). This implies that productivity, level of technology and land management practices are uniform between the regions, which is not always the case.

The following limitations also apply to the analysis:

- The input-output table used in this analysis is for the financial year 2001-02, and can therefore be considered to be somewhat dated.
- The 2001-02 input-output table for Australia, which is the basis on which all of the derived input-output tables – the Western Australian, rest of Australia and import producing world input-output tables – is not an official Australian Bureau of Statistics product, but has been estimated based on the ABS 1996-97 input-output tables.
- The IPW was defined as an abstract region that produces all of Australia’s imports while not taking any of the country's exports. In reality, some of our exports return to our shores within processed/manufactured goods supplied from the rest of the world. The assumptions used to define the IPW therefore prevent potential “feedback”² effects from being captured by the input-output analysis.
- The footprint excludes other wastes than waste to landfill and CO₂, such as hazardous wastes and other atmospheric pollutants as these are not easily accounted for when using a land area metric. For example, only CO₂ emissions are included in the ‘emissions’ component of the footprint. Other greenhouse gas emissions are excluded, which in WA, represents approximately 35% of all emissions for the State.
- The inclusion of sea products does not easily fit the land metric. It introduces hypothetical land into the analysis while the remainder of the production land component is based on actual land use.

4. Results and discussion

4.1 Western Australia’s ecological footprint

Western Australia's ecological footprint for 2001-02 is calculated to be 27.7 million hectares (mha), including energy land. This equates to 14.5 hectares (ha) per person (the population of WA in 2002 was 1.91 million). This is the land required to produce the goods and services consumed by the Western Australian population in a year, including both locally produced and imported products. If energy land is excluded, the footprint of WA is calculated to be 22.2 mha or 11.6 ha per person. Table 2 shows the composition of the WA footprint divided into broad consumption categories. These categories represent groupings of industries from a consumer perspective. The results are presented with and without energy land as this component of the ecological footprint is very different to the actual land component.

Land embodied in food and beverages represent the largest portion of the ecological footprint for WA (46%). This category includes land required for agricultural production, processing and manufacturing, food and beverage products, as well as land for all other inputs to food and beverage production. Most of the land in this consumption category is land used for agricultural production. The energy land component of the food and beverages footprint is only 3%.

Trade, which includes the industries of ‘trade and repairs’ and ‘accommodation, cafes and restaurants’, is the second largest component of the WA footprint at 2.02 ha/person (14%). This reflects, primarily, the very large share trade has in final consumption.

² Feedback effects refer to the impact of increased Western Australian demand for imports causing an increase in demand for the state’s exports.

Table 2: Composition of the Western Australian ecological footprint (ha/person)

Consumption categories	Including energy land	Actual land only
Food and beverages	6.69	6.48
Clothing	0.50	0.47
Other manufactured products	1.56	0.90
Housing	0.19	0.08
Energy supply	0.41	0.02
Trade	2.02	1.66
Other services	1.13	0.59
Degraded land	0.74	0.74
Other	1.25	0.65
TOTAL	14.50	11.60

Note: details of which industries are included in each consumption category are provided in Appendix C.

Other manufactured products is the third largest group, with an ecological footprint of 1.56 ha/person (11%). Other manufactured products includes 24 manufacturing industries (see Appendix C). Three industries: ‘textiles’ (with significant inputs from the agricultural sector), ‘printing and publishing’, and ‘furniture’ (with large inputs from the forestry sector) represent 42% of the other manufactured products category.

The degraded land component of the ecological footprint is a miscellaneous category for land that has been severely disturbed by human activity but which, in most cases could not readily be allocated to any single using industry. For example, it includes land that has become non-productive due to salinisation, which is one of the most serious land degradation issues affecting Western Australia and is the result of past and present agricultural practices. It also includes land consumed by the road network. The housing category includes land used directly for residential purposes and the land embodied in the maintenance and operation of residential properties.

Approximately 66% of the WA ecological footprint (9.56 ha per person) is from direct and indirect land within WA. The remainder is from land embodied in goods and services imported from the rest of Australia and from overseas. If energy land is excluded then the ‘local’ component of the WA footprint is 69%. Table 2 shows the amount of land embodied in ‘local’ production compared with land embodied in imports for each consumption category of the WA ecological footprint. This gives an indication of the relative dependence of WA on trade in supporting different types of consumption. For example, the ‘local’ component of the clothing category is only 10% (0.05 ha per person) of the total clothing footprint reflecting the paucity of local production of clothing products and the State’s dependence on imported clothing products.

Table 3: WA land components of the WA ecological footprint (ha/person)

Consumption categories	Land from within WA	Land embodied in imports	Total EF
Food and beverages	5.30	1.39	6.69
Clothing	0.05	0.45	0.50
Other manufactured products	0.35	1.21	1.56
Housing	0.15	0.04	0.19
Energy supply	0.37	0.04	0.41
Trade	1.28	0.74	2.02
Other services	0.61	0.52	1.13
Degraded land	0.74	0	0.74
Other	0.70	0.55	1.25
TOTAL	9.56	4.94	14.50

Note: details of which industries are included in each consumption category are provided in Appendix C.

4.2 Land embodied in WA production and the ecological balance of trade

The ecological footprint for Western Australia outlined above accounts for consumption (and waste generation) by the Western Australian population. This conventional scope of the ecological footprint does not take into account the appropriation of resources within a region that are embodied in exports. Land embodied in trade is particularly important from a WA perspective because the State is highly dependent on exports of natural resources, particularly from mining, petroleum and agriculture, to sustain its economy. Consumption by the Western Australian population is inherently linked to exports of natural resources since earnings from these contribute significantly to the WA economy, income and therefore expenditure.

The use of WA land for domestic production for 2001-02 by final usage category is shown in Table 4. In 2001-02, 58.7 mha of land was embodied in WA production which equates to 31.03 ha per person. WA's exports to the ROA and the IPW required 21.47 ha per person, accounting for 69% of WA land used in production. In the same period, WA imported 13.9 mha of embodied land for domestic use.

McDonald and Patterson (2003) refer to the net flow of embodied land to/from a region as the 'ecological balance of trade'. From the figures above, WA can be seen as a net provider of natural capital to other countries and the ROA with an ecological balance of trade of 27.2 mha. This reflects especially, the vast areas of land used for agriculture in Western Australia and is consistent with a national ecological footprint study which found that almost half of Australia's production footprint is generated by grazing sheep and beef cattle for exports (see Lenzen and Murray, 2003).

Table 4: Western Australian land use in production by final usage category (ha/person)

Use categories	Including energy land	Actual land only
Private consumption	5.83	4.82
Government consumption	0.42	0.25
Investment	2.57	2.14
Exports	21.47	18.83
Degraded land	0.74	0.74
TOTAL	31.03	26.78

4.3 Comparison of the ecological footprint with WA's biocapacity

A common interpretation of the ecological footprint is the comparison of a region's consumption footprint with the region's available biocapacity to determine if the population is in ecological deficit. Further, the footprint of production can also be compared to biocapacity to determine if a region is in ecological overshoot. Biocapacity is classified as those areas that provide economically useful concentrations of renewable resources (Monfreda, Wackernagel & Deumling, 2004).

McDonald and Patterson (2001) compare the New Zealand ecological footprint with 'usable land', rather than total biocapacity. This approach accounts for the land set aside for biodiversity conservation and is defined as the total area of New Zealand excluding non-productive land plus national parks and reserves.

As part of this project, a spatial analysis was undertaken to determine the biocapacity of WA. The calculation of bioproductive land areas was derived from the Australian Greenhouse Office Forest Productivity Index to determine areas of significant biomass potential. For more information see the metadata statement in Appendix D. As with McDonald and Patterson, areas in conservation reserves were excluded in the biocapacity analysis as they were also excluded from the calculations for the ecological footprint.

Using this approach, the biocapacity of WA was calculated to be nearly 180 mha. Western Australia's consumption footprint by comparison was calculated to be 27.7 mha which equates to approximately 15%

of the estimated biocapacity. The footprint of production equates to approximately 33% of WA's estimated biocapacity. These results suggest WA is neither in ecological deficit or ecological overshoot.

However, both comparisons appear unreasonably low and are likely to be partly due to the approach taken for determining grazing land. In the analysis of WA's ecological footprint, only land classified as pasture by the ABS was included in the land area for 'sheep' and 'beef cattle', which amounts to 38.3 mha for these two industries. Land classified as 'other grazing' by the ABS was excluded. This additional agricultural land, amounts to a further 21.8 mha of grazing land.

It should also be noted that the inclusion of fisheries in WA's ecological footprint account generates an artificial overshoot to the equivalent area calculated for fisheries, as fisheries have not been captured in the estimation of WA's biocapacity. However, this area is negligible compared to WA's total estimated footprint and biocapacity and therefore does not affect the results significantly.

5. Further research requirements

The purpose of this analysis was to develop and outline a methodology for calculating the ecological footprint of Western Australia and establishing a baseline ecological footprint value. The methodology outlined in this report is by no means definitive and limitations and assumptions made in the analysis have been identified accordingly. It is anticipated that this methodology should serve as a starting point for application of the ecological footprint in WA and that it should be subject to review and refinement.

This section highlights some recommendations for refining the methodology and extending the application of the ecological footprint beyond the scope of the current project.

5.1 Methodology refinements and improvements

The use of an explicit input-output table for the import producing world in calculating the ecological footprint for Western Australia is one of the key innovations in this application of the ecological footprint technique. However, the use of an Australian input-output table to estimate the relationships in the IPW input-output table is clearly not optimal. While it was necessary for this analysis to make some assumptions regarding cost structures in regions outside of Australia, better data is available.

The Global Trade Analysis Project (GTAP) at Purdue University in the United States produces a global database which includes:

- 57 sectors/industries
- 87 regions of the world, including Australia
- input-output data for each region
- trade, by industry, between each region.

The data in the GTAP database could be used to develop input-output tables for Western Australia, the rest of Australia and the rest of the world, eliminating the need to using Australian cost structures to estimate the cost structures of foreign industries.

Beyond the use of the GTAP database to facilitate the calculation of ecological footprints via input-output analysis lies the more exciting prospect of using the database in a Computable General Equilibrium (CGE) model of the world economy to calculate ecological footprints in Australia over time.

CGE models use the input-output tables in their database as a starting point to determine how an economy will respond in various situations. Using various parameter/elasticities, CGE models estimate the responses of various economic agents - industries, consumers, government - to changing economic conditions. CGE models are therefore well suited to project, industry and policy analysis.

A CGE model of the world economy that incorporated ecological footprints would allow for a variety of issues to be analysed, such as:

- ecological footprints in Australia and its states over time;
- intergenerational equity in terms of land use;
- cross-country equity in land use/exploitation; and
- policy measures for reducing the ecological footprint.

5.2 Comparability with other footprint accounts

One approach with the ecological footprint in communicating human burden on the environment is to compare a region's footprint with those of other regions. The Global Footprint Network (GFN) produces the national footprint accounts for most countries, including Australia (go to www.globalfootprintnetwork.org).

In its current format, the results of this analysis cannot be compared directly with the GFN national accounts due to methodological differences. In the GFN accounting approach, the results are presented in units called global hectares, which account for productivity differences between different regions. Other Australian analyses also differ in some methodological respects, preventing direct comparison with the results of the current study. For example, Lenzen and Murray (2001) apply a disturbance weighting to different land use types based on their relative levels of impact.

The GFN accounts are designed to answer a specific research question: whether humanity is living within the ecological constraints of nature, the biological carrying capacity of the earth. They include a measure of global available biocapacity against which ecological footprints are compared to determine if populations are consuming within their 'fair share' of resources. It is possible however, to extend the current accounts for WA by converting to global hectares to provide a comparison with global biocapacity. Taking this approach would effectively result in two ecological footprint values for Western Australia; one based on actual land area and the other based on global hectares. The results would still not be comparable with the GFN accounts however, as the GFN base their accounts on consumption data modified by yield factors rather than actual land areas.

It is worth noting that significant collaborative efforts are occurring globally through the GFN to progress the development of standards for application and communication of the ecological footprint as well as establishing a scientific review process for the footprint methodology. There are several Australian partners to the network including EPA Victoria, the University of Sydney and the South Australian Government Office of Sustainability.

5.3 Updating the ecological footprint

The ecological footprint will be reported as an indicator of consumption in the 2007 State of the Environment Report for Western Australia. State of the Environment Reporting is a cyclical process with reports released roughly every five years. It is recommended that the ecological footprint for WA be updated with each State of the Environment report. This will enable trends in resource consumption to be measured over time.

Environmental indicators for State of the Environment Reporting must be based on sound methodological frameworks. Any subsequent refinements to the methodology should be accounted and adjusted for in comparing the WA ecological footprint over time.

5.4 Policy relevance

The ecological footprint has been widely promoted as a guide for policy and planning for sustainability. The tool is gaining prominence in WA policy, mostly in terms of overarching goals for sustainability (e.g. the State Sustainability Strategy and Network City). However, practical application of the ecological footprint in this capacity has been limited to date.

The analysis presented in this paper needs to be given further consideration of its applicability to policy and planning for sustainability.

The Department of Environment, through its role in State of the Environment reporting, is a partner to an Australian Research Council linkage project for advancing the application of the ecological footprint to policy development. The project is due to commence in 2007.

5.5 Regional application

This study can be seen as an application of the Ecological footprint technique at a regional - sub-national - level. It is therefore similar in depth to the work of McDonald and Patterson (2003) who looked at the ecological footprints of regions of New Zealand. In the Australian context, regional analysis is considered a sub-state level issue, and it is in this context that further consideration of the potential for regional applications of ecological footprint analysis in Western Australia are warranted.

The need for regional application of the ecological footprint has been identified in *Network city: community planning strategy for Perth and Peel* (Western Australian Planning Commission, 2004). This document provides a framework for the future growth of Perth, Mandurah and Murray. The strategy calls for the development of standardized processes to calculate Perth's ecological footprint and a supporting data collection system, as well as strategies and education programs to reduce resource consumption.

As the hub of economic, social and political activity in Western Australia, Perth would be an appropriate area to begin regional footprint analysis within the state. An ecological footprint analysis of the Perth metropolitan area would reveal the extent to which consumption in the region draws upon land resources in the rest of the state, as well as upon land resources in the rest of Australia and the rest of the world. It would be expected that, given that Perth contains the majority of Western Australia's population, that the region runs an ecological footprint deficit, relying on production from outside the region to meet many, if not most, of the needs of private and government consumption.

The remainder of Western Australia is separated into nine Regional Development Council regions: Gascoyne, Goldfields-Esperance, Great Southern, Kimberley, Mid West, Peel, Pilbara, South West and Wheatbelt. For each of these regions - or for any other region of WA that may be defined - it is possible to determine an ecological footprint. The benefits of calculating a footprint for any non-metropolitan region would be to determine:

- the demands made by communities in each region on land resources;
- the position of WA regions as net importers or net exporters of land; and
- one element of sustainability in the region.

Appendix A: Abbreviations, units and symbols

ABS	Australian Bureau of Statistics
CGE model	Computable general equilibrium model
CO ₂	Carbon dioxide
EPA	Environmental Protection Authority
GFN	Global footprint network
GTAP	Global trade analysis project
ha	hectares
IPW	Import producing world
LGA	Local government area
m	metres
mha	million hectares
ROA	Rest of Australia
SoE	State of the Environment

Appendix B: Area of land use by each industry for WA, rest of Australia and rest of the world.

		WA	RoA	RoW		
	Input-output industry	Area (ha)	Area (ha)	Area (ha)	Comments	Data sources
1	Sheep all pastures	15,023,222	47,445,630	n/a		Australian Bureau of Statistics, 2003a; Australian Bureau of Statistics, 2003b; Australian Dairy Corporation, 2001; Food and Agriculture Organisation, 2005. <i>Data period - 2000–01 (WA & Aus), 2001 (World).</i>
1	Sheep sown pastures only	3,540,713	3,460,871	n/a		
2	Grains	9,104,410	11,702,590	909,789,590		
3	Beef cattle all pastures	23,296,353	98,036,616	n/a		
3	Beef cattle sown pastures only	1,191,484	12,407,661	n/a		
4	Dairy cattle	140,151	2,579,120	n/a		
5	Pigs	1,856	14,664	n/a		
6	Poultry	1,331	22,013	n/a		
8	Other agriculture	12,776	1,170,768	254,804,588		
7	Crops & pastures for hay	243,042	1,417,958			
10	Forestry and logging	1,185,685	7,676,015	1,791,887,216	Figures relate to area of forest available for harvest (native plus plantation).	Department of Conservation and Land Management, 2004; National Forest Inventory, 2003; National Plantation Inventory 2002; FAO, 2005. <i>Data period - as at 2001.</i>
11	Commercial fishing	42,031	n/a	n/a	Based on land area required to grow equivalent protein in wheat crops. Fisheries production data for 1999-00.	Fisheries WA, pers. comm. <i>Data period - 1999–2000.</i>
12	Coal	1,329	n/a	n/a	Reported area of disturbance from mining operations in WA. Net disturbed area.	Department of Industry and Resources, Mindex database. <i>Data period - as at 2001.</i>
14	Iron ores	13,707	n/a	n/a		
15	Non-ferrous metal ores	75,255	n/a	n/a		
16	Other mining	41,300	n/a	n/a		
13	Oil and gas	495	n/a	n/a	Internal analysis of disturbance from land-based oil and gas operations disturbance only. Excludes offshore operations.	Department of Environment. <i>Data period - as at 2005.</i>

		WA	RoA	RoW		
	Input-output industry	Area (ha)	Area (ha)	Area (ha)	Comments	Data sources
9	Services to agriculture; hunting and trapping	606	n/a	n/a	Geo-spatial analysis of detailed survey information from Department for Planning and Infrastructure, Town Planning Scheme data and ABS Census data.	Western Australian Land Information System, 2006; Department for Planning and Infrastructure, 2004; DPI, 2001; Department of Land Information, 1998; Australian Bureau of Statistics, 2003c. <i>Data period - land use survey data current to 2001, TPS data to 2004.</i>
17	Services to mining	131	n/a	n/a		
18	Meat and meat products	464	n/a	n/a		
19	Dairy products	116	n/a	n/a		
20	Fruit and vegetable products	75	n/a	n/a		
21	Oils and fats	110	n/a	n/a		
22	Flour mill products, cereal foods and bakery products	33	n/a	n/a		
23	Confectionery, other food products and soft drinks	231	n/a	n/a		
24	Beer and malt	27	n/a	n/a		
25	Wine and spirits	10,441	122,931			
26	Tobacco products	n/a	n/a	n/a		
27	Textile fibres, yarns, woven fabrics + textile products	103	n/a	n/a		
28	Knitting mill products	n/a	n/a	n/a		
29	Clothing, footwear and leather	243	n/a	n/a		
30	Sawmill products	856	n/a	n/a		
31	Other wood products	242	n/a	n/a		
32	Pulp, paper and paperboard	5	n/a	n/a		
33	Paper containers and products	53	n/a	n/a		
34	Printing and publishing	176	n/a	n/a		
35	Petroleum and coal products	97	n/a	n/a		
36	Basic chemicals and paints	1,648	n/a	n/a		
37	Medicinal, pharmaceutical, pesticides, soap, cosmetics	35	n/a	n/a		
38	Other chemical products	23	n/a	n/a		
39	Rubber products	14	n/a	n/a		

		WA	RoA	RoW		
	Input-output industry	Area (ha)	Area (ha)	Area (ha)	Comments	Data sources
40	Plastic products	57	n/a	n/a	Geo-spatial analysis of detailed survey information from Department for Planning and Infrastructure, Town Planning Scheme data and ABS Census data.	Western Australian Land Information System, 2006; Department for Planning and Infrastructure, 2004; DPI, 2001; Department of Land Information, 1998; Australian Bureau of Statistics, 2003c. <i>Data period - land use survey data current to 2001, TPS data to 2004.</i>
41	Glass, glass products and ceramic products	300	n/a	n/a		
42	Other non-metallic mineral products	1,573	n/a	n/a		
43	Iron and steel	135	n/a	n/a		
44	Basic non-ferrous metal and products	4,853	n/a	n/a		
45	Structural, sheet and fabricated metal products	7,259	n/a	n/a		
46	Transport equipment and machinery	1,107	n/a	n/a		
47	Electronic, household and electrical equipment	707	n/a	n/a		
48	Prefabricated buildings	-	n/a	n/a		
49	Furniture	30	n/a	n/a		
50	Other manufacturing	112	n/a	n/a		
51	Electricity supply	534	n/a	n/a		
52	Gas supply	1,429	n/a	n/a		
53	Water supply; sewerage and drainage services	3,520	n/a	n/a		
54	Residential & other building construction	9,632	n/a	n/a		
55	Trade and repairs	10,782	n/a	n/a		
56	Accommodation, cafes and restaurants	4,423	n/a	n/a		
57	Road transport	291	n/a	n/a		
59	Water transport	202	n/a	n/a		
60	Air and space transport	1,587	n/a	n/a		
61	Services to transport; storage	1,706	n/a	n/a		
62	Communication services	346	n/a	n/a		
63	Finance and insurance	751	n/a	n/a		
64	Ownership of dwellings	62,094	n/a	n/a		
65	Other property services	262	n/a	n/a		
66	Business services	443	n/a	n/a		

		WA	RoA	RoW		
	Input-output industry	Area (ha)	Area (ha)	Area (ha)	Comments	Data sources
67	Government administration	919	n/a	n/a	Geo-spatial analysis of detailed survey information from Department for Planning and Infrastructure, Town Planning Scheme data and ABS Census data.	Western Australian Land Information System, 2006; Department for Planning and Infrastructure, 2004; DPI, 2001; Department of Land Information, 1998; Australian Bureau of Statistics, 2003c. <i>Data period - land use survey data current to 2001, TPS data to 2004.</i>
68	Defence	30	n/a	n/a		
69	Education	7,510	n/a	n/a		
70	Health services	624	n/a	n/a		
71	Community services	66	n/a	n/a		
72	Entertainment and the arts	2,213	n/a	n/a		
73	Sport, gambling and recreational services	32,461	n/a	n/a		
74	Personal and other services	1,891	n/a	n/a		
58	Rail, pipeline and other transport	131,247	n/a	n/a		Auslig, 1995
Other land uses that can't be allocated to a particular industry						
	Roads	372,588	n/a	n/a	Spatial analysis of Main Roads WA's road centreline dataset.	Main Roads, 2002
	Waste disposal	11,354	n/a	n/a		WALIS, 2006; DPI, 2004; DPI, 2001; DLI, 1998, ABS, 2001
	Other -disturbed	6,880	n/a	n/a		
	Degraded agricultural land - affected by salinity	1,027,581	n/a	n/a	Estimated area of land affected in 2000. Data on extent of land affected by soil erosion and soil acidification not available.	Land Monitor, Department of Land Information (version 2005)
Unused/ largely unimpacted						
	Conservation estate	17,916,372	n/a	n/a	Includes marine parks	Department of Conservation and Land Management, 2002
	Other uncleared land unused	20,033	n/a	n/a		WALIS, 2006; DPI, 2004; DPI, 2001; DLI, 1998, ABS, 2003c

Appendix C: Western Australian domestic consumption aggregate industries

Aggregate industry	Input-output industry	
1 Food and drink	1 Sheep	
	2 Grains	
	3 Beef cattle	
	4 Dairy cattle	
	5 Pigs	
	6 Poultry	
	8 Other agriculture	
	11 Commercial fishing	
	18 Meat and meat products	
	19 Dairy products	
	20 Fruit and vegetable products	
	21 Oils and fats	
	22 Flour mill prods, cereal foods and bakery prods	
	23 Confectionery, other food prods and soft drinks etc	
	24 Beer and malt	
	25 Wine and spirits	
	2 Clothing	29 Clothing, footwear and leather
		26 Tobacco products
	3 Other manufactured products	27 Textiles
		28 Knitting mill products
		30 Sawmill products
		31 Other wood products
		32 Pulp, paper and paperboard
		33 Paper containers and products
		34 Printing and publishing
36 Basic chemicals and paints		
37 Medicinal, pharmaceutical, pesticides, soap, cosmetics		
38 Other chemical products		
39 Rubber products		
40 Plastic products		
41 Glass, glass products and ceramic products		
42 Other non-metallic mineral products		
43 Iron and steel		
44 Basic non-ferrous metal and products		
45 Structural, sheet and fabricated metal products		
46 Transport equipment and machinery		
47 Electronic, household and electrical equipment		
48 Prefabricated buildings		
49 Furniture		
50 Other manufacturing		
4 Housing		64 Ownership of dwellings
	12 Coal	
5 Energy	13 Oil & gas	
	35 Petroleum and coal products	
	51 Electricity supply	
	52 Gas supply	
6 Trade	55 Trade and repairs	
	56 Accommodation, cafes and restaurants	
7 Other services	9 Services to agriculture; hunting and trapping	

	17	Services to mining
	57	Road transport
	58	Rail, pipeline and other transport
	59	Water transport
	60	Air and space transport
	61	Services to transport; storage
	62	Communication services
	63	Finance and insurance
	65	Other property services
	66	Business services
	67	Government administration
	68	Defence
	69	Education
	70	Health services
	71	Community services
	72	Entertainment and the arts
	73	Sport, gambling and recreational services
	74	Personal and other services
8	Other	7 Hay
		10 Forestry and logging
		14 Iron ores
		15 Non-ferrous metal ores
		16 Other mining
		53 Water supply; sewerage and drainage services
		54 Construction
9	Degraded land	Roads
		Other disturbed land
		Waste disposal
		Land affected by salinity

Appendix D: Metadata statement for determination of biocapacity

Dataset Title: WA State of the Environment Report 2007 - Area of potential biomass

Custodian: Environmental Protection Authority of Western Australia

Jurisdiction: Western Australia.

Abstract:

This is an area analysis supporting State of Environment reporting on ecological footprint. The outcome was to calculate an area which represents the total area of available for land use activities supporting human settlement in Western Australia.

The area figure is an interpretive calculation based on data supplied by The Australian Greenhouse Office's National Carbon Accounting System and CALM's Collaborative Protected Areas Database.

The total area of available for land use activities supporting human settlement in Western Australia is:

179 912 587 Ha

or 71.06% of the land mass of Western Australia (253 179 633 ha)

Search Word: HUMAN ENVIRONMENT

GEOGRAPHIC EXTENT NAME

Geographic Extent Name Category: not applicable

Geographic Extent Name Custodial Jurisdiction: Western Australia

Geographic Extent Name: not applicable

Geographic Extent Polygon: Western Australia

Geographic Bounding Box:

North Bounding Latitude: -12

South Bounding Latitude: -39.00

East Bounding Longitude: 129

West Bounding Longitude: 113

Horizontal Coordinate: Geographic System.

Geodetic Model: GDA 1994.

Vertical Coordinate System: Australian Height Datum 1971 (AHD71), in metres.

Beginning Date: 2006-08-20

Ending Date: 2006-09-01

Progress: Complete.

Update Frequency: Not Planned

Stored Data Format: ESRI GRID format

Available Format Types: None.

Access Constraint: Area figure publicly available, grid data for internal use only.

Lineage: The area was calculated by;
i) identifying areas of existing protected conservation areas
ii) identifying areas of negligible biomass potential (SoE\Ecofootprint definitions)
iii) removing these areas from the land mass of WA

i) identifying areas of existing protected conservation areas

The GIS dataset of Collaborative Australian Protected Areas Database - CAPAD (Environment and Heritage, Reserve Systems Section, 2004) was used directly . This polygon dataset was converted to grid format (25m cell resolution)

ii) identifying areas of negligible biomass potential (SoE\Ecofootprint definitions)

. investigations were made into existing sources of biomass potential
. the Australian Greenhouse Office's Forest Productivity index was identified as the best surrogate for biomass potential *(see notes below)
. A threshold of FPI = 1.8 within the FPI spectrum was selected by SoE officers as areas of negligible biomass potential (decided after reviewing vegetation mapping (bare soil), pastoral leases (areas used to support human settlement, and IBRA definitions of deserts)
. A presence\absence grid dataset was calculated (25m cell resolution)

iii) removing these areas from the land mass of WA

. the two grid datasets were subtracted from a grid version of WA (25m cell resolution)

All grids were in geographic projection in GDA94.

Final area was determined by:

. multiplying a SoE biomass potential grid (presence\absence) with the Australian Greenhouse Office's Equal Area Spatial Index (EASI) grid
. This resulted in a 25 m resolution grid with each cell representing SoE Biomass potential attributed with a cell value equivalent to it's area calculated by Alber's Equal Area projection.
. All the cell values representing SoE Biomass potential were summed to determine the final area of 1799125.872 Ha

Notes on the Forest Productivity index:

The Forest Productivity index is derived from a productivity model, using monthly climate data in conjunction with solar radiation and leaf area index. These data provide a measure of potential forest productivity on a relative scale of 1 to 25. The calculation does not take into account factors such as site disturbance or age of forest and the resulting index values do not form a linear relationship with biomass. For more information please contact the Australia Greenhouse Office, National Carbon Accounting System Programme.

Positional Accuracy: Good, Cell resolution of 25m

Attribute Accuracy: Good

Logical Consistency: Good

Completeness: Complete

Contact Organization: Environmental Protection Authority of Western Australia.

Contact Position: Policy and Co-ordination Branch, Environmental Protection Authority

Scientific Custodian Contact Position:

Environmental Officer – State of Environment (Karen Crews)

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Metadata Date: 2006-09-01

Other Metadata: Forest Productivity Index, Australia Greenhouse Office

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