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Productivity Commission

Australia's Urban Water Sector

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The Productivity Commission

The Productivity Commission is the Australian Government's independent research and advisory body on a range of economic, social and environmental issues affecting the welfare of Australians. Its role, expressed most simply, is to help governments make better policies, in the long term interest of the Australian community.

The Commission's independence is underpinned by an Act of Parliament. Its processes and outputs are open to public scrutiny and are driven by concern for the wellbeing of the community as a whole.

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The Commission’s report is in two volumes. Volume 2 contains appendices, technical supplements and references. The first volume contains the terms of reference for the inquiry, key points, overview, recommendations and findings and the chapters of the report.

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A Public consultation

Outlined in this appendix are details relating to consultations through:

- submissions received (table A.1)
- initial visits (table A.2)
- public hearings (table A.3)
- roundtables (table A.4).
- modelling workshop (table A.5)

The Commission received the terms of reference for this inquiry on 22 July 2010. Following receipt of the terms of reference, the Commission placed notices in the press and on its website inviting public participation in the inquiry. Information about the inquiry was also circulated to people and organisations likely to have an interest in it. The Commission released an issues paper on 27 September 2010 to assist inquiry participants with preparing their submissions. The Commission received 167 submissions.

Public hearings were held in Sydney, Canberra, Melbourne, Adelaide, Perth and Hobart in November and December 2010 which attracted 35 participants, and in Sydney, Brisbane, Canberra and Melbourne in May and June 2011 which attracted 31 participants. In addition roundtables were held in Perth, Sydney and Melbourne and a modelling workshop was held in February 2011.

The Commission has conducted meetings with a range of organisations and individuals.

Table A.1 **Submissions received**

Individual or organisation	*Submission number*
Academy of the Social Sciences in Australia	41
ACTEW Corporation	45, 69, DR119
Agritech Smartwater	DR126
Aisbett, Emma and Steinhauser, Ralf	DR141
Anglicare Tasmania	44
Aqua Piovana Pty Ltd	2
AquaNet	49
Australian Academy of Technological Sciences and Engineering	34
Australian Building Codes Board	23
Australian Bureau of Agricultural and Resource Economics and Sciences	DR166
Australian Conservation Foundation	DR128
Australian Council of Social Service	32
Australian River Deltas	DR139
Australian Water Association	42, DR157
Barry Trembath Consultant Pty Ltd	82
Bathurst Regional Council	DR108
Ben-David, Dr Ron	DR158, DR163
Burdekin Shire Council	27
Burton, Michael, Cooper, Bethany and Crase, Professor Lin	28
Business Council of Australia	66
Cameron, Greg	DR120
Centre for Water Sensitive Cities	75
Centroc and the Lower Macquarie Water Utilities Alliance	DR90, DR131, DR136
City of Salisbury	10
City of Sydney	DR124
City of Wanneroo	55, 76, DR150
Clark, Martin	DR95
Coliban Water	73
Colligan, Professor Peter	DR98
Consumer Action Law Centre	DR133
Consumer Utilities Advocacy Centre	46, 67, DR143
Cooma-Monaro Shire Council	DR106
Cooper, Bethany, Crase, Professor Lin and Burton, Michael	28
Cootamundra Shire Council	DR100
Council of Mayors (South East Queensland) Pty Ltd	77, DR159
Crase, Professor Lin, Cooper, Bethany and Burton, Michael	28
Crase, Professor Lin and O’Keefe, Dr Sue	5
Department of Environment and Resource Management (Qld)	60
Department of Health (Vic)	16

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Table A.1 (continued)

Individual or organisation	*Submission number*
Department of Water (WA)	38, DR122
Dollery, Professor Brian	1
Dubbo City Council	86
Dwyer, Dr Terry	57, 74, DR105
Economic Regulation Authority	36, DR140
Engineers Australia	4
Environmental Defenders Office (SA) Inc	39
General Electric (GE) Energy	DR142
Gladstone Area Water Board	87
Goldenfields Water	56
Grafton, Professor Quentin	22
H2O Organiser	DR94
Head, Professor Brian	8
Independent Competition and Regulatory Commission	DR148
Independent Pricing and Regulatory Tribunal of NSW	58, 72, DR118
Infrastructure Australia	6, 62, DR107
Institute of Public Affairs	DR93
Institute for Sustainable Futures	DR137
Irrigation Australia	14, DR112
Jones, Laurence	35, DR135
Joseph, Alison	40
Kempsey Shire Council	30
Koerner, Richard	7, 25, 81, 84, DR91*, DR97
Lane, Peter	DR92
Lithgow City Council	DR155
Local Government Association of NSW & Shires Association of NSW	63, 85, DR154
Local Government Association of Queensland	20, DR134
Local Government Association of Tasmania	64
Macauley, Ian	DR127
Midcoast Water	51, DR104
Melbourne Water	DR156
Moree Plain Shire Council	DR101
National Centre for Excellence in Desalination	DR110
National Competition Council	12
National Water Commission	53, DR130
New South Wales Government	65, DR146
Nicholas, Neil	88, DR161
Nubian Water Systems	11
Public Interest Advocacy Centre	61, DR144
Queensland Government	DR167

(continued next page)

Table A.1 (continued)

Individual or organisation	*Submission number*
Queensland Water Directorate	DR138
Quiggin, Professor John	26
Riverina and Murray Regional Organisation of Councils	DR164
Riverina Eastern Regional Organisation of Councils	DR165
Riverina Water County Council	50
Rockhampton Regional Council	33
Ruff, Larry and Swier, Geoff	47, DR162
SA Health	DR117
Save Byrrill Creek Campaign	DR125
Shires Association of NSW & Local Government Association of NSW	63, 85, DR154
Shoalhaven City Council	15, DR147
Sibley, Dr Hugh and Tooth, Dr Richard	DR153
South Australian Government	52, 79, DR132
South East Water	DR149
Southern Cross Water and Infrastructure Corporation	DR99
Steinhauser, Ralf and Aisbett, Emma	DR141
Stormwater NSW	DR111
Swier, Geoff and Ruff, Larry	47, DR162
Sydney Water	21, 68, 83, DR152
Tasmanian Council of Social Service	13
Tasmanian Government	70
Tasmanian Water and Sewerage Corporations	43
T Bowring and Associates Pty Ltd	17
Tenants Advice Service	DR103
Tenants Union of New South Wales	DR129
Tooth, Dr Richard and Sibley, Dr Hugh	DR153
Wagga Wagga City Council	54, DR116
Water and Carbon Group	31
Water Corporation	78, DR151
Water Directorate (NSW)	89, DR121
Water Factory Company	48, DR123
Waterplus (Aust) Pty Ltd	3
Water Quality Research Australia Ltd	37
Water Services Association of Australia	29, DR145
Water Utilities Sharing Group	DR102
Waterwise Systems Pty Ltd	DR113
West, Amy-Rose	9, 59, 80, 96
Western Australia Council of Social Services	DR160
Worthington, Professor Andrew	DR109
Wyong Shire Council	24, DR114
Yarra Valley Water	19, DR115

Table A.2 **Visits**

Individual or organisation
ACT
ACTEW Corporation
Australian Bureau of Agricultural and Resource Economics and Sciences
Department of Environment, Water, Heritage and the Arts (Cwlth)
Department of Finance (Cwlth)
Department of Prime Minister and Cabinet (Cwlth)
Department of Sustainability, Environment, Water, Population and Communities (Cwlth)
National Water Commission
Treasury (Cwlth)
New South Wales
Australian Council of Social Service
Department of Premier and Cabinet (NSW)
Independent Pricing and Regulatory Tribunal
Infrastructure Australia
Local Government Association of NSW & Shires Association of NSW
NSW Office of Water
NSW Treasury
Sydney Water Corporation
Northern Territory
Department of Housing, Local Government and Regional Services (NT)
Department of Natural Resources, Environment, the Arts and Sport (NT)
Northern Territory Council of Social Service
Northern Territory Treasury
Utilities Commission
Power and Water Corporation
Queensland
Department of Environment and Resource Management (Qld)
Department of Premier and Cabinet (Qld)
Local Government Association of Queensland
Queensland Competition Authority
Queensland Treasury
Queensland Water Commission
Queensland Water Directorate
South East Queensland Water
South East Queensland Water Grid Manager
South Australia
Department for Water (SA)
Department of Treasury and Finance (SA)
Essential Services Commission of South Australia
SA Water
South Australian Council of Social Service
United Water

(continued next page)

Table A.2 (continued)

Individual or organisation
Tasmania
Anglicare Tasmania
Department of Premier and Cabinet (Tas)
Department of Primary Industries, Parks, Water and Environment (Tas)
Department of Treasury and Finance (Tas)
Office of the Tasmanian Economic Regulator
Southern Water
Tasmanian Council of Social Service
Victoria
City West Water
Committee for Economic Development of Australia (CEDA)
Consumer Utilities Advocacy Centre
Department of Sustainability and Environment (Vic)
Department of Treasury and Finance (Vic)
Essential Services Commission (Vic)
Melbourne Water
South East Water
Water Services Association of Australia
Yarra Valley Water
Western Australia
Department of Treasury and Finance (WA)
Department of Water (WA)
Economic Regulation Authority
Syme, Professor Geoff, Edith Cowan University
Water Corporation

Table A.3 **Public hearings**

Individual or organisation	*Transcript page numbers*
Sydney — 9 November 2010	
Local Government Association of NSW & Shires Associations of NSW	2–22
Independent Pricing and Regulatory Tribunal	23–39
Australian Council of Social Service	40–48
Nubian Water Systems	49–58
Public Interest Advocacy Centre	59–67
Jones, Laurence	68–73
T Bowring and Associates Pty Ltd	74–78
Canberra — 29 November 2010	
ACTEW Corporation	80–91
Sydney Water	92–114
Infrastructure Australia	115–127
Water Services Association of Australia	128–142
National Water Commission	143–155
Grafton, Professor Quentin, Australian National University	156–165
Dwyer, Dr Terry	166–174
Melbourne — 30 November 2010	
Local Government Association of Queensland	176–188
National Competition Council	189–196
Coliban Water	197–208
Joseph, Alison	209–216
Yarra Valley Water	217–231
Consumer Utilities Advocacy Centre	232–242
Adelaide — 7 December 2010	
City of Salisbury	244–258
Australian Academy of Technological Sciences and Engineering	259–270
Water Quality Research Australia	271–281
Department for Water (SA)	282–305
CSIRO Land and Water	306–313
Perth — 8 December 2010	
Water Corporation	315-333, 343, 354, 357-358, 366, 369–370
Department of Water (WA)	327
Economic Regulation Authority	334–346
Resource Economics Unit	346–354
City of Wanneroo	355-366 , 368–369
Hall, Doug	362–370
Marsden Jacob Associates	366, 371–373
Hobart — 13 December 2010	
Local Government Association of Tasmania	374–399
Southern Water	400–418
Thorley, Dianne	419–431

(continued next page)

Table A.3 (continued)

Individual or organisation	*Transcript page numbers*
Sydney — 31 May 2011	
Australian Water Association	433–444
Independent Pricing and Regulatory Tribunal	445–459
Centroc and the Lower Macquarie Water Utilities Alliance	460–473
NSW Water Directorate	474–485
Midcoast Water	486–496
Infrastructure Australia	497–505
H20 Organiser	506–514
Australian River Deltas	515–522
Tooth, Richard	523–532
Local Government Association of NSW & Shires Association of NSW	533–548
New South Wales Office of Water	549–552
Brisbane — 1 June 2011	
Local Government Association of Queensland	554–567
Council of Mayors (South East Queensland)	568–579
Koerner, Richard	580–582
Canberra — 6 June 2011	
Collignon, Professor Peter	593–605
Water Factory Company	606–616
Riverina Water County Council	617–631
Dwyer, Dr Terry	632–642
Australian Services Union	643–654
Wagga Wagga City Council	655–668
Water Services Association of Australia	669–687
Dickinson, Geoff	688–693
Independent Competition and Regulatory Commission	694–708
ACTEW Corporation	709–715
Melbourne — 10 June 2011	
Institute of Public Affairs	717–723
Market Reform (Larry Ruff) and Geoff Swier	724–733
Waterwise Systems	734–742
Yarra Valley Water	743–759
SA Health	760–770
Nicholas, Neil	771–776
Water Corporation	777–791

(continued next page)

Table A.4 **Roundtables**

Individual or organisation
Perth — 18 October 2010
Aqwest
Australian Water Association (WA)
Brennan, Donna, University of Western Australia
Compost Western Australia
Department of Treasury and Finance (WA)
Department of Water (WA)
Economic Regulation Authority
GHD
McLeod, P, University of Western Australia
Resource Economics Unit
Water Corporation
Sydney — 20 October 2010
ACIL Tasman
ACTEW Corporation
Australian Council of Social Service
Centre for International Economics
Department of Premier and Cabinet (NSW)
Gosford City Council
Independent Competition and Regulatory Commission
Independent Pricing and Regulatory Tribunal
Local Government Association of NSW & Shires Association of NSW
London Economic Consulting Group (now Sapere Research Group)
NSW Office of Water
NSW Water Directorate
South East Queensland Water Grid Manager
Sydney Catchment Authority
Sydney Water Corporation
The Treasury (Cwlth)
Water Services Association of Australia
Yarra Valley Water
Melbourne — 27 October 2010
Australian Competition and Consumer Commission
Australian Water Association
Business Council of Australia
City West Water
Coliban Water
Commissioner for Water Security in South Australia
Committee for Economic Development of Australia (CEDA)
Consumer Utilities Advocacy Centre
Crase, Lin, La Trobe University
Department for Sustainability, Environment, Water, Population and Communities (Cwlth)

(continued next page)

Table A.4 (continued)

Individual or organisation
Melbourne — 27 October 2010
Department of Environment and Resource Management (Qld)
Department of Primary Industries, Parks, Water and Environment (Tas)
Department of Sustainability and Environment (Vic)
Department of Treasury and Finance (Vic)
Edwards, Geoff
Essential Services Commission
Essential Services Commission of South Australia
Farrier Swier Consulting
Freebairn, J, University of Melbourne
Frontier Economics
Grattan Institute
Ilex Consulting
Infrastructure Australia
Langford, J, University of Melbourne
Marsden Jacob Associates
Melbourne Water
National Water Commission
PricewaterhouseCoopers
Queensland Water Commission
Ruff, Larry
Sibly, Hugh, University of Tasmania
South East Water
Southern Water
Victorian Competition and Efficiency Commission
Victorian Water Industry Association
Watson, Alistair
Sydney — 2 December 2010
Barwon Water
Local Government Association of NSW & Shires Association of NSW
Lower Macquarie Water Utilities Alliance
Midcoast Water
NSW Water Directorate
Orange City Council
Queensland Water Directorate
Riverina and Murray Regional Organisation of Councils
Townsville City Council
Unitywater
Wagga Wagga City Council

Table A.5 **Modelling Workshop**

Individual or organisation
Melbourne — 2 February 2011
ActewAGL
Centre for International Economics
City West Water
Department of Sustainability and Environment (Vic)
Economic Regulation Authority
Freebairn, John, University of Melbourne
Marsden Jacob Associates
Melbourne Water
Sapere Research Group (formerly London Economic Consulting Group)
South East Water
Smith, Olivia, University of Melbourne
Yarra Valley Water
Ward, Michael, Australian National University
Water Corporation
Water Services Association of Australia
Watson, Alistair
Woodland, Alan, University of New South Wales

B Further information on Australia's urban water sector

This appendix provides more detail on some of the material presented in chapter 2, including information on recent rainfall and inflows in select places around Australia, and more information on the structural, institutional, governance and regulatory arrangements of each jurisdiction. This includes information on supply arrangements, key legislation and stakeholders, key policies and strategies, economic regulation (pricing, licensing and third party access arrangements), health regulation (drinking water and recycled water) and environmental regulation (as it relates to wastewater discharges).

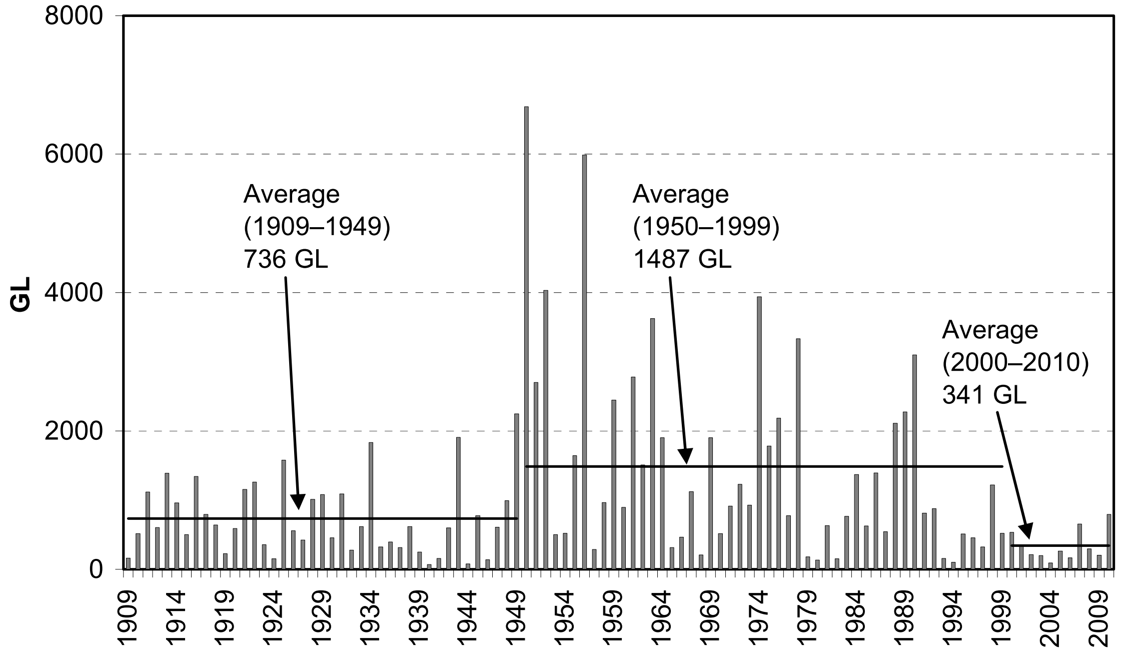
B.1 Rainfall and inflows

Chapter 2 highlights that Australia experiences high variability in rainfall and inflows, and that some places have experienced reduced rainfall and inflows in recent years, using Melbourne as an example. Here, the experiences in Sydney, south-east Queensland and Perth are discussed.

Sydney

Sydney, like other areas of Australia, has experienced water shortages in recent years. Average annual inflows into Sydney's largest dam, Warragamba, over the past decade have been much lower than for the preceding century (figure B.1). The average annual inflow for the period 2000–10 was 341 GL, compared with 1487 GL for the period 1950–99. Rainfall and inflows improved in 2010, and available storage in Sydney's dams was about 78 per cent in July 2011 (Sydney Catchment Authority 2011b).

Figure B.1 **Annual inflows into Warragamba Dam 1909–2010**



Source: Sydney Catchment Authority (unpublished data).

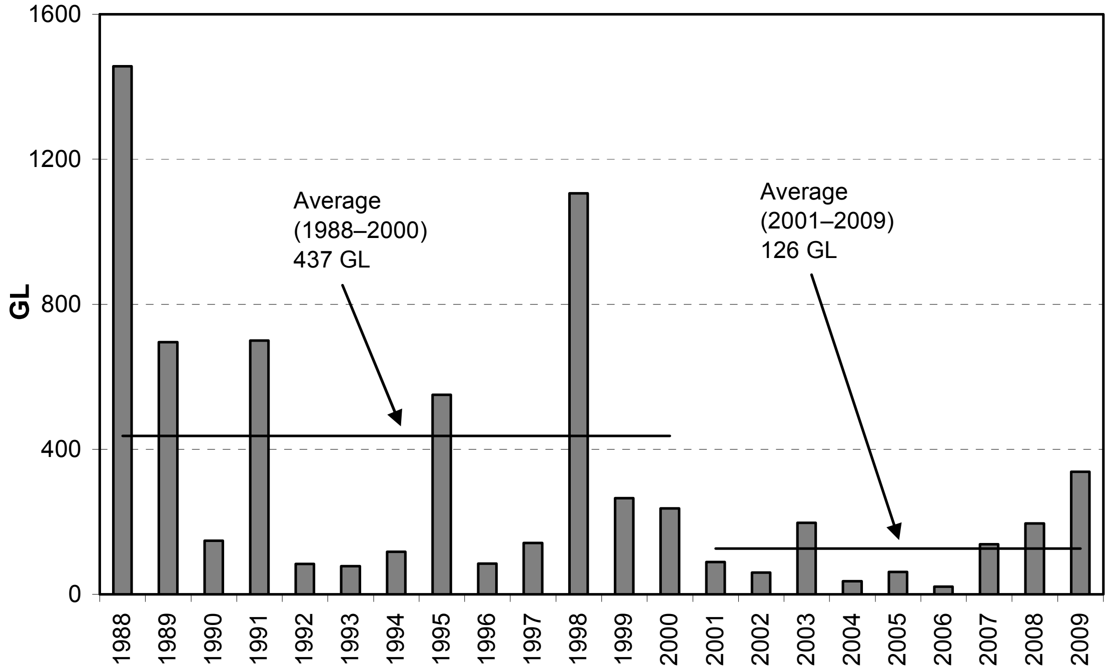
South-east Queensland

In south-east Queensland, average rainfall over the past decade has been substantially lower than for the preceding century. Average yearly rainfall at south-east Queensland's largest dam, Wivenhoe, over the period 2001–09 was 685 mm, substantially lower than for the period 1949–2001 (at 1069 mm) (QWC 2010b).

Annual inflows over the period 2001–10 were also low compared with previous years. The average annual inflow into the Wivenhoe Dam over the period 2001-02 to 2009-10 was 126 GL, much lower than for the period 1988-89 to 2000-01, when the average annual inflow was 437 GL (figure B.2).

However, there has been a turnaround in rainfall in the past couple of years in south-east Queensland and by the end of 2010, south-east Queensland's dams were considered to be full. This pattern has continued and severe flooding occurred in January 2011. As at July 2011, combined storage levels were about 84 per cent (Seqwater 2011).

Figure B.2 **Annual Inflows into Wivenhoe Dam 1988–2010[a]**



[a] Years in this figure represent the July to June period.

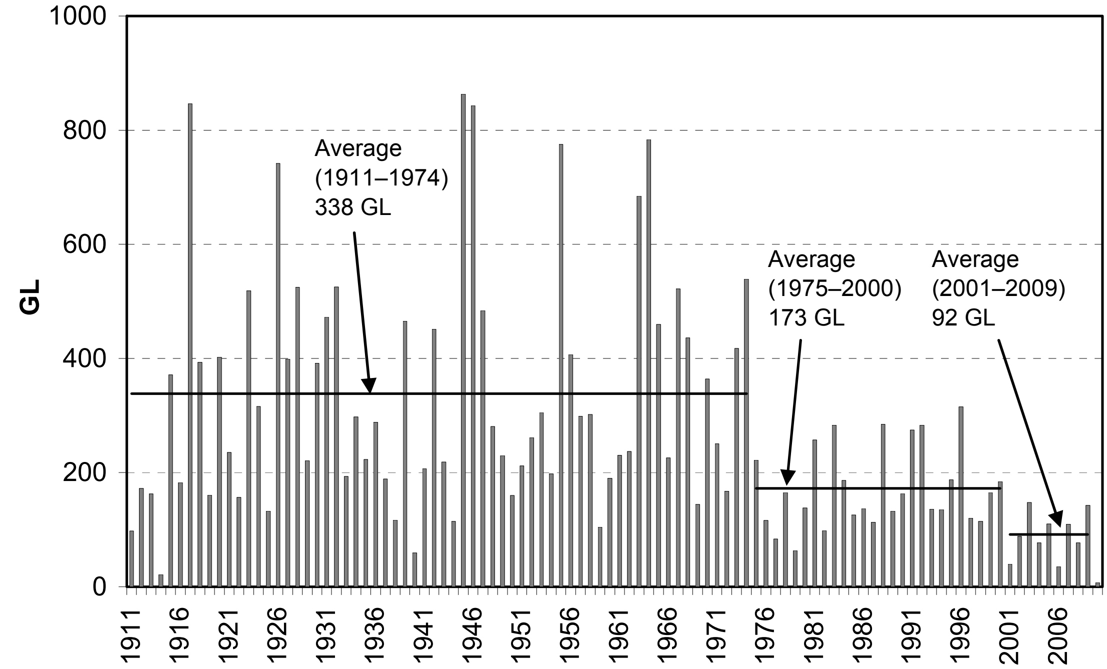
Source: Queensland Water Commission (unpublished data).

Perth

Rainfall in south-west Western Australia undertook a downward step in the 1970s with lower rainfall in the years following (CSIRO 2007). Very low rainfall has occurred in recent years, and south-west Western Australia experienced its driest year on record in 2010 (Raphael 2011).

This reduced rainfall has led to an even greater reduction in inflows (figure B.3). Average annual inflow into Perth's dams decreased from 338 GL for the period 1911–1974, to 173 GL for the period 1975–2000, and further to 92 GL for the period 2001–09. Unlike other states, there has not been an increase in rainfall and inflows more recently. As of July 2011, dam storages for south-west Western Australia were about 26 per cent (Water Corporation 2011b).

Figure B.3 **Annual inflows into Perth's dams 1911–2010[a]**



[a] Years in this figure represent the May to April period. Inflows for 2010 are not for the full year.

Source: Water Corporation (2011c).

B.2 New South Wales' structural, institutional, governance and regulatory arrangements

Information on the New South Wales urban water sector's structural, institutional, governance and regulatory arrangements is provided in this section.

Structural arrangements

Metropolitan arrangements

In Sydney, water and wastewater services are vertically separated. The Sydney Catchment Authority and Sydney Desalination Plant Pty Ltd (a subsidiary of Sydney Water) provide bulk water services and Sydney Water provides treatment, transmission, distribution, retail water and wastewater services, and stormwater services. Treatment plants are generally owned and operated by private companies (NWC 2009b; Sydney Water, sub. 21).

In Newcastle and the wider Hunter region, Hunter Water, a State Government-owned, vertically-integrated utility, provides water, wastewater and stormwater services (NWC 2009b; PWC 2010).

Regional urban arrangements

In regional urban New South Wales, Local Government-owned water utilities provide water and wastewater services in most places. In the 1980s, there were 126 local water utilities. This was reduced to 107 by June 2004, following a number of council amalgamations, and to 106 by July 2008 (Armstrong and Gellatly 2008).

These 106 local water utilities have a number of different service delivery models (Armstrong and Gellatly 2008):

- Ninety-six are general purpose Local Government councils — these local water utilities are not separate legal entities.
- Four are water supply county councils and one is a water supply and sewerage county council — these are single-purpose organisations that operate independently of local councils. The boards of management (councillors) are appointed by the constituent councils.
- Five are water supply authorities — these are designated under the *Water Management Act 2000*:
  - Gosford City Council — a general purpose council.
  - Wyong Shire Council — a general purpose council.
  - Essential Water (Essential Energy) — a State Government-owned corporation.
  - Fish River Water Scheme (State Water) — a State Government-owned corporation.
  - Cobar Water Board — a board established by the Water Management Act comprising membership from three mining companies and Cobar Shire Council with responsibility for ensuring water supply to each member of the Board.

In the Gosford and Wyong Council areas, the Gosford/Wyong Councils' Water Authority provides water, wastewater, and stormwater services (PWC 2010). From 2013, these areas will be serviced by the Central Coast Water Corporation, which was formed in early 2011 (New South Wales Government, sub. DR146).

The Sydney Catchment Authority and State Water provide bulk water services to some local water utilities (PWC 2010). Stormwater services are provided by Local Governments (NWC 2009b).

Institutions and governance arrangements

The New South Wales institutional and governance arrangements discussed below include key urban water sector legislation, institutions, and policies and plans for the sector.

Legislation

Key urban water related legislation include:

- *Water Management Act 2000* — provides the basis for the sustainable management of water, including the legal basis for water planning, the allocation of water resources and water access entitlements (NWC 2009b).
- *Water Industry Competition Act 2006* (WICA)— establishes a third party access regime for water and wastewater infrastructure and a licensing regime for private sector providers (NSW Government nd).
- *Sydney Water Act 1994* — establishes Sydney Water and its functions.
- *Sydney Water Catchment Management Act 1998* — establishes the Sydney Catchment Authority and its functions.
- *Hunter Water Act 1991* — establishes Hunter Water and its functions.
- *Central Coast Water Corporation Act 2006* — establishes the Central Coast Water Corporation and its functions.
- *Independent Pricing and Regulatory Tribunal Act 1992* — establishes the Independent Pricing and Regulatory Tribunal (IPART) and its functions.
- *Local Government Act 1993* — establishes local council responsibilities for water, wastewater and stormwater services (NWC 2009b).
- *Public Health Act 1991* — provides the framework for regulating drinking water quality (NWC 2009b). The *Public Health Act 2010* replaces this Act and is expected to commence in 2012 (New South Wales Government, sub. DR146).
- *Protection of the Environment Operations Act 1997* — provides the framework for regulating environmental health, including licensing waste discharges (NWC 2009b).

Institutions

Key institutions include State Government entities, the metropolitan and regional urban water utilities, IPART, the Energy and Water Ombudsman, and the Murray–Darling Basin Authority.

NSW Office of Water

The NSW Office of Water, within the Department of Primary Industries, manages New South Wales' surface water and groundwater resources. Key responsibilities include (New South Wales Government, sub. 65):

- determining allocation volumes
- developing statutory water sharing plans
- negotiating interstate and national water agreements
- approving the extraction and use of water
- policies and procedures for water trading
- coordinating metropolitan and regional urban water policy
- monitoring the quantity, quality and health of water sources and extractions.

Department of Premier and Cabinet

The Department of Premier and Cabinet's[1] key responsibilities include protecting the environment, managing water resources, and developing and coordinating programs to address climate change. The Department is also responsible for environmental regulation of water utilities, and oversees some water efficiency and conservation measures (New South Wales Government, sub. 65).

NSW Health

NSW Health regulates drinking water quality. This includes developing standards for drinking water quality, undertaking a drinking water monitoring program for local utilities and providing guidelines on household, and swimming pool and spa water quality (New South Wales Government, sub. 65).

[1] And within this department, the Office of Environment and Heritage.

Division of Local Government

The Division of Local Government (within the Department of Premier and Cabinet) oversees Local Government Councils (Division of Local Government 2010).

Independent Pricing and Regulatory Tribunal

IPART is New South Wales' independent economic regulator. Its water related responsibilities mostly relate to the metropolitan sector, and include price setting, licensing of water utilities and providing advice to Government regarding the issuing of licences under the WICA (New South Wales Government, sub. 65).

Energy and Water Ombudsman

The Energy and Water Ombudsman NSW is an industry-based ombudsman funded by members, which include Sydney Water, Hunter Water, Gosford City Council, Wyong City Council, Essential Water, Shoalhaven Water and State Water. It can make binding decisions (EWON 2011a).

Murray–Darling Basin Authority

The Murray–Darling Basin Authority is an Australian Government agency responsible for planning and management of water resources in the Murray–Darling Basin (Engineers Australia 2010c).

Key policies and plans

Key metropolitan policies and plans include the Metropolitan Water Plan, the $H_2$50 plan and the Water Plan 2050, which aim to secure long-term water supplies for greater Sydney, Hunter and Gosford and Wyong respectively. For example, Sydney's Metropolitan Water Plan (2010) focuses on four main areas to secure water: dams, recycling, desalination and water efficiency (NSW Government 2010b).

The *Best-Practice Management of Water Supply and Sewerage Guidelines*, developed by the Department of Water and Energy (now the Department of Primary Industries), encourage best practice management of local water utilities in regional urban areas. They cover effective and efficient delivery of services, and promoting sustainable water conservation practices and water demand management. Demonstrating best practice management is a requirement for a Local

Government's water utility to pay a dividend (Department of Water and Energy 2007).

Economic regulation

Pricing

IPART sets the water prices of the Sydney Catchment Authority, Sydney Water, Hunter Water, Gosford City Council, Wyong City Council and Essential Water. IPART sets prices via a public process that includes publishing draft and final determinations, receiving submissions and holding public hearings. Water utilities provide submissions to IPART detailing expected capital and operating expenditure, which are examined by IPART and an independent consultant (NWC 2009b).

Local Government utilities set their own prices, under guidance given in the *Best-Practice Management of Water Supply and Sewerage Guidelines* (Department of Water and Energy 2007).

Licensing

The metropolitan water utilities — Sydney Water, Sydney Catchment Authority and Hunter Water — are licensed by IPART. Licences set out a range of requirements relating to drinking water quality, infrastructure performance, customer and consumer rights, system performance standards, water efficiency, demand management and recycling, and environmental indicators and management. IPART audits performance against the operating licences, with the results provided to Government (Sydney Water ndb).

Private entities can obtain a licence from IPART under the WICA to provide water or wastewater services. This includes constructing, maintaining or operating any water industry infrastructure or providing water or wastewater services by means of water industry infrastructure (IPART nd).

Third party access

Third party access arrangements were introduced in 2006 through WICA. The arrangements cover the areas of operation of Sydney Water and Hunter Water. To gain access to the network, an application must be made to IPART, which then makes a recommendation to the Premier on whether the infrastructure should be declared. The Premier makes the final decision (IPART 2008c).

Health regulation

Drinking water management

NSW Health regulates drinking water quality in New South Wales under the Public Health Act. For Sydney Water, the Sydney Catchment Authority and Hunter Water, drinking water quality is regulated through their operating licences and memoranda of understanding. The licences set out the standards the utilities must meet, including providing a reliable supply of safe drinking water. In addition, NSW Health has a memorandum of understanding with each utility which defines the roles that NSW Health and the utilities play in protecting public health (New South Wales Government, sub. DR146; NWC 2009b).

Sydney Water and Hunter Water are required to develop a Drinking Water Quality Management Plan every five years, which outline strategies for managing water quality, public health issues associated with water supply and catchment management, and wastewater disposal and reuse. They are also required to produce annual drinking water quality reports which outline performance in meeting the *Australian Drinking Water Guidelines* (2004). The Sydney Catchment Authority is required to publish an Annual Water Quality Monitoring Report containing water quality data collected from its catchments and storages. These reports are provided to NSW Health and are made public (NWC 2009b). Under the Public Health Act 2010, these utilities, and regional urban utilities, will be required to prepare a risk-based drinking water quality management plan (New South Wales Government, sub. DR146).

NSW Health also monitors drinking water quality in regional urban areas. This includes undertaking a drinking water monitoring program, which involves water quality testing. Water utilities are notified if they are not meeting the Australian Drinking Water Guidelines. Utilities also monitor water quality against the guidelines, and are encouraged under the *Best-Practice Management of Water Supply and Sewerage Guidelines 2007* to develop a risk-based plan for monitoring drinking water quality. Water quality reporting is provided in the annual *NSW water supply and sewerage: performance monitoring report* (NWC 2009b; PWC 2011).

Recycled water management

Recycled water schemes managed by Sydney Water and Hunter Water are regulated through their operating licence, which require them to operate schemes according to relevant guidelines specified by a number of government departments, including NSW Health (Power 2010).

Recycled Water schemes run by other utilities require approval from the Minister for Primary Industries under either the Local Government Act or the Water Management Act, depending on the type of utility. NSW Health plays an advisory role in relation to potential public health risk and the final use of water (New South Wales Government, sub. DR146; Power 2010).

Private sector recycled water schemes are licensed under the WICA. Licence applications to IPART are passed onto NSW Health and the NSW Office of Water for comment and potential conditions of approval. They might also need approval to install and operate from the local council under the Local Government Act (Power 2010).

Under the Local Government Act, households require approval from local council to install and manage on-site water recycling systems (PWC 2011).

Environmental health regulation

The Department of Premier and Cabinet regulates environmental health under the Protection of the Environment Operations Act, and the supporting Protection of the Environment Operations (General) Regulations 1998. The Protection of the Environment Operations Act provides the framework for preventing pollution and licensing waste discharges. Under this Act, the Office of Environment and Heritage issues environmental protection licenses, which include operating and discharge limits, monitoring requirements, and reporting requirements (NWC 2009b; PWC 2011).

Under the Local Government Act, households require approval from local council to install and manage on-site wastewater management systems (PWC 2011).

B.3 Victoria's structural, institutional, governance and regulatory arrangements

Information on the Victorian urban water sector's structural, institutional, governance and regulatory arrangements is provided in this section.

Structural arrangements

Victoria's metropolitan and regional urban water sectors have undergone significant structural reform in recent years.

Metropolitan arrangements

Prior to reform, Melbourne Water was the vertically-integrated State Government-owned utility providing water and wastewater services. In 1995, Melbourne Water became responsible for bulk water and wastewater, and stormwater services, and three retailer-distributors, Yarra Valley Water, South East Water and City West Water, were established to provide retail and distribution services in specific geographic areas (YVW 2010). Local councils also play a role in stormwater, being responsible for the local drains, road networks and street and property drainage (Melbourne Water 2011a).

Regional urban arrangements

Prior to structural reforms, Local Government-owned utilities provided water, wastewater and stormwater services in regional urban areas. In 1994, these suppliers were amalgamated to create 15 State Government-owned vertically-integrated utilities responsible for water and wastewater. Catchment Management Authorities were also established to coordinate the management of catchments in their area. In 2005, these utilities were further merged reducing the number to 13. Although these regional urban utilities are vertically integrated, some source bulk water from Melbourne Water, and rural water providers such as Southern Rural Water and Goulburn Murray Water (Armstrong and Gellatly 2008; DSE 2011a; NWC 2009b).

Local Governments provide stormwater services in regional urban areas (NWC 2009b).

Institutions and governance arrangements

The Victorian institutional and governance arrangements discussed below include key urban water sector legislation, institutions, and policies and plans for the sector.

Legislation

Key urban water related legislation include (VCEC 2008):

- *Water Act 1989* — the principle water related Act in Victoria, covering integrated water resource management and the orderly, equitable, efficient and sustainable use of water. It details the objectives and governance arrangements for Melbourne Water and the regional urban water corporations.
- *Water Industry Act 1994* — enabled the separation of Melbourne Water and established a licensing system for service providers.

- *Melbourne Water Corporation Act 1992* — establishes Melbourne Water and its functions.
- *State Owned Enterprises Act 1992* — the Melbourne retailer–distributors are State Government-owned companies under this Act.
- *Catchment and Land Protection Act 1994* — provides a framework for management and protection of catchments, including establishing Catchment Management Authorities and their functions (NWC 2009b).
- *Essential Services Commission Act 2001* — provides an economic regulatory framework for regulated industries, and establishes the Essential Services Commission (ESC) and its functions.
- *Safe Drinking Water Act 2003* — provides a framework for regulating drinking water quality.
- *Food Act 1984* — plays a role in regulating drinking water quality by prohibiting the supply or sale of water for human consumption that is unsafe or unsuitable.
- *Environment Protection Act 1970* — provides a framework for the protection of the environment. Establishes the Environment Protection Authority (EPA) and its functions.

Institutions

Key institutions include State Government departments, water utilities, the EPA, the ESC, the Energy and Water Ombudsman Victoria, the Consumer Utilities Advocacy Centre and the Murray–Darling Basin Authority (section B.2).

Department of Sustainability and Environment

The Department of Sustainability and Environment (and the Office of Water within it) is the lead agency that manages water resources in Victoria. It develops and implements water policy, develops and manages appropriate operational and governance frameworks, and coordinates the conduct of the water sector intergovernmental policy and program obligations (DSE 2011a).

Environment Protection Authority

The EPA regulates recycled water quality and environmental health (NWC 2009b).

Department of Health

The Department of Health regulates drinking water quality, and helps manage recycled water quality (NWC 2009b).

Essential Services Commission

The ESC is Victoria's independent economic regulator. Its water related roles are set out in the Essential Services Commission Act and the Water Industry Regulatory Order (2003), which is made by the Governor in Council. Roles include setting prices, regulating the standards and conditions of service of water utilities, publishing customer service codes and publishing performance reports (DSE 2011a; ESC 2009d).

Energy and Water Ombudsman Victoria

The Energy and Water Ombudsman Victoria can investigate and resolve disputes related to electricity, gas and water companies. It is a fully member-funded industry service that utilities are required to participate in as part of their licence obligations. It can make binding decisions (EWOV 2011).

Consumer Utilities Advocacy Centre

The Consumer Utilities Advocacy Centre is a Victorian Government-funded independent advocacy organisation established under the *Corporations Act 2001* (Cwlth). It promotes fair, equitable and balanced regulatory outcomes in the electricity, gas and water industries, with a particular focus on low-income, disadvantaged and rural and regional consumers (CUAC 2011b).

Key policies and plans

Key policies and plans of Victoria's urban water sector include *Our Water, Our Future*, sustainable water strategies and water utilities' water plans.

Our Water Our Future

Victoria's key water policy statement is *Our Water, Our Future*, published in 2004. It sets out 110 different initiatives that aimed to secure water supplies over the next 50 years. The follow up document *Our Water, Our Future: The Next Stage of the Government's Water Plan* published in 2007 sets out long-term solutions to secure water supply, including building the desalination plant and expanding the water grid (Victorian Government 2009; 2010b).

Sustainable water strategies

Sustainable water strategies, developed by the Department of Sustainability and Environment, are long-term plans to secure water for local growth, while maintaining the balance of the area's water system and safeguarding the future of its rivers and other natural water sources (Engineers Australia 2010h).

Water plans

Water utilities are required to develop water plans under their Statement of Obligations. They feed into the price setting process, and set out how the organisation will deliver on service standards, costs, revenue requirements, and the prices proposed to meet these revenue requirements. These plans are reviewed by the ESC and independent consultants (Engineers Australia 2010h).

Economic regulation

Pricing

The ESC sets prices Victoria-wide. Water utilities submit water plans to the ESC, and based on these plans, the ESC makes both draft and final price determinations. Public consultation is undertaken before and after the draft determination (DSE 2011a; NWC 2009b).

Statement of obligations

The main regulatory instrument used to regulate water utilities is the statement of obligations. Statements of obligations are issued to utilities by the Minister for Water, Environment and Climate Change under the Water Industry Act 1994. They impose obligations on the water businesses in relation to their performance and the exercise of their powers (DSE 2011a).

Health regulation

Drinking water management

The Department of Health regulates drinking water quality under the Safe Drinking Water Act. This Act requires drinking water providers to comply with drinking water standards, prepare risk management plans, and publicly disclose relevant water quality information. Supporting the Safe Drinking Water Act, the Safe Drinking Water Regulations 2005 set out the requirements and procedures for the preparation and auditing of the risk management plans, including specifying quality standards, testing requirements and reporting schedules. Standards are based on the Australian Drinking Water Guidelines. The risk management plans are audited by the Department of Health and the results published in annual safe drinking water reports (DSE 2011a; NWC 2009b).

Along with the risk management plans, water providers are also required to submit monthly water quality testing results and annual drinking water quality reports. The Department of Health prepares the Annual Report on Drinking Water Quality, which includes a summary of compliance by water businesses to drinking water standards and water quality incidents (DSE 2011a; NWC 2009b).

Recycled water management

The EPA regulates recycled water quality under the Environment Protection Act. To operate a recycled water scheme, approval and a licence must be obtained, except where schemes are deemed large enough that they can be exempt from licensing provisions, and the scheme meets EPA guidelines. Class A schemes require both EPA approval and Department of Health endorsement. All schemes require a risk management plan, which includes monitoring and reporting to be undertaken. The EPA's *Guidelines for environmental management: use of reclaimed water* sets out the framework for managing recycled water quality (NWC 2009b).

Households require approval from Local Governments to install an on-site water recycling system (PWC 2011)

Environmental health regulation

The EPA regulates environmental health under the Environment Protection Act. This includes regulating the discharge of wastewater to the environment. Utilities are required to obtain a license from the EPA to discharge wastewater, which set out a number of requirements, including a joint commitment by the water business and the EPA to increase sustainability of the water business, performance requirements and providing an Annual Performance Statement to the EPA (DSE 2011a; NWC 2009b).

B.4 Queensland's structural, institutional, governance and regulatory arrangements

Information on the Queensland urban water sector's structural, institutional, governance and regulatory arrangements is provided in this section.

Structural arrangements

South-east Queensland

South-east Queensland's urban water sector has undergone significant structural reform in recent years. Prior to reform, Seqwater provided bulk water services, and city councils provided retail water and wastewater services. From 2008 and up until recently, bulk water and transmission services were the responsibility of four entities:

- Seqwater, which owned the dams, groundwater infrastructure and water treatment plants.
- WaterSecure, which owned the Tugun desalination plant and Western Corridor Recycled Water Scheme.
- Linkwater, which owns all the major pipelines.
- The South-east Queensland water grid manager, which owns the water entitlements, and manages the strategic operations of the water grid by selling treated water bought from Seqwater to retailer–distributors and other customers (QWC 2010b; SEQ Water Grid Manager 2011).

Seqwater and WaterSecure merged in July 2011, making Seqwater responsible for all of bulk supply and water treatment (Fraser and Robertson 2010). As of July 2010, the city council utilities were amalgamated in three Local Government-owned retailer–distributors — Unity Water, Queensland Urban Utilities and Allconnex Water — each serving a different area of south-east Queensland (QWC 2010b). In April 2011, the legislation establishing these retailer–distributors was changed allowing Local Governments to go back to the previous structure, where individual Local Governments provided retail and distribution services (Bligh 2011).

Local Government provides stormwater services (NWC 2009b).

Regional urban Queensland

Outside of south-east Queensland, vertically-integrated Local Government-owned utilities provide water and wastewater services. As a result of local council amalgamations in 2008, there is currently 71 regional urban utilities. The majority of these are local council utilities, although there are two commercialised water boards, the Gladstone Area Water Board and the Mount Isa Water Board, and a corporatised utility, the Local Government-owned Wide Bay Water Corporation. Some utilities source bulk water from the rural water utility SunWater. Local Governments provides stormwater services (Department of Environment and Resource Management (Qld), sub. 60; Local Government Association of Queensland, sub. 20; NWC 2009b).

Institutions and governance arrangements

The Queensland institutional and governance arrangements discussed below include key urban water sector legislation, institutions, and policies and plans for the sector.

Legislation

Key urban water related legislation include:

- *Water Supply (Safety and Reliability) Act 2008* — provides the framework for regulating infrastructure management and service provision by service providers, including the supply of drinking water and recycled water, asset management, customer service standards and water conservation, and regulates dam safety (DERM 2009b).
- *Water Act 2000* — provides a framework for the planning, allocation and use of water, as well as establishing the regulatory framework for the provision of water and wastewater services. It also sets out the Queensland Water Commission's roles (DERM, sub. 60; Engineers Australia 2010e; NWC 2009b).
- *South East Queensland Water (Restructuring) Act 2007* — facilitates the restructuring of south-east Queensland's urban water sector. Establishes Seqwater, Linkwater and the South-east Queensland water grid manager and their functions.
- *South-East Queensland Water (Distribution and Retail Restructuring) Act 2009* — facilitates the restructuring of south-east Queensland's urban water sector. Establishes the three retailer–distributors and their functions.

- *Environmental Protection Act 1994* — provides the regulatory framework for the protection of the environment (NWC 2009b).
- *Public Health Act 2005* and the Public Health Regulation 2005 — sets standards for drinking water and recycled water (DERM, sub. 60).
- *Local Government Act 2009* —includes provisions for Local Government utilities setting water prices.
- *Queensland Competition Authority Act 1997* — establishes the Queensland Competition Authority (QCA) and its functions.

Institutions

Key institutions include State Government departments, utilities, the Queensland Water Commission and the QCA.

Department of Environment and Resource Management

The Department of Environment and Resource Management (DERM) is the key State Government department in urban water. Its responsibilities include setting and leading water policy and reform, water supply planning, water resource allocation, regulation and monitoring, and assessment. It administers the Water Supply (Safety and Reliability) Act, the Water Act, and the Environmental Protection Act and its associated regulations and policies (DERM, sub. 60).

Queensland Health

Queensland Health helps regulate drinking water and recycled water quality (DERM 2011).

Utilities

Along with providing water and wastewater services, urban water utilities are also responsible for planning for current and future growth, setting retail — and where utilities are vertically integrated — bulk prices, maintaining assets, establishing customer service protocols, processes and standards, and ensuring adequate workforce skills and capacity (DERM, sub. 60).

Queensland Water Commission

The Queensland Water Commission is responsible for achieving safe, secure and sustainable water supplies in south-east Queensland and other designated areas. Its main functions are to advise the Minister on matters relating to water supply and demand management, delivery of level of service objectives, implementation and management of regional water security programs, and ensuring compliance with these programs and water restrictions (DERM, sub. 60).

Queensland Competition Authority

The QCA is Queensland's independent economic regulator. Its water related roles include investigating and reporting on pricing practices of water utilities, and mediating on access and water supply disputes (QCA 2010c).

Queensland Ombudsman

The Queensland Ombudsman is an independent complaints agency that aims to ensure public agencies (such as State Government departments and bodies and Local Councils) act fairly (Queensland Ombudsman 2008).

Key policies and plans

Key Queensland water policies and plans include regional plans, water resource plans, regional water supply strategies and total water cycle management plans.

Regional Plans

Regional plans play a key role in helping Queensland to meet challenges associated with managing growth, population change, economic development, protecting the environment, and infrastructure provision. Water management is one of the topics covered. Currently, statutory and non-statutory regional plans are in place for south-east Queensland and other areas (DERM, sub. 60).

Water resource plans

Water resource plans provide a framework for the allocation and management of water on a catchment basis. They define the availability of water, provide a framework for managing and taking water, identify priorities and mechanisms for dealing with future water requirements, and provide a framework for reversing degradation in natural ecosystems. The majority of Queensland has water resource plans in place at this stage (DERM, sub. 60; QWC 2010b).

A resource operations plan is developed to implement the water resource plan by setting out the day-to-day arrangements used to put the strategies into effect (DERM, sub. 60).

Regional water supply strategies

Regional water supply strategies are used to ensure water supply security is met on a regional basis in the short and long term. They balance the water demand and supply requirements, and provide regional water supply solutions for the next 50 years. Regional water supply strategies have been completed for south-east Queensland, central Queensland and far-north Queensland. Strategies for north Queensland, Mackay, Whitsunday, Wide Bay Burnett and north-west Queensland are expected to be released in 2011 (DERM 2010b, sub. 60).

Total water cycle management plans

Under the Environmental Protection (Water) Policy 2009, Local Governments with populations of greater than 25 000 are required to develop total water cycle management plans. These consider all the elements of the water cycle to deliver community needs while optimising social and environmental benefits, and minimising costs (DERM, sub. 60).

Other key south-east Queensland plans

Other key south-east Queensland plans include the South East Queensland Regional Water Security Program, which focuses on providing greater water security, and the South East Queensland Healthy Waterways Strategy 2007–2012, which includes 500 actions to maintain and improve waterway health (DERM, sub. 60; QWC 2010b).

Economic regulation

Pricing

In south-east Queensland, the State Government sets bulk water prices, with it recently setting a 10 year bulk water price path in 2008, which was adjusted downwards in December 2010. The retailer–distributors set retail prices, however, the State Government has recently capped retail price increases for the next few years (Robertson 2011b). The State Government can request the QCA to monitor or investigate the pricing practices of utilities. It is proposed retail prices will be subject to full price regulation by the QCA from 2013. Until then, there is currently an interim price monitoring framework in place, developed by the QCA (Council of Mayors (SEQ), sub. 77; DERM, sub. 60; NWC 2009b; QCA 2010c).

In regional urban areas, water utilities set prices in accordance with the Local Government Act. The QCA has developed the Statement of Regulatory Pricing Principles for the Water Sector to assist Local Governments set prices (DERM, sub. 60, NWC 2009b).

Licensing

DERM issues water licences under the Water Act. They are required in order for water to be taken or interfered with. Licences contain conditions such as requirements to monitor how much water is taken, threshold flow conditions that must be met before water is taken, the volume of and rate at which water can be taken, and the locations where water can be taken (DERM 2009a).

Third party access

The Queensland Competition Authority Act includes a third party access regime that covers water, as well as other utilities and transport infrastructure. The QCA oversees the regime.

Health regulation

Drinking water management

DERM regulates drinking water in Queensland under the Water Supply (Safety and Reliability) Act. It is regulated using a phased approach with two stages. In the first stage, the regulator issues a notice requiring water quality criteria to be met, along with the monitoring of and reporting on drinking water quality. The drinking water provider must report monitoring results on a quarterly basis, and notify the regulator when water quality criteria are not met. The notice continues to apply until an approved Drinking Water Quality Management Plan is in place (DERM 2011, sub. 60).

Under stage two, water providers develop and implement a Drinking Water Quality Management Plan. The requirement to have a plan in place is being phased in from July 2011. The plan documents the risks to the drinking water service, as well as the steps taken to manage these risks, and the operational and monitoring requirements for managing the drinking water service. This approach is based on the Australian Drinking Water Guidelines. Drinking water must meet the quality requirements set out in the Public Health Act and the Public Health Regulation 2005. The Drinking Water Quality Management Plan must be submitted to the regulator for approval. If water quality criteria are not met the regulator must be notified, and Queensland Health can become involved where there are public health risks (DERM 2011, sub. 60).

Recycled water management

Recycled water in Queensland is regulated under the Water Supply (Safety and Reliability) Act. This requires recycled water providers to either have an approved recycled water management plan, have an exemption from having a plan, or be covered by transitional arrangements that stage the introduction of requirements over time.

Recycled water management plans must comply with the Recycled Water Management and Validation Guidelines, which are based on the Australian Guidelines for Water Recycling. The plans aim to protect public health and provide a risk-based system for managing recycled water. All recycled water providers, including those with exemptions, are required to report to DERM, which includes submitting annual reports (except those under transitional arrangements) and reporting on non-compliance with water quality criteria. A number of guidelines have been prepared to ensure compliance with the Act. Queensland Health can also set standards for recycled water quality under the Public Health Regulation 2005 (DERM 2010d; NWC 2009b; PWC 2011).

On-site recycling systems (such as household greywater systems) are regulated under the *Plumbing and Drainage Act 2002* and the Standard Plumbing and Drainage Regulation 2003. Depending on the capacity of the system, approval might be required from council and the Chief Executive of the Department of Infrastructure and Planning, and the system might need to comply with the Queensland Plumbing and Wastewater Code. Some systems might also require approval from the Office of the Water Supply Regulator (within DERM) (PWC 2011).

Environmental health regulation

DERM regulates environmental health under the Environmental Protection Act and the Environmental Protection Regulation 2008. The Environmental Protection Act sets out the framework for the protection of the environment and regulates environmentally relevant activities, which are set out in the Environmental Protection Regulation 2008. DERM licences environmentally relevant activities, including discharges to waterways, through issuing either environmental authorities, if the entity undertaking the activity is a petroleum or mining company, or development approvals or registrations otherwise. These regulate the type, frequency and amount of discharge (NWC 2009b).

On-site wastewater management systems (such as septic tanks) with a peak capacity of less than 21 equivalent persons are regulated under the Plumbing and Drainage Act (PWC 2011).

B.5 South Australia's structural, institutional, governance and regulatory arrangements

Information on the South Australian urban water sector's structural, institutional, governance and regulatory arrangements is provided in this section.

Structural arrangements

In South Australia, SA Water, a State Government-owned, vertically-integrated utility, provides water and wastewater services to the majority of South Australia. There are some small Local Government service providers, such as Coober Pedy Council. Currently, provision of water and wastewater services to Adelaide is contracted to two private entities: Allwater, which is in charge of operations and maintenance; and KBR, which is in charge of project management and procurement (SA Water 2011d). Stormwater services are provided by Local Governments and Natural Resource Management Boards (PWC 2010).

Institutions and governance arrangements

The South Australian institutional arrangements discussed below include key urban water sector legislation, institutions, and policies and plans for the sector.

Legislation

Key urban water related legislation include:

- *Natural Resources Management Act 2004* — provides the framework for managing South Australia's natural resources, and includes natural resource planning and water allocation and management. Establishes the National Resource Management Boards and their functions (NWC 2009b).
- *South Australian Water Corporation Act 1994* — establishes SA Water and its functions.
- *Sewerage Act 1929* — empowers SA Water to construct and operate sewerage systems (Engineers Australia 2010f).
- *Waterworks Act 1932* — empowers SA Water to construct and operate water supply systems (Engineers Australia 2010f).
- *Environment Protection Act 1993* — provides the regulatory framework for protecting South Australia's environment. It provides for the development of environmental protection policies and the issuing of licences (NWC 2009b). Establishes the Environment Protection Authority (EPA) and its functions.
- *Safe Drinking Water Act 2011* — provides the framework for regulating drinking water quality.
- *Public and Environmental Health Act 1987* — plays a role in regulating recycled water (NWC 2009b).
- *Essential Services Commission Act 2002* — establishes the Essential Services Commission of South Australia (ESCOSA) and its functions.
- Proposed Water Industry Act — This will replace some of the existing legislative arrangements, and will cover water demand and supply planning arrangements, appointing ESCOSA as the independent economic regulator, licensing arrangements for service providers and technical regulation (South Australian Government, sub. 52).

Institutions

Key institutions include State Government entities, SA Water, Natural Resource Management Boards, ESCOSA and the Murray–Darling Basin Authority (section B.2).

Department for Water

The Department for Water is the main department responsible for water. Its responsibilities include urban water policy, planning and management, research, monitoring and evaluation, and overseeing major water programs (South Australian Government, sub. 52).

Department of Environment and Natural Resources

The Department of Environment and Natural Resources administers the Natural Resources Management Act 2004 and oversees Natural Resource Management Boards (South Australian Government, sub. 52).

Department of Treasury and Finance

The Department of Treasury and Finance plays a role in setting SA Water's prices (NWC 2009b).

Department of Health

The Department of Health helps regulate drinking water and recycled water quality (NWC 2009b).

Environment Protection Authority

The EPA helps regulate recycled water quality and regulates environmental health (NWC 2009b).

SA Water

Along with providing water and wastewater services, SA Water has a number of other functions, including:

- investing in and maintaining infrastructure
- carrying out research
- providing consultancy
- developing and marketing commercial products
- advising water users in the efficient and effective use of water

- encouraging and facilitating public and private sector participation (Engineers Australia 2010f; South Australian Government, sub. 52).

Natural Resource Management Boards

Natural Resource Management Boards are responsible for managing natural resources. This includes developing and implementing natural resource management and water allocation plans, and ongoing monitoring and evaluation of water resources and dependent ecosystems (NWC 2009b).

Essential Services Commission of South Australia

ESCOSA can currently undertake inquiries into Government's price setting processes (NWC 2009b). Under the proposed Water Industry Act, ESCOSA will take on the role of independent economic regulator from July 2012, which will include setting prices (South Australian Government, sub. 52).

Ombudsman SA

The Ombudsman SA can investigate complaints relating to South Australian Government and Local Government agencies, and make recommendations to correct any identified problems (Ombudsman South Australia 2011).

Key policies and plans

The South Australian urban water sector's major policy document is *Water for Good* (2009). It sets out broad objectives for the urban water sector and water security over the coming years. It includes key objectives and 94 actions to ensure water supplies are safe, secure and reliable until 2050. The key elements of Water for Good cover a number of topics including:

- establishing new regulatory arrangements (including economic regulation)
- adaptive management approaches to supply and demand
- introducing independent planning processes where needed
- water sensitive urban design
- water restrictions and water conservation measures (South Australian Government 2009, sub. 52).

Economic regulation

Pricing

Up until July 2012, the South Australian Cabinet will set water and wastewater prices. The Department of Treasury and Finance prepares the Transparency Statement for Water and Wastewater Prices in Metropolitan and Regional South Australia, of which prices are set out in Part A. This statement allows for public scrutiny of the process undertaken by Government to determine prices (DTF 2010; NWC 2009b).

The Treasurer can give ESCOSA directions to undertake inquiries into State Government price setting processes. ESCOSA's final report is published as Part B of the Transparency Statement. Government's response to this is set out in Part C (DTF 2010; NWC 2009b).

From July 2012, ESCOSA will set water and wastewater prices, with its first price determination coming into effect July 2013 (South Australian Government, sub. 52).

Licensing

Under the proposed new arrangements, water providers will be required to be licensed. ESCOSA will issue licences and oversee the regime (Department for Water 2010).

Third party access

The South Australian Government has committed to developing a state-based third party access regime by 2015 under Water for Good. There are currently some voluntary access arrangements SA Water has negotiated within its rural water supply network (Department for Water 2010).

Health regulation

Drinking water management

The Department of Health regulates drinking water under the Safe Drinking Water Act. The Act is based on the Australian Drinking Water Guidelines. Drinking water providers are required to be registered with the Department of Health and prepare and implement a risk management plan. These include identification and assessment of risks and the steps to be taken to manage those risks. They must also include a monitoring program and a incident identification and notification protocol, which must be approved by the Department of Health. Water quality results are required to be submitted to the Department of Health and information must be made public. Water supplies are subject to audit on a regular basis. The Department of Health must be notified of any incidents (Department of Health (SA) 2010).

Recycled water management

The Department of Health and the EPA manage recycled water quality under the Public and Environmental Health Act and the Public and Environment Health (Waste Control) Regulation 1995. The Department of Health must approve any recycled water schemes. The EPA also becomes involved once schemes reach a certain capacity, which can include assessment, and imposing environmental performance agreements on operators of large schemes. Large schemes also require an authorisation under the Environment Protection Act (NWC 2009b; PWC 2011; Power 2010).

The Department of Health and the EPA also produce the *South Australian Reclaimed Water Guidelines (treated effluent)*, which describe methods for the use of reclaimed water from sewage treatment plants that minimise risks to public health and the environment (NWC 2009b).

Smaller on-site recycling systems require approval from local council and the Department of Health (PWC 2011).

Environmental health regulation

The EPA regulates environmental health under the Environment Protection Act and the Environment Protection (Water Quality) Policy 2003. As part of its requirement to protect water quality and manage pollution, the EPA issues environmental authorisations to entities undertaking activities of environmental significance. Authorisations can specify conditions in relation to a licence to ensure compliance with the Act, such as monitoring and reporting requirements. These requirements are described in the *Environment Protection Authority Guidelines for Monitoring Plan Requirements and Reporting Requirements* (NWC 2009b).

The Environment Protection (Water Quality) Policy 2003 provides for the development of the environmental values and water quality objectives that feed into the authorisations and licences. Referred to in the Policy, non-statutory Codes of

Practice and Guidelines describe how persons undertaking particular activities can comply with their general environmental duty (NWC 2009b).

Local councils regulate on-site waste management systems under the Public and Environment Health Act and the Environment Protection Act, which provide guidance on installation, licensing and operation of systems (PWC 2011).

B.6 Western Australia's structural, institutional, governance and regulatory arrangements

Information on the Western Australian urban water sector's structural, institutional, governance and regulatory arrangements is provided in this section.

Structural arrangements

In Western Australia, Water Corporation, a State Government-owned vertically-integrated utility, provides water and wastewater services to most of urban Western Australia, except Bunbury, Busselton, Rottnest Island, Dampier, Paraburdoo and Tom Price. In Bunbury, Busselton and Rottnest Island, the Government statutory authorities, Aqwest, Busselton Water and Rottnest Island Authority provide water and wastewater services. In Dampier, Paraburdoo and Tom Price, Hamersley Iron Pty Ltd, a private company, supplies water and wastewater services. In addition, some Local Governments provide sewerage services. Stormwater services are provided by the Water Corporation and Local Governments (PWC 2010; NWC 2009b).

Institutions and governance arrangements

The Western Australian institutional and governance arrangements discussed below include key urban water sector legislation, institutions, and policies and plans for the sector.

Legislation

Key urban water related legislation include:

- *Water Services Licensing Act 1995* — establishes the regulatory framework for the industry, including the licensing of water service providers.

- *Health Act 1911* — provides the framework for regulating drinking water and recycled water quality (NWC 2009b).
- *Environmental Protection Act 1986* — provides the framework for regulating environmental health (NWC 2009b) and establishes the Environmental Protection Authority (EPA) and its functions.
- *Water Corporation Act 1995* — establishes the Water Corporation and its functions.
- *Water Agencies (Powers) Act 1984* — gives the Minister for Water the power to determine Water Corporation's prices (NWC 2009b).
- *Water Boards Act 1904* — gives the Minister for Water the power to approve Aqwest and Busselton Water's prices (NWC 2009b).
- *Metropolitan Water Supply, Sewerage and Drainage Act 1909* and the *Country Areas Water Supply Act 1947* — define the legal boundaries for drinking water sources in metropolitan and regional areas, and provide by-laws that help protect the quality of these sources (Department of Water nda).
- *Economic Regulation Authority Act 2003* — establishes the Economic Regulation Authority (ERA) and its functions.

Institutions

Key institutions include State Government entities, utilities and the ERA.

Department of Water

The Department of Water is the main department responsible for water. Its responsibilities include:

- developing water policies and plans
- advising the Minister for Water
- implementing and monitoring water reform and legislative change
- developing community education and engagement strategies
- monitoring and protecting water sources, including planning and allocation of water resources
- identifying and assessing water resources suitable for new drinking water supplies (Department of Water 2011).

Minister for Water

The Minister for Water sets or approves water and wastewater prices (NWC 2009b).

Department of Health

The Department of Health regulates drinking water quality, and helps manage recycled water quality (NWC 2009b).

Department of Environment and Conservation

The Department of Environment and Conservation helps manage recycled water quality and environmental health (NWC 2009b).

Environmental Protection Authority

The EPA helps manage recycled water and environmental health, through conducting environmental impact assessments, and initiating measures to protect the environment from environmental harm and pollution (NWC 2009b).

Water Corporation

Along with providing water and wastewater services, the Water Corporation also plays a role in planning and developing future water sources (Water Corporation ndc).

Economic Regulation Authority

The ERA is Western Australia's independent economic regulator. Its responsibilities include licensing water service providers and conducting inquiries into, and making recommendations on, water and wastewater prices, which the Minister for Water uses to set final prices (ERA 2011b, NWC 2009b).

Ombudsman Western Australia

The Western Australian Ombudsman is an independent entity that can investigate and resolve complaints relating to public authorities (Ombudsman Western Australia nd).

Key policies and plans

Key water plans include the Water Corporation's *Water Forever*, the *State Water Plan* and regional water plans.

Water Forever

Water Forever is the Water Corporation's 50 year plan to deliver water and wastewater services to Perth and surrounding areas. It includes a number of sub-plans which set out actions and goals to achieve targets around reducing consumption, increasing water recycling and developing new water sources (Water Corporation 2009b).

State Water Plan

The *State Water Plan*, released in 2007, provides a strategic policy and planning framework for meeting the State's water demands until 2030. It builds on the *State Water Strategy 2003*, the 2004 National Water Initiative and the *Blueprint for Water Reform in Western Australia 2006*. It is a whole-of-government initiative with 11 Government agencies sharing over 100 priority actions that were to be completed by 2011 (Department of Water ndb).

Regional water plans

The Department of Water is currently developing regional water plans. These assess current resource management and service delivery, identify current and future water availability and demand, and set priority actions to implement water policy and planning, improve water resource management and establish water management plans (Engineers Australia 2010i).

Water management plans cover topics such as drinking water source protection, water allocation, drainage, floodplains and waterways (Engineers Australia 2010i).

Economic regulation

Pricing

The Minister for Water sets prices for the Water Corporation through a by-law process under the Water Agencies (Powers) Act. The prices of other utilities (for example, Aqwest and Busselton Water) are set by their boards and approved by the Minister for Water (NWC 2009b).

The Treasurer can request the ERA to undertake investigations into the prices of any water provider to assist Government in setting prices. The ERA also has an ongoing reference to provide an annual review of the Water Corporation's prices. Outside of regular price determination procedures, water service providers can request the Minister for Water to approve changes to prices (NWC 2009b).

Licensing

The ERA issues licences allowing entities to provide water, wastewater and stormwater services under the Water Services Licensing Act. Licence holders are required to meet water quality and customer service standards. Performance against licence conditions is monitored through a compliance and performance reporting regime, and through regular operational audits and asset management reviews (ERA 2011c).

Health regulation

Drinking water management

The Minister for Health (supported by the Department of Health) regulates drinking water quality under the Health Act and Water Services Licensing Act. They are supported by the Advisory Committee for the Purity of Water, which advises on issues associated with protecting public drinking water (NWC 2009b).

Under the Water Services Licensing Act, operating licences specify drinking water quality standards, which are also set out in a memorandum of understanding between the water provider and the Department of Health. These memoranda define the Department of Health as the regulator of drinking water quality. The Department of Health, as the regulator, audits utilities water quality, data and reporting systems, and provides for the development of a drinking water quality framework. Under the operating licence, a water service provider is required to report quarterly to the ERA and the Department of Health on their compliance with drinking water standards (NWC 2009b; PWC 2011).

Recycled water management

Recycled water is regulated in a similar way to drinking water, with operating licences setting standards. In addition, the Environmental Protection Authority undertakes impact assessments to determine if the scheme should go ahead, and under what conditions. The Department of Environment and Conservation is required to grant approvals to schemes with a high capacity and issue a licence for discharges. This licence ensures the impact of discharges on the environment is acceptable and includes monitoring and reporting requirements. The Department of Health has developed a number of guidelines and codes of practice related to recycling (NWC 2009b).

Smaller on-site recycling systems require approval from Local Governments and the Department of Health. Larger schemes require approval from the Executive Director of Health (PWC 2011).

Environmental health regulation

The Department of Environment and Conservation and the EPA regulate environmental health under the Environmental Protection Act and the Environmental Protection Regulations 1987. The Department of Environment and Conservation issues licences for activities that might impact on environmental health. Conditions of these licences can include regular audits, and monitoring and reporting on compliance with a standard or code of practice. The Environmental Protection Regulations provide detail on what activities should be licensed, licence conditions, and administration and enforcement of licences. The EPA undertakes environmental impact assessments to determine if the activity will significantly impact on the environment, and if so, under what conditions it should go ahead (NWC 2009b).

B.7 Tasmania's structural, institutional, governance and regulatory arrangements

Information on the Tasmanian water sector's structural, institutional, governance and regulatory arrangements is provided in this section.

Structural arrangements

Tasmania's urban water sector has undergone significant structural reform in recent years. Prior to reform, much of Tasmania's water sector was vertically separated.

Twenty-eight of the State's twenty-nine Local Government Councils provided retail, and sometimes bulk, water services, and twenty-seven of them provided wastewater services, in their geographical area. Many sourced bulk water from three bulk water utilities, Hobart Water, Esk Water and Cradle Coast Water (Tasmanian Government, sub. 70).

As of July 2009, three vertically-integrated Local Government-owned corporations, Southern Water, Ben Lomond Water and Cradle Mountain Water, provide water and wastewater services in their own geographic area (Tasmanian Government, sub. 70). A common service provider owned by the three corporations, Onstream, was established to provide such services as information technology, finance and billing (Onstream 2010). Local Governments provide stormwater services (NWC 2009b).

Institutions and governance arrangements

The Tasmanian institutional and governance arrangements discussed below include key urban water sector legislation and institutions.

Legislation

Key urban water related legislation include:

- *Water and Sewerage Industry Act 2008* — establishes an economic regulatory framework for the water and sewerage industry, including a licensing regime, provisions for price regulation, customer service standards and performance monitoring of the industry (DPIPWE 2010; NWC 2009b).
- *Water and Sewerage Corporations Act 2008* — establishes the three corporations and Onstream, and their functions.
- *Water Management Act 1999* — provides the framework for managing Tasmania's freshwater resources (NWC 2009b).
- *Environmental Management and Pollution Control Act 1994* — provides the regulatory framework for protecting Tasmania's environment. Establishes the Environment Protection Authority (EPA) and its functions.
- *Public Health Act 1997* — provides the framework for regulating drinking water and recycled water quality (NWC 2009b).

Institutions

Key institutions include State Government departments, the EPA, utilities, and the Office of the Tasmanian Economic Regulator (OTTER).

Department of Primary Industries, Parks, Water and Environment

The Department of Primary Industries, Parks, Water and Environment is the main department responsible for water. Along with administering the Water Management Act, it is responsible for overall water policy, planning and management (NWC 2009b).

The Director of Public Health and the Department of Health and Human Services

The Director of Public Health, supported by the Department of Health and Human Services, regulates drinking water quality (NWC 2009b).

Office of the Tasmanian Economic Regulator

OTTER is Tasmania's independent economic regulator, and is the economic regulator for water under the Water and Sewerage Industry Act. Its roles include licensing service providers, establishing and administering the customer service code, and monitoring and reporting on the performance of the service providers. OTTER is taking over responsibility for setting prices, with its first determination commencing July 2012 (OTTER 2010b).

Environment Protection Authority

The EPA regulates activities relating to wastewater disposal (EPA Tasmania 2010).

Ombudsman Tasmania

The Ombudsman is an independent entity that can investigate complaints relating to public authorities, including the water and sewerage corporations (Ombudsman Tasmania 2011).

Economic regulation

Pricing

Pricing is currently going through a transitional phase. Under the Water and Sewerage Industry Act, the water corporations set prices under an Interim Price Order issued by the Treasurer in July 2009. The Interim Price Order included a nominal revenue cap of five per cent annually for the period 2009-10 to 2011-12. This was revised up to ten per cent in 2011 (Giddings 2011; NWC 2009b; Tasmanian Government, sub. 70).

From July 2012, OTTER will determine prices. The service providers will be required to submit a Price and Service Plan submission to OTTER which will set out proposed prices and compliance improvement paths. OTTER will prepare draft and final determinations, and consult publicly (NWC 2009b; Tasmanian Government, sub. 70).

Licensing

OTTER issues licences to the three water corporations under the Water and Sewerage Industry Act to provide water and wastewater services. Licence requirements include carrying out activities with regard to public and environmental health risks, developing management plans and reporting to the regulator (OTTER 2011b).

Health regulation

Drinking water management

The Director of Public Health, supported by the Department of Health and Human Services, regulates drinking water quality under the Public Health Act. This Act requires water suppliers to ensure drinking water does not pose a threat to public health. The Director of Public Health issued the *Drinking Water Quality Guidelines* (2005), which are based on the Australian Drinking Water Guidelines, and contain information, recommendations and requirements relating to the provision of drinking water. Under these guidelines, water suppliers are required to prepare and implement drinking water quality management plans, monitor drinking water quality and provide an annual drinking water quality report to the Director of Public Health. The Department of Health and Human Services issues an annual report summarising the results from water quality testing reports (NWC 2009b; PWC 2011).

Recycled water management

The State Government does not directly regulate recycled water quality. The Water and Sewerage Industry Act covers the treatment process for recycled water schemes, but not the delivery infrastructure. However, the State Government has developed the *Environmental Guidelines for the Use of Recycled Water in Tasmania* (2002) which provides guidance on the planning, design, operation and monitoring of wastewater reuse systems, and defines the required procedures for environmental assessment and approval of a recycling system (Engineers Australia 2010g; Power 2010).

On-site recycling systems may require a Special Plumbing Permit under the *Building Act 2000*, and a certificate of accreditation granted by the Minister for Justice and Workplace relations under the Tasmania Plumbing Code (PWC 2011).

Environmental health regulation

The State Government and local councils regulate environmental health under the Environmental Management and Pollution Control Act and the *Land Use Planning and Approvals Act 1993*. Under the Environmental Management and Pollution Control Act activities of a certain capacity are defined as Schedule 2 Premises. The EPA approves these schemes and sets conditions for discharge. If discharge is going to be to the environment, then a development proposal and environmental management plan is required (PWC 2011).

Schemes that are not classified as Schedule 2 Premises under the Environmental Management and Pollution Control Act might be defined as a Level 1 Activity under the Land Use Planning and Approvals Act. These schemes require a permit from local council. The *State Policy on Water Quality Management 1997* requires monitoring on compliance with guidelines and permits issued by the EPA and local councils (PWC 2011).

On-site wastewater management systems may require a Special Plumbing Permit under the Building Act and a certificate of accreditation granted by the Minister for Justice and Workplace relations under the Tasmania Plumbing Code (PWC 2011).

B.8 Northern Territory's structural, institutional, governance and regulatory arrangements

Information on the Northern Territory urban water sector's structural, institutional, governance and regulatory arrangements is provided in this section.

Structural arrangements

In the Northern Territory, Power and Water Corporation, a State Government-owned vertically-integrated utility, provides water and wastewater services. A subsidiary of the Power and Water Corporation, Indigenous Essential Services Pty Ltd, provides water and wastewater services in remote Indigenous communities (Power and Water Corporation 2010). Local Governments provide stormwater services (Engineers Australia 2010d).

Institutions and governance arrangements

The Northern Territory's institutional and governance arrangements discussed below include key urban water sector legislation, institutions, and policies and plans for the sector.

Key legislation

Key urban water related legislation include:

- *Water Act 1999* — provides for the investigation, allocation, use, control, protection, management and administration of water resources. (NRETAS nda).
- *Water Supply and Sewerage Services Act 2000* — provides a framework for licensing water suppliers, and plays a key role in establishing guidelines for the protection of public health by setting minimum drinking water quality standards (Engineers Australia 2010d; NWC 2009b).
- *Public Health Act 2005* — plays a key role in setting guidelines for the protection of public health (Engineers Australia 2010d).
- *Power and Water Corporation Act 2002* — establishes the Power and Water Corporation and its functions.
- *Utilities Commission Act 2000* — establishes the Utilities Commission and its functions.

- *Waste Management and Pollution Control Act 1998* — regulates the discharge of wastewater.
- *Local Government Act* — states that Local Government is responsible for stormwater (Engineers Australia 2010d).

Institutions

Key institutions include Territory Government departments, Power and Water Corporation and Indigenous Essential Services Pty Ltd, and the Utilities Commission.

Department of Natural Resources, Environment, the Arts and Sport

The Department of Natural Resources, Environment, the Arts and Sport (NRETAS) is the main department responsible for water. It is responsible for the assessment, monitoring, management, planning, protection and sustainable utilisation of water resources, and administers the Water Act (NRETAS 2007b, nda).

Department of Health and Families

The Department of Health and Families plays a role in regulating drinking water and recycled water quality (NWC 2009b).

Treasurer

The Treasurer sets water and wastewater prices (NWC 2009b).

Power and Water Corporation

Along with providing water and wastewater services, Power and Water Corporation also investigates and develops water related infrastructure (NWC 2009b).

Utilities Commission

The Utilities Commission is the Northern Territory's independent economic regulator. Under the Water Supply and Sewerage Services Act, the Utilities Commission licenses water service providers, advises on price setting, and monitors and enforces compliance with set prices (NWC 2009b; Utilities Commission nd).

Ombudsman Northern Territory

The Northern Territory's Ombudsman can investigate complaints relating to the Power and Water Corporation (Ombudsman Northern Territory 2011).

Key policies and plans

The NRETAS's main tool for managing water resources is water allocation plans. The Water Act allows for the development of these plans to enhance water resource management. Water allocation plans include allocations for towns, agriculture, industry and the environment, strategies to achieve water use efficiency, information about the reliability of water allocations, and a monitoring and reporting program. Water allocation plans have been prepared for three areas — Tindall Limestone Aquifer (Katherine), Alice Springs and Ti Tree. Water allocation plans are under development for another seven areas (NRETAS ndb).

Economic regulation

Pricing

The Treasurer sets water and wastewater prices via a Water and Sewerage Pricing Order. In setting prices, the Treasurer can seek advice from the Utilities Commission. The Utilities Commission is responsible for monitoring and enforcing compliance with the pricing order, and the Treasurer can assign some price and service standard monitoring functions to the Utilities Commission under their regulatory powers (NWC 2009b).

Licensing

Under the Water Supply and Sewerage Services Act, the Power and Water Corporation requires water and sewerage operating licences to provide water and wastewater services, and under the Water Act, a waste discharge licence to discharge wastewater to the environment. The Utilities Commission issues, and monitors compliance with, the operating licences. They set out Power and Water Corporation's requirements, including service standards it must meet, documentation that must be prepared and reporting requirements to the Utilities Commission (Utilities Commission 2009).

The Controller of Water Resources, through NRETAS, issues Power and Water's water discharge licence. It sets out quality and quantity requirements, standards and reporting requirements (NRETAS 2007a).

Health regulation

Drinking water management

Drinking water quality is managed through licensing of water providers under the Water Supply and Sewerage Services Act. The Minister for Health, supported by the Department of Health and Families, can specify the minimum standards for drinking water quality. These minimum standards are set to the Australian Drinking Water Guidelines. The Power and Water Corporation conducts routine water quality tests to ensure water quality meets the Australia Drinking Water Guidelines, and must report on its compliance with the minimum standards to the Utilities Commission, the Chief Health Officer, and other stakeholders, such as customers (NWC 2009b).

Recycled water management

Recycled water quality is managed under the Public Health Act and the Water Management and Pollution Control Act. Under these Acts, recycled water schemes require approval from the Department of Health and Families, and might require a licence from NRETAS. The Department of Health and Families' *Guidelines for Management of Recycled Water Systems* (2009) sets out the framework for managing recycled water, as well as the requirements of recycled water scheme operators, including monitoring and reporting requirements (Power 2010).

Environmental health regulation

The Controller of Water Resources, supported by NRETAS, oversees environmental health under the Water Act and the Waste Management and Pollution Control Act. Water Discharge Licences, issued by NRETAS, specify the quality and quantity of wastewater that can be discharged, and specify environmental monitoring programs that must be implemented to verify that discharge limits and ambient water quality objectives are being met. The results of monitoring are required to be provided to the Controller for Water Resources and made publicly available (NWC 2009b).

B.9 ACT's structural, institutional, governance and regulatory arrangements

Information on the ACT urban water sector's structural, institutional, governance and regulatory arrangements is provided in this section.

Structural arrangements

ACTEW, a State Government-owned vertically-integrated utility, provides water and wastewater services to the ACT. ACTEW contracts ActewAGL Distribution to operate and maintain its water and sewerage networks, which includes billing, sales, planning, design and maintenance of the network (Engineers Australia 2010a). Roads ACT provides stormwater services (TAMS 2009).

Institutions and governance arrangements

The ACT's institutional and governance arrangements discussed below include key urban water sector legislation, institutions, and policies and plans for the sector.

Legislation

Key urban water related legislation include:

- *Water Resources Act 2007* — provides a framework for the sustainable management of water resources, including the issuing of water access entitlements and water licences, and the preparation of the Water Sharing Plan (DECCEW 2009; NWC 2009b).
- *Independent Competition and Regulatory Commission Act 1997* — establishes the Independent Competition and Regulatory Commission (ICRC) and its functions.
- *Utilities Act 2000* — provides a regulatory framework for licensing utilities (ICRC 2010a).
- *Public Health Act 1997* — provides the framework for licensing drinking water suppliers (NWC 2009b).
- *Environment Protection Act 1997* — provides the framework for managing environmental health (NWC 2009b). Establishes the Environment Protection Authority (EPA) and its functions.

Institutions

Key institutions involved include Territory Government entities, ACTEW, the ICRC and the Murray-Darling Basin Authority (section B.2).

Department of the Environment, Climate Change, Energy and Water

The Department of the Environment, Climate Change, Energy and Water is the main department responsible for water. It is responsible for high-level strategic water policy, including the national water reform agenda, and national competition issues relating to water access, pricing and trading. It also regulates the ACT's water resources, and monitors and reports on water quality (DECCEW 2011).

Department of Territory and Municipal Services

The Department of Territory and Municipal Services urban water related responsibilities include overseeing land management and planning, managing stormwater infrastructure, and investigating non-potable water supplies for priority sportsgrounds (ACTEW 2010b).

ACT Planning and Land Authority

The ACT Planning and Land Authority's urban water related responsibilities include:

- administering the Utilities Act, the *Water and Sewerage Act 2000* and the Water and Sewerage Regulations 2001
- water and sewerage technical regulation
- assisting in the design work for water services to new urban developments
- implementing policies relating to urban water management and water efficiency
- investigating the feasibility of non-potable water supplies (ACTEW 2010b).

ACT Health

ACT Health regulates drinking water quality. It administers the Public Health Act and licences drinking water providers (ACTEW) under this Act (NWC 2009b).

Environment Protection Authority

The EPA regulates recycled water schemes and environmental health (NWC 2009b).

ACTEW

As well as providing water and wastewater services, ACTEW is also responsible for investigating and recommending new supply options to government (NWC 2009b).

Independent Competition and Regulatory Commission

The ICRC is the ACT's independent economic regulator. It sets water prices, licenses utilities and ensures compliance with licensing conditions (ICRC 2009, 2010b).

ACT Ombudsman

The ACT Ombudsman can investigate complaints related to ACTEW (ACT Ombudsman nd).

Key policies and plans

The ACT's main water resource strategy is *Think water, act water — a strategy for sustainable water resource management* (ACT Government 2004). It provides guidance for water resource management until 2050, and defines actions to achieve sustainability objectives for water use, including:

- increasing water use efficiency
- providing a long-term water source
- developing a cross-border (ACT–New South Wales) water supply agreement
- incorporating water sensitive design principles into urban, commercial and industrial development (Engineers Australia 2010a).

Volume 3 of *Think water, act water* has since been replaced by the ACT's Water Sharing Plan. This identifies how much water is required to manage river systems, and associated ecosystems, and how much is available for off-stream use (DECCEW 2009).

Economic regulation

Pricing

The ICRC determines water and wastewater prices, and recommends the method for setting and calculating the water abstraction charge (this charge reflects the environmental cost of extracting water and the value of water as a resource). The ICRC receives terms of reference from the ACT Government to undertake a review and determines prices for a set period. ICRC undertakes a public process, including issuing a number of documents. The ICRC makes a draft determination and final determination, and stakeholders can make submissions. ACTEW provides the ICRC with a submission detailing its proposed capital expenditure and operating costs. The efficiency of these estimates is examined by an independent consultant (ICRC 2010b; NWC 2009b).

Licensing

Under the Utilities Act, ACTEW requires a utilities services license to provide water and wastewater services. The ICRC issues this licence, which sets out ACTEW's requirements, including service standard requirements and reporting requirements to the ICRC (ICRC 2002, 2009).

Under the Public Health Act, ACTEW also requires a drinking water utility licence, which is issued by ACT Health. Under the conditions of this licence, ACTEW must comply with the *Drinking Water Quality Code of Practice 2007* (ACTEW 2006).

Under the Water Resources Act, the EPA issues a licence to ACTEW covering abstracting water and releasing environmental flows (ACTEW 2006).

Health regulation

Drinking water management

ACT Health is responsible for regulating drinking water quality under the Public Health Act. ACT Health licences drinking water providers and prepared the *Drinking Water Quality Code of Practice 2007*, which licence holders must comply with. The Code provides a framework for reporting and water quality management, and refers to the Australian Drinking Water Guidelines. Under the Code, and its licence conditions, ACTEW must undertake a performance monitoring program and report the results in an annual drinking water quality report, which it submits to the Chief Health Officer of ACT Health and makes public (NWC 2009b).

Recycled water management

The EPA regulates recycled water schemes under the Environment Protection Act. Smaller schemes are Class B schemes under the Act and require an environmental protection agreement issued by the EPA. Larger schemes are Class A schemes and require an environmental authorisation issued by the EPA and ACT Health (NWC 2009b; Power 2010).

On-site recycling schemes may require an activity licence or approval from ACT Health under the Public Health Regulation 2000 (PWC 2011).

Environmental health regulation

The EPA regulates environmental health under the Environment Protection Act, and the Environment Protection Regulations 1997 (Schedule 4 Water Quality Standards). Wastewater treatment and discharge activities are class A activities under the Act and require an environmental authorisation issued by the EPA. The Environmental Protection Regulations provide more detail on the regulation of activities that might pollute waterways and specifies water quality standards that are based on the *National Water Quality Management Strategy* (NWC 2009b).

On-site wastewater systems require approval from ACT Health under the Public Health Regulation 2000 (PWC 2011).

C Lessons from other water sectors

The inquiry terms of reference request the Commission to have regard to lessons from reform in Australia's rural water sector and overseas' water sectors. In this appendix reform in the rural water sector as well as reform that has occurred, or has been proposed, in Scotland, Auckland, New Zealand and England and Wales is discussed. The focus is on reforms that might hold lessons for urban water reform in Australia.

C.1 Scotland

Scotland has introduced a water and wastewater retail market for non-household (business and public sector) customers. The primary motivation was that competition could bring about lower prices, improved services, increased innovation and wider choice (WICS 2009a). This section describes the sector prior to reform, and sets out the approach to reform and key outcomes to date.

Prior to retail competition

Historically, 12 Regional and Island Councils were responsible for providing water and wastewater services. In 1996, the structure of Local Government in Scotland was reorganised, and responsibility for water and wastewater was transferred to three Central Government-owned water authorities — North of Scotland, West of Scotland and East of Scotland Water Authorities (Lobina and Terhorst 2005).

In 2002, the three regional utilities were merged into one utility, Scottish Water, to help avoid regional price disparities, finance capital investment, and maximise economies of scale (Lobina and Terhorst 2005). Scottish Water is a vertically-integrated utility responsible for both water and wastewater.

Establishment of retail competition

In 2005, the Scottish Parliament passed the *Water Services etc. (Scotland) Act 2005*, which provides for the establishment of a non-household retail market for water and wastewater services. Licensed retailers are able to purchase wholesale services from Scottish Water and provide retail services (WICS 2009b). The Water Services Act also established the Water Industry Commission for Scotland (WICS).

Governance and regulatory arrangements

WICS was assigned the responsibility of overseeing the introduction and operation of the retail market, and facilitated the development of the framework under which the market operates. In 2005, WICS established the Licensing Framework Implementation Group, which developed the agreements and codes that would form the retail market framework. The documents setting out how licensed retailers are required to operate are summarised in box C.1.

Box C.1 **Market documents that govern the Scottish retail market**

Market Code — Sets out the duties of market participants and details the establishment and governance of the Central Market Agency.

Operational Code — Governs the way Scottish Water provides services to licensed retailers, such as new connections, metering and tradewaste.

Wholesale Service Agreements — Sets out terms for which Scottish Water agrees to provide wholesale services. A separate Wholesale Service Agreement is negotiated between Scottish Water and each retailer.

Disconnections document — Outlines the procedures in the event services need to be disconnected.

Default directions — Each licensed retailer is obliged to provide, at the minimum, a default level of service at a default price, which is determined by WICS.

Source: WICS (2009b).

In 2007, WICS established the Central Market Agency (CMA) to administer and help oversee the operation of the market. The CMA is owned and governed by market participants. Licensed retailers are required to become members of the CMA. Its functions include:

- operating the market's computer systems
- holding information on retailers' activities
- facilitating the transfer of customer information when they change retailers
- acting as a vehicle for participants' views via a technical panel and market participants forum

- calculating the wholesale charges retailers must pay Scottish Water (Central Market Agency Scotland 2011; Waterwatch Scotland 2010b; WICS 2009b).

The Water Services Act also provided for the establishment of a retail subsidiary of Scottish Water, Business Stream, to provide non-household retail services. This was seen as necessary to demonstrate that a level playing field existed between the incumbent and new retailers. Business Stream is legally separate from Scottish Water, and was granted its licences in January 2008 (WICS 2009b). In recognition of Business Stream being the incumbent retail service provider, its licenses impose additional obligations, including publishing details of all its charges and ensuring they are cost reflective (WICS 2010d).

WICS is responsible for the administration of licences, which are required to provide retail services. There are three types of licences:

- General licences — The most common licences that allow retailers to compete for all non-household customers. They must offer the default package of services and tariffs. They can also supply customers that receive discounts on their wholesale charge[1] (WICS 2010d, nda).
- Self-supply licences — Allow businesses to purchase wholesale water direct from Scottish Water without the services of a retailer. The business is responsible for putting in place its own emergency and maintenance measures (WICS 2010d).
- Specialist licences — Designed for retailers that want to focus on identifying cost savings and help customers apply for reduced wholesale charges. Holders of these licences are only eligible to supply customers that are applying for, or have successfully applied for, a reduction in the wholesale charge (WICS ndc).

Water and sewerage licences are granted separately, so two licences are usually necessary. All of the licences allow the holder to participate in the CMA technical panel and nominate and vote for members of the CMA board. To be granted a licence the entity must undergo a series of checks to prove their competence and reliability (WICS 2010b). Supplier of last resort arrangements exist in the event that retailers cannot meet their obligations (Central Market Agency Scotland 2010).

WICS is also the economic regulator for water, and sets Scottish Water's household and wholesale charges. WICS also sets the maximum default tariff retail customers can be charged. This ensures non-household customers will pay no more than they

[1] If a customer and supplier can demonstrate to Scottish Water that their actions have reduced Scottish Water's charges, the supplier can receive a discount on the wholesale charges it pays Scottish Water (WICS 2010c).

would have if retail competition had not been introduced (WICS 2009b). Retailers can set their own prices and levels of service subject to the default tariff and level of service (WICS 2010c).

The retail market

The retail market began operating in April 2008 (WICS 2010d). As of July 2011, five entities had been granted water and sewerage licences (WICS ndb):

- Satec Limited (licences granted 2 August 2007).
- Scottish Water Business Stream Limited (licences granted 11 January 2008).
- Osprey Water Services Limited (licences granted 1 April 2008).
- Aimera Limited (licences granted 20 April 2009).
- Wessex Water Enterprises Ltd (licences granted 28 October 2009).

The five entities service about 96 000 non-household customers in total. Business Stream is the largest retailer, servicing over 90 per cent of the market (Waterwatch Scotland 2010b).

Another retailer, Aquavitae, had its licence revoked in 2008. Customers were transferred to other licensed retailers under supplier of last resort provisions (WICS 2008).

Evidence of the performance of the retail market

WICS, in its 2009-10 report on competition in the Scottish water industry, reported retail competition has benefited customers. Over 45 000 customers had renegotiated the terms of their supply, receiving better prices and/or more tailored levels of service. In addition, the number of customers switching to a new retailer had increased by 40 per cent on the previous year. However, as seen in Great Britain's gas and electricity sectors, switching does not always lead to better outcomes for customers (box C.2). WICS also reports competition has raised customer awareness of the environmental benefits and cost savings of being more water efficient (WICS 2010a).

WICS has also commissioned consultants Grant Thornton to undertake a cost-benefit analysis of retail competition. Using information on the set-up costs, and data from the first full financial year of operations, Grant Thornton estimated the costs and benefits over the 15 year period 2005-06 (when the first set-up costs were likely to have been incurred) to 2020-21. The costs, including set up and administration costs, were estimated to be about £45 million (about A$73 million) for the 15 year period. However the benefits, including lower bills, returns to owners and reduced carbon impact were estimated to be anywhere between £112 million (about A$181 million) and £142 million (about A$229 million), making the introduction of the market economically justifiable (Grant Thornton 2010).

Box C.2 **Evidence on switching in the Great Britain gas and electricity markets**

In Great Britain's gas and electricity markets, customers are allowed to switch service providers. Since the markets were opened to competition in the mid 1990s, most consumers have switched gas and/or electricity service providers at least once. Switching rates are some of the highest in the world.

Switching is often seen as a proxy for success of a market. However, not all of this switching has benefitted consumers. For example, a 2008 survey found about 40 per cent of consumers had not benefitted from switching service providers. Disadvantaged customers appear to have benefitted less than advantaged customers. Reasons for this include they were more likely to have switched based on the information provided by door-to-door salespeople, and were less likely to compare prices of different service providers.

Sources: Ipsos MORI (2008); Ofgem (2008, 2010).

In addition, WICS also undertook an analysis of the costs and benefits of the retail market. Using information on the costs and savings achieved through to 2009-10, WICS estimated the net present value of the overall savings from introducing retail competition to be £333 million (about A$540 million) (WICS 2011).

Waterwatch Scotland, a customer representative body, published a report on retail competition in 2010, which found there was scope for improvement in retail competition. It believed WICS, in being both the market developer and market regulator, had a potential clash of priorities. It also found customers have had mixed experiences, with some insights from customers' experiences including:

- The number of contacts made to Waterwatch Scotland by non-household customers far exceeded pre-competition levels, increasing from 25 per cent of all contacts/complaints to about half. However, not all of the increase in contacts is attributable to the retail market.
- Many customers still did not know competition existed.
- Many customers had experienced difficulties switching retailers.
- Retailers were not always providing the minimum required services.

- Many customers were frustrated by extra bureaucracy (Waterwatch Scotland 2010a).

Lessons from the introduction of the Scottish retail market

Given that the Scottish retail market, apart from the market in England and Wales, is the only urban water retail market in the world of which the Commission is aware, the Scottish retail market could be a model on which other places could draw. However, the market is still relatively new and so it might be too early to draw strong conclusions about its success, and its potential to be replicated in other places.

The market appears to be functioning well. As a result, the governance, regulatory and administrative arrangements could provide a useful precedent for other jurisdictions. Using these arrangements as a starting point in other jurisdictions could reduce set-up costs.

The introduction of the retail market appears to have resulted in benefits to non-household customers. The market has provided consumers with the opportunity to negotiate for better prices and standards of service. This opportunity has been taken up by many, as evidenced by switching and the reduced market share of Business Stream. It appears the benefits of introducing the retail market will outweigh the costs.

However, although four other retailers have entered the market, Business Stream still remains the dominant retail service provider with about 90 per cent market share. In addition, there might be a need to refine some of the arrangements, as some customers have complained that retailers were not always providing the required services, and some were having difficulty switching retailers.

C.2 Auckland, New Zealand

Auckland restructured its water supply industry in November 2010, as part of a broader restructure of its council system. Auckland's water and wastewater services were vertically and horizontally integrated into one government-owned monopoly utility, Watercare. This section discusses Auckland's water supply arrangements before reform, the impetus and process of reform, and the post-reform situation.

Background

Prior to reform, Watercare was responsible for bulk water supply, and was jointly owned by the six territorial authorities to which it provided bulk water. Watercare also provided bulk wastewater services (treatment and disposal) to four of those six councils.[2] The seventh territorial authority district, Franklin, had its own water and wastewater supply scheme. Retail services were provided by the seven territorial authorities through a number of different structures, including directly by councils, through council-owned organisations and via contracting out (RCAG 2009).

Impetus and lead up to reform

Reviews of Auckland's water sector

An influential review of Auckland's water sector, announced by the Government in 1998, resulted in the territorial authorities (excluding Franklin) participating in an industry stakeholders' forum in 2000. From this, the authorities endorsed three possible options for reform (RCAG 2009):

- Improved status quo — no change to the organisation of the industry, but greater cooperation and coordination.
- Shared network — one public entity would own all the pipes, and retail would be opened up to competition.
- One provider — combining Auckland's water industry into a single entity.

Following this, a public consultation process was undertaken. The 'one provider' option was preferred by 68 per cent of the respondents. However, the process stalled at this point, at least in part due to a lack of consensus among industry stakeholders (RCAG 2009).

There have been other reviews of Auckland's water sector, such as Saha International Limited (2006, cited in RCAG 2009), which included a summary of previous reviews, and highlighted a number of concerns and areas for improvements, including:

- the industry structure was fragmented
- there was a role for regulation
- considerable scope existed for greater coordination and cooperation

[2] North Shore and Rodney were responsible for their own wastewater treatment and disposal.

- different stakeholders had different priorities and objectives
- large-scale investment was needed to deal with stormwater issues.

However, these reviews have generally resulted in little action.

Royal Commission on Auckland Governance

The New Zealand Government established the Royal Commission on Auckland Governance (Royal Commission) in 2007 to investigate the Local Government arrangements in the Auckland region, and reported on how they could be improved (RCAG 2009).

The Royal Commission highlighted a number of problems with Auckland's water sector:

- The age and condition of the pipe network, which was plagued by leaks.
- There was no detailed stormwater management and funding plan. Runoff was degrading and polluting waterways, posing a major environmental threat.
- The industry was fragmented. The retailers each had different priorities and philosophies. For example, although one retailer was prioritising keeping water affordable, another placed greater priority on environmental concerns. This fragmentation led to poor regional planning and decision making.
- There were significant governance issues. For example, many plans and reports had been produced but there was little in the way of action, mostly due to the fragmented nature of the industry (RCAG 2009).

The Royal Commission made a number of water, wastewater and stormwater related recommendations (box C.3). The most significant recommendations relating to the water and wastewater industry involved it being vertically and horizontally integrated, leading to one monopoly utility. The Royal Commission believed these recommendations would lead to better demand management, better environmental management and cost savings (RCAG 2009).

The Royal Commission also recommended the dissolution of the Auckland Regional Council and the seven territorial authorities, and replacing them with one region wide council, Auckland Council (RCAG 2009).

The New Zealand Government accepted the recommendation of one Auckland Council-owned water and wastewater utility. It also made Auckland Council responsible for environmental management (New Zealand Government 2009).

Box C.3 Royal Commission's recommendations relating to water, wastewater and stormwater

- The Auckland Council should have overall responsibility for setting policy in relation to the three waters (water, wastewater and stormwater).
- In urban areas, all drinking water and wastewater services should be supplied by one council-controlled organisation (Watercare Services Limited) owned by the Auckland Council. (This is subject to existing contractual arrangements in the Papakura region.)
- The water and wastewater operations (including assets and relevant staff) of all abolished local authorities should be transferred to Watercare Services Limited on the establishment date.
- No compensation should be payable for the transfer of water-related assets from the existing territorial authorities to the Auckland Council.
- All assets relating to Auckland's water services should remain in public ownership.
- The Auckland Council should determine the extent to which responsibilities for the delivery of stormwater services are shared between local councils and Watercare Services Limited.
- The current obligation on Watercare Services Limited to maintain prices for water and wastewater services at minimum levels (subject to obligations to be an effective business and maintain its assets in the long term) should continue. So too should the prohibition on paying a dividend, to avoid potential subsidisation and high rate of return issues.
- Both water and wastewater charges should be calculated on a volumetric (or notionally volumetric) basis.
- Uniform charges for water and wastewater should apply across the region.

Source: RCAG (2009).

Reform process and the new arrangements

In November 2010, Watercare became the single vertically-integrated utility providing services to about 1.3 million people (about Adelaide's population) in six of Auckland's seven regions (Watercare 2010b). In Papakura, United Water is still contracted to provide retail services, and receives bulk water from Watercare (Watercare 2010a).

As Watercare is council-owned, Auckland Council is responsible for appointing the Company's board, which in turn appoints the Chief Executive (Watercare 2010b). Although Watercare is independent of the council's operations, it is accountable to Auckland Council. Watercare and Auckland Council must agree to a public

Statement of Intent, which includes performance measures (Auckland Council 2010).

Lessons from the structural reform of Auckland's water sector

Auckland's water sector has only recently been restructured, so it is too early to know if the reform has, or will, bring significant benefits. However, lessons can be drawn from the problems identified, and the recommendations made, by the Royal Commission.

There appears to be scope for better resource management through having one single body, rather than several entities trying to coordinate and cooperate with each other.

There are also other efficiency benefits from integration. Better demand management could lead to deferred investment in infrastructure, and better integrated planning can result in capital being used more effectively. Elimination of duplication in many functions can also reduce costs and increase operational efficiency (RCAG 2009).

C.3 England and Wales

The water industry in England and Wales has undergone significant reform over several decades, including privatisation, the introduction of a form of competition for the market, and the introduction of a retail business market. Currently there are calls for further reform with the release of the *Independent Review of Competition and Innovation in Water Markets* (Cave review) in 2009.

Privatisation

The water industry in England and Wales was privatised in 1989. Prior to this, the water sector comprised ten publicly-owned vertically-integrated water authorities that provided water and wastewater services to their own geographic areas, and 28 privately-owned water authorities that provided only water services in parts of the areas serviced by the vertically-integrated utilities (Cowan 1997).

Leading up to privatisation the water sector faced a number of challenges, including:

- years of underinvestment in the sector

- meeting higher European Union drinking water and environmental quality standards
- securing competitive and sustainable financing and driving down costs (Cave 2009).

The Government privatised the water industry for a number of reasons, arguing:

- privatisation would result in more efficient companies
- private water owners would fund the investments needed to meet tighter water quality standards and make up for past underinvestment (van den Berg 1997).

Through this process the previously public and private companies were brought under the same regulatory regime. Since privatisation, many water companies have merged, significantly reducing the number of utilities (van den Berg 1997).

Along with privatisation, the regulatory arrangements of the water industry in England and Wales were changed. These changes included establishing The Water Services Regulation Authority (Ofwat), which is responsible for the economic regulation of the sector (Ofwat 2011a).

Views on the privatisation of England and Wales' water industry

There are mixed views on the privatisation of England and Wales' water industry. The Cave review on competition and innovation in water markets noted:

> Over the last 20 years, the industry has risen to the challenges investing around £80 billion, often borrowed at favourable rates. This investment has delivered higher quality drinking water, with an average of 99.96 per cent compliance with European Union standards. It has also resulted in improvements to aquatic ecological quality and near universal compliance with minimum European Union standards for Britain's beaches. However, … customer expectations, environmental standards and efficiency, remain ongoing challenges. (Cave 2009, p.17)

However, the Cave review also pointed out privatisation might have cost consumers financially, with household charges rising by 42 per cent in real terms since privatisation (Cave 2009).

Van den Berg (1997) pointed out privatisation succeeded in attracting a significant amount of investment, with investment by water companies in the six years post-privatisation more than five times the level in the six years pre-privatisation. However, all of this investment might not have been efficient:

- The regulatory regime could have created incentives to gold plate assets.

- Economic and environmental regulatory responsibilities were separated during privatisation. This might have made creating the right environmental incentives difficult, especially since customers had a low willingness to pay for the water quality improvements mandated in European Union directives.
- Ofwat's mandate is limited to ensuring the financial viability of water utilities. As a result, it might not sufficiently take the public costs and benefits of water policies into consideration when assessing companies' investment programs.
- Investment has generally occurred in a cycle that corresponds with the regulatory cycle. This can distort the timing of investments and weaken water utilities' incentives to generate cost savings towards the end of the regulatory cycle.

Van den Berg (1997) also noted:

- the per unit operating costs of water increased during the first regulatory cycle, even though staff numbers were reduced
- as a result of the increased investment, there have been significant increases in the prices customers face
- the profitability of water companies increased significantly after privatisation, which resulted in public backlash against the reforms.

Comparative competition

Although there are a number of vertically-integrated geographically-based utilities, there is no direct competition between utilities for household customers in England and Wales (a non-household retail market is discussed below). As part of its role as the economic regulator, Ofwat uses comparative competition to place competitive pressures on the utilities (Ofwat 2007b).

Ofwat benchmarks the water companies to assess their relative efficiency. This information is published in an annual report on the costs and efficiencies of the companies and feeds into the price setting process (IPART 2007a). In its price setting, Ofwat rewards outperforming utilities and penalises underperforming utilities (Ofwat 2003).

As discussed in appendix G, a form of comparative competition is also used by the Essential Services Commission to compare Melbourne's three retailers. It is different from that used in England and Wales; in particular, the information is not used in the price setting process.

Ofwat reported comparative competition has delivered benefits for users:

> comparative competition has delivered significant benefits for users over the past 18 years. It has accommodated a very large programme of capital investment, improved the quality of service for customers significantly and provided incentives for efficiency improvements worth more than £100 per year in bill reductions for the average customer. England and Wales scored reasonably well in international comparisons of water and sewerage quality and efficiency. (Ofwat 2007b, p.5)

The United Kingdom Department for Environment, Food and Rural Affairs has noted comparative competition, along with the competitive pressures of having to obtain private sector finance, has been an effective incentive for reducing costs and providing higher standards of service. However, the incentives are unlikely to be as strong as those provided by direct market competition (DEFRA and Welsh Assembly Government 2002, in IPART 2007a).

Inset appointments

Inset appointments are a form of competition for the market. They allow a water company to replace the existing water service provider at a specific site. To be granted an inset appointment the application must meet one of three criteria (Ofwat and DEFRA 2006):

- The customer uses (or is likely to use) at least 50 ML of water per year in England, or 250 ML in Wales.
- The existing water and/or sewerage service provider agrees to the inset.
- The site is not currently served by a water and/or wastewater service provider.

For an application to be granted, along with meeting the above criteria, the applicant has to satisfy Ofwat that it is financially, technically and operationally viable (Ofwat ndb). An inset appointee can supply the customer using its own assets or by requesting the use of the existing undertaker's (the incumbent utility in the geographic area) assets (Ofwat and DEFRA 2006). Inset appointment service providers are subject to the comparative competition regime (Ofwat 2007c).

As at July 2011, 34 new appointments and appointment variations had been granted (Ofwat 2011b).

Views on inset appointments

The Department for Environment, Food and Rural Affairs and the Welsh Assembly Government believe inset appointments have sharpened incentives for utilities to offer lower tariffs and better service for large users. However, the impact is lessened because not all potential entrants want to become appointed service providers. The

Government also noted the application process had been criticised for being onerous and slow (DEFRA and the Welsh Assembly Government 2002, in IPART 2007a).

Cowan (1997) found the introduction of inset appointments induced water companies to introduce ‘large-user tariffs’. Between 1995 and 1997, the introduction of these tariffs resulted in discounts available that varied between about 1 per cent and 30 per cent for a customer with consumption of 300 ML.

However, Cave found the current inset framework did not guarantee beneficial outcomes:

> While these have the potential to offer customers choice, lower prices, better service and reduced environmental impact, the current framework does not guarantee these outcomes because there are significant barriers to entry, costs may not [be] distributed appropriately and there may be inefficient entry. (Cave 2009, p. 13)

Water supply licensing and retail competition

In 2005, the Water Supply Licensing regime was introduced, allowing retail competition in the provision of water (but not wastewater) services to non-household customers. The objective was to develop competition that would benefit consumers, through greater efficiencies, keener prices, innovation and better services, while at the same time, balancing the wider objectives of protecting public health, protecting and improving the environment, meeting the Government’s social goals, and safeguarding services to customers (DEFRA and Welsh Assembly Government 2002, in IPART 2007a).

Companies can compete to supply non-household customers whose annual water consumption is likely to exceed 50 ML each year. When competition was introduced, about 2200 non-household customers would have been eligible (Ofwat and DEFRA 2006).

Prospective service providers have to obtain a licence from Ofwat to compete in the market. There are two types of licences, retail licences and combined licences (Ofwat ndc):

- Retail licence — authorises the licensee to purchase water from an appointed water company and use its supply system to supply water to the customer’s premises.
- Combined licence — authorises the licensee to introduce water into an appointed water company’s supply system and to supply the water to the customer’s premises.

With the introduction of water supply licences, the water undertaker in each geographic area developed access codes which set out the terms on which licensees can access the supply system (Ofwat and DEFRA 2006). Undertakers are also required to publish an indicative price for access to the supply system, with guidance on how to calculate these prices issued by Ofwat (Ofwat 2009a).

If a water undertaker wants to participate in the market in another undertaker's area of operation, it must set up an associate company. This company cannot compete in the associated undertaker's supply region (Ofwat nda).

Ofwat has expressed concern that the Water Supply Licensing regime has not been successful. In a letter to the Government, Ofwat identified two factors it believed were limiting the development of competition (Ofwat 2006, in IPART 2007a):

- The threshold for contestability was limiting the size of the market.
- The application of the pricing rule (according to the costs principle) was resulting in low margins for entrants.

A review by Ofwat of market competition in the water and sewerage industries (Ofwat 2007c) recommended the costs principle should be removed and replaced with general criteria for access pricing, and that the threshold should be reduced from 50 ML to 5 ML initially, then removed completely.

Cave review

In 2008, the United Kingdom Government and Welsh Assembly Government commissioned Professor Martin Cave to lead an independent review on competition and innovation in water markets. The aim of the review was to 'recommend changes to the legislation and regulation of the industry in England and Wales to deliver benefits to consumers, particularly the most vulnerable, and the environment through greater competition and innovation' (Cave 2009, p.3).

The Cave Review identified a number of new and ongoing challenges that needed addressing, including climate change, population growth, the need to reduce water consumption, meeting consumer expectations, continued efficiency, environmental concerns and resource management concerns (Cave 2009).

Along with these challenges, a number of problems with the current operation of the water industry were identified, and recommendations made (box C.4).

Box C.4 **Main findings and recommendations of the Cave review**

Abstraction and discharge

The abstraction licence and discharge consent regimes failed to ensure resources were used efficiently and sustainably. The review recommended the Environment Agency should be given new powers to tackle over-abstraction and to encourage the trading of licences. Licence conditions should be reformed to take greater account of the impacts of abstraction and discharge on the environment.

Upstream activities

The review saw benefits from introducing greater competitive pressure. Initially incumbents should be given an independent purchasing order and the water supply licensing regime should be reformed. At a later stage, a contracting entity for new capacity could prove to be more effective. Ofwat should encourage greater innovation by increasing the incentives for outperformance and addressing the potential bias to capital expenditure.

Retail activities

The review recognised there could be benefits in removing the non-household threshold for retail competition on the introduction of appropriate accompanying changes and legal separation. This will allow all non-household customers to choose a service provider. The review also proposed that customers and their representatives take a greater role in determining the services provided.

The review found the special merger regime represented a significant barrier to further consolidation, adversely affecting the scope for efficiency gains, financing costs and resource optimisation. The review recommended the regime be reformed and restricted to those mergers which are likely to have a significant impact on Ofwat's ability to undertake comparative competition. Stakeholders should also be given greater certainty about the process.

Innovative capacity

The review proposed the creation of a research and development body to coordinate a shared research and development program for the industry. The organisation would be supported by funding, including revenue from customers and water companies' shareholders.

Source: Cave (2009).

Some of the main findings and recommendations related to the topics presented above (comparative competition, inset appointments and the Water Supply Licensing regime) included (Cave 2009):

- The Water Supply Licensing regime was flawed in conception and implementation. Only one customer has recently been able to switch to a new service provider. The review recommended the regime be reformed, including potentially removing the threshold and legislating the legal separation of retail functions from water businesses.

- The special merger regime — which is in place to limit mergers if they impact on Ofwat's ability to regulate prices on the basis of comparative competition — should be reformed. This would include removing retail only mergers from the regime on the introduction of competition.
- The current inset appointment framework has significant issues. For example, so far appointments have only undertaken retailing activities and built new infrastructure, none have abstracted and treated water or treated and discharged wastewater directly. The review recommended changing the inset appointment framework in the short term and, in the medium term, replacing it with a reformed system for the provision of upstream and infrastructure services.

The United Kingdom Government responded to the final report of the Cave review in the 2009 Budget. It agreed with the Cave review's conclusion that there is no convincing case for extending competition to the household sector. In addition, it will consult with stakeholders on the legal separation of large companies' retail operations and further reforms to the water supply regime, mergers regime and inset appointments regime (UK Government 2009).

Ofwat published its response to the Cave review in June 2009. Ofwat agreed with most of the recommendations, believing 'it represents a valuable contribution to developing reforms that will deliver more sustainable and innovative water and sewerage sectors in England and Wales' (Ofwat 2009b, p. 2).

Lessons from reform in England and Wales

The privatisation of the water industry increased investment, however, perhaps because of the regulatory system, some of this investment might not have been efficient. Prices and profits of water companies have risen in the post-privatisation period, making privatisation unpopular with some.

Comparative competition appears to have been beneficial. It has helped price setting, and consumers might have benefited from reduced bills. However, stakeholders have indicated comparative competition might not provide as strong incentives as direct competition.

Inset appointments appear to have been beneficial in reducing prices and improving services, however, the current arrangements appear to be limiting the potential benefits from the regime.

The Water Supply Licensing regime has not resulted in the benefits that stakeholders would have hoped. A key issue Ofwat has identified is the threshold on non-household customers participating, currently at 50 ML consumption per year. Ofwat (2007c) and Cave (2009) have both recommended at least reducing this threshold. The Scotland retail market has no threshold limiting non-household entry.

A requirement of the introduction of the Scottish retail market was the separation of non-household retail operations from Scottish Water. This was seen as important to show that the market was a level playing field. This has not been done in England and Wales. However, legal separation has been brought up as a potential option by Cave (2009).

C.4 Australia's rural water sector

Australia's rural water sector has undergone significant reform in the past couple of decades. It has been the main focus of such COAG agreements as the 1994 water reform agreement, 1995 National Competition Policy and the 2004 National Water Initiative. The focus of this section is on the lessons that can be drawn upon from the successful establishment and benefits of water trading and carryover rules, particularly in the southern Murray-Darling Basin.

Water trading

Water trading first began in the early 1980s in response to emerging pressures on water resources. Trade was generally restricted by the location in which it could occur (for example, trading between regions in Victoria was not allowed until 1994), and its type. The main types are trade in water entitlements and trade in seasonal water allocations (Frontier Economics 2007):

- Water entitlements — An entitlement gives the holder a perpetual or ongoing entitlement to exclusive access to water in each irrigation season (seasonal allocation). It is specified in volumetric terms or as a share of a specified consumptive pool.
- Water allocations — A specified volume of water (based on percentages) allocated to a water entitlement in a given season.

For water trading to occur water rights needed to be separated from land. Before reform, in many irrigation districts allocations of water were matched to land size. To access more water, irrigators had to purchase more land to gain the entitlements (Frontier Economics 2007).

The main impetus for the development of water trade came through the 1994 water reform agreement and 1995 National Competition Policy. The 1994 agreement required:

- implementation of a comprehensive system of water entitlements and seasonal allocations, backed by the separation of water rights from land, with clear specification in terms of ownership, volume, reliability, transferability, and if appropriate, quality
- cross-border trade to be facilitated and trading arrangements to be consistent
- delivery pricing reform based on user pays and the principle of full cost recovery (PC 2010a, p. 36).

The reform agenda was given a further push by the 2004 National Water Initiative. Through this agreement, the Murray-Darling Basin states agreed to:

- remove barriers to trade in water and minimise transaction costs
- implement nationally-compatible characteristics for securing water entitlements
- introduce water accounting to meet the information needs of different water systems including for planning, monitoring, trading, environmental management and on-farm management (PC 2010a, p. 37).

Water trading has been increasing since its introduction. Between the period of 1998-99 and 2007-08 the volume of trading in allocations grew from the equivalent of 6 per cent of total water allocated for consumptive use in the southern Murray-Darling Basin to 24 per cent, and trade in entitlements increased ten-fold. Trade in allocations is significantly greater than trade in entitlements (NWC 2010a).

Benefits and costs of water trading

Water trading can bring about benefits by reallocating water to ‘higher value’ uses. Frontier Economics (2007) found water trade had resulted in significant economic benefits:

- Without temporary trade the dairy industry would have fared much worse than it did during the past 10 years of drought.
- Even with temporary trading many dairy enterprises collapsed as a result of the extraordinarily low seasonal allocations of 2002-03 and 2006-07. Permanent trading meant farmers left farming with more money than they otherwise would have had.
- Without temporary trading many existing horticultural enterprises in the Goulburn system would not have survived the extraordinarily low seasonal allocations.

- Many mixed farms survived the low seasonal allocations by selling water on the temporary market, thus making more money than they would have done by growing crops. (Frontier Economics 2007, p. xiii)

However, Frontier Economics found the social impacts could be mixed, with the negative impacts including:

- Some farmers have been ostracised by their community for selling their permanent water entitlements.
- Trade in a region can lead to increased competition in production, queuing for timely irrigation water delivery, and higher water tables. Trade out of a region can lead to increased water delivery charges to remaining users (because of stranded assets), the build-up of disease and pest plants and animals, and depopulation.
- Communities in regions exporting water can experience reduced populations and less spending. Communities in regions importing water can experience increased populations without necessarily having the infrastructure and services to properly accommodate these new arrivals. (Frontier Economics 2007, p. xiv)

The National Water Commission (NWC 2010a) also found water trading had yielded significant benefits to individual water users, and regions. It also found water trading increased Australia's gross domestic product by $220 million in 2008-09.

Carryover

Carryover rules allow entitlement holders, subject to certain limits, to carry over unused allocated water to the next season. Prior to the introduction of carryover provisions, entitlement holders generally lost any water that they had not used or traded away. Carryover was introduced in the southern Murray-Darling Basin states of New South Wales in 1998-99, Victoria in 2006-07 and South Australia in 2007-08. South Australia's carryover arrangements ceased in June 2011 (Department for Water 2011a; PC 2010a).

Benefits of carryover

Carryover rules encourage more efficient use of water resources by allowing entitlement holders to make intertemporal decisions, maximising their own water efficiency. Entitlement holders can use their water when it is of greater value to them and better manage their risks. Carryover arrangements are most beneficial the greater the water scarcity, the greater the variability in allocations season to season, and when options for trading and on-site storage are limited (PC 2006d).

Lessons from reform in Australia's rural water sector

Water trading has been successfully established in the rural water sector, bringing with it significant economic benefits, including making a positive contribution to Australia's gross domestic product. However, water trading might have also imposed some limited social costs.

Allowing water users to make intertemporal decisions on their water use can lead to more efficient use of water resources, allowing irrigators to use water when it is most valuable to them, and helping them to better manage risk.

C.5 Overall lessons from reform in other water sectors

The precise approach to reform varies considerably across Scotland, Auckland, England and Wales, and Australia's rural water sector. In the case of Scotland, England and Wales and Australia's rural water sector, different types and levels of competition have been established. By contrast, Auckland's reform program has focused on integration of water and wastewater service provision. In England and Wales, there has been a shift away from government involvement in the water sector through privatisation. In Scotland, similar outcomes are being pursued by encouraging competition with the government-owned, functionally separate, incumbent utility. On the other hand, in Auckland, water and wastewater services are provided by a government-owned utility, and there is no indication that these arrangements will cease.

The diverse reform paths taken by these jurisdictions reflect the different demand and supply conditions of each region, and the institutional arrangements in place prior to reform. These experiences demonstrate there is a range of feasible reform options available, and the importance of developing a reform program that is location (and context) specific.

Notwithstanding the diverse nature of the reforms there are some common themes. For example, separation of the natural monopoly elements of the supply chain (networks) from the contestable elements can allow competition to develop, with corresponding efficiency benefits for customers. However, evidence from reform in England and Wales demonstrates that establishing efficient and appropriate governance and regulatory arrangements is critical to realise the potential benefits of reform.

D Lessons from reform in other utility sectors

Since the 1980s, the Australian economy has been reshaped by a widespread program of microeconomic reform across many sectors, including urban water. There are a number of lessons from these programs of reform that should be considered when assessing further potential reforms for the urban water sector.

This appendix briefly outlines some of these key lessons.

Reform can have significant benefits

One overarching message from the reforms of recent years is that reform can lead to significant efficiency gains. This is particularly the case in areas of the economy that have not previously been subject to competitive pressures. These efficiency gains are likely to have benefits for consumers in terms of price, service quality and innovation (for example, reform of the telecommunications sector).

Importantly, the post-reform era in Australia has also been associated with sustained economic growth, rising real per capita incomes, relatively low rates of inflation and, following the global financial crisis, favourable employment outcomes compared to most developed world economies.

There has also been a productivity pay-off from reform. Australia's annual multifactor productivity growth rate averaged an extraordinary 2.3 per cent during the 1993-94 to 1998-99 productivity cycle, substantially above the rates in any other productivity cycle and more than twice the long-term average rate of 1.1 per cent. Australia's international ranking increased from twelfth to second amongst key OECD countries. (In recent years, Australia's multi-factor productivity performance has been below average, which the Commission largely attributes to lags between high levels of investment and subsequent output in the mining industry, increased capital investment in the utility sectors — including water — and drought conditions reducing agricultural output) (PC 2009b).

Getting market design right is important

An important lesson from the reforms in other sectors, and particularly electricity, is that market design is important and lead times for reform are often quite long. The development of the national electricity market took many years. However, if reform is to provide anticipated benefits, it is more important to get market structure and governance arrangements 'correct' than to implement reforms quickly.

The reform era has also shown that more areas of the economy can be subjected to competition than might previously have been assumed to be case. Although many infrastructure areas have natural monopoly components, they also often have contestable elements. When initiating reform, it is important to define the natural monopoly elements of utility sectors, which should generally be kept as monopolies, and those other elements that might be effectively opened to competition (chapter 12).

However, competition, although generally beneficial, should be seen as a means to an end (such as more efficient outcomes), rather than as an end in itself. Seeking to introduce competition for its own sake will sometimes be counterproductive, especially where competitive outcomes are unlikely to be achieved. For example, in the area of freight rail, the costs of vertical separation on some lightly trafficked rural rail freight routes are likely to be greater than any offsetting benefits from increased competition (PC 2006c). If competition is unlikely to emerge, the case for vertical separation is greatly diminished (although there might still be benefits from increased transparency, or potential efficiencies to be gained that might not have been discovered internally). Regardless of whether or not there is potential for competition, it is important to ensure that the benefits of vertical separation exceed the associated transaction and coordination costs associated with it before pursuing separation (chapter 12).

Sector dynamics change after implementing market reforms

The reform era has highlighted that once competition is introduced to a sector, the dynamics of that sector are fundamentally changed. For example, bringing new players into an industry, as has occurred in the Australian telecommunications sector, can accelerate the uptake of innovation, and help ensure that cost reductions are passed on to consumers (PC 2005c).

However, vertical separation can introduce difficulties associated with the need for coordination between sector entities. This is particularly true where there are interdependencies between industry players. For example, a company involved in electricity generation might be reluctant to invest if it was uncertain whether there would be complementary investment in transmission. Vertically-integrated operators do not have this problem.

These coordination issues can present problems even with otherwise highly successful reforms. For example, although reforms in the electricity sector have been successful in achieving efficient dispatch, they have not necessarily been as successful in encouraging investment (although uncertainty over future carbon emission reduction policies has undoubtedly contributed to this).

Governance arrangements are important

Reform in other sectors highlights the need to get governance arrangements correct if the benefits of reform are to be fully captured. The separation of policy, commercial and regulatory functions is important in order to remove conflicts of interest that are otherwise almost impossible to resolve, and to prevent the public monopoly provider from having a competitive advantage over its rivals (by effectively being both a 'player' and 'umpire' in the market).

Clear objectives, and the inclusion of objects clauses in legislation, are important. For example, the objects clause of the legislation enabling the national electricity market highlights the objective of the law as being to 'promote efficient investment in, and efficient operation and use of, electricity services for the long term interests of consumers of electricity' (Ruff and Swier, sub. 47, p.7). Where objectives are conflicting and guidance about priorities is not provided, accountability of both governments and government trading enterprise managers is diminished, and regulators are often given an undesirable level of discretion.

The Commission considers it important that new regulatory arrangements associated with microeconomic reforms should be well scrutinised in advance and subjected to regular review to ensure their benefits exceed their costs (PC 2005c). In particular, there is a need to be conscious of compliance and administration costs, and the need to strike the right balance between pricing decisions today and providing incentives for investment into the future.

Highlighting the benefits of regularly reviewing regulation, it can be seen that once competition has been able to develop, or if it becomes apparent that initial concerns about potential misuse of market power have been overstated, regulatory arrangements have often been eased. In a number of areas that have been subject to microeconomic reform (such as ports, airports, gas and electricity), initial levels of regulation have been 'wound back', either through reductions in the number of organisations subject to regulation, or by moving to more light handed forms of regulation.

For example, in the case of ports in Victoria, over time there has been a reduction in the number of services subject to price regulation, and price monitoring has replaced potentially more heavy handed regulation for those still subject to price regulation. Following a review, several ports are no longer subject to price regulation, however a complaints mechanism is in place. The Victorian Government has also announced the repeal of the Victorian Channels Access Regime (ESC 2010a).

Importantly, where regulation has been wound back, outcomes have often been found to be superior. In its 2011 draft report on the price monitoring regime for airport services, the Commission found that there had been a marked increase in aeronautical investment since the move to price monitoring, that aeronautical charges do not indicate systemic misuse of market power, and that there was no support for a return to price setting (although airlines have expressed dissatisfaction with negotiations with some airports) (PC 2011b).

Experience has taught governments that regulatory arrangements between wholesale and retail markets need to be consistent or compatible. The Californian electricity crisis of 2000 and 2001 stemmed, in part, from price capping at the retail level while wholesale prices were uncapped. The capped retail prices promoted electricity consumption, while electricity wholesalers had incentives to withhold production. As wholesale prices increased substantially, retailers were unable to recoup costs and were effectively rendered insolvent (Borenstein 2002).

Third party access arrangements can be problematic

Reform has demonstrated that third party access arrangements for infrastructure, although being potentially valuable in promoting competition, can be problematic. On one hand, by limiting potential returns they can represent a disincentive for infrastructure owners to invest. On the other, they can be ineffective in providing for competition, particularly where 'deep pocketed' infrastructure owners can delay access for many years.

In its 2010 report on wheat export marketing arrangements, the Commission found that an 'access test' designed to ensure rival exporters had access to port terminal facilities had provided benefits in the short term by allowing competition to develop, but that, were the test kept in place over time, the costs associated with the test would come to exceed the benefits (PC 2010b).

Third party access is likely to be more problematic where there is a vertically-integrated infrastructure owner as there is an incentive for the infrastructure owner to favour their upstream or downstream operations. However, in 2001 the Commission found there are still likely to be benefits in having third party access arrangements applying potentially to all ‘bottleneck’ facilities (subject to meeting the criteria under Part IIIA of the *Competition and Consumer Act 2010* (Cwlth)) rather than just vertically-integrated ones, not least because of the possibility of firms otherwise restructuring to try to avoid being subject to them (PC 2001b).

Adjustment and distributional issues should be considered up-front

Major reform, even where creating significant net benefits, is likely to have adjustment and distributional implications associated with it. To ensure the net benefits from reform are maximised, there are likely to be gains from assessing these implications of reform at the outset (before the reforms are implemented).

Consideration of the adjustment and distributional impacts up-front will assist in developing appropriate principles to indicate whether transitional support is likely to be warranted, and in determining the most efficient method of providing assistance. Specifying the assistance that will be on offer can also assist in gaining support for change. Further, it will also reduce the likelihood of adjustment assistance being subsequently provided, or appearing to be provided, in an ad hoc manner (PC 2005c).

E Supply augmentation case studies

E.1 Adelaide desalination plant

This case study examines the merits of the decision to build a desalination plant for Adelaide, rather than continuing to rely on water purchases from the Murray River.

Background

Adelaide's main sources of water are dams in the Mount Lofty Ranges catchment and diversions from the Murray River. Water for Adelaide has been sourced from the Murray River for many years and in recent drought years extra seasonal allocations have been purchased from irrigators to meet urban demand shortfalls. During 2008-09, 106 gigalitres (GL) of temporary water (seasonal allocation) was purchased for critical human needs, and a further 60 GL was purchased in 2009-10 (Maywald 2009; Caica 2010). On average the Murray River provides about 40 per cent of Adelaide's mains water and in a drought year this can be as high as 90 per cent (South Australian Government 2005).

In December 2007, the South Australian Government announced that a 50 GL per year seawater desalination plant would be constructed to provide additional water for Adelaide (SA Water 2009). The Australian Government initially provided a grant of $100 million towards the construction of this plant, but in 2009 committed a further $228 million on the condition that the plant's capacity was expanded to 100 GL per year (Wong 2009). This capacity is equivalent to 80 per cent of Adelaide's total consumption in 2009-10. The plant is being constructed at Port Stanvac and is expected to be completed by the end of 2012 (SA Water 2011c).

Analysis

The analysis examines the purchase of water entitlements, but the results would likely be similar for seasonal allocation purchases.

The desalination plant as a supply augmentation for Adelaide

The Port Stanvac desalination plant is being built at an estimated cost of $1.83 billion. In addition, under the contract with Adelaide Aquasure, the operating cost for running the plant at full capacity will be $130 million per year, or $1.30 per kilolitre (kL) (SA Water 2009). Should the plant be shut down, the annual cost will be $30 million, and less than this should the shut down continue beyond 12 months.

If instead of building this plant, 105 GL of high reliability Victorian Murray entitlements had been purchased, this would have cost around $190 million (based on the average price in the February 2011 tender round of the Australian Government's environmental water purchasing program (DSEWPC 2011a)). According to the Australian Government, this quantity of entitlements would be expected to yield an average of 100 GL per year. There is existing infrastructure capable of transporting this quantity of water to Adelaide. Operating costs for this option would be between $0.20 to $0.30 per kL for pumping and treatment (based on data contained in SA Water 2009).

This simple comparison suggests that the capital costs for the entitlement purchasing option might be not much more than one-tenth of those for the desalination plant. In addition, operating costs would also be much lower. On this basis, the entitlement purchasing option appears to be vastly superior. There are, however, two additional considerations that are important — flexibility and reliability/security.

There is some flexibility in the desalination option because production levels can be lowered to save on operating costs when dam levels are high. However, the majority of the costs are in construction and these costs are sunk. The entitlement purchasing option is very flexible because any unneeded allocations can be sold to irrigators and there are no significant sunk costs. Accordingly, the entitlement purchasing option is more flexible, which is an important additional advantage over the desalination option.

The desalination option is very secure because production levels are independent of rainfall. Barring plant breakdowns, 100 GL can be produced each and every year. In contrast, allocations on entitlements are dependent on rainfall. For example, during the ten year dry period ending in 2008-09, the average annual allocation for high reliability Victorian Murray entitlements was 87 per cent, and they fell to a low of 35 per cent in 2008-09. Due to climate change, it is possible that there will be a downward trend in allocations in future. There are, however, reasonably low-cost ways of managing the risks associated with the reliability of allocations, such as purchasing different types of entitlements, carrying over water in dams and purchasing additional allocations (this latter option could be reasonably costly in a year like 2008-09, but on average it would be much lower).

Another aspect of security relates to water quality. Being at the end of the Murray Darling system, salinity and other water quality problems can arise in the locations on the Murray River from which Adelaide's water is taken. Climate change could exacerbate these problems in future. However, the Australian Government is investing over $8 billion in programs designed to improve the health of the Murray Darling system (PC 2010a) and it would be expected that this would reduce risks associated with water quality. In summary, while the desalination option is likely to be more secure than purchasing entitlements, this advantage appears not to be significant enough to overcome its cost and flexibility disadvantages.

The Commission has undertaken this analysis using available data. A number of assumptions have been made and, as these may not all be accurate, the results should be regarded as indicative only. It might even be that alternative analysis would show the desalination plant to be a preferable option to purchasing rural water. To the Commission's knowledge, however, no such alternative analysis is publicly available. When asked whether analysis supporting the desalination decision was made public, the South Australian Department for Water stated that the decision was made through a cabinet process, implying that analysis was not publicly available (Department for Water (SA), trans., p. 289).

The desalination plant as a means of recovering water for the environment

The funding agreement for the desalination plant expansion (released in August 2011) suggests that the plant has a dual purpose (Ministerial Council for Federal Financial Relations 2011). The first is to augment Adelaide's water supply, thereby increasing urban water security. The second is to indirectly obtain extra water for the environment to meet the anticipated requirements of the Murray-Darling Basin Plan. That is, in return for Australian Government funding for the desalination plant, the South Australian Government has agreed to reduce consumptive use from the Murray River, leaving more water for the environment.

This second purpose is made clear by the requirement in the funding agreement that up to 24 GL per year (and up to 120 GL over 10 years) be allocated to an 'Environmental Provision' and that (in addition) the South Australian Government secures a 6 GL high reliability water entitlement for environmental purposes. The agreement (or 'Implementation Plan') states:

> South Australia will establish the Environmental Provision as an environmental entitlement that will be held by the South Australian Government, to be used for

environmental purposes in the South Australian portion of the Murray Darling Basin. (Ministerial Council for Federal Financial Relations 2011, p. 9)

And also:

> The Commonwealth intends that any water provided to the environment as a result of this Implementation Plan will be available to offset South Australia's sustainable diversion limit established by the Murray Darling Basin Plan. (Ministerial Council for Federal Financial Relations 2011, p. 1)

The purchase of irrigation entitlements is the main way that extra water is being obtained for the environment to meet the anticipated requirements of the Murray-Darling Basin Plan (PC 2010a). If the desalination plant were not indirectly providing environmental water it is likely that this shortfall would be made up by purchasing more irrigation entitlements. In other words, without the funding agreement for an expanded desalination plant the same amount of water would go to the environment, but more of it would come from purchasing irrigation water. The cost for such purchases would be around $33 million.[1]

The preceding analysis suggests that building the Port Stanvac desalination plant is a much less efficient way of augmenting Adelaide's water supply system than purchasing irrigation entitlements. The fact that the plant is to be used to indirectly recover extra water for the environment, however, is likely to make this inefficiency greater. This is because:

- while 105 GL of high reliability entitlements might still have needed to be purchased as an alternative to building the plant, not all of this water would need to be treated and transported to Adelaide (some water would simply be released to provide environmental flows in the river, or diverted to selected environmental assets)
- the water security advantage of desalination is much less relevant for environmental water because natural ecosystems are adapted to variable water flows.

Arguments raised in support of the desalination decision

The South Australian Government argued that the Commission's analysis of this issue in the draft report was deficient, stating:

> … the Water for Good plan … spells out very clearly that — among supply options — the desalination plant offered the best overall value for money … . (sub. DR132, p. 4)

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1 Assuming that the quantity of environmental water brought about through the funding agreement is equivalent to 18 GL of high reliability entitlements.

The Water for Good plan, however, referred to an assessment that compared *expanding* the Port Stanvac desalination plant with water purchasing and other options. This is a quite different from the Commission's analysis, which compares building the plant in the first place, to the option of water purchasing.

In addition, the Commission has concerns about the assessment referred to in the Water for Good plan, based on the limited information available. Importantly, it assumes in its base case that the value of water to society is $5 per kL (including a use value, option value and an ecological services value) (South Australian Government 2009). This is problematic for at least two reasons. First, it does not take into account the fact that the value of water varies significantly over time and space, in response to changes in inflows and other factors. For example, in the Commission's modelling for Melbourne the value of water varies mainly between $0.90 and $2.70 per kL, depending on rainfall and investment in supply sources (technical supplement 1).

Second, the figure of $5 per kL seems very high. During 2008-09, water prices in the southern-connected Murray-Darling Basin averaged approximately $0.35 per kL (PC 2010a). This water can be transported and treated for use in Adelaide at an additional cost of around $0.20 to $0.30 per kL. Water was relatively scarce in 2008-09 and water prices tend to be lower still in wetter years like the ones experienced more recently.

It could be argued that these prices have occurred at a time when too little water is being allocated to the environment and that if this were rectified prices would be higher. However, experience with environmental water purchases to date would suggest that any impact on water prices is likely to be relatively modest (PC 2010a). It could also be argued that the traded price of water does not incorporate the full social value of irrigation water to local communities. Even if this were accepted, however, it is implausible that this would explain anything like a $5 per kL value for water.

Assuming a constant and high value of water will tend to overstate the merits of options that create extra potable water, such as desalination, relative to options that reallocate water for urban use as needed, such as rural–urban trade. An overriding concern with the assessment referred to in the Water for Good plan is that it is not available for public scrutiny, including for the purposes of this report.

E.2 Sydney desalination plant

This case study examines whether the decision to commit to building a desalination plant for Sydney was consistent with a real options approach, and, if not, whether efficiency gains from a real options approach were possible.

Background

Sydney is supplied by 11 dams, which have a combined storage capacity equal to just over five times the volume of water that was supplied in 2009-10. In early 2007, after dam levels dropped to around 34 per cent, the NSW Government announced that a desalination plant would be built to bolster supplies. In early 2010, a 90 GL per year capacity plant (expandable to 180 GL per year) was completed at Kurnell and began supplying water. This capacity is equivalent to 18 per cent of Sydney's total consumption in 2009-10. The desalination project was delivered slightly under budget at a cost of $1.89 billion.

Analysis

Desalination was identified as a potential supply option in the *NSW Metropolitan Water Plan 2004*. The NSW Cabinet Office commissioned the Institute for Sustainable Futures and ACIL Tasman to review this plan and they found it to be 'relatively deterministic' and 'designed to invest sufficiently to cover 'worst case' possibilities' (White et al. 2006, p. 6). It advocated adopting 'a more adaptive strategy that can insure against worst-case possibilities at a much lower up-front cost' (White et al. 2006, p. 6).

Features of this adaptive strategy included:

- planning and preparation for a 125 megalitre (ML) per day desalination plant (to reduce the lead time for construction)
- investigating groundwater resources with a view to extracting groundwater during drought
- undertaking a range of recycling and demand management initiatives
- proceeding with the desalination plant when dam levels dropped below 30 per cent (with a view to lowering this 'trigger' point pending more information).

In effect, the adaptive strategy employed a range of real options to allow the desalination plant to be deferred without threatening water security. The review also suggested that further options be investigated, including the use of scarcity pricing.

The review estimated that expected savings of around $1.1 billion were available from adopting the 30 per cent trigger relative to immediately committing to constructing the desalination plant with dam levels at 48 per cent (48 per cent was chosen in part to 'approximate the immediate context' (White et al. 2006, p. 90)). White et al. (2006) found that there was a small probability that the trigger would be reached within a few years (resulting in a fairly small cost saving), but a much higher probability that the trigger would not be reached for several decades (resulting in a much larger cost saving). Their estimate is an average based on these probabilities and is claimed to be conservative.

The authors of the review provided an interim report in February 2006, and by the time the review was released in April the NSW Government had adopted an adaptive strategy with a trigger of around 30 per cent (White et al. 2006). The details of this strategy were set out in the *NSW Metropolitan Water Plan 2006*, which was released in May. This plan states:

> Rather than prescribing now how water needs will be met over the next 25 years, adaptive management means having the capacity to respond to circumstances as they change, taking advantage of new information and technologies as they emerge, and avoiding costs by deferring investment until it is needed. The approach adopted in this Plan reflects this new thinking — particularly with respect to measures required to provide security of supply in deep drought. (NSW Government 2006, p. 121)

In the lead up to the March 2007 state election the NSW Government committed to proceeding with the desalination plant when dam levels were at 34.3 per cent (table E.1). Dam levels rose during the election campaign and over the following few months. Despite this, the returned Government delivered on its election commitment to build the plant. Construction contracts were signed when dam levels were at 57.2 per cent.

The decision to proceed with the plant has been criticised by a number of analysts. Soon after the election, a review author, Professor Stuart White, said that the plant should only be built in the unlikely event that dam levels hit 30 per cent. He stated that constructing the desalination plant regardless of storage levels would be 'a significant burden on the public purse, and is in direct contrast to the advice that was provided to, and accepted by, the NSW Government in 2006' (Clennell 2007).

Grafton and Ward (2008b) stated:

> Our research shows the expected loss to Sydneysiders from building the plant [after dams had reached 57 per cent] and using it at capacity for its first two years while maintaining water restrictions until it is operational adds up to a bungle costing more than $1 billion.

Detailed analysis of the desalination decision by these authors is contained in Grafton and Ward (2010).

Table E.1 **Sydney desalination plant: event timeline**

Date	*Dam levels*[a]	*Event*
February 2006	44.6%	NSW Government announces that a desalination plant will be built for Sydney if dam levels drop to around 30 per cent
April 2006	41.2%	Expert review endorses the 30 per cent trigger (and suggests moving to a lower trigger level once more information becomes available)
February 2007	34.3%	Reported that the forthcoming election in New South Wales will be dominated by water
		Premier Iemma commits to proceeding with a desalination plant
		Opposition leader Debnam announces a plan for a wastewater recycling plant and states that voters will be 'offered a clear choice between recycling and desalination' (McDougall 2007)
24 March 2007	38.4%	Labor returned to government at the state election
25 June 2007	51.4%	Premier Iemma announces the government's preferred tenderer to build and operate the desalination plant (with the plant having a capacity of 250 ML per day, twice that originally planned)
18 July 2007	57.2%	Sydney Water and Blue Water Joint Venture sign contracts relating to the design, construction, operation and maintenance of the desalination plant — a contract to construct the water pipeline for the project is also signed around this time
January 2010	52.7%	The completed plant starts supplying desalinated water

[a] Available storage in Sydney's dams as a proportion of full operating storage.

Sources: Clennell (2007); Hildebrand and Sikora (2007); McDougall (2007); Sydney Catchment Authority (2011b); Sydney Water (2007, 2011a); White et al. (2006).

Sydney Water, however, defended the NSW Government's decision:

> The 2006 Plan, included a desalination construction trigger of 'around 30 per cent' of storage capacity. The 2006 Plan states this trigger could also be 'adaptively modified over time'.
>
> A critical assumption of the 2006 Plan was that if the decision to build was made at around 30 per cent storages, the full 500 ML per day plant (around one third of supply) would be available if storages dropped to 15 per cent.
>
> As storage levels continued to deplete throughout 2006, at a rate of around two per cent per month, it became clear that there was a risk that a desalination plant would not be ready at 15 per cent storages, given the three-year construction timeframe. (sub. DR152, p. 2)

The Sydney Water submission concentrates on the decision to call for tenders when dam levels were at 34 per cent, rather than waiting until they reached 30 per cent.

Support for this decision was provided by the expert Metropolitan Water Plan Independent Review Panel, headed by Professor Peter Cullen:

> The Panel urged commencing the desalination option a little earlier than the trigger point set out in the Metropolitan Water Plan, because of concerns about potential delays in building the desalination plant given the number of desalination plants under construction around the world. (NSW Government 2007)

The submission, however, does not address the important issue of why contracts were signed when dam levels were at 57 per cent. A progress report on the 2006 Metropolitan Water Plan, however, did offer a reason:

> The NSW Government determined that the request for tenders would be accompanied by a firm commitment to construct the plant in order to provide certainty to industry and facilitate an efficient procurement process. (NSW Government 2007, p. 9)

What this means is that the cost of building the desalination plant was effectively treated as being sunk well before any work had started. A true real options approach would have been likely to pay more attention to the potential cost of doing this. That is, it would have been recognised that there was a potentially large value in keeping open the option of deciding not to proceed during the tender process. Although achieving effective engagement with industry might have necessitated payments to tenderers in the event of a decision not to proceed, it seems likely that the cost of this would have been small relative to the option value.

E.3 Rainwater tanks

This case study examines whether government policies to encourage the installation of rainwater tanks are efficient.

Background

Prior to the development of reticulated water systems, urban water was commonly sourced from rainwater tanks and other local storages. In the 1800s some governments actively discouraged the use of rainwater storages so as to improve the economics of reticulated water systems (Coombes and Kuczera (nd)).

Currently in Australia, rainwater tanks function as the sole source of supply in some rural areas, whereas elsewhere they provide a partial substitute for reticulated water. Some domestic rainwater tanks are used exclusively for outdoor watering, while others are also used for toilet flushing and clothes washing. Some people drink untreated tank water in preference to mains water due to the taste; however, health regulators have concerns about this practice (Marsden Jacob Associates 2007b).

The use of rainwater tanks has become more common over recent years. Twenty six per cent of Australian households used a rainwater tank as a source of water in 2010 compared with 17 per cent in 2004 (ABS 2010b). Over this period the number of households with a rainwater tank increased by about 664 000, with most of this growth occurring in capital cities (ABS 2010b). Many schools, sports facilities and businesses have also installed rainwater tanks.

Analysis

Water yields from rainwater tanks are generally affected less by declines in rainfall than are inflows to dams. For example, Coombes and Barry (2008) found that a 50 per cent decline in median rainfall for Brisbane would cause a 60 per cent reduction in runoff into Wivenhoe Dam, but only a 15 per cent reduction in yield from a 3 kL tank. On the other hand, rainwater tanks are a relatively inflexible source in that they can usually only supply water for certain uses on the allotment on which they are located.

If there were no government policies that promoted or discouraged the use of rainwater tanks, decisions about installing them would depend on their costs relative to the costs of mains water and people's perceptions of their other advantages and disadvantages. For example, some people might have a preference for rainwater tanks for environmental reasons, while others might be put off by the need to maintain them. There is evidence to suggest that rainwater tanks are generally not cost effective for households, although performance varies from place to place (Marsden Jacob Associates 2007b). Rainwater tanks tend to perform less well in areas that have very distinct wet and dry seasons (Martin Clark, sub. DR95).

A 'hands off' approach by governments would not produce efficient outcomes if there were significant positive (or negative) externalities from the use of rainwater tanks. That is, people would tend not to install and use rainwater tanks to the extent warranted by their overall net benefits to the community. Where there are significant positive externalities there may, therefore, be an efficiency rationale for governments to encourage their use. The efficiency of such measures would depend on how well they align with the externalities associated with rainwater tanks, as well as on their administrative and compliance costs.

In Australia, governments do encourage the installation of rainwater tanks directly by providing rebates and through regulations that require rainwater tanks, or other measures that reduce mains water use, to be installed for new dwellings (box E.1). In some cases, rebates have been reduced or terminated during 2011.

Box E.1 **Rainwater tanks: examples of subsidies and regulations**

Subsidies

- The Water Smart Gardens & Homes Rebate Scheme is a Victorian Government scheme that offers rebates for the installation of rainwater tanks, as well as other water saving appliances. Over 200 000 rebates (for all water saving items) have been claimed under this scheme. Rainwater tank rebates range from $500 to $1000. The $1000 rebate is for a tank with a capacity of at least 4000 litres that is connected to the toilet and laundry (DSE 2011b).
- The Rainwater Tank and Plumbing Rebate in South Australia provided rebates of up to $1000 for installing a rainwater tank plumbed for indoor use. However, from July 2011 the maximum rebate available was reduced to $200 for a stand-alone rainwater tank (SA Water 2011e).
- Some Local Governments offer rebates on rainwater tanks. For example, the Whitehorse City Council in Melbourne offers a 7 per cent rebate on the price of a rainwater tank or bladder (City of Whitehorse 2011).
- The Australian Government's National Rainwater and Greywater Initiative provided rebates of up to $500 for the purchase and installation of new rainwater tank(s) that were connected to the toilet and/or laundry. These rebates have been discontinued (systems purchased after 10 May 2011 are not eligible) (DSEWPC 2011b).

Regulations

- BASIX is a mandatory NSW Government initiative that sets energy and water reduction targets. It requires new houses and residential units in Sydney and some other areas of the state to be designed to use at least 40 per cent less potable water compared to the average NSW dwelling (BASIX ndb). Ninety per cent of new homes in New South Wales are covered by this target. While a range of measures can be used in meeting the target, the most common is installation of a rainwater tank.
- In Victoria all new homes are required to have either a solar hot water system or a rainwater tank for toilet flushing (Building Commission Victoria 2011).
- In South Australia building rules require new dwellings (and some extensions or alterations) to have an additional water supply (such as a rainwater tank) to supplement mains water. The additional water supply has to be plumbed to a toilet, to a water heater or to all cold water outlets in the laundry of a new home. The same rules will apply to new extensions or alterations where the area of the extension or alteration is greater than 50 m^2 and includes a toilet, water heater or laundry cold water outlet (Department of Planning and Local Government (SA) 2010).
- The Queensland Development Code requires new Class 1 buildings (houses and townhouses) to achieve water savings targets, through means such as the installation of rainwater tanks. The targets range from 16 to 70 kL per year, depending on the location and the type of house (Department of Local Government and Planning (Queensland) 2011).

In addition, the use of water restrictions indirectly promotes the installation of rainwater tanks for those households that can afford them, as it provides a source of water that can be used for any purpose, including to maintain gardens in a healthy condition. Survey results indicate that rebates, regulations and water restrictions are a reason for the installation of rainwater tanks in between one-third and one-half of cases (ABS 2010b).

Three commonly cited reasons for government policies to encourage the installation of rainwater tanks are to:

- lessen the need for investment in large-scale water supply augmentation
- reduce water and stormwater infrastructure costs
- achieve environmental benefits associated with reduced stormwater flows.

First, increased use of rainwater tanks does have the potential to lessen the need for investment in large-scale water supply augmentation, but this does not provide a valid rationale for government intervention. This is because such reduced investment would only be brought about by thousands of small-scale investments in rainwater tanks. The need for investment is not avoided, there is just a change from one type of investment to another. Efficient investment in supply augmentation can be promoted by ensuring that mains water is priced efficiently (chapter 6) and leaving people to decide for themselves whether or not to buy a rainwater tank. Provided mains water is priced efficiently, there is no augmentation-related externality that would justify a subsidy.

Second, the use of rainwater tanks reduces water flows through the mains water system. If a large proportion of households in an area use rainwater tanks this might allow smaller mains water pipes to be laid, which would provide a cost saving. Also, some water may be captured in rainwater tanks during storm events, lessening the volume of runoff. With reduced runoff, the scale of stormwater infrastructure that is needed to provide adequate flood protection might be reduced and this might allow cost savings to be made. Where either type of cost saving occurs, rainwater tanks may produce a positive externality because the savings accrue to the community generally.

Marsden Jacob Associates (2007b) found, however, that the potential cost savings were largely confined to greenfield sites. In other areas, infrastructure is already in place and reducing its use would generally not translate into a cost saving. Sydney Water reported that this was not always the case:

> Generally Sydney Water's water, wastewater and in some areas stormwater systems have capacity to accommodate new infill development. In some areas though, there are capacity constraints. In these areas, the costs of system upgrades may be reduced [by a

range of measures, including stormwater detention, regulatory measures such as BASIX and small-scale localised recycling units]. (sub. 21, p. 9)

Marsden Jacob Associates (2007b) also found that rainwater tanks were not always effective at reducing the necessary scale of stormwater infrastructure. Stormwater infrastructure is generally designed for peak events. Marsden Jacob Associates analysed the top ten rainfall events for Sydney over the past 100 years and determined that in many cases rainwater tanks would have been full or nearly full prior to the event (due to rainfall over preceding days) and, therefore, would have caused only a negligible reduction in runoff. In contrast, Coombes et al. (2002) found that for the Parramatta region on New South Wales, rainwater tanks plumbed for indoor use would have 42 per cent of their capacity available prior to a once in 100 year storm event.

In general, the extent to which rainwater tanks are effective at reducing the necessary scale of stormwater infrastructure will depend on the number and size of tanks, the area of roof from which they receive water, whether they are used for indoor as well as outdoor uses, the condition in which they are maintained and climatic factors. Where existing stormwater infrastructure has excess capacity, however, increasing the use of rainwater tanks will not result in infrastructure savings.

Third, capture of runoff in rainwater tanks may reduce the quantity of nutrients entering environmentally sensitive waterways, thereby providing an environmental benefit. For example, Melbourne Water have identified that rainwater tanks can reduce the amount of nitrogen entering waterways. In recognition of this benefit, they do, under certain circumstances, reduce developer charges where rainwater tanks are installed. For example, the reduction for rainwater tanks connected to a large roof area (150 m^2) was $160 in 2007 (Marsden Jacob Associates 2007b).

This appears to be an example of a sound approach to encouraging the installation of rainwater tanks as the incentive is aligned with the environmental benefit. It contrasts with approaches by the Australian and State and Territory Governments that do not generally bear any relationship to environmental benefits.

In summary, if policies to encourage the use of rainwater tanks are to be efficient they need to be aligned with the positive external benefits they provide and have low administrative and compliance costs. There is evidence that the external benefits are generally fairly small (relative to the cost of rainwater tanks), but in specific circumstances may be substantially higher due mainly to infrastructure cost savings or environmental benefits. By contrast, the incentives for installing rainwater tanks resulting from government policies are generally high and do not vary according to circumstance.

It can be concluded, therefore, that current policies to encourage the installation of rainwater tanks are likely to be inefficient and that redesigning or discontinuing them could provide an efficiency gain. Marsden Jacob Associates (2007b) examined the communitywide costs and benefits of installing rainwater tanks plumbed for indoor use in the five largest capital cities and found that in most cases costs exceeded benefits by more than $2000 per tank. While this does not include the intangible benefits that some people experience from owning a rainwater tank, and the figures are a few years old, this analysis suggests that the inefficiencies associated with current policies may amount to several tens of millions of dollars per year. The inefficiencies will tend to be highest in regions that currently have surplus water supply capacity.

F Portfolio managers, opportunity cost and tariffs

As identified in this report, the largest gains from reform to the urban water sector are likely to come from the more efficient procurement of water from an increasingly diverse set of sources. Further, in the presence of rainfall variability and with storage possible, significant efficiency gains can be made from the way these sources are managed and operated under different rainfall scenarios.

The challenges to unlocking these gains are:

- expanding competition for the supply of bulk water services or any other urban water supply services (for example, wastewater treatment and stormwater disposal)
- preserving the operating and investment efficiencies that are associated with vertical and horizontal integration
- mitigating the significant costs that the existing institutional and regulatory arrangements for water utilities have created.

One way to meet these challenges is through adoption of the portfolio manager model, which was one of the two models[1] under active consideration when electricity reform was being debated in the 1980s and early 1990s (Joskow 1991, 1997). As outlined in chapters 9 and 12, the Commission considers the portfolio manager model a more appropriate place to start further reform of Australia's urban water sector.

The purpose of this appendix is to outline in more technical detail how a portfolio manager model could be applied to emulate a market-like approach to investment and operations, including estimating dynamic opportunity costs of supply and their translation into tariff and demand-side management options. Once again, the relevant economic–engineering frameworks and computational methods can be adopted from those used widely in the gas and electricity industries.

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1 The other model was the creation of electricity markets, as widely applied today, for example, the Australian National Electricity Market.

This appendix outlines how a portfolio manager could operate in the water sector (section F.1). It provides details about a practical method for estimating the opportunity costs of supplying a unit of water in the absence of a market (section F.2), and specifies how these costs can be translated into tariffs for consumers (section F.3).

F.1 Portfolio manager

To preserve the operating and investment efficiencies inherent in the vertically-integrated utility, the portfolio manager is established as a monopoly retailer–distributor with an obligation to serve customers and procure water to meet customer demand. The portfolio manager controls the dispatch of (but does not necessarily own or physically operate) various sources of water supply in their portfolio (including changes to storage) and the transmission and distribution of water from the bulk sources to consumers.

To increase competition in the supply of bulk water services, the portfolio manager runs a competitive procurement process for the expansion of supply capacity, which can include a diverse set of sources (dams, aquifers, rivers, rural–urban trade, recycled water and desalination).

With the vertical and horizontal disaggregation of bulk water suppliers, risk allocation becomes important. A principle for efficient risk allocation is to allocate risk to the party best able to manage it. In the water sector, a key risk is rainfall variability. From the view point of the competing bulk suppliers, this is seen as a demand-side risk.[2] From the point of view of the portfolio manager, operating and investment efficiencies are best achieved if the portfolio manager can control the operations of, and investment in, water supply from diverse sources in order to achieve supply at the lowest expected cost. For these reasons, demand-side risk is best managed by the retailer–distributor.

In practice, this means that the retailer–distributor is most likely to enter into contractual arrangements with bulk water suppliers that consist of:

- operational payments that reflect the operating costs of the water provider
- capacity payments to procure the supply capacity desired by the retailer–distributor (Joskow 1989).

2 The demand for water from an individual bulk water supplier is a residual demand, that is a demand not met by other (cheaper) bulk suppliers. If rainfall is high, then the demand for water from bulk sources other than dams could be low, and if rainfall is low, the residual demand could be higher.

Risks associated with construction, maintenance and operation of the bulk water source are best managed by the bulk water provider. The portfolio manager is in control of the dispatch of the bulk water supply assets, but does not necessarily own or physically operate the assets.

An issue that arises in the portfolio manager model is who bears the risks of the portfolio manager (shareholders or consumers) in the absence of a competitive market. In a competitive market, the risk is borne by the shareholders as a result of the competitive process because no individual firm is able to influence the price. Under the portfolio manager model, the retailer–distributor is a government-owned monopoly and is able to structure the tariff so that either party bears the risk. Although consumers have no long-term contractual obligation to take a service from the retailer–distributor, if they want to purchase reticulated water they must buy it from the retailer–distributor. This provides some of the protections that the utility might have achieved with long-term take or pay contracts between the retailer–distributor and individual customers.

One of the factors influencing the appropriate assignment of the risk is the marginal efficiency of the various taxation instruments used by governments to provide equity capital (that is whether it should be funded by all taxpayers using general taxation measures or specifically by taxes on water users in the form of fixed charges).

Another important factor is the creation of incentives for the portfolio manager to efficiently invest in and operate the utility for the benefit of its customers and the community. Applying full cost recovery is likely to strengthen these incentives compared with potential government subsidisation (or taxation). Customers can exert pressure on the utility to keep prices as low as possible for the services on offer. This pressure can be increased by adopting the best practice institutional arrangements set out in chapter 10, in particular, the charter for utilities.

The final element to achieving operating and investment efficiency is the pricing of water by the retailer–distributor to consumers. There are two basic principles which the portfolio manager should apply to designing tariffs:

- the expected present value of future cash flows is equal to the cost of providing an economical and reliable service
- at each point in time, prices should reflect the marginal opportunity cost of providing the relevant service, reflecting changes in cost and demand conditions (for example rainfall) over time.

The next two sections outline frameworks and computational techniques that can be applied by the portfolio manager to undertake this task.

F.2 The opportunity cost of supplying a unit of water

As explained in chapter 6, flexible pricing of bulk water — reflecting the opportunity cost of supplying a unit of water — facilitates the efficient allocation of water resources, and more efficient supply augmentation in the long run.

In the absence of a market for water, a framework for implementing flexible pricing can be designed that emulates an efficient market outcome and encompasses the real options approach to supply augmentation discussed in chapter 5. A portfolio manager could utilise this framework to better understand the opportunity cost of supply, and inform their operating and investment decision making. Such an approach would achieve efficiency gains not achieved using a static approach based on long-run marginal cost, currently practiced by regulators and utilities.

The opportunity cost of supplying a unit of water is a dynamic concept. It reflects changes in the supply–demand balance, which is affected by factors that change dynamically, such as inflows and storage levels. The opportunity cost of supplying a unit of water sends more appropriate signals about when to use or conserve various water sources, leading to a more efficient allocation of water resources. It also sends more appropriate signals on when, and how much, to invest in new sources of supply, leading to increased dynamic efficiency.

The approach should be based on ex ante analysis, using the best available supply cost data and demand forecasts (Scherer 1976). Based on this data, the minimum-cost way of meeting forecast levels of demand over the planning period — subject to the probabilistic nature of future rainfall and inflows into dams — could be used to estimate the opportunity cost of supply.

Mathematical programming is an appropriate tool for estimating the opportunity cost of supply subject to inflow variability, particularly where a portfolio manager has a range of operational and investment options. It provides a practical way to estimate the opportunity cost of supply. The mathematical programming framework can incorporate variability of inflows using a state-contingent approach. The case for adopting the state-contingent approach is based on the idea that risk can be represented by a set of possible states of nature. This approach is a logical extension of the economic theory in the core mathematical programming framework. For more detail on the mathematical programming framework, see technical supplement 1 to this report.

These approaches were developed and applied in the energy sector throughout the 1970s and 1980s when utilities were still vertically integrated, prior to the introduction of markets. They are also widely used today by market operators to set market clearing spot prices in gas and electricity markets (see for example, AEMO 2010c).

In the absence of a market clearing equilibrium, mathematical programming approaches were used to combine the engineering and economic considerations facing utilities, emulating an efficient (market) outcome. One of the benefits of these approaches is that environmental and technical constraints can be included, for example environmental policies (such as emissions policies, see Scherer 1976) or transmission constraints. This 'pseudo-market' was used to gain insights into appropriate pricing strategies for the sector, and to help suppliers understand the cost drivers of their businesses (see for example Oyama 1983, 1987; Delson and Shahidehpour 1992). The models were also used to select a portfolio of cost-minimising supply options to meet consumer demands for energy. These concepts and models that have been applied in the energy sector can be adapted for the water industry.

The linear programming based methodology would identify optimal investment and storage decisions to minimise the cost of running the system, for forecast levels of demand. The framework would provide insights into the opportunity cost of supplying a unit of water at each point in time for each state of nature, by combining engineering and environmental constraints with economic considerations.

The opportunity cost of supplying water would be given in the cost minimisation model by the shadow price (or Lagrangean variable) on the fixed forecast demand quantities (technical supplement 1). There would be a unique opportunity cost of supplying a unit of water for each year and each state of nature. This could be used to design tariffs for consumers (section F.3). This approach would be more dynamic than the long-run marginal cost framework currently used, as it reflects the unique supply circumstances — such as the level of inflows and storages — facing the portfolio manager at each point in time.

Multiple models could be implemented to serve different purposes. For example, a short time-horizon model could be used for pricing decisions. Such a model would include sunk investments and limited new supply sources (reflecting the limited options for supply augmentation in the short term). This would allow more states of nature to be included in the model. A longer time-horizon model might be used for planning and supply augmentation decisions, with all supply augmentation options included. The investment decisions and storage levels identified in both models should align.

The model could also be extended to include demand responses. The cost minimisation framework implicitly assumes the demand for water is perfectly inelastic — regardless of the price of water, consumers demand the same forecast quantity. In practice, consumers are likely to adjust their demand in response to changes in prices. The Commission has used a price endogenous model — with consumers responding to changes in price — in the modelling undertaken for this inquiry.

F.3 Using the opportunity cost of supply to formulate tariffs

Flexible pricing to consumers would yield additional benefits from more efficient demand management (chapter 6). It would ensure that consumers receive signals on the opportunity cost of water, so that during times of water scarcity they have incentives to conserve water, and during times of abundance they are not deprived of valuable water use.

As detailed in chapter 6, the Commission favours an approach where utilities have the flexibility to offer a range of tariffs to consumers. The opportunity cost of supplying water detailed in section F.2 would form the basis of these tariffs. This would allow consumers to express their preferences on security of supply and price stability, and provide an opportunity for the portfolio manager to manage demand more efficiently as water availability changes over time.

The Australian Bureau of Agricultural and Resource Economics and Sciences considered that a multiple tariff approach 'may introduce inefficiencies in the allocation of water relative to a system involving a single price' (sub. DR166, p. 1).

However, there is no loss in efficiency compared to charging all consumers fully flexible prices. Allowing consumers to express their preferences through increased choice would increase net social welfare relative to a mandated pricing policy (based on long-run marginal cost pricing or fully flexible pricing). Consumers would be better off as they have the freedom to choose a tariff that best suits them (and hence maximises their welfare) (Cowan 2004). Utilities would be no worse off, as the tariffs could be structured so that the utility is indifferent between them.

Additionally, the tariff options allow the portfolio manager to implement non-price demand management measures on a commercial basis where they are cost effective to consumers and the utility (for example the interruptible tariff). These measures would not be mandatory. Chapter 7 provides more detail on the use of restrictions and water use efficiency measures.

Some examples of tariffs based on the opportunity cost of supplying water are considered below.

A flexible pricing contract

Under a flexible pricing contract the volumetric charge would vary from period to period to reflect the opportunity cost of water. Consumers would be able to use all the water they desire at the quoted price (the equivalent of a 'spot price' for a unit of supply) (Caramanis, Schweppe and Tabors 1983). They would have the opportunity to take advantage of using more water when prices are low, and cutting back consumption when prices are higher. The utility would be able to manage bulk water supply risk by simply passing on the opportunity cost of the optimally managed portfolio.

An interruptible contract with lower levels of reliability

Under an interruptible contract, consumers would contract to reduce their water usage when required to the contracted level (Caramanis, Schweppe and Tabors 1983). This would manifest itself as an 'option' for the portfolio manager: if a certain condition is triggered, the quantity restriction could be imposed on consumers who have signed such contracts.

In general, the consumer incentives for an interruptible tariff can be thought of as having three components (Barakat and Chamberlin Inc. 1990):

- participation incentive — a payment made regardless of whether or not any request to interrupt supply is made
- performance incentive — a payment based on the reduction in demand or consumption when an interruption takes place
- penalty — a charge for failure to participate or honour the contract.

Contracts can be structured to include some or all of the above incentives. For example, a contract might have only a performance and penalty incentive. The consumer would pay the flexible price (with no participation incentive) when an interruption was not requested. However when the portfolio manager requests an interruption, the consumer would receive a performance payment to reduce demand. Consumption above the contracted volume would incur a penalty, such as a premium on the volumetric price or reduced flow. Importantly, the incentives should be calculated to reflect the value to the portfolio manager of being able to restrict demand. Under this type of contract, utilities would be implementing demand side management on a commercial and efficient basis and consumers would only be agreeing to the contract if it was beneficial to them.

This tariff could be structured to achieve consumer behaviour as close as possible to what it would have been under a flexible pricing tariff. As Caramanis, Schweppe and Tabors (1983) note, under certain conditions of incentives and penalties this contract is equivalent to the flexible pricing contract (for example if the premium for exceeding the contracted volume was calculated to yield what a consumer would have paid under a flexible pricing contract).

A fixed price contract

Under a fixed price contract, the volumetric charge would be fixed over the contracted period (this could be several years) and customers would have guaranteed supply (without any risk of restrictions) at this price. Theoretically, the lower bound for the fixed volumetric component under this tariff option is the expected value of the opportunity cost of supply. However, in practice the volumetric component would be charged at a premium to lock in guaranteed supply at a fixed price, to account for the risk faced by the portfolio manager (the portfolio manager cannot vary supply to these customers in line with changes in water availability). This risk premium would be eliminated if the firm could perfectly hedge the risk in an efficient futures market.

A partially fixed price contract

Under this tariff option, consumers would pay a fixed volumetric charge for all water purchased up to a threshold level. Above the threshold level, opportunity cost pricing would apply. This tariff provides an option value for the consumer. When the price of marginal units is high, a consumer faces incentives to reduce demand, but when the price above the threshold is low, the consumer can exercise the option of buying additional water (Cowan 2004). The fixed volumetric charge would be discounted relative to the fixed price contract, as the portfolio manager is able to shift some of the risk to the consumer.

F.4 Conclusion

As noted above, the tools to determine the dynamic opportunity cost of supply are readily available and widely used in other sectors such as gas and electricity. There is scope for the water industry to adopt these tools and frameworks, particularly under the portfolio manager model. The water industry needs to be comfortable about applying these tools in order to achieve the efficiency gains associated with moving to flexible pricing.

G Competition and structural reform

G.1 Types of competition

Competition for the market

Competition for the market — in the context of the urban water sector — is where businesses compete (for example, via auction or tender) for the right to provide water and wastewater services. This approach facilitates private sector participation and imposes a strong incentive on bidders to reveal the minimum cost of providing services. For example, where there is competition for the provision of bulk water services, service providers would compete on their merits to fulfil the bulk water demand requirement (including any required supply augmentations). This process is consistent with achieving efficient bulk water resource allocation.

Competition for the market underpins the approach taken to water and wastewater service provision in South Australia. Since 1996, the South Australian Government has contracted out the management, operation and maintenance of Adelaide's water, wastewater and recycled water treatment plants, and the city's water and wastewater network infrastructure. Other examples of competitive outsourcing by urban water and wastewater utilities are identified in chapter 5.

Competition in the market

Competition in the market can develop 'naturally' (if well-functioning markets already exist) or can be administratively established (that is, markets can be created).

Where competition in the market exists (or is successfully established), multiple providers compete to supply a good or service to the same group of consumers, and consumers are able to choose between these competing providers. Market prices coordinate supply and demand decisions, including supply investment decisions, and forward and contingent markets allow market participants to manage risk and uncertainty.

Administering competitive markets is a complex and costly task, and has relatively onerous preconditions. There are no examples of competitive urban water markets anywhere in the world, although some progress has been made toward a competitive retail market in the non-residential water sectors in Scotland, and England and Wales (appendix C). By contrast, retail and wholesale markets are well established in the Australian electricity and gas industries.

Notwithstanding the absence of competitive urban water markets in Australia, some urban water consumers are able to source water from multiple supply alternatives. For example, a growing number of urban water utilities are buying water from irrigators under bilateral agreements, in place of relying on traditional sources. This provides utilities with greater choice over the type, quality and price of water they can purchase.

Likewise, growth in the number of locally embedded supply systems (including recycled, non-potable water products, rainwater tanks and so on) represents an increase in the number of supply options (albeit small-scale) available to water customers. Although these examples do not constitute evidence of competitive urban water markets, the emergence of alterative service providers can deliver some of the efficiency gains that a market might be expected to generate, such as imposing a competitive constraint on incumbent suppliers.

Yardstick competition

The concept of yardstick (or comparative) competition was developed in the 1980s as a way to limit the abuse of market power in monopolised utility industries, and is possible where there are multiple, comparable utilities. In practice, yardstick competition has been employed in several ways, ranging from simply reporting publicly on the performance of utilities, to the active use by economic regulators of 'league tables' as a means of setting prices (VCEC 2008). Marques and De Witte noted:

> Yardstick competition is mainly aimed at public utilities where competition is not possible, where the main actors have little incentive to reduce the costs or where asymmetric information exists. This is particularly important in the water utilities sector, usually characterized by monopolistic features and by the presence of asymmetric information (moral hazard and adverse selection) which encourage rent seeking and a quiet life. (Marques and De Witte 2010, p. 42)

Specifically, yardstick competition is expected to impose considerable pressure and incentives on utilities to:

- become more efficient, leading to lower prices

- innovate
- improve service quality (Mizutani, Kozumi and Matsushima 2009).

Yardstick competition may also strengthen information sharing and transparency, and provide opportunities for making comparative judgments about management performance, thereby driving out even further efficiency gains and supporting a market for managerial talent. The development of yardstick competition can also improve the effectiveness of regulation, where relevant. Specifically, the existence of multiple comparable utilities can help to reduce the incidence of asymmetric information between regulator and regulated utility (IPART 2005).

The anticipated benefits of yardstick competition stem from the incentives this information provides for utilities to improve performance. Mizutani, Kozumi and Matsushima (2009) argue that some conditions must exist in order for yardstick competition to work properly, namely:

- homogeneity among businesses
- no collusion among businesses
- incentives for businesses to improve performance, including rewards and penalties.

The costs of yardstick competition are limited to the administrative and regulatory costs associated with monitoring, benchmarking and reporting on utility performance, assuming that horizontal separation has already been undertaken.

The Victorian water businesses are subject to a form of comparative competition by virtue of the performance benchmarking undertaken by the Essential Services Commission (ESC). The ESC has reported on the performance of the three metropolitan retailer–distributors since 1995. In 1996, the coverage of the ESC reports was expanded to include all Victorian urban water and wastewater businesses.

The NSW Office of Water reports annually on the performance of all water and wastewater utilities in New South Wales, and carries out some benchmarking of utility performance (NSW Office of Water 2010a). Performance reporting is also undertaken by the National Water Commission (NWC) and Water Services Association of Australia (WSAA), via the annual *National Performance Report* series (NWC and WSAA 2011).

The economic regulator for water services in England and Wales (Ofwat) uses information on the relative performance of water businesses to set prices (appendix C). Variations of yardstick competition are also in place in Portugal, the Netherlands and Belgium (Marques and De Witte 2010).

Commentary on yardstick competition

Yarra Valley Water recognised the benefits of using comparative performance reporting in regions where monopoly utilities can be readily compared:

> One of the unique aspects of the regime in Melbourne is the fact that the retailers operate within one jurisdiction. This provides the Government (as owner) and regulators with greater capacity to compare performance than would otherwise be the case. For example, while comparisons can be made with interstate utilities — different regulatory regimes, local conditions and customer expectations — can make comparisons difficult. In addition, localised comparators provide additional impetus in that comparative performance and innovations are more readily observed, for example, when one retailer innovates it is difficult to ignore as the retailers share a common regulator, owner, stakeholders and media environment. …
>
> One of the major benefits of comparative competition is the impetus it provides for innovation and the diverse approaches that are taken to solve common problems. The most successful approaches over time are validated and adopted by the other retailers. Having three retailers competing through comparative performance has delivered many examples of innovative solutions at state, national, and in many cases, international level. The existing structure drives each retailer to distinguish itself from the others. Having three organisations striving to position their own companies to be leaders diversifies the opportunities for innovative improvements. (sub. 19, p. 18)

Likewise, scope for innovative product offerings was identified by the Queensland Water Commission (QWC) as a significant potential benefit of urban water reform in south-east Queensland:

> There is significant potential for retailers to offer their customers a range of segmented products based on a number of different attributes including: volume (which may have a time dimension, for example peak daily demand); quality, including variations in the supply source such as raw water, potable water, desalinated water and recycled water; reliability or security (expressed in terms of certainty of supply and the extent to which it may be subject to restrictions; and location (where it is delivered to, or taken from, which impact on transport costs). (QWC 2007, p. 37)

A number of studies have sought to estimate the productive efficiency of the three Melbourne retailer–distributors, and claim that yardstick competition explains some of the observed efficiency improvements. For example, Coelli and Walding (2005) found that the Melbourne businesses performed at or near the determined efficiency frontier in 2002-03. Likewise an Ofwat study (2007a), covering a number of international water businesses, found:

- on measures of cost efficiency for water services, the Melbourne retailer–distributors have performed well relative to other countries
- for wastewater services, the performance of the Melbourne retailer–distributors is better than that of UK wastewater businesses
- the Melbourne retailer–distributors performed relatively well on customer contact indicators, including complaints and call centre responsiveness.

Marques and De Witte (2007) used data envelope analysis to evaluate the performance of 122 drinking water utilities in Europe and Australia. South East Water was identified as being on the efficiency frontier (the other two retailer–distributors were considered outliers and excluded from the analysis).

Despite considerable evidence to indicate that the Melbourne retailer–distributors are performing efficiently, it is difficult to directly attribute this to the establishment of yardstick competition. The Victorian Competition and Efficiency Commission (VCEC) note:

> Domestic and international comparisons indicate that Melbourne's retailers have performed relatively well against a range of service delivery indicators, with gains concentrated in the ten years immediately after the sector was disaggregated in 1995 … overall, this suggests that the extent to which competition by comparison operates to drive efficiencies in the sector has diminished over time, and that the potential role of competition by comparison will be relatively smaller in the future. However, the Commission considers there will continue to be a significant role for performance benchmarking carried out by the ESC and, at the national level, by the National Performance Report. (VCEC 2008, p. 54)

Likewise, the Independent Pricing and Regulatory Tribunal (IPART) were cautious about promoting the benefits of yardstick competition in Melbourne:

> Before such a regime is introduced elsewhere, it is imperative that expected efficiency gains from comparative competition outweigh the potential losses from the duplication of administration costs, and any scale efficiency loss. It should also be considered as to whether comparative competition can be achieved without zonal disaggregation through transparent and publicly accessible benchmarking of inter-catchment utilities. (sub. 58, pp. 10–11)

Competition for the resource

Competitive markets for the exchange and trade of water allow users to buy and sell water according to the value they place on it, with corresponding allocative efficiency gains. There are no formal, competitive markets for the exchange of urban water products, and the Commission has heard evidence that there are some restrictions on trading certain types of urban water entitlements (chapter 5). This contrasts with the Australian *rural* water market, where water is traded through the buying and selling of water access entitlements and allocations. The rural water market effectively constitutes a 'cap and trade' market arrangement (appendix C).

Establishing arrangements for formal trade in urban water entitlements would only be possible once property rights to water, wastewater and stormwater products have been clarified (chapter 5). Urban water trading would also require development of an appropriate water entitlement framework, trading arrangements and market rules, and various administrative mechanisms (such as establishing water accounting principles and a water register).

G.2 Economies of scale

The theory

There is considerable evidence to suggest that water and wastewater services are characterised by economies of scale, which occur when the unit cost of production decreases as the volume of output increases. However, it is also true that when water utilities reach a certain size they could begin to experience diseconomies of scale, such that the unit costs of production increase as output increases (IPART 2005).

It is important to distinguish between economies of scale and other related concepts, such as economies of production density and economies of customer density. Studies of scale economies in water supply and wastewater service provision often use these measures interchangeably, making it difficult to draw robust conclusions and comparisons. Nauges and van den Berg (2008) provide a useful framework for thinking about these concepts (box G.1).

Likewise, it is important to delineate between economics of scale in technology (at the 'plant level') and 'firm level' economies of scale. Economies of scale at the plant level means that the average cost of production decreases as the plant size increases. Economies of scale at the firm level means that as the number of plants operated by the firm increases, the average cost of production falls.

The following discussion focuses on how an individual water utility's costs change in response to an increase in the operating scale of the utility (that is, the number of customer connections). In this context, economies of scale in technology is more relevant than firm level economies of scale.

Box G.1 **Terminology**

Economies of production density

How the costs of the utility change if the total volume of water produced and the total volume of wastewater treated are increased, but the number of water connections served (population) and network length (kilometres) are held constant.

Economies of customer density

How the costs of the utility change if total water produced, total volume of wastewater treated and the number of water connections (population) increase, but network length is held constant.

Economies of scale

How the costs of the utility change if all inputs (volume of water produced, volume of wastewater treated, the number of connections to be served, and the network length) are all increased.

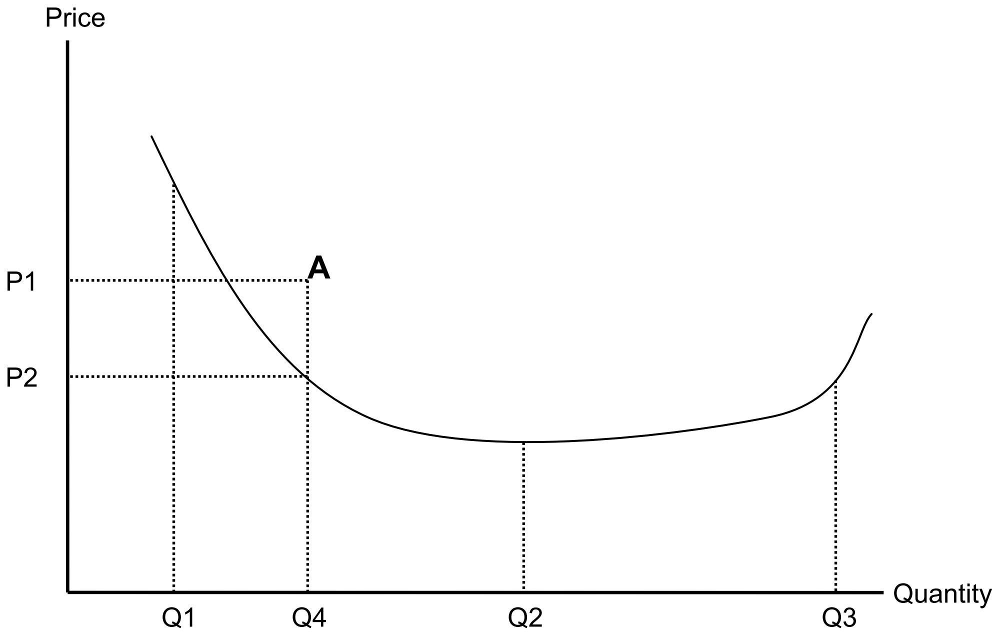
Source: Nauges and van den Berg (2008).

Returns to scale can be described by reference to the long-run average cost curve (figure G.1). The long-run average cost curve reflects the minimum or lowest average total cost at which a business can produce any given level of output in the long run (defined as being when all inputs are variable), and is often termed the efficiency frontier.

Businesses that produce above the long-run average cost curve (at A in figure G.1) are regarded as 'inefficient' (P1 > P2). In a contestable industry, new businesses are able to freely enter the market, and this provides sufficient incentive for the inefficient business to either become efficient or to exit the industry. In contrast, where the market is not contestable, competition from new entrants is not a source of improvement in productive efficiency. In this circumstance, structural reform may be regarded as an attractive option for driving efficiency improvements.

The typical long-run average cost curve is u-shaped, reflecting increasing returns to scale (or economies of scale) where negatively sloped (Q1) and decreasing returns (diseconomies of scale) where it is positively sloped (Q3). The minimum point on the long-run average cost curve (Q2) is the minimum efficient scale — the long-run level of output where all economies of scale have been exploited. Minimum efficient scale is rarely a single level of output. More likely it is a range of output levels across which average cost is minimised, such that the business achieves constant returns to scale.

Figure G.1 **Long-run average cost curve**



Structural reform of the urban water sector will alter the operating scale of affected water businesses. Generally speaking, structural reform that involves horizontal aggregation of water businesses is motivated by moving businesses operating at Q1 toward Q2, so as to realise economies of scale efficiencies. In contrast, horizontal disaggregation may be desirable where a very large utility is exhibiting decreasing returns to scale (Q3), and there are expected efficiencies from reducing operating scale. Where constant returns to scale exist over a range of output levels, it may be possible to separate a utility in such a way that the disaggregated utilities are also of efficient scale.

To determine the precise efficiency impacts of changes in scale it is necessary to understand:

- the shape of the long-run average cost curve
- whether the utility is likely to be below, at, or above minimum efficient scale initially, and how structural reform will change this
- how efficiently the utility operates relative to the efficiency frontier, and if/how structural reform will change this.

In practice, it is difficult to observe these cost curves — economic regulators and/or corporation boards cannot be completely certain that any given level of output is being produced at minimum cost. One way to manage this is to use observable ‘best-practice’ examples as a proxy for the long-run average cost curve. However, these utilities may still incur costs above the efficient level.

This predicament is complicated by the heterogeneous nature of water businesses. Utility costs are driven by a range of factors that vary between locations and utilities, giving rise to unique cost structures (and long-run average cost curves) for individual businesses. This circumstance poses a number of risks from relying too heavily on existing studies of scale economies, as discussed below.

A cautious approach to assessing scale impacts

Despite the breadth of available literature on scale impacts, it is difficult to draw comparisons between two or more studies of economies of scale, or to extend the findings of one study to another region or circumstance. This is due to the highly diverse nature of the assumptions made by industry researchers and academics (such as the key drivers of a utility’s costs), and the considerable influence these assumptions can have in driving the results. In addition, it is often not clear whether studies control for factors such as production and customer density, drinking water standards and customer service standards.

This point was made by IPART:

> These studies cannot provide direct ‘evidence’ of the optimal size for water utilities in Sydney — operational characteristics differ significantly between water utilities, and so the conclusions of a study on one particular utility cannot be automatically applied to another. Given the lack of information specific to Sydney, the Tribunal considers there is insufficient information or evidence to determine whether Sydney Water is currently characterised by diseconomies of scale, let alone to determine the extent of any such diseconomies. (IPART 2005, p. 53)

Likewise, ACIL Tasman, in referring to a 2007 report by IPART on industry costs concluded:

> There is no general consensus on the question of whether there are increasing, constant or decreasing returns to size/scope in providing water and wastewater services. This might be seen as rather unhelpful — but it does tend to highlight the reality that strong conclusions will generally be very context-specific. (ACIL Tasman 2007b, pp. ix–x)

The VCEC (2008, p. 59) made a similar point, suggesting ‘the point when diseconomies emerge probably will depend on a variety of local factors including the usage of the existing network, the condition of the infrastructure, and governance and regulatory frameworks’.

Against this backdrop, it is imperative that any assessment of scale impacts is undertaken with due regard to the particular circumstances of the affected water utilities. One of the most critical assumptions implicit in economies of scale studies is the relationship between scale and network costs. These costs represent a significant component of total utility costs, and can vary dramatically across different locations and circumstances.

For example, if a study has assumed that scale is increased without any increase in the number of networks managed by the utility (that is, new customers are connected to existing networks and there is no need for significant capacity expansion to accommodate additional customers), it would be inappropriate to expect the same scale impacts in a water system where new customers are connected to a separate network (especially if the new network is located at a considerable distance from the existing network). This point was emphasised by Frontier Economics:

> One has to be very careful about drawing inferences from cost studies in jurisdictions whose institutional arrangements are markedly different from our own. One of these differences relates to the size of the networks of pipes. For reasons of history, Japan and the United States have networks that are very small compared with that of Sydney Water. If scale economies are evaluated at the means of the sample data, the evidence of economies of scale from these much smaller networks may have little relevance to the Sydney Water pipes. (Frontier Economics 2004, p. 20)

To properly assess the net impact on network operating costs it is necessary to understand what a change in scale will imply for:

- the number of discrete water supply and wastewater networks managed by the utility
- network density and length
- distance between networks (relative location), including the scope for interconnection between networks
- the volume of water supplied, and the volume of wastewater treated
- size of the area served by the utility.

Other relevant considerations for assessing the costs and benefits of a change in scale include the geography, geology and topography of the region (as this affects pumping costs), variability of wastewater flows (wet weather flows), asset life cycles, climate and rainfall variability, and the distances between centres of urban demand (IPART 2007a).

Evidence of scale economies in urban water supply

Notwithstanding the risks associated with relying on existing evidence to draw general inferences about scale impacts, the available literature provides some important insights. This analysis generally considers how scale influences costs at the utility level:

- Strategic Management Consultants, in a 2002 report to Ofwat, use evidence from England and Wales to conclude that economies of scale are exhausted at about 400 000 connected properties (IPART 2005).
- Tynan & Kingdom (2005) consider a range of international data and conclude that utilities serving a population of 125 000 or less could reduce per customer operating costs by increasing their scale of operation.
- Mizutani & Urakami (2001) find that the optimal number of connections for a water supply utility in Japan is about 766 000.
- Martins, Coelho and Fortunato (2006) studied 218 municipal water and wastewater utilities in Portugal and found that small water utilities should merge where possible. The minimum efficient scale was estimated to be 15.6 megalitres (ML) per day.
- Fraquelli and Moiso (2005) suggest that size economies of water supply in Italy disappear as the number of customers served grows beyond 150 000 to 200 000.
- Torres and Morrison Paul (2006) find evidence that consolidation of small utilities in the United States might generate cost efficiencies, depending on the concurrent expansion of the network, but consolidation of already large utilities without corresponding increases in output density is not likely to be cost effective.
- Stone and Webster (2004) find that for English and Welsh water and sewerage companies there are strong diseconomies of size, such that a one per cent expansion in output implies a one and a half per cent increase in total cost.

In the Australian context, IPART observed:

> In serving approximately 1.6 million connections, Sydney Water is at or approaching a size at which water utilities in other jurisdictions have been found to experience diseconomies of scale. The Tribunal also noted that this number of connections is significantly larger than the minimum number that some sources assert is required to achieve economies of scale. (IPART 2005, p. 53)

The VCEC (2008, p. 58) found 'there are modest economies of scale for small water utilities, with those supplying more than 200 ML of water per day (around

73 gigalitres (GL) per annum[1]) experiencing constant returns to scale'. ACIL Tasman (2007b, p. 11) conclude that 'estimates of the minimum efficient scale for water supply suggest a range from 125 000 to 1 million services inhabitants. For wastewater, the minimum efficient scale is less clear'.

The Economic Regulation Authority of Western Australia (ERA), drawing on the ACIL Tasman (2007b) report, found that 'regional and remote areas in Western Australia are below the minimum efficient scale for water and wastewater utilities' (2008a, p. 108). It should be noted, however, that because Western Australia consists of a large number of separate and isolated networks, the primary source of diseconomies of scale may not be addressed through establishing a single statewide utility.

There is little empirical evidence on economies of scale in specific elements of the urban water and wastewater supply chain. However, Byrnes, Crase, Dollery and Villano considered the efficiency of wastewater utilities in Victoria and New South Wales and found:

> While the generally bigger utilities in Victoria appear able to attract better management expertise, giving rise to technical efficiencies, set against this is a loss of scale efficiency, insomuch as the results suggest that Victorian utilities exceed 'optimal' size. This finding adds weight to the argument that 'bigger in not better' in local public service delivery … with the obvious caveat that this result is confined to wastewater services. (Byrnes, Crase, Dollery and Villano 2009, p. 168)

IPART (2007a) canvassed the literature on economies of scale in bulk water supply and water and wastewater treatment. IPART concluded that 'individual (water) sources generally experience increasing returns to scale (with respect to volume)' (2007a, p. 19) but this only applies up to a certain point, and in many areas (over a period of time) more than one source is required. This upper bound might be determined by the geology of the site, or the intertemporal variation in water flow.

Likewise, individual water and wastewater treatment plants were considered to exhibit increasing returns to scale to a certain point. However, IPART noted:

> As demand increases it is possible that more complex treatment is required, offsetting the economies of larger treatment works, or that extra capacity is required. Tasman Asia Pacific (1997) also report that recent technological innovations have made small scale water and wastewater treatment operations increasingly feasible. (IPART 2007a, p. 19)

[1] The VCEC pointed out that the Melbourne retailers supplied well in excess of this amount (~150 GL per annum) at that time.

More recently, Abbott and Cohen (2010) reviewed some of the existing analysis on scale economies and concluded:

> In respect of Australian water businesses, relatively little research has been undertaken on this issue. Nonetheless, a general consensus has emerged over the past twenty years that consolidating small water agencies into larger units achieves economies of scale. This has resulted in some consolidation of water companies in regional areas in most states. In regard to urban-based businesses, there is some recognition that in the largest state capital cities such as Melbourne, Sydney and Brisbane/SEQ, economies of scale may have been reached at levels below the size of the total urban market, making it possible to have multiple distributors and retailers of water. (Abbott and Cohen 2010, p. 50)

Worthington and Higgs (2011) estimated the scale efficiency of 55 major urban water utilities (with 10 000 or more connected properties) in Australia over the period 2005-06 to 2008-09 and concluded:

> The evidence suggests that there are strong economies of scale at relatively low levels of output (50–75% of mean output) … it is likely that increasing economies of scale also prevail for the many hundreds of smaller water utilities in the Australian population, but not included in this analysis. (Worthington and Higgs 2011, p. 16)

In responding to this inquiry, Yarra Valley Water considered:

> Outside the situation of very small suppliers, there are likely to be diseconomies of scale. That is, as utilities get larger, costs actually increase because of the complexities of larger organisations … Studies generally show that water utilities of comparable size to those in Melbourne are already at scale. (sub. 19, pp. 11–12)

This view was supported by econometric work undertaken by the Centre for Efficiency and Productivity Analysis, which indicated that the three Melbourne retail water utilities were either at or near the efficiency frontier (Yarra Valley Water, sub. 19). In regard to the prospect of establishing multiple retailer–distributors in Sydney, Sydney Water commented:

> It [horizontal separation] has been looked at a few times. The difficulty is the geography. If you were going to split up Sydney's area, the obvious split-off would be Illawarra, which we service. How you'd actually define Illawarra in area terms you'd need to have a close look at. There have been some studies, about the time of corporatisation, of splitting Sydney more or less down the middle of the harbour and the Parramatta River. That always sort of foundered because the network is more like a spider web, and you lose quite a lot of network efficiency doing that. It would be possible, but that hasn't really ever got anywhere. The Illawarra is not really big enough. If they split off, their prices would probably rise, largely because their wastewater treatment is very high quality. We would probably need another 30 000 or so people down there for it to be doable, but it's coming I think. (trans., p. 111)

In contrast, a 2004 report by Frontier Economics claimed:

> There is prima facie evidence that it may be efficient to divide the activities of Sydney Water into a number of enterprises … there may well be within Sydney three separate retail natural monopolies, serving the regions of North Head, Bondi and Malabar … The retail businesses should combine the activities of billing, customer service, and distribution of water and wastewater within each region. (Frontier Economics 2004, p. 31)

G.3 Economies of scope

Economies of scope exist if it is more economical to provide two or more related products together, than for each of them to be provided separately. Economies of scope may arise because there is significant sharing of inputs or facilities across multiple activities. The existence of economies of scope is often used to justify the production of upstream and downstream products in an integrated environment.

There are a number of ways that scope economies might arise in the urban water sector. Specifically, there is potential for economies of scope between two or more:

- water supply functions
- wastewater functions
- stormwater functions
- supply chains (for example, water supply and wastewater)
- functions of Local Government (for example, water supply and roads provision) — this issue is primarily relevant for regional water utilities, and is considered in chapter 13.

Little attention has been paid to assessing economies of scope efficiencies, particularly in Australia. The available literature does not lend itself to a definitive conclusion on scope economies between water supply and wastewater services. IPART notes:

> Evidence of economies of scope from the horizontal integration of water and wastewater services is mixed. While Hunt and Lynk (1995) found evidence of economies of scope, Stone and Webster (2004) found evidence of diseconomies of scope. On the other hand, Saal and Parker (2000) did not find evidence of economies of scope, but nor did they report finding evidence of diseconomies of scope. (IPART 2007a, p. 23)

Notwithstanding this, some researchers have found that joint provision of water supply and wastewater services can generate efficiency gains. For example, Nauges and van den Berg (2008) find evidence of economies of scope between water supply and wastewater services in Brazil, Moldova and Romania, and conclude that it is more economical to deliver water and wastewater services simultaneously in these countries. Abbott and Cohen (2010) also suggest that there might be scope efficiencies between water supply and wastewater services, at least for smaller utilities:

> There is considerable support for the view that economies of scope accrue to businesses that operate both activities jointly, although it appears that it is more strongly the case for small companies as opposed to large ones. (Abbott and Cohen 2010, p. 51)

A number of respondents to this inquiry supported integration of water supply and wastewater utilities where this is not already the case. For example, Wagga Wagga City Council (sub. 54) considered that there are scope economies between water supply and sewerage services and recommended that integrating these services would create greater opportunities for integrated water cycle management (chapter 13).

Wagga Wagga City Council considered that an alliance should be established between the regions' water supply county councils (Riverina and Goldenfields) and the Local Government councils that provide wastewater services, to capitalise on these efficiencies:

> We strongly believe that there is a case for aligning or re-aligning the water supply and the waste water services in our area. They are currently provided through separate organisations … I think there's some fairly significant efficiency advantage that could be gained out of that. Some of the things for us are fairly basic things. We currently bill separately for sewer, for water, both organisations need to do it; under an alliance type of agreement, maybe we could do that collectively, so one bill goes out to the customer for both water and sewer … Obviously multiskilling of staff, running a crew out to Tarcutta or Mangoplah or somewhere to deal with a sewer issue, they could also deal with a water issue while they're there. (trans., pp. 226–7)

In contrast, ACIL Tasman conclude that there are currently few, if any, economies of scope in combining water and wastewater functions. However, ACIL Tasman note:

> The trend towards wastewater being considered increasingly as a potential source of water supply (through indirect, and even direct, potable supply of recycled water) does flag the possibility of increasing scope economies in the future — that suggests some caution in seeking a separation based only on historical use patterns. However, joint ownership of the water and wastewater streams should not be essential to exploiting these growing synergies under institutional arrangements that embody sound procurement planning and, possibly, access arrangements. Care is needed — but not necessarily avoidance. (ACIL Tasman 2007b, p. xii)

Evidence of economies of scope efficiencies between different water supply activities is somewhat stronger, providing some support for vertical integration of water supply functions (at least for smaller utilities). For example:

- Stone and Webster (2004) found some evidence of economies of scope from the vertical integration of water production and distribution functions in England and Wales, but diseconomies of scope from the vertical integration of wastewater collection and treatment/disposal functions.
- Torres and Morrison Paul (2006) cite efficiencies between retail and wholesale functions due to sharing of source water resources, pumps, treatment facilities and transmission lines, and consider that these efficiencies are particularly significant for smaller utilities.
- Hayes (1987) finds significant scope economies for joint production of retail and wholesale water services for small utilities, but these scope efficiencies decline with size.
- Garcia, Moreaux and Reynaud (2004) consider there to be potential gains from vertical integration due to transaction costs and market imperfections, but note that total economies of vertical integration dissipate at 2 300 to 2 400 ML per year, and suggest that strong diseconomies of vertical integration are present at 2 700 ML per year.

In contrast, lessons from the water reform experience in Scotland (appendix C) suggests that there have been benefits from vertically separating the retail function from other elements of the supply chain:

> The separation of retail activities from the rest of the vertically-integrated business has meant that the interests of the retailers and the end-users of water services are more closely aligned. This is because the retailer is responsible for collecting charges from customers and would experience, first hand, the consequences of any adverse movement in prices or a worsening of service. This has led to retailers naturally taking up the position of customer champion. … The legal separation of retail activities has thus created informed buyers of wholesale services. These informed buyers are well placed to represent the priorities of customers and exert pressure on the wholesaler to improve efficiency over the medium to long run, thereby delivery benefits to customers and investors in the industry. (Oxera 2011, p. 5)

In Australia, ACIL Tasman considered the extent of scope economies between retail and wholesale water supply, and determined that these are most significant for small utilities:

> It would appear that economies of scope are derived from economies of 'shared common costs'. Within relatively small utilities, the cost difference between maintaining separate organisations and a single combined entity represents a significant portion of unit cost. By contrast, the large urban water and wastewater utilities have grown far beyond the point at which the cost difference is likely to impact significantly on unit cost. Indeed, it is more likely that other inefficiencies, such as increased bureaucracy, overwhelm any cost saving. (ACIL Tasman 2007b, p. 33)

However, ACIL Tasman also acknowledged:

> The threshold output at which economies of vertical integration dissipate may be imprecise and specific to the economic and environmental circumstances in which the water suppliers are operating. (ACIL Tasman 2007b, p. 33)

Abbott and Cohen (2010) considered that the literature provides no definitive conclusion on scope economies between water supply activities, but noted that where there are scope economies these will reduce as the size of the market increases:

> In relation to the vertical integration of water supply activities, the research indicates that this is efficient for small companies but not necessarily for large ones … In essence, the Australian policy response appears to be crudely aligned with the research in that the larger the urban market, the more likely it is that some form of vertical separation has occurred. (Abbott and Cohen 2010, p. 50)

The VCEC (2008, p. xxv) considered the case for separating the retail and distribution functions in Melbourne, but concluded that it was not efficient (at least not in the short term) due to uncertainty about the potential benefits and costs. Sydney Water commented on the merits of vertically separating the retail function from distribution services:

> We had a look at taking retail out — we try to run it as a least cost operation rather than one that's making margins — but it is such a small part of our operations that we can't see why the British think that taking retail out is going to make it more competitive. (trans., p. 112)

Frontier Economics considered the potential for scope economies between wastewater network services and wastewater treatment and discharge:

> The evidence supports the possibility that independent contractors could undertake the treatment and disposal of wastewater. Stone and Webster found that there were diseconomies of scope between the volume of raw sewage and the number of sewerage connections. This led them to suggest that there may be diseconomies of scope between the collection of waste water and its treatment/disposal … the implication of this finding would be that sewerage services could be more efficiently provided by separating the business functions of treatment and disposal and waste water collection. (Frontier Economics 2004, p. 29)

Although there is no definitive consensus in the literature on scope economies between water supply and wastewater services, a number of studies have found that — at least for small utilities — there are likely to be efficiency benefits associated with joint provision. This is consistent with the views of a number of inquiry participants that explicitly advocated integrated, rather than separate, provision of these services, particularly in regional areas.

The case for vertical integration of various water supply functions tends to depend on the specific functions under consideration, and the location, size and circumstances of the utility. In particular, smaller utilities are considered to be more appropriate candidates for vertical integration than larger utilities.

In this context, the observations made earlier regarding the limited generality of economies of scale studies apply equally to studies of economies of scope — to understand the true magnitude of scope efficiencies between two or more supply chains or supply chain elements, a location-specific (and utility-specific) assessment is required.

Finally, the Commission recognises that economies of scope might also be achieved by integrating different types of utilities. For example, establishing a combined electricity and water utility (a multi-utility) might be more efficient than having two industry-specific utility businesses. Examples of multi-utilities in Australia include Power and Water Corporation (Northern Territory), ActewAGL (ACT), and Essential Energy (Broken Hill).

Few respondents to this inquiry have specifically commented on the merits (or otherwise) of pursuing a multi-utility approach to service provision. However, in 2008 the ERA considered the merits of establishing a multi-utility in regional and remote areas of Western Australia and recommended that a more detailed business case be developed. The Water Corporation has indicated that this work did not support integration of utility functions at this stage:

> We did a joint study with Horizon Power and ourselves to look at whether there was any possibility of getting geographic synergies between their country operations and ours; the opportunity of putting our country water together with their regional power and seeing whether those geographic synergies were there. What turned out on that one was that we thought that you would need 15 to 20 per cent more people to deliver that structure, basically because you had to duplicate all the functions in the water. (trans., p. 317)

The Commission is not opposed to a multi-utility approach to service provision provided the expected benefits of integration outweigh the expected costs. Where there is support for integration of utility functions in regions of Australia, the merits of this should be considered in the context of all reform options.

G.4 Transaction costs

Transaction costs are the costs of providing a good or service through the market rather than having it provided from within the business. Vertical separation may increase total transaction costs, as costs that were previously internalised are revealed:

> Outside the firm, price movements direct production, which is coordinated through a series of exchange transactions on the market. Within the firm, these market transactions are eliminated and in place of the complicated market structure with exchange transactions is substituted the entrepreneur-co-ordinator, who directs production … the operation of a market costs something and by forming an organisation and allowing some authority to direct the resources, certain marketing costs are saved. (Coase 1937, p. 388 and 392)

Transaction costs comprise search and information costs, bargaining and decision costs and policing and enforcement costs — including costs associated with administering relevant legislative, regulatory and licensing requirements. IPART considered the impact on transaction costs as part of its review of Sydney Water:

> Vertical unbundling can involve significant transactions costs, and … there is insufficient information available to guarantee that the cost of such structural reform would be outweighed by the associated benefits at this point in time. (IPART 2005, p. 60)

Ballance and Taylor (2005), in response to a finding made by Stone and Webster that UK water utilities are too large, cautioned:

> While the findings from the study might indicate that a more efficient structure than the one observed at present is possible, the transaction costs associated with changing the current structure should not be ignored and one would want to be a lot more confident of the benefits. (Ballance and Taylor 2005, p. 61)

However, evidence from reform in other industries suggests that these costs may not be prohibitively high. For example, ACIL Tasman found that the transition and transaction costs of structural reform of the electricity industry turned out to be significantly less than first envisaged:

> Economies of vertical integration existed in the electricity industry as vertically-integrated electricity commissions undertook new investment, operated both power stations and the transmission network and scheduled these assets to meet demand. However, it now appears that the transaction costs in separating out this function are not significant. In the case of the National Electricity Market (NEM), they appear to be lower by an order of magnitude than the wholesale price reductions experienced shortly after the NEM commenced. (ACIL Tasman 2007b, p. xiii)

Likewise, ACIL Tasman (2007b) suggests that no major transaction costs have been incurred since reform of the gas sector.

TECHNICAL SUPPLEMENT 1: PARTIAL EQUILIBRIUM MODELS OF THE URBAN WATER SECTORS IN MELBOURNE AND PERTH

1 About this supplement

The Australian Government has asked the Productivity Commission to examine the case for microeconomic reform and to identify pathways to achieving improved resource allocation and efficiency in Australia's urban water sector.

This supplement documents modelling undertaken by the Commission to assist it in evaluating the case for microeconomic reform and to identify priorities for reform. In accordance with the *Productivity Commission Act 1998* (Cwlth), the Commission appointed Professor Alan Woodland (University of New South Wales) and Professor John Freebairn (University of Melbourne) to a reference panel for the purpose of reporting on the modelling. Their reports are included in appendix D. The Commission is also making publicly available the computer files to run the models (box 1.1).

Box 1.1 Modelling files

The computer files required to run the models are available on the Commission's web page for this inquiry report.

The Commission will not provide users of these programs with any support. In addition, users of these programs will require licensed software to be able to run the models, including:

- A compiler for C++ programs (for example, Microsoft Visual Studio 2010).
- GAMS software and an associated large scale, mixed integer programming solver licensed under GAMS, such as GUROBI. (see www.gams.com)

The Commission's modelling approach, together with some preliminary applications for Melbourne and Perth, were discussed at a modelling workshop on 1 February 2011. Participants included the two referees, representatives from academia and water utilities, expert consultants that work in the sector, and government officials.

The preliminary modelling results were included in the draft inquiry report and the preliminary documentation was published as a draft technical supplement.

The terms of reference imply that the overarching objective for policy development is to improve the economic efficiency of the sector. In this context, a component of the case for microeconomic reform is evidence about:

- the economic costs (which would now be irreversible (sunk) and cannot be undone) that have arisen if resource misallocation has occurred in the past
- the economic benefits that would arise if resource allocation could be improved in the future (which takes as given the sunk costs of past decisions).

The urban water sector includes potable water supply in large capital cities and small regional communities, as well as the management of wastewater and stormwater. In the context of the inquiry, the scope for efficiency improvement across all these systems is important.

However, the modelling discussed here is limited to assessing efficiency and resource allocation in the water system for two case-study capital cities, Melbourne and Perth. The focus of the modelling is on consumptive demands for water (and their supply), and does not include the treatment and disposal of wastewater and stormwater.

Some aspects of the terms of reference relating to structural and institutional reforms could also be investigated using the model developed here, but the economic impact would need to be specified exogenously as a separate exercise. For example, if a productivity improvement arose from structural and institutional reform that generated cost savings in the supply chain (as considered in Cave 2009), then these cost savings would need to be determined outside the model. The model could then be solved with and without these cost savings to investigate their impact. This has not been pursued for this inquiry.

Similarly, institutional and regulatory arrangements required to achieve the simulated outcomes in the real world (in particular, scarcity based pricing) are outside the scope of the modelling. However, the model does provide a strong theoretical basis to define in economic terms what scarcity based pricing might mean as well as empirical insights into the economic outcomes.

The framework used for the model is based on mathematical programming, which enables the use of commercially available, computationally efficient, computer software for model building, solution and post-simulation calculations of large scale models. This facilitates a greater focus on:

- alternative model formulations and specifications
- calibration
- validation

- error checking
- testing.

Although other related frameworks could have been used, such as stochastic dynamic programming, they would have required more time and resources developing computer algorithms from the ground up to solve each of the numerous model formulations.

It also needs to be borne in mind that all models are a simplification of the real world. The insights and interpretation of policy matters based on this modelling should take into account the limitations of the modelling.

In addition, no single model can provide insights into all urban water issues, and the approach presented here complements other models used to undertake analysis of urban water systems.

Notwithstanding these caveats, the modelling framework used for this inquiry, and its applications to the relevant policy issues, has provided useful insights into the issues identified in the inquiry that were not directly available from the results of other models that have been published and documented.

2 Modelling framework

The choice of the modelling framework has been driven, to a large extent, by its suitability to provide insights into, and estimates of, the impacts on net social welfare (discussed below) of policies that are a central focus of the inquiry.

The types of policies of interest include:

- policy bans prohibiting certain augmentations of water supply
- mandated sources of augmentation, such as desalination
- smoothed pricing over time
- restrictions on end-use demand for water.

A fit-for-purpose modelling framework would have the following attributes:

- a capability to simulate economic equilibria for an urban water system, which includes spatial, temporal and risk (rainfall) dimensions
- a spatial and temporal representation of consumer demand, utility supply and equilibrium prices
- a time horizon sufficient to capture efficient inter-temporal consumption and pricing, as well as investment in water supply and the operation of supplies
- capacity to model a variety of pre-existing and new sources of water supply such as dams, desalination, recycling, rural–urban trade and aquifers, including engineering and environmental factors that constrain their operation
- a stochastic representation of risk arising from the variability of inflows to dams, and the corresponding impacts on investment risk and consumer prices
- scope to simulate the impacts on economic equilibria of policies that are a central focus of the inquiry.

The remainder of this chapter outlines the reasons for development of a model based on stochastic mathematical programming.

2.1 The underlying core (deterministic) framework

In developing a stochastic programming model, the first step is to identify the underlying core deterministic model, which is solved in a mathematical programming framework. In this study, the core model is based on the spatial and temporal price and allocation models developed by: Enke (1951); Samuelson (1952); Yaron, Plesner and Heady (1965); and Takayama and Judge (1971).

There is a large body of literature describing the application of this framework to study the economic consequences of policy and resource allocation issues in fields such as electricity, natural gas, agriculture, and the environment. Examples include: Heady and Srivastava (1975); Meister, Chen and Heady (1978); Hazell and Norton (1986); Labys, Takayama and Uri (1989); Heady and Vocke (1992).

Price endogenous mathematical programming is based on long established and accepted microeconomic theory. The base framework computes an economically efficient market equilibrium, as documented in: Takayama and Judge (1971); McCarl and Spreen (1980); and Hazell and Norton (1986).

It does this by maximising net social welfare (net social payoff), which is equivalent to:

- the sum of Marshallian consumer plus producer surplus
- gross consumer benefit less total cost of supply, including any imputed economic rents from resource or policy constraints (Pressman 1970)
- consumer surplus plus total revenue less total cost of supply (Williamson 1966) or
- setting consumption to equate marginal social benefit with marginal social cost.

McCarl and Spreen (1980) note that price endogenous mathematical programming has proven to be a particularly useful tool to simulate the effect of new policies upon a sector.

The modelling framework is rich in terms of simulating the effect of policies through the specification of new production activities, new constraints and changes to the right-hand-side resource constraints, objective function coefficients and technical coefficients within the constraints (McCarl and Spreen 1980).

The approach documented in this study formally encapsulates the theory for efficient pricing embedded in the literature discussing urban water policy — such as

Ng (1987), Mayo (1989), and Sibly (2006a) — using an explicit inter-temporal (dynamic) mathematical programming framework.

2.2 Extension of the core model to stochastic mathematical programming

Urban water demand and supply is complicated by the probabilistic nature of future rainfall and inflows to dams. The Commission has adopted a state contingent approach to incorporating variability of inflows into dams. The case for adopting the state contingent approach is based on the idea that risk can be represented by a set of possible states of nature (in this case low, medium and high inflows). The uncertainty of inflows can be represented by a vector of state contingent right-hand-side terms (low inflow, medium inflow and high inflow). In this situation, risk is represented as a multi-output technology (Quiggin and Chambers 2006). This means that the treatment of risk is analogous to:

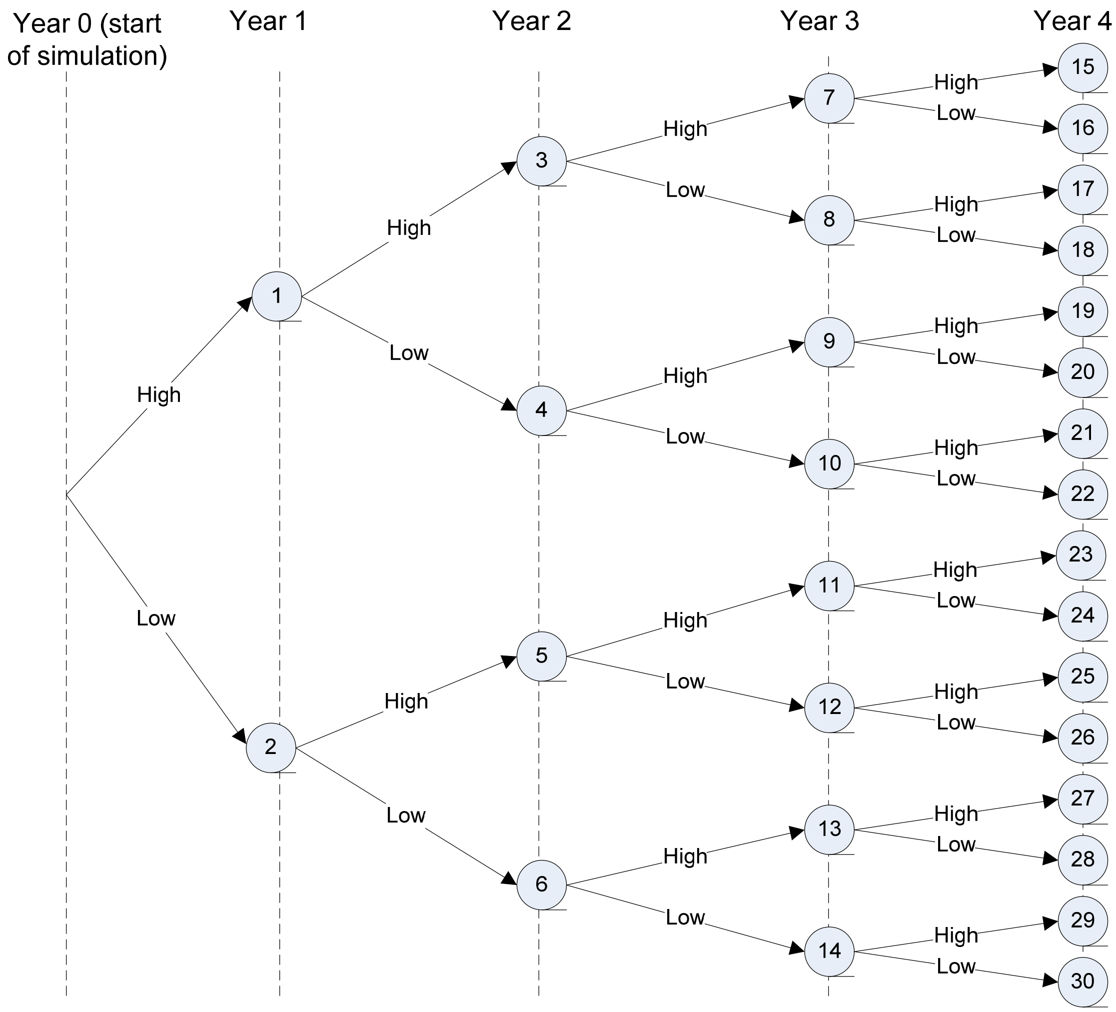
- production technologies, such as Leontief fixed coefficients, which are commonly applied in computable general equilibrium models and input/output models (Chambers and Quiggin 2000)
- the theory used in the analysis of peak-load pricing, where the production capacity of a facility is not substitutable across time (Steiner 1957; Williamson 1966; and Littlechild 1970) (for example, if a 150 GL desalination plant is not used this year, the unused capacity cannot be added to next year to produce 300 GL)
- production of public goods exhibiting non-rivalry in consumption.

The state contingent approach is just a logical extension (albeit complicated in practice) of the economic theory already in the core price endogenous mathematical programming frameworks (Lane and Littlechild 1976 and 1980), a point that has been emphasised more generally by Quiggin and Chambers (2006). This extends the core mathematical programming framework to include risk, an important consideration when modelling investment decision making with stochastic inflows.

Although risk is explicitly incorporated into the state contingent model, it is a risk-neutral framework. In order to use the area under the demand function as a cardinal measure of welfare, it is necessary to assume that the marginal utility of income is constant. It is common practice to assume that the marginal utility of income is unity, so that one dollar of income or expenditure is equal to one unit of utility. This requirement does not allow risk-averse behaviour to be incorporated because risk-averse behaviour requires the marginal value of income to vary.

Using a state contingent approach results in a scenario tree for inflows over time, illustrated in figure 2.1. A state contingent model includes variables at each node in the scenario tree (for a given state of nature), which are in turn affected by the nodes that preceded them. In an urban water system, the consumption, pricing and investment decisions at a particular node will not only be a function of present inflow levels, but also past storage and investment decisions. The state contingent nature means that nodes are only directly impacted by decisions that come before them in the scenario tree. For example, if a desalination plant was built in node 1 (figure 2.1), it could be relied on to supply water in nodes 3 and 4, but not in nodes 5 and 6.

Figure 2.1 **Illustrative scenario tree for only two states of nature over four years[a]**



[a] The full models contain 3 states of nature (high, medium and low) over 10 time periods.

Embedding a state contingent framework within a mathematical programming framework results in a stochastic mathematical programming model. These types of model are well documented in the operations research literature (for example, Birge and Louveaux 1997). The two frameworks are combined through the use of expected values: the outcome of the core mathematical programming model is replaced by the expected value resulting from the weighting of all outcomes in the scenario tree.

The incorporation of expected values results in a deterministic equivalent formulation of the model (Kall and Wallace 1994), which can be expressed as a single linear programming problem. Linear programs can be solved using commercially available, computationally efficient, computer software, without the need to design specific solution algorithms for each of the numerous simulations. This allows for greater freedom in conceptualising and designing the model, and including a range of constraints important for gaining insight into the policies of interest (such as inter-temporal engineering constraints, price smoothing over time, and inter-temporal water restriction triggers).

On the other hand, the large size of the deterministic equivalent linear programming models and computational limits mean that the number of states of nature and length of the planning horizon are necessarily limited.

An alternative to stochastic mathematical programming is stochastic dynamic programming (box 2.1). Stochastic dynamic programming has been applied to a range of policy areas in the past, in particular urban water (for example, Hughes, Hafi and Goesch 2009; and Grafton and Ward 2008a). However, as explained in box 2.1, mathematical programming was chosen based on practical considerations given the resources (time and cost) available to the inquiry.

Figure 2.2 describes how multistage stochastic programming models compare to alternative frameworks.

Box 2.1 Stochastic dynamic programming as an alternative to multi-stage stochastic programming

The linear programming model used in this study considers all variables, constraints and stages (multi-stage stochastic scenario tree) simultaneously as one large model. There are alternative approaches to solving the same problem, based on breaking the large problem into a series of recursive, smaller problems. One of these is stochastic dynamic programming.

Stochastic dynamic programming solves models by optimising the level of a specified function for each decision point in the decision tree (Wagner 1974). Example functions include the cost of operating a supply system, or the net social welfare in a market.

In the case of the model used in this study, the key to applying stochastic dynamic programming is being able to formulate (or reformulate) the original linear programming model (by creating a decision tree) so that the equivalent formulation has the pre-requisite properties to apply the Principle of Optimality, which states:

> An optimal policy [solution] has the property that, whatever the initial state and decision [that is, control] are, the remaining decisions must constitute an optimal policy [solution] with regard to the state resulting from the first decision. (Intriligator 1971, p. 327)

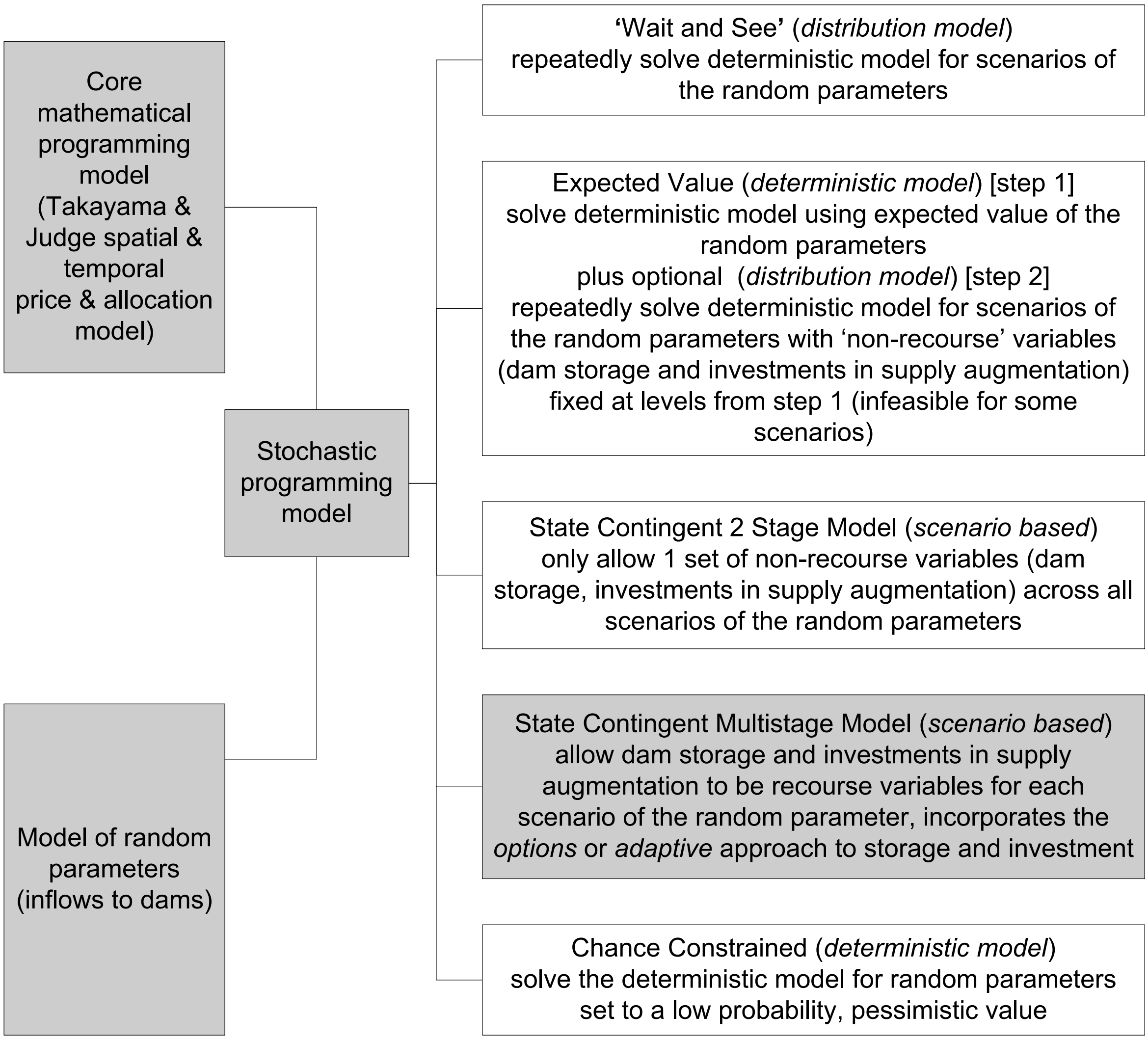
The decision-making tree for a stochastic dynamic programming model is comprised of all the decisions that a policy-maker or investor can control. These 'state variables' directly influence the function that is optimised at each decision point, thereby optimising the path taken through the decision-making tree (Kall and Wallace 1994). The size of the tree is dependent on a range of variables: the number of investment options; the capacity of each investment constructed at a given decision point; an investment's utilisation at each point in the tree; the level of water in storage; and environmental constraints limiting the utilisation of certain supply sources.

The application of stochastic dynamic programming to the model used in this study would require the nested discretisation of many of the continuous variables (such as storages) in the linear programming model as state variables, in order for the Principle of Optimality to apply. For the existing linear programming model, this state space would be large. The process of defining the appropriate state space (decision tree) would need to be redefined for the various policy formulations of the models used.

There is no single efficient computer programming software to handle all formulations of dynamic programming models, notwithstanding that the dynamic programming recursion process is not particularly difficult to write using computer programming languages. Furthermore, calculating an efficient, wholesale price for a model of the same form as the one used in this study would be difficult, requiring post-optimisation calculation techniques (AEMO 2010c).

When the number of state variables are limited, stochastic dynamic programming is a viable approach to modelling water systems. By limiting the number, order and size of investments as well as discretising storages, stochastic dynamic programming models can be used to simulate long planning horizons (for example Hughes, Hafi and Goesch 2009; and Grafton and Ward 2008a).

Figure 2.2 **Comparing stochastic programming frameworks**[a]



a Shaded areas identify the frameworks that form the basis of the Commissions modelling

Source: Based on combining material from figures 2 and 5 published in Valente, Mitra, Poojari and Kyriakis (2001).

A stochastic mathematical programming model can be formulated as either a two-stage or a multi-stage problem (for summaries, see Kall and Wallace 1994, and Birge and Loveaux 1997). Both allow for some decisions to be made based on expectations about future inflow variability (for example, decisions about dam storage and new investment in supply capacity, which are known as state variables) while other recourse decisions (for example, about the quantity of water delivered) can be made after observing inflow outcomes, and are conditioned by the previous decisions about the state variables.

A two-stage stochastic programming approach calculates the optimal investment plan across all future inflow scenarios. Multi-stage stochastic programming is differentiated from two-stage stochastic programming in that it allows supply augmentation decisions (state variables) to be made over time as inflows (the state of the stochastic parameter) are revealed (Birge and Loveaux 1997). All of the investment decisions in the planning period do not need to be collectively committed to in advance. Rather, investment decisions are made over time as the sequence of inflows, and hence water scarcity, is revealed. It encapsulates the real options or adaptive management approach referred to in discussions of water policy supply augmentation (WSAA 2008a). This approach is discussed in greater detail in chapter 5.

As outlined above, the core mathematical programming model forms the basis of the model. Stochastic inflows are incorporated using a state-contingent approach, resulting in a stochastic mathematical programming model. Given the stochastic mathematical programming framework, the model is formulated as a multi-stage stochastic problem.

For the modelling for this study the multistage stochastic framework is used because it does not require unique solution algorithms to be developed to solve the multitude of models. The main objective of this work is to acquire insights in to the effects of policies commonly applied in the urban water sector in Australia. For this reason, the model needs to be able to deal with complex policy simulations in a simple and transparent manner.

A basic introduction to the partial equilibrium modelling framework and concepts, and their stochastic counterparts using a simplified model is presented in appendix A. Appendix B contains the mathematics for the full model used in this supplement.

3 Model calibration

The calibration of the model to the Melbourne and Perth urban water systems is described in this chapter. There are two separate models, one for each city, each of which is built to reflect the specific characteristics of water supply in that city and the policy issues that apply.

In addition, two versions of the model are created for each city: a historic model and a present model. The two versions are used to examine:

- the economic costs of resource misallocation in the past
- the economic benefits of improved resource allocation in the future.

For Melbourne and Perth, the 'present' version of the model is calibrated to represent the urban water systems at the start of 2011, taking as given existing supply capacity, including committed supply augmentations that are now irreversible. For Melbourne, the 'historic' version is calibrated to represent the system before the construction of the Wonthaggi desalination plant and the Sugarloaf pipeline. For Perth, the 'historic' version is calibrated to represent the system prior to the construction of the Southern Seawater desalination plant.

The mathematical specification of the model is provided in appendix B.

3.1 Model size and computational limits

The number of nodes in the inflow scenario tree increases with both the number of inflow states and the number of time periods in the model (table 3.1).

The variables in the model are specified for each node in the scenario tree (for example, quantity demanded, storage in dams, production from desalination plants). Over a ten period time horizon, the model contains approximately 6.2 million variables and 1.3 million constraints, although this will vary for different models and simulations. This was determined to be the largest model solvable given existing linear programming software and computer hardware.

Two versions of a ten period model are solved: a short-run simulation with ten single year time periods, and a longer-run simulation with ten biennial time periods (each time period represents two years). Both versions of the model use a discount rate of 6 per cent. Aggregate time periods are used to examine investment decisions over a longer timeframe, while staying within the practical computational limits. This approach of aggregating time periods has been documented previously (for example, Kolstad 1989 and Uri 1989).

Table 3.1 **Number of nodes and scenarios as the number of time periods increase, for three contingent states in each year**

Year	*Nodes in the scenario tree*	*Scenarios in the scenario tree*
1	3	3
2	12	9
3	39	27
4	120	81
5	363	243
6	1 092	729
7	3 279	2 187
8	9 840	6 561
9	29 523	19 683
10	88 572	59 049

The remaining sections of this chapter cover the calibration of the Melbourne and Perth models. Section 3.2 discusses inflows and scenarios, section 3.3 outlines the demand for potable water and section 3.4 provides detail on the water supply technologies modelled.

3.2 Inflows and scenarios

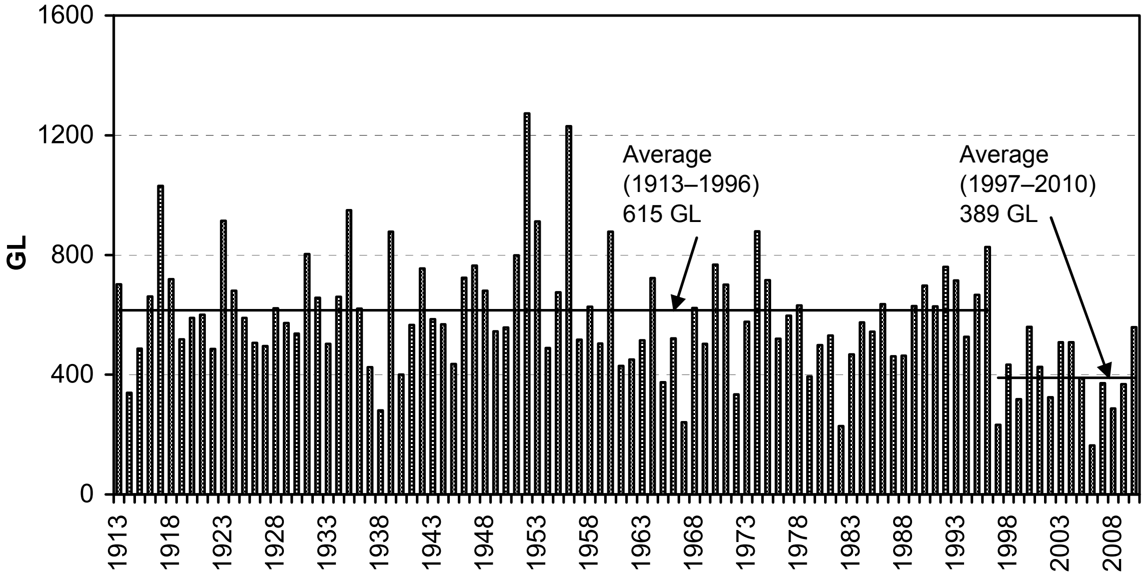
Records of inflows into storages in Melbourne and Perth display variability over time (figures 3.1 and 3.2). To create the 59 049 inflow scenarios for a ten period model, a three point discrete distribution of inflows is estimated.

In order to represent the variability in inflows in the model, there are several characteristics of inflows that need to be considered.

First, inflows vary from year to year and can be extremely high or low. For example, in 2010, Perth received 12 GL of water into storages which is very low relative to the average for the last 30 years.

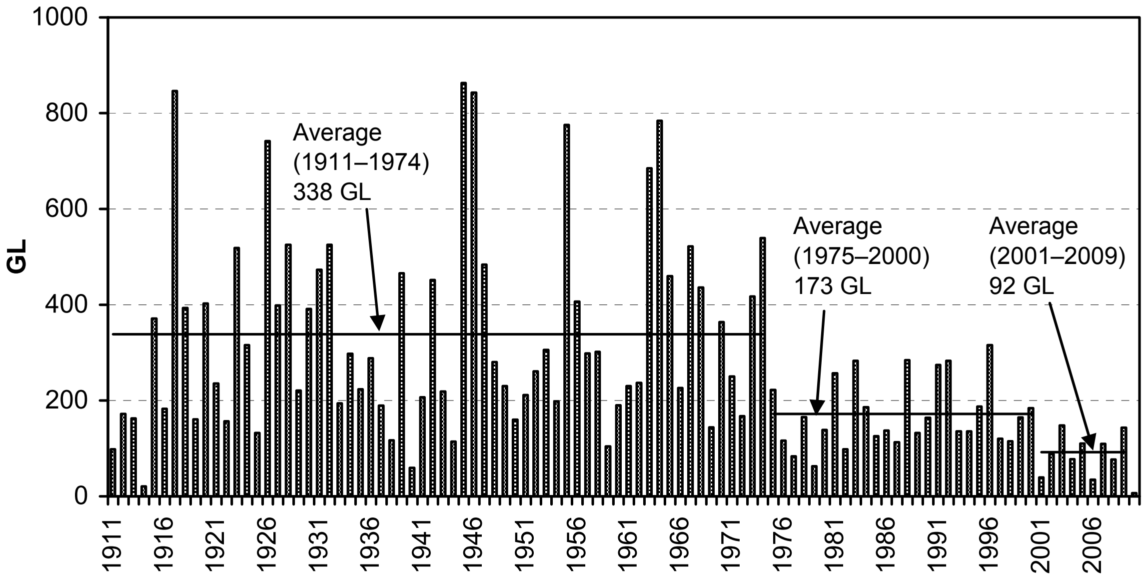
Second, average inflows might be declining over time. Inflows into the Perth system undertook a downward step in the 1970s (figure 3.2) and have been very low in recent years. There also appears to be a downward trend over time for inflows into the Melbourne system (figure 3.1).

Figure 3.1 **Annual inflows for Melbourne, 1913 to 2010**



Source: Melbourne Water (2011b).

Figure 3.2 **Annual inflows for Perth, 1911 to 2010**



Source: Water Corporation (2011c).

Third, there can be sequences of wet and sequences of dry years. Planning and operation of water systems needs to be cognisant that there can be several dry years and several wet years in a row. Examining the historical data for five-year cumulative inflows shows, however, that on average, extreme *scenarios* over long periods of time are rare. In the scenario approach used in this modelling, the distribution of cumulative inflows are particularly important.

Finally, inflows might be correlated over time (McMahon et al. 2007).

Consideration of all of these characteristics has influenced the estimation of the stochastic three point discrete distributions that are used for the Melbourne and Perth models.

Calibrating the discrete probability distribution used to generate scenarios

There is 100 years of inflow data for Melbourne and Perth (Melbourne data are for 1913 to 2008 and Perth data are for 1911 to 2010) (figures 3.1 and 3.2). Although 100 years of data is available, it is appropriate to use only a recent subset of the data, given that inflows appear to be declining over time (for example, inflows into the Perth system show a break in the series in the 1970s).

For Melbourne, the observations for the last 30 years were chosen as the relevant subset upon which to base the distribution used in the model. For this data, there is no statistically significant (at the five per cent level) evidence of correlation between inflow events or drying over time.[1]

For Perth, the Water Corporation provided its own generated inflow data consisting of 1000 scenarios, each over 102 years. These data are used to calibrate the three point discrete distribution for Perth. No serial correlation was evident in the Water Corporation data.

Fitting a three point discrete distribution

The three point inflow distribution should satisfactorily represent both the inflow data for one year and the cumulative or mean inflow scenarios over a number of years. In order to achieve this, a four step process is used to estimate the three point discrete inflow distributions from the appropriate data:

1. estimate the first three moments from the inflow data
2. fit a gamma distribution to the data (only done for Melbourne)
3. generate a five year cumulative inflow distribution

[1] The Durbin-Watson statistic is used to test for serial correlation of annual inflows.

4. generate the three point distribution to match the moments from the data and the tails of the five year distribution.

The first step to estimating the three point distributions that are used in the model is to estimate the first three moments in the selected data set: mean, variance and skewness.

The second step (required only for the Melbourne model) is to fit a gamma distribution to the data. This is done because there are not enough observations to construct a five year cumulative distribution (step three). The fitted continuous distribution is a close fit to the original data according to the first three moments. A gamma distribution is chosen because gamma distributions do not have negative values and the skewness of the function is appropriate for the inflow data — that is, it is skewed towards the left, so there is more likelihood of below average inflows than above average inflows.

Step two is not required for the Perth data because the generated distribution of inflows used contains 102 000 observations.

The third step is to generate a five year cumulative distribution. It is important that the model captures the variability in inflows that accumulate over several years, as the water system comes under stress when there are consecutive extreme events. These successive inflows have more effect on investment decisions in the model because supply has to be sufficient to meet demand.

For Melbourne, a five year cumulative distribution is estimated from the one year gamma distribution. This is done by randomly sampling inflow events from the gamma distribution using a Monte Carlo simulation. Each successive five events are averaged to form one observation in the cumulative five year distribution. For Perth, groups of five consecutive data points are selected from the data and averaged to form one observation in the cumulative distribution.

The cumulative distribution has the same mean as the original gamma distribution. However, the variances are smaller. This is because the extreme high and low events in the annual average out over a five year period.

The tails on the cumulative distributions represent extremely unlikely sequences of inflow events. The highest and lowest one per cent of observations are, on average, likely to occur once in every 100 years. These inflow events are considered to be unlikely enough to reflect a reasonably extreme scenario of inflows over a five year period. Therefore, they are chosen as the levels of the 'high' and 'low' inflow levels in the final three point distributions used in the modelling.

The final step in the process is to enter the moments and the 'high' and 'low' inflow values into an optimisation model (an approach similar to that used in Hoyland and Wallace 2001). The optimisation model chooses the 'medium' inflow level and the three corresponding probabilities for each of the inflow levels so that the resulting three point distribution has the mean, variance and skewness in the original data.

Table 3.2 contains the levels and probabilities that correspond to the final three point distributions applied in the models. The three point distribution cannot account for annual inflows that are outside the range captured by the three discrete points on an annual basis. For example, the scenario tree does not account for the possibility of Perth receiving a year of very low inflows of less than the low point in the distribution (54.7 GL) for any given year.

However, the scenario tree does capture extreme cumulative inflow events. At the extremes, the low inflow and high inflow 10 year scenarios generated from these distributions are more extreme than any historical sequence (with the probability of these scenarios occurring being less than one in 50 000) (figure 3.3).

Further, sensitivity analysis was undertaken in order to account for the uncertainty with respect to inflow parameters and to take account of the possibility of higher or lower inflow levels. The impact of a 30 per cent change in the mean level of inflow was examined.

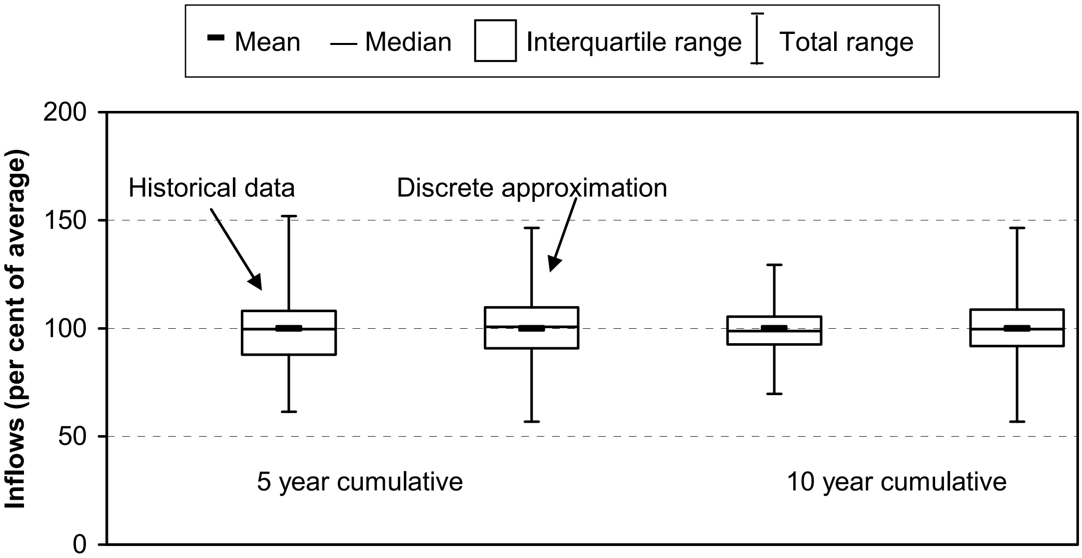
Table 3.2 **Three point discrete distribution of annual inflows**

	Melbourne		*Perth*	
	GL	Probability	GL	Probability
Low inflow	221.994	0.250	54.682	0.240
Medium inflow	377.104	0.555	154.905	0.557
High inflow	571.469	0.196	265.580	0.203
	Melbourne statistics		*Perth statistics*	
Mean	376.391		153.319	
Variance	13 396.381		4894.737	
Skewness	0.344		0.166	

Source: Productivity Commission estimates.

Figure 3.3 **Box plot comparison of approximating inflows over 5 and 10 years for Melbourne**

Historical data compared with discrete approximation



Source: Productivity Commission estimates.

Inflows in the 20 year model

In the 20 year model, each time period represents two years. It is therefore necessary to calibrate a three point discrete inflow distribution to inflows over a two year period. The four step process outlined above is repeated, with the 'high' and 'low' inflow values taken from a ten year cumulative inflow distribution. Table 3.3 contains the levels and probabilities that correspond to the final three point distributions applied in the 20 year applications.

Table 3.3 **Three point stochastic discrete distribution of two year cumulative inflows**[a]

	Melbourne		*Perth*	
	GL	Probability	GL	Probability
Low inflow	255.149	0.2277	81.117	0.210
Medium inflow	374.559	0.5755	155.280	0.597
High inflow	526.134	0.1968	232.773	0.193
	Melbourne statistics		*Perth statistics*	
Mean	377.199		154.662	
Variance	7761.223		2303.646	
Skewness	0.345		0.076	

[a] The inflow levels represent the average inflows over a two year period.

Source: Productivity Commission estimates.

3.3 Demand

This section describes the consumer demand characteristics used for the Melbourne and Perth models. Table 3.4 provides a summary of the data used, and the sensitivity analysis undertaken.

Table 3.4 **Consumer demand characteristics for Melbourne and Perth models**

Parameter	*Units*	*Melbourne central estimate*	*Perth central estimate*	*Sensitivity*
Annual water usage				
Total consumption historic model	GL	390	276	± 10 per cent
Price historic model	$/kL	1.30	0.88	..
Total consumption present model	GL	426	291	± 10 per cent
Price present model	$/kL	1.50	1.237	..
Demand shares of aggregate consumption by class				
Outdoor	%	11	31.5	..
Indoor household	%	59	38.5	..
Commercial	%	30	30	..
Price elasticity of demand by class				
Outdoor		- 0.30	- 0.30	double/half
Indoor household		- 0.10	- 0.10	double/half
Commercial		- 0.30	- 0.30	double/half
Annual growth rate of consumption				
	%	1.6	2.1	±0.5

.. Not applicable.

Quantity and price

For Melbourne, the unrestricted aggregate demand[2] in the 'present' model is 426 GL per annum (Melbourne Water, pers. comm., 19 January 2011) at a (marginal) price of $1.50 per kilolitre (ESC 2010b) (table 3.4). For the historic model, the unrestricted aggregate demand is 390 GL.

For Perth, aggregated demand in the 'present' model is 291 GL per annum at a price of $1.237 per kilolitre.[3] This level of demand assumes current permanent efficiency measures of two day a week sprinkler rosters and winter sprinkler bans. In the

2 Aggregate demand in the absence of water restrictions

3 Aggregate consumption is based on (forecast) total annual demand in 2010 of 285 GL (Water Corporation 2009b) with growth of 2.1 per cent per annum. The price is equal to the second pricing block tier for January to June 2011 (up to 350 kL).

historic model, aggregated demand is 276 GL per annum (Water Corporation 2008b) at a price of $0.88 per kilolitre (based on ERA 2008b).

Categories of demand

There are three types of demand specified in the model. In Melbourne, the three categories of demand are household indoor, commercial indoor, and total outdoor. More than half of aggregate demand is assumed to be for indoor use by residential customers, with the remainder split between outdoor use and indoor commercial use. The disaggregation of aggregate demand allows water restrictions to be imposed selectively on outdoor use.

In Perth, the demand categories are defined as household indoor, household outdoor, and commercial. Perth aggregate demand is disaggregated differently to Melbourne due to the availability of data. Seventy per cent of total demand is assumed to be for household use, of which 55 per cent is used indoors and 45 per cent is used outdoors (based on Water Corporation 2010). The remaining 30 per cent is used for commercial purposes (table 3.4).

The impact of modelled policies on net social welfare is likely to be underestimated because the diverse preferences of consumers are underrepresented in the model, which only has three categories of demand.

Price elasticity of demand

Consumers are likely to adjust their demand for water in response to changes in prices. However, accurate estimation of the magnitude of these responses is difficult. The relationship between demand and price (known as price elasticity of demand) has been chosen based on a large number of studies, for which the estimates of price elasticity vary widely (see for example Worthington and Hoffman 2008). Estimating price elasticities using historical data is also challenging, due partly to limited variation in prices over time and because of the impact of non-price demand management measures, which include restrictions, education campaigns and moral suasion. The timing of these measures is often correlated with price changes so that disentangling the impact of price and these other factors on demand is difficult. Estimating price elasticities is further complicated in some jurisdictions by the multi-tiered pricing structure of inclining block tariffs. Alternative methods include surveys to elicit water use plans under different prices, but these suffer from drawbacks too — in particular, stated preferences have often been found to contradict actual (revealed) preferences (Maler and Vincent 2005).

Further complicating matters, demand is likely to be more price responsive over several years than in the short run. Over longer periods of time, consumers are able to modify their behaviour, install water saving technologies and change to less water-intensive gardens in response to water shortages and higher water prices. A study by Abrams et al. (2011) found it takes households on average one year to adjust from their immediate to long-term position. Incorporating a time-varying elasticity (both short-run and long-run) into modelling requires a dynamic representation of demand (for example, along the lines of the partial adjustment model in Phlips 1974). This cannot be easily incorporated into the Takayama and Judge (1971) framework as welfare needs to be separable across time periods and this separability is violated under dynamic representation of demand.

In this model, an elasticity estimate is used for each of the three demands, which should be interpreted as a 'medium term' elasticity somewhere between the immediate response and the eventual, long-term response to prices. Since the model is annual or biannual, this assumption was thought reasonable. The elasticity of household indoor demand is assumed to be -0.1, and the outdoor and commercial elasticities are both assumed to be -0.3 (table 3.4).

To incorporate the wide range of views regarding price elasticities of demand, sensitivity analyses are undertaken for a range of elasticity estimates. The more elastic end of the range reflects the academic literature (as summarised in Worthington and Hoffman 2008) and the less elastic end is based on industry views (for example, as reported in PWC 2009 and Abrams et al. 2011). The central estimate for household elasticity of demand is slightly lower than that used by Grafton and Ward (2008a) and Hughes et al. (2008) for similar modelling work. Outdoor and commercial uses of water are assumed to be more elastic than indoor household use.

Calibration of initial demand

The demand functions in the model are assumed to be linear and downward sloping. The demand functions are calibrated to the elasticity figures using an arc elasticity over a representative potential price range ($1 to $5 per kilolitre for Melbourne and $0.50 to $5 per kilolitre for Perth) (box 3.1).

Negative elasticities of demand imply that the net social welfare objective function of the model — which includes the area under the linear demand curve — is non-linear. Finding the solution to a non-linear programming model is computationally difficult, and not practical for a model of this size. It is possible to solve larger linear programming models. For this reason, the model contains linearised demand functions (with between 20 and 50 linear segments). For a description of the mechanics behind linearisation, see box 3.2.

Box 3.1 **Calibrating demand using an arc elasticity**

The degree of impact that a change in price has on demand is measured by the price elasticity of demand — the percentage change in the quantity demanded resulting from a one per cent change in price. The arc elasticity is the average elasticity between two points on a demand curve. It is calculated based on the average of two values of price and quantity (rather than for a single point). The arc elasticity is defined in equation 1:

$$\varepsilon = \frac{(Q_2 - Q_1)}{(P_2 - P_1)} \cdot \frac{(P_2 + P_1)}{(Q_2 + Q_1)} \qquad (1)$$

With a linear demand function of the form $P = a + bQ$,

$$a = \tfrac{1}{2}(P_2 + P_1) - \tfrac{1}{\varepsilon} \cdot \tfrac{1}{2}(P_2 + P_1) \qquad (2)$$

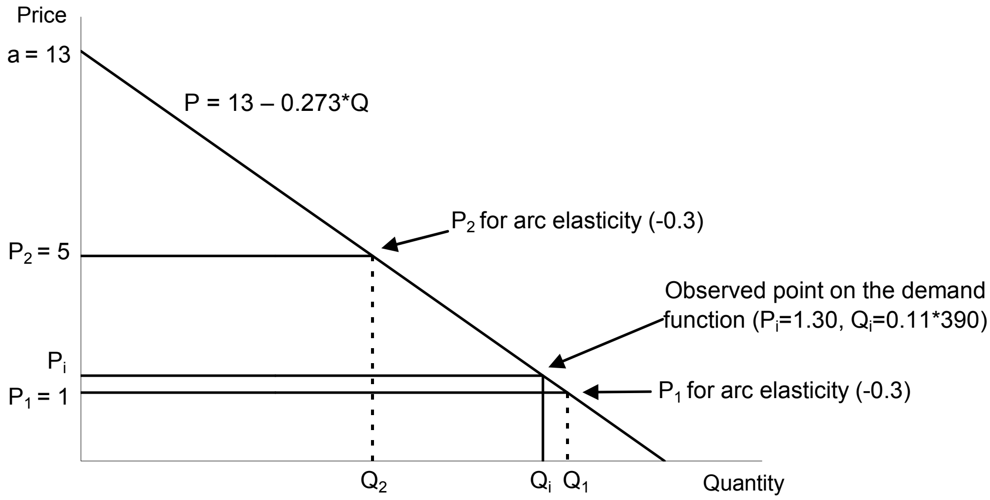
$$b = \frac{1}{\varepsilon} \cdot \frac{(P_2 + P_1)}{(Q_2 + Q_1)} \qquad (3)$$

$$P_i = a + bQ_i \qquad (4)$$

Example: Melbourne outdoor demand

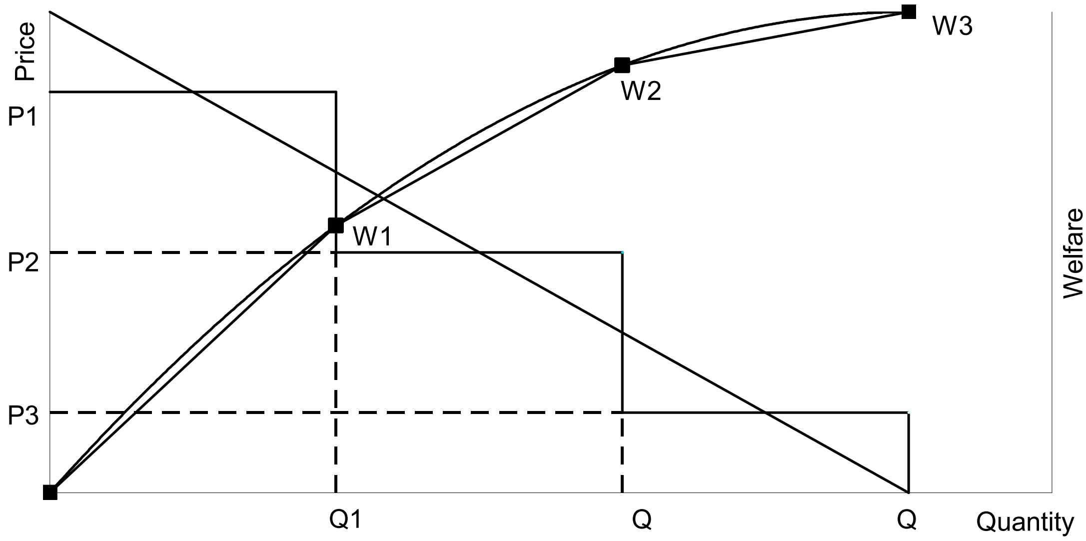
In this calibration, assume $P_1 = 1$, $P_2 = 5$ and $\varepsilon = -0.3$, but Q_1 and Q_2 are unknown. Also assume that one point on the demand function is known ($P_i = 1.30$, $Q_i = 0.11 \times 390$). The demand function is calibrated as follows:

- step 1: solve for the intercept using equation 2 (a = 13)
- step 2: solve for slope coefficient using equation 4 (b = –0.273).



Box 3.2 **Linearising demand**

The objective function term with respect to quantity demanded is gross consumer welfare, defined as the integral (area) under the demand function. For a linear demand function, $P = a - bQ$, the gross consumer welfare is $W = aQ - 0.5bQ^2$. Piecewise linearisation of the gross welfare function is used to convert the non-linear programming problem to a linear programming approximation, as set out in the stylised illustration below.



Variable / Row	D_1	D_2	D_3	Quantity supplied	Right hand side
Objective function	W_1	W_2	W_3	-cost	Max NSW
Demand–supply balance	Q_1	Q_2	Q_3	-1	≤ 0
Convex demand	1	1	1	0	≤ 1

The non-linear welfare function is approximated using three piecewise linear segments (defined by demand activity variables D_1, D_2 and D_3), that represent demand quantities Q_1, Q_2, Q_3 respectively and welfare levels W_1, W_2 and W_3 respectively. The demand function is therefore a stepwise approximation of the original linear demand function. As the quantities associated with each linear segment represents the total level of water consumed (and not incremental additions), a 'convexity' constraint is added to ensure that the sum of the linear segments does not exceed unity.

As the welfare function is convex, at the optimal solution the quantity demanded will correspond to a corner point (one of the demand activities equals one) or a linear combination of two adjacent points. The Lagrangean variable (or shadow price) on the convex demand constraint is consumer surplus, and the Lagrangean variable on the demand–supply balance constraint is the unit (demand) price of water.

Sources: Duloy and Norton (1975); Hazell and Norton (1986).

Growth in demand

Consumption is projected to grow over time with population growth but the price elasticity of demand is assumed to be constant.

Growth in consumption is based on ABS population growth projections for the respective cities (ABS 2008). Consumption is projected to grow at 1.6 per cent per annum for Melbourne and 2.1 per cent per annum for Perth.

Growth in consumption is modelled by rotating the linear demand function upwards about the intercept (box 3.3). The idea is that for any given price held constant over time:

- there is an increase in the quantity demanded (from growth)
- the price elasticity of demand is held constant as demand grows over time.

Box 3.3 **Growth and constant elasticity for a linear demand function**

The slope of the linear demand function is related over time, such that:

$$b_t = \frac{Q_t}{Q_{t-1}}.b_{t-1}$$

$$b_t = \frac{(1+growth)Q_{t-1}}{Q_{t-1}}.b_{t-1}$$

$$b_t = (1+growth).b_{t-1}$$

Source: Duloy and Norton 1975.

Impact of water restrictions on demand

Water restrictions apply to outdoor demand only in the model. The impact of water restrictions in curtailing outdoor demand is calibrated to level 3a restrictions in Melbourne and a total sprinkler ban in Perth (table 3.5). For Perth, a total sprinkler ban is assumed to be invoked when dam storages fall below 25 per cent.[4] When invoked, outdoor demand for water is restricted to 67 GL (table 3.5).[5]

4 There are no published trigger levels for water restrictions in Perth. The Western Australian Government has subsequently removed sprinkler bans with dams at much lower levels.

5 Restricted demand is based on a reduction of 25 GL per year (Water Corporation 2008c).

Table 3.5 **Impact of water restrictions**

Parameter	*Units*	*Melbourne*	*Perth*
Restricted outdoor demand	GL	33	67
Storage level trigger	Per cent of storage capacity	35	25

3.4 Supply technologies

Each new supply option modelled requires data on three categories of cost: construction cost; annual fixed maintenance cost; and the marginal cost associated with releasing, delivering or obtaining a unit of water from the supply source. The capital costs are truncated, reflecting that the investments have lives that extend beyond the modelling period (box 3.4).

Box 3.4 **Truncation of investment costs**

Each possible new future supply source in the model has an investment cost and economic life that typically extends beyond the planning horizon of the model (10 years and 20 years). In such cases it is inappropriate to attribute all of the investment cost to the planning horizon being modelled.

In net present value terms, the investment cost is the sum of the discounted annual payments to capital over the life of the asset. However, correction needs to be made for the proportion of the investment that operates outside of the time horizon modelled.

The investments made in the model often have operating lives of more than 30 years. Further, investment possibilities in later years of the modelled planning horizon will be used for fewer years, and thus have less time within the planning horizon to achieve a positive benefit–cost ratio. For this reason, capital costs of investments are truncated.

Capital costs are truncated by firstly calculating the Equivalent Annual Value (EAV) of the investment over its life. The EAV is then summed over all years in which the investment will be operational in the model. The present value of the truncated EAV is then further discounted by the lag (lead-time) between the year the decision is taken to invest and the year in which the supply source becomes operational.

For example, in a 10 year model, an investment made in year two with a two year lag would come on-line in year four. This would leave six periods in which payments to capital could be made. The truncated capital cost would therefore be the sum over six years of the equivalent annual value of the asset, discounted for two time periods to derive the capital cost at the time the investment decision was taken.

Further, each new supply option modelled has additional unique attributes, which preclude ranking the investment options on investment and operating costs alone. For example, the desirability of each investment is influenced by:

- the economic life of the supply source
- the lag time between the decision to invest and the supply of water
- whether the source of water is included or excluded from restrictions (for example, water provided by tanks is not restricted).

An economic assessment of new supply options should include all relevant costs associated with supplying water from that source, including any environmental costs (where known). Data limitations have meant that, for this inquiry, environmental costs are only incorporated exogenously to the extent that they affect costs incurred in building or operating the facility. For example, where environmental assessment and remediation is required as part of building a dam, this is included in the cost of constructing the dam. Similarly, for desalination, additional energy costs required to run the facility using renewable power are included in its operating costs.

Environmental externalities associated with particular supply sources could also be included in the modelling approach used for this inquiry. Additional costs (in the case of a negative externality) and benefits (in the case of a positive externality) beyond the urban water sector could be added to the objective function. If included in this way, externalities would impact on the desirability, order and timing of supply source augmentations, as well as their operation. For example, there are negative environmental impacts associated with large amounts of nitrogen flowing into waterways. Rainwater tanks (and the corresponding water use in gardens) can help to reduce this nitrogen run-off and therefore have a positive environmental impact (appendix E of the inquiry report). This could be represented in the model as a benefit associated with the use of household tanks, which would make them more desirable as a supply source.

Environmental constraints can also be imposed on the operation of facilities or sources. If such constraints are binding, there will be a shadow price on the environmental constraint, resulting in an economic rent to the restricted use of the resource. An example is the limits placed on extraction from existing aquifers included in the model for Perth (in any single year and accumulating over a number of years) (see section below for details). Environmental constraints on other sources of supply could also be included in the model, but the Commission has not been given evidence of any such constraints.

The list of options considered is not exhaustive. For example, sourcing water from Tasmania and the Kimberley have not been included as a possibilty for Melbourne and Perth respectively. Other alternatives that require water of different quality to be used for different purposes — such as dual reticulation systems — are also not modelled. Including these sources would require a much larger model. Additionally, economies of scale for new supply sources are not included in the model due to limited data on scale costs.

Further, there is no 'backstop technology' included in the modelling. A backstop technology is a source of water supply that is available at short notice, albeit at a high price. This source of supply would set an upper bound on the market clearing price. For example, water was trucked in to supply some areas of rural Victoria during 2007, at a cost of about $10 per kilolitre (Goulburn Valley Water 2008). In large cities, supplying water through such a last resort measure is likely to be more difficult, given the quantities of water involved. However, it is not without international precedent. During 2008, water was transported to Barcelona by tanker ships, at a cost of about $5 per kilolitre (Time Magazine 2008). The availability of a backstop technology — at an acceptable price — allows water storages to be operated at a lower level than without such a backstop technology. However, a backstop supply source was not included in the simulations included in this paper due to the difficulty of supplying a large quantity of water at short notice, and uncertainty about the costs and practicalities of such a technology given the lack of experience in large cities of Australia. Further, it is unlikely that under efficient operation of the sector such a situation would arise, particularly when a framework of multi-stage stochastic (real options) approach to production is taken.

Omitting a backstop technology does not impact general economic inferences that can be illustrated using this model since prices are unlikely to rise above the cost of backstop sources of supply.

Dams

Dams provide an existing source of water in both Melbourne and Perth. Table 3.6 provides a summary of the data used. New dams are not included in the model as a supply augmentation option. There are likely to be long delays between the decision to build a new dam and the supply of water, as time is needed for planning and environmental approval, construction, and filling of the dam. There is also a diminishing number of sites available for dams, with increasing costs of procurement. Due to a lack of reliable data, dams are not included as a possible source of supply in the modelling for this paper. With more consistent data, they could be included in future modelling work.

For Melbourne, mean inflows into dams are assumed to be 376 GL per year. This is net of environmental flows and system losses (for example evaporation). The bottom 10 per cent of water in existing dams is assumed to be in deep storage and not readily available for use without the construction of new infrastructure (which would increase the cost of supply). Initial dam storages in the present model are set at 50 per cent of capacity, based on observed levels in January 2011 in Melbourne (Melbourne Water 2011d). Initial dam storages in the historic model are set at 35 per cent. Existing dams are assumed to have an operating cost of 10 cents per kilolitre of water delivered and maintenance costs of $45 million per year.[6] Only variable costs of supply are included in the model for existing supply sources. This is because past investments are considered to be sunk.

Increased environmental flows from dams could be, but are not, included in the parameter for dam inflows as is done for existing environmental flows. Increasing environmental flows would result in less water being available for urban water use. Environmental flows could be increasingly important over time if more water is allocated in future for this purpose.

Mean inflows to dams in Perth are assumed to be equal to 153 GL per year. Storage capacity in existing dams is 622 GL. The bottom 110 GL of water in existing dams is not readily available for use (Water Corporation 2011b). Initial dam storages are set at 30 per cent of capacity in both the present and historic models, based on observed storage levels (Water Corporation 2011b).

Table 3.6 **Characteristics of dams**

Parameter	*Units*	*Melbourne*	*Perth*	*Sensitivity*
Mean annual inflows to dams	GL	376.391	153.319	± 30 per cent
Total storage capacity	GL	1812	622	..
Initial storage (present model)	Per cent of total capacity	50	30	± 10 per cent
Initial storage (historic model)	Per cent of total capacity	35	30	± 10 per cent
Storage capacity not readily available	GL	181.2	110	..
Evaporation loss	Per cent of previous storage	..[a]	4	..
Annual maintenance cost	$ million/year	45	27.8[b]	..
Operating costs	$/kL	0.10	0.10[c]	..

[a] For Melbourne, inflow data already accounts for evaporation equal to the rain falling over dams. [b] Water Corporation (2009a) [c] ERA (2009) .. Not applicable.

6 These costs are for dams in Perth. Melbourne specific data were not available.

Desalination

Desalination offers a source of water that is independent of rainfall. However, obtaining water from desalination involves relatively high per unit costs due to its intensive use of energy. There are also high fixed annual costs to maintain a desalination plant.

In Melbourne, the Wonthaggi desalination plant is included as a supply option in the historic model, with investment modelled as a continuous variable. In the present model, the plant is entered as an existing supply source with a capacity of 150 GL, with water available for supply from the second year. An extra 50 GL of capacity is treated as a possible new source in the present model with additional capital costs. Given the desalination options for Melbourne, in the historic model the desalination investment variable is treated as continuous. In the present model, the 50 GL expansion of the existing plant is treated as binary.

The Perth Seawater desalination plant at Kwinana is included in both the present and historic Perth models as a sunk investment. The Perth Seawater desalination plant is able to supply 45 GL per year at a variable cost of $0.47 per kilolitre. The Southern Seawater plant currently under construction is included in the present version of the model as a sunk investment, and is able to supply 50 GL of water from the second time period in the model. In the historic version of the model, the Southern Seawater plant is included as a new supply option, with investment modelled as a binary variable. Additionally, an upgrade to the Southern Seawater plant to supply 100 GL is included. The costs associated with upgrading the desalination plant (table 3.7) are based on using the upgrade as a contingency water supply with limited integration assets. The additional capacity would utilise existing integration assets, and therefore would only be used in dry years when supply from dams was not utilising the integration network. Full integration to access the water as base load supply irrespective of inflows would cost a further $600 million and increase the operating costs to $0.96 per kilolitre (due to additional costs for green energy).

Table 3.7 **Characteristics of desalination**

Parameter	*Units*	*Melbourne*	*Perth*
Desalination plant 1[a]			
Quantity of water available	GL/year	150[b]	45
Investment cost[c]	$ million	3048[b]	..
Annual maintenance cost	$ million/year	2.352[b]	5[d]
Operating costs	$/kL	1.37	0.47[d]
Economic life	years	27.7[b]	..
Time: inception → supply	years	3[b]	..
Desalination plant 2			
Quantity of water available	GL/year	..	50
Investment cost[c]	$ million	..	955
Annual maintenance cost	$ million/year	..	5[d]
Operating costs	$/kL	..	0.86[d]
Economic life	years	..	30[e]
Time: inception → supply	years	..	4[f]
Desalination upgrade[g, h]			
Quantity of water available	GL/year	50[b]	50[i]
Investment cost[c]	$ million	1016[b]	450[i]
Annual maintenance cost	$ million/year	0.784[b]	3[j]
Operating costs	$/kL	1.37	0.63[j]
Economic life	years	27.7[b]	30[e]
Time: inception → supply	years	3[b]	2

[a] For Melbourne, desalination plant 1 refers to the plant at Wonthaggi. For Perth, desalination plant 1 refers to the Perth Seawater plant at Kwinana. [b] VAGO (2010). [c] Total undiscounted investment cost. [d] Water Corporation (2009a). [e] Reverse osmosis membranes are likely to have shorter lifetimes while bulk pipelines are likely to have longer lifetimes (Water Corporation, pers. comm., 12 January 2011). [f] Announced in May 2007, supply expected to begin late 2011. [g] For Perth, central estimates are based on using the upgrade for contingency supply only. Costs for using the upgrade as a base load supply are: capital cost $1050 million, annual maintenance cost $5 million and operating costs $0.96 per kilolitre. (Water Corporation, pers. comm., 25 January 2011). [h] For Melbourne, based on a third of the costs of the initial desalination plant. Operating costs and economic life are assumed to be the same. [i] Barnett and Marmion (2011). [j] Water Corporation (pers. comm., 25 January 2011) **..** Not applicable.

Rural–urban trade

For the present model of Melbourne, the Sugarloaf pipeline is treated as a sunk investment and has the capacity to supply 100 GL per year (table 3.8). In the historic model, rural–urban trade is included as a new supply augmentation option, with investment modelled as a continuous variable.

Rural–urban trade using pipelines allows urban water to be obtained by purchasing water rights from irrigation regions and delivering it to urban centres. This is modelled as an opportunity for urban regions to purchase annual water allocations from rural markets. Given the small size of urban markets relative to rural markets (PC 2008d), the price of water in irrigation markets is assumed to be unaffected by the quantity purchased for urban use. This assumption is made to limit the size of the model by avoiding the need to linearise the supply function of water from irrigation regions. However, the unit price of water purchased depends upon the inflow state. In a dry year price is higher, while in a wet year prices are lower. The Sugarloaf pipeline that runs from the Goulburn River in Yea to the Sugarloaf Reservoir in Melbourne provides the means for delivering the water from rural–urban trade. The costs and capacity of the Sugarloaf interconnection are shown in table 3.8.

For the Perth model, water can be purchased from on-farm water savings, with costs and capacities shown in table 3.8. In practice, the quantity of water traded is likely to depend on water availability (and hence price) in the irrigation district. A more detailed treatment of trade could allow for the price of water to vary with rainfall and inflows, as is modelled for Melbourne. Investment in rural–urban trade is modelled as a continuous variable.

Table 3.8 **Characteristics of rural–urban trade**

Parameter	*Units*		*Melbourne*	*Perth*
Quantity of water available	GL/year		100[a]	10[b]
Investment cost[c]	$ million		750[d]	157[b]
Annual maintenance cost	$ million/year		7.5[e]	0[b]
Operating costs	$/kL	dry	0.70[f]	
		med	0.48[f]	1.00[g]
		wet	0.25[f]	
Economic life	years		50[h]	80
Time: inception → supply	years		3[d]	3[b]

[a] In the historic model, the pipeline has a capacity of 75 GL according to the recorded capacity at that time. [b] Water Corporation (2009a). [c] Total undiscounted investment cost. [d] Victorian Government (2008). [e] Estimated at 1 per cent of initial investment cost. [f] Data from NWC (2008), Peterson et al. (2004) and Waterexchange (2009) as well as a cost of pumping and treatment of $0.20/kL (IPA 2008). [g] Water Corporation (pers. comm., 23 February 2011). [h] Bulk pipelines are likely to have lifetimes longer than 50 years while pumps have shorter lifetimes.

Recycling

Investment in recycling in Melbourne is based on the unpublished cost data provided by Melbourne Water (pers. comm., 19 January 2011) and is modelled as a binary variable. The costs apply to the Yarra River Option supply augmentation, detailed in Our Water Our Future (DSE 2008; Victorian Government 2007). From a modelling perspective, the water is treated as a highly processed potable substitute, as reflected in the high unit cost of $1.50 per kilolitre.

For Perth, water recycling is included as a supply augmentation option in both the historic and present models, with investment modelled as a binary variable. The costs are based on groundwater replenishment (table 3.9). Water is treated and then stored in aquifers before being re-extracted for use.

Table 3.9 **Characteristics of recycling**

Parameter	*Units*	*Melbourne*	*Perth*
Quantity of water available	GL/year	70[a]	50[b]
Investment cost[c]	$ million	2200[a]	540[b]
Annual maintenance cost	$ million/year	22[d]	5[b]
Operating costs	$/kL	1.5[e]	0.86[b]
Economic life	years	27.7[f]	50[b]
Time: inception → supply	years	3	3

[a] Melbourne Water (pers. comm., 19 January 2011). [b] Water Corporation (2009a). [c] Total undiscounted investment cost. [d] Estimated at 1 per cent of initial investment cost. [e] IPA (2008). [f] Same as desalination plant.

Aquifers

Aquifers provide one existing source of water in the historic and present models for Perth. Groundwater extraction from existing aquifers is independent of rainfall and is assumed to have a sustainable yield of 120 GL per year. However, the quantity of water extracted each year from existing aquifers is allowed to vary but is capped at a maximum of 165 GL. The sustainable yield is achieved by constraints that ensure the five year moving average of extractions for a scenario is no more than 120 GL. In the present model, an initial abstraction deficit is included to take account of the recent extraction by Water Corporation. Abstractions are not directly linked to dam storages in the model.

In addition, options for new aquifers are included in the present and historic models (table 3.10). New aquifers are assumed to provide a fixed annual sustainable yield. Two types of aquifers are included. Low-cost aquifers are assumed to be developed close to the point of end use. This supply option represents small scale groundwater schemes and expansions of existing aquifers. Investment in low-cost aquifers is modelled as a continuous variable as it is assumed lumpy investment in interconnection pipelines is not required. There is an investment capacity constraint of 48 GL on the low-cost aquifers (the sum of total capacity of all low-cost aquifers cannot be more than 48 GL).

Table 3.10 **Characteristics of aquifers**

Parameter	*Units*	*Data*	*Source*
Existing aquifers			
Maximum quantity of water available	GL/year	165	Department of Water (WA) (2009)
Average quantity of water available	GL/year	120	Department of Water (WA) (2009)
Annual maintenance cost	$ million/year	27.8	Water Corporation (2009a)
Operating costs	$/kL	0.20	ERA (2009)
Aquifers (low-cost)			
Quantity of water available	GL/year	24	Water Corporation (2009a)
Investment cost[a]	$ million	225.1	Water Corporation (2009a)
Annual maintenance cost	$ million/year	3.2	Water Corporation (2009a)
Operating costs	$/kL	0.20	ERA (2009)
Economic life	years	50	Water Corporation (2009a)
Time: inception → supply	years	3	
Aquifers (high-cost)			
Quantity of water available	GL/year	45	
Investment cost (historic)[a]	$ million	729	Water Corporation (sub. DR151)
Investment cost (present)[a]	$ million	1200	Water Corporation (pers. comm., 23 February 2011)
Annual maintenance cost (historic)	$ million/year	7[b]	
Annual maintenance cost (present)	$ million/year	10	
Operating costs	$/kL	0.40[c]	
Economic life	years	50	Water Corporation (pers. comm., 12 January 2011)
Time: inception → supply (historic)	years	3	
Time: inception → supply (present)	years	4[d]	

[a] Total undiscounted investment cost. [b] Estimated at approximately 1 per cent of initial investment cost. [c] Estimated as double the cost of low-cost aquifers. [d] Additional time is required in the present model to obtain permits and approvals.

High-cost aquifers are developed further from the point of end use. This option represents larger groundwater schemes (45 GL per year yield) and has additional capital costs for interconnection to the integrated water supply system and higher variable costs for pumping the water. Investment in this supply option is modelled as a binary variable. In the historic model, the capital cost is $675 million. This increases to $1200 million in the present model due to the increased integration costs following the building of the Southern Seawater desalination plant. This is because the transfer infrastructure was common to these two investment options, and following the completion of either investment, further transfer infrastructure becomes more costly.

Household tanks

Household tanks are included as a supply option in both the historic and present models for Melbourne, with investment modelled as a continuous variable. Tanks provide households with additional water at a relatively low per-unit cost, but involve substantial capital costs per unit of water delivered (table 3.11). Supply from tanks is rainfall dependent, but like rainfall itself, yields from tanks do not vary as much as inflows to dams (since dams need significant rainfall just to saturate the soil and begin the runoff process — Marsden Jacob Associates (MJA) 2007b). Annual yields from tanks are assumed to be half as variable as inflows to dams, based on the observed relationship between rainfall variability and dam inflows in Melbourne (BOM 2009; Melbourne Water 2009). The chief advantage of tanks over other supply options is their scope to supply water that can be used outdoors at times when water restrictions are enforced. Also, unlike other supply options, in the model there is no limit imposed on the total amount of water that can be supplied from tanks.[7]

Table 3.11 **Characteristics of household tanks in Melbourne[a]**

Parameter	*Units*		*Data*	*Source*
Quantity of water available	kL/year	dry	23	MJA (2007b)
		med	29	
		wet	37	
Investment cost[b]	$		2300	MJA (2007b)
Annual maintenance cost	$/year		20	MJA (2007b)
Operating costs	$/kL		0.05	MJA (2007b)
Economic life	years		30	VCEC (2005)

[a] Each with 5 kL storage capacity. [b] Total undiscounted investment cost.

Reticulation costs

There is also a reticulation cost associated with transporting water from bulk storage to end users, assumed to be 12 cents per kilolitre for all sources in Perth (ERA 2009) and 35 cents per kilolitre for all sources in Melbourne (this does not apply to household tanks, which supply water directly to households).

7 In practice, roof area is likely to constrain the amount of water that can be supplied from tanks in any particular city. However, this would only be an issue after a vast number of tanks had been installed throughout the city, which does not occur in the modelling results.

3.5 Calibrating the terminal condition for water storages in dams

Storage decisions reflect expectations about the value of water in the future. This future value of water includes both the expected, discounted value of future consumption and cost savings resulting from using storage to delay investment decisions. In models with finite planning horizons, stocks in the terminal period will be assigned zero value unless a terminal condition is imposed. This is because there is no future consumption nor are there any future investment decisions beyond the horizon modelled. The inclusion of a terminal condition to ensure storages are carried forward in the terminal period is an important inclusion for finite horizon models. It also has important implications for variables (such as prices, investment and storages) in the periods leading up to the terminal period.

The terminal condition should proxy the expected value of a unit of water storage outside of the time period modelled. It can be thought of as a representation of the demand for water stored in the terminal period.

There are three possible approaches to modelling the terminal condition for water storages, outlined below:

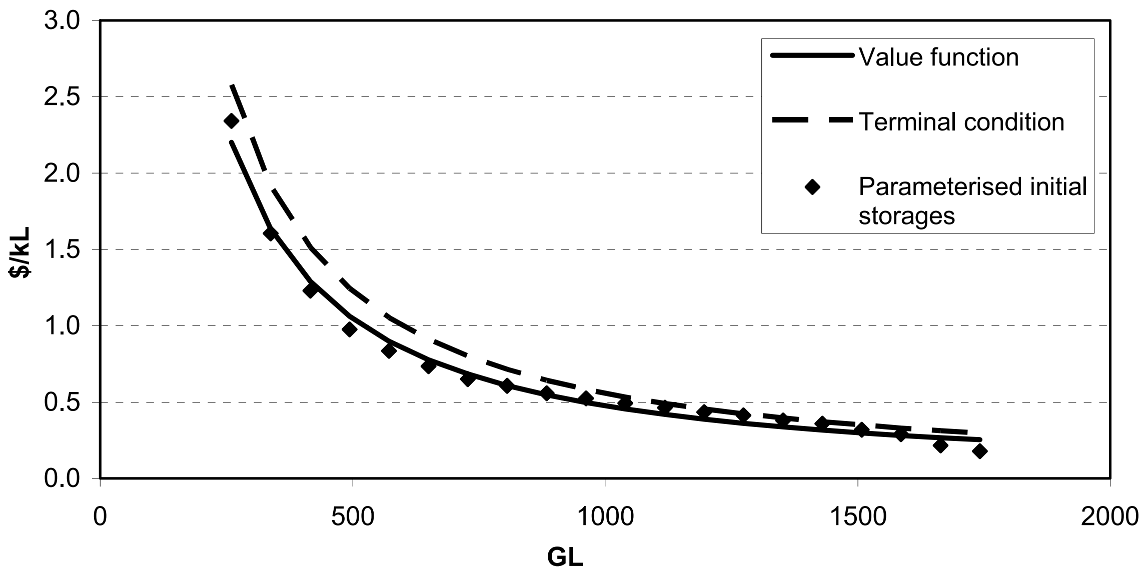
- A fixed, target level of storage for the terminal period. This is equivalent to a perfectly inelastic demand for terminal storage.
- An exogenous, fixed price for stored water in the terminal period. This is equivalent to a perfectly elastic demand for terminal storage.
- A response function, with the price of water stored in the terminal period being a function of the level of storage.

Here, the third approach is utilised. This was felt to best reflect the value of water in a forward-looking model: if storages are low, water scarcity would be expected to be relatively acute in the future (and therefore water would be of high value); while if storages are high, water would be expected to be relatively abundant (and low value) in the future.

The terminal response function was estimated by examining the value the model attached to initial storages. As mentioned, the terminal problem arises in finite horizon models because they do not include future periods. In principle, every terminal node (figure 2.1) should have another probability tree flowing from it, and the forward-looking expected value of water would drive the value of storages. The implicit value of initial storages reflects the opportunity value of stored water. Therefore, by parameterising initial storages an idea of the initial imputed value of water as a function of the initial storage level can be obtained. This can then be used to estimate a demand function for storage, which can be adapted to be a terminal value response function[8] by reflecting expected growth in demand. An illustration of the terminal condition — as well as the values attached to paramaterised initial storages, and the estimated value function before applying the growth rate — can be seen in figures 3.4 (Melbourne model) and 3.5 (Perth model).

The differences in the terminal conditions (and the value of storages) for each city reflect the different roles of storages in each city. For the Melbourne historic model, all existing supply is sourced from dams. For Perth, storages play a lesser role in balancing supply and demand as aquifers and desalination provide additional sources of water.

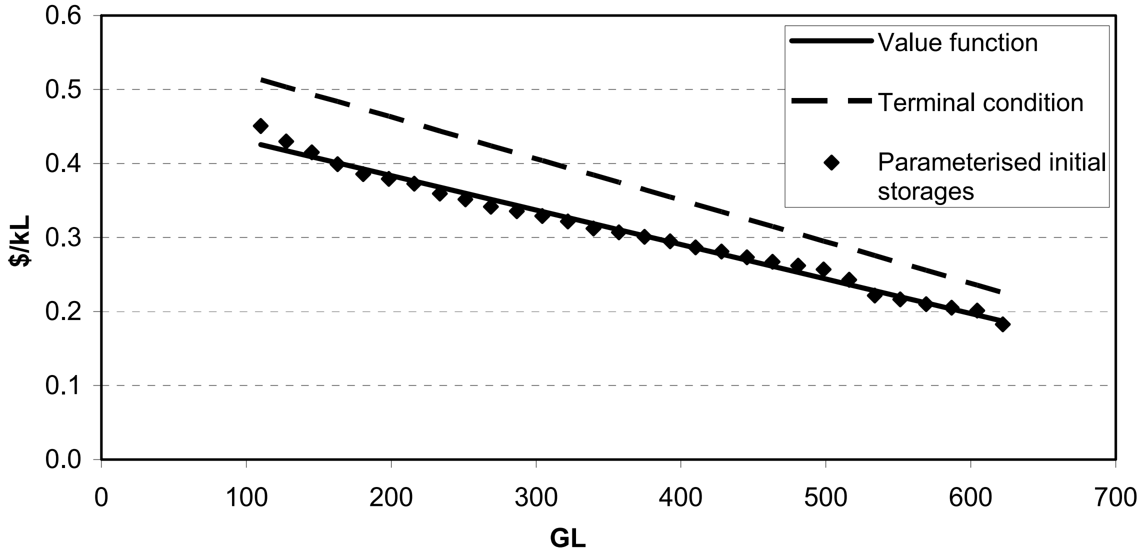
Figure 3.4 **Value of storage in the Melbourne model**



Source: Productivity Commission estimates — Melbourne historic model.

8 Given that the distribution of inflows does not change over the simulation period.

Figure 3.5 **Value of storage in the Perth model**



Source: Productivity Commission estimates — Perth historic model.

4 Theory and results for basecase models of Melbourne and Perth

The results for the basecase models of Melbourne and Perth, and some insights in to the underlying economic principles, are presented in this chapter. The basecase model has flexible pricing. The results presented here are for the historic version of the model in each city. The discussion in this chapter describes the economic principles guiding pricing, efficient investment in new sources of supply, and storage in the model.

The results are based on the 10 year time horizon with three possible inflow states in each period: high, medium and low. Each model has over 59 000 inflow scenarios and more than 88 000 nodes with investment, storage and consumption variables at each node.

4.1 Pricing

Economic efficiency requires that price is set where the marginal value that consumers place on a unit of a good or service is equal to the marginal cost of supplying an additional unit. The marginal cost of supply is also known as the marginal opportunity cost, equivalent to the value of the best alternative foregone (Ng 1987; Lane and Littlechild 1980). Water should be supplied up to the point that the value consumers place on the last unit of water produced is equal to the marginal cost of supplying it.

This section sets out the nature of the relationship between costs and prices as defined in the model, and outlines the key pricing principles embedded in the model. It also contains a description of how prices are determined in the model and how they relate to investment in augmentation of supply capacity.

Key cost and pricing principles

The linear programming model is specified using the quantity formulation of spatial and temporal price models (Takayama and Judge 1971). As such, all the variables in the model are quantities, such as the quantity of water demanded by end users or the number of desalination plants constructed.

Prices in the model arise in two ways (box 4.1):

- the exogenously specified objective function coefficients of variables
- the Lagrangean variables for each constraint in the model, which represent the (shadow) prices that are endogenously determined.

The structure of key exogenous and endogenous prices are set out in table 4.1. The pricing embodied in the model can be interpreted as those that would result from an efficient market for water.

Table 4.1 **Structure of key prices and welfare functions in the basecase model**

Exogenous prices and welfare functions
• Linearised welfare function for each class of demand • Unit cost of reticulation/transmission of water • Variable operating (unit) cost for supply from each source • Fixed annual maintenance cost for each source of supply • Investment cost for each new source of supply • Linearised welfare function for the value of water in the terminal period of each inflow scenario
Endogenous prices
• Retail price of water • Volumetric rent for each source of water, which arises when the price received for each unit of water supplied exceeds the short-run operating cost of the supply source. This rent contributes to the recovery of the investment cost and any rent attributable to constraints on the capacity size of the source • Capacity rent that arises when the scope for further expansion of a supply source is constrained • Price of water in the terminal period of each scenario

The linear demand function (and its integral — gross social welfare from consumption) is exogenously set (as calibrated in chapter 3). The retail price is the value of the Lagrangean variable on the retail demand–supply commodity balance constraint, and is the derivative of the gross welfare function with respect to quantity consumed (which is also the demand price for the quantity consumed).

Box 4.1 **Pricing concepts in a linearised partial equilibrium model**

The linearised partial equilibrium model is a linear programming model and general linear programming theory can be used to illustrate the pricing concepts. The generalised linear programming model is as follows:

$$\text{Max NSW } = \sum_{i=1}^{N} c_i.x_i$$

$$\text{subject to} \quad \sum_{i=1}^{N} a_{ji}.x_i \le b_j \quad \text{for } j = 1,...,M$$

Where N is the number of variables, M is the number of constraints, x_i are the demand and supply activity variables, c_i are the exogenous benefit and cost ($c_j < 0$) coefficients for each activity in the objective function for the demand and supply activities (x_i). The a_{ji} are the technological coefficients in the constraints and b_j are the resource availability constraints.

The Lagrangean for the problem is given by:

$$L\left(x_i, \lambda_j\right) = \sum_{i=1}^{N} c_i.x_i + \sum_{j=1}^{M} \lambda_j.\left(b_j - \sum_{i=1}^{N} a_{ji}.x_i\right)$$

Where λ_j are the endogenous prices (Lagrangean multipliers associated with the constraint).

The Karush–Kuhn–Tucker maximisation conditions are as follows

$$\frac{\partial L}{\partial x_i} = c_i - \sum_j \lambda_j.a_{ji} \le 0 \quad \text{for } i = 1,...,N$$

$$\left(\frac{\partial L}{\partial x_i}\right).x_i = c_i.x_i - \sum_j \lambda_j.a_{ji}.x_i = 0 \quad \text{for } i = 1,...,N$$

$$\frac{\partial L}{\partial \lambda_j} = b_j - \sum_i a_{ji}.x_i \le 0 \quad \text{for j} = 1,...,M$$

$$\left(\frac{\partial L}{\partial \lambda_j}\right).\lambda_j = b_j.\lambda_j - \sum_i a_{ji}.x_i.\lambda_j = 0 \quad \text{for j} = 1,...,M$$

Source: Baumol (1977).

There are exogenously set costs for reticulation, transmission and the operating costs of water supply from each source. The retail price less the reticulation, transmission and operating cost (per unit of water supplied) is the volumetric rent paid for water from each source. This price is the value of the Lagrangean variable for the constraint on supply of water from each source.

The volumetric rent makes a contribution to the recovery of the investment costs of the source of supply and an additional capacity rent if the size of the augmentation is constrained.

In order to bring about the market equilibrium, prices in the model are fully flexible (on an annual basis). In many cases, the retail price exceeds the short-run marginal cost of water from existing sources of supply. When this occurs, a rent accrues to bulk suppliers of water (price received exceeds short-run operating cost).

If the expected rents exceed the discounted cost of supply of the next least-cost new source of supply, supply augmentation takes place (section 4.2). Put another way, supply augmentation occurs if the expected present value of future rents exceeds the investment cost of the next supply source. On an expected value basis, investment costs are recovered through the volumetric charge for water, even investment and ongoing, annual maintenance costs (which are not directly tied to supplying the marginal unit of water). However, this does not mean that in all rainfall scenarios the investment costs are recovered.

Given that the unit cost of successive augmentations are increasing, even in the efficient equilibrium there are economic rents accruing to the capacity constrained bulk sources of supply (Ng 1987). The efficient operation of the market involves the full capacity utilisation of lower-cost supply sources first, meaning that those sources can accrue rents (if they are fully utilised and become constrained). Further, as demand grows over time, and new, more expensive supply augmentations are chosen, the long-run marginal cost of water increases.

Long-run marginal cost pricing is a forward looking concept, influencing the timing and choice of investments and their capacity utilisation. However, in the economically efficient equilibrium, once an investment is built, the investment costs are sunk. At this point, water supply decisions are made on the basis of short-run marginal cost.

This underlying theoretical base includes many of the building blocks to derive the economic principles embodied in the concept of scarcity pricing, a term used widely in discussion of water pricing policy and the real options or adaptive approach to supply augmentation (WSAA 2008a). In fact, it is the mathematical programming framework being used here that was originally used by Steiner (1957), Williamson (1966), Pressman (1970),and Littlechild (1970) to derive the theory of peak-load pricing (section 4.2 and box 4.3).

Across the full range of inflow scenarios modelled, flexible pricing leads to prices that can vary significantly depending on realised inflows. During a series of wet years, prices move downwards to the short-run marginal operating cost of supplying and distributing water from the lowest cost sources of supply. On the other hand, an extended series of dry years leads to higher prices (above the short-run marginal operating cost).

The expected price in the Melbourne historic model remains below $1.40 per kilolitre, and in 90 per cent of scenarios, prices remain below $1.70 (table 4.2). Prices range between a minimum of $0.45 and a maximum of $5.89. However, the probability of these extreme scenarios is low. For example, the maximum price path has a probability of less than one in 50 000.

The expected price in the Perth historic model is $0.87 per kilolitre. The average price remains below $0.96 and in 90 per cent of scenarios, prices remain below $1.65 (table 4.3). Prices range between a minimum of $0.22 and a maximum of $8.70. Results depicting scenarios for both Melbourne and Perth, including price paths, can be seen in section 4.3.

Table 4.2 **Distribution of retail prices in the Melbourne model[a]**
$/kL

Year	*Minimum*	*5th percentile*	*10th percentile*	*25th percentile*	*Mean*	*75th percentile*	*90th percentile*	*95th percentile*	*Maximum*
Yr01	1.05	1.05	1.05	1.22	1.24	1.22	1.44	1.44	1.44
Yr02	0.95	1.08	1.08	1.08	1.29	1.45	1.45	1.84	1.84
Yr03	0.87	0.97	1.11	1.12	1.34	1.45	1.64	1.87	2.20
Yr04	0.81	1.00	1.08	1.15	1.40	1.44	1.80	1.92	5.56
Yr05	0.76	1.00	1.03	1.15	1.43	1.43	1.89	2.20	3.93
Yr06	0.72	0.97	1.06	1.16	1.45	1.42	1.89	2.18	4.00
Yr07	0.64	0.93	1.04	1.20	1.45	1.38	1.81	2.16	4.40
Yr08	0.45	0.95	1.03	1.16	1.45	1.52	1.70	2.19	4.56
Yr09	0.45	0.94	1.01	1.18	1.45	1.56	1.70	2.29	5.27
Yr10	0.45	0.94	1.01	1.10	1.46	1.68	1.68	2.68	5.89

a The number of outcomes in each year are given by $n = 3^{yr}$. In the first year of the model, there are three outcomes. In the second there are nine, in the third 27. This means that the percentiles for the early years are based on a small number of outcomes (table 3.1).

Source: Modelling results — Melbourne historic model.

Table 4.3 **Distribution of retail prices in the Perth model**
$/kL

Year	*Minimum*	*5th percentile*	*10th percentile*	*25th percentile*	*Mean*	*75th percentile*	*90th percentile*	*95th percentile*	*Maximum*
Yr01	0.59	0.59	0.59	0.69	0.72	0.69	0.91	0.91	0.91
Yr02	0.56	0.59	0.59	0.59	0.77	0.97	0.98	1.25	1.25
Yr03	0.52	0.56	0.59	0.59	0.83	0.94	1.22	1.67	2.26
Yr04	0.50	0.56	0.59	0.60	0.89	0.95	1.65	1.83	4.24
Yr05	0.47	0.56	0.59	0.61	0.96	0.89	1.31	2.48	8.70
Yr06	0.43	0.55	0.59	0.60	0.86	0.92	1.09	1.47	4.60
Yr07	0.32	0.53	0.57	0.59	0.88	0.90	1.28	1.67	5.77
Yr08	0.32	0.53	0.54	0.59	0.90	0.91	1.46	1.67	5.77
Yr09	0.40	0.54	0.55	0.58	0.91	0.99	1.54	2.02	6.36
Yr10	0.22	0.58	0.58	0.61	0.92	0.69	1.59	2.85	8.11

Source: Modelling results — Perth historic model.

The highest prices in both applications generally occur in the driest scenarios. There are several reasons for this. First, only a limited quantity of water is available from relatively low-cost options for additional supply, so additional water needs to be supplied from higher cost sources. Second, investment decisions are based on expected values across the range of future inflow scenarios. Even after several dry years, most future scenarios will involve some periods of higher future inflow, reducing the benefits from an investment made at an earlier point in time. This is analogous to intertemporal peak-load pricing, whereby incremental capacity costs are recovered from consumption in future dry years, but not in wet years. This means that in many scenarios, additional capacity will not be built as, despite periods of short-run scarcity, the investment would not break even on an expected value basis. Finally, most new supply options take several years to construct, so the investment decision needs to be made several years in advance, further increasing the cost of augmenting supply.

4.2 Investment, pricing and cost recovery in supply augmentation

Investment theory in the model is forward looking. Supply augmentation takes place if the expected present value of future net revenue streams is at least equal to the cost of the investment. In these situations, the gross benefit that consumers derive from the water an investment supplies exceeds the sum of costs, on an expected value basis. This concept is illustrated in box 4.2, based on the scenario tree shown in figure 2.1 (chapter 2). There are a variety of characteristics that influence the expected benefit–cost ratio of an investment, including the cost and reliability of supply, the time lag to construction, and the minimum plant size (where augmentations are of an indivisible size).

Box 4.2 **Investment and pricing**

Drawing on the scenario tree in figure 2.1 (chapter 2) assume a four year time horizon with 2 states of nature in each year, implying a total of 30 nodes (2 in the first year, 4 in the second, 8 in the third and 16 in the fourth) and 16 individual inflow scenarios. The example benefit–cost ratios detailed below are for an investment decision made in year 1, node 1 (a high inflow state), with a 1 year lag on production (so that production is available in year 2):

Ex ante benefit–cost ratio

$$\text{Ratio} = \text{Expected Value}\left(\frac{\text{Unit rents}}{\text{Investment cost}}\right)$$

$$\text{Ratio} = \frac{\left(\begin{array}{l}\sum_{n=3}^{4}\text{UnitRent}_{yr=2,n}.\text{QuantitySupplied}_{yr=2,n}\\ +\sum_{n=7}^{10}\text{UnitRent}_{yr=3,n}.\text{QuantitySupplied}_{yr=3,n}\\ +\sum_{n=15}^{22}\text{UnitRent}_{yr=4,n}.\text{QuantitySupplied}_{yr=4,n}\end{array}\right)}{\text{Prob}_{\text{yr=1,n=1}}.\text{df}_{yr=1}.\text{UnitInvCost}.\text{InstalledCapacity}_{yr=1,n=1}}$$

Ex post benefit–cost ratio (for each realised scenario)

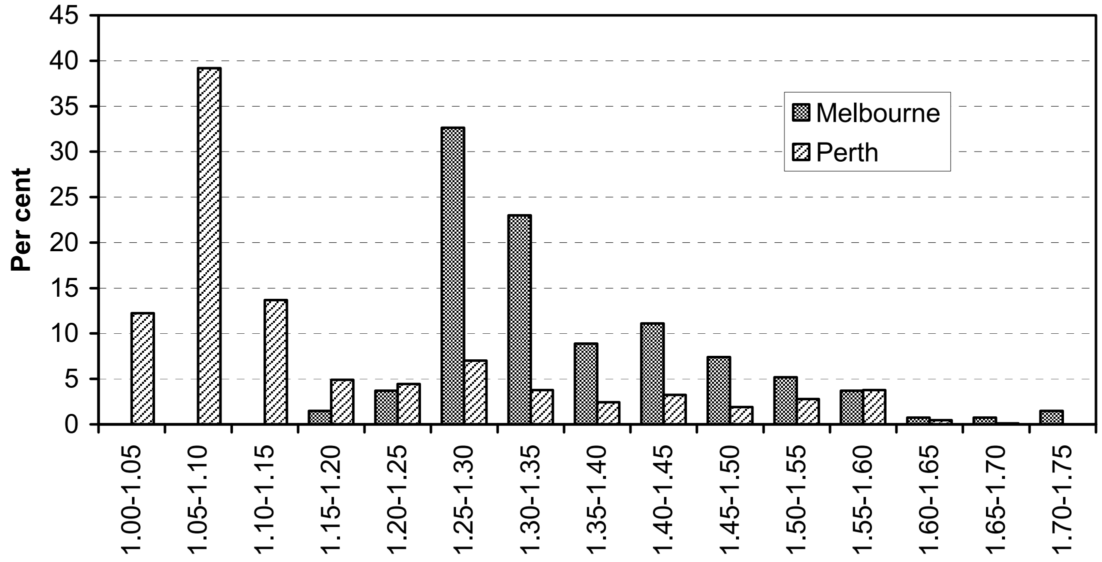
Consider the first scenario (nodes 1, 3, 7 and 15) with the investment decision in node 1 and subsequent production in nodes 3, 7 and 15.

$$\text{Ratio} = \frac{\text{Realised capacity rents}}{\text{Investment cost}}$$

$$\text{Ratio} = \frac{\left(\begin{array}{l}\text{UnitRent}_{yr=2,n=3}.\text{QuantitySupplied}_{yr=2,n=3} / \text{Prob}_{\text{yr=2,n=3}}\\ +\ \text{UnitRent}_{yr=3,n=7}.\text{QuantitySupplied}_{yr=3,n=7} / \text{Prob}_{\text{yr=3,n=7}}\\ +\ \text{UnitRent}_{yr=4,n=15}.\text{QuantitySupplied}_{yr=4,n=15} / \text{Prob}_{\text{yr=4,n=15}}\end{array}\right)}{\text{df}_{yr=1}.\text{UnitInvCost}.\text{InstalledCapacity}_{yr=1,n=1}}$$

At each point that an investment is made, the ex ante expected ratio of benefits to costs is greater than or equal to one. Each investment decision has its own ex ante expected return. Figure 4.1 shows the frequency of benefit–cost ratios for investments in the Melbourne and Perth historic models.

Figure 4.1 **Distribution of ex ante benefit–cost ratios of rural–urban trade investment in Melbourne and a low cost aquifer in Perth**



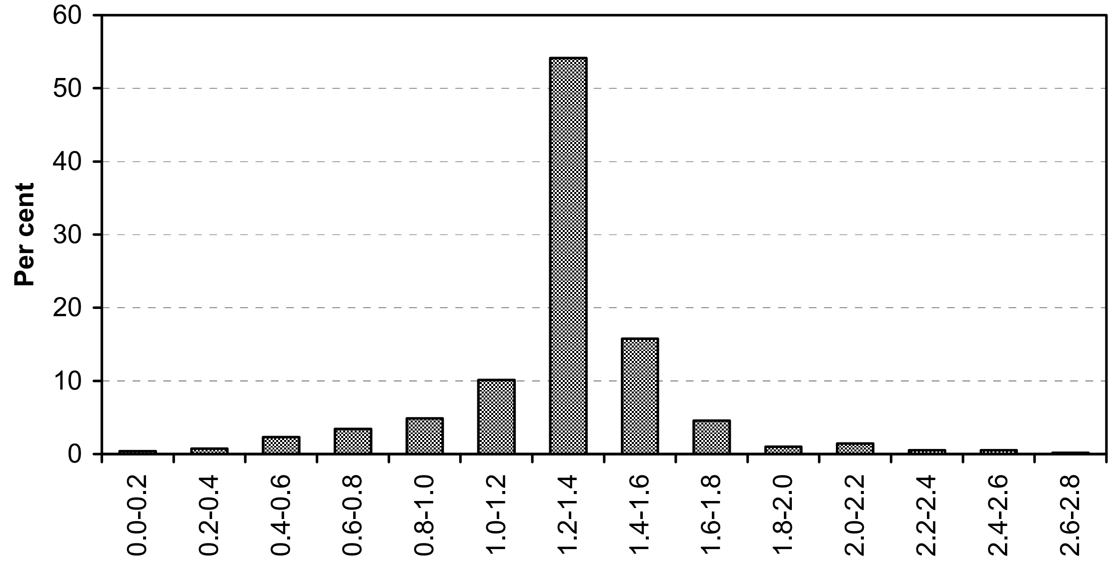
Source: Modelling results — Melbourne and Perth historic models.

Figure 4.1 indicates that in many cases, the expected benefits will be in excess of the costs associated with an investment. This is due to capacity rents. Each investment option has a maximum capacity that can be supplied. When capacity is constrained, the price consumers are willing to pay for the constrained supply exceeds the long-run marginal cost for that technology and capacity rents accrue to the asset (section 4.1).

For rural–urban trade in Melbourne, the investment has an average expected benefit–cost ratio of 1.29. For the low-cost aquifer investment made in Perth, the expected benefit–cost ratio is 1.10.

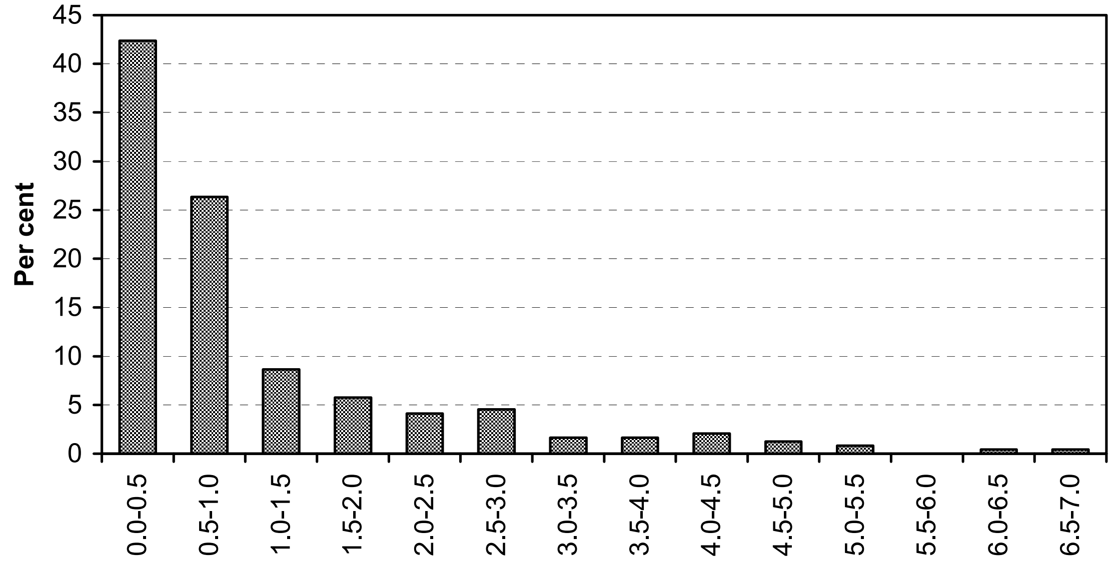
Once a supply augmentation decision is made, the investment cost is sunk, and it is efficient for supply decisions to be made on the basis of short-run marginal cost. Investment decisions are irreversible, and the returns to the asset vary with the realised inflow states and market clearing prices in each scenario. This implies that any given decision is unlikely to be optimal (ex post) for a specific realised inflow scenario compared with the situation where the future was known with certainty (Kall and Wallace 1994).

Figure 4.2 **Example of the frequency of ex post benefit–cost ratios for a rural–urban interconnection investment in the Melbourne model**



Source: Modelling results — Melbourne historic model.

Figure 4.3 **Example of the frequency of ex post benefit–cost ratios for a low-cost aquifer in Perth**



Source: Modelling results — Perth historic model.

Ex post, individual investments have benefit–cost ratios less than one, and some greater than one. Even in the presence of binding capacity constraints (and the corresponding capacity rents), individual investments can still have a benefit–cost ratio less than one if the market clearing price is greater than the operating cost of the plant (short-run marginal cost), but still lower than the price required to cover the investment cost. Figures 4.2 and 4.3 show examples of the distribution of the ex post returns for an illustrative investment decision in Melbourne and Perth respectively.

Although unit rents can provide benefit–cost ratios in excess of unity, these are not the same as monopoly rents. The prices that bring about market clearance in the model describe an efficient market, and assume bulk suppliers are not exploiting market power. These capacity rents reflect the limited water available from certain lower cost sources of supply. Some scenarios with benefit–cost ratios greater than unity are required to offset other scenarios for which the benefit–cost ratio is less than one, so that the ex ante benefit–cost ratio is in excess of unity. Examples of the capacity rents paid under different scenarios can be seen in figures 4.4 and 4.5. Note that some of the scenarios have a very low probability of occurring.

This highlights the riskiness of investments in bulk water infrastructure. There is a significant variation in the ex post returns that a given investment can have, even when the expected, ex ante returns are positive. The risk associated with investments in the modelling is driven solely by inflows which, it is assumed, are uncorrelated with economywide returns. This means that the risk, as modelled, is solely project-specific risk.[1]

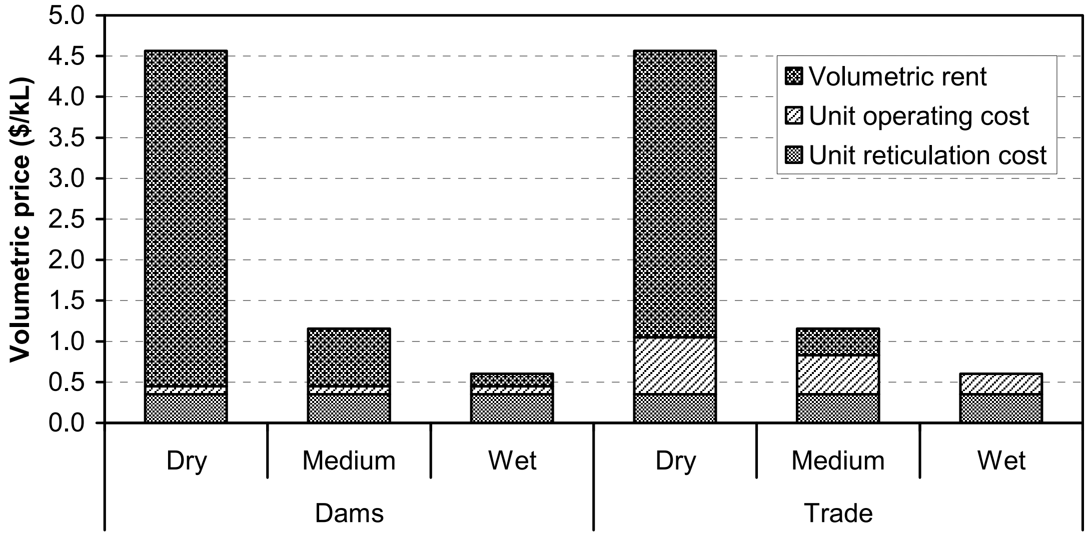
Investment timing is sensitive to inflows, with investment occurring earlier in relatively dry scenarios. Some supply options offer a tradeoff between the cost of water supply and reliability of supply, and might only be worthwhile during particularly dry periods. For example, in some cases, desalination presents a relatively expensive source of water (with a significant time lag between the decision to invest and commencement of operation) but provides a guaranteed quantity of water that is not affected by rainfall.

Supply augmentation timing is complicated by the ‘lumpy’ nature of investments. The term lumpy has two meanings:

- first, once built, investments are irreversible and have capacity to supply or produce over the remaining years in the planning horizon
- second, some investments have to be made in defined increments (modelled using binary variables).

[1] The standard, capital asset pricing model (CAPM) indicates that if risk is project-specific and uncorrelated with market returns, then the premium attached to those investments should be zero (Brealey, Myers and Marcus 1984).

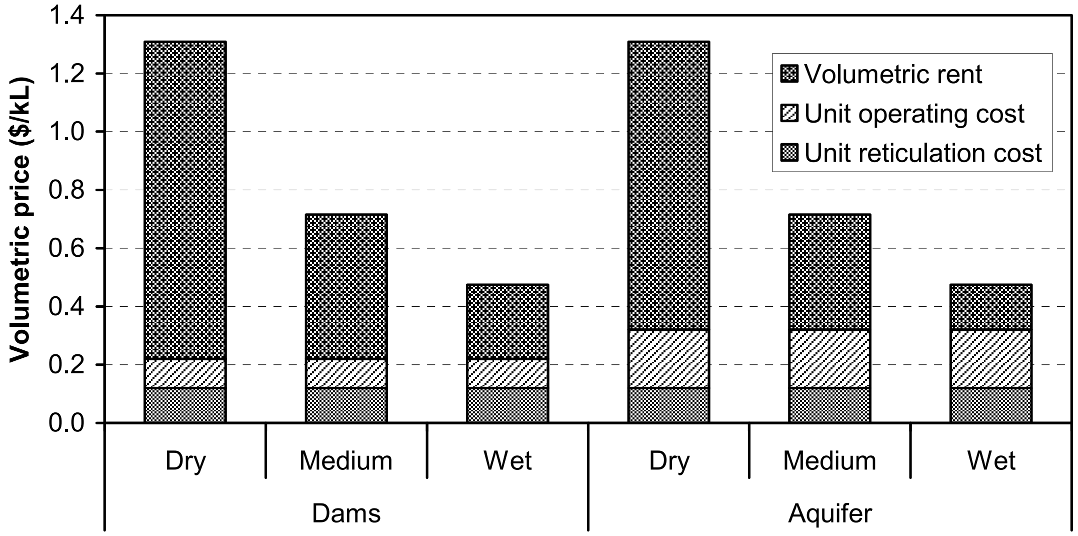
Figure 4.4 **Capacity rents in Melbourne for three example scenarios[a]**



[a] This diagram does not separately identify the recovery of capital costs (investment costs plus return on investment).

Source: Modelling results — Melbourne historic model.

Figure 4.5 **Capacity rents in Perth for three example scenarios[a]**



[a] This diagram does not separately identify the recovery of capital costs (investment costs plus return on investment).

Source: Modelling results — Perth historic model.

This first consideration — that investments have capacity to supply water throughout the remainder of the planning horizon — has important implications for investment decision making. Investment decisions at a point in time have to be made reflecting the fact that an asset will continue to have productive capacity across a range of years and possible future inflow states. The joint production over different inflow states is analogous to the peak-load pricing problem discussed by Turvey (1968), Williamson (1966) and others. The approach has been explicitly acknowledged by Littlechild (1970) as an appropriate tool for estimating optimal prices in the presence of uncertainty:

> [the theory of joint production] offers an interesting approach to pricing and investment under uncertainty, for equipment can be regarded as jointly providing capacity in different states of the world. (Littlechild, 1970, p. 331)

These concepts are illustrated in box 4.3.

4.3 Storages

Water storages play an important role in smoothing consumption and the timing of investments. Melbourne and Perth both have a significant capacity to store water in their dams from one period to the next. Melbourne has the capacity to store nearly five years' consumption while Perth can store about two.

The economic theory of water storage is well documented. The benefits of water storage exist because of the high variability in inflows and the high costs associated with not having enough water in any one period (Brennan 2010). For example, it might be preferable to consume less water in one year in order to save some to consume next year, if there is a chance that there will be low inflows in future.

According to Hughes, Hafi and Goesch (2009, p. 9), '[t]he essence of the water storage problem is to compare the marginal value of consuming water with the marginal value of storing water, where the marginal value of water in storage is equal to the expected marginal value of future water use'. Williams and Wright (1991, p. 51) describe this intertemporal price relationship when they say that 'price in the current period should never be below the price expected for next period by more than the cost of storage; nor above it unless the total amount stored is zero'. Expectations about the variations in inflows in the future therefore determine the level of consumption and storage in each period.

Box 4.3 **Pricing for efficient capacity and its utilisation**

The investment theory in the model is based on the principles of peak-load pricing (applied intertemporally across states). Decisions to augment capacity are made at a point in time and are irreversible. Once a new supply source is constructed, it then has a fixed maximum supply capacity in all subsequent nodes, regardless of the state of nature. This joint production capacity across years and states means that the flexible prices implied in the model reflect peak-load pricing principles, which in turn drive investment decision making (size, timing) and capacity utilisation post-construction.

The theory of peak-load pricing describes the optimal way to choose the capacity of a facility and price the output so that output is efficiently allocated over time. It applies where production is a joint output from a facility over time.

The stylised tableau below illustrates how joint production from a facility appears in the model, and draws upon the probability tree in figure 2.1 (chapter 2). The illustration contains a single production year, but is easily extended to a multi-period setting.

Variable Row	Invest yr=1 n=1	Invest yr=1 n=2	Supply yr=2 n=3	Supply yr=2 n=4	Supply yr=2 n=5	Supply yr=2 n=6	Right hand side
Objective function	-c	-c	-vc	-vc	-vc	-vc	Max NSW
Investment capacity yr=1, n=1	1						≤ 1
Investment capacity yr=1, n=2		1					≤ 1
Supply capacity yr=2, n=3	-cap		1				≤ 0
Supply capacity yr=2, n=4	-cap			1			≤ 0
Supply capacity yr=2, n=5		-cap			1		≤ 0
Supply capacity yr=2, n=6		-cap				1	≤ 0

Investment decisions in year 1 (for nodes 1 and 2) create supply capacity in nodes that follow each of them in the scenario tree, regardless of the realised state of nature. In this way, the model contains joint production. For example, the investment in year 1, node 1 provides production capacity in year 2, node 3 and year 2, node 4. In this way, an investment might provide an expected, ex ante benefit–cost ratio greater than one, but still have a negative ex post ratio for some scenarios.

This tableau contains all the necessary elements to calculate the benefit–cost ratios described in box 4.2. The unit rents are obtained from the Lagrangean variables attached to each supply capacity constraint, and the investment costs are found in the objective function. Investment capacity and quantity supplied are variables.

Source: Turvey (1968); Williamson (1966).

More water is stored when the expected present value of future consumption is greater than the value of current consumption at the margin, and storages will be drawn down when the value of current water consumption exceeds the expected present value of future consumption. This relationship in the model is shown in box 4.4.

Box 4.4 **The economics of storage**

In each time period, the shadow price of water stored can be represented as:

$$\text{Water price}_t - \text{reticulation cost} - \text{variable cost from dams} =$$

$$\text{Price of storage}_t =$$

$$\sum_{s \in \{L,M,H\}} \left(\text{Discounted water price}_{s,t+1} - \text{reticulation cost} - \text{variable cost from dams}\right).\text{Prob}_s$$

$$- \text{Price of binding dam storage capacity} + \text{Terminal value}\Big|_{t=last}$$

This relationship indicates that in non-terminal nodes, the price of storage is equal to the expected discounted price of water in the next period. There are two special exceptions to this: when dams are at capacity, the marginal value of water stored will be below the retail price; and in the terminal period, the terminal condition is used to provide a value for water in storage at the end of the planning horizon.

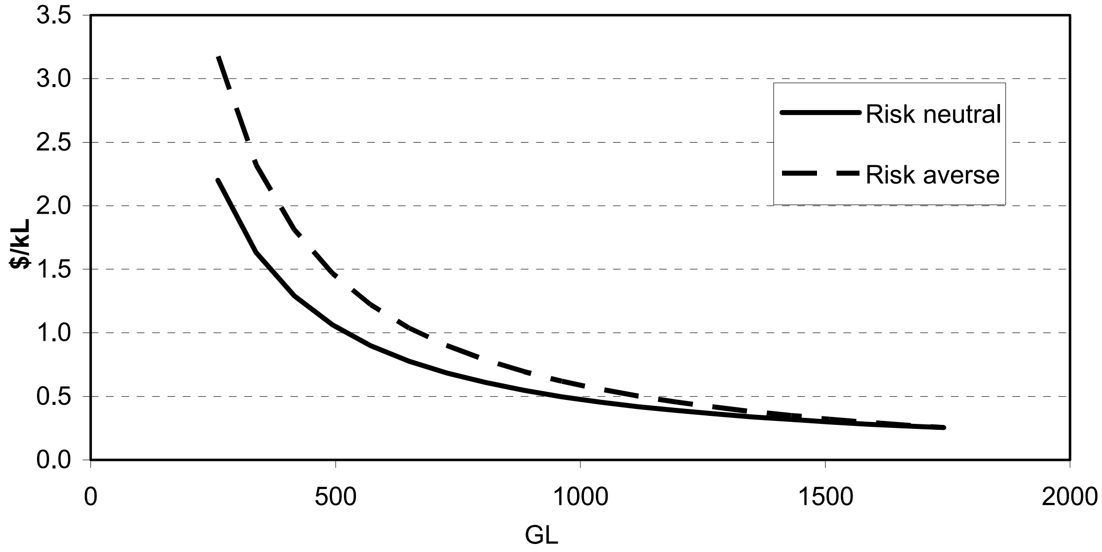
Source: Commission model.

Storages in the model are driven by prices today and the future expected price of water, which are in turn driven by (and a driver of) investment. There is no penalty value for reducing storages beyond the foregone value of future consumption (box 4.5). In this way, storages respond to future expected prices and augmentation decisions. Figures 4.6 and 4.7 show how storages interact with prices and investment timing in the models.

Box 4.5 **A penalty for low storages**

In the model used for this inquiry, water storages are increased or drawn down with a view of maximising the expected net present value of consumption (both present and future). This does not reflect any additional disutility that policy makers might attach to the political risk associated with low levels of water storage.

One approach to internalise this type of risk averse behaviour by consumers and utilities would be to attach a 'penalty' in the objective function for low levels of water storages. This would be expected to proxy an increased imputed price of storage for any given level of storage, as seen below:



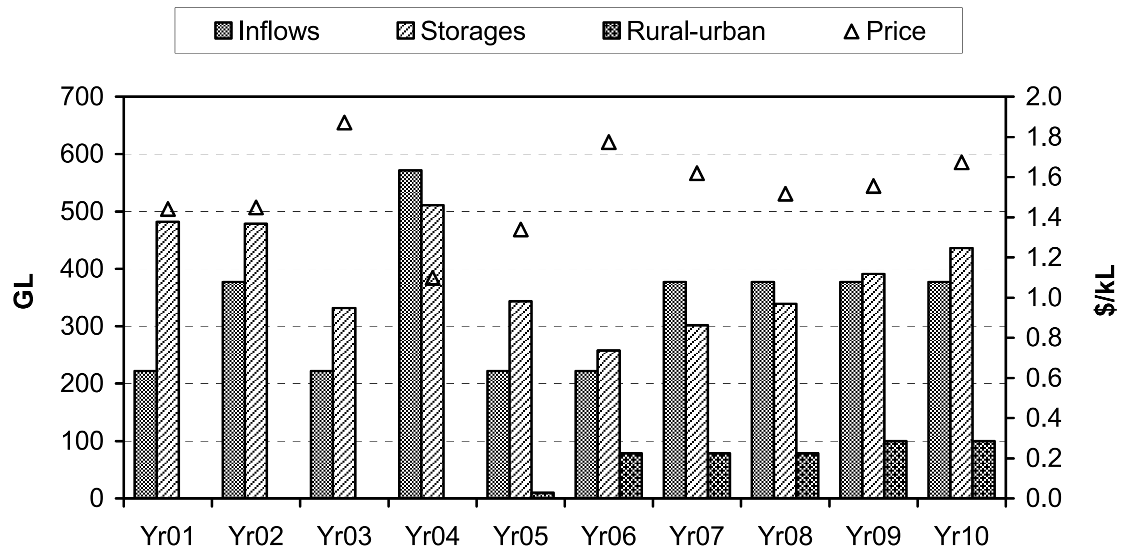
This could be represented mathematically as either:

- a single penalty value associated with particular storage trigger levels, attaching a discrete cost to a set level of storage
- a penalty function, attaching increasing costs to successively lower levels of storage.

These approaches are analogous to the penalty value used in Hughes, Hafi and Goesch (2009). In their model, a penalty value is associated with an inability of the system to meet an 'essential' level of water demand. Given limited investment options, this is comparable to a storage penalty.

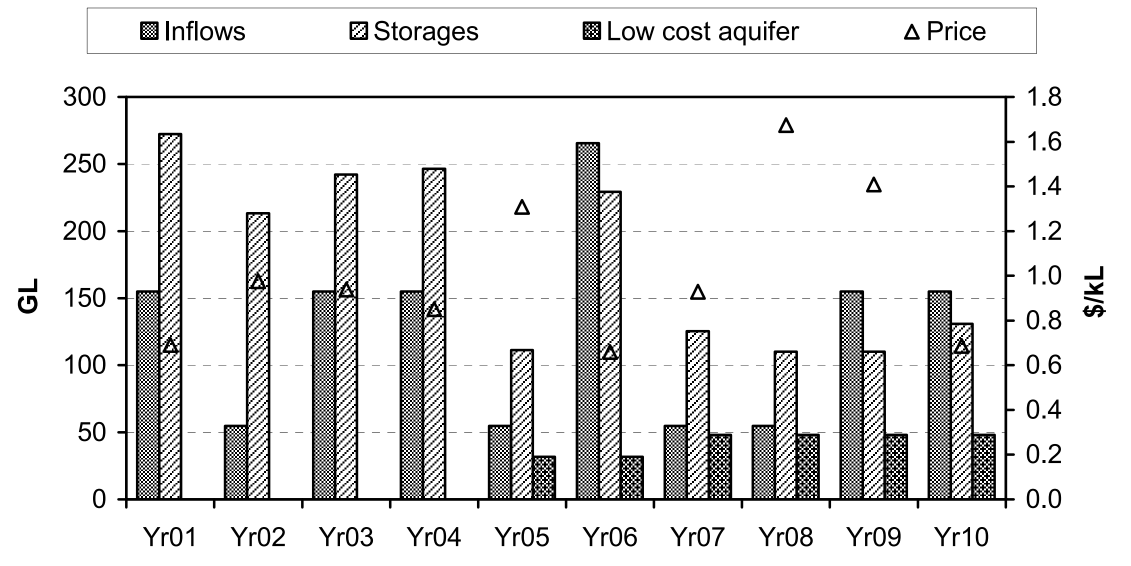
In practice, implementing a penalty for low levels of storages is difficult. In the absence of empirical evidence, the choice of the functional form and its calibration would be challenging. A low-storage penalty would also introduce further computational difficulties. Given the non-linear nature of the cost (varying with the level of storages), it would require linearisation of the storage variable (box 3.2, chapter 3). This would dramatically increase the size of the model.

Figure 4.6 **Water price, investment and storage in Melbourne for a given inflow scenario**



Source: Modelling results — Melbourne historic model.

Figure 4.7 **Water price, investment and storage in Perth for a given inflow scenario**



Source: Modelling results — Perth historic model.

Figure 4.6 shows the results from an example scenario in the Melbourne model. In year 1, a low level of inflow is recorded. Despite this, storages increase due to the low level of initial water in storage. Medium and low inflows cause prices to rise in years 2 and 3, and the construction of the rural–urban interconnection begins. A high level of inflows causes a rapid fall in price in year 4, and the rural–urban interconnection has a poor financial performance in its first year (year 5). Throughout the remainder of the scenario, inflows are mid-level, causing a steady increase in storages. Prices slowly rise with the growth in demand.

Figure 4.7 shows the results of an example scenario in Perth. In year 2, low inflows and a drop in storages trigger investment in a low-cost aquifer (which is able to provide water in year 5). Although storages slowly increase for a few years, further investment is made in low-cost aquifers in year 4, which increases available aquifer capacity in year 7. Even with this added capacity, two dry years in a row result in a drop in storages and a price spike. With mid-level inflows, the storages increase slightly in the last period and the price drops.

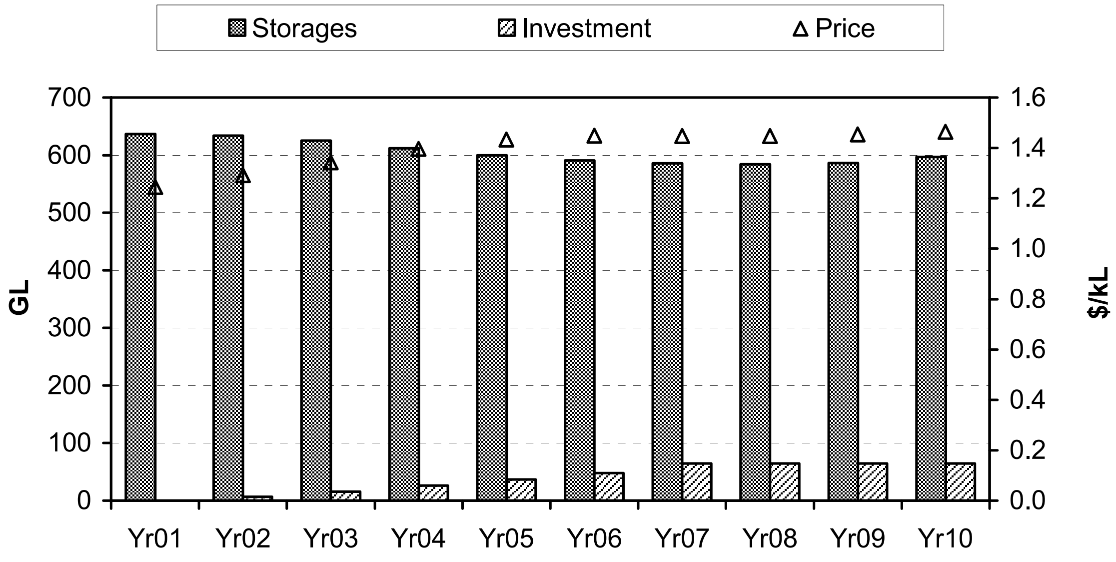
4.4 Aggregate (expected value) results

The expected level of storages, cumulative additions to supply capacity and prices for each time period for Melbourne and Perth are illustrated in figures 4.8 and 4.9. These are the sum of the probability weighted outcomes for these variables in each period. They are used in chapter 5 to summarise the impacts of policies modelled.

The expected outcomes are driven primarily by initial storages, mean inflows and population growth, and peak-load pricing to improve efficiency in investment and operation of new capacity.

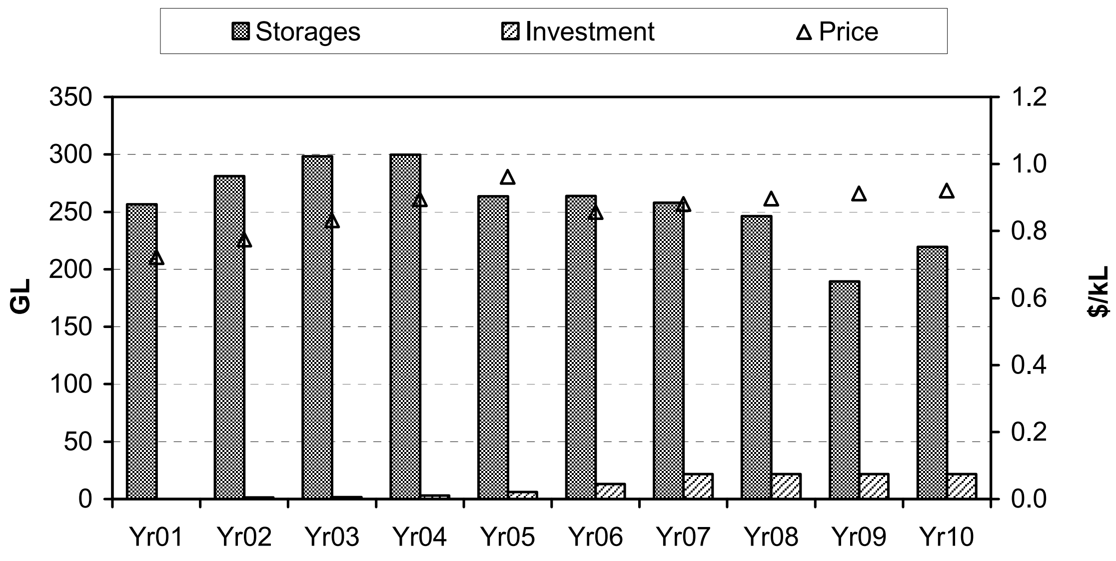
Expected prices rise over the simulation period. On average, prices level off (for Melbourne) or decline (for Perth) when the bulk of new investments have been brought online (in the middle of the simulation period). Levels of water in storage are driven by the tradeoff between the present opportunity cost of supplying a unit of water, and the expected value of water in the future.

Figure 4.8 **Expected water storage, investment in new capacity and prices in the Melbourne model**



Source: Modelling results — Melbourne historic model.

Figure 4.9 **Expected water storage, investment in new capacity and prices in the Perth model**



Source: Modelling results — Perth historic model.

5 Policy scenarios and results

The purpose of developing the partial equilibrium model was to provide insight into the net benefits, pricing and supply implications of policy issues identified in the inquiry. As outlined in chapter 2, policies are modelled by modifying the basecase model. To quantify the impacts of policies, the solutions to the policy models are compared with the basecase model. The policies modelled include:

- water restrictions
- policy bans and investment mandates on some forms of supply augmentation
- simulation of the impact of adopting a real options approach to planning and investment in supply augmentation
- uniform retail pricing of water over time.

As discussed in chapter 4, the basecase (market) model can be described as a flexible pricing model of demand and supply for urban water. Prices are allowed to adjust to bring about a market equilibrium that maximises the expected value of net social welfare (Marshallian consumer surplus plus producer surplus).

Impacts of different policies on pricing and investment decisions can be examined by adding constraints to the market model (Pressman 1970; McCarl and Spreen 1980). The cost of policy interventions can then be estimated by comparing welfare in the basecase model with that of the policy constrained model. If the policy is binding, it distorts this market outcome and leads to a reduction in welfare compared with the basecase. Further, the partial equilibrium framework attaches a shadow price to every constraint imposed on the model (if it is binding), which provides information about the marginal costs (marginal reduction in net social welfare) of the binding policies.

The remainder of this chapter is divided into sections discussing each policy. Water restrictions are discussed in section 5.1. Section 5.2 examines policy bans and mandates on supply augmentation options, including a policy ban on the use of a recent investment. Section 5.3 analyses the benefits of adopting a real options approach. Uniform retail pricing of water over time is discussed in section 5.4. Section 5.5 presents a summary of the impacts of the policies modelled. Each section provides a description of how each policy is modelled, followed by results for the Melbourne and Perth models. The ‘central estimates’ are based on the calibration of parameters outlined in chapter 3. Results from sensitivity analysis of key parameters (inflows and demand elasticities) are also included. Appendix C provides details of the 'low and high' parameters used for sensitivity analysis and contains results for sensitivity analysis of other, less important parameters.

5.1 Water restrictions

Water restrictions have been used widely throughout Australia during times of water scarcity due to drought.

How are water restrictions modelled?

Water restrictions are modelled as a constraint on the maximum aggregate quantity of water that can be used outdoors. This means that water restrictions only apply to one of the three classes of demand included in the model. The impact of water restrictions in curtailing outdoor demand is calibrated to level 3a restrictions in Melbourne and a total sprinkler ban in Perth (see chapter 3 for details of the model calibration).

Water restrictions are triggered when storages fall below a specified threshold level. This is achieved using binary (integer) variables. The restriction binary variable has a value of 1 when the restriction is triggered and 0 when it is not. Whether or not a restriction is triggered at a point in time depends on storage levels at the end of the preceding period. An example of how restrictions are implemented in the model is presented in box 5.1.

The modelling framework approximates stated government policies regarding restrictions (DSE 2008). However, in the model used here, storage levels are influenced by price, consumption and investment in preceding periods. Therefore, in this model, restrictions can be avoided, and they are only triggered when the opportunity cost of avoiding them is higher than the cost to the community of triggering them. This means that the model optimally chooses when to allow storages to drop below the trigger levels. The simulation therefore is not modelling the actual scenarios in the past when restrictions were in place for a long time. Rather, it is optimising their use, conditional on the pre-determined trigger level of storage.

In this model, restrictions are costly because the demand for outdoor water is reasonably inelastic and consumers place a high value on consumption. In some cases in this model, the net social welfare with a restrictions policy is lower than the basecase even though restrictions were not triggered. This is an example of taking action by modifying consumption (prices) and/or supply from other sources in order to avoid the high cost of triggering restrictions.

Box 5.1 **Modelling water restrictions**

Modelling water restrictions requires the addition of three constraints and two binary variables (integer variables that can only have a value of zero or one) for each outdoor demand function. The stylised tableau illustrates how restrictions are modelled, and draws upon the linearised demand tableau in box 3.2.

Variable / Row	D_{1t}	D_{2t}	D_{3t}	$Rest_t$ (binary)	$NoRest_t$ (binary)	$Storage_{t-1}$	Right hand side
Demand–supply	Q_1	Q_2	Q_3			-1	≤ 0
Convex demand	1	1	1				≤ 1
Storage level trigger					SLT	-1	≤ 0
Binary constraint				1	1		= 1
Restricted demand	Q_1	Q_2	Q_3	-RD	-UD		≤ 0

There are two binary variables representing demand, one when water restrictions are in effect ($Rest_t$) and one when they are not in effect ($NoRest_t$). However, only one of these variables ($Rest_t$) is formally defined to be binary. As $Rest_t$ is binary and the restriction/no restriction constraint is a strict equality, when $Rest_t$ is zero, $NoRest_t$ must be one, and vice-versa. Defining $NoRest_t$ to be a positive, continuous variable (rather than binary) reduces the number of formally declared binary variables in the model, making it computationally easier to solve.

The logic of the approach is as follows:

- If $NoRest_t$ is 1 ($Rest_t$ = 0), then there must be at least SLT units (GL) of water in storage in period t-1. In this case, consumption is unconstrained because the coefficient UD is sufficiently large so as not to restrict demand. However, the demand–supply balance constraint still ensures the demand for water has to be less than or equal to the quantity supplied from storage.
- If $Rest_t$ is 1 ($NoRest_t$ = 0), then storage is below SLT and the demand for outdoor use must be less than RD units (the restricted level of demand). Once again, the demand–supply balance constraint ensures that the quantity demanded has to be less than or equal to the quantity supplied from storage.

Although this model captures water restrictions by imposing a quantity constraint, there are other ways that restrictions could have been incorporated into the model. For example, restrictions can be considered as a cost imposed on water users from having to comply with the rules, including time costs from watering only in specified blocks of time, or costs from not having a choice about watering lawns instead of gardens.

Results

The welfare impacts of water restrictions for both cities (under a variety of parameter values) are presented in table 5.1.

Table 5.1 **Welfare costs of water restrictions over 10 years**
Expected net present values ($m)

	Melbourne model		*Perth model*	
	Historic	Present	Historic	Present
Central estimate	**691**	**765**	**18**	**39**
Sensitivity estimates				
Low inflows	1 502	860	35	80
High inflows	419	779	8	17
Low price elasticity[a]	1 139	1 308	22	48
High price elasticity[a]	445	495	16	35

[a] Low and high elasticity describe the absolute value of the elasticity used for the simulations. The low elasticity is half of the central estimate, and the high elasticity is twice the central estimate.

Source: Modelling results — Melbourne and Perth historic and present models.

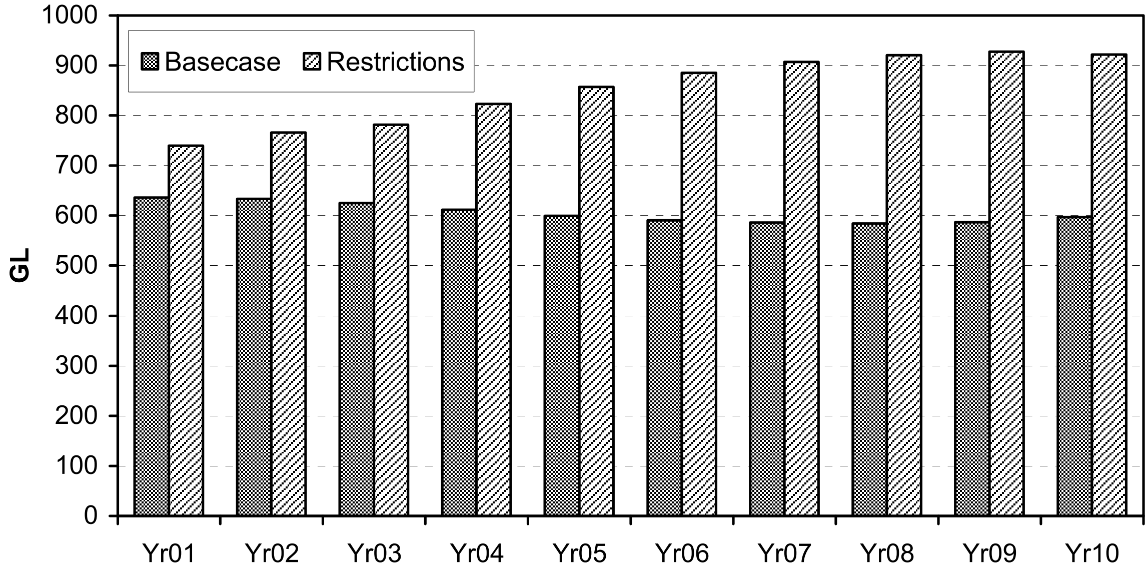
Estimates of the welfare impact of restrictions, as modelled, are a lower bound on their costs. The restriction is applied to aggregate demand and not individual consumer demand. In practice, a large part of the cost of restrictions comes from the fact that they apply to individual consumers (not in aggregate) regardless of the value individual users may attach to the use of water relative to other users. Further, restrictions target certain uses of water (most notably, watering of gardens and lawns) that might not be the least-valued outdoor use of water for many consumers.

Restrictions are only turned on in 7.9 per cent of nodes for Melbourne and 2.6 per cent of nodes for Perth (historic central estimate). With flexible pricing, water scarcity can, in most cases, be dealt with more efficiently by increasing prices in earlier periods and increasing supply from new sources, rather than rationing demand through quantity restrictions.

Expected storages are higher with restrictions. It is welfare enhancing to keep storages above the trigger level in order to avoid the high cost of restrictions. Figures 5.1 and 5.2 show the mean level of storages for the basecase and restriction simulations for both the Melbourne and Perth models.

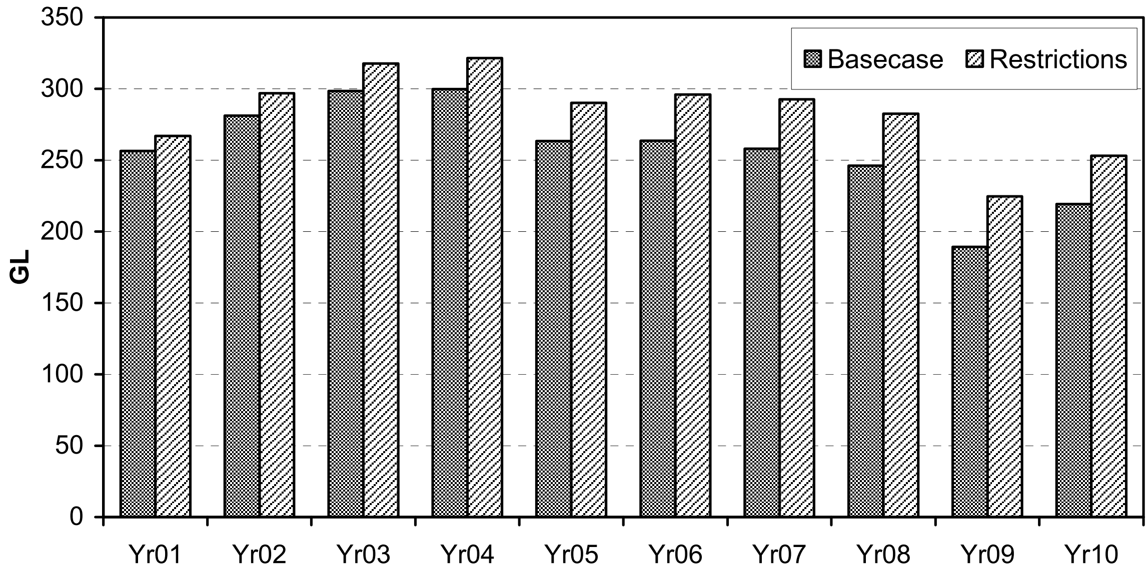
Investment is brought forward with water restrictions, and more capacity is added (figures 5.3 and 5.4). This is done to facilitate higher storages and avoid the costs associated with restrictions.

Figure 5.1 **Expected storage levels for basecase and water restrictions models of Melbourne**



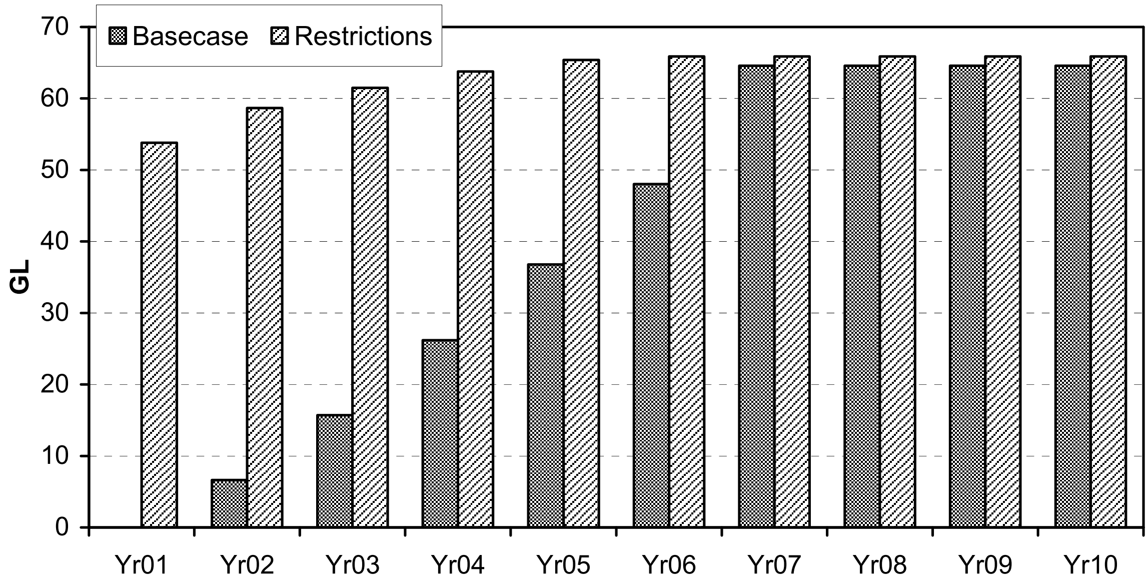
Source: Modelling results — Melbourne historic model.

Figure 5.2 **Expected storage levels for basecase and water restrictions models of Perth**



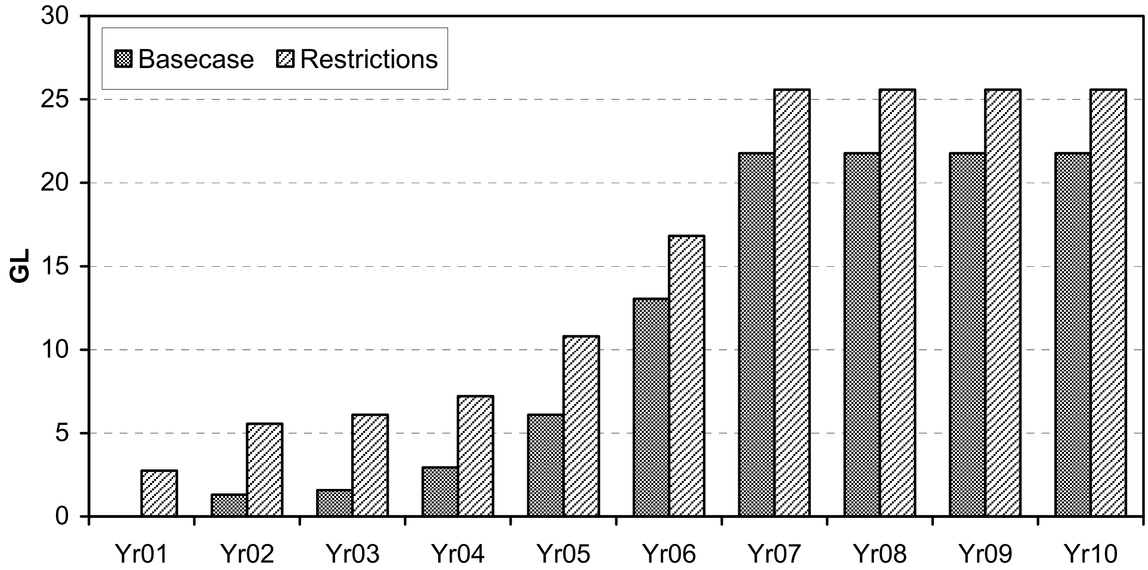
Source: Modelling results — Perth historic model.

Figure 5.3 **Expected investment in new supply capacity for basecase and water restrictions models of Melbourne**



Source: Modelling results — Melbourne historic model.

Figure 5.4 **Expected investment in new supply capacity for basecase and water restrictions models of Perth**



Source: Modelling results — Perth historic model.

5.2 Policy bans and mandates on select augmentation options

In both cities, there has been significant investment in capacity recently. In Melbourne, the Sugarloaf pipeline with an engineering supply capacity of 100 GL per year was completed in 2010, and a desalination plant with a supply capacity of 150 GL per year is due to come on-line in 2012. In Perth, a second desalination plant (50 GL per year capacity) is currently under construction and is expected to be available for production in late 2011. When this desalination plant was announced in 2007, the Water Corporation's preferred plan was to use the south-west Yarragadee aquifer. However, the Western Australian Government made the decision to proceed with the second desalination plant (chapter 5 of the inquiry report).

For each city these investment options were analysed using the historic version of the Melbourne and Perth models. For Melbourne, a mandate to build the desalination plant and the Sugarloaf pipeline was modelled. In addition, a ban on using the Sugarloaf pipeline was modelled in the present Melbourne model to quantify the costs of the current Victorian Government's policy to restrict the use of the Sugarloaf pipeline for supply only in the event of a 'critical human needs emergency'.

For Perth, the mandate to build the second desalination plant was modelled using the historic model, simultaneously with a policy ban on new large aquifers. This is compared to Water Corporation's preferred alternative of building the south-west Yarragadee aquifer, and also to the optimal basecase.

Modelling policy bans

The impact of a policy ban is estimated by comparing the basecase and policy constrained models. Policy bans are modelled by fixing the upper bound on the investment option to zero. The difference in the net social welfare between the two models is the expected value of the loss of welfare from the policy constraint. Policy bans on investment options result in sub-optimal (loss of community welfare) decisions if they are binding by preventing the use of lower cost sources of supply. If lower-cost investments are not allowed, then prices adjust to ration limited water supplies and/or the next least costly investment is made.

Modelling mandatory investment

Mandated options are modelled by exogenously fixing the supply augmentation variable to the mandated level, so that construction of these investments must begin in the first year of the simulation (upper and lower bounds set to the mandated level).

In a model like this one, forcing a sub-optimal investment does not lead to higher prices because the investment is exogenously determined (sunk) and it is socially optimal to price according to short-run marginal operating costs. In this model, long-run marginal cost pricing (discussed in chapter 4) only applies when investment decisions are endogenous (investment is a variable). Consequently, the volumetric prices charged for water under sub-optimal mandatory investment scenarios do not recover all of the investment cost.

If investment costs were required to be recovered through higher volumetric prices to consumers, an additional constraint would be required to enforce full cost recovery. However, this would be through a 'Ramsey' type pricing mark-up (a higher mark-up on the more inelastic demand — in this case, indoor demand), which minimises the loss in net social welfare of achieving cost recovery.

Ex ante and ex post assessments are made to check whether the investment recovers its capital costs over the planning horizon. Any loss incurred could be recovered through transfer payments in one of two ways:

- the revenue short fall could be recovered from an adjustment of the fixed part of a two-part tariff
- taxpayers in general could pay for the loss.

There could be further losses in net social welfare from the marginal cost of using these taxation instruments. Similarly, applying 'Ramsey' type prices or raising the valuation price uniformly across classes of demand would increase losses in net social welfare further.

Results

The discounted present value of the net social welfare loss associated with the decision to build both a desalination plant as well as the Sugarloaf pipeline for Melbourne is between $1526 million and $2154 million over 10 years, and between $2746 million and $3679 million over 20 years (table 5.2) depending on modelling assumptions. The cost of not using the Sugarloaf pipeline in the present model is between $159 million and $512 million over 10 years, and between $229 million and $736 million over 20 years.

For Perth, the mandate to build the second desalination plant and the ban on large aquifers results in a welfare loss of between $249 million and $282 million over a 10 year period, and between $468 million and $557 million over a 20 year period (table 5.2). When compared to the alternative of building a high-cost aquifer, the mandate on desalination results in a welfare loss of between $51 million and $114 million over a 10 year period, and between $241 million and $335 million over a 20 year period.

Table 5.2 **Welfare loss from mandated investments and policy bans over 10 and 20 years**

Expected net present values ($m)

	Melbourne model		*Perth model*	
	10 years	20 years	10 years	20 years
Welfare loss from mandated investments and policy bans relative to basecase (historic model)				
Central estimate	**1 978**	**3 476**	**267**	**533**
Sensitivity estimates				
Low inflows	1 526	2 746	249	468
High inflows	2 154	3 679	282	557
Low price elasticity	1 964	3 472	258	523
High price elasticity	1 963	3 449	272	546
Welfare loss from mandated desalination relative to mandated aquifer (historic model)				
Central estimate	..	..	**73**	**288**
Sensitivity estimates				
Low inflows	..	..	114	335
High inflows	..	..	51	241
Low price elasticity	..	..	75	287
High price elasticity	..	..	76	296
Welfare loss from banning use of Sugarloaf pipeline (present model)				
Central estimate	**217**	**312**	..	..
Sensitivity estimates				
Low inflows	512	736	..	..
High inflows	159	229	..	..
Low price elasticity	281	405	..	..
High price elasticity	198	285	..	..

.. Not applicable.

Source: Modelling results — Melbourne and Perth historic models.

Prices

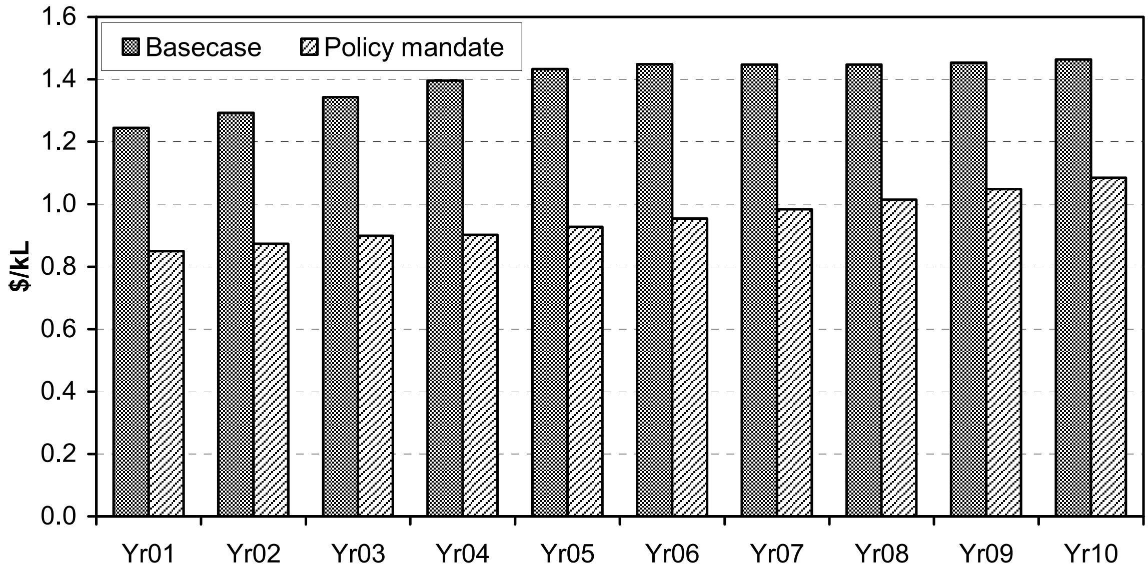
For both Melbourne and Perth, prices are lower with mandated supply augmentation and policy bans compared with the basecase.

For Melbourne, the expected price is about $0.40 per kilolitre lower over a 10 year period. If the cost of investments were recovered through the volumetric charge retrospectively, prices would be much higher and the loss in net social welfare would be higher because of the distortion in consumption.

For Perth, the expected price is $0.76 per kilolitre and remains below $1.31 per kilolitre in 90 per cent of scenarios (prices are for the 10 year central estimate). The mean prices for policy bans are compared to the basecase in figures 5.5 and 5.6.

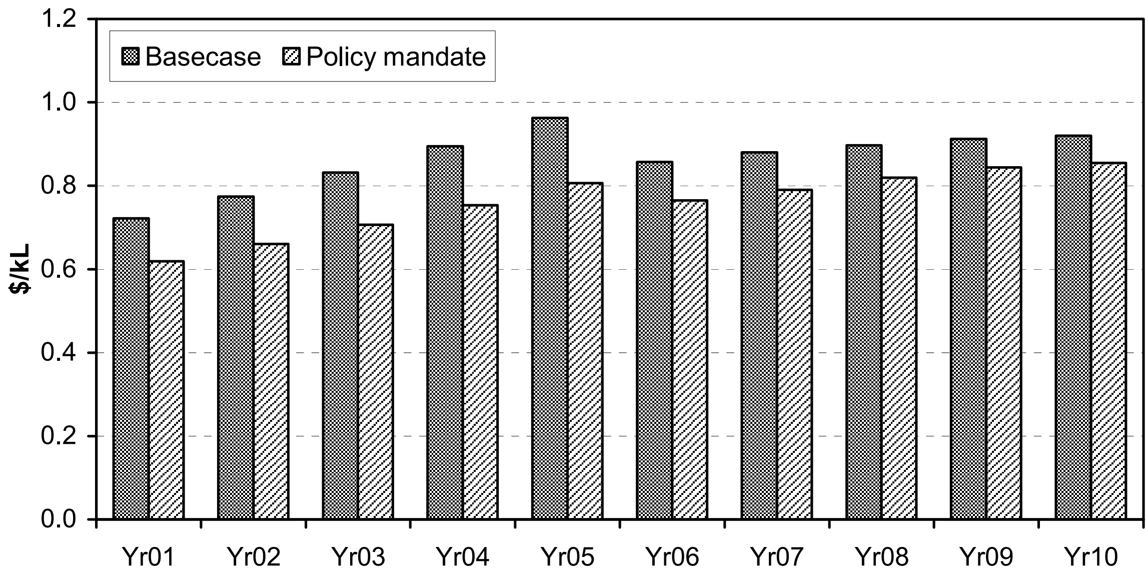
Consumers are better off from the forced investment as there is more water available that can be consumed at lower prices. The net social welfare losses are all on the supply side due to the lower prices that suppliers receive for their water (reduction in producer surplus).

Figure 5.5 **Expected retail prices under policy mandates and bans in the Melbourne model**



Source: Modelling results — Melbourne historic model.

Figure 5.6 **Expected retail prices under policy mandates and bans in the Perth model**



Source: Modelling results — Perth historic model.

Prices are higher in the present model for Melbourne when use of the Sugarloaf pipeline is banned compared with the basecase. This is because the marginal cost of a unit of water from the pipeline is lower than the marginal operating cost of the desalination plant. In many scenarios the marginal cost of water from the pipeline is below the resultant market price even when the marginal operating cost of desalination is above the market price.

Investment

For both Melbourne and Perth, the investment in desalination has an ex ante benefit–cost ratio less than one, indicating that it is not an efficient investment. For Perth, the ex ante benefit–cost ratio is 0.057 over 10 years and 0.035 over 20 years. The benefit–cost ratios are similarly small for the Melbourne simulations.

This is because the mandated investments remain unused in many rainfall scenarios, and even when they are used, they are rarely used at a capacity high enough to generate rents to recover the costs of capital. The operation of these plants most often falls in to one of three categories:

- the augmentations are not utilised at all when the retail price is below the marginal operating costs

- when the retail price exactly equals the marginal operating cost, the augmentation is used to supply water but does not earn rents that contribute to recovery of capital costs
- even when the plant is used to capacity and the price received is above marginal operating cost, the unit rent is insufficient to recover the capital cost associated with the augmentation.

In the Melbourne application, once the mandated trade and desalination augmentation have been built, there is no further investment. For some scenarios in the Perth model, additional investment is made in low-cost aquifers and the desalination plant upgrade.

5.3 Insights into real options or adaptive planning

Under a conventional approach to supply planning, a single supply augmentation plan is developed which best meets future inflow scenarios for a specified level for security of supply. As ACIL Tasman reported, supply planning of this nature is observed in many jurisdictions:

> Source planning in many jurisdictions … is predicated on an approach that seeks an approximately *least cost strategy under one assumed forward scenario regarding climate change and demand*, coupled with stress testing to ensure that the strategy is robust enough to deal with the assumed 'worst case scenario'. This typically means planning a strategy that is reasonably cost effective in relation to *either the worst case scenario or a highly conservative, low inflow scenario*. (ACIL Tasman 2007a, p. viii)

As outlined in chapter 5 of this inquiry report, making supply augmentation efficiently requires a sophisticated approach to dealing with uncertainty. Under a real options approach, there is no fixed plan, rather decisions are made over time depending on observed inflow outcomes. A real options approach considers all plausible future scenarios and seeks to achieve a least expected cost means of balancing supply and demand. This allows for greater flexibility in investment decision making (both the timing and type of investment), while still meeting the security of supply objective.

How a less flexible investment strategy is modelled

In order to obtain insights into the benefits of using a real options approach, a two-stage model that contains a single, optimal investment strategy for all scenarios is compared with the basecase multi-stage model that contains an optimal investment strategy for each scenario. To isolate the benefits of a real options approach, a cost minimisation framework is used. This reflects current approaches to supply planning, and demonstrates the value of real options in the absence of demand responses.

A cost minimisation model of each potable water supply system determines optimal investment and storage decisions to minimise the cost of running the system, for predetermined levels of consumption. This framework implicitly assumes that the demand for water is perfectly inelastic: regardless of the price of water, consumers demand the same quantity. Box 5.2 provides a description of how the basecase model is converted to a cost minimisation model.

Box 5.2 **Converting a price endogenous model to a cost minimisation model**

The following steps convert the basecase price endogenous model to a cost minimisation model to meet fixed demands by end-users:

- delete the objective function terms for the areas under the demand curves for the quantities demanded by consumers
- fix the quantities demanded based on expected demand from the basecase model
- multiply the remaining objective function coefficients by minus one and solve the model as a cost minimising model.

The shadow price on the fixed quantities demanded now represent the expected discounted marginal cost of supply of the exogenously specified demands.

A two-stage model is solved to find the single, optimal investment plan that best meets all possible inflow scenarios. This single strategy has to be able to deal with all extreme scenarios, from the very wet to the very dry. This can be contrasted with the solution from a multi-stage model, which contains unique investment strategies for each scenario. This is analogous to the real options or adaptive management approach to investment decision making described by Borison et al (2008).

The difference between the costs of the two-stage and multi-stage models gives insights into the value of a flexible or adaptive planning approach to investment decision making. The multi-stage model is able to achieve cost savings and efficiency gains by adjusting the timing and mix of investments to better meet changes in circumstances brought about by scenario-specific inflows.

Results

Expected net present value of cost to meet a given demand is lower under the multi-stage model framework than the two-stage model (table 5.3).

Table 5.3 **Cost savings of a real options approach to planning over 10 years**

Expected net present values ($m)

	Melbourne model		*Perth model*	
	Historic	Present	Historic	Present[a]
Net present value of costs under a real options approach to planning				
Central estimate	**1 865**	**2 374**	**979**	**836**
Sensitivity estimates				
Low inflows	2 642	3 363	997[b]	1 056
High inflows	1 403	1 786	743	683
Net present value of costs under a two-stage approach to planning				
Central estimate	**2 772**	**3 151**	**1 206**	**969**
Sensitivity estimates				
Low inflows	4 456	4 838	1 159[b]	1 154
High inflows	1 715	2 108	969	778
Net present value of cost savings arising from a real options approach to planning				
Central estimate	**907**	**776**	**227**	**133**
Sensitivity estimates				
Low inflows	1 815	1 474	162[b]	97
High inflows	312	322	225	95

[a] For the Perth present model, the abstraction deficit on existing aquifers is reduced to avoid model infeasibility in the early dry years. [b] The level of fixed demand is reduced for the low inflows sensitivity analysis for the Perth historic model (analogous to water restrictions being enforced) to ensure the model is feasible.

Source: Modelling results — Melbourne and Perth historic and present models.

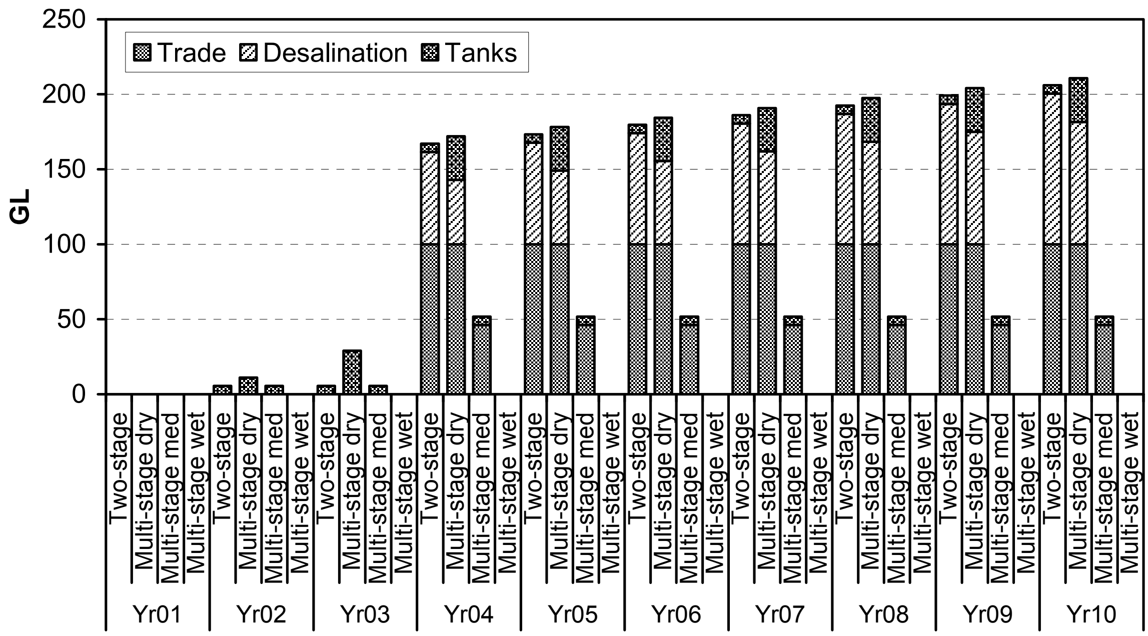
Investment

Investment is brought forward in the two-stage model so that water can be supplied if a dry year occurs early in the planning period. The trade-off is that the expected capacity utilisation of the new capacity is low because capacity is installed for the worst case scenario, and consequently is under utilised in other scenarios.

For Melbourne, the two-stage model solution has more investment than is required in a large proportion of scenarios. A large amount of rural–urban interconnection, desalination and tank capacity is created, more than is needed in all but the driest of scenarios. The multi-stage model meets the demand targets at lower expected cost by only investing in the extreme situations (although, this does require a higher level of investment in those situations).

This highlights that less flexible investment decision making leads to outcomes driven by a greater emphasis on worst case scenarios. In many scenarios, high costs are incurred for investments that are unused. For example, in the extremely wet scenario shown in figure 5.7 (which has approximately the same likelihood of occurring as the worst case scenario that the investment plan accommodates), there is a large amount of excess capacity that is not utilised. In this wet scenario a multi-stage investment planning process would have avoided supply augmentation.

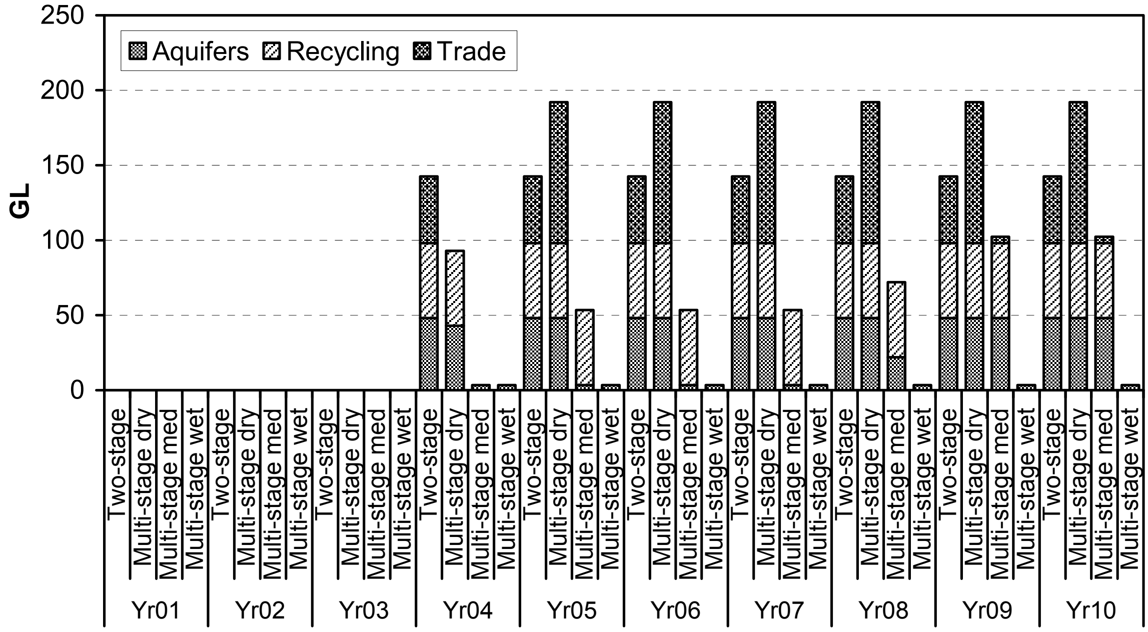
Figure 5.7 **Two-stage versus multi-stage investment planning in the Melbourne model**



Source: Modelling results — Melbourne historic model.

For Perth, in the two-stage model, the decision about how much capacity to build is taken in year 1 and comes on line in year 4 (figure 5.8). Enough capacity is built to allow for the worst case scenario. If a more typical inflow pattern is observed (indeed, anything other than the worst case scenario), there will be excess capacity.

Figure 5.8 **Two-stage versus multi-stage investment planning in the Perth model**



Source: Modelling results — Perth historic model.

In the multi-stage model, investment decisions are taken over time for scenarios of inflows as they evolve. This approach makes it possible to delay or even avoid new investment in capacity. Under a wet scenario, only a small amount of capacity is added. Under a 'medium inflows' scenario, investment in aquifers is initially low, but increases overtime in response to observed inflows. Further, the decision to invest in trade is delayed until year 6 (to come on line in year 9), and only a small amount of capacity is required. In a dry scenario, the decision to invest in aquifers and recycling is taken in year 1 (as was the case in the two-stage model). However, the investment decision in trade is not taken until year 2 (to come on line in year 5). A higher capacity is required relative to the two-stage model because waiting to invest means the existing aquifers and dams are drawn upon more heavily as the dry persists. However, the probability of the dry scenario occurring is low.

5.4 Uniform retail pricing over time

Regulators and governments in Australia typically set prices for periods of time (approximately 3–5 years) based on estimates of long-run marginal cost (LRMC). There are a variety of approaches used to estimate LRMC prices, with the most prominent being 'average incremental cost' and 'perturbation' methods. Each of these methods require capital expenditure forecasts for a suitable investment planning horizon, typically 20 to 25 years (ESC 2005).

How are uniform prices modelled?

The Commission's basecase model uses flexible long-run marginal cost pricing (chapter 4). Therefore government LRMC pricing policies were approximated in the Commission's modelling as a 'smoothed' retail pricing policy (box 5.3). Uniform pricing policies have been previously modelled in a stochastic linear programming framework (for example Lane and Littlechild 1976, 1980). Uniform pricing over time is modelled by constraining retail prices to be the same for set periods of time (three years for Melbourne and four years for Perth). Although prices must be uniform over periods of time, the level of these uniform prices is endogenous — that is, the level of uniform prices are those that maximise net social welfare subject to the policy constraint.

Figure 5.9 is a representation of the uniform pricing structure in the model, with the price determined every two years and only two states of nature (this is for illustrative purposes). All nodes in years 1 and 2 must have the same consumer price, regardless of the inflow state in these years. In year 3, consumer prices are reset for nodes in years 3 and 4. All nodes in the same box share a single price. Prices set in year 3 reflect the inflow states in years one and two. At the start of a new regulatory period, there will be the same number of prices as nodes in the previous period. For example, in years one and two there is one price, and in years three and four, there are four uniform prices.

Another approach to modelling the current LRMC pricing policies would be to mimic the perturbation and average incremental cost methodologies used by regulators. However, this was not pursued because endogeneity between pricing and capital expenditure makes it difficult to implement a constraint based on perturbation or average incremental cost methodologies.

Box 5.3 **Modelling uniform pricing as a constraint on consumer prices**

Uniform pricing is modelled as a constraint on consumer prices. Investment decisions and supply are optimally determined, subject to the distortion in consumption induced by imposing uniform retail prices.

This approach captures the key cost of a smoothed pricing regime within a regulatory price setting period: consumers do not face higher prices for water during times of scarcity, nor do they face lower prices when water is abundant.

This results in a 'wedge' between the retail price and the supply price based on the opportunity cost of supply. The wedge is positive when the consumer price is less than the opportunity cost of supply, and negative when the consumer price exceeds the opportunity cost of supply. On an expected value basis, the gaps between the demand price and the opportunity cost of water even out, as the extra revenue when price is in excess of marginal cost exactly offsets the losses when price is less than marginal cost.

The distortions in the consumption patterns brought about by imposing uniform pricing distort investment and supply procurement. Under uniform prices, several consecutive dry years (within a regulatory period) could trigger investment in new, more expensive sources of supply required to meet the level of demand implied by a uniform price. This would mean that supply costs increase and diverge from demand prices. However, under flexible prices, prices would have risen, and consumption would have fallen, potentially alleviating the need for costly new investment.

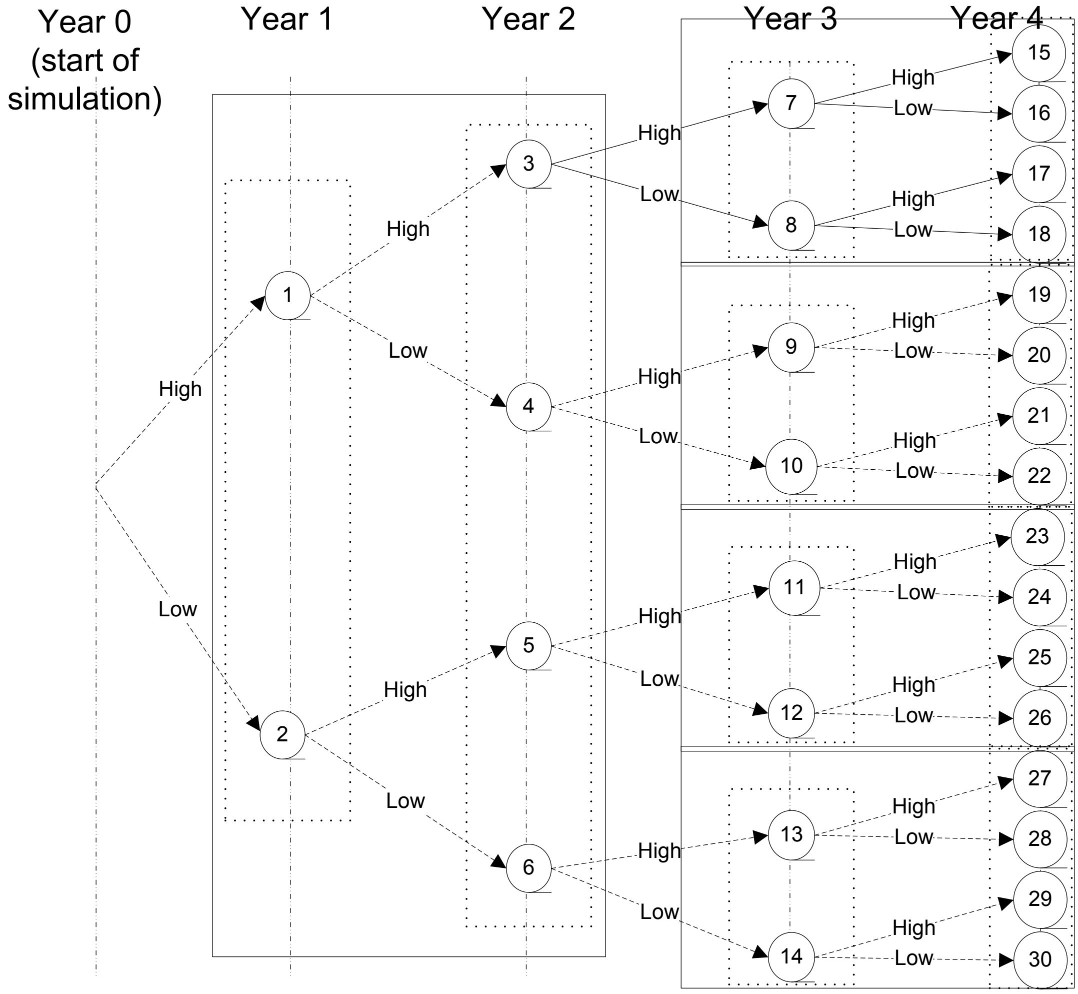
Uniform prices reduce the flexibility of prices to reduce demand when water is scarce, increasing the need for supply augmentation. The improvements in capacity utilisation brought about by flexible pricing give overall net social payoff gains.

The stylised tableau below illustrates how uniform pricing was modelled for a single year (fixing prices across nodes), and draws upon the linearised demand tableau in box 3.2 and the tree diagram in figure 5.9.

Variable / Row	D_1 n=1	D_2 n=1	D_3 n=1	D_1 n=2	D_2 n=2	D_3 n=2	Supply n=1	Supply n=2	UP	Right hand side
Demand–supply$_{n=1}$	Q_1	Q_2	Q_3				-1			≤ 0
Demand–supply$_{n=2}$				Q_1	Q_2	Q_3		-1		≤ 0
Convex demand$_{n=1}$	1	1	1							≤ 1
Convex demand$_{n=2}$				1	1	1				≤ 1
Uniform price$_{n=1}$	P_1	P_2	P_3						-1	= 0
Uniform price$_{n=2}$				P_1	P_2	P_3			-1	= 0

The uniform price (UP) is endogenously determined. Each node has unique supply and demand activity variables (Supply$_n$, D_{1n}, D_{2n} and D_{3n}) as well as demand–supply balance and convexity constraints (Demand–supply$_n$ and Convex demand$_n$). The node-specific uniform price constraints (Uniform price$_n$) ensure that the uniform price variable (UP) jointly applies at both nodes.

Figure 5.9 **Illustrative representation of uniform pricing in the model**[a]



[a] In this example, the regulatory period is two years, for ease of diagrammatic exposition. In the model, the regulatory period is three years for Melbourne and four years for Perth.

Results

Applying uniform prices reduces welfare (table 5.4) because consumption decisions do not reflect the cost of supply. Net social welfare can be improved if prices are flexible, as in the basecase model.

Table 5.4 **Welfare costs of uniform retail pricing over 10 years**
Expected net present values ($m)

	Melbourne model		*Perth model*	
	Historic	Present	Historic	Present
Central estimate	**27**	**5**	**83**	**332**
Sensitivity estimates				
Low inflows	102	12	126	468
High inflows	2	1	47	207
Low price elasticity	30	6	98	509
High price elasticity	0	0	83	249

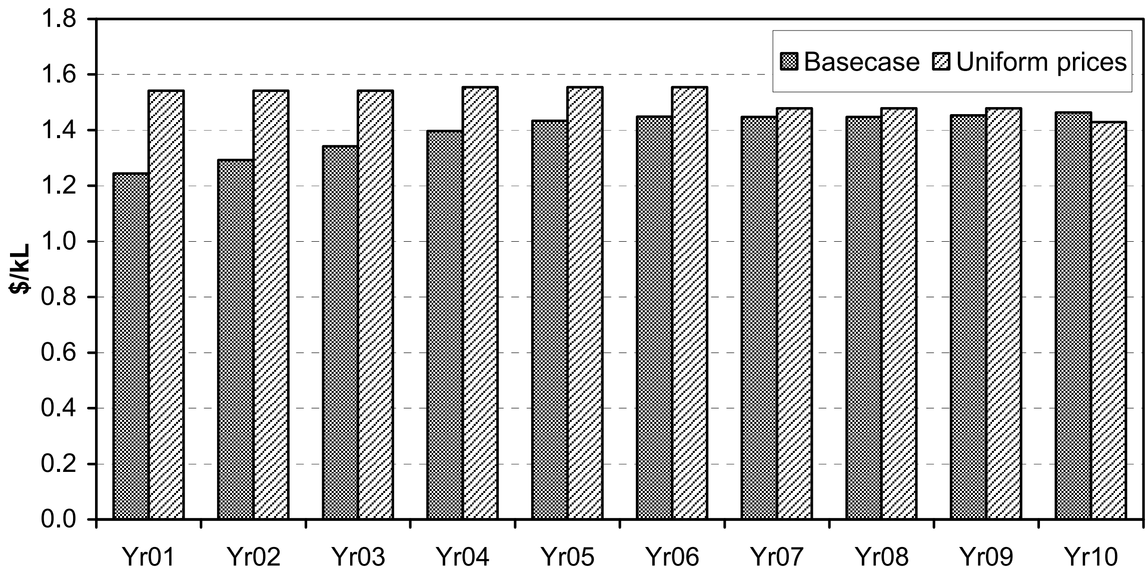
Source: Modelling results — Melbourne and Perth historic and present models.

The welfare impact of this approximation of uniform pricing is a lower bound estimate of the cost of actual LRMC pricing for two main reasons. First, the approach used is, in effect, a smoothed scarcity price. The only distortion caused by the policy results from a lack of price flexibility. Second, the uniform constraint is imposed only on the prices charged to consumers (box 5.3). To the extent that LRMC pricing by regulators is built up using an estimate of the incremental cost of new capacity, then used to determine a price for consumers *and* suppliers, this is likely to distort investment decisions, resulting in higher costs than estimated in the modelling.

Prices

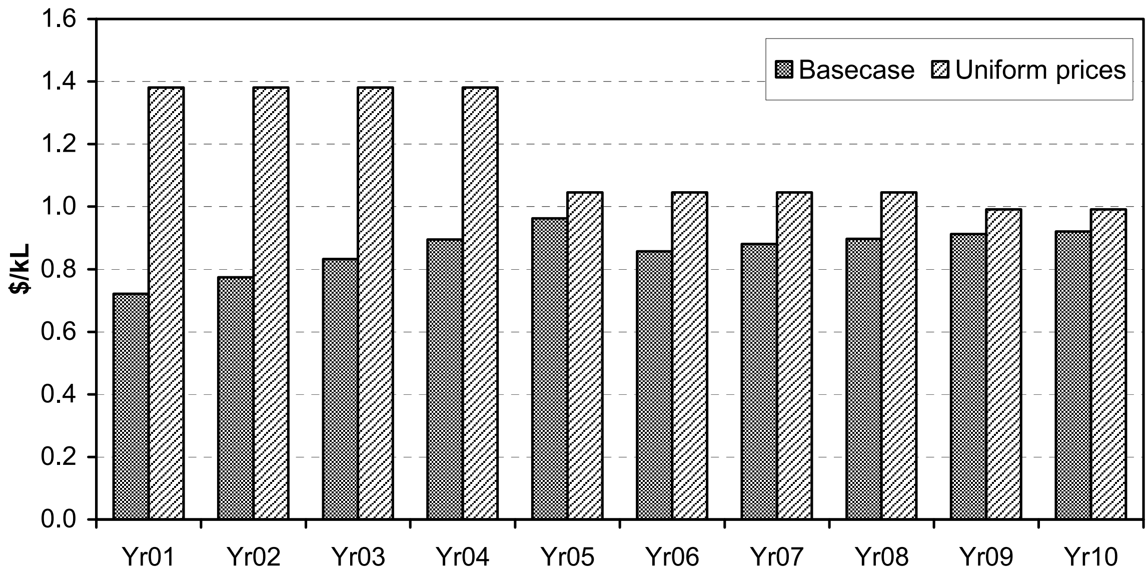
Prices are on average higher under uniform retail pricing (figures 5.10 and 5.11). Relatively high prices are also still possible under uniform pricing. This is particularly the case in the present version of the Perth model, where a high price is needed in early periods to reduce demand and reduce drawdown so that water can be supplied in later, dry scenarios.

Figure 5.10 **Expected prices with flexible and uniform pricing in the Melbourne model**



Source: Modelling results — Melbourne historic model.

Figure 5.11 **Expected prices with flexible and uniform pricing in the Perth model**

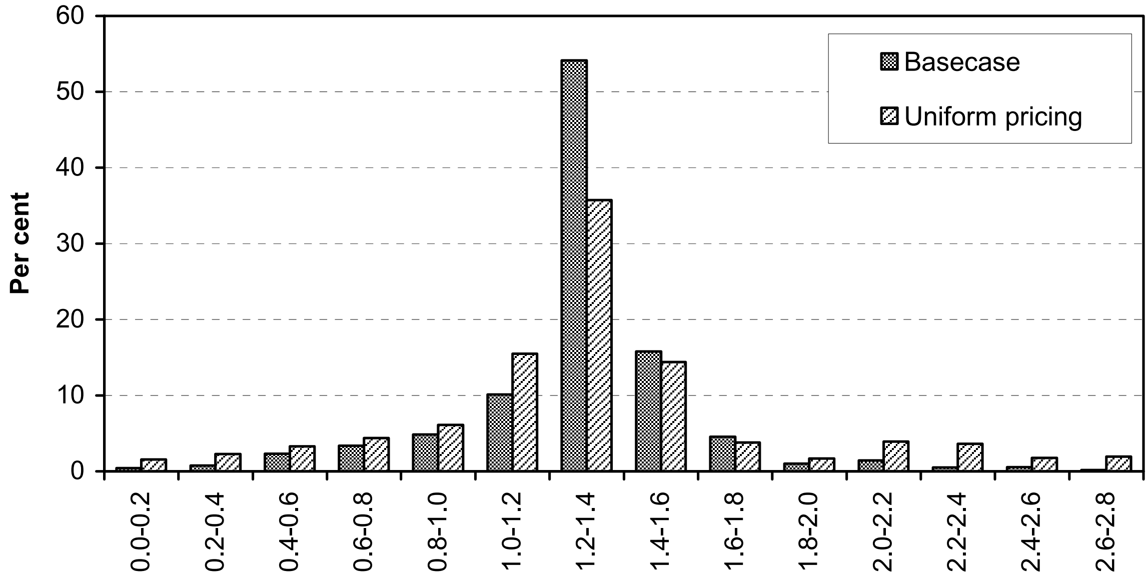


Source: Modelling results — Perth historic model.

Investment

Investment is more risky under uniform pricing. Figure 5.12 shows that the distribution of ex post benefit–cost ratios for a given investment is more heavily distributed in the tails under uniform pricing. Reducing risk to consumers through uniform pricing shifts the burden of the risk on to suppliers. This is because water suppliers need to deal with variable inflows without any assistance from consumers (within a pricing block) through changes in consumption induced by changes in price.

Figure 5.12 **Ex post benefit–cost ratios of an investment in rural–urban interconnection in Melbourne**



Source: Modelling results — Melbourne historic model.

5.5 Summary

A summary of the welfare costs associated with all the policies discussed in this chapter is presented in table 5.5.

Table 5.5 **Benefits and costs of policy scenarios**

Expected net present values ($m)

	Melbourne model		*Perth model*	
Welfare costs of water restrictions over 10 years				
	Historic	Present	Historic	Present
Central estimate	**691**	**765**	**18**	**39**
Sensitivity estimates				
Low inflows	1 502	860	35	80
High inflows	419	779	8	17
Low price elasticity	1 139	1 308	22	48
High price elasticity	445	495	16	35
Welfare loss from mandated investments and policy bans over 10 and 20 years (historic model)				
	10 years	20 years	10 years	20 years
Central estimate	**1 978**	**3 476**	**267**	**533**
Sensitivity estimates				
Low inflows	1 526	2 746	249	468
High inflows	2 154	3 679	282	557
Low price elasticity	1 964	3 472	258	523
High price elasticity	1 963	3 449	272	546
Welfare loss from mandated desalination relative to mandated aquifer (Perth historic model)				
			10 years	20 years
Central estimate	..	..	**73**	**288**
Sensitivity estimates				
Low inflows	..	..	114	335
High inflows	..	..	51	241
Low price elasticity	..	..	75	287
High price elasticity	..	..	76	296
Welfare loss from banning use of Sugarloaf pipeline (Melbourne present model)				
	10 years	20 years		
Central estimate	**217**	**312**	..	..
Sensitivity estimates				
Low inflows	512	736	..	..
High inflows	159	229	..	..
Low price elasticity	281	405	..	..
High price elasticity	198	285	..	..
Cost savings of a real options approach to planning				
	Historic	Present	Historic	Present
Central estimate	**907**	**776**	**227**	**133**
Sensitivity estimates				
Low inflows	1 815	1 474	162	97
High inflows	312	322	225	95

(continued next page)

Table 5.5 (continued)

	Melbourne model		Perth model	
Welfare costs of uniform retail pricing over 10 years				
	Historic	Present	Historic	Present
Central estimate	**27**	**5**	**83**	**332**
Sensitivity estimates				
Low inflows	102	12	126	468
High inflows	2	1	47	207
Low price elasticity	30	6	98	509
High price elasticity	0	0	83	249

.. Not applicable.

Source: Modelling results — Melbourne and Perth present and historic models.

A Introduction to modelling framework

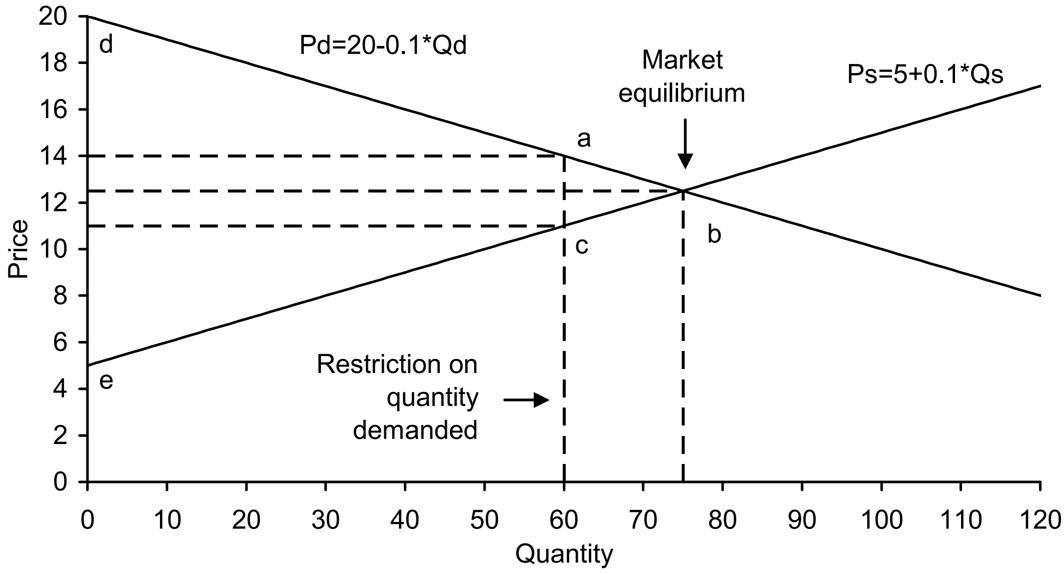
The purpose of this appendix is to provide a basic introduction to the partial equilibrium modelling framework and concepts, and their stochastic counterparts. This is achieved using simple 'text book' demand and supply models.

A.1 Market equilibrium

The market equilibrium is computed by maximising net social welfare (the sum of Marshallian consumer and producer surplus), as illustrated in box A.1. That is, the maximisation of the area under the demand function (integral of the demand function) less the total cost of supply activities (in this simple case, the area under the supply function). This maximisation problem is subject to the commodity balance constraint, whereby the quantity demanded must be less than or equal to the quantity supplied.

The tableau in panel A (box A.1) represents the mathematical programming model that yields the solution to the market equilibrium depicted in the figure. The market equilibrium is at point b, where the quantity demanded (Qd) equals the quantity supplied (Qs), which is 75. At point b, the demand price (marginal utility given by the derivative of the area under the demand function) equals the supply price (marginal cost given by the derivative of the area under the supply function), which is 12.5. In the programming tableau in panel A, the equilibrium price is given by the value of the Lagrangean multiplier associated with the commodity balance constraint. The objective function value is consumer surplus plus producer surplus (welfare), which is 562.5.

Box A.1 **A simple illustration of the core model framework**



Panel A – Programming tableau for the market model

Objective function: Max welfare	$20QD–0.1/2QD^2$	$–5QS–0.1/2QS^2$	RHS Type	RHS Term
Variable	QD	QS		
Row				
Commodity balance	1	–1	≤	0

Panel B – Programming tableau for the policy constrained market model

Objective function: Max welfare	$20QD–0.1/2QD^2$	$–5QS–0.1/2QS^2$	RHS Type	RHS Term
Variable	QD	QS		
Row				
Commodity balance	1	–1	≤	0
Policy constraint	1		≤	60

A.2 Incorporating a restriction on quantity demanded

To simulate the impact of a restriction on the quantity demanded (like a water restriction), a constraint on the quantity demanded is added to the programming model. The tableau in panel B of box A.1 represents the model used to simulate the restriction on demand policy.

The quantity demanded is restricted to being less than or equal to 60. In this case, the equilibrium quantity is 60 and the price is 11 (the marginal cost of supply), as indicated at point c in the figure in box A.1. At a quantity of 60, consumers are willing to pay a price of 14. At the margin, the restriction is costing 3 (the gap between the demand price and supply price) for the restricted quantity. In the programming model, this gap is given by the value of the Lagrangean multiplier on the policy constraint used to restrict demand.

The value of the objective function (540) is welfare for the policy constrained model. The difference between the objective functions of the two models is the loss of welfare from imposing the policy, which is 22.5 and is represented by the triangle abc in the figure in box A.1.

A.3 Incorporating risk using a state-contingent approach

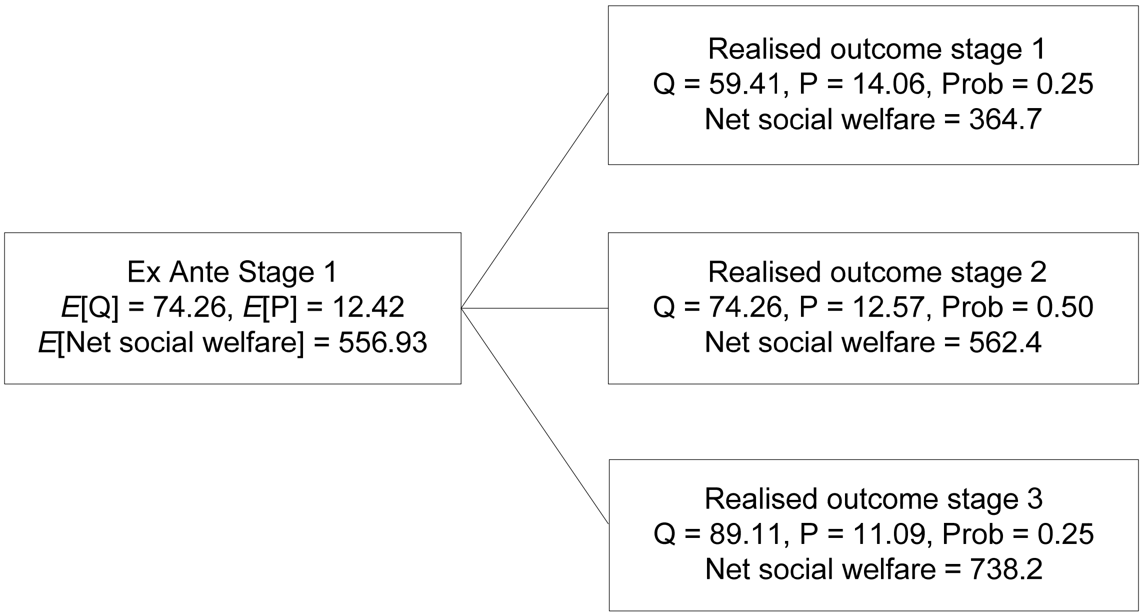
A simple illustration of the incorporation of the risk approach into the core programming model using a state-contingent approach is presented in box A.2, which is based on the market model in box A.1. Three states of nature are assumed to represent production or supply risk. In the first stage (before the states of nature are revealed), the market needs to decide on the quantity to supply using the expected (ex ante) supply function.

In the second stage, the states of nature are revealed. The realised (ex post) production levels may be 0.8, 1, or 1.2 times the expected level (with probabilities of 0.25, 0.5, and 0.25, respectively). The programming tableau for this two stage, three state market model is set out in box A.2. The shaded vertical column of numbers under the variable for quantity supplied (QS) is the representation of risk as a multi-output technology described by Quiggin and Chambers (2006).

Box A.2 State-contingent price endogenous programming model

Objective function: Max *Expected* Welfare	$f_1(QD1)$[a]	$f_2(QD2)$[b]	$f_3(QD3)$[c]	$g(QS)$[d]	RHS Type	RHS Term
Variable	QD1	QD2	QD3	QS		
Row						
Commodity balance state 1	1			–0.8	≤	0
Commodity balance state 2		1		–1.0	≤	0
Commodity balance state 3			1	–1.2	≤	0

[a] $f_1(QD1) = 0.25(20QD–0.1/2\ QD1^2)$ [b] $f_2(QD2) = 0.5(20QD2–0.1/2QD2^2)$
[c] $f_3(QD3) = 0.25(20QD3–0.1/2QD3^2)$ [d] $g(QS) = –5QS–0.1/2QS2$



A condition for optimality is that the sum over the three demand prices weighted by their probabilities and relative yields is equal to the expected (ex ante) marginal cost of supply.

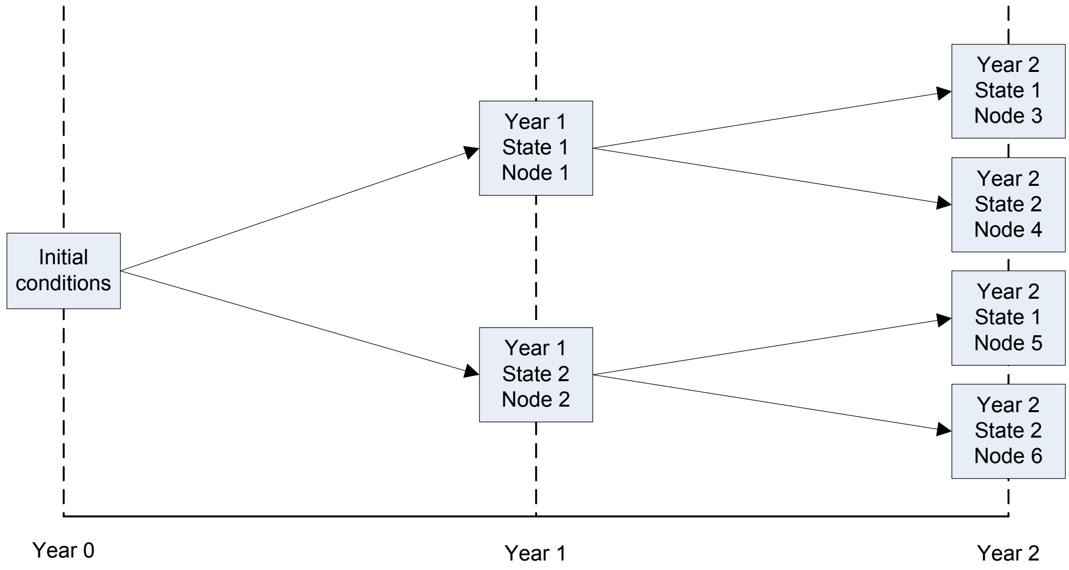
That is (0.25 x 0.8 x 14.06) + (0.5 x 1 x 12.57) + (0.25 x 1.2 x 11.09) = 5 + 0.1 x 74.26.

The market equilibrium has an expected supply of 74.26. The actual ex post supply in each state of nature is 59.41, 74.26, and 89.11, which when weighted and summed gives the expected quantity. The market clearing realised prices are 14.06, 12.51, and 11.09. The equilibrium price condition is that the sum over the market clearing prices arising in the three states of nature (weighted by their probability and relative yield) is equal to the expected (ex ante) marginal cost of supply. The objective function is the expected value of welfare. Ex post, there are three realised levels of welfare. The sum of these realised outcomes, weighted by their probability, is equal to the expected value of welfare.

A.4 A miniature urban water model

A miniature urban water model is presented in table A.1 as a programming tableau. It is based on the scenario tree in figure A.1.

Figure A.1 **Scenario tree for the miniature urban water model**



The scenario tree has:

- a two year time horizon (year 1 and 2)
- two contingent states of nature (states 1 and 2)
- four scenarios
  – year1.state1/year2.state1
    year1.state1/year2.state2
    year1.state2/year2.state1
    year1.state2/year2.state2
- six nodes (nodes 1 to 6).

In the variable and constraint names:

- the Yr number represents the year in the time horizon
- the N number represents the node number in the scenario tree.

For the linearised demand variables, L represents the number of the linearised segment.

Table A.1 **Tableau for state-contingent model[a] (left-hand-side page)**

Variable	DamStorageYr1N1	QDesalCapYr1N1	DamStorageYr1N2	QDesalCapYr1N2	DamStorageYr2N3	DamStorageYr2N4	DamStorageYr2N5	DamStorageYr2N6	DemandYr1N1L1	DemandYr1N1L2	QsDamYr1N1	DemandYr1N2L1	DemandYr1N2L2	QsDamYr1N2	DemandYr2N3L1	DemandYr2N3L2
ObjectiveFn		-a		-a					b	b	-c	b	b	-c	b	b
ConvexDemYr1N1									1	1						
WaterBalYr1N1									g	g	-1					
DamsupplyYr1N1	1										1					
ConvexDemYr1N2												1	1			
WaterBalYr1N2												g	g	-1		
DamsupplyYr1N2			1											1		
ConvexDemYr2N3															1	1
WaterBalYr2N3															g	g
DamsupplyYr2N3	-1				1											
DesalSupplyYr2N3		-i														
TerWaterBalYr2N3					-1											
ConvexDemYr2N4																
WaterBalYr2N4																
DamsupplyYr2N4	-1					1										
DesalSupplyYr2N4		-i														
TerWaterBalYr2N4						-1										
ConvexDemYr2N5																
WaterBalYr2N5																
DamsupplyYr2N5			-1				1									
DesalSupplyYr2N5				-i												
TerWaterBalYr2N5							-1									
ConvexDemYr2N6																
WaterBalYr2N6																
DamsupplyYr2N6			-1					1								
DesalSupplyYr2N6				-i												
TerWaterBalYr2N6								-1								
Lower Bnd	k	0	k	0	k	k	k	k	0	0	0	0	0	0	0	0
Upper Bnd	l	1	l	1	l	l	l	l	+	+	+	+	+	+	+	+

[a] The lower case letters represent a category of non-zero coefficients relevant to the variable (column) in the equation (row), bounds on a variable (column), or a constraint/right-hand-side term. For bounds, a plus sign (+) represents an unbounded variable.

Table A.1 **(right-hand-side page)**

QsDamYr2N3	QsDesalYr2N3	TermDamStorYr2N3	DemandYr2N4L1	DemandYr2N4L2	QsDamYr2N4	QsDesalYr2N4	TermDamStorYr2N4	DemandYr2N5L1	DemandYr2N5L2	QsDamYr2N5	QsDesalYr2N5	TermDamStorYr2N5	DemandYr2N6L1	DemandYr2N6L2	QsDamYr2N6	QsDesalYr2N6	TermDamStorYr2N6	RHS TYPE	RHS TERM
-c	-d	e	b	b	-c	d	e	b	b	-c	d	e	b	b	-c	d	e		
																		≤	1
																		≤	0
																		≤	h_1
																		≤	1
																		≤	0
																		≤	h_2
																		≤	1
-1	-1																	≤	0
1																		≤	h_1
	1																	≤	0
		1																≤	0
			1	1														≤	1
			g	g	-1	-1												≤	0
					1													≤	h_2
						1												≤	0
							1											≤	0
								1	1									≤	1
								g	g	-1	-1							≤	0
										1								≤	h_1
											1							≤	0
												1						≤	0
													1	1				≤	1
													g	g	-1	-1		≤	0
															1			≤	h_2
																1		≤	0
																	1	≤	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		

Model variables

Demand for water (Demand)

The model has demand for water at each node, represented by two variables representing the linearisation of the consumer welfare function into two segments.

Sources of water supply (QsDam, QsDesal)

There are two sources of water supply, a pre-existing dam and potential investment in a desalination plant. Supply from the dam (QsDam) can occur at any node (subject to water available in storage). Supply from desalination (QsDesal) can only occur in year 2 (nodes 3 to 6). This is because the investment decision (QDesalCap) needs to be taken in year 1 with a one year lag between investment and production.

Investment in desalination (QDesalCap)

There are two investment decisions in desalination in year 1, one for state 1 (node 1) and the other for state 2 (node 2). Investment at node 1 can supply water at nodes 3 and 4 in year 2. Investment at node 2 can provide supply at nodes 5 and 6 in year 2. There is an upper bound on the size (annual production capacity) of each desalination investment.

Dam storage (DamStorage, TermDamStor)

There are dam storage variables at each node in the scenario tree. There is an upper and lower bound on the volume of water that can be stored in the dam.

There is also a terminal storage variable for water stored at the end of the planning period (one for each terminal period nodes — nodes 3 to 6).

These variables represent the (perfectly price elastic) demand for water to be stored at the end of the planning period.

Objective functions and model constraints

Objective function (ObjectiveFn)

The objective function maximises the expected present value of net social welfare, which is the sum (over time and across states) of:

- the gross consumer welfare from water consumption
- minus the annualised investment cost in desalination
- minus the operating cost of water supplied from the dam
- minus the operating cost of producing water from desalination
- plus the benefit from water in storage in the terminal period.

The coefficients in the objective function are probability and discount weighted to reflect the probability of the events at each node and the year in which the relevant event occurs.

Convexity constraint on linear demand activities (ConvexDem)

This constraint ensures that the linearised demand variables are a corner point (single variable) or the linear combination of two adjacent variables. The Lagrangean multiplier for the constraint is the probability and discount weighted consumer surplus.

Water balance constraint (WaterBal)

This constraint ensures that water used by consumers has to be less than or equal to that supplied from water stored in the dam and desalination (if available).

The Lagrangean multiplier on the constraint represents the probability and discount weighted retail price of water.

Water supplied from the dam constraint (DamSupply)

This constraint ensures that storages in dams (sources and uses of dam water) balance over time and across scenarios. Dam supplies to consumers during the current period plus closing storage for the next period must be less than or equal to the opening storage in the current period plus inflows during the current period.

The Lagrangean multiplier on this constraint represents the probability discounted unit rent (imputed price) of water supplied from the dam (and held in storage).

Supply from desalination constraint (DesalSupply)

This constraint ensures that the water supplied from a desalination plant (if built) must be less than or equal to the installed capacity of the desalination plant.

The Lagrangean multiplier on this constraint represents the probability discounted unit (volumetric) rent paid for water supplied from the plant. It is only positive when the plant is at capacity and it is a measure of the margin above the operating cost of the plant. This rent contributes to the recovery of the investment cost of the plant, and any capacity rents if the installed capacity of the plant is at its upper bound.

Terminal water balance constraint (TerWaterBal)

This constraint ensures that the demand for water in the terminal period of each scenario is less than or equal to the water stored in the terminal period.

In this simple model, there is a fixed price (perfectly elastic) demand for water in the terminal period.

The Lagrangean multiplier for this constraint is the probability discounted weighted price of water held in storage in the terminal period.

B Mathematics of the model

A complete mathematical specification of the urban water model is presented in this appendix.

All variables in the model are positive (i.e. greater than or equal to zero). The variables vRestr and vRestr0 are binary: taking only a value of 0 or 1. Investment variables may either be binary or continuous, depending on the nature of the supply source.

Equations for the basecase, market model, representing flexible prices are presented first (B.1). Policy interventions are modelled by constraining the basecase model according to the equations listed in section B.2. All sets, parameters and variables in the model are detailed in section B.3.

B.1 Core market model

Objective function

$$\text{Max } NSW = \tag{B.1}$$

Objective function: area under the linearised demand functions

$$\sum_{YrNd(Yr,N)} \sum_{d} \sum_{l} Area_{YrNd(Yr,N),d,l} . Qd_{YrNd(Yr,N),d,l}$$

plus linearised benefit from storage in the terminal period

$$+ \sum_{LastYrNd(Yr,N)} \sum_{m} TermStorArea_{LastYrNd(Yr,N),m} . QdDam_{LastYrNd(Yr,N),m}$$

less total cost of desalination investment and water supply

$$- \sum_{YrNd(Yr,N)} CapExDesal_{YrNd(Yr,N)} . QDesalCap_{YrNd(Yr,N)}$$

$$- \sum_{YrNd(Yr,N)} OpExDesal_{YrNd(Yr,N)} . QsDesal_{YrNd(Yr,N)}$$

less total cost of recycling investment and water supply

$$- \sum_{YrNd(Yr,N)} CapExRecyc_{YrNd(Yr,N)}.QRecycCap_{YrNd(Yr,N)}$$
$$- \sum_{YrNd(Yr,N)} OpExRecyc_{YrNd(Yr,N)}.QsRecyc_{YrNd(Yr,N)}$$

less total cost of tank investment and water supply

$$- \sum_{YrNd(Yr,N)} CapExTanks_{YrNd(Yr,N)}.QTanksCap_{YrNd(Yr,N)}$$
$$- \sum_{YrNd(Yr,N)} OpExTanks_{YrNd(Yr,N)}.QsTanks_{YrNd(Yr,N)}$$

less total cost of trade investment and water supply

$$- \sum_{YrNd(Yr,N)} CapExTrade_{YrNd(Yr,N)}.QTradeCap_{YrNd(Yr,N)}$$
$$- \sum_{YrNd(Yr,N)} OpExTrade_{YrNd(Yr,N)}.QsTrade_{YrNd(Yr,N)}$$

less total cost of aquifer investment and water supply

$$- \sum_{YrNd(Yr,N)} CapExAquif_{YrNd(Yr,N)}.QAquifCap_{YrNd(Yr,N)}$$
$$- \sum_{YrNd(Yr,N)} OpExAquif_{YrNd(Yr,N)}.QsAquif_{YrNd(Yr,N)}$$

less total cost of new dam investment and water supply

$$- \sum_{YrNd(Yr,N)} CapExNwDam_{YrNd(Yr,N)}.QNwDamCap_{YrNd(Yr,N)}$$
$$- \sum_{YrNd(Yr,N)} OpExNwDam_{YrNd(Yr,N)}.QsNwDam_{YrNd(Yr,N)}$$

less the marginal operating cost of existing dam water supply

$$- \sum_{YrNd(Yr,N)} OpExDam_{YrNd(Yr,N)}.QsDam_{YrNd(Yr,N)}$$

Demand and convexity constraints

Convexity of linearised demands

$$\sum_{l} Qd_{YrNd(Yr,N),d,l} = 1 \qquad \text{(B.2)}$$

Convexity of linearised demand for terminal storage

$$\sum_{m} QdDam_{LastYrNd(Yr,N),m} = 1 \qquad \text{(B.3)}$$

Balance of the demand for dam water storage in the terminal period

$$QstDam_{LastYrNd(Yr,N)} - \sum_{m} QtySt_{m}.QdDam_{LastYrNd(Yr,N),m} = 0 \qquad \text{(B.4)}$$

Water demand balance

$$\sum_{d}\sum_{l} Qty_{YrNd(Yr,N),d,l}.Qd_{YrNd(Yr,N),d,l} - QsDam_{YrNd(Yr,N)} - QsDesal_{YrNd(Yr,N)}$$
$$-QsRecyc_{YrNd(Yr,N)} - QsTanks_{YrNd(Yr,N)} - QsTrade_{YrNd(Yr,N)} - QsAquif_{YrNd(Yr,N)} \leq 0 \qquad \text{(B.5)}$$

Existing dam constraints

Water supply from existing dams

$$QsDam_{YrNd(Yr,N)} + QstDam_{YrNd(Yr,N)} - (1 - EvapLoss).QstDam_{YrNd(Yr-1,NP)}$$
$$\sum_{NwDamCapMap(Yr,N,YrP,NP)} NwDamInflowAtNode_{YrNd(Yr,N)}.QNwDamCap_{YrNd(YrP,NP)} \qquad \text{(B.6)}$$
$$\leq InflowAtNode_{YrNd(Yr,N)} + S0\big|_{Yr=FirstYr}$$

Maximum dam storage capacity

$$QstDam_{YrNd(Yr,N)} -$$
$$\sum_{NwDamCapMap(Yr,N,YrP,NP)} NwDamAdStCap.QNwDamCap_{YrNd(YrP,NP)} \qquad \text{(B.7)}$$
$$\leq MaxS0_{Yr}$$

Desalination constraints

Maximum desalination supply capacity

$$QsDesal_{YrNd(Yr,N)} - \sum_{DesalCapMap(Yr,N,YrP,NP)} DesalUnitSize.QDesalCap_{YrNd(YrP,NP)} \leq 0 \qquad \text{(B.8)}$$

Upper bound on total installed desalination capacity

$$\sum_{DesalCapMaxMap(Yr,N,YrP,NP)} QDesalCap_{YrNd(YrP,NP)} \leq DesalICap \tag{B.9}$$

Recycling constraints

Maximum recycling supply capacity

$$QsRecyc_{YrNd(Yr,N)} - \sum_{RecycCapMap(Yr,N,YrP,NP)} RecycUnitSize.QRecycCap_{YrNd(YrP,NP)} \leq 0 \tag{B.10}$$

Upper bound on total installed recycling capacity

$$\sum_{RecycCapMaxMap(Yr,N,YrP,NP)} QRecycCap_{YrNd(YrP,NP)} \leq RecycICap \tag{B.11}$$

Tank constraints

Maximum tank supply capacity

$$\begin{aligned} &QsTanks_{YrNd(Yr,N)} - \\ &\sum_{TanksCapMap(Yr,N,YrP,NP)} TanksSupCap_{YrNd(Yr,N)}.QTanksCap_{YrNd(YrP,NP)} \leq 0 \end{aligned} \tag{B.12}$$

Upper bound on total installed recycling capacity

$$\sum_{TanksCapMaxMap(Yr,N,YrP,NP)} QTanksCap_{YrNd(YrP,NP)} \leq TanksICap \tag{B.13}$$

Rural–urban interconnection constraints

Maximum rural–urban interconnection supply capacity

$$QsTrade_{YrNd(Yr,N)} - \sum_{TradeCapMap(Yr,N,YrP,NP)} TradeUnitSize.QTradeCap_{YrNd(YrP,NP)} \leq 0 \tag{B.14}$$

Upper bound on total installed rural–urban interconnection capacity

$$\sum_{TradeCapMaxMap(Yr,N,YrP,NP)} QTradeCap_{YrNd(YrP,NP)} \leq TradeICap \tag{B.15}$$

Aquifer constraints

Maximum aquifer supply capacity

$$QsAquif_{YrNd(Yr,N)} - \sum_{AquifCapMap(Yr,N,YrP,NP)} AquifUnitSize.QAquifCap_{YrNd(YrP,NP)} \leq 0 \tag{B.16}$$

Upper bound on total installed aquifer capacity

$$\sum_{AquifCapMaxMap(Yr,N,YrP,NP)} QAquifCap_{YrNd(YrP,NP)} \leq AquifICap \tag{B.17}$$

New dam constraints

Maximum supply capacity of new dams

$$QsNwDam_{YrNd(Yr,N)} - \sum_{NwDamCapMap(Yr,N,YrP,NP)} NwDamUnitSize.QNwDamCap_{YrNd(YrP,NP)} \leq 0 \tag{B.18}$$

Upper bound on total installed capacity of new dams

$$\sum_{NwDamCapMaxMap(Yr,N,YrP,NP)} QNwDamCap_{YrNd(YrP,NP)} \leq NwDamICap \tag{B.19}$$

B.2 Policy constraints and variables

Water restrictions

The water restrictions constraints restrict outdoor water demand when storage is below the trigger level in the preceding year. The restrictions are controlled with the binary variables $vRestr_{Yr,N}$, which have a value of 1 when the restriction is 'on', and 0 when the restriction is 'off'.

Water restrictions convexity constraint

$$vRestr0_{YrNd(Yr,N)} + vRestr_{YrNd(Yr,N)} = 1 \qquad \text{(B.20)}$$

Water consumption when restrictions are imposed

$$\sum_l Qty_{YrNd(Yr,N),d,l} \cdot Qd_{YrNd(Yr,N),d,l}\Big|_{dr(d)} - vRestr_{YrNd(Yr,N)}.Rest_d \\ -vRestr0_{YrNd(Yr,N)}.Rest0_d - QsTanks_{YrNd(Yr,N)} \le 0 \qquad \text{(B.21)}$$

Water restrictions triggered when storage is below threshold

$$vRestr_{YrNd(Yr,N)}.Trig \\ + vRestr0_{YrNd(Yr,N)}.Trig0 - QstDam_{YrNd(yr-1,NP)} \le S0\Big|_{Yr=FirstYr} \qquad \text{(B.22)}$$

Long-run marginal cost pricing (with scope for water restrictions)

The long-run marginal cost policy constraints set a uniform price for all demand classes during the regulatory period.

Setting uniform prices for all classes of demand during each regulatory period

$$\sum_l DPrice_{YrNd(Yr,N),d,l}.Qd_{YrNd(Yr,N),d,l}\Bigg|_{NdPrBlk(Yr,N,PrBlk)} \le Equil_{PrBlk} \qquad \text{(B.23)}$$

B.3 Sets, parameters and variables

Table B.1 **Sets in the model**

Name	*Dimensions*	*Description*
AquifCapMap	Yr,N,YrP,NP	Mapping of aquifer investment decisions in Yr and N to the years YrP, NP in which the investment is active, reflecting the lag of investment
AquifCapMaxMap	Yr,N,YrP,NP	Mapping of aquifer investment decisions in Yr and N to all preceding years in which that investment decision could have been made
d		Classes of demand for water
DesalCapMap	Yr,N,YrP,NP	Mapping of desalination investment decisions in Yr and N to the years YrP, NP in which the investment is active, reflecting the lag of investment
DesalCapMaxMap	Yr,N,YrP,NP	Mapping of desalination investment decisions in Yr and N to all preceding years in which that investment decision could have been made
dr	d	Subset of demand which are subject to restrictions
FirstYear		First year in the simulation period
l		Linear segments in the demand function
LastYrNd	Yr,N	Final year and corresponding node
m		Linear segments in the function for terminal storage
N, NP		Nodes in the scenario tree
NdPrBlk	Yr,N,PrBlk	Mapping of nodes to uniform pricing blocks
NwDamCapMap	Yr,N,YrP,NP	Mapping of new dam investment decisions in Yr and N to the years YrP, NP in which the investment is active, reflecting the lag of investment
NwDamCapMaxMap	Yr,N,YrP,NP	Mapping of new dam investment decisions in Yr and N to all preceding years in which that investment decision could have been made
PrBlk		Uniform pricing blocks
RecycCapMap	Yr,N,YrP,NP	Mapping of new recycling investment decisions in Yr and N to the years YrP, NP in which the investment is active, reflecting the lag of investment
RecycCapMaxMap	Yr,N,YrP,NP	Mapping of recycling investment decisions in Yr and N to all preceding years in which that investment decision could have been made
TanksCapMap	Yr,N,YrP,NP	Mapping of tank investment decisions in Yr and N to the years YrP, NP in which the investment is active, reflecting the lag of investment
TanksCapMaxMap	Yr,N,YrP,NP	Mapping of tank investment decisions in Yr and N to all preceding years in which that investment decision could have been made
TradeCapMap	Yr,N,YrP,NP	Mapping of rural-urban interconnection investment decisions in Yr and N to the years YrP, NP in which the investment is active, reflecting the lag of investment
TradeCapMaxMap	Yr,N,YrP,NP	Mapping of rural-urban interconnection investment decisions in Yr and N to all preceding years in which that investment decision could have been made
Yr, YrP		Time period. Single years for the shorter planning horizon model, aggregate years for the larger planning horizon model
YrNd	Yr,N	Mapping each node to its matching year in the scenario tree

Source: Productivity Commission urban water model.

Table B.2 **Parameters in the model**

Name	*Dimensions*	*Description*
AquifICap	scalar	Total available units of installable aquifers
AquifUnitSize	scalar	The size of a unitary investment in aquifers
Area	Yr,N,d,l	The probability weighted, discounted welfare from curve d, at node N in Yr, for linear segment l
CapExAquif	Yr,N	The probability weighted, discounted and truncated CapEx for aquifers
CapExDesal	Yr,N	The probability weighted, discounted and truncated CapEx for desalination
CapExNwDam	Yr,N	The probability weighted, discounted and truncated CapEx for new dams
CapExRecyc	Yr,N	The probability weighted, discounted and truncated CapEx for recycling
CapExTanks	Yr,N	The probability weighted, discounted and truncated CapEx for tanks
CapExTrade	Yr,N	The probability weighted, discounted and truncated CapEx for rural-urban interconnection
DesalICap	scalar	Total available units of installable desalination
DesalUnitSize	scalar	The size of a unitary investment in desalination
DPrice	Yr,N,d,l	Retail price of water from curve d, at node N in Yr, for linear segment l
EvapLoss	scalar	Proportionate losses from storages in a given year as a result of evaporation
InflowAtNode	Yr,N	Level of inflows in period Yr at node N
MaxS0	scalar	Maximum dam storage capacity in existing dams
NwDamAdStCap	Yr,N	Additional storage capacity from new dam investment
NwDamICap	scalar	Total available units of installable new dams
NwDamInflowAtNode	Yr,N	Level of inflows from new dams in period Yr at node N
NwDamUnitSize	scalar	The size of a unitary investment in new dams
OpexAquif	Yr,N	The probability weighted OpEx (including reticulation costs) for aquifers
OpexDam	Yr,N	The probability weighted OpEx (including reticulation costs) for existing dams
OpexDesal	Yr,N	The probability weighted OpEx (including reticulation costs) for desalination
OpexNwDam	Yr,N	The probability weighted OpEx (including reticulation costs) for new dams
OpexRecyc	Yr,N	The probability weighted OpEx (including reticulation costs) for recycling
OpexTanks	Yr,N	The probability weighted OpEx (including reticulation costs) for tanks
OpexTrade	Yr,N	The probability weighted OpEx (including reticulation costs) for rural-urban interconnection
Qty	Yr,N,d,l	Level of water demanded from curve d, at node N in Yr, for linear segment l
QtySt	m	Final period storage level linear segment m
RecycICap	scalar	Total available units of installable recycling
RecycUnitSize	scalar	The size of a unitary investment in recycling
Rest	d	Restricted maximum demand for demand type d
Rest0	d	Maximum demand for type d for unrestricted demand (999)
S0	scalar	Water in storage at the start of the simulation period
TanksICap	scalar	Total available units of installable tanks
TankSupSize	Yr,N	The supply capacity a unitary investment in tanks in period Yr and node N
TermStorArea	Yr,N,m	The probability weighted, discounted welfare from terminal storage at node N for linear segment m (including restriction penalty)
TradeICap	scalar	Total available units of installable rural-urban interconnection
TradeUnitSize	scalar	The size of a unitary investment in rural-urban interconnection
Trig		Minimum water in storage to trigger restrictions
Trig0	scalar	Minimum water in storage for unrestricted demand

Source: Productivity Commission urban water model.

Table B.3 **Variables in the model**

Name	*Dimensions*	*Description*
Equil	PrBlk	Price equilibration for all prices uniform pricing block PrBlk
QAquifCap	Yr,N	Incremental investment in period Yr at node N in aquifers
Qd	Yr,N,d,l	Activity variable for linear demand segment l at node N in Yr for demand type d
QdDam	Yr,N,m	Activity variable for terminal storage demand segment l at node N in Yr
QDesalCap	Yr,N	Incremental investment in period Yr at node N in desalination
QNwDamCap	Yr,N	Incremental investment in period Yr at node N in new dams
QRecycCap	Yr,N	Incremental investment in period Yr at node N in recycling
QsAquif	Yr,N	Quantity of water supplied in period Yr at node N from aquifers
QsDam	Yr,N	Quantity of water supplied in period Yr at node N from existing dams
QsDesal	Yr,N	Quantity of water supplied in period Yr at node N from desalination
QsNwDam	Yr,N	Quantity of water supplied in period Yr at node N from new dams
QsRecyc	Yr,N	Quantity of water supplied in period Yr at node N from recycling
QsTanks	Yr,N	Quantity of water supplied in period Yr at node N from tanks
QstDam	yr,pt	Quantity of water stored at node N in Yr
QsTrade	Yr,N	Quantity of water supplied in period Yr at node N from rural-urban interconnection
QTanksCap	Yr,N	Incremental investment in period Yr at node N in tanks
QTradeCap	Yr,N	Incremental investment in period Yr at node N in rural-urban interconnection
vRestr	Yr,N	Binary variable determining if restrictions are active in at node N in Yr
vRestr0	Yr,N	Continuous variable determining if demand is unrestricted at node N in Yr

Source: Productivity Commission urban water model.

C Sensitivity testing

This appendix contains details of the sensitivity testing conducted to examine the robustness of the model results to changes in parameter values.

Table C.1 describes each of the sensitivities conducted and the changes to the parameters used relative to the parameters used throughout the rest of this technical supplement (referred to as the 'central estimate' values).

Table C.1 **Sensitivities examined**

	Change relative to the central estimate	
Sensitivity	*Lower bound*	*Upper bound*
Mean inflows in to dams	-30%	+30%
Price elasticities of demand	$\varepsilon / 2$	$\varepsilon \times 2$
Discount rate	-1 percentage point	+1 percentage point
Growth rate of demand	-0.5 percentage points	+0.5 percentage points
Calibration quantity for the demand curve	-10%	+10%
Initial storages in dams	-30%	+30%

The results contained in this technical supplement come from a very large number of simulations. Table C.2 identifies the different permutations of the model implied by the nature of the analysis.

Table C.2 **Potential permutations of the model**

Permutation	*Details*
City	Melbourne, Perth
Simulation period	Historic, present
Simulation timeframe	10 year horizon, 20 year horizon
Basecase/policy models	Basecase; restrictions; investment mandates and bans; two-stage cost minimisation; multi-stage cost minimisation; uniform price
Sensitivity testing	Central estimate, mean inflows in to dams, price elasticities of demand, discount rate, growth rate of demand, calibration quantity for the demand curve, initial storages in dams

Several hundred permutations of the model could have been run. However, solving models of this size (see chapter 3) takes between 6 and 111 hours. It was not practical or necessary to run all permutations identified in table C.2.

Tables C.3 and C.4 contain the results for a subset of the sensitivity tests of parameter values relating to:

- the Melbourne and Perth models
- the historic model
- 10 and 20 year time horizons
- the basecase and policy mandate scenarios
- all sensitivity tests and the central estimate.

Table C.3 **Sensitivity of the net social welfare results to changes in parameters for Melbourne**
$m

	10 year horizon			*20 year horizon*		
	Basecase	*Policy*	*Change*	*Basecase*	*Policy*	*Change*
Central estimate	39 371	37 393	1 978	64 945	61 469	3 476
Low inflows	38 294	36 768	1 526	63 494	60 749	2 746
High inflows	39 853	37 699	2 154	65 443	61 764	3 679
Low elasticity	72 916	70 952	1 964	120 534	117 062	3 472
High elasticity	22 598	20 636	1 963	37 162	33 713	3 449
Low discount rate	40 996	39 113	1 883	120 249	116 937	3 313
High discount rate	37 855	35 790	2 065	37 283	33 660	3 623
Low growth rate	38 623	36 612	2 011	67 639	64 107	3 532
High growth rate	40 134	38 191	1 943	62 455	59 043	3 412
Low Q point	35 703	33 614	2 089	63 720	60 051	3 669
High Q point	42 963	41 131	1 832	66 202	62 994	3 208
Low initial storages	39 192	37 297	1 895	58 898	55 556	3 342
High initial storages	39 505	37 462	2 044	70 883	67 293	3 590

Source: Modelling results — Melbourne historic model.

Table C.4 **Sensitivity of the net social welfare results to changes in parameters for Perth**

$m

	10 year horizon			*20 year horizon*		
	Basecase	*Policy*	*Change*	*Basecase*	*Policy*	*Change*
Central estimate	22 539	22 272	267	38 681	38 148	533
Low inflows	22 313	22 065	249	38 299	37 831	468
High inflows	22 687	22 405	282	38 930	38 373	557
Low elasticity	41 543	41 284	258	71 360	70 836	523
High elasticity	13 041	12 768	272	22 353	21 808	546
Low discount rate	23 464	23 205	259	41 707	41 172	535
High discount rate	21 674	21 400	274	36 007	35 472	535
Low growth rate	22 106	21 836	270	37 335	36 789	546
High growth rate	22 980	22 717	263	40 083	39 569	514
Low Q point	20 382	20 100	282	34 977	34 420	557
High Q point	24 645	24 397	249	42 313	41 825	488
Low initial storages	22 509	22 247	261	38 641	38 113	529
High initial storages	22 564	22 293	271	38 716	38 179	537

Source: Modelling results — Perth historic model.

D Referee reports

In accordance with the general policy guidelines of the *Productivity Commission Act 1998* (Cwlth), the Commission appointed Professor John Freebairn (University of Melbourne) and Professor Alan Woodland (University of New South Wales) to a reference panel for the purpose of reporting on the modelling. This appendix contains their reports.

D.1 Professor John Freebairn

The objective of the modelling is to provide an assessment of the order of magnitude of gains in economic efficiency of potential microeconomic reforms in the urban water sector, using Melbourne and Perth as illustrative case studies. Reforms considered include: removing quantitative restrictions on household outdoor water use; removing bans and mandates restricting the choice of potential water supply infrastructure investment options; removing restrictions on uniform water prices over several years; and using a form of real option investment planning to choose the form, time and scale of supply augmentation investments rather than a conservative strategy of investment for the worst case scenario. The underlying model of demand for and supply of potable water, and of different investment options to expand supply capacity, explicitly seeks to incorporate: the variability of dam inflows; the inter-temporal flows and stocks of water; investments once made become sunk costs; and, the different lead times, cost structures and supply reliability of different infrastructure investment options. A very large linear programming model is used to determine investment type and time of investment decisions, and water price and quantity outcomes, to maximise economic efficiency, which is measured as expected economic surplus. The base case scenario solves for the competitive market with no policy restrictions. Then, with the addition of the policy restrictions, the model is resolved, and comparisons are made for prices, quantities, investment and economic surplus relative to the base case. The difference in economic surplus between the base case and policy constrained scenario provide estimates of the order of benefits of each category of microeconomic reform.

A summary picture of the order of gains in economic efficiency from different microeconomic reforms to Melbourne water is given in Table 1, which draws on estimates in the report.

Table D.1 Different expressions of the gains in economic efficiency from policy reforms for Melbourne Water

Policy Reform	*Expected net present value over ten years: central estimate*	*Expected net present value over ten years: central estimate*	*Expected net gain per year as share of water sales: central estimate*
	$ million	% of economic surplus	% of consumer outlay
Remove water restrictions	691	1.76	8.1
Remove mandated investments and bans on investment options	1978	5.02	23.1
Remove restrictions on uniform prices over time	27	0.07	0.3
Cost savings with real options investment planning	907	2.30	10.6

Source: Central estimate gains from table 5.5; economic surplus from table C.3; and, market outlay based on average annual efficiency gain (0.1 of column 2) and annual water sale of $585 million (390 GL at $1.50/kL from table 3.4).

The potential gains from microeconomic reform are large when assessed in terms of dollars, either absolutely or as a share of current household expenditure on water. The biggest gains are for removing restrictions on the choice of lowest cost water supply augmentation to meet the needs of the projected growing population, or in the event of climate change resulting in lower inflows into dams.

Further, as noted in the Productivity Commission report, the estimated gains of the reforms summarised in Table 1 are lower bound estimates. For example, in the case of water restrictions, the model estimates are for the triangle abc in the diagram of Box A.1. But, because of the heterogeneity of household preferences (as opposed to the implicit homogeneity assumption) many of the households facing restrictions have marginal valuations of water along the da segment of the demand curve way above the price of 14 shown; these higher valuations are included in the much higher efficiency estimates obtained in the choice modelling studies reported by Hensher et al. (2006), Brennan et al. (2007) and Grafton and Ward (2008) who find the average costs per household at up to a half of the water bill. As another example, in the case of decisions about the time of investment in water expanding infrastructure, considerable benefits under the real options investment model can be anticipated by transparent policy and business decision planning to reduce the elapsed time between the decision to undertake an investment project and its installation.

An important implication of the modelling is the importance of different constraints and investment options across different urban areas. There is no simple "one size fits all" set of guidelines. The comparative results for Melbourne and Perth reported in the study reveal quite different efficient pricing and investment rules, and different relative ranking and magnitudes of benefits of different microeconomic reforms. Compared with Melbourne, Perth now is more dependent on existing investments in high security water, both from desalination and artesian, even though its dams face greater variability of inflow. The set of potential supply augmentation investment options and their relative attributes vary between the two cities. The general idea and structure of the Productivity Commission model is widely applicable, but the specific parameters and investment options are likely to vary from one urban centre to another.

The general model framework, and in some cases with further refinements, likely will be an important addition to the decision making tools for use by utilities and others involved in managing water and investing in infrastructure to increase supply.

All models by their very nature simplify a much more complex reality. Relevant questions to ask about appropriate simplifying assumptions include: would alternative assumptions both provide a better approximation to reality and materially change the results, and for this study estimates of the order of benefits of microeconomic reform; and the costs of a more complicated model, or a different model, in terms of resources required for the analysis, and the clarity of the intuition behind the results? Two sets of more general assumptions might be considered in future work, namely risk aversion and uncertainty on the demand side.

The present model assumes risk neutrality for households, the utilities and government. It seems likely that each of these three players have risk averse utility functions, and particularly against the prospect of running out of water or requiring very restrictive water restrictions. That is, there is a penalty increasing at an increasing rate as a function of the fall in the available water in storage, or a willingness to pay a premium for greater security of supply or stability of water prices over time. Of course, there will be challenges in finding estimates of the risk aversion parameter(s); and perhaps the use of choice modelling techniques could be explored. A number of effects of risk aversion on decisions generated from the model can be anticipated. First, in terms of water management from the available infrastructure capital stock, a risk premium for security of supply would be generated by a more conservative storage rule resulting in higher prices and/or tighter and more frequently applied restrictions on average, and more so the lower the opening stock and the more variable the inflow. Second, in terms of the desired portfolio of capital infrastructure to supply water, the preferred portfolio will contain a higher share of less variable water supply but more expensive on average water. Relative to the risk neutral model results, risk aversion favours manufactured water and artesian water relative to rain fed dams, and then for rain fed dams a more diverse set of regionally located dams (assuming less than perfect correlation of different dam stream inflows) and investment in inter-system connections. Third, the timing of new investments is likely to change, but here there are conflicting forces on the direction of change. From the first effect discussed above, less water will be consumed, and so delaying the need for investment. At the same time, risk aversion against running-out of water, severe water restrictions, higher prices or a combination calls for more carryover capacity to reduce the probability of very low supply. Risk aversion on the part of the investor against a realised negative cash flow would favour delaying investment. The net effect of these different forces likely will vary with such parameters as the variability of supply, the effectiveness of higher prices and restrictions reducing consumption, and the form of and magnitude of risk aversion. Ultimately, the net effect of risk aversion on the timing of investments in additional water supply requires empirical resolution.

The current version of the model allows for uncertainty about the inflow of water into dams, and assumes perfect knowledge on other parts of the decision problem. In reality, there is uncertainty about demand in the future, and about the relative costs of different infrastructure investment options (with, for example, different rates of technical change, changes in relative input costs, and policy regarding environment approvals and energy prices). Demand uncertainty arises with imperfect knowledge about population growth and the per capita demand function. Uncertainty about per capita demand arises with imperfect information about the future values of key explanatory variables, sample estimates of the parameters, and the error term. The paper does run sensitivity scenarios for different aggregate consumption growth rates and own price demand elasticities; and in Table C.3 reports relatively small effects of the costs of restrictions on investment options for Melbourne. Extending the model to incorporate further sources of unknown variation to key determinates of realised economic surplus seems likely to mean more conservative water releases for consumption, and bringing forward the time of investments in infrastructure than obtained from the current model. And, the effects will be larger the more important is risk aversion and the more highly correlated are the new uncertainties with the already included stochastic inflow variable.

An interesting further sensitivity test would be to increase the variability of the dam inflow as a potential feature of climate change. Comparison of the model results for Perth with its lower dependence on dam water relative to reliable desalination and aquifer source water versus Melbourne indicates that greater variability of dam inflows with climate change will have important effects on the choice of decisions over the management of water and of investment in new supply capacity.

Overall, the model provides an appropriate technique to make estimates of the order of magnitudes of benefits of microeconomic reform in the urban water industry. In the benchmark or efficient scenario, water is priced at its marginal social opportunity cost and new investments are undertaken if the expected present value of additional future revenue exceeds the investment and operating costs. Decisions are made in the context of stochastic information on dam inflows but recognising new information becomes available each decision period, with a time sequence of decision periods sensitive to observed water in storage, and that investments in expanding supply are large, lumpy and require investment lead times, and that once made the capital costs are sunk costs. A large linear programming model with state contingent options is solved to derive the water management and investment decisions which maximise economic efficiency. A rich set of data on probability distribution functions is generated for outcomes in terms of prices, quantities, economic surplus and so forth. Then, the effects of different policy options associated with microeconomic reform are analysed by changing the constraints of the programming model. Sensitivity of the results of the scenario comparisons is illustrated with model re-runs for variations of key demand side and supply side parameters. The model offers a general framework which can be reworked for different urban centres, and which can be modified to represent different and alternative assumptions and parameters, for use in policy analysis and decision making by the water utilities.

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D.2 Professor Alan Woodland

Introduction

The Productivity Commission has undertaken analyses of various water policy scenarios making use of a specially developed partial equilibrium model of urban water storage, supply and demand. This model has been calibrated to urban water markets in Melbourne and Perth. The purpose of the present paper is to provide an evaluation of the nature and appropriateness of the modeling strategy and resulting model.

In the following, I first provide a brief overview of the main features of the model and, in doing so, I comment on its appropriateness. Secondly, I highlight some features of the model that provide potential limitations and qualifications of the Commission's modeling exercises.

Model overview

This model involves the specification of urban water demand by various types of consumers, the supply of water from various types of storage or production facilities, the way in which water storage levels change, the capacities of water storage facilities and how these can be changed through investment and, finally, the spot market for urban water. All of this is done in a model that is inter-temporal to take account of the dynamic nature of the water storage and capacity investment aspects of the problem and that involves stochastic inflows of water to storage facilities. Moreover, the model is set up with a mind to undertaking various forms of policy simulation analysis. Overall, the model addresses the essential and main aspects of water allocation, production and storage.

Two aspects of the model are of particular importance. First, the model appropriately assumes that the inflows to dams are stochastic, being realized only in the year in question. This is a crucial aspect of the model that characterizes an important part of the water problem. Second, the model is appropriately inter-temporal and deals with the allocation of water over time and with the decisions to invest in additional storage and production capacities. Each year, demands, supplies and carryover water stocks are chosen to maximize the sum of current and discounted expected net social payoff, the expectation taking account of the stochastic future inflows. In this way, the future and uncertainty impact upon current water decisions.

The data and parameter values for the model are based upon information obtained from the industry and previous research. Since results from any such model depend heavily upon these assumed values, the Commission undertook detailed sensitivity analysis. Appropriately, the report considers higher and lower values for demand elasticities and mean inflows to dams (the crucial parts of the model) and other parameters to evaluate the sensitivity of results to assumptions. The model was appropriately used to simulate a range of policy scenarios such as water restrictions, policy restrictions, mandated augmentations and uniform pricing, each with sensitivity analysis.

The Productivity Commission approach is to determine the model's solution by solving the problem of maximizing a discounted sum of net social payoff over a horizon of years subject to constraints and taking into account the stochastic nature of future inflows. By treating it as one optimization problem, various approximations are needed and all future inflow scenarios have to be explicitly considered. This turns out, even for a ten year horizon, to be a massively large constrained linear programming problem.

Some model features

Horizon of 10 years

Because the computational procedure used by the Productivity Commission results in a very large linear programming problem that is at the limits of computational feasibility, the time horizon for the analysis is set at ten years. This is potentially problematic because it is a rather short horizon for the economic problem of inter-temporal water allocation and storage decisions (e.g., dams last much longer). Accordingly, the simulation results obtained over such a short horizon will lack future detail and may depend heavily upon the assumed terminal conditions.

The model specification, being time invariant except for the constant growth rate for demands, suggests a stochastic balanced growth path in the long run. With a ten year horizon imposed by the model, there is no guarantee that the assumed terminal value of water stocks is the appropriate value. This raises the issues of how to specify the terminal value and of what affect an inaccurate terminal value will have on the solution.

In dynamic models, the horizon is often chosen to be sufficiently long that any further increase in that horizon would have inconsequential effects on the model solution over years of interest, so the terminal condition ceases to be important. Because of the computational constraints facing the modeling team, this opportunity to deal with the terminal condition was not available. However, its potential implications should be noted.

Expected welfare maximization

An implicit consequence of the model formulation is that behaviour of consumers and producers in the model exhibit risk neutrality. They take account only of expected values of outcomes. They are not risk averse, as might be assumed to be the case. This implicit risk neutral behaviour limits the role played by water inflow uncertainty, which is at the heart of the Productivity Commission model. In the context of water supply and allocation, it is arguable that non-neutral (risk averse) attitudes to risk would be an important aspect of behaviour.

Approximations

Demand functions

The Productivity Commission model begins with linear demand functions. If this assumption had been maintained then net social payoff would be a quadratic function of demand quantities, since the area under a linear demand function is a quadratic function. This would have then required the solution of a quadratic programming problem, not a linear programming problem — a substantially more complicated computational procedure that would have further limited the dimensionality of the model.

The approximation involves replacing linear demand functions by step functions with given demands at from 20 to 50 different prices. Given that each point is modeled via a new variable for each demand type in each period and for each inflow scenario, these approximations involve the cost of adding a significant number of variables to the model. Increasing the number of points of approximation to increase accuracy would substantially increase the dimensionality of the resulting linear program without any real gain. The model already contains sufficient points of approximation to make the approximated demand functions accurate enough for modeling purposes.

Probability distribution

A second very important approximation concerns the assumed probability distributions for stochastic inflows. Empirically, stochastic inflows to dams (based largely upon stochastic rainfalls) should be treated as continuous variables with a rather wide support (range of possible values). Clearly, use of such a distribution would provide insurmountable computational challenges and so, following the standard approach in stochastic dynamic analyses, the model approximates the continuous distribution with a discrete distribution.

The continuous distribution is approximated by just three discrete points — high, medium and low inflows. This choice is the one that is crucial to the model's dimensionality. With three discrete inflow points, the number of possible inflow scenarios is $3^{10} = 59049$ for the assumed ten year horizon. Since the model structure deals separately with each such scenario and variables are defined for each node in the decision tree, there are a large number of variables. Clearly, increasing the number of discrete points of approximation further would increase the dimensionality substantially and beyond the linear program's solution capability.

The Productivity Commission report details how the approximations are chosen to best fit observable inflows over time. Nevertheless, it is arguable that it is not possible for this three-point approximation to reflect extremes in annual inflows sufficiently accurately. Moreover, the approximation may not well reflect the less extreme inflow possibilities because of its coarse nature.

Dimensionality of model

It was noted earlier that the number of variables in the model rises much faster than the number of periods and that the approximations used to generate a linear programming problem exacerbates this dimensionality problem. As a result, the approximations and relatively short time horizon may limit the economic specification.

This raises the issue of whether there might be better solution methods that are both computationally feasible and less restrictive in terms of approximations and time horizon. One alternative is to solve the model using a stochastic dynamic programming computational method. The Commission has correctly argued that there does not exist a commercially available software package that can be readily used for their task; devoting resources to specialized software development would divert attention away from important modeling tasks.

Nevertheless, stochastic dynamic programming methods might be worth pursuing in the future. The idea of dynamic programming methods is to break a long horizon inter-temporal problem into a set of recursive optimization problems, one for each period. In the present context, each period's optimization problem conditions on existing dam storage levels and inflows and chooses demand and supply quantities of water consistent with the water balance conditions and dam storage levels carried forward by maximizing the sum of current and discounted expected future net social welfare.

Importantly, this expectation takes place over only the three inflow possibilities assumed by the model and the number of endogenous variables for each year is very small. This constitutes a big gain in dimensionality, which could obviate the need to approximate demand functions and allow a more general model specification. On the downside, dam storage levels need to be treated as discrete state variables and so a large number of these small period-by-period problems need to be solved. Given that the current linear programming problem has approximately 6.2 million variables and 1.3 million constraints, it seems a reasonable conjecture that the stochastic dynamic approach is worthy of serious future consideration, thus allowing a more general model specification and a longer time horizon.

Conclusion

In summary, the overall modeling approach taken by the Productivity Commission is appropriate for the task at hand, namely the modeling of water storage and allocation, both over consumers and inter-temporally, and the analysis of alternative policy scenarios. The model has addressed the important aspects of the issue. Especially, it deals with the stochastic nature of inflows of water into dams, the changes in storage resulting from these inflows and usage, alternative water supplies such as aquifers and desalination plants, investment in new capacities and with the allocation of water via the market. Importantly, it deals with inter-temporal allocation and pricing issues that are at the heart of the water supply problem.

Given this overall assessment, my comments have focused on the potential limitations of the modeling approach that arise because of the large dimensionality of the resulting linear programming computational technique. These should be kept in mind, but should not detract from the general applicability of the modeling method.

TECHNICAL SUPPLEMENT 2: INSIGHTS INTO RESIDENTIAL WATER CONSUMPTION AND EXPENDITURE USING COMBINED CENSUS AND UTILITY BILLING DATA

1 Introduction

As part of its inquiry into Australia's Urban Water Sector, the Commission has sought to better understand the factors affecting residential water consumption and the affordability of water and wastewater services for Australian households.

Specifically the Commission wanted information about the impact of:

- socio-economic factors on water consumption, such as household size, household income, housing tenure, dwelling type and receipt of a concession
- inclining block water tariffs on large households
- water charges on low-income households.

To investigate these issues, aggregated billing data was sought from water utilities and matched with Australian Bureau of Statistics (ABS) data from the Australian Census. This allowed econometric and other analysis to be undertaken.

The Commission would like to thank all those who assisted with this research. In particular, the Commission thanks Yarra Valley Water for its invaluable advice and assistance in trialling the data request for water utilities. The Commission is also grateful to Queensland Urban Utilities, South East Water, Sydney Water Corporation and the Water Corporation for providing data for analysis.

In addition, the modelling framework and some preliminary results were presented at a modelling workshop on 1 February 2011 and the Commission is grateful for the feedback received from workshop participants. A draft of this technical supplement was also released for public consultation on 4 May 2011.

The structure of this technical supplement is as follows. Section 2 summarises recent research on the determinants of residential water consumption and section 3 outlines the data collected and analysed. Section 4 presents the results of econometric models of average household water consumption, average per capita water consumption and average volumetric price for water by collection district or suburb. In section 5, an analysis of water and wastewater service consumption and expenditure patterns of different income groups are discussed. In the last section (section 6), a summary of results is provided.

2 Recent research on the determinants of residential consumption

There has been a large volume of research undertaken internationally and also in Australia on residential water consumption. These studies have primarily sought to inform demand management policies by assessing either the price elasticity of demand for water (for example, Hoffman, Worthington and Higgs 2006) or the effect of household characteristics, including the use of particular appliances, on consumption (for example, Kemp 2004; Troy, Holloway and Randolph 2005; IPART 2004, 2007b, 2008a, 2010a).

Most studies have found that the income elasticity of water is positive but inelastic, reflecting the observation that expenditure on water represents a larger proportion of the income of low-income households than of high-income households (Worthington and Hoffman 2008). Kemp (2004) found a small link between water demand and income, but surmised that some of the effect was being captured by the household appliances (such as pools and spas) explicitly accounted for in the chosen model.

However, the positive relationship between income and consumption might be complicated by the adoption of household water saving devices. A 2009 survey of household choices related to water and energy in Western Australia (ABS 2010e), found that the adoption of water saving devices was greatest in high-income households and in those not receiving concessions. Worthington and Hoffman (2008) have suggested that income acts as a proxy for education in determining the adoption of water saving appliances and practices.

Studies have also consistently found that household size is positively related to household water consumption, as larger families (other things equal) will consume more water than smaller families. Kemp (2004), for instance, found that household size was the biggest contributor to household water consumption. In a survey of water demand modelling, Worthington and Hoffman (2008) observe that there is strong but limited empirical evidence of scale economies in water consumption — where the volume of water consumed by a household increases with household size but at a decreasing rate due to competition for water using appliances (such as showers) and greater scope for communal water uses (for example, cooking and clothes washing).

In addition, household composition has been proposed as a determinant of water consumption. IPART (2004), in a survey of water use by households in and around Sydney found that within households with children, those with pre-school aged children used less water than those with children aged six or older, and households with children used less water than households of comparable size composed entirely of adults. Worthington and Hoffman (2008) cite international evidence that residential areas with a higher proportion of younger and older persons have higher levels of water consumption. For younger people, this related to more frequent laundering and use of water-intensive outdoor leisure activities and older people were assessed as more likely to be keen gardeners.

A number of studies have tested the hypothesis that dwelling type, block size and housing tenure might have a significant effect on water consumption. Households occupying free-standing houses are sometimes believed to consume more water than households occupying flats or semi-detached houses which have smaller household sizes, no or smaller gardens and pools, and use less water outdoors. Troy, Holloway and Randolph (2005) and IPART (2010a) found that once household size was accounted for, dwelling type contributed only marginally to household consumption. However, those living in houses on large blocks have been shown to consume more water than those living in houses on smaller blocks, due to larger gardens (IPART 2004).

Hoffman, Worthington and Higgs (2006), in a study of household consumption in Brisbane, found that the price elasticity of demand for tenants was less elastic than for owner occupiers. This reflected a legislated requirement for landlords to provide an unmetered minimum allowance of water to their tenants that effectively meant they did not receive a water usage bill. Kemp (2004) also found that water use was higher for those that did not receive a water bill. However, IPART (2010a) concluded that amongst tenants, paying water usage charges did not have a significant influence on the volume of water a household consumed. Conversely, Grafton et al (2009) in a study of residential water consumption in OECD countries found that households paying a volumetric water charge consume about a quarter less water than those that do not.

A number of studies have shown residential water consumption to be highly sensitive to seasonal factors (Worthington and Hoffman 2008), reflecting the influence of weather and climate. A 2011 study of the residential price elasticity of demand for water in Sydney found that rainfall and evaporation in different areas of Sydney had a statistically significant effect on residential water consumption (Abrams et al. 2011).

3 Data

The approach taken for this study was to merge 2005-06 and 2009-10 billing data for water and wastewater services from Australian water utilities with socio-economic data about households collected by the ABS in the 2006 Census. It was hoped that this would:

- provide a rich dataset to investigate the factors affecting residential water consumption and distributional effects of different tariff regimes
- enable the collection of data from a wide geographic area and be inclusive of consumers in different jurisdictions, and in metropolitan and regional urban localities, consistent with the scope of the Commission's inquiry.

The most robust dataset would have included information from households at the household level, but due to confidentiality constraints, this was not possible.

Instead, Census data from the ABS was obtained and merged with billing data from water utilities aggregated at the Census collection district level and in one case at the suburb level. The Census collection district is the most detailed level of Census data published by the ABS and equates to about 250 households on average. A similar approach was undertaken by Hoffman, Worthington and Higgs (2006) (at the suburb level) to estimate the price elasticity of demand for water in Brisbane.

The use of aggregated data necessarily generates values for consumption and socio-economic factors that represent means and medians over a geographical area. This must be taken into account in interpreting the results of the analysis. On the whole, the analysis of mean and median values is likely to understate the variation that occurs at the household level.

ABS Census data

The ABS data were taken from the 2006 Census, and provided information for Australian households such as income, household size, dwelling type and tenure. In addition, the Socio-Economic Index for Areas (SEIFA) compiled by the ABS provide sophisticated summary statistics for social advantage and disadvantage. There are four SEIFA, each of which measures advantage and disadvantage in a different way (ABS 2006a).

Water utility billing data

A range of consumption and expenditure data for water and wastewater services was sought from water utilities to enable calculation of a number of mean statistics by collection district or suburb including average household consumption, average per capita consumption and the average volumetric price for water. The data sought included the number of connections, billing days, water consumption in kilolitres (kL), volumetric charges, service charges, value of concessions and rebates and number of customer accounts receiving them.

The information was sought for two years, 2005-06 and 2009-10, for water and wastewater accounts with a full year of billing data. The benefit of obtaining data at different points in time is that it provides a basis with which to assess the stability of the estimates or changes in the estimates over time.

A data request was trialled with the assistance of Yarra Valley Water, a Victorian water utility servicing some 620 000 residential customers within the Melbourne metropolitan area, to confirm the feasibility of aggregating data at the Census collection district level. Aggregating the data required the mapping of individual customers to Census collection districts in a geographical information system and cross referencing with a metering or billing system.

The data request was then provided to major water utilities in each state except Tasmania. The Commission received data from four water utilities at the Census collection district level — Yarra Valley Water and South East Water in Melbourne, Sydney Water Corporation (Sydney) and Queensland Urban Utilities (Brisbane). The Water Corporation in Western Australia provided data at the suburb level. The task of aggregating billing data for geographical areas required considerable skill and effort on the part of water utility staff and the Commission is grateful for their assistance.

Due to differences in utility billing systems, the data able to be aggregated at Census collection district or suburb level varied. At a minimum, all water utilities were able to provide customer numbers and annual water consumption for 2009-10. Some utilities were also able to provide data for 2005-06. The coverage of the resulting data sets included the cities of Melbourne, Sydney and Brisbane and the majority of Western Australia, including Perth.

Cleaning the data

There were two main challenges with merging Census data with water utility billing data.

First, the boundaries of the utility’s service areas might overlap only partially into a collection district or suburb, or only a proportion of dwellings in a Census collection district or suburb might be serviced. If this occurs there is a risk that consumption patterns of a small sample of water utility customers might not be reflective of the entire collection district.

Second, changes to the demographics of Census collection districts and suburbs might have occurred between the 2006 Census and 2009-10. Although the demographics of areas will tend to change slowly over time, residential developments within existing boundaries might result in a rapid change in their demography.

To ensure there was a material degree of overlap between utility billing data and Census data, the datasets were cleaned of all observations where the difference between the number of dwellings reported in the Census and the number of customers reported by water utilities in each collection district or suburb was greater than 50 per cent of the number of customers. In addition, collection districts with average annual household consumption of less than 25 kL and more than 800 kL were removed as outliers.

As the Census collection district and suburb dwelling numbers are based on a household's principal place of residence, this approach also acts to reduce the effect of observations from areas with a high proportion of holiday homes that are only occupied during part of the year.

Table 1 provides a summary of selected statistics for each of the five water utilities. Of particular note is the relatively large mean of average household water consumption for suburbs in Western Australia in 2009-10, of about 300 kL per annum[1], compared to the mean for collection districts in Melbourne, Brisbane and Sydney which ranged between 140 and 220 kL per annum in 2005-06 and 2009-10.

Also of note is the significant reduction in average household water consumption in Melbourne between 2005-06 and 2009-10 of about a quarter. This was a period in which water restrictions in Melbourne increased from level 2 to level 3a and greatly constrained outdoor water use, public information campaigns urged people to consume less water and prices increased considerably.

4 Water consumption model

In order to provide greater insights into the complex interrelationships between socio-economic factors affecting residential water consumption and the distributional effects of different tariff regimes, an econometric modelling exercise was undertaken.

[1] This is the mean of suburb average household consumption in Western Australia. The average consumption of all households in Western Australia in 2009-10 was 268 kL and is presented in table 9.

Table 1 **Data summary, selected statistics**

		Average household water consumption (kL/year)				*Average per capita consumption (kL/year)*				*Average volumetric price (cents/kL)*			
	Number of observations[a]	Mean	Standard deviation	Min	Max	Mean	Standard deviation	Min	Max	Mean	Standard deviation	Min	Max
Queensland Urban Utilities (Brisbane)													
2009-10	1536	154	27	49	301	62	8	20	130	190	3	183	213
South East Water (Melbourne)													
2005-06	2149	186	52	88	611	73	15	33	204	86	5	68	119
2009-10	2102	143	32	42	420	56	9	24	140	130	6	119	186
Sydney Water Corporation													
2005-06	5028	220	55	28	698	78	15	11	239	–	–	–	–
2009-10	5023	213	52	33	645	75	15	22	233	187	0	187	187
Water Corporation[b]													
2009-10 (WA)	460	313	96	105	763	122	31	50	305	95	21	68	252
2009-10 (Perth)	247	298	67	162	552	114	18	70	176	84	6	68	106
Yarra Valley Water (Melbourne)													
2005-06	2412	207	54	104	661	77	14	54	220	87	4	78	115
2009-10	2408	157	32	77	414	59	8	40	143	131	5	122	166

a The number of observations equates to the number of collection districts, with the exception of the Water Corporation, for which it equates to the number of suburbs. **b** The dataset Water Corporation (WA) includes all suburbs in Western Australia serviced by the Water Corporation. The dataset for Water Corporation (Perth) includes only those suburbs in the Perth metropolitan area. – Data not available.

Source: Productivity Commission estimates.

Model specification

Based on the findings of previous studies of the determinants of household water consumption and the factors of interest to the Commission, the following model of residential water consumption was hypothesised.

$$Water\ consumption = \beta_1 + \beta_2 Price + \beta_3 Household\ size + \beta_4 Income + \beta_5 Dwelling\ type + \beta_6 Block\ size + \beta_7 Housing\ tenure + \beta_8 Household\ composition + \beta_9 Concession\ status + \beta_{10} Other\ socio\text{-}economic\ factors\ (education) + \beta_{11} Climate + \beta_{12} Other\ jurisdictional\ differences\ (restrictions)$$

The inclusion of price in the model is complicated by the inclining block tariff (IBT) structure in place in a number of areas of Australia. Under IBTs, the average price paid per kilolitre of water increases as consumption rises beyond an initial consumption block. As a result, price is endogenous to consumption (simultaneity) and when using the ordinary least squares technique, regressing consumption against price results in the anomalous result of a positive coefficient. Other econometric techniques might be more appropriate in the presence of simultaneity, however, these are more complex and there is no consensus as to which technique is most appropriate or whether the resulting estimates vary greatly from ordinary least squares (Arbués, García-Valiñas and Martínez-Espiñeira 2003). In addition, there is some debate about whether consumers respond to the average price or marginal price of water, and consequently, how price should be specified. As price elasticity was not a major factor of interest to the Commission in the study and the considerable complexity in terms of both technique and data requirements involved in including it, price was excluded from the model.

However, various utility or jurisdiction specific differences, such as water restrictions and concession arrangements, mean that demand functions for water are likely to vary considerably in each jurisdiction anyway. A decision was made to run separate regressions for each water utility, eliminating the need to include some variables representing jurisdictional differences. The results should therefore be interpreted as the effect of the explanatory variables on the dependent variable, given price and other jurisdictional characteristics.

The inclusion of household composition in the model also presented difficulties. Various measures of household composition, such as proportions of different age groups, are highly correlated with household size. For example, households with persons over 65 years tend to be smaller and those with persons under 19 years tend to be larger.

The proportions of people in two age groups, those over 65 years and those under 19 years of age, were initially included in the model to reflect differences in household composition. The results from these models showed an unexpectedly high influence of the over 65 age variable, particularly relative to average household size. Given the high correlation between the age groups considered and average household size, investigation of multicollinearity was warranted and variance inflation factors (VIF) were calculated. The highest VIF was within the rule of thumb threshold for multicollinearity of a VIF of 10 indicating that though multicollinearity was present, it was not of significant concern. The regressions were also rerun excluding the age and average household size variables in turn. The R^2 of the resulting models were materially lower, however not as low as would be expected from the exclusion of a principal explanatory variable, suggesting a significant overlap in explanatory power between the variables. As household size was the primary interest of the analysis, the household composition variable was excluded from the model.

As such, the following fit-for-purpose model of water consumption was chosen.

$$Water\ consumption = \beta_1 + \beta_2 Household\ size + \beta_3 Income + \beta_4 Dwelling\ type + \beta_5 Block\ size + \beta_6 Housing\ tenure + \beta_7 Concession\ status + \beta_8 Other\ socio\text{-}economic\ factors\ (education) + \beta_9\ Climate$$

Choice of representative statistics

The Census contains a wide range of statistical measures and there were several choices for representative measures for some of the hypothesised influences on residential water consumption. Table 2 provides a summary of the chosen explanatory variables and the expected sign of their coefficients in the regression results.

There was only one relevant measure of household size, average household size (*AvgHHSize*), and this was expected to be positively related to residential water consumption.

For income, variable choices included median individual income, median household income and median family income. Median household income (*MedHHIncome*) was chosen on the basis that it better reflects the prevalence of multiple income families and shared living arrangements, and was expected to be positively related to residential water consumption.

For housing tenure, the proportion of owner occupied dwellings (*PropOwnOcc*) was chosen over the proportion of rented dwellings. On one hand, owner occupiers might be more likely to receive a bill for water usage and have greater incentive to invest in water saving appliances and this variable would be expected to be negatively related to consumption. On the other hand, being an owner occupier might signal greater wealth, and increase water consumption in a similar way as higher incomes are expected to do.

Table 2 **Definition of variables**

Factor	*Variable name*	*Description*	*Expected sign*
Household size	*AvgHHSize*	Average household size	+
Income	*MedHHIncome*	Median household income	+
Housing tenure	*PropOwnOcc*	Proportion of households that are owner occupied	+ / –
Dwelling type	*PropFlatsUnitsApts*	Proportion of dwellings that are flats, units and apartments	+
Block size	*CustDensity*	Customer density per square km	–
Concession status	*PropConCust*	Proportion of concession customers	+
Other socio-economic factors	*SEIFAPercentile*	The SEIFA state percentile for the Index of education and occupation	–
Climate	*Latitude and Longitude*	The latitude and longitude coordinates of the collection district or suburb.	+ / –

For dwelling type, the proportion of flats, units and apartments (*PropFlatsUnitsApts*) was chosen as opposed to the proportion of separate houses, semi-detached houses or other dwelling types. As many multi-dwelling buildings have a single water meter and individual occupants do not receive a water bill, the proportion of dwellings in a collection district or suburb that are flats, units and apartments was expected to be positively related to water consumption, once other factors (household size, block size) were taken into account.

There are no measures in the Census that directly represent block size. However, the number of water utility customers per square kilometre of a collection district or suburb (*CustDensity*) can be calculated and used as a proxy for housing density. Customer density is likely to be negatively correlated with block size and was expected to be negatively related to residential water consumption.

Concessions for low-income and disadvantaged households are commonly provided by state, territory and local governments on water and wastewater bills. If concessions apply to the variable component of a water bill, they can reduce the marginal price of water and might increase consumption. The proportion of customers in a collection district or suburb receiving a concession was calculated (*PropConCust)* and was expected to be positively related with water consumption for utilities where concessions are applied to the volumetric component of the bill.

As prior research has indicated that higher levels of education and occupational status might increase water saving behaviour, the ABS's SEIFA Index of Education and Occupation, was included (*SEIFAPercentile*). It was anticipated that this measure would be negatively related to water consumption.

No annual climate or weather information such as mean temperatures or rainfall were available by collection district or suburb level. Instead, the latitude (*Latitude*) and longitude (*Longitude*) coordinates of each collection district and suburb were included in the model to capture differences in climate between different areas moving from north to south and from east to west. Geographical coordinates were anticipated to be more influential on water consumption in the case of water utilities with large service areas incorporating a range of climates, such as the Water Corporation in Western Australia, than for utilities servicing a single city or an area of a city — although as indicated by Abrams et al. 2011, the effect of climate and weather can be statistically significant within cities. For latitude, a positive (negative) coefficient indicates greater (less) water use in the north than in the south, and for longitude, a positive (negative) coefficient indicates greater (less) consumption in the east than in the west. Australia's latitude coordinates are negative (reflecting its position in the southern hemisphere) and get larger in absolute terms moving towards the south. Longitude coordinates are positive and get larger moving towards the east.

Modelling results

Ordinary least squares regressions of average household consumption, average per capita consumption and the average volumetric price of water against the chosen explanatory variables were run. Tables 3, 5 and 7 show standardised coefficients, heteroscedasticity corrected p-values, coefficients of determination (R^2 or 'goodness of fit') and F-values, for 2005-06 and 2009-10 for each of the five water utilities where data was available.

Standardised coefficients are presented due to the difficulty in comparing the relative influence of variables with different units of measurement such as income (measured in dollars) and household size (measured in persons). Standardised coefficients show the estimated change in the dependent variable in units of standard deviation, from a one standard deviation change in the explanatory variable. They are primarily used to estimate the relative influence on a dependent variable of explanatory variables with different units of measurement — greater absolute values of a standardised coefficient imply greater influence of that variable on the dependent variable. Full regression results, including nominal coefficients and standards errors, are included in appendix A.

Grouped data exhibits heteroscedasticity (unequal variance of the disturbances) if the number of observations in each grouping differs. This is the case within collection districts, which contain 250 households on average, but this can vary. Heteroscedasticity will not bias the estimates but can result in calculated coefficients that are not the best possible and can affect the standard deviation and p-values, resulting in incorrect conclusions about the significance of the coefficients (Gujarati 1995). As a result, White's heteroscedasticity-consistent variances and standard errors are used.

The resulting R^2 of about 0.5–0.6 for the 2005-06 and 2009-10 models of average household consumption were atypically high for cross-sectional regressions indicating the model accounts for about 50 to 60 per cent of the variation in the data. The R^2 values of the per capita annual use and average volumetric price models were lower, ranging between 0.15 and 0.60.

The high R^2 are, in part, a function of the grouped nature of the data under analysis. If the model was applied to household level data, the R^2 values of each of the regressions would be considerably lower. This is because the means of the grouped data tend to cluster around the regression line more closely than household level observations (Koutsoyiannis 1977).

The correct interpretation of the model is therefore as a model of average consumption or prices across collection districts and suburbs regressed on mean and median characteristics of those collection districts and suburbs. Given the purpose of this study is to show the relative influence and sign of different factors on water consumption and prices, rather than the impact of a unit change in a particular variable, this will not affect the validity of the results.

Average household consumption

Table 3 shows the results for the regression of average household consumption on the chosen explanatory variables for the five utilities for 2009-10, and where data was available, 2005-06.

Table 3 Regression results – Average annual household consumption

	Queensland Urban Utilities (Brisbane)[a]		*South East Water (Melbourne)*		*Sydney Water Corporation*[b]		*Water Corporation (WA)*[a, c]		*Yarra Valley Water (Melbourne)*	
	Standardised coefficient	*P-value*	*Standardised coefficient*	*P-value*	*Standardised coefficient*	*P-value*	*Standardised coefficient*	*P-value*	*Standardised coefficient*	*P-value*
2005-06										
AvgHHSize	–	–	0.4947	<.0001	0.5499	<.0001	–	–	0.4048	<.0001
MedHHIncome	–	–	0.3482	<.0001	0.3595	<.0001	–	–	0.6892	<.0001
PropOwnOcc	–	–	0.0983	0.0038	-0.1247	<.0001	–	–	-0.0271	0.3499
CustDensity	–	–	-0.1185	0.0020	-0.1499	0.0002	–	–	-0.1847	<.0001
PropFlatsUnitsApts	–	–	0.0683	0.0323	0.0860	<.0001	–	–	0.1482	<.0001
PropConCust	–	–	0.0815	0.0418	–	–	–	–	0.1775	<.0001
SEIFAPercentile	–	–	0.1726	<.0001	-0.1815	<.0001	–	–	-0.0976	0.0017
Longitude	–	–	-0.0090	0.7105	0.1300	<.0001	–	–	-0.0961	<.0001
Latitude	–	–	-0.1767	<.0001	0.1028	<.0001	–	–	0.0128	0.4681
R^2	–	–	0.5734	–	0.4661	–	–	–	0.6809	–
Adjusted R^2	–	–	0.5716	–	0.4652	–	–	–	0.6796	–
F value	–	–	318.85	<.0001	547.52	<.0001	–	–	550.42	<.0001
2009-10										
AvgHHSize	0.7334	<.0001	0.7360	<.0001	0.5769	<.0001	0.2104	<.0001	0.5602	<.0001
MedHHIncome	0.1635	0.0005	0.2984	<.0001	0.3474	<.0001	0.3057	<.0001	0.5555	<.0001
PropOwnOcc	0.0215	0.6420	-0.0941	0.0064	-0.0889	<.0001	0.0541	0.3251	-0.1636	<.0001
CustDensity	-0.0442	0.3331	-0.1204	0.0038	-0.1445	0.0001	-0.2428	<.0001	-0.1757	<.0001
PropFlatsUnits	0.1496	0.0009	0.0895	0.0046	0.1486	<.0001	0.0378	0.2460	0.1441	<.0001
PropConCust	-0.0451	0.1761	0.0441	0.1681	–	–	-0.0104	0.8455	0.1452	<.0001
SEIFAPercentile	-0.0071	0.7743	0.1124	0.0046	-0.19851	<.0001	–	–	-0.1841	<.0001
Longitude	-0.0265	0.2009	-0.0241	0.3732	0.12262	<.0001	-0.0176	0.6659	-0.2296	<.0001
Latitude	-0.0354	0.0304	-0.0548	0.0119	0.12225	<.0001	0.5434	<.0001	-0.0397	0.0330
R^2	0.6106	–	0.6070	–	0.4837	–	0.6873	–	0.6506	–
Adjusted R^2	0.6083	–	0.6053	–	0.4828	–	0.6817	–	0.6493	–
F value	265.92	<.0001	358.87	<.0001	586.95	<.0001	123.89	<.0001	479.82	<.0001

a Data for Queensland Urban Utilities and Water Corporation (WA) were not available for 2005-06. **b** No data for the proportion of customers who receive a concession was available for Sydney Water Corporation. **c** Data for the Water Corporation is aggregated at the suburb level and a statistic for *SEIFAPercentile* is not available.

Source: Productivity Commission estimates.

In relation to changes in the influence of these factors over time, for the Melbourne water utilities, South East Water and Yarra Valley Water, the standardised coefficient for average household size increased between 2005-06 (0.49, 0.40) and 2009-10 (0.74, 0.56) and the coefficients for median household income decreased (from 0.35 to 0.30 for South East Water and from 0.69 to 0.56 for Yarra Valley Water). This was a period in which average household water consumption in Melbourne decreased by about a quarter due to a heightening of water restrictions, public information campaigns urging water conservation and increases in price. The change in relative influence of the two variables might therefore indicate that average household size is a stronger determinant of non-discretionary water use and household income of discretionary consumption.

To test this conclusion, South East Water provided water consumption data for 2005-06 and 2009-10 recorded quarterly[2], to see if standardised coefficients were different for winter usage, of which a greater proportion of water use was assumed to be non-discretionary, and summer usage, of which a greater proportion was assumed to be discretionary. The average quarterly household consumption and standardised coefficients for average household size and median household income from the regression of average quarterly water consumption on the chosen explanatory variables for South East Water for 2005-06 and 2009-10 is presented in table 4 (standardised coefficients and p-values for all explanatory variables are presented in appendix A).

Consistent with the pattern observed for annual consumption between 2005-06 and 2009-10, the standardised coefficients for average household size were greater in the quarters where recorded consumption overlapped with winter (quarters 1 and 2) and in which average consumption was relatively low, than in those quarters overlapping the summer (quarters 3 and 4) in which consumption was relatively high. Likewise, the standardised coefficients for median household income are higher in the quarters overlapping summer than those overlapping winter.

In contrast to the Melbourne water utilities, the relative influence of household size and income on household consumption for Sydney Water did not vary greatly between 2005-06 (0.55, 0.36) and 2009-10 (0.58, 0.35) but Sydney did not experience a significant change in household water consumption during the period — Sydney Water Corporation's average water consumption per household declined by less than 3 per cent.

2 Quarterly consumption figures reflect the consumption recorded by meters read in the quarter and do not necessarily reflect actual consumption within that period. As such, a proportion of consumption recorded in a quarter would have actually been consumed in the previous quarter.

Table 4 Consumption by collection district recorded quarterly and standardised coefficients for selected explanatory variables, South East Water, 2005-06 and 2009-10

	Quarter 1 *1 Jul – 30 Sep*	*Quarter 2* *1 Oct – 31 Dec*	*Quarter 3* *1 Jan – 31 Mar*	*Quarter 4* *1 Apr – 30 Jun*
Average household consumption				
2005-06 (kL)	42.0	42.5	53.3	49.2
2009-10 (kL)	34.0	34.4	38.3	36.7
Standardised coefficient				
Average household size				
2005-06	0.56	0.62	0.39	0.40
2009-10	0.77	0.84	0.63	0.63
Median household income				
2005-06	0.31	0.29	0.34	0.33
2009-10	0.26	0.25	0.30	0.31

Source: Productivity Commission estimates.

For the Water Corporation (WA) in 2009-10, the standardised coefficient for latitude (0.54) was the largest in absolute terms, indicating that climate had the most influence on consumption, and was positive, indicating that suburbs in the north of the state consumed more water than those in the south of the state. This is despite a pattern of average prices for water generally increasing with latitude.[3] This conformed with expectations that households in warmer climates would consume more water than those in cooler climates. For the other utilities, geographical coordinates were either not statistically significant or had smaller standardised coefficients. The second largest standardised coefficient for one of the geographical coordinate variables in absolute terms was longitude for Yarra Valley Water in 2009-10 (-0.23) indicating consumption was higher in the west of that utility's service area than in the east — this itself conformed with expectations as Melbourne's eastern suburbs receive more rainfall than its western suburbs (BOM 2011a).

For each of the utilities in 2005-06 and 2009-10 except Queensland Urban Utilities, customer density was statistically significant and had a negative sign indicating that smaller block sizes are associated with less water use.

3 In 2009-10, the Water Corporation applied a few different nine block IBTs to residential users in towns outside the Perth metropolitan area on a cost basis. In most cases, residential country customers paid the metropolitan usage charge up to 300 kL in the south and 500 kL in the north (above the 26th parallel) and then higher prices in subsequent blocks. In the dataset, there is a general pattern of rising use and higher average volumetric prices as latitudes become more northerly. In 2009-10, the average price paid per kilolitre of water in Western Australia was $0.88, $0.83 in Perth, $0.99 in country towns below the 26th parallel and $1.16 for those above it.

In all cases except for the Water Corporation (WA), the coefficient for the proportion of flats, units and apartments was positive and statistically significant, indicating that living in a multi-dwelling property increases water consumption when other factors are taken into account. This supports the contention that the use of a single meter for multi-dwelling buildings and lack of individual billing might increase water consumption.

The results for the other variables included in the model of water consumption were less clear.

The coefficient of the proportion of concession customers was positive and statistically significant for both Melbourne water utilities in 2005-06 and for Yarra Valley Water in 2009-10 suggesting concessions increase water consumption. However, the coefficient for the concessions variable was not statistically significant in regressions for other water utilities and years.

It was expected that the proportion of owner occupiers could have a negative coefficient, reflecting the greater likelihood of receiving a water bill and increased incentives to install water saving appliances, or a positive coefficient, reflecting greater wealth of these households. Although statistically significant and negative in half the regressions, the coefficient for this variable was also statistically significant and positive in one regression (South East Water, 2005-06) and not statistically significant in another three cases. The mixed results for this variable could be due to different relative strengths of water conservation and wealth influences between utilities and years but this could not be confirmed.

The SEIFA percentile, which was expected to be negative given prior research that higher education and occupation skills resulted in greater water saving behaviour, was statistically significant in six of the seven regressions in which the variable was included and negative in four of these. On balance, this supports the contention that educational and occupational status has a negative relationship with household water consumption.

Average per capita consumption

The results for the regression of average per capita annual water consumption on the chosen model of water demand are presented in table 5. The signs of the coefficients for this regression mirror the results for average household consumption, except for the standardised coefficient for average household size, which is negative (and statistically significant) in all cases except for Sydney Water Corporation in 2009-10. This conforms with the expectation that there would be scale economies in the use of water within households.

Table 5 **Regression results – Average per capita annual consumption**

	Queensland Urban Utilities (Brisbane)[a]		South East Water (Melbourne)		Sydney Water Corporation[b]		Water Corporation (WA)[a, c]		Yarra Valley Water (Melbourne)	
	Standardised coefficient	*P-value*	*Standardised coefficient*	*P-value*	*Standardised coefficient*	*P-value*	*Standardised coefficient*	*P-value*	*Standardised coefficient*	*P-value*
2005-06										
AvgHHSize	–	–	-0.2511	<.0001	-0.0483	0.0247	–	–	-0.26396	<.0001
MedHHIncome	–	–	0.4310	<.0001	0.4146	<.0001	–	–	0.88765	<.0001
PropOwnOcc	–	–	0.1441	0.0047	-0.1476	<.0001	–	–	-0.00789	0.8561
CustDensity	–	–	-0.1641	0.0018	-0.1578	0.0025	–	–	-0.27308	<.0001
PropFlatsUnits	–	–	0.1053	0.0319	0.1338	<.0001	–	–	0.23240	<.0001
PropConCust	–	–	0.0892	0.0892	-	-	–	–	0.22275	<.0001
SEIFAPercentile	–	–	0.2050	0.0002	-0.2317	<.0001	–	–	-0.13371	0.0038
Longitude	–	–	-0.0158	0.6166	0.1840	<.0001	–	–	-0.15936	<.0001
Latitude	–	–	-0.1990	<.0001	0.1300	<.0001	–	–	-0.00384	0.8760
R^2	–	–	0.2545	–	0.1514	–	–	–	0.3847	-
Adjusted R^2	–	–	0.2514	–	0.1500	–	–	–	0.3823	-
F value	–	–	80.99	<.0001	111.88	<.0001	–	–	161.31	<.0001
2009-10										
AvgHHSize	-0.3077	<.0001	-0.1388	0.0009	-0.0332	0.1095	-0.2654	<.0001	-0.2505	<.0001
MedHHIncome	0.1569	0.0120	0.3733	<.0001	0.4077	<.0001	0.3427	<.0001	0.7054	<.0001
PropOwnOcc	0.0670	0.2955	-0.1395	0.0065	-0.1067	<.0001	0.0804	0.2291	-0.2133	<.0001
CustDensity	-0.0391	0.5210	-0.1506	0.0053	-0.1556	0.0018	-0.3018	<.0001	-0.2471	<.0001
PropFlatsUnits	0.2895	<.0001	0.1542	0.0013	0.2158	<.0001	0.0358	0.3807	0.2364	<.0001
PropConCust	-0.0828	0.0733	0.0441	0.3559	–	–	-0.0226	0.7273	0.1593	0.0001
SEIFAPercentile	-0.0174	0.6242	0.1539	0.0056	-0.2544	<.0001	–	–	-0.2673	<.0001
Longitude	-0.0160	0.5303	-0.0182	0.6184	0.1717	<.0001	-0.0361	0.4677	-0.3311	<.0001
Latitude	-0.0598	0.0086	-0.0441	0.1263	0.1574	<.0001	0.6382	<.0001	-0.0729	0.0052
R^2	0.2266	–	0.2487	–	0.1650	–	0.5438	–	0.2956	–
Adjusted R^2	0.2220	–	0.2455	–	0.1637	–	0.5357	–	0.2929	–
F value	49.68	<.0001	76.91	<.0001	123.86	<.0001	67.20	<.0001	108.13	<.0001

a Data for Queensland Urban Utilities and Water Corporation (WA) were not available for 2005-06. **b** No data for the proportion of customers who receive a concession was available for Sydney Water Corporation. **c** Data for the Water Corporation is aggregated at the suburb level and a statistic for *SEIFAPercentile* is not available.

Source: Productivity Commission estimates.

Average volumetric price

As well as the determinants of household and per capita consumption, the Commission wanted to investigate whether IBTs disadvantage large households.

Inclining block tariffs are common in Australia and are often supported on the basis that they can provide an initial or essential level of water use at a low or affordable price while imposing incentives to conserve water at high levels of consumption. However, it has also been suggested that IBTs impose higher average volumetric charges on large households. Table 6 shows the inclining block tariffs in place in Brisbane, Melbourne and Perth in 2005-06 and 2009-10 for which the Commission has relevant expenditure data.

Sydney Water Corporation maintained a two block IBT in 2005-06, but figures for expenditure in the second block (usage greater than 400 kL) were not available by collection district for this year and by 2009-10 Sydney Water had reverted to a flat volumetric tariff. As a consequence it was excluded from the analysis. In Western Australia, five different IBTs are applied to towns outside the Perth metropolitan area based on cost of service of a particular area. The data used for the Water Corporation regression was therefore limited to the metropolitan area of Perth to enable interpretation of the results for a single tariff regime.

Table 6 **Inclining block tariffs, 2005-06 and 2009-10**

	Queensland Urban Utilities (Brisbane)[a]		*South East Water (Melbourne)*		*Water Corporation (Perth)*[a]		*Yarra Valley Water (Melbourne)*	
Block	Use	Price	Use	Price	Use	Price	Use	Price
	kL	$	kL	$	kL	$	kL	$
2005-06								
First	–	–	0–40	0.78	–	–	0–40	0.78
Second	–	–	40–80	0.92	–	–	40–80	0.92
Third	–	–	>80	1.44	–	–	>80	1.36
2009-10								
First	0–255	1.84	0–160	1.24	0–150	0.73	0–160	1.25
Second	256–310	1.88	160–320	1.50	150–350	0.88	160–320	1.47
Third	>310	2.39	>320	2.43	351–550	1.02	>320	2.17
Fourth	–	–	–	–	551–950	1.54	–	–
Fifth	–	–	–	–	>950	1.78	–	–

[a] The Commission did not have consumption and expenditure data for 2005-06 for these utilities and tariff information for this year was excluded from the table to improve readability.

Sources: ESC (2011b); NWC and WSAA (2011).

The results from regression of average volumetric price paid by residents of collection districts in Melbourne and Brisbane and of suburbs in Perth is shown in table 7.

The standardised coefficients for average household size were positive and statistically significant for each utility in 2005-06 and 2009-10, except for the Perth metropolitan area where the coefficient was not statistically significant. This indicates that the average volumetric price is positively related to household size and IBTs result in higher average volumetric prices for larger households.

The coefficients for median household income were statistically significant and positive and exceeded the coefficients for average household size in all cases except for Queensland Urban Utilities in 2009-10 where the coefficient for median household income was actually negative (-0.17), implying the IBT was regressive for that utility.

An explanation for the insignificant coefficient result for household size for Perth might lie in the higher housheold water consumption levels in Perth, compared to those in other jurisdictions. As discussed in relation to the results for the model of average household water consumption, average household size might be a stronger determinant of non-discretionary consumption, and income a stronger determinant of discretionary consumption.

In 2009-10, the mean of average household water consumption for Perth suburbs was 298 kL per year (table 1) and almost twice as much as that for collection districts serviced by Queensland Urban Utilities (154 kL), South East Water (143 kL) and Yarra Valley Water (157 kL). During 2009-10, households in Perth are therefore likely to have engaged in more discretionary water consumption than those in Melbourne and Brisbane and as such, household size could reasonably be expected to have relatively less influence on consumption and average volumetric price than income in that city (which was the most influential variable).

Table 7 **Regression results – Average volumetric price**

	Queensland Urban Utilities (Brisbane)[a]		South East Water (Melbourne)		Sydney Water Corporation[b]		Water Corporation (Perth)[a, c]		Yarra Valley Water (Melbourne)	
	Standardised coefficient	*P-value*	*Standardised coefficient*	*P-value*	*Standardised coefficient*	*P-value*	*Standardised coefficient*	*P-value*	*Standardised coefficient*	*P-value*
2005-06										
AvgHHSize	–	–	0.2710	<.0001	–	–	–	–	0.1884	<.0001
MedHHIncome	–	–	0.2959	<.0001	–	–	–	–	0.8222	<.0001
PropOwnOcc	–	–	0.0662	<.0001	–	–	–	–	-0.0561	0.0452
CustDensity	–	–	-0.2376	0.0908	–	–	–	–	-0.2713	<.0001
PropFlatsUnitsApts	–	–	0.0493	<.0001	–	–	–	–	0.2270	<.0001
PropConCust	–	–	0.0580	0.2751	–	–	–	–	0.2629	<.0001
SEIFAPercentile	–	–	0.2823	0.1685	–	–	–	–	-0.0222	0.5224
Longitude	–	–	-0.0753	<.0001	–	–	–	–	-0.0887	<.0001
Latitude	–	–	-0.2667	0.0042	–	–	–	–	0.0899	<.0001
R^2	–	–	0.4001	–	–	–	–	–	0.5714	–
Adjusted R^2	–	–	0.3975	–	–	–	–	–	0.5698	–
F value	–	–	158.20	<.0001	–	–	–	–	343.98	<.0001
2009-10										
AvgHHSize	0.5362	<.0001	0.2579	<.0001	–	–	0.0732	0.3492	0.1154	0.0014
MedHHIncome	-0.1656	0.0042	0.3439	<.0001	–	–	0.4842	<.0001	0.6916	<.0001
PropOwnOcc	0.2604	<.0001	-0.1414	0.0021	–	–	0.0183	0.7945	-0.2738	<.0001
CustDensity	0.0011	0.9589	-0.2748	0.0001	–	–	-0.3749	<.0001	-0.2821	<.0001
PropFlatsUnitsApts	0.0647	0.1552	0.0527	0.2718	–	–	0.0764	0.1954	0.1829	<.0001
PropConCust	-0.0314	0.4854	0.0687	0.1110	–	–	0.0356	0.3907	0.1613	<.0001
SEIFAPercentile	-0.2700	<.0001	0.0998	0.0480	–	–	–	–	-0.1838	<.0001
Longitude	0.0695	0.0070	-0.0731	0.0397	–	–	0.2714	<.0001	-0.1672	<.0001
Latitude	0.0300	0.1953	-0.2355	<.0001	–	–	0.0967	0.0283	0.1893	<.0001
R^2	0.2371	–	0.2489	–	–	–	0.6246	–	0.3662	–
Adjusted R^2	0.2326	–	0.2456	–	–	–	0.6120	–	0.3637	–
F value	52.68	<.0001	76.98	<.0001	–	–	49.50	<.0001	148.85	<.0001

a Data were not available for 2005-06. **b** Data for expenditure in the second block of consumption (>400 kL per annum) was not available for 2005-06, and a flat tariff regime applied in 2009-10. **c** Data for the Water Corporation is aggregated at the suburb level and a statistic for *SEIFAPercentile* is not available.

Source: Productivity Commission estimates.

5 Affordability, consumption and expenditure patterns

During the course of its inquiry, the Commission has received evidence that a number of households in Australia have difficulty meeting the costs of water and wastewater services (Tasmanian Council of Social Service, sub. 13; Anglicare Tasmania, sub. 44; Consumer Utilities Advocacy Centre, trans, p. 239). Table 8 shows average annual water and wastewater bills in Melbourne and Sydney and as a proportion of average household income, by quintile of 2006 Census collection district median household income for 2005-06.

Table 8 **Average annual water and wastewater service bills for collection districts, by income quintile[a], 2005-06**

		Quintile of median household income					
	Units	*1 Lowest*	*2*	*3*	*4*	*5 Highest*	*Total*
Melbourne[b]							
Median household income[c]	$'000	37	51	57	65	86	57
Average annual use	kL	174	181	192	207	255	202
Average total annual bill	$	454	467	481	503	570	494
Proportion of income	%	1.27	0.93	0.84	0.76	0.64	0.89
Range - low	%	0.79	0.61	0.56	0.42	0.28	0.28
Range - high	%	3.00	1.37	1.45	1.15	1.11	3.00
Sydney[d]							
Median household income[c]	$'000	38	53	63	78	102	63
Average annual use	kL	199	208	218	221	251	219
Average total annual bill	$	658	673	688	692	728	688
Proportion of income	%	1.75	1.26	1.10	0.89	0.71	1.10
Range - low	%	0.94	0.91	0.70	0.55	0.30	0.30
Range - high	%	4.88	2.21	1.79	1.52	1.19	4.88

[a] Quintiles of median household income are estimated by ranking all collection districts according to median household income, and then dividing the total number of collection districts into five equal or nearly equal sized groups. [b] Data for Melbourne represents the combined data of South East Water and Yarra Valley Water. [c] Median of the 2006 Census collection district median household income within the quintile. [d] Does not include expenditure in the second tariff block (>400 kL).

Source: Productivity Commission estimates.

Although interpretation of the table should factor in the tendency for aggregated data to suppress extreme ranges in observations, it shows:

- in 2005-06, the average water and wastewater service bills by collection district were in the region of 0.3–3.0 per cent of the median household income in Melbourne and 0.3–4.9 per cent in Sydney
- in both cities the average water and wastewater service bill as a proportion of income was relatively small, about 1 per cent of household income
- higher income households on average spend more on water and wastewater services than lower income households, but expenditure on water and wastewater services as a proportion of household income falls as income rises.

Table 9 shows average annual use of water and average bills for 2009-10 and where available for 2005-06, for each utility.

The table shows that for each water utility, average water consumption by high-income earners (those in collection districts or suburbs with the highest 20 per cent of incomes), were significantly larger than for low and moderate income households.

For the two Melbourne water retailers, South East Water and Yarra Valley Water, from 2005-06 to 2009-10 — a period in which prices increased and water restrictions heightened — households with lower incomes on average decreased their consumption by less than those with higher incomes. As a consequence, the bills of low-income households increased by relatively more than for those in the highest income quintile in this period.

This might indicate that low-income households have less discretionary water consumption on average or fewer means and/or less preparedness to invest in water conservation measures such as garden replacement and low water use appliances. Low-income households might therefore have less ability to reduce consumption in response to higher prices or water restrictions than high-income households.

Table 9 **Average annual water and wastewater service bills and water use, by income quintile[a], 2005-06 and 2009-10**

	Units	*Quintile of median household income* 1 *Lowest*	2	3	4	5 *Highest*	*Total*
Queensland Urban Utilities (Brisbane)							
2009-10							
Average annual consumption	kL	143	143	152	161	178	156
Average total annual bill	$	870	867	885	899	912	887
South East Water							
2005-06							
Average annual consumption	kL	154	172	181	194	221	183
Average total annual bill	$	426	452	467	486	532	471
2009-10							
Average annual consumption	kL	124	131	139	149	166	141
Average total annual bill	$	592	607	623	645	689	630
Change in consumption	%	-19.5	-23.8	-23.2	-23.2	-24.9	-23.0
Change in bill	%	39.0	34.3	33.4	32.7	29.5	33.8
Sydney Water							
2005-06							
Average annual consumption	kL	199	208	218	221	251	219
Average total annual bill[b]	$	658	673	688	692	728	688
2009-10							
Average annual consumption	kL	194	203	211	213	240	212
Average total annual bill	$	944	968	988	993	1046	988
Change in consumption	%	-2.5	-2.4	-3.2	-3.6	-4.4	-3.2
Change in bill	%	43.5	43.8	43.6	43.5	43.7	43.6
Water Corporation (WA)							
2009-10							
Average annual consumption	kL	215	237	237	285	337	268
Average total annual bill	$	722	789	805	897	1035	864
Yarra Valley Water							
2005-06							
Average annual consumption	kL	184	185	193	211	267	207
Average total annual bill	$	482	482	493	521	603	515
2009-10							
Average annual consumption	kL	142	139	142	153	181	151
Average total annual bill	$	668	657	665	688	753	685
Change in consumption	%	-22.8	-24.9	-26.4	-27.5	-32.2	-27.1
Change in bill	%	38.6	36.3	34.9	32.1	24.9	33.0

[a] Quintiles of median household income are estimated by ranking all collection districts according to median household income, and then dividing the total number of collection districts into five equal or nearly equal sized groups. [b] Does not include expenditure in the second tariff block (> 400kL).

Source: Productivity Commission estimates.

6 Summary of results

Based on econometric modelling and other analysis presented above, a number of observations can be made.

Household size and income are the most influential determinants of residential water consumption. Household size is a relatively stronger determinant of non-discretionary consumption and income is a stronger determinant of discretionary water consumption.

Block size, (or housing density) is positively (negatively) related to water consumption and climate also appears to have significant impact on consumption over large geographical areas. Other factors such as dwelling type, concession status, and educational and occupational status of households might also affect water consumption depending on jurisdictional and utility specific factors.

Although household water consumption increases with household size, it does so at a decreasing rate as there are economies of scale in water consumption within households.

Average volumetric prices are positively related to household size under inclining block tariff arrangements and disadvantage larger households compared with smaller households.

Regarding affordability, average water and wastewater bills represent a small proportion of income for all income groups. Expenditure on water and wastewater services represents a smaller proportion of income for high-income households than for low-income households.

Low-income households appear to have less discretionary water use or fewer means and/or less preparedness to invest in water conservation measures than high-income households. As a result, their usage is less sensitive to water restrictions and price increases than that of high-income households.

A Raw regression results

Table A1 **Regression results – Queensland Urban Utilities**

	Average annual household consumption (kL)				*Average per capita annual consumption (kL)*				*Average volumetric price (cents/kL)*			
	Coefficient	*SC*	*SE*	*P-value*	*Coefficient*	*SC*	*SE*	*P-value*	*Coefficient*	*SC*	*SE*	*P-value*
2005-06												
Intercept	–	–	–	–	–	–	–	–	–	–	–	–
AvgHHSize (no)	–	–	–	–	–	–	–	–	–	–	–	–
MedHHIncome ($'000)	–	–	–	–	–	–	–	–	–	–	–	–
PropOwnOcc (%)	–	–	–	–	–	–	–	–	–	–	–	–
CustDensity (no/sqkm)	–	–	–	–	–	–	–	–	–	–	–	–
PropFlatsUnitsApts (%)	–	–	–	–	–	–	–	–	–	–	–	–
PropConCust (%)	–	–	–	–	–	–	–	–	–	–	–	–
SEIFAPercentile (%)	–	–	–	–	–	–	–	–	–	–	–	–
Longitude (degrees)	–	–	–	–	–	–	–	–	–	–	–	–
Latitude (degrees)	–	–	–	–	–	–	–	–	–	–	–	–
R^2	–	–	–	–	–	–	–	–	–	–	–	–
Adjusted R^2	–	–	–	–	–	–	–	–	–	–	–	–
F value	–	–	–	–	–	–	–	–	–	–	–	–
2009-10												
Intercept	1478.87	0	1404.1533	0.2924	212.1022	0	504.2595	0.6741	-241.7302	0	165.5419	0.1444
AvgHHSize (no)	45.2598	0.7334	2.6687	<.0001	-5.5293	-0.3077	1.0908	<.0001	3.1461	0.5362	0.2686	<.0001
MedHHIncome ($'000)	0.2220	0.1635	0.0634	0.0005	0.0621	0.1569	0.0247	0.0120	-0.0214	-0.1656	0.0075	0.0042
PropOwnOcc (%)	0.0309	0.0215	0.0664	0.6420	0.0280	0.0670	0.0267	0.2955	0.0355	0.2604	0.0079	<.0001
CustDensity (no/sqkm)	-0.0008	-0.0442	0.0008	0.3331	-0.0002	-0.0391	0.0003	0.5210	0.0000	0.0011	0.0001	0.9589
PropFlatsUnitsApts (%)	0.1473	0.1496	0.0444	0.0009	0.0830	0.2895	0.0197	<.0001	0.0061	0.0647	0.0043	0.1552
PropConCust (%)	-0.1735	-0.0451	0.1282	0.1761	-0.0927	-0.0828	0.0518	0.0733	-0.0115	-0.0314	0.0165	0.4854
SEIFAPercentile (%)	-0.0086	-0.0071	0.0298	0.7743	-0.0061	-0.0174	0.0125	0.6242	-0.0247	-0.2700	0.0055	<.0001
Longitude (degrees)	-11.8732	-0.0265	9.2784	0.2009	-2.0895	-0.0160	3.3288	0.5303	2.9657	0.0695	1.0974	0.0070
Latitude (degrees)	-13.1804	-0.0354	6.0816	0.0304	-6.4860	-0.0598	2.4639	0.0086	1.0641	0.0300	0.8213	0.1953
R^2	0.6106	–	–	–	0.2266	–	–	–	0.2371	–	–	–
Adjusted R^2	0.6083	–	–	–	0.2220	–	–	–	0.2326	–	–	–
F value	265.92	–	–	<.0001	49.68	–	–	<.0001	52.68	–	–	<.0001

SC, standardised coefficient; SE, standard error; – Data not available.

Table A2 **Regression results – South East Water**

	Average annual household consumption (kL)				*Average per capita annual consumption (kL)*				*Average volumetric price (cents/kL)*			
	Coefficient	*SC*	*SE*	*P-value*	*Coefficient*	*SC*	*SE*	*P-value*	*Coefficient*	*SC*	*SE*	*P-value*
2005-06												
Intercept	-2232.2876	0	1727.1237	0.1963	-567.5072	0	654.6010	0.3861	101.5144	0	184.0601	0.5813
AvgHHSize (no)	52.7546	0.4947	3.0109	<.0001	-7.8576	-0.2511	1.2036	<.0001	2.8739	0.2710	0.3846	<.0001
MedHHIncome ($'000)	0.9470	0.3482	0.1431	<.0001	0.3439	0.4310	0.0530	<.0001	0.0800	0.2959	0.0157	<.0001
PropOwnOcc (%)	0.2907	0.0983	0.1004	0.0038	0.1251	0.1441	0.0442	0.0047	0.0195	0.0662	0.0115	0.0908
CustDensity (no/sqkm)	-0.0034	-0.1185	0.0011	0.0020	-0.0014	-0.1641	0.0004	0.0018	-0.0007	-0.2376	0.0002	<.0001
PropFlatsUnitsApts (%)	0.1330	0.0683	0.0621	0.0323	0.0602	0.1053	0.0280	0.0319	0.0095	0.0493	0.0087	0.2751
PropConCust (%)	0.3457	0.0815	0.1697	0.0418	0.1110	0.0892	0.0653	0.0892	0.0245	0.0580	0.0178	0.1685
SEIFAPercentile (%)	0.3001	0.1726	0.0736	<.0001	0.1046	0.2050	0.0285	0.0002	0.0488	0.2823	0.0081	<.0001
Longitude (degrees)	-3.6437	-0.0090	9.8135	0.7105	-1.8770	-0.0158	3.7480	0.6166	-3.0216	-0.0753	1.0545	0.0042
Latitude (degrees)	-71.4145	-0.1767	11.0579	<.0001	-23.5882	-0.1990	4.0970	<.0001	-10.7210	-0.2667	1.1878	<.0001
R^2	0.5734	–	–	–	0.2545	–	–	–	0.4001	–	–	–
Adjusted R^2	0.5716	–	–	–	0.2514	–	–	–	0.3975	–	–	–
F value	318.85	–	–	<.0001	80.99	–	–	<.0001	158.20	–	–	<.0001
2009-10												
Intercept	342.7803	0	1101.9313	0.7558	124.6289	0	440.3630	0.7772	197.4588	0	290.2574	0.4964
AvgHHSize (no)	48.3736	0.7360	1.9120	<.0001	-2.7022	-0.1388	0.8106	0.0009	3.3583	0.2579	0.5588	<.0001
MedHHIncome ($'000)	0.4974	0.2984	0.0843	<.0001	0.1842	0.3733	0.0333	<.0001	0.1135	0.3439	0.0199	<.0001
PropOwnOcc (%)	-0.1715	-0.0941	0.0629	0.0064	-0.0753	-0.1395	0.0276	0.0065	-0.0511	-0.1414	0.0166	0.0021
CustDensity (no/sqkm)	-0.0021	-0.1204	0.0007	0.0038	-0.0008	-0.1506	0.0003	0.0053	-0.0009	-0.2748	0.0002	0.0001
PropFlatsUnitsApts (%)	0.1084	0.0895	0.0382	0.0046	0.0553	0.1542	0.0172	0.0013	0.0126	0.0527	0.0115	0.2718
PropConCust (%)	0.1159	0.0441	0.0841	0.1681	0.0343	0.0441	0.0371	0.3559	0.0357	0.0687	0.0224	0.1110
SEIFAPercentile (%)	0.1201	0.1124	0.0423	0.0046	0.0486	0.1539	0.0175	0.0056	0.0211	0.0998	0.0107	0.0480
Longitude (degrees)	-5.9968	-0.0241	6.7325	0.3732	-1.3400	-0.0182	2.6896	0.6184	-3.6062	-0.0731	1.7521	0.0397
Latitude (degrees)	-13.7290	-0.0548	5.4524	0.0119	-3.2706	-0.0441	2.1383	0.1263	-11.6804	-0.2355	1.4558	<.0001
R^2	0.6070	–	–	–	0.2487	–	–	–	0.2489	–	–	–
Adjusted R^2	0.6053	–	–	–	0.2455	–	–	–	0.2456	–	–	–
F value	358.87	–	–	<.0001	76.91	–	–	<.0001	76.98	–	–	<.0001

SC, standardised coefficient; SE, standard error; – Data not available.

Table A3 **Regression results – Sydney Water Corporation**

	Average annual household consumption (kL)				Average per capita annual consumption (kL)				Average volumetric price (cents/kL)			
	Coefficient	*SC*	*SE*	*P-value*	*Coefficient*	*SC*	*SE*	*P-value*	*Coefficient*	*SC*	*SE*	*P-value*
2005-06												
Intercept	-4919.1569	0	629.8115	<.0001	-1930.8339	0	228.5351	<.0001	–	–	–	–
AvgHHSize (no)	70.5851	0.5499	2.1776	<.0001	-1.7501	-0.0483	0.7790	0.0247	–	–	–	–
MedHHIncome ($'000)	0.7605	0.3595	0.0656	<.0001	0.2476	0.4146	0.0234	<.0001	–	–	–	–
PropOwnOcc (%)	-0.3861	-0.1247	0.0614	<.0001	-0.1290	-0.1476	0.0222	<.0001	–	–	–	–
CustDensity (no/sqkm)	-0.0088	-0.1499	0.0024	0.0002	-0.0026	-0.1578	0.0009	0.0025	–	–	–	–
PropFlatsUnitsApts (%)	0.2626	0.0860	0.0610	<.0001	0.1153	0.1338	0.0270	<.0001	–	–	–	–
PropConCust (%)	–	–	–	–	–	–	–	–	–	–	–	–
SEIFAPercentile (%)	-0.3550	-0.1815	0.0455	<.0001	-0.1280	-0.2317	0.0168	<.0001	–	–	–	–
Longitude (degrees)	39.0585	0.1300	4.1394	<.0001	15.6034	0.1840	1.5029	<.0001	–	–	–	–
Latitude (degrees)	28.1935	0.1028	2.5413	<.0001	10.0686	0.1300	0.8622	<.0001	–	–	–	–
R^2	0.4661	–	–	-	0.1514	–	–	–	–	–	–	–
Adjusted R^2	0.4652	–	–	-	0.1500	–	–	–	–	–	–	–
F value	547.52	–	–	<.0001	111.88	–	–	<.0001	–	–	–	–
2009-10												
Intercept	-4168.1676	0	575.4684	<.0001	-1607.5724	0	209.9912	<.0001	–	–	–	–
AvgHHSize (no)	70.3437	0.5769	1.9181	<.0001	-1.1425	-0.0332	0.7138	0.1095	–	–	–	–
MedHHIncome ($'000)	0.6950	0.3474	0.0676	<.0001	0.2302	0.4077	0.0236	<.0001	–	–	–	–
PropOwnOcc (%)	-0.2602	-0.0889	0.0519	<.0001	-0.0881	-0.1067	0.0200	<.0001	–	–	–	–
CustDensity (no/sqkm)	-0.0080	-0.1445	0.0021	0.0001	-0.0024	-0.1556	0.0008	0.0018	–	–	–	–
PropFlatsUnitsApts (%)	0.4338	0.1486	0.0565	<.0001	0.1780	0.2158	0.0252	<.0001	–	–	–	–
PropConCust (%)	–	–	–	–	–	–	–	–	–	–	–	–
SEIFAPercentile (%)	-0.3672	-0.19851	0.0441	<.0001	-0.1328	-0.2544	0.0161	<.0001	–	–	–	–
Longitude (degrees)	34.7621	0.12262	3.78759	<.0001	13.7360	0.1717	1.3804	<.0001	–	–	–	–
Latitude (degrees)	31.5834	0.12225	2.28652	<.0001	11.4767	0.1574	0.7934	<.0001	–	–	–	–
R^2	0.4837	–	–	–	0.1650	–	–	-	–	–	–	–
Adjusted R^2	0.4828	–	–	–	0.1637	–	–	-	–	–	–	–
F value	586.95	–	–	<.0001	123.86	–	–	<.0001	–	–	–	–

SC, standardised coefficient; SE, standard error; – Data not available.

Table A4 **Regression results – Water Corporation (WA)**

	Average annual household consumption (kL)				*Average per capita annual consumption (kL)*				*Average volumetric price (cents/kL)*			
	Coefficient	*SC*	*SE*	*P-value*	*Coefficient*	*SC*	*SE*	*P-value*	*Coefficient*	*SC*	*SE*	*P-value*
2005-06												
Intercept	–	–	–	–	–	–	–	–	–	–	–	–
AvgHHSize (no)	–	–	–	–	–	–	–	–	–	–	–	–
MedHHIncome ($'000)	–	–	–	–	–	–	–	–	–	–	–	–
PropOwnOcc (%)	–	–	–	–	–	–	–	–	–	–	–	–
CustDensity (no/sqkm)	–	–	–	–	–	–	–	–	–	–	–	–
PropFlatsUnitsApts (%)	–	–	–	–	–	–	–	–	–	–	–	–
PropConCust (%)	–	–	–	–	–	–	–	–	–	–	–	–
SEIFAPercentile (%)	–	–	–	–	–	–	–	–	–	–	–	–
Longitude (degrees)	–	–	–	–	–	–	–	–	–	–	–	–
Latitude (degrees)	–	–	–	–	–	–	–	–	–	–	–	–
R^2	–	–	–	–	–	–	–	–	–	–	–	–
Adjusted R^2	–	–	–	–	–	–	–	–	–	–	–	–
F value	–	–	–	–	–	–	–	–	–	–	–	–
2009-10												
Intercept	733.8291	0	271.3000	0.0071	430.2272	0	106.8993	<.0001	–	–	–	–
AvgHHSize (no)	58.6874	0.2104	11.4502	<.0001	-23.9244	-0.2654	4.6312	<.0001	–	–	–	–
MedHHIncome ($'000)	1.6647	0.3057	0.2361	<.0001	0.6032	0.3427	0.0927	<.0001	–	–	–	–
PropOwnOcc (%)	0.3340	0.0541	0.3390	0.3251	0.1603	0.0804	0.1331	0.2291	–	–	–	–
CustDensity (no/sqkm)	-0.0521	-0.2428	0.0075	<.0001	-0.0209	-0.3018	0.0030	<.0001	–	–	–	–
PropFlatsUnitsApts (%)	0.4861	0.0378	0.4185	0.2460	0.1487	0.0358	0.1695	0.3807	–	–	–	–
PropConCust (%)	-0.1275	-0.0104	0.6539	0.8455	-0.0892	-0.0226	0.2558	0.7273	–	–	–	–
SEIFAPercentile (%)	–	–	–	–	–	–	–	–	–	–	–	–
Longitude (degrees)	-0.9066	-0.0176	2.0983	0.6659	-0.5991	-0.0361	0.8242	0.4677	–	–	–	–
Latitude (degrees)	17.8348	0.5434	1.8115	<.0001	6.7694	0.6382	0.7273	<.0001	–	–	–	–
R^2	0.6873	–	–	–	0.5438	–	–	–	–	–	–	–
Adjusted R^2	0.6817	–	–	–	0.5357	–	–	–	–	–	–	–
F value	123.89	–	–	<.0001	67.20	–	–	<.0001	–	–	–	–

SC, standardised coefficient; SE, standard error; – Data not available.

Table A5 **Regression results – Water Corporation (Perth Metropolitan Area)**

	Average annual household consumption (kL)				*Average per capita annual consumption (kL)*				*Average volumetric price (cents/kL)*			
	Coefficient	*SC*	*SE*	*P-value*	*Coefficient*	*SC*	*SE*	*P-value*	*Coefficient*	*SC*	*SE*	*P-value*
2005-06												
Intercept	–	–	–	–	–	–	–	–	–	–	–	–
AvgHHSize (no)	–	–	–	–	–	–	–	–	–	–	–	–
MedHHIncome ($'000)	–	–	–	–	–	–	–	–	–	–	–	–
PropOwnOcc (%)	–	–	–	–	–	–	–	–	–	–	–	–
CustDensity (no/sqkm)	–	–	–	–	–	–	–	–	–	–	–	–
PropFlatsUnitsApts (%)	–	–	–	–	–	–	–	–	–	–	–	–
PropConCust (%)	–	–	–	–	–	–	–	–	–	–	–	–
SEIFAPercentile (%)	–	–	–	–	–	–	–	–	–	–	–	–
Longitude (degrees)	–	–	–	–	–	–	–	–	–	–	–	–
Latitude (degrees)	–	–	–	–	–	–	–	–	–	–	–	–
R^2	–	–	–	–	–	–	–	–	–	–	–	–
Adjusted R^2	–	–	–	–	–	–	–	–	–	–	–	–
F value	–	–	–	–	–	–	–	–	–	–	–	–
2009-10												
Intercept	-10036	0	2814.9120	0.0004	-3372.598	0	1051.705	0.0015	-1426.1413	0	298.3347	<.0001
AvgHHSize (no)	55.6934	0.2928	11.3301	<.0001	-19.4048	-0.3823	4.6366	<.0001	1.2650	0.0732	1.3486	0.3492
MedHHIncome ($'000)	1.4595	0.3507	0.2281	<.0001	0.5151	0.4638	0.0855	<.0001	0.1832	0.4842	0.0231	<.0001
PropOwnOcc (%)	0.6121	0.1154	0.3076	0.0478	0.1958	0.1383	0.1307	0.1355	0.0088	0.0183	0.0338	0.7945
CustDensity (no/sqkm)	-0.0314	-0.2202	0.0072	<.0001	-0.0122	-0.3222	0.0029	<.0001	-0.0048	-0.3749	0.0010	<.0001
PropFlatsUnitsApts (%)	0.3363	0.0410	0.3719	0.3668	0.0865	0.0396	0.1509	0.5668	0.0569	0.0764	0.0439	0.1954
PropConCust (%)	0.4521	0.0420	0.4600	0.3267	0.1560	0.0544	0.1785	0.3831	0.0348	0.0356	0.0405	0.3907
SEIFAPercentile (%)	–	–	–	–	–	–	–	–	–	–	–	–
Longitude (degrees)	113.5703	0.2000	24.0687	<.0001	40.1197	0.2648	8.9065	<.0001	14.0067	0.2714	2.5036	<.0001
Latitude (degrees)	96.8412	0.2157	17.3115	<.0001	36.0788	0.3011	6.4549	<.0001	3.9473	0.0967	1.7894	0.0283
R^2	0.7321	–	–	–	0.4550	–	–	–	0.6246	–	–	–
Adjusted R^2	0.7231	–	–	–	0.4367	–	–	–	0.6120	–	–	–
F value	81.30	–	–	<.0001	24.84	–	–	<.0001	49.50	–	–	<.0001

SC, standardised coefficient; SE, standard error; – Data not available.

Table A6 **Regression results – Yarra Valley Water**

	Average annual household consumption (kL)				Average per capita annual consumption (kL)				Average volumetric price (cents/kL)			
	Coefficient	*SC*	*SE*	*P-value*	*Coefficient*	*SC*	*SE*	*P-value*	*Coefficient*	*SC*	*SE*	*P-value*
2005-06												
Intercept	6004.9650	0	762.8158	<.0001	2477.6934	0	271.7024	<.0001	693.7901	0	82.8190	<.0001
AvgHHSize (no)	51.0734	0.4048	3.1962	<.0001	-8.5912	-0.2640	1.1535	<.0001	1.9466	0.1884	0.2765	<.0001
MedHHIncome ($'000)	1.7376	0.6892	0.1444	<.0001	0.5774	0.8877	0.0485	<.0001	0.1697	0.8222	0.0104	<.0001
PropOwnOcc (%)	-0.0946	-0.0271	0.1012	0.3499	-0.0071	-0.0079	0.0391	0.8561	-0.0160	-0.0561	0.0080	0.0452
CustDensity (no/sqkm)	-0.0165	-0.1847	0.0017	<.0001	-0.0063	-0.2731	0.0006	<.0001	-0.0020	-0.2713	0.0002	<.0001
PropFlatsUnitsApts (%)	0.4400	0.1482	0.0684	<.0001	0.1780	0.2324	0.0291	<.0001	0.0552	0.2270	0.0071	<.0001
PropConCust (%)	0.6966	0.1775	0.1199	<.0001	0.2255	0.2227	0.0449	<.0001	0.0844	0.2629	0.0119	<.0001
SEIFAPercentile (%)	-0.1828	-0.0976	0.0581	0.0017	-0.0646	-0.1337	0.0223	0.0038	-0.0034	-0.0222	0.0053	0.5224
Longitude (degrees)	-39.2752	-0.0961	6.3658	<.0001	-16.7930	-0.1594	2.2890	<.0001	-2.9658	-0.0887	0.6800	<.0001
Latitude (degrees)	8.8111	0.0128	12.1414	0.4681	-0.6837	-0.0038	4.3823	0.8760	5.0816	0.0899	1.2278	<.0001
R^2	0.6809	–	–	–	0.3847	–	–	–	0.5714	–	–	–
Adjusted R^2	0.6796	–	–	–	0.3823	–	–	–	0.5698	–	–	–
F value	550.42	–	–	<.0001	161.31	–	–	<.0001	343.98	–	–	<.0001
2009-10												
Intercept	7711.6410	0	494.8734	<.0001	2932.4777	0	189.4389	<.0001	1419.5439	0	110.8586	<.0001
AvgHHSize (no)	43.4309	0.5602	2.2520	<.0001	-5.1284	-0.2505	0.8556	<.0001	1.2903	0.1154	0.4047	0.0014
MedHHIncome ($'000)	0.8587	0.5555	0.0891	<.0001	0.2880	0.7054	0.0311	<.0001	0.1542	0.6916	0.0146	<.0001
PropOwnOcc (%)	-0.3502	-0.1636	0.0662	<.0001	-0.1206	-0.2133	0.0260	<.0001	-0.0845	-0.2738	0.0105	<.0001
CustDensity (no/sqkm)	-0.0099	-0.1757	0.0012	<.0001	-0.0037	-0.2471	0.0005	<.0001	-0.0023	-0.2821	0.0002	<.0001
PropFlatsUnitsApts (%)	0.2641	0.1441	0.0445	<.0001	0.1144	0.2364	0.0191	<.0001	0.0484	0.1829	0.0090	<.0001
PropConCust (%)	0.3587	0.1452	0.0706	<.0001	0.1039	0.1593	0.0272	0.0001	0.0575	0.1613	0.0137	<.0001
SEIFAPercentile (%)	-0.2107	-0.1841	0.0385	<.0001	-0.0808	-0.2673	0.0147	<.0001	-0.0303	-0.1838	0.0070	<.0001
Longitude (degrees)	-57.2049	-0.2296	4.1956	<.0001	-21.7877	-0.3311	1.6014	<.0001	-6.0077	-0.1672	0.9237	<.0001
Latitude (degrees)	-16.2262	-0.0397	7.6049	0.0330	-7.8675	-0.0729	2.8113	0.0052	11.1637	0.1893	1.7401	<.0001
R^2	0.6506	–	–	–	0.2956	–	–	–	0.3662	–	–	–
Adjusted R^2	0.6493	–	–	–	0.2929	–	–	–	0.3637	–	–	–
F value	479.82	–	–	<.0001	108.13	–	–	<.0001	148.85	–	–	<.0001

SC, standardised coefficient; SE, standard error; – Data not available.

Table A7 **Regression results – South East Water – Average Quarterly Household Consumption**

	Quarter 1 1 Jul – 30 Sep		*Quarter 2 1 Oct – 31 Dec*		*Quarter 3 1 Jan – 31 Mar*		*Quarter 4 1 Apr – 30 Jun*	
	Standardised coefficient	*P-value*	*Standardised coefficient*	*P-value*	*Standardised coefficient*	*P-value*	*Standardised coefficient*	*P-value*
2005-06								
AvgHHSize	0.5563	<.0001	0.6229	<.0001	0	<.0001	0.3971	<.0001
MedHHIncome	0.3148	<.0001	0.2933	<.0001	0.3869	<.0001	0.3380	<.0001
PropOwnOcc	0.0233	0.5342	0.0196	0.5534	0.3491	<.0001	0.1297	0.0004
CustDensity	-0.0895	0.0073	-0.0791	0.0251	0.1458	<.0001	-0.1454	0.0006
PropFlatsUnitsApts	0.0401	0.2439	0.0616	0.0594	-0.1136	0.0013	0.0628	0.0767
PropConCust	0.0602	0.1258	0.0455	0.2638	0.0813	0.0070	0.0974	0.0204
SEIFAPercentile	0.0658	0.1047	0.0459	0.2980	0.0909	0.0212	0.2098	<.0001
Longitude	-0.0278	0.2621	-0.0238	0.3435	0.2478	<.0001	-0.0260	0.3244
Latitude	0.0576	0.0176	-0.1594	<.0001	0.0264	0.2639	-0.0633	0.0420
R^2	0.510	–	0.5870	–	0.5881	–	0.4820	–
Adjusted R^2	0.508	–	0.5853	–	0.5864	–	0.4798	–
F value	247.26	<.0001	337.16	<.0001	338.72	<.0001	220.76	<.0001
2009-10								
AvgHHSize	0.7681	<.0001	0.8372	<.0001	0.6259	<.0001	0.6298	<.0001
MedHHIncome	0.2613	<.0001	0.2485	<.0001	0.3017	<.0001	0.3114	<.0001
PropOwnOcc	-0.1869	<.0001	-0.1643	<.0001	-0.0078	0.8287	-0.0450	0.2076
CustDensity	-0.0992	0.0170	-0.0947	0.0045	-0.1136	0.0035	-0.1437	0.0027
PropFlatsUnitsApts	0.0618	0.0549	0.0986	0.0017	0.0884	0.0039	0.0900	0.0082
PropConCust	-0.0037	0.9105	0.0363	0.2716	0.0665	0.1323	0.0538	0.1792
SEIFAPercentile	0.0211	0.6093	0.0371	0.3492	0.1850	<.0001	0.1439	0.0013
Longitude	-0.0182	0.5049	-0.0171	0.5609	-0.0005	0.9871	-0.0553	0.0498
Latitude	0.0556	0.0076	-0.0274	0.1943	-0.2021	<.0001	0.0115	0.6503
R^2	0.5523	–	0.6220	–	0.5836	–	0.5324	–
Adjusted R^2	0.5504	–	0.6203	–	0.5818	–	0.5304	–
F value	286.63	<.0001	382.24	<.0001	325.63	<.0001	264.52	<.0001

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