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An input–output analysis of Australian water usage

M. Lenzen[a,*], B. Foran[b]

[a] School of Physics, A28, The University of Sydney, NSW 2006, Australia

[b] Resource Futures Program, CSIRO Sustainable Ecosystems, GPO Box 284, Canberra ACT 2601, Australia

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Abstract

Australia's annual water use of 22,000 Gl is dissected using input–output techniques, showing that 30% of Australia's water requirement was devoted to domestic food production and a further 30% to exports, compared with 7% required for direct consumption by households. There is a net annual trade deficit in embodied water of approximately 4000 Gl. A strong relationship exists between water requirement and expenditure. If by 2050 Australia's population grows to 25 million people and per-capita expenditure doubles, the annual water requirement may more than double to 50,000 Gl, equivalent to half the nation's water flows. While this increase may be improbable it gives the challenge that the water required to deliver a unit of output across the whole economy may have to reduce by a factor of two, if population growth and economic growth are to meet policy expectations.

Keywords: Water account; Input–output analysis; Australia

1. Introduction

Apart from being one of the driest continents, Australia experiences a spatially and temporally highly variable climate that includes periodic drought, leading to a relatively unpredictable water supply. On the other hand, Australian net water demand has increased by 19% between 1994 and 1997, mainly due to increased use on pastures, and to a lesser extent for cotton and rice, resulting in water being a critical resource in some Australian agricultural and urban areas. For example, in the Murray-Darling Basin in the south-east of the continent, which accounts for more than 50% of Australian water use, water resources are already fully committed (see Fig. 1), and State and Commonwealth governments recently agreed on capping water diversions from all sources at 1994 levels. Nevertheless, significant environmental damage has occurred because of considerable water

*Corresponding author. Tel.: +61-02-9351-5985; fax: +61-02-9351-7725.

E-mail addresses: m.lenzen@physics.usyd.edu.au (M. Lenzen), barney.foran@cse.csiro.au (B. Foran).

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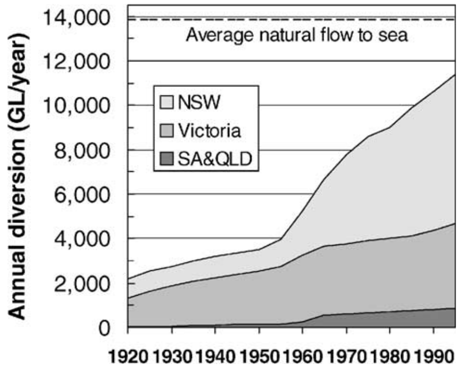

Fig. 1. Water diversion in the Murray-Darling Basin, south-east Australia (after MDBMC, 1995). Abbreviations: NSW, New South Wales; SA, South Australia; QLD, Queensland.

diversion from the Murray and Snowy Rivers, and widespread soil and water salinisation. In this "water-stressed" region, irrigation-based industries are likely to face further environmental degradation as well as income losses, unless a number of adaptive initiatives in water management are pursued, such as transfers to more profitable users and less water-stressed regions, water pricing and trading,[1] and increases in water use efficiency (AATSE & EIEA, 1999; Quiggin, 2001).

Despite these facts, there is a paucity of data on water resources, supply and use in Australia (ABS, 2000b). In this work, we therefore, aim at providing information to guide forecasting and policy decisions from a demand-side point-of-view. Examples for demand-side factors affecting overall water use are immigration, income growth, and changes in commuting patterns, household size, diets, women participation in the workforce, and composition of exports. We use input–output analysis in order to translate recently released data on industrial water use into water multipliers and embodiments for final consumption categories. Input–output-based water multipliers have been calculated previously already in the late 1960s (Isard & Romanoff, 1967b), and applied in an impact analysis for a hypothetical new town in Plymouth Bay, USA (Isard et al., 1967a). More recently, Lange (1998) incorporated water uptake data in her dynamic input–output model to assess the environmental implications of Indonesia's second long-term development plan. Kim, Jin, and Yun (2001) use a multi-region input–output approach to analyse water quality enhancing policies for Korea.

2. Methodology and data sources

Input–output analysis is a top–down economic technique, which uses sectoral monetary transactions data to account for the complex interdependencies of industries in modern economies. The result of generalised input–output analyses is a $f \times n$ matrix of *factor multipliers*, that is embodiments of f production factors (such as water, labour, energy, resources and

[1] Tisdell's (2001) linear programming analysis of water markets in the Northern Rivers region yielded that trade in water entitlements is likely to increase the gap between extractive demand and historical flows, because water use is concentrated on more profitable crops, and therefore, on particular months and locations.

pollutants) per unit of final consumption of commodities produced by n industry sectors. A multiplier matrix $\mathbf{M}$ can be calculated from a $f \times n$ matrix $\mathbf{F}$ containing sectoral production factor usage, and from a $n \times n$ *direct requirements* matrix $\mathbf{A}$ according to

$$\mathbf{M} = \mathbf{F}(\mathbf{I} - \mathbf{A})^{-1}, \tag{1}$$

where $\mathbf{I}$ is the $n \times n$ unity matrix. $\mathbf{A}$ comprises requirements from current as well as capital intermediate demand of domestically produced and imported commodities.

The multiplier matrix as in Eq. (1) refers to the output of *industries* valued in farm or factory gate prices, so-called *basic values* (bv). It can be converted to refer to *commodities* valued in *purchasers' prices* (pp) via

$$\mathbf{M}^* = \mathbf{F}(\mathbf{I} - \mathbf{A})^{-1}(\mathbf{Y}_{(\mathrm{bv})} + \mathbf{P})\mathbf{Y}_{(\mathrm{pp})}^{-1}\mathbf{D}, \tag{2}$$

where $\mathbf{Y}_{(\mathrm{bv})}$ and $\mathbf{Y}_{(\mathrm{pp})}$ are $n \times n$ matrices of diagonalised vectors of final consumption in basic values and purchasers' prices, respectively, $\mathbf{P}$ is a $n \times n$ *margin* matrix describing margins $\{P_{ij}\}$ supplied by industries i to industries j, and $\mathbf{D}$ is a $n \times n$ *market share* matrix describing the amount S_{ij} of commodity j supplied by industry i per unit of total output of commodity j, that is, the market share of industry i in the production of commodity j. The derivation of Eq. (2) can be found in Appendix A. The $f \times 1$ *factor inventory* $\boldsymbol{\Phi}$ of a given set of commodity consumption represented by a $n \times 1$ commodity inputs vector $\mathbf{y}$ is then simply

$$\boldsymbol{\Phi} = \mathbf{M}^*\mathbf{y}. \tag{3}$$

An introduction into the input–output method and its application to environmental problems can be found in papers by Leontief and Ford (1970) and Proops (1977). The mathematical formalism used to derive Eqs. (1)–(3) and some of the results presented in this article is described in detail in a previous article (Lenzen, 2001).

In this work, $\mathbf{F}$ is a $1 \times n$ vector containing sectoral net water use data, and hence, $\mathbf{M}$ is a $1 \times n$ vector of sectoral *water multipliers*, and $\boldsymbol{\Phi}$ is a 1×1 (scalar) *water budget* for a consumption vector $\mathbf{y}$. The data used to calculate $\mathbf{F}$ are the 1993–1997 Water Accounts (ABS, 2000b), which are the first comprehensive Australian water data. They were sourced by the Australian Bureau of Statistics (ABS) from a range of state, territory, and local government agencies, water authorities, and private enterprises, and were released in May 2000. These accounts contain the use and supply on state and territory level of self-extracted and mains water, as well as effluent reuse and regulated discharge of households and industries. Industries are classified according to the Input Output Broad Industry Group (IOBIG) classification, which distinguishes 37 industry groups.

The matrices $\mathbf{A}$, $\mathbf{Y}_{(\mathrm{bv})}$, $\mathbf{Y}_{(\mathrm{pp})}$, $\mathbf{P}$, and $\mathbf{D}$ were derived from the most recent (1994–1995) Australian input–output tables (ABS, 1999a). Including data for a number of additional industries (ABS, 1999b), these tables comprise $n = 118$ industry groups classified according to the Input Output Industry Classification (IOIC).

Water use data had to be re-classified from IOBIG to the more detailed IOIC. In accordance with practices applied during the compilation of the ABS Water Accounts, water use was prorated on a per-employee basis in service industries, on a per-hectare basis for zoos, parks and gardens, on a per-unit-of-turnover basis for manufacturing industries, and on a per-unit-of-production basis for mining industries (ABS, 2000a). An allocation according to the revenue of the IOIC industry "Water supply, sewerage and drainage" would not map sectoral water usage, because (1) only about 40% of this industry's revenue is from water supply, and (2) water prices vary considerably amongst using sectors (AATSE & EIEA, 1999, pp. 50–51). Water usage classified in the ABS Water Accounts as "Stock Usage" (mostly in Queensland) was allocated equally to sheep and beef cattle.

Fig. 2 shows a breakdown of 1996–1997 *net* mains and self-extracted water use. It excludes the regulated discharge of instream users such as hydro-electric power plants (96% of total regulated discharge) or aquaculture (<0.1%), and non-instream users such as drainage, sewerage, and fossil power plants (4%). More than two-thirds of water use in Australia is for irrigation of crops for animal and human consumption (38% livestock and pastures, 3% grains excluding rice, 7% sugar, 7% rice, 6% cotton, 6% fruit and vegetables). All other industry sectors use comparatively small amounts. Amongst manufacturing industries, the main water users are basic metals (0.9%), pulp and paper (0.3%), and food processing (0.6%). Within mining establishments, the largest amounts of water are used for the extraction of non-ferrous metal ores (1.6%) and coal (0.6%). The net water use of the water supply industry includes releases due to commitments for environmental flows, transmission losses, and losses due to reservoir spills, evaporation, seepage, and dam overflows (ABS, 2000b). While agriculture, fisheries, forestry, and households use more mains than self-extracted water, the opposite is true for mining, electricity and water supply. More than half of Australian water use occurs in the Murray-Darling Basin (for mixed cropping/livestock farming, cotton, rice, horticulture, and viticulture), while another 30% is used in the coastal regions of Queensland (15%, sugar cane), the coastal regions of New South Wales, Victoria and south-east South Australia (10%, irrigated pastures for beef and dairy cattle), and in south-west Western Australia (5%, irrigated pastures for dairy cattle, horticulture).

3. Results

Water multipliers calculated according to Eq. (1) are shown in Table 1 for $n = 118$ IOIC industry groups. Both mains and self-extracted water multipliers show large variations between around 2 l/A$ (insurance and finance) and more than 1000 l/A$ (rice and cotton). In general, agricultural sectors rank highest around 200 l/A$, followed by food (100 l/A$), mining (20 l/A$), and manufacturing and services (5–15 l/A$). Industries with high water multipliers are most sensitive to changes in water price. Using Eq. (3), the multipliers in Table 1 were applied to conventional monetary National Accounts, yielding the 1994–1995 National Mains and Self-extracted Water Accounts shown in Tables 2 and 3. The tables are organised in order to reflect the

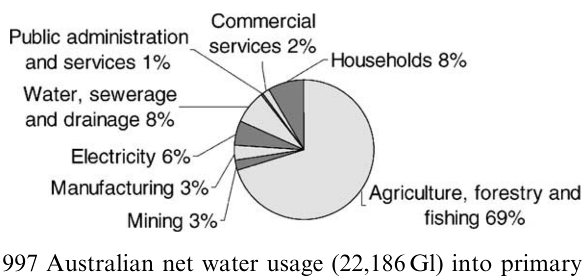

Fig. 2. Breakdown of 1996–1997 Australian net water usage (22,186 Gl) into primary user categories (ABS, 2000b).

Table 1
1994–1995 mains and self-extracted water multipliers (in l/1994–1995A$)

IOIC category	Mains	Self-extracted	IOIC category	Mains	Self-extracted
Sheep and shorn wool	138.5	160.5	Plastic products	11.7	14.3
Barley, unmilled	111.2	180.2	Glass and glass products	6.9	10.2
Rice, in the husk	422.2	36.6	Bricks and other ceramic products	5.4	8.3
Wheat, legumes for grain, oilseeds, oats, and other grains	93.6	151.1	Cement, lime, concrete and mortar	5.4	9.7
Beef cattle	475.5	336.3	Plaster and other concrete products	5.7	8.2
Dairy cattle and untreated whole milk	915.5	552.6	Mineral wool, abrasives, other non-metallic mineral products	13.9	18.0
Pigs	153.3	104.2	Basic iron and steel, pipes, sheets, bars, rails, fittings, etc.	9.5	11.0
Poultry and eggs	79.9	88.0	Alumina, aluminium alloys and aluminium recovery	10.8	41.9
Sugar cane	258.5	980.7	Basic non-ferrous metal recovery, pipes, sheets, wires etc.	10.8	44.4
Seed cotton	509.8	1090.4	Frames, mesh and other structural metal products	11.0	11.2
Vegetable and fruit growing, plant nurseries, flowers	173.3	205.3	Sheet containers and other sheet metal products	8.1	11.9
Services to agriculture, ginned cotton, shearing, hunting	189.3	401.4	Bolts, nails, springs, tools, and other fabricated metal products	7.8	10.5
Forestry	7.8	11.1	Motor vehicles and parts	6.1	8.7
Commercial fishing	15.2	15.5	Ships and boats	5.9	9.0
Black coal	4.0	17.8	Railway equipment	5.7	7.9
Crude oil	3.9	9.9	Aircraft	3.7	5.9
Natural gas	3.9	11.9	Photographic, medical, radio and scientific equipment, watches	6.2	9.4
Liquefied natural gas, liquefied natural petrol	3.9	9.2	Electronic equipment, photocopying, vending machines	5.8	10.1
Brown coal, lignite	4.2	48.8	Household appliances and hot water systems	7.7	9.5
Iron ores	3.9	19.5	Cable, batteries, lights, motors and other electrical equipment	7.3	11.5
Bauxite	22.5	343.4	Agricultural, mining and construction machinery	5.4	8.2
Copper	5.1	17.4	Pumps, bearings, aircond., and other machinery and equipment	4.6	7.6
Gold and lead	4.8	10.9	Prefabricated buildings	10.3	11.2
Silver and zinc ores	5.8	30.1	Furniture	11.6	12.0
Uranium, nickel, tin, and other non-ferrous metal ores	5.7	27.7	Jewellery, sporting goods, toys, and other manufacturing	13.4	17.0

Table 1 (*continued*)

IOIC category	Mains	Self-extracted	IOIC category	Mains	Self-extracted
Sand, gravel, other construction materials, and other mining	4.3	13.9	Electricity supply	7.5	66.5
Exploration and services to mining	5.5	20.1	Gas production and distribution	3.5	5.7
Meat and meat products	217.2	163.7	Water supply, sewerage and drainage	65.0	279.3
Dairy products	422.4	257.4	Roads, bridges, and other non-residential construction	4.5	6.3
Vegetables, fruit, juices, and other fruit and vegetable products	58.5	44.9	Wholesale trade	5.7	6.9
Oils and fats	43.8	44.8	Retail trade	15.4	13.0
Flour, cereal foods, rice, pasta and other flour mill products	528.0	44.7	Vehicle and machinery repairs	2.3	3.4
Bread, cakes, biscuits and other bakery products	108.0	37.1	Household equipment, wholesale and retail repairing	3.2	5.6
Confectionery	66.1	43.0	Accommodation, cafes and restaurants	41.7	32.6
Sugar, processed seafoods, coffee, spices and other foods	67.0	159.6	Road transport	4.6	5.2
Soft drinks, cordials and syrups	31.0	83.3	Railway transport	6.0	8.8
Beer and malt	25.3	33.3	Water transport	5.3	6.9
Wine and spirits	282.1	220.1	Air and space transport	5.3	6.2
Tobacco products	52.0	56.7	Travel agencies, forwarding, and other services to transport	4.3	4.5
Processed wool and textiles	71.5	91.7	Communication	4.8	5.9
Carpets, curtains, tarpaulins, sails, tents, and other textiles	32.7	40.1	Banking	4.2	5.1
Knitting mill products	29.5	34.3	Money market corporation and other non-bank finance	5.6	4.6
Clothing	44.5	44.9	Insurance	2.6	2.8
Footwear	36.4	30.1	Security broking and other services to finance	1.1	1.1
Leather and leather products	80.0	66.7	Property devel, real est, plant and vehicle hire, other prop serv	6.6	11.6
Sawn timer, woodchips and other sawmill products	6.1	6.1	Scientific research, technical and computer services	6.1	9.6
Plywood, frames, doors, boards, and other wood products	11.6	8.6	Legal, accounting, marketing and management services	6.6	11.3
Pulp, paper and paperboard	37.5	13.1	Typing, staff placement, cleaning, and other business services	6.0	11.4

Table 1 (*continued*)

IOIC category	Mains	Self-extracted	IOIC category	Mains	Self-extracted
Paper containers and products	19.0	10.7	Government administration	6.0	7.0
Printing, stationery and services to printing	12.9	8.4	Defence	6.2	6.7
Newspapers, books, recorded media and other publishing	8.1	6.7	Education	3.5	3.4
Automotive petrol, kerosene, jet fuel and other refinery prod	5.8	10.0	Health	3.0	3.6
Basic chemicals	16.7	18.8	Childminding and other community care services	10.9	15.7
Paints	10.6	12.4	Cinemas, radio and television	8.4	11.2
Pharmaceutical goods, insecticides and other agric chemicals	10.8	13.4	Libraries, parks, museums and the arts	11.2	27.5
Soap and other detergents	17.6	20.0	Sport, gambling and recreational services	13.9	19.2
Cosmetics and toiletry preparations	13.0	18.0	Hairdressing, goods hiring, laundry and other personal services	9.6	8.6
Adhesives, inks, polishes, and other chemical products	11.8	14.8	Sanitary and garbage disposal services	5.0	5.1
Rubber products	9.7	12.3	Police, interest groups, fire brigade, corrective and other services	5.0	5.1

National Accounting Identity (see header), and enable the identification of important water embodiments within consumption and production categories.

Table 2 shows that considerable amounts of mains water are embodied in the private final consumption of meat and dairy products, fruit, vegetables and other food products, wholesale and retail trade, meals out, and in the export of meat and dairy products. The reader should bear in mind that within our input–output framework, multipliers of domestically produced commodities and imports are assumed to be identical. As a consequence, embodiments in imports of textiles and food are probably overestimated. This is because these products, when produced overseas, are likely to require much less mains water than for their production in Australia. Moreover, the domestic consumption of meat is based on more densely stocked, mainly rain-fed pastures in the south-east of Australia, while the majority of irrigated pastures in the extensive land use zone in inland Australia produce meat for exports. Hence, the embodiments in domestic consumption as given in Table 2 are probably too high, and those in exports too low. Nevertheless, Australia is a net water exporter.

Table 3 shows a National Self-Extracted Water Account, which was obtained in the same way as the National Mains Water Account (Table 2), but using self-extracted water multipliers. It shows that significant amounts of self-extracted water are embodied in the private final

Table 2
1994–1995 National Mains Water Account (all figures in Gl, per-capita mains water use in l)

	Private final consumption	+ Government final consumption	+ Changes in stocks	= GNE	+ Exports	= GNT	− Consumer imports	− Imports into stocks	− Industrial imports	= GDP
Sheep and shorn wool	2.0	0.0	−45.1	−43.1	293.3	250.1	0.0	0.0	0.0	250.1
Grains	9.4	0.0	−39.7	−30.3	164.4	134.1	0.2	0.6	11.6	121.7
Beef cattle	19.9	0.0	55.7	75.6	84.9	160.5	0.0	0.0	0.0	160.5
Fruit and vegetables	431.5	0.0	−19.2	412.3	91.1	503.4	23.6	−7.4	63.6	423.6
Other agriculture	31.0	23.3	−13.4	40.9	112.6	153.6	0.5	0.0	3.0	150.1
Forestry	0.1	2.8	0.0	2.9	0.2	3.1	0.0	0.0	0.1	3.0
Fishing	14.0	1.6	0.0	15.6	7.1	22.7	0.5	0.0	0.3	21.9
Coal mining	0.1	0.0	−1.3	−1.2	27.4	26.2	0.0	0.0	0.0	26.1
Crude oil, natural gas and LPG	1.4	0.0	−2.4	−1.0	10.6	9.6	0.0	−1.2	11.5	−0.8
Other mining	0.1	0.5	−2.1	−1.5	45.2	43.7	0.0	2.6	2.2	38.9
Meat products	838.9	0.0	21.2	860.1	884.2	1744.3	13.0	0.6	7.2	1723.4
Dairy products	1280.4	0.0	−13.0	1267.4	640.2	1907.6	74.7	12.1	33.0	1787.7
Sugar	300.1	0.0	1.0	301.1	180.1	481.1	66.9	2.7	7.8	403.7
Other food products	1176.6	0.0	14.6	1191.2	294.7	1485.9	111.9	1.0	64.8	1308.2
Alcohol and tobacco	142.7	0.0	26.1	168.8	148.3	317.1	53.4	3.8	132.6	127.4
Textiles and clothing	365.6	0.0	6.3	371.8	146.8	518.6	146.3	1.9	172.2	198.1
Saw mill products	0.6	0.0	0.1	0.7	4.2	5.0	0.3	0.1	9.3	−4.7
Paper products	43.5	1.0	−4.4	40.1	7.5	47.6	9.9	−1.3	88.9	−49.9
Refinery products	14.6	0.0	2.7	17.3	4.2	21.5	1.8	0.6	8.4	10.8
Chemical products	58.7	23.1	6.3	88.1	33.8	121.9	17.6	3.3	126.9	−25.8
Non-metal construction materials	1.8	0.0	0.5	2.3	2.2	4.5	1.1	0.1	8.0	−4.7
Basic iron and steel	0.1	0.0	1.3	1.4	15.2	16.6	0.0	0.2	16.2	0.3

Aluminium	0.0	0.0	0.8	0.8	46.4	47.3	0.0	0.0	0.2	47.0
Other non-ferrous basic metals	2.7	0.0	−0.3	2.4	35.4	37.8	0.3	0.3	6.9	30.3
Metal products	4.1	0.0	0.8	4.9	5.2	10.0	1.6	0.2	14.4	−6.1
Motor vehicles	33.4	0.0	5.3	38.8	7.2	45.9	13.7	2.2	44.7	−14.8
Other transport equipment	1.3	0.0	−0.5	0.8	4.1	4.9	0.5	0.0	8.5	−4.1
Other manufacturing	75.0	0.0	5.7	80.6	27.4	108.1	36.8	4.2	141.8	−74.7
Electricity supply	33.8	1.2	0.0	35.0	0.2	35.2	0.0	0.0	0.0	35.2
Gas supply	1.4	0.0	0.0	1.4	0.0	1.4	0.0	0.0	0.0	1.4
Water supply	209.1	5.1	0.0	214.2	0.4	214.7	0.3	0.0	0.3	214.0
Construction	0.0	10.1	0.0	10.1	0.5	10.7	0.0	0.0	0.2	10.5
Wholesale and retail trade	671.9	0.1	1.8	673.8	54.4	728.2	4.4	0.0	0.0	723.7
Accommodation and restaurants	767.8	0.1	0.0	767.9	83.8	851.7	31.9	0.0	23.6	796.2
Road transport	15.4	3.1	0.5	19.0	7.1	26.1	1.2	0.0	0.2	24.7
Rail transport	10.2	2.4	−0.2	12.4	6.5	18.9	1.0	0.0	0.0	18.0
Water transport	1.0	0.0	−0.1	1.0	9.8	10.8	−0.9	0.0	8.2	3.4
Air transport	23.2	0.0	0.0	23.2	17.1	40.4	8.3	0.0	7.9	24.2
Ownership of dwellings[a]	193.6	-0.1	0.0	193.5	0.0	193.5	0.0	0.0	0.0	193.5
Commercial services	250.0	38.9	0.0	288.9	35.7	324.7	7.0	0.0	30.8	286.8
Public administration and services	127.1	359.7	0.1	486.8	8.5	495.4	2.3	0.0	2.6	490.5
All industries	7154.0	472.9	9.0	7636.0	3548.0	11188.3	629.9	26.6	1058.0	9469.5
Residential usage	1769.7			1769.7		1769.7				1769.7
Total mains water use	8923.8			9405.7		12958.1				11241.4
Per-capita mains water use	501336	26568	508	528411	199328	727739	35390	1494	59438	631417

[a] Note: Output of industry is rent for dwellings; GNE, gross national expenditure; GNT, gross national turnover; GDP, gross domestic product.

Table 3
1994–1995 National Self-Extracted Water Account (all figures in Gl, per-capita self-extracted water use in l)

	Private final consumption	+ Government final consumption	+ Changes in stocks	= GNE	+ Exports	= GNT	– Consumer Imports	– Imports into stocks	– Industrial imports	= GDP
Sheep and shorn wool	2.3	0.0	–52.3	–50.0	339.9	289.9	0.0	0.0	0.0	289.9
Grains	15.2	0.0	–46.6	–31.4	228.9	197.5	0.3	1.0	17.3	178.9
Beef cattle	14.1	0.0	39.4	53.5	60.0	113.5	0.0	0.0	0.0	113.5
Fruit and vegetables	511.4	0.0	–22.8	488.6	108.0	596.6	28.0	–8.7	75.3	502.0
Other agriculture	41.0	49.5	–28.3	62.3	238.3	300.6	0.6	0.0	6.4	293.6
Forestry	0.2	3.9	0.0	4.1	0.3	4.3	0.0	0.0	0.1	4.2
Fishing	14.3	1.6	0.0	15.9	7.2	23.1	0.5	0.0	0.3	22.3
Coal mining	0.7	0.0	–5.5	–4.8	122.5	117.7	0.0	0.0	0.2	117.6
Crude oil, natural gas and LPG	4.0	0.0	–5.9	–2.0	25.9	23.9	0.0	–3.0	29.1	–2.2
Other mining	0.3	1.9	–6.5	–4.2	177.0	172.8	0.0	5.8	8.2	158.7
Meat products	632.2	0.0	15.9	648.2	666.4	1314.6	9.8	0.5	5.4	1298.9
Dairy products	780.2	0.0	–7.9	772.3	390.1	1162.4	45.5	7.4	20.1	1089.3
Sugar	714.5	0.0	2.4	716.9	428.7	1145.6	159.3	6.4	18.6	961.2
Other food products	494.9	0.0	6.0	500.9	61.5	562.3	65.0	0.6	26.1	470.6
Alcohol and tobacco	136.5	0.0	23.2	159.7	122.1	281.8	49.4	4.1	105.2	123.2
Textiles and clothing	377.6	0.0	6.0	383.6	160.0	543.6	145.3	1.7	210.3	186.3
Saw mill products	0.5	0.0	0.1	0.6	3.9	4.5	0.2	0.0	7.9	–3.7
Paper products	30.0	0.6	–1.0	29.6	4.3	33.9	7.2	–0.3	36.4	–9.4
Refinery products	25.2	0.0	4.7	29.9	7.3	37.2	3.2	1.0	14.5	18.6
Chemical products	72.3	28.5	7.3	108.1	39.6	147.7	22.0	3.8	148.9	–26.9
Non-metal construction materials	2.7	0.0	0.8	3.5	3.0	6.5	1.6	0.1	11.5	–6.7
Basic iron and steel	0.1	0.0	1.6	1.6	17.6	19.2	0.0	0.2	18.7	0.3

Aluminium	0.0	0.0	3.2	3.2	179.8	183.0	0.0	0.1	0.9	182.0
Other non-ferrous basic metals	11.1	0.0	−1.2	9.8	145.3	155.2	1.1	1.3	28.4	124.4
Metal products	5.7	0.0	0.9	6.6	6.5	13.1	2.2	0.2	19.4	−8.7
Motor vehicles	47.7	0.0	7.6	55.4	10.3	65.6	19.6	3.2	63.9	−21.1
Other transport equipment	2.0	0.0	−0.7	1.3	6.2	7.5	0.7	0.0	13.2	−6.4
Other manufacturing	97.5	0.0	8.2	105.7	41.9	147.6	51.1	6.4	226.3	−136.2
Electricity supply	298.2	10.5	0.0	308.7	1.8	310.5	0.2	0.0	0.4	310.0
Gas supply	2.2	0.0	0.0	2.2	0.0	2.2	0.0	0.0	0.0	2.2
Water supply	897.9	22.0	0.0	919.9	1.9	921.8	1.5	0.0	1.3	919.0
Construction	0.0	14.2	0.0	14.2	0.8	15.0	0.0	0.0	0.3	14.7
Wholesale and retail trade	603.0	0.1	2.2	605.3	59.0	664.3	3.7	0.0	0.0	660.6
Accommodation and restaurants	599.4	0.1	0.0	599.5	65.5	664.9	24.9	0.0	18.4	621.6
Road transport	17.6	3.5	0.6	21.8	8.1	29.9	1.4	0.0	0.2	28.3
Rail transport	15.0	3.6	−0.3	18.3	9.7	28.0	1.4	0.0	0.0	26.5
Water transport	1.3	0.0	−0.1	1.2	12.7	14.0	−1.1	0.0	10.7	4.4
Air transport	27.5	0.0	0.0	27.5	20.3	47.8	9.8	0.0	9.4	28.6
Ownership of dwellings[a]	234.6	−0.1	0.0	234.4	0.0	234.4	0.0	0.0	0.0	234.4
Commercial services	312.4	51.9	0.0	364.3	50.1	414.3	9.2	0.0	44.2	360.9
Public administration and services	174.5	419.8	0.1	594.4	10.4	604.8	3.1	0.0	5.8	595.9
All industries	7217.8	611.8	−49.0	7780.6	3842.7	11632.8	666.7	31.7	1203.4	9721.6
Residential Usage	30.3			30.3		30.3				30.3
Total self-extracted water use	7248.1			7810.8		11663.1				9751.8
Per-capita self-extracted water use	407196	34370	−2756	438811	215885	654696	37455	1779	67605	547857

[a] Note: Output of industry is rent for dwellings; GNE, gross national expenditure; GNT, gross national turnover; GDP, gross domestic product.

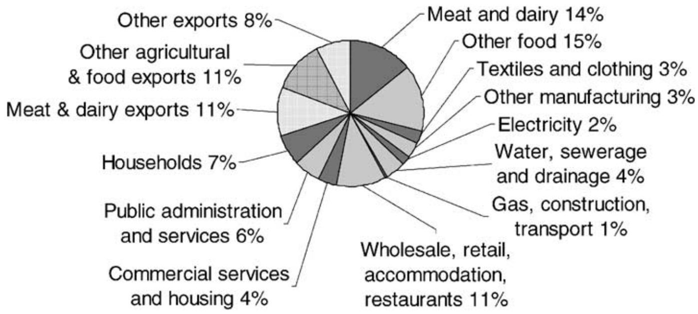

Fig. 3. Breakdown of 1994–1995 Australian net water usage (21,537 Gl) plus water embodiments in imports (3551 Gl) into final consumption categories.

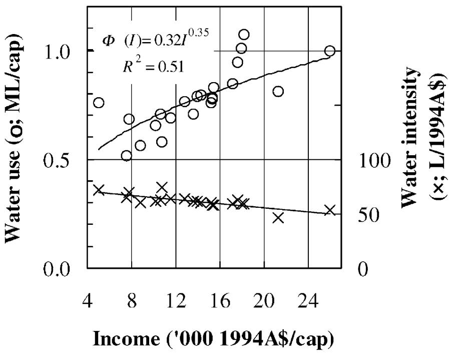

Fig. 4. Total water use as a function of household income.

consumption of meat and dairy products, sugar, fruit, vegetables and other food products, household electricity and water, wholesale and retail trade, and meals out. A considerable amount of self-extracted water leaves Australia embodied in exports of mostly primary commodities such as meat and dairy products, sugar, wool, non-ferrous metals, coal, and metal ores. In contrast, secondary commodities such as chemicals, motor vehicles, and other manufactured goods dominate imports. Once again, self-extracted water in imports of food and textiles should be treated cautiously, because of potential differences between domestic and overseas irrigation practices. Similarly, the self-extracted water embodied in meat exports is probably underestimated, while the self-extracted water embodied in the domestic meat consumption is overestimated. Nevertheless, Australia is a net self-extracted water exporter.

The end-use picture is summarised in Fig. 3, which shows a breakdown of 1994–1995 Australian net (mains and self-extracted) water usage (25,373 Gl) plus water embodiments in imports (3,789 Gl) into Australian final consumption categories. Outstanding domestic consumption areas are food (29%), retail and other commercial services (15%), and household use (7%), while exports accounted for 30% of water embodiments, mostly in meat and dairy.

The influence of demographic variables can be investigated by applying water multipliers calculated according to Eq. (2) to the Australian Household Expenditure Survey (ABS, 1995). This technique uses Eq. (3) and is described for energy and greenhouse gas multipliers in detail elsewhere (Lenzen, 1998). Fig. 4 shows the influence of per-capita income (I) on the water

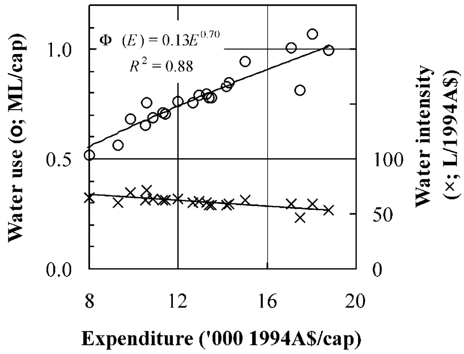

Fig. 5. Total water use as a function of household expenditure.

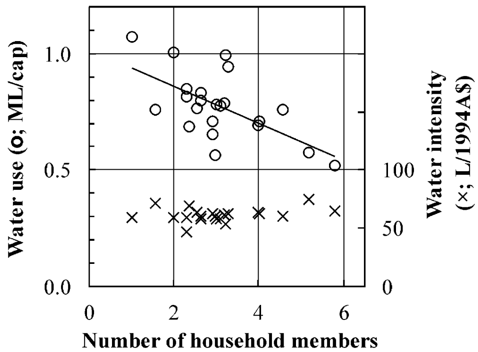

Fig. 6. Total water use as a function of the number of household members.

intensity and the per-capita total (mains and self-extracted) water use Φ. It can be observed that Φ increases with I. This increase is, however, not proportional, but can be characterised by an *income elasticity* $\eta_I = (\mathrm{d}\Phi/\Phi)/(\mathrm{d}I/I) = 0.35$ (exponent in regression formula in Fig. 4). This means that for an income increase of 10%, the water use increases by only 35%. This rigidity is due to the fact that consumption at high incomes is less water intensive than consumption at low incomes (see intensity data in Fig. 4), which in turn is because the production of necessities such as food and energy is more water-intensive than that of luxuries such as personal and financial services. $\Phi(I)$ exhibits a relatively low correlation factor of 0.51, whereas the correlation with per-capita expenditure (E) is much better at $R^2 = 0.88$ (see Fig. 5). Furthermore, $\Phi(E)$ is more elastic than $\Phi(I)$, since $\eta_E = 0.7$. Both findings indicate, that expenditure is a better proxy for water use than income. This also holds for Australian energy consumption, greenhouse gas emissions, and land disturbance (Lenzen, 1998; Lenzen & Murray, 2001), suggesting that, within consumer activities, spending money rather than earning money exerts environmental pressure.

Fig. 6 shows that, in general, the per-capita water use is lower in larger households than in smaller households. The intensity data prove that this is not due to differences in the composition of consumer baskets, but occurs simply because large households share items. Finally, it can be found that metropolitan households (state and territory capitals) use more water (0.83 Ml/cap) than other urban (towns with more than 1000 inhabitants, except capital cities; 0.76 Ml/cap) and rural households (towns with less than 1000 inhabitants; 0.65 Ml/cap). This is, however, mainly because metropolitan households exhibit higher expenditures. As a result, the water intensity is high for rural households (62.0 l/A$) and other urban households (63.7 l/A$), and low for metropolitan households (58.4 l/A$). Note that the per-capita water use figures above deviate from the total of 1.179 Ml/cap derived from Tables 2 and 3. This is due to a discrepancy in the coverage of monetary final consumption between the Household Expenditure Survey and the input–output tables.

4. Relevance for water policy

4.1. Embodied water use

At higher levels of aggregation this input–output analysis provides unsurprising results, that Australians require a yearly 1.179 Ml/cap of water or that generating a dollar of Gross Domestic Product requires 50 l, can be obtained through simple division of the appropriate national statistics. However, the next two levels of analysis provide discrimination that is useful for national water policy. The production of the nation's food requires 30% of the nations water account and so does its export trade. By comparison, the provision of household water requires only 7% of the account. Attribution of blame to the nation's farmers and exporters for potential water problems is seemingly indefensible for urban dwellers who consume food and require export income to pay for imports of capital equipment and consumer merchandise. Detailed examination of each sector allows judgements on whether economic productivity or environmental flows are reasonable uses of water resources that are often limited in a regional sense. When water quality is an issue, particularly on the downstream side of a water using industry, then the detailed sectoral breakdown per dollar of contribution to gross domestic product, should improve decision making.

In this accounting context, however, water use should not be seen in a negative context where some economic sectors are more environmentally and resource benign than others. In a world now dominated by a globalised trade flows, a well run national economy could be judged on the degree to which it balances the embodiment of water (this paper), land (Lenzen & Murray, 2001), energy (Lenzen, 1998) and labour requirement (Lenzen, 2001) in the production of its economic output and value adding. In this way, comparing the sectoral embodiments of land and water (as a proxy for environmental issues), fossil and renewable energy (as a proxy for economic issues) and the requirement for labour (as a proxy for social issues) would allow triple bottom line accounting to be conducted on the same base (the contribution to a dollar of GDP) and would allow each sector to judged on its contribution to evolving sustainability issues.

4.2. Water and consumers

The graphs describing the linkage between water use, per-capita income and per-capita expenditure are perhaps the most insightful outputs of this study since they use the embodiment concept to link water, economic growth, lifestyle and the urban-country divide. Simple city-based statistics note that urban water consumers require approximately 0.2 Ml/cap/yr depending on location (AATSE & EIEA, 1999). However, once the full water embodiment of their consumption mix is included this value increases to between 0.6 and 1.1 Ml/cap depending on per-capita expenditure. Equally important is the rate of decline in water intensity across the expenditure range. A doubling of per-capita expenditure equivalent to a 100% increase will give a 70% increase in per-capita water use. This is not due to longer showers, swimming pools or green lawns, but is due to the water embodied in the extra goods and services that are consumed. Studies across 14 statistical sub-divisions in the city of Sydney extended these results in the following manner (Luxton, 2000). The upper range of the data distribution extended from 1 Ml/cap in this study to 2 Ml/cap but the statistical correlation ($R^2 = 0.79$) and the elasticity (0.77) were of the same order for per-capita expenditure data. High embodied water budgets were associated with the affluent suburbs on the coast where the water use was twice that of the less affluent suburbs on the western fringes of the city.

4.3. Trade in virtual water

Trade in virtual water is defined as the water embodied in the goods and services that are imported and exported. At a global level the virtual water trade is how many countries obtain their food necessities by bartering commodities, such as, oil and elaborately transformed manufactures through the medium of international currency exchange. In a managed water use of 22,000 Gl/yr, Australia exports the equivalent of 7500 Gl of water embodied in goods and services and imports the equivalent of 3500 Gl. This leaves a net outflow of approximately 4000 Gl/yr, roughly equivalent to the water consumption of the entire urban sector excluding manufacturing (Tables 2 and 3). If the total amount of water transpired in crop growth (irrigation water plus natural rainfall) is used, then the export in agricultural produce alone is approximately 28,000 Gl/yr (Dunlop, personal communication). Given the possibility of future environmental stress in Australia's water system (river salinity, depleted inland fisheries, rural industry decline) an important national question to be addressed is whether Australia receives adequate monetary compensation for the net outflow of 4000 Gl of its managed water resource. The current status of export farm prices, the physical trade balance, the current account deficit, and the status of international debt levels suggest that the trade in 'virtual or embodied' water could represent a loss for the nation and many of its land and water regions.

A nation seeking to garner reasonable economic returns from international trade could adopt a strategic approach to the monetary returns expected for the virtual water trade. Countries with a looming problem of water stress and water scarcity are a matter of public record (Raskin, Hansen & Margolis, 1996; Ohlsson, 2000; Falkenmark, 1999). National water scarcity is usually judged around a threshold of 1 Ml/cap of water flow per year. Trading partners such as Japan have in excess of 4 Ml/cap and with a stable or declining population, this ensures that relative water security for Japan will be maintained. However, countries such as the Republic of Korea (1.47 Ml/cap), Singapore (0.22 Ml/cap), Saudi Arabia (0.225 Ml/cap), United Arab Emirates (0.566 Ml/cap), former Soviet Union (1.24 Ml/cap), and Venezuela (0.208 Ml/cap) are all countries with oil reserves and/or advanced manufacturing capability that Australia might require in the future. A series of trade negotiations which attempt to balance equity levels being achieved for the exchange of goods and services with various embodiments of water, energy, labour, intellect and environmental integrity could help fund re-investment into the repair and maintenance of Australia's water resources. Focusing on countries with looming water deficits does not avoid

Table 4
Total embodied water use in Australia under different assumptions of growth in population number, and growth in per-capita income and per-capita expenditure

Population (Million)	Per-capita annual embodied water requirement (Ml/cap)	Total population-based embodied water requirement (Gl)	Population plus doubling of per-capita income (Gl)	Population plus doubling of per-capita expenditure (Gl)
20	1.179	23,580	31,833	40,086
25	1.179	29,475	39,791	50,107
32	1.179	37,728	50,932	64,376

Australia's obligation for food aid and crisis assistance for a wide range of countries that are already badly stressed in water and food terms. Rather it focuses on the chance to build reasonable foundations for physical and monetary exchange mechanisms over timeframes of human generations. Then the prices exchanged in international trade could cover the full environmental cost of the exchanged goods and services.

4.4. Growth in domestic population and income

Contemporary policy analyses by Foran and Poldy (2000) have tested the resource requirements of different population scenarios which give 20, 25 and 32 million people in Australia by the year 2050. If the current embodied water requirement of 1.179 Ml/cap/yr (addition of values in Tables 2 and 3) is applied to these populations, then water use could remain relatively stable at current levels for a population of 20 million, or increase to 37,000 Gl/yr under the 32 million scenario (Table 4). This is a relatively static analysis which presupposes that the water intensities in each sector will not change over the next 50 years.

However, as the technical efficiency of water use increases, the parallel process of economic growth is likely to proceed. It is, therefore, assumed for discussion purposes that per-capita income and expenditure will double in the next 50 years when these population targets are met. This requires growth in income or expenditure on a yearly basis of 1.5% in a contemporary policy setting when political leaders expect growth in Gross Domestic Product to oscillate around 3% per annum. When an assumed income and expenditure growth of 100% over the next 50 years is used with the water consumption elasticities from Figs. 4 and 5, then growth in per-capita water consumption could increase by 35% on a per-capita income basis and by 70% on a per-capita consumption basis. This means that the water requirement increase to between 32,000 and 51,000 Gl per annum and between 40,000 and 64,000 Gl per annum, respectively. These simplistic projections must be viewed against an average yearly water flow in Australia of approximately 100,000 Gl (ABS, 2000b).

It is improbable that water requirements will expand over the next 50 years to some of the higher levels in Table 4. Viewed in inverse, however, the scenarios present the technical and consumption efficiencies in the use of water that must be gleaned if expectations of population growth and economic growth are to proceed. For the 25 million people scenario whose per-capita expenditure doubles over the next 50 years, this will require a halving of water intensities per unit of good or service delivered, if a policy goal is to maintain total water use at around current levels of the 22,000 Gl/yr used in this analysis.

4.5. National water reform

Both the quality and quantity of water resources is under increasing policy scrutiny in Australia. While water management issues are the responsibility of the individual states and territories, The Conference of Australian Governments (COAG) has developed a strategic framework for the reform of the Australian water industry (HLSG, 1999). The key issues in the national reform agenda include water allocation and trading, environmental flows, groundwater use, water pricing and full cost recovery, and comprehensive changes in institutional arrangements to remove perverse policy outcomes. As well as this national framework specific water reforms are focused on The Murray-Darling Basin, The Great Artesian Basin and the Lake Eyre Basin.

The reform agenda is making substantial progress in specific areas with caps on water use being set for water allocation in the Murray-Darling Basin, for example (MDBMC, 1996). Catchments in southern Australia that are mature in development terms are focusing on productivity growth that entails product quality and increasing economic returns by product switching rather than expansion of irrigated area. At the same time, however, the expectations of growth in water based agriculture remain imbedded within the national economic growth agenda. The relatively under-utilised rivers of northern Australia are being targeted for expansion of crops such as sugar, cotton, tropical horticulture and irrigated pastures for beef cattle (Dunlop, Hall, Watson, Gordon, & Foran, 2001). Two issues possibly conflicting issues thereby arise. The experience of southern Australia will require that further irrigation development is undertaken only under exacting environmental standards. However the water requirements per unit of product for tropical agriculture are at least double that for temperate agriculture, because of higher evapo-transpiration rates. Thus, the water tension between the economy and the environment enumerated in this analysis will probably remain.

5. Conclusions: to the future of water in Australia

This study has highlighted three important issues for future water use in Australia. Firstly, by using the embodied water concept, it has shown that the predominantly urban population base of Australia is responsible for all water used in Australia because of its consumption activities and the lifestyle gleaned therefrom. It is, therefore, not valid to apportion the environmental damage from inappropriate water use to irrigators when city populations consume irrigated produce or the nation benefits from export earnings. Secondly, it has shown that Australia currently runs a net deficit of 4000 Gl/yr in terms of the virtual water trade, that managed water resource that is embodied in the export of commodities and manufactured goods. The development of international trading mechanisms whereby the full environmental and monetary cost of water use might be recognised and recompensed, provides fertile opportunities for new institutional arrangements in world trade. Thirdly, it has highlighted that growth in population and per-capita expenditure over the next 50 years may at least double the requirement of water use in the economy. While this scenario may not happen it poses the challenge over the whole economy that the intensity of water use per dollar of output or per physical unit of productivity must be reduced by at least one-half. This is a substantial challenge for both technology and governance.

Appendix A. Derivation of Eq. (2)

In the Australian input–output tables, final consumption $\mathbf{y}$ is valued in "farm or factory gate prices", the so-called *basic values* (bv). These are also referred to as *net producers' prices*, because they differ from *producers' prices* (prp) by commodity taxes less subsidies ("direct taxes") $\mathbf{t}_\mathrm{d}$, so that

$$\mathbf{y}_{(\mathrm{bv})} + \mathbf{t}_\mathrm{d} = \mathbf{y}_{(\mathrm{prp})}.$$

In addition to producers' prices, *purchasers' prices* (pp) contain margins incurred by services such as transport, storage, insurance, wholesale and retail. From an input-output point of view, these margins represent movements of production factor requirements from margin-supplying industries to all other industries. If $\mathbf{P}$ is a *margin matrix* describing margins supplied by industries i to industries j, final consumption in purchasers' prices is

$$y_{(\mathrm{pp}),j} = y_{(\mathrm{prp}),j} + \sum_i P_{ij} = y_{(\mathrm{bv}),j} + t_{\mathrm{d},j} + \sum_i P_{ij}.$$

Let M_{fj} be an element of a multiplier matrix $\mathbf{M}$ referring to basic values. The elements M_{fj}^{**} of a multiplier matrix $\mathbf{M}^{**}$ referring to purchasers' prices can then be calculated from

$$M_{fj} y_{(\mathrm{bv}),j} + \sum_i M_{fi} P_{ij} = M_{fj}^{**} y_{(\mathrm{pp}),j}. \tag{A.1}$$

Let $\delta_{ij} = 1$ if $i = j$ and $\delta_{ij} = 0$, otherwise. Let $\mathbf{Y}_{(\mathrm{bv})}$ be a matrix with $Y_{(\mathrm{bv}),ij} = y_{(\mathrm{bv}),i}\delta_{ij}$, and $\mathbf{Y}_{(\mathrm{pp})}$ be a matrix with $Y_{(\mathrm{pp}),ij} = y_{(\mathrm{pp}),i}\delta_{ij}$. Eq. (A.1) can then be written in matrix notation as

$$\mathbf{M}^{**} = \mathbf{M}(\mathbf{Y}_{(\mathrm{bv})} + \mathbf{P})\mathbf{Y}_{(\mathrm{pp})}^{-1}.$$

All matrices defined so far describe transactions of industries, and the multipliers describe production factor requirements per unit of industry output. It is also possible to determine multipliers that describe commodities rather than industries. These multipliers are not necessarily identical because of the joint production of commodities by several industries. Australian examples are the leather product industry, which produces mainly leather products, but also some meat products. Similarly, Australian fruit and vegetable products are mainly produced by the fruit and vegetable industry, but to a small extent also by the dairy industry. Let $\mathbf{D}$ be a *market share matrix*, that is, D_{ij} describes the amount of commodity j (domestically produced or imported) supplied by industry i per unit of total output of commodity j (the market share of industry sector i in the production of commodity j). Typically, the elements D_{ii} on the matrix diagonal will be close to 1, as commodity i is primary to industry i. A multiplier $\mathbf{M}^{*}$ which describes commodities can then be calculated via

$$\mathbf{M}^* = \mathbf{M}^{**}\mathbf{D} = \mathbf{M}(\mathbf{Y}_{(\mathrm{bv})} + \mathbf{P})\mathbf{Y}_{(\mathrm{pp})}^{-1}\mathbf{D}$$

which is identical to Eq. (2).

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