Government of **Western Australia**
Department of **Water**

Ord surface water allocation plan methods report

Background information and description of methods for the Ord surface water allocation plan

May 2012

Looking after all our water needs

Ord surface water allocation plan methods report

Background information and description of methods for the Ord surface water allocation plan

Looking after all our water needs

Department of Water

May 2012

Department of Water
168 St Georges Terrace
Perth Western Australia 6000
Telephone +61 8 6364 7600
Facsimile +61 8 6364 7601
National Relay Service 13 36 77
www.water.wa.gov.au

© Government of Western Australia 2012

May 2012

This work is copyright. You may download, display, print and reproduce this material in unaltered form only (retaining this notice) for your personal, non-commercial use or use within your organisation. Apart from any use as permitted under the *Copyright Act 1968*, all other rights are reserved. Requests and inquiries concerning reproduction and rights should be addressed to the Department of Water.

ISBN 978-1-921992-54-4 (print)
ISBN 978-1-921992-55-1 (online)

Acknowledgements

The Department of Water would like to thank the following for their contribution to this publication. Ian Loh, Clare Meredith, Mike Braimbridge, Jacinta Thompson, Kathryn Smith, Simone McCallum, Guy Chandler, Robyn Loomes, Susan Worley, Patrick Seares, John Connolly, Dave Munday, Chris Gunby and Jessica Seares.

For more information about this report, contact:

Kununurra Regional Office
Kimberley Region, Department of Water
27 Victoria Highway Kununurra WA 6743
Telephone 08 9166 4116

Disclaimer

This document has been published by the Department of Water. Any representation, statement, opinion or advice expressed or implied in this publication is made in good faith and on the basis that the Department of Water and its employees are not liable for any damage or loss whatsoever which may occur as a result of action taken or not taken, as the case may be in respect of any representation, statement, opinion or advice referred to herein. Professional advice should be obtained before applying the information contained in this document to particular circumstances.

This publication is available at our website <www.water.wa.gov.au> or for those with special needs it can be made available in alternative formats such as audio, large print, or Braille.

Contents

Figures

Tables

Tables in appendices

How to use this document

The Department of Water has prepared this document to supplement the *Ord surface water allocation plan* (DoW 2012). It provides supporting information and describes how we made the decisions in the allocation plan.

Chapter 1 sets out the document's purpose in more detail and outlines the background to the allocation plan's development. Chapter 2 details the hydrology of the Ord River catchment. Chapter 3 describes the current and projected commercial demands on the Ord River water resource, while chapters 4 and 5 describe the ecological water requirements and social, recreational and cultural demands on the river.

Chapter 6 describes the reservoir simulations undertaken to determine how best to balance and manage the competing demands for Ord River water. This includes defining five demand scenarios that may emerge during the next seven to ten years (over the allocation plan's expected life) and determining appropriate reservoir operating rules for each scenario.

Chapter 7 describes the releases from storage and the electricity generated, water supplied and resulting flows in the lower Ord River expected under the five demand scenarios. Chapter 8 discusses the ecological changes likely to result from the expected range of flows in the lower Ord River. Additional detail, especially in relation to providing water for the environment, is included in appendices.

As the report is designed to supplement the *Ord surface water allocation plan* (DoW, 2012), we expect readers will select specific chapters, sections or appendices to read when seeking additional information. For this reason each chapter has been written to stand on its own.

1 Introduction

1.1 Purpose

The Department of Water has prepared this document to support the *Ord surface water allocation plan – for public comment* (DoW 2012). In it we:

- describe how we made the decisions for the allocation plan, outlining the analyses undertaken and rationale used
- outline the flow regimes to remain in the lower Ord River given the water allocation and management provisions (licensing policies) in the plan
- estimate the environmental changes in the lower Ord River likely to result from the range of flow regimes considered acceptable in the plan.

The intent is to provide a document that supports the assessed environmental impacts of applying the allocations and management regimes outlined in the plan.

The allocation plan updates and replaces the 2006 *Ord River water management plan* (DoW 2006).

Since 2006, our understanding of the Ord River catchment's hydrology has improved. In 2007 comprehensive environmental water requirements were developed for the lower Ord River. During the second half of 2008, Pacific Hydro Ltd sought, via the Water Corporation, to generate more hydro-electricity from their Ord River Dam power station. Also the Western Australian Government committed funds to establish a further 8000 ha of serviced irrigation farmland in the Ord River Irrigation Area.

This improved knowledge and extra demand for water from Lake Argyle will affect the range of expected flows in the lower Ord River and has required us to refine our management of the Ord River water resource since 2006. We prepared the *Ord surface water allocation plan – for public comment* (DoW 2012) and this report to document these changes. While the 2012 allocation limits remain the same as in 2006, the licensing policies have been updated and the flow regimes of the lower Ord River recalculated. This has enabled ecological changes likely to result from the revised flow regimes to be assessed and described in this document.

1.2 Background

DoW (2006) provides a general description of the Ord River irrigation project and planning work undertaken from the mid 1990s to December 2006. Key aspects of the development, early history and planning to 2006 are repeated here. This document also includes background on recent changes in water planning and management since 2006 and outlines the current Ord River irrigation expansion project.

1.2.1 Irrigation

Stage 1

Stage 1 of the Ord River irrigation project began in the early 1960s with completion of the Kununurra Diversion Dam and release of the first serviced farmlands to the Ord

River's east on the Ivanhoe Plain. By the mid 1970s the Ord River Dam had been constructed and additional serviced farmlands released to the west of the river on Packsaddle Plain (Le Page 1986). By 1975 10 375 ha of irrigated land had been developed. Appendix 1 of DoW (2006) documents the initial planning, early development years and subsequent period of consolidation for the Ord River Irrigation Area (ORIA).

Irrigated agriculture proved marginal in the ORIA for its first two decades of operation and provoked much debate about the economics of irrigated agriculture in northern Australia (Davidson & Graham-Taylor 1982; Powell 1998). After the cotton crop failures of the mid 1970s, the area under irrigation was reduced to 3500 ha and remained low for many years. In the late 1980s new horticultural crops were introduced as better roads and improved transport methods made it possible to deliver the produce to major markets in southern Australia in good condition.

Areas under irrigation and the amount of water being used increased during the 1990s as the horticultural industry expanded and sugarcane growing began. By 2000 the area of developed irrigable farmland reached close to 15 000 ha. A further 1000 ha has been developed since, primarily in 2008 and 2009 (Greens location). The actual area under irrigation in recent years has ranged between 12 000 and 13 500 ha.

The first decade in the 21st century saw a major change in the crops being grown. Except for a small area grown for molasses, sugarcane is no longer grown and processed to raw sugar in the ORIA. Tree plantations established as hosts for Indian sandalwood have expanded greatly during the past five years and taken up much of the area previously used to grow sugarcane.

Stage 2

After a decade of planning and investigations, and the resolution of native title and Aboriginal heritage matters, in 2008 the state government committed to establishing the first 8000 ha of new serviced irrigation land in the M2 supply area. This development is now known as the Ord Irrigation Expansion Project (OIEP). (The full M2 supply area involves more than 30 000 ha of serviced irrigation farmland, 14 000 ha of which is in the Northern Territory. Both the Western Australian and Northern Territory governments gave the initial environmental approvals in 2002.) In 2009 the Australian Government committed to supporting complementary investment in social infrastructure in the east Kimberley region, known as the Ord-East Kimberley Development Project (OEKDP). Subject to final environmental conditions being met and construction being on schedule, additional irrigation water is expected to be supplied to the new OIEP area during the 2014 dry season.

1.2.2 Hydropower generation

The original design of the Ord River Dam allowed for a hydro-electric power station to be constructed when demand was sufficient to justify the additional investment. Planning to establish a power station began in the early 1990s and culminated in Pacific Hydro Pty Ltd reaching an agreement with the state government to construct a station to supply Kununurra and Wyndham and the Argyle Diamond Mine. The 30

MW hydro-electric power station was built in 1995 and became fully operational in 1996. Since that time the station has provided more than 90 per cent of the electricity needs of the towns and the mine. As part of the power station's development, the base of the Ord River Dam spillway was raised 6 m, so that the station could increase the amount of electricity generated.

In 2005 the Argyle Diamond Mine's owner, Rio Tinto, committed to extending the mine deep underground. This substantially increased the projected power demand on the station until 2018 (DoW 2006). As operations extended further underground, electricity demand began to increase; but in 2008, in response to poor world diamond prices following the global financial crisis, Rio Tinto scaled back mining and ore processing and the electricity demand reduced. More recently (late 2009) electricity demand has recovered to pre-2005 levels and is likely to return to projected levels as the mine gears up to full capacity in the future.

1.2.3 Environmental water

Planning for the ORIA's expansion began in the mid 1990s, coinciding with the time the Council of Australian Governments (COAG) agreed to implement a major program of national water industry reform. A key element of the reform was to ensure that explicit water allocations were made to protect the environment when water was being allocated for commercial use. The Water and Rivers Commission (WRC), now the Department of Water, was charged with implementing this reform as part of its water allocation planning function and overall responsibility for managing the Western Australia's water resources.

The *Draft interim water allocation plan, Ord River* was released for public review in May 1999 (WRC 1999b). The plan considered what the water-dependent ecosystems of the lower Ord River needed, the socio-cultural expectations of the community for the river and the resource commitments already made; and sought to balance these against future irrigation and hydro-electricity demands.

The Environmental Protection Authority (EPA) reviewed the draft plan and public comments received, and advised the WRC on the plan's proposed interim environmental water provisions (EWPs) in December 1999 (Appendix 2, EPA 1999).

The EPA considered that *'… the interim and final EWP should be based on protecting environmental values, which are sustainable under post-dam flows'.* After the Ord River Dam was built in 1972, dry season flows in the lower Ord River had increased significantly. Flows had become continuous throughout the year and the large flood storage capacity of Lake Argyle had greatly reduced the frequency of downstream flooding during the wet season. A modified riverine ecology had established along the lower Ord in response to this altered flow regime. The EPA considered that a revised EWP regime should be developed that would protect this modified riverine environment.

1.2.4 Native title

In 2003 and 2006 the Federal Court established native title rights to the Miriuwung Gajerrong and Balangarra peoples over much of the lower Ord River area. These were consent determinations that followed extensive negotiations from 2001 between the Western Australian and Northern Territory governments, the Miriuwung Gajerrong and Balangarra peoples and affected pastoralists in the region. The consent determinations resolved a series of court decisions and appeals stemming from the first native title claim made by the Miriuwung Gajerrong people in the 1990s.

After further negotiations a benefits package and compensation for access to land required for Ord Stage 2 developments in Western Australia, known as the Ord Final Agreement, was agreed to in October 2005.

The Ord Final Agreement resolved native title and Aboriginal heritage issues over land proposed to become irrigated farmland, while enshrining the right of the local Aboriginal people to participate in and benefit from investment associated with the expansion of irrigated agriculture in the east Kimberley.

The agreement enables approximately 65 000 ha of land to be released for agricultural, industrial and residential development and includes buffer areas around the new agricultural land. It also provides for a further 154 000 ha of conservation land to be established in six new conservation parks. The agreement includes a range of initiatives for the benefit of the Miriuwung Gajerrong people, with a total value of $57 million.

These initiatives focus on developing the capacity of the Miriuwung Gajerrong people to engage in the local economy and benefit from any future development. Importantly it also includes financial support for improved land management to be carried out in conjunction with the Miriuwung Gajerrong.

1.2.5 The 2006 Ord River water management plan

Given the growing demand on the Ord River water resource, the *Ord River water management plan* (DoW 2006) was prepared to:

- protect the riverine environment of the lower Ord as it has adapted to the changed flow regimes since the Ord River Dam was constructed
- provide for existing commitments to irrigation and hydropower generation
- guide planning for Western Australia’s portion of the M2 supply area and irrigation developments on the lower Ord downstream of House Roof Hill
- identify the potential for further hydro-electricity to be generated at the Ord River and Kununurra Diversion dams
- indicate the potential for additional irrigation allocations to be made in the future.

In seeking to meet these needs the 2006 plan:

- specified an interim environmental water regime for the lower Ord River
- determined sustainable diversion limits from the Ord River below Lake Argyle and specified allocations for current and proposed irrigation use
- described the environmental effects of the proposed allocations on the flow regime of the lower Ord and Ramsar wetlands in the area

- documented current irrigation licence conditions designed to improve practices so that risks to the lower Ord environment and agricultural production were reduced, and water use efficiency was improved
- outlined how water allocations and management would be implemented through the licensing powers of the *Rights in Water and Irrigation Act 1914*.

The details are presented in the original document (DoW 2006). The main in-stream allocations and sustainable diversion limits are repeated here for easy reference.

In-stream allocations

The plan established the following (interim) flow regime to protect the lower Ord's riverine environment until a more comprehensive regime was developed:

- When water levels in Lake Argyle are above 76 m AHD (expected 95 per cent of the time), the lower Ord River is to be maintained at an average monthly flow rate of at least:
  - 45 m^3/s from the Dunham River confluence to House Roof Hill (situated 56 km downstream of the Kununurra Diversion Dam), and
  - 40 m^3/s downstream of House Roof Hill.
- During drought periods when water levels in Lake Argyle are less than 76 m AHD (expected five per cent of the time)[1]
  - 35 m^3/s from the Dunham River confluence and House Roof Hill, and
  - 30 m^3/s downstream of House Roof Hill.
- No significant increase will be permitted to the regulation of the Dunham River tributary.

Sustainable diversion limits

The sustainable diversion limit for the Ord River between Lake Kununurra and Tarrara Bar (situated 33 km downstream of the Kununurra Diversion Dam) was set at 750 GL/yr. This diversion limit provided 350 GL/yr for use on developed Stage 1 land and for minor demand growth in Stage 1 areas. The diversion limit also provided for an initial allocation of 400 GL/yr for future demand in new areas. Future demand was expected to grow in increments, especially as the M2 supply area was to be developed in stages, and new demands were not expected to exceed 400 GL/yr during the plan's life.

The 350 GL/yr allocation for Stage 1 areas had two components. The first 250 GL/yr was based on an expected annual reliability of 95 per cent, and provided for historic use, corrected for the required efficiency gains. The second 100 GL/yr was based on an expected annual reliability of 90 per cent, and provided for demand growth in Stage 1 areas. (When the allocation was initially made, sugarcane plantations in Stage 1 areas were planned to increase from approximately 3800 to 6000 ha.) The

[1] Restrictions on irrigation diversions and hydropower generation will also apply during these drought periods.

initial 400 GL/year allocation for future demand was based on an expected annual reliability of 95 per cent.

The sustainable diversion limit from the lower Ord River, downstream of House Roof Hill, was 115 GL/year. This allocation had an expected annual reliability of at least 95 per cent (similar to the EWP reliability) and was planned to supply future developments in the Mantinea Plain and Carlton Plain areas.

1.2.6 Ord Irrigation Expansion Project

From the mid 1990s extensive planning, investigations, environmental studies and negotiations over native title and Aboriginal heritage issues were undertaken to support the ORIA's expansion. In October 2008 the Western Australian Government committed to develop about 8000 ha of irrigated farmland on the Weaber Plains to the north-east of the Stage 1 areas (see Figure 1). The investment included establishing off-farm infrastructure to supply the water, drain the land and protect the area from local flooding. Roads to the farms were also included.

Termed the Ord River Expansion Project (OIEP), the state's land development agency, LandCorp, was given responsibility to establish the off-farm infrastructure and arrange the land release. The project includes co-ordinating the necessary planning and environmental approvals, construction of the infrastructure, the land tenure and related land title arrangements, and undertaking the land release process.

The OIEP forms the first phase of the larger M2 channel supply area development and for the purposes of seeking environmental approval under the *Environmental Protection and Biodiversity Conservation Act 1999,* is also known as the Weaber Plains Development Project.

Final environmental approval for the development of 7340 ha of irrigation farmland on the Weaber Plains (now called the Goomig farmlands) was granted by the federal Minister for the Environment on 13 September 2011. On 8 November 2011, LandCorp released 'requests for proposals' from prospective new irrigators to develop the 17 lots in the Goomig farmlands area. Construction of the required off-farm infrastructure and most of the on-farm development is expected to occur during the next two to three dry seasons, with the first water being supplied to the Goomig farmlands in 2014 or 2015.

1.2.7 Further development in the near term

Previous negotiations with the Miriuwung Gajerrong people (under the Ord Final Agreement) resolved issues of native title and Aboriginal heritage on the remaining M2 supply area in Western Australia and other land within the state known as the West Bank, Packsaddle, Carlton Plain and Mantinea areas (Figure 2).

While the remaining parts of the M2 supply area have state environmental approval, applications for approval to clear and develop other land in Western Australia have yet to be made.

At the same time as the Goomig farmlands land release, the state government sought expressions of interest from the private sector to develop up to 1700 ha in the

West Bank area and 6000 ha in the Knox Plain portion of the M2 supply area. The successful ‘preferred proponents’ for each area are expected to complete investigations and preliminary project designs sufficient to progress statutory planning and, where applicable, environmental approvals for their respective developments. They must also fulfil obligations under the Ord Final Agreement.

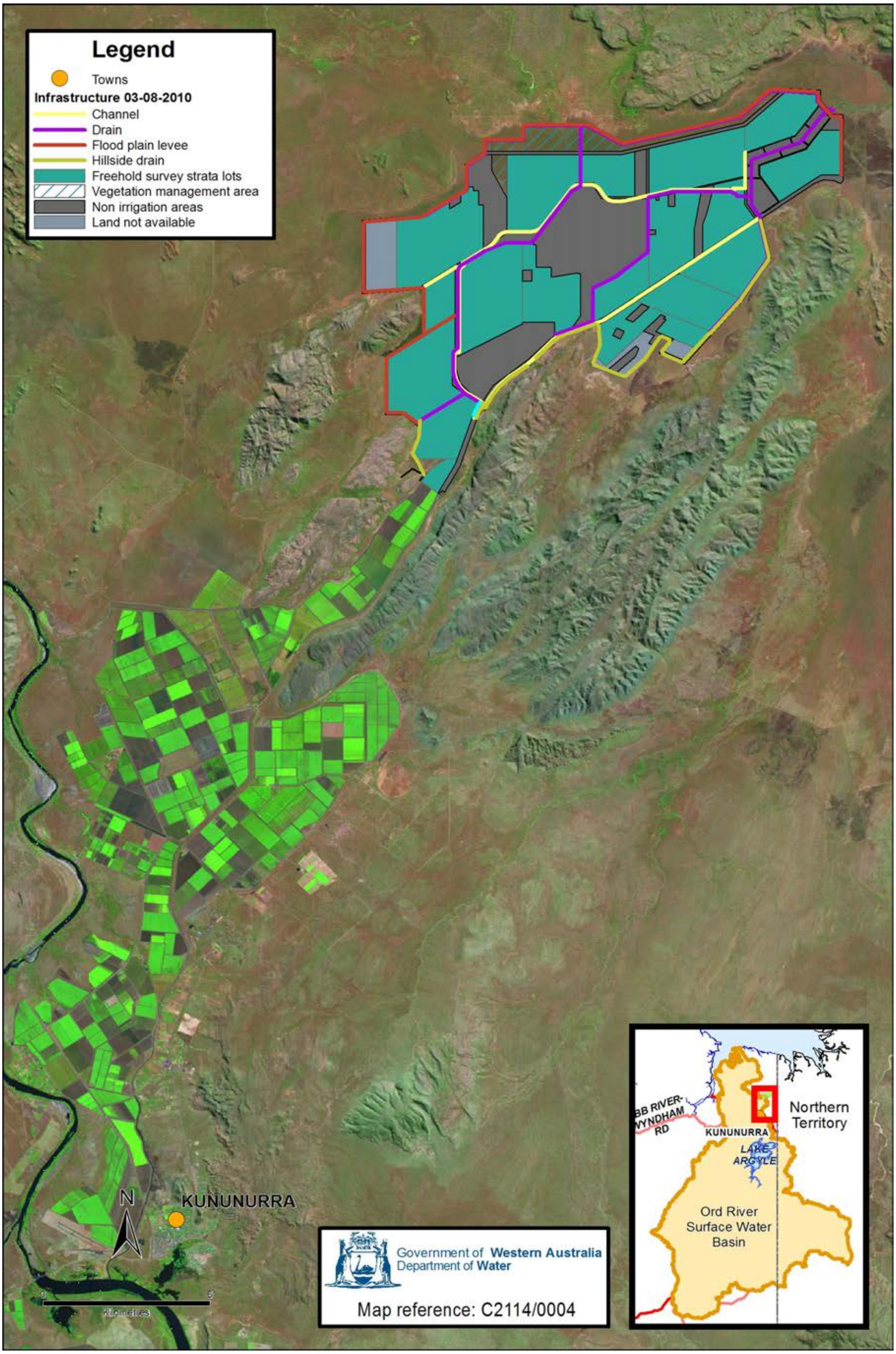


Figure 1 The area of the Ord Irrigation Expansion Project

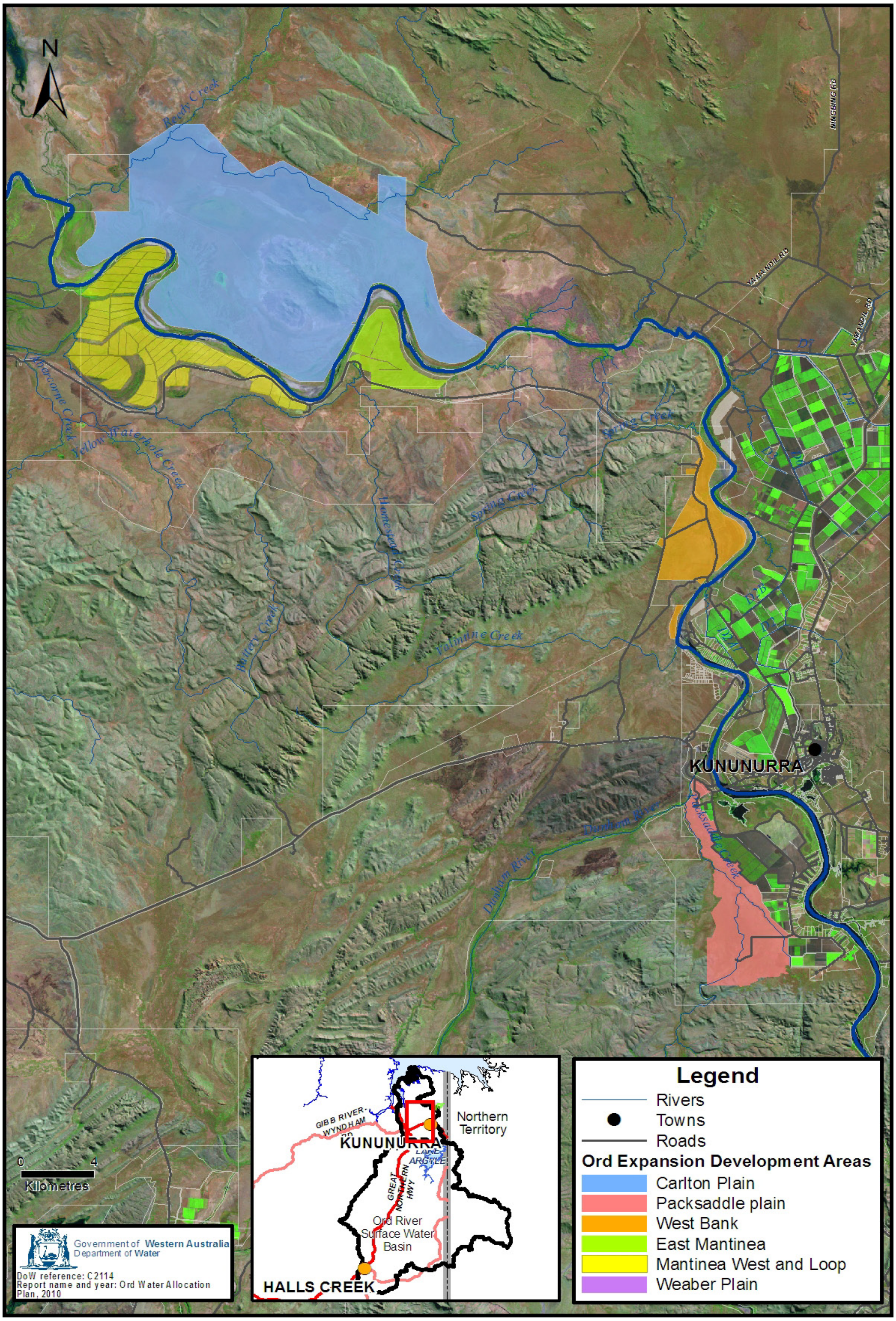


Figure 2 Location of Packsaddle, Ord West Bank and down-river developments

Figure 2 also shows freehold land on Carlton Plain that was recently granted as part of implementing the Ord Final Agreement (whereby pastoral leases and native title holders were compensated for land needed for the other Stage 2 developments) (State Solicitor's Office 2005).

In February 2010, the department received an application to divert 103 GL/yr from the lower Ord to irrigate approximately 8000 ha of the freehold land. Subject to environmental clearances and assessment of the water licence application, irrigation may begin in this area in 2013.

Table 1 summarises the development areas most likely to proceed in the next five years and lists the main planning matters and approvals that need to be resolved.

Table 1 Near-term developments – status of current planning and approvals

Planning and approval issues	Carlton Plain ~ 8 200 ha	West Bank ~ 1 700 ha	Knox Plain ~ 6 000 ha
Current/imminent land tenure	Freehold	VCL	VCL
Agreement to surrender native title?	Yes	Yes	Yes
State/NT EP Act approval?	No	No	Yes
EPBC Act approvals – needed	Likely	Likely	Likely
– granted	No	No	No
Soil/water investigations sufficient for planning?	Yes	Yes	Yes

VCL – vacant Crown land

1.2.8 Longer-term developments

Table 2 lists the remaining parts of the complete M2 supply area and other areas with potential for development in the longer term (five years plus).

Table 2 Longer-term development areas – status of current planning and approvals

Planning and approval issues	P'saddle Plain ~ 1 700 ha	Mantinea Flats ~ 4 200 ha	Sorby Hills (post mining ~4 000 ha	Cockatoo Sands ~6000 ha	NT ~16 000 ha
Current/imminent land tenure	VCL	VCL	VCL	VCL	VCL
Agreement to surrender native title?	Yes	Yes	Yes	No	No
State/NT EP Act approval?	No	No	Yes	No	Yes
EPBC Act approvals – needed	Likely	Yes	Likely	Likely	Likely
– granted	No	No	No	No	No
Soil/water investigations sufficient for planning?	Yes	Yes	Yes	No	Yes
Dominant soil type	Mixed	Alluvial	Clays	Sands	Clays

VCL – vacant Crown land

2 Ord River hydrology

2.1 Ord River catchment

The Ord River catchment's main rivers, subcatchments and annual rainfall characteristics are shown in Figure 3. The catchment covers an area of more than 50 000 km^2 in Western Australia's east Kimberley region. The Ord River forms the drainage outlet and discharges to the Ord Estuary and Cambridge Gulf near Wyndham.

The Ord River catchment experiences a semi-arid monsoonal climate with two distinct seasons: one is warm and dry and the other is hot and wet. Mean annual rainfall ranges from 780 mm in the catchment's north to 450 mm in its south (Figure 3). Rainfall in the wet season – from November to April – develops from thunderstorm activity (resulting in localised rainfall) and monsoonal low pressure systems (often generating widespread heavy falls). The aerial extent, frequency and severity of these rainfall events cause the large variations in monthly rainfall statistics characteristic of the wet season. During the rest of the year rainfall is light and sporadic: it is not uncommon to have several consecutive months without any rain.

The catchment's geology includes a wide range of rocks of Precambrian and Cambrian age. Plutonic, metamorphic and sedimentary rocks form the basement rocks in different parts of the catchment. The main ridges and plateaus are characterised by stony skeletal soils derived from these hard basements. Deeper sandy soils characterise most of the valley floors while the major floodplains are dominated by grey and brown cracking-clay soils. Vegetation coverage is generally sparse. The flat or slightly undulating plains are primarily grasslands or grassland/savannah woodlands, with the rough hilly country supporting mainly Spinifex and small trees. River gums, paperbarks and coolabahs are common along creeks, while the trees on the plains are primarily small eucalypts (WRC 1999a)

The intense wet season rains, combined with the shallow soils and sparse vegetation, generate a series of rapid runoff events during the wet season. Thunderstorms are the dominant form of rainfall in the early wet season. While the early season storms can generate significant local runoff, the larger tributaries of the Ord tend not to flow strongly until late December or January. Catchments are usually 'primed' by this time and heavy rainfall events more widespread. In response, runoff tends to be larger and more extensive, resulting in large flows in the major tributaries and the Ord. Given the underlying hard rocks of the catchment, groundwater contributions are generally minor. Hence (unregulated) flows usually decline rapidly within days of rainfall. Streams rarely continue to flow beyond April unless late wet season rains occur. There is virtually no runoff during the dry season.

Sediment accumulation in Lake Argyle was seen as a risk to the lake's long term storage capacity when the Ord River Dam was being designed in the 1960s. In 1967, the erosion risk was considered of sufficient concern to establish the Ord River Regeneration Reserve over the most eroded parts of the catchment and start a program of destocking and regeneration. A recent (2006) survey of sediments in the lake (Nixon and Palmer, 2010) reduced earlier estimates of the incoming sediment load. Wark and Nixon (2012) have recently reviewed all the sediment survey data available and the history of the destocking and regeneration program. They consider destocking of the fragile parts of the land systems and re-establishment of vegetation on the more severely degraded portions of the catchment has been successful. The risk of losing large amounts of storage to sediment accumulation in the medium term has therefore reduced, although it remains a long term issue for the future .

Ord River streamflows are highly variable from wet season to wet season and strongly depend on the amount and distribution of wet season rainfall. Sound quantification of the Ord's variability, as well as that of its major tributaries, is essential to guide water allocation planning of this water resource.

The following sections describe the key streamflow characteristics of the Ord River and its tributaries and the data series on which these were based.

2.2 Ord River Dam inflow series

2.2.1 Previous studies

Ord River flows were first studied in detail during the 1960s when the Ord River Dam was being designed. These were based on recorded flow data at the dam site (from 1955), monthly catchment rainfalls (back to 1906) and monthly rainfall-runoff relationships developed over the period of recorded streamflow data.

During investigations for the Ord River Dam power station the earlier inflow dataset was extended by using reservoir operating records (1972–92). This resulted in a combined dataset covering 86 (water) years from 1906–07 to 1991–92, which was used to underpin the 1994 Water Supply Agreement for the power station. The data series was a combination of recorded streamflow (1955–71), estimates of streamflow from catchment rainfall (pre-1955) and reservoir water balance estimates of Ord River Dam inflows between 1972 and 1992.

To ensure consistency with the 1994 Water Supply Agreement, the same Ord River Dam monthly inflows were used for the reservoir simulations that guided the *Ord River water management plan* (DoW 2006). However, the reservoir simulations were extended to include the contribution of the Dunham River to flows in the lower Ord. This enabled calculation of flows in the lower Ord under a range of reservoir operating rules and helped with the adoption of interim environmental provisions for the lower Ord. Dunham River flows were simply taken as a percentage of the inflows to the Ord River Dam in these studies.

2.2.2 Current inflow series (1906-07 to 2003-04)

The need to update the Ord River catchment's basic hydrology was recognised while DoW (2006) was being prepared. A daily hydrologic dataset (from January 1906 to December 2004) was developed, which extended and improved on the previous monthly dataset by including daily data from hydrologic modelling of the Ord River catchment (Bari & Rodgers 2006).

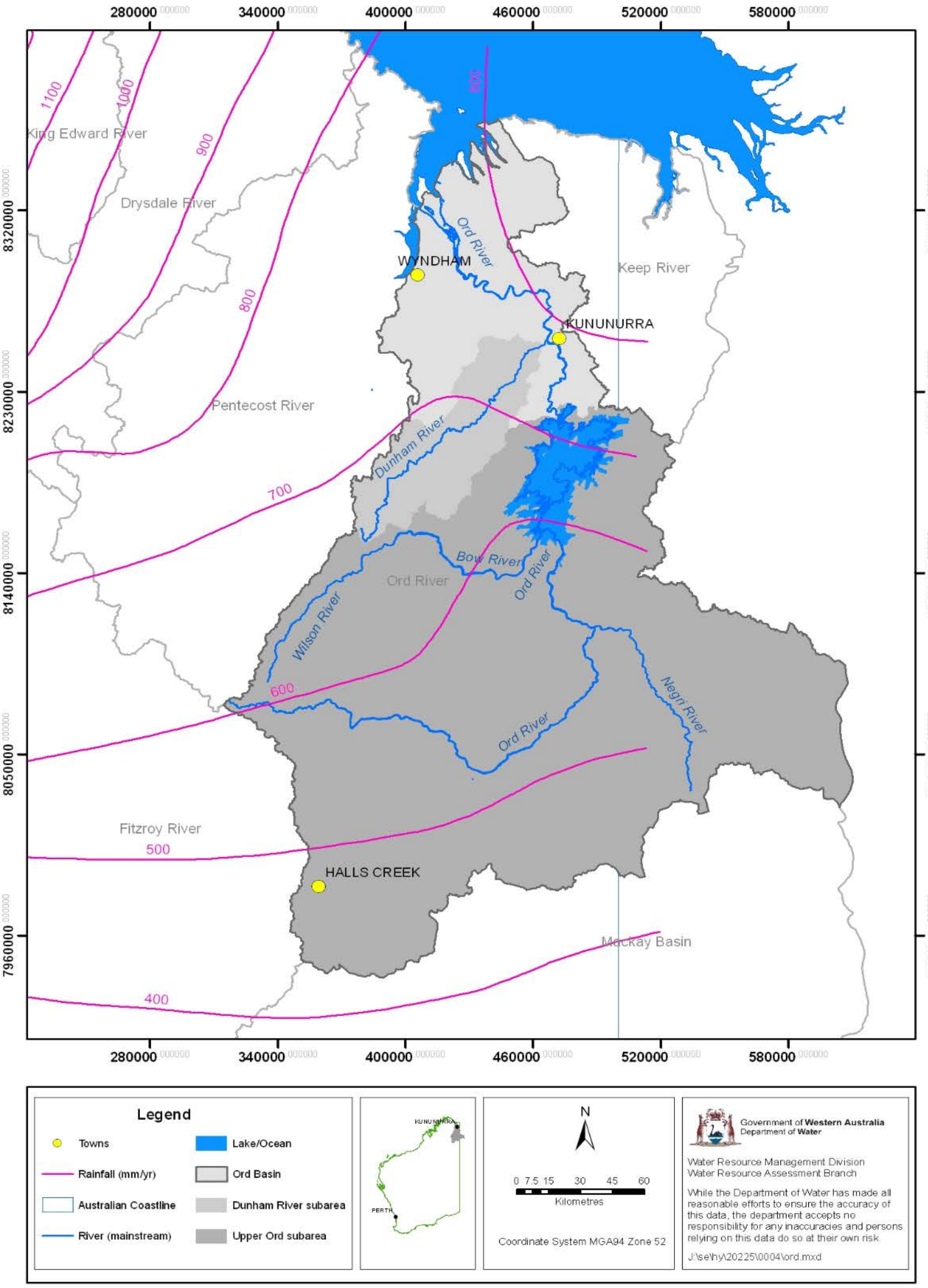


Figure 3 Ord River catchment with rainfall isohyets and the main subcatchments

The hydrologic modelling of the Ord River catchment was conducted using the LUCICAT (Land Use Change Incorporated Catchment) model. The model was calibrated to observed streamflow data from seven gauging stations, from 1970 to 2002, then run with rainfall data from January 1906 to December 2004 to generate a 99-year series of daily streamflows. The modelling simulated runoff from 93 subcatchments of the Ord River catchment to the Dunham River confluence. Flows were calculated at nodes located on watercourses throughout the catchment (including at each subcatchment outlet). The three main nodes relevant to the allocation plan (DoW 2012) were on the Ord River at the Ord River Dam, the Kununurra Diversion Dam and the Dunham River confluence.

The final streamflow dataset used to inform the allocation plan covered the period November 1906 to October 2004. The dataset formed 98 water years (from 1 November to 31 October the next year). The statistics quoted are for this period unless otherwise stated.

Modelled streamflow compared well with the previous (water balance) dataset on an annual and monthly basis. The model was calibrated to years with average to above-average rainfall. Figure 4 shows a close similarity between annual flow from the water balance and LUCICAT during a drier-than-average period.

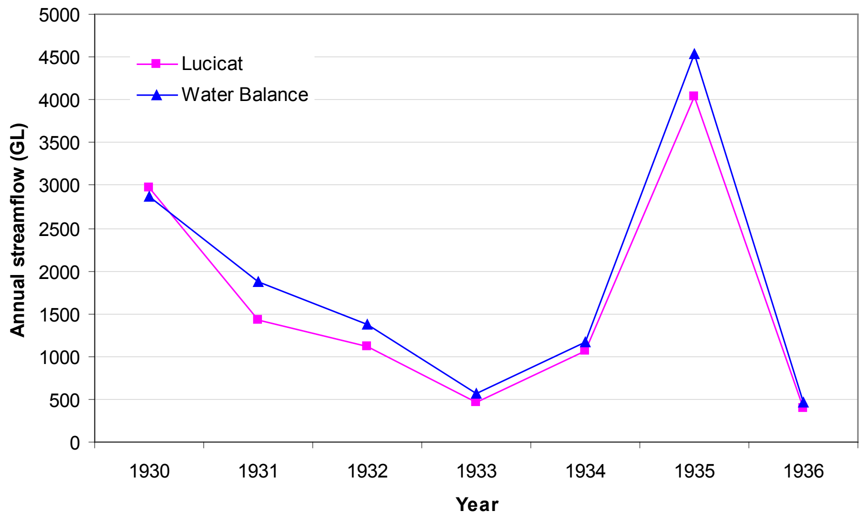


Figure 4 Annual inflow to the Ord River Dam from LUCICAT and water balance modelling

To ensure consistency with the 1994 Water Supply Agreement water release rules for the power station, daily flows for the reservoir simulations were derived by disaggregating flows from the monthly dataset (from 1906 to 1991, and a monthly water balance for the reservoir from 1992 to 2004) using daily flow data from the LUCICAT modelling of the Ord River catchment. The resulting daily flow dataset has the same monthly and annual statistics as the previous dataset (from 1906 to 1991), and includes the recent period of higher inflows (1992 to 2004).

2.2.3 Independent estimates of inflows

As part of CSIRO's Northern Australia Sustainable Yields (NASY) project (CSIRO 2009), Petheram et al. (2010) undertook an independent study of the hydrology of the Ord River catchment. In developing inflows to the Ord River Dam, CSIRO followed a similar approach to the Department of Water – extending recorded streamflow data using earlier rainfall records and rainfall-runoff modelling. However, the inflow period, raw datasets and rainfall-runoff models used were different in detail. Nevertheless, Table 3 shows the final inflow series were remarkably similar over the common 70 (water) years.

Table 3 Comparison of Department of Water and CSIRO Ord River Dam inflows series

Organisation that developed the series	Period of complete series	Annual statistics for the common period (1930–31 to 2003–04)			
		90th %ile GL/yr	Mean GL/yr	Median GL/yr	10th %ile GL/yr
Department of Water	1906–07 to 2003–04	8514	4198	3424	1015
CSIRO NASY A series	1930–31 to 2006–07	8338	4191	3304	857

2.2.4 Climate change

The NASY study was regional in nature and included the key objective of quantifying streamflow responses to the range of possible future climates across northern Australia. The study developed daily runoff estimates modelled from historic sequences of rainfall and potential evaporation for the period 1930–31 to 2006–07 (CSIRO 2009). These were determined for 5 km by 5 km cells across the study area (most of northern Australia). This historic dataset (scenario A) was then contrasted with sets of estimated runoff for a range of climate scenarios projected to develop by 2030.

The range of likely future climates was based on results from 15 global circulation models (GCMs) reported by the Intergovernmental Panel on Climate Change, each with three levels of global warming (producing 45 separate series). Termed the C scenarios, these were determined by first scaling the daily historic rainfall and potential evaporation time-series (scenario A) to reflect the amount of global warming for each scenario. This approach maintained the same patterns of daily rainfall, while adjusting the amount of rain on each day, see CSIRO (2009) and Petheram et al. (2010). The scaled climate datasets were then used as input to rainfall-runoff models to produce estimates of daily runoff for each 5 km by 5 km cell over the 77-year sequence, and each C scenario. Results were then aggregated into different regions of the study area and compared with the runoff of the historic series (scenario A).

Figure 5 shows the percentage change in annual runoff from the A series for the 45 C scenarios for the Ord Bonaparte region (the Ord, Keep and Victoria river basins) – the ‘x’ axis labels being the names of 15 GCMs used. The figure indicates that projected runoff under future climates is as likely to increase as decrease by 2030. Moreover, scenario A runoff estimates (based on the historic sequence) are very similar to the runoff estimates expected under the median of the future scenarios.

As current climate modelling does not indicate a clear future trend, the department considers its historic dataset the most appropriate series to inform the allocation plan

(DoW 2012) and support water resource management in the catchment during the next five to 10 years.

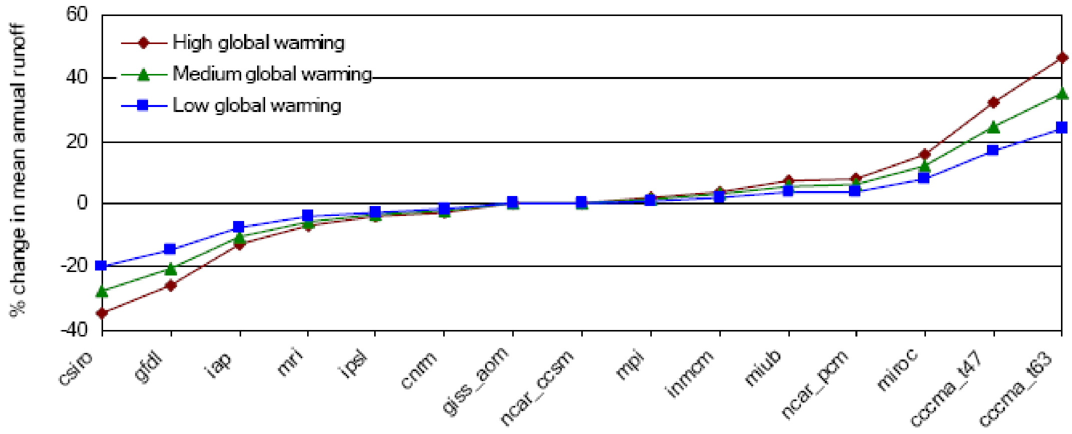


Figure 5 Changes in mean annual runoff across the Ord Bonaparte region under future climate scenarios (from Figure OB–10, CSIRO 2009)

Modelling of tropical rainfall under global warming conditions is expected to significantly improve in the next few years. This may lead to fewer discrepancies between GCM projections, unlike the range of projections resulting from the current generation of models (see Figure 5). Before the Ord catchment's hydrology is next updated, we will review the GCMs once again to assess their capacity to reliably predict tropical rainfalls.

2.3 Characteristics of inflows to the Ord River Dam

This section compares the hydrologic characteristics of Ord River Dam inflows with those used in previous Department of Water studies.

2.3.1 Annual mean inflows

The updated dataset (1906–2004) has a mean annual flow (Nov–Oct) of 4278 GL/yr. This is 339 GL/yr or about 9 per cent higher than the previous long-term average of 3939 GL for the 1906–07 to 1991–92 period.

Recent inflows have been well above the long-term average (Figure 6). The mean inflow from 1992–93 to 2003–04 (6712 GL) was almost 170 per cent of the previous long-term mean (1906–07 to 1991–92).

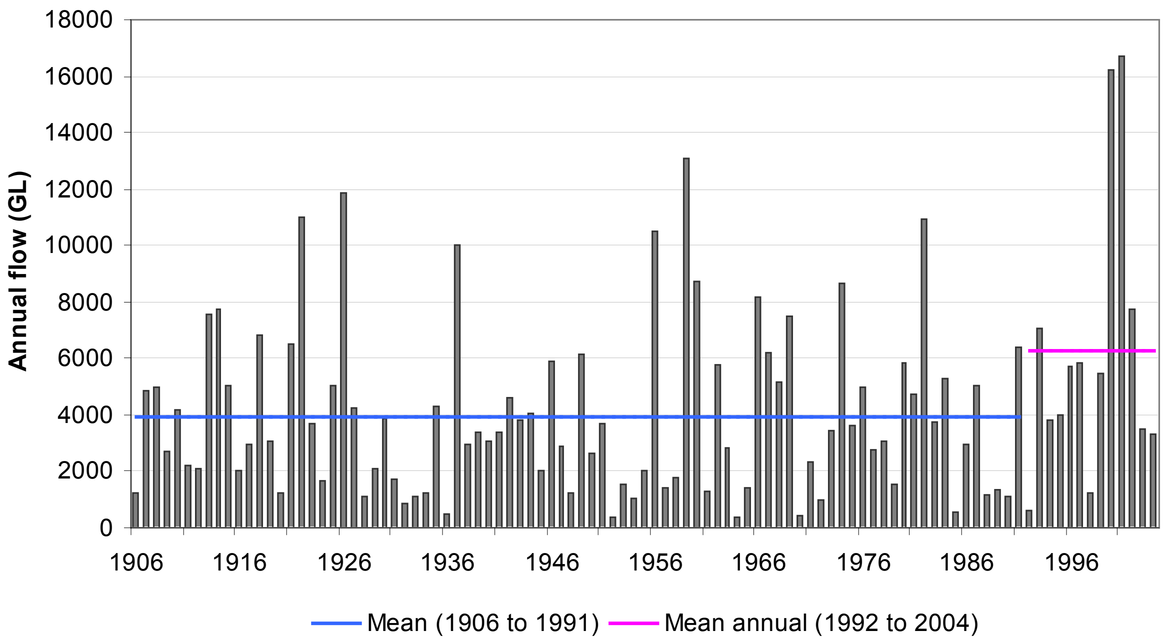


Figure 6 Annual inflow to the Ord River reservoir

2.3.2 Annual and seasonal variability

Ord River Dam inflows are highly variable (see Figure 6). In the lowest 10 per cent of years annual inflows are less than 1090 GL (the 10th percentile). In the highest 10 per cent of years, inflows exceed 8331 GL/yr (the 90th percentile).

The 10th and 90th percentiles are, respectively, less than a third and almost twice the average annual flow. Their ratio is a high 7.6 (the ratio of the 90th to 10th percentiles is a common measure of variability). The annual flow series is also significantly skewed (the mean being significantly greater than the median).

Table 4 Annual and seasonal inflow to the Ord River Dam (1906–07 to 2003–04)

	Water year Nov–Oct (GL)	Wet season Nov–Apr (GL)	Dry season May–Oct (GL)
Mean	4278	4133	145
Historic maximum	16 680	15 874	1754
90th percentile	8331	8185	341
50th percentile	3556	3441	39
10th percentile	1090	1041	3
Historic minimum	362	350	0

While such variability is common in Australia's semi-arid areas, the statistics emphasise that Lake Argyle's large storage is essential to harnessing the Ord River resource and thus ensuring a reliable water supply.

Table 4 also presents inflow statistics for the wet and dry seasons and shows that inflow occurs mostly in the wet season. On average, 83 per cent of annual flow occurs between

January and March. Very little flow occurs in the dry season; on average, three per cent of annual flow. The variability of wet and dry season flows are also greater than the annual variability.

2.3.3 Monthly inflows

Monthly statistics of inflows to the Ord River Dam (for the extended 1906 to 2004 data series) are shown in Figure 7.

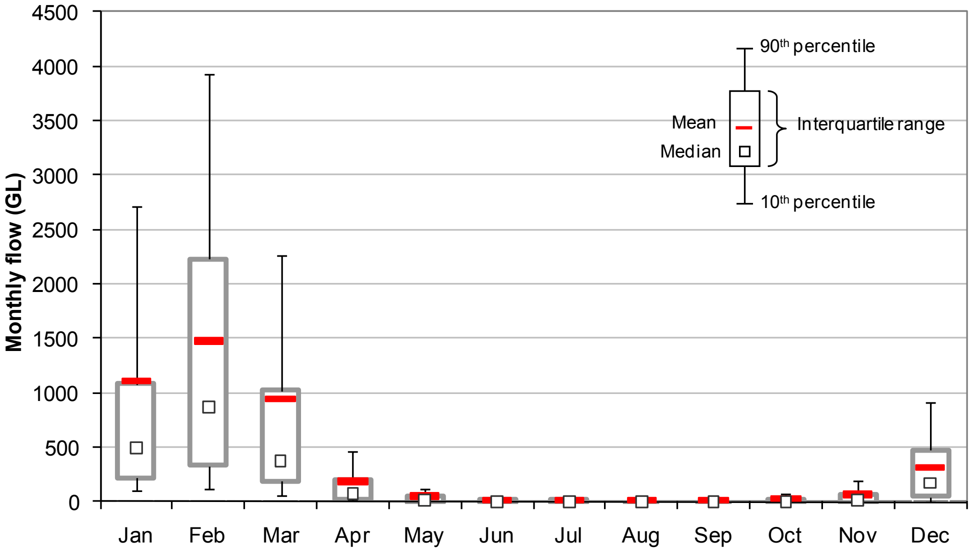


Figure 7 Variation in monthly inflow to the Ord River Dam from 1906 to 2004

The monthly means and medians from 1906–91 and 1992–2004 also illustrate the highly seasonal nature of Ord River flows (Figure 8) and the wetter sequence in recent years. In particular, February and March averages are much higher in the more recent period (1992–2004). In all months with flow and for both periods, the means were much greater than the medians (Figure 8), indicating monthly flow distributions were positively skewed, similar to the annual flow series.

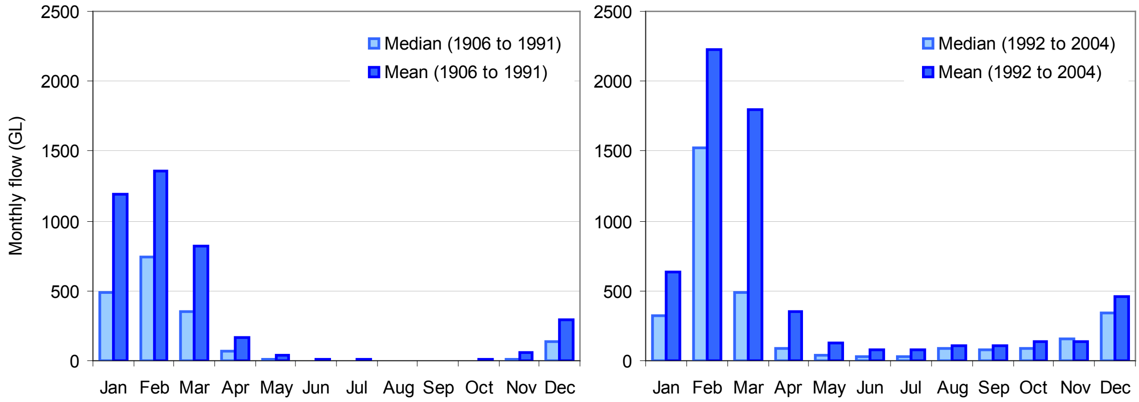


Figure 8 Mean and median monthly inflow to the Ord River Dam for the period 1906–91 and more recent period 1992–2004

2.4 Ord River flows downstream of the Ord River Dam

Runoff from the catchment between the dams and the Dunham River catchment was estimated using the LUCICAT model. Dunham River catchment runoff was used to estimate runoff from catchments between the confluence and the tidal limit (outlet of the Carlton-Mantinea subarea) and enabled Ord River flows to be estimated down to the tidal limit.

2.4.1 Pre-dam conditions

Table 5 presents the pre-dam mean and median annual flows of the Ord River at key locations from the Ord River Dam site to the start of the tidal reach.

The catchment downstream of the Ord River Dam represents 12 per cent of the total catchment to the tidal reach. About 15 per cent of the total flow at the tidal reach is generated from catchments downstream of the Ord River Dam.

The Dunham River contributes most of the additional input, providing approximately 10 per cent of the 15 per cent. The additional streamflow is generated from catchments between the Ord and Kununurra Diversion dams (approximately two per cent) and local creeks downstream of the Dunham River (approximately three per cent).

Table 6 lists the pre-dam annual and seasonal statistics of the Ord River just below the Dunham River confluence. Flows at this location were larger and more variable than flows at the Ord River Dam site pre-development (compare Table 6 with Table 4).

Table 5 Pre-regulation annual flows along the lower Ord River

Location on Ord River	Catchment area km^2	Mean annual flow (Nov–Oct) GL	Median annual flow (Nov–Oct) GL
Ord River Dam (Upper Ord subarea outlet)	45 227	4278	3556
Kununurra Diversion Dam	46 235	4397	3660
Just below the Dunham River confluence	50 508	4902	4046
Tarrara Bar (Main Ord River subarea outlet)	51 286	4994	4091
Outlet of the Tarrara-Carlton subarea	51 437	5012	4100
Start of the tidal reach (Carlton-Mantinea subarea outlet)	51 466	5015	4102

Table 6 Pre-regulation flow statistics for Ord River just below the Dunham River confluence

Statistic	Water year (Nov–Oct) GL	Dry season (Apr–Oct) GL	Wet season (Nov–Mar) GL
Mean	4902	158	4744
Historic maximum	19 969	1921	18 048
95th percentile	11 597	687	11 298
90th percentile	9671	381	9092
50th percentile	4046	50	3932
10th percentile	1386	4	1295
Historic minimum	432	0	420

2.4.2 Impact of regulation

Construction of the Kununurra Diversion Dam (in the early 1960s) and, in particular, the Ord River Dam (in the early 1970s) has had a profound effect on the lower Ord River's flow regime. The frequency of flooding of the lower Ord floodplain has been substantially reduced (Rodgers & Ruprecht 2000) and releases through the Ord River Dam power station sustain flows in the lower Ord throughout the year and dominate flows during the dry season. These changes are described in DoW (2006). The effects of the revised hydrology on the regulated flow regimes are detailed in chapters 6 and 7 of this document.

2.5 Tributaries that contribute to the lower Ord River

The lower Ord River is defined here as the Ord River watercourse downstream of the Kununurra Diversion Dam and includes the upper parts of its tidal reach before the river becomes fully estuarine.

The three main inputs to the lower Ord River are releases from Lake Kununurra, inflows from the Dunham River and contributions from the series of creeks downstream of the Dunham River. This section describes inflows from the Dunham River and the creeks that enter upstream of the tidal limit. Also described are the patterns of local drainage further downstream in the estuarine reach of the Ord River. The description is included to clarify the relationship between flows in the Ord River channel, local runoff, lower Ord floodplain drainage and the Ord River floodplain Ramsar site.

2.5.1 The Dunham River

The Dunham River is the most significant tributary to the lower Ord River, joining 0.4 km downstream of the Kununurra Diversion Dam. As noted above, Dunham River flows were modelled using LUCICAT (Bari & Rodgers 2006) and the results used to develop the environmental flow regime for the lower Ord River post-regulation. As the Dunham River is not significantly regulated, its wet season flows are a vital component of lower Ord River flows – having provided most of the flow variability in the lower Ord since regulation.

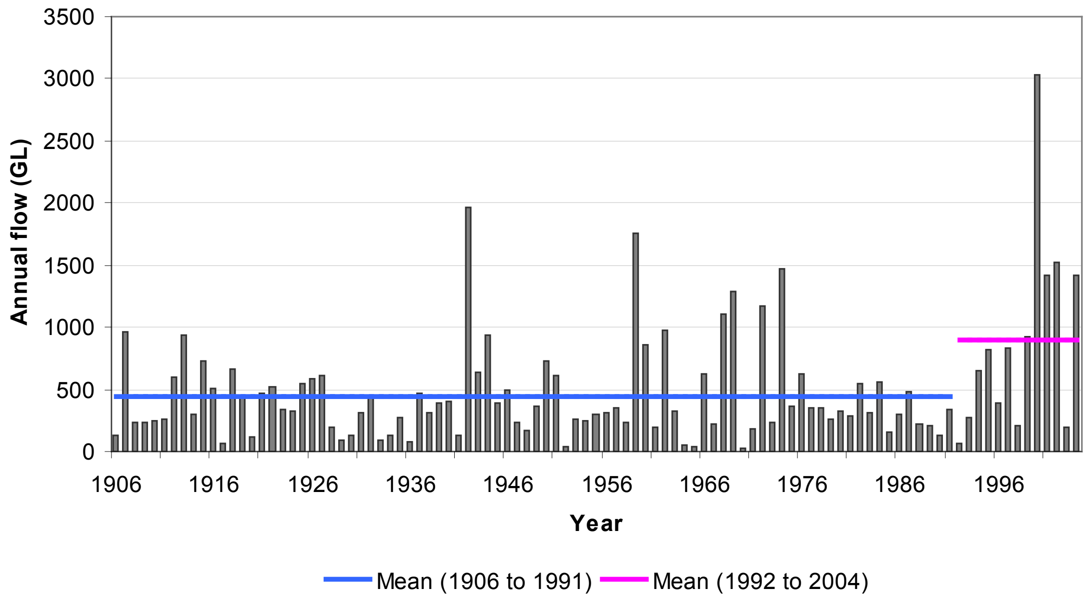


Figure 9 Annual Dunham River flow

Table 7 summarises the annual and seasonal statistics of Dunham River flows. Mean annual flow is 505 GL. Similar to inflows to the Ord River Dam, Dunham River flows have been higher in recent years than the previous long-term average (Figure 9). Mean annual flow from 1992–93 to 2003–04 (974 GL) was more than twice that of the period 1906–07 to 1991–92 (439 GL).

Table 7 indicates that Dunham River flows are highly variable. In the driest 10 per cent of years, annual flow is less than a quarter of the mean annual flow; while in the wettest 10 per cent of years, annual flow is more than twice the mean. When scaled by average or median flows, it is more variable than the Ord River pre-regulation.

Table 7 Annual and seasonal Dunham River flows at the confluence between the Ord and Dunham rivers (1906–07 to 2003–04)

	Water year Nov–Oct (GL)	**Wet season Nov–Apr (GL)**	**Dry season May–Oct (GL)**
Mean	505	494	11
Maximum	3031	2896	154
90th percentile	1017	975	26
50th percentile	342	331	0
10th percentile	125	121	0
Minimum	24	24	0

Figure 10 and Figure 11 illustrate the seasonal pattern and monthly variability of Dunham River flows. Most flow occurs from January to March (approximately 82 per cent). Similar to the Ord River Dam inflows, Dunham River flows were much higher in February and March in the recent period (1992–2004) than for the previous longer-term period (1906–91).

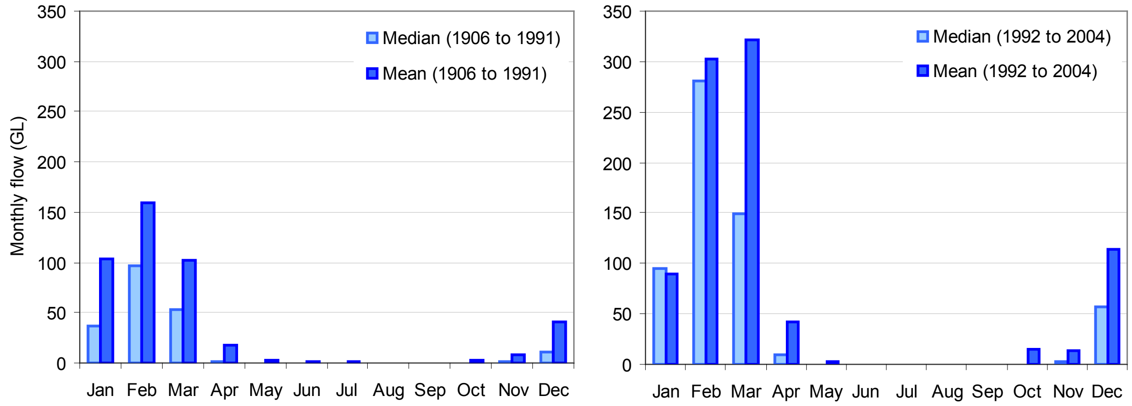


Figure 10 Mean and median monthly Dunham River flows for the period 1906–91 and the more recent period 1992–2004

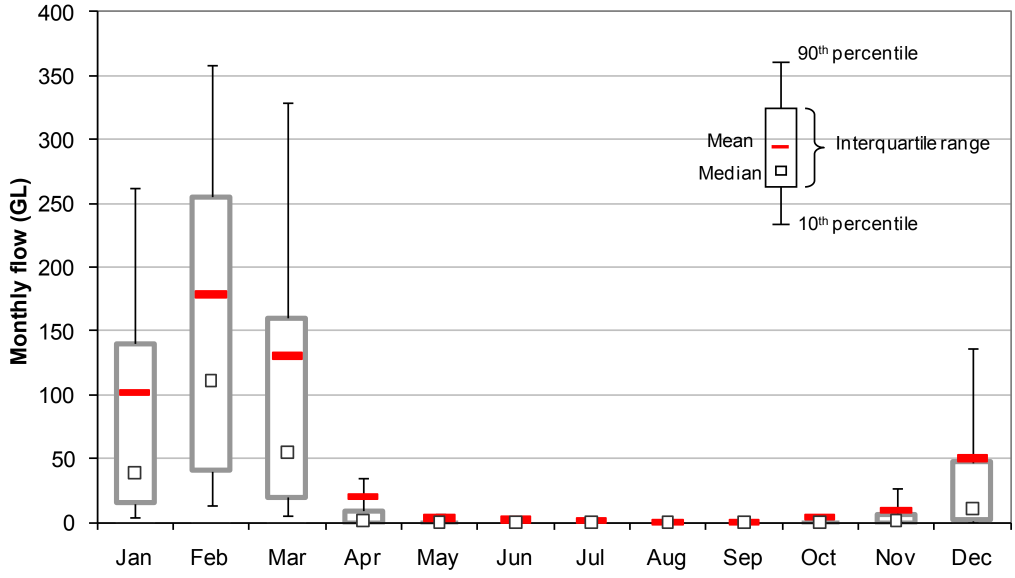


Figure 11 Variation in monthly Dunham River flow from 1906 to 2004

2.5.2 Contributions from the Dunham River confluence to the tidal limit

Many creeks drain into the lower Ord downstream of the Dunham River confluence (see Figure 12). While contributing only about three per cent of the total inflow to the Ord River estuary, the creeks contribute to the variability of flows in the lower Ord, as well as the diversity of its riverine environment. In particular, local rainfall can often generate significant runoff in these creeks, causing (relatively) frequent inundation in parts of the lower Ord floodplain. Inundated areas are common after heavy rains in most wet seasons, and occur when the Ord is not in flood.

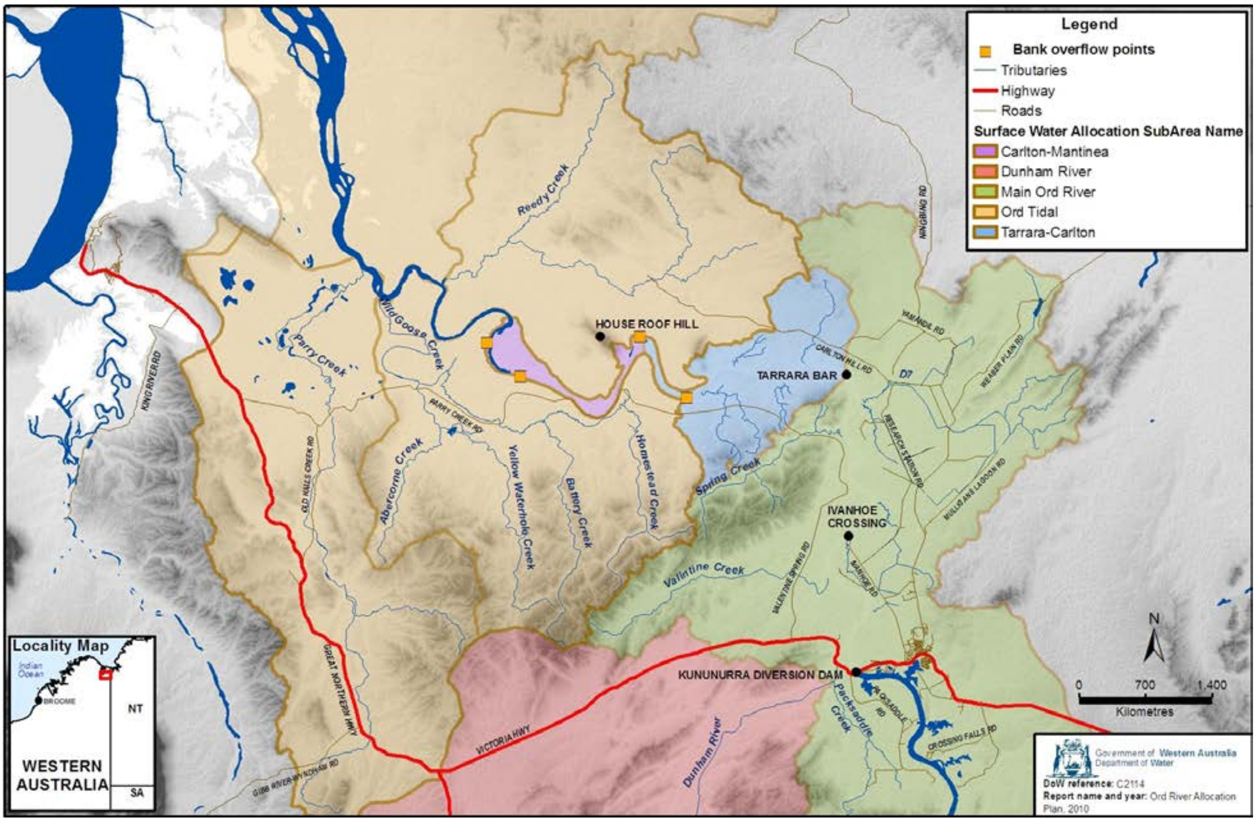


Figure 12 Drainage to the lower Ord River downstream of the Dunham River

The watercourses shown in Figure 12 reflect the drainage pattern in non-flood times.

Table 8 lists areas that contribute to the river downstream of the Dunham River confluence to its tidal reach. Three catchments and associated (freshwater) reaches have been defined. The first area, from the Dunham River to Tarrara Bar, forms the lower portion of the Main Ord subarea defined in DoW (2012). The second and third areas form the Tarrara-Carlton and Carlton-Mantinea subareas. The river channel morphology changes at the boundary of these subareas, enabling different environmental flow provisions (Appendix B) and allocation limits (DoW, 2012) to be defined for each subarea.

Table 8 also gives the length of each river reach, as well as the key low points along the river banks where the Ord breaks out onto the floodplain during floods. At these times, the contributions from local creeks are usually minor, though their flows affect the duration and patterns of inundation across the floodplain in complex ways.

Table 8 Lower Ord contributions below the Dunham River to the Ord Estuary

River reach/subarea	Drainage area (km^2)	Ord River length (km)	Average annual inflow (GL)	Key low points on Ord levees
Dunham River confluence to Tarrara Bar	780	30	92.0	0
Tarrara-Carlton subarea	151	23	17.8	1
Carlton-Mantinea subarea	29.5	22	3.5	3

Dunham River to Tarrara Bar (outlet of the Main Ord subarea)

The catchment between the Dunham River confluence and Tarrara Bar is 775 km^2. The main tributaries from the west are Spring and Valentines creeks (303 km^2 or 39 per cent of the total), draining the southern and central parts of the Livistonia Range.

Contributions from the east (472 km^2 or 61 per cent of the total) consist of drainage and runoff from the Ivanhoe Plain portion of the Stage 1 ORIA and runoff from the adjacent eastern hills. The Ivanhoe Plain, part of the ORIA that drains back to the Ord River, represents about 111 km^2 of the total 472 km^2 contributing from the east (excluding 8.8 km^2 of the D8 drain catchment which currently discharges to the ORIA's north-east but will eventually be redirected to Border Creek). Irrigation and hillside drains (and levees) were constructed on the plain to transport extra runoff from the irrigation area in the wet season and protect the irrigation infrastructure from flooding. The drains also carry surplus irrigation water (return flows) from the ORIA during the dry season. All flows that drain from the Ivanhoe Plain contribute upstream of Tarrara Bar, with the largest drain (D4) entering about 3 km upstream of Tarrara Bar. Dry season runoff would not normally have occurred from these areas pre-development. Now surplus irrigation supply water and irrigation return flows commonly contribute about 2 m^3/s throughout the dry season.

Along most of this reach, the Ord River is contained within its levee banks in all but the largest flood events and most adjacent areas are not prone to frequent flooding. An extensive floodplain exists further downstream on both sides of the river.

Tarrara-Carlton subarea

Downstream of Tarrara Bar the Ord River remains contained between its levee banks most of the time. However, several minor tributaries contribute to the river from both sides and form a combined additional subarea of 151 km^2. Creeks from the south rise in the north-eastern portion of the Livistonia Range, while creeks from the north drain mainly flatter areas – with the exception of a small area that drains the eastern slopes of False House Roof Hill.

Downstream of the lowest tributary (Mantinea Creek), the subarea boundary extends along the top of the levee banks on both sides of the river to the eastern end of House Roof Hill (Figure 12). Drainage along this section is away from the main river.

At times of high (flood) flow the levee banks can be overtopped, inundating the lower Ord River floodplain. Such overflows start at low points along the levees or where local tributaries enter the main watercourse. Previous studies and recent LIDAR survey work indicate that the lowest point in this reach is a small tributary that enters from the south (see Figure 12). During high flows in the Ord River, water backs up the tributary and overflows near the south-eastern end of the proposed East Mantinea development. River hydraulic modelling suggests bankfull conditions are around 4000 m^3/s at this site.

Carlton-Mantinea subarea

The start of the Carlton-Mantinea subarea is determined by a particular point on the river, below which the main channel becomes predominantly U shaped. As a consequence, a lower environmental flow rate is acceptable downstream of this point (see DoW 2006). This has enabled additional water to be allocated for diversion along this lower reach.

Drainage to the river in the Carlton-Mantinea subarea (29 km^2) is limited to small areas within the main levees plus a small area that drains from House Roof Hill directly into the river. Similar to the lower portion of the Tarrara-Carlton subarea, the levee banks are generally higher than the surrounding floodplain and form much of the subarea boundary. Again, the adjacent (local) drainage is away from the river (see next section).

Figure 12 also shows the low points on the levees in the Carlton-Mantinea reach. Two of these occur on the south bank near the West Mantinea and Loop proposed development areas. Current information suggests overtopping occurs at flow rates of around 3000 to 4000 m^3/s, depending on the size of the tide at the time of the flood peak.

At higher flow rates (> 8000 m^3/s) the river breaks out onto the northern floodplain near House Roof Hill at the upstream end of the subarea (see Figure 12). These floodwaters drain around the north of House Roof Hill, and merge with Reedy and Collins creeks before returning to the Ord Estuary from the north.

2.5.3 Contributions to the Ord Estuary

The tidal or estuarine reach of the Ord River is not part of the allocation plan area because the river is estuarine and not subject to water licensing. However, drainage to the tidal reach and related flood risks are relevant to planning irrigation developments in the Carlton-Mantinea subarea. If development proceeds in these areas water will be supplied from the Carlton-Mantinea river reach (subarea)

Most of the Ord River floodplain drains directly into the estuarine reach of the Ord River downstream of the Carlton-Mantinea subarea. Wild Goose and Parry creeks drain the southern floodplain, while Collins and Reedy creeks drain the northern floodplain. The combined catchment area of the creeks is 1750 km^2 or 3.4 per cent of the Ord River catchment to the tidal limit (Table 5). Direct runoff also occurs after heavy rains from mainly tidal areas further downstream and contributes additional inflow to the estuary and Cambridge Gulf.

The drainage pattern across the floodplain is, of course, overwhelmed when the Ord River breaks its levee banks. At these times, floodplain flows become a complex mix of overbank flows from the Ord River and local input – as discussed below.

Southern floodplain drainage

The headwaters of the southern floodplain watercourse are a series of creeks that drain northward from the Livistonia Range (Figure 12). Most of these creeks discharge into the westward-draining Wild Goose Creek at the foot of the range. Wild Goose Creek is a complex multi-channelled watercourse that drains the southern floodplain and includes the low-lying Wild Goose Creek lagoon. Its total catchment, including feeder streams, is 508 km^2. The drainage pattern across the floodplain varies between rainfall events, depending on the timing and amount of local runoff, the timing of the tidal cycle and the size and timing of flows in the main Ord watercourse.

At times of low flow, Wild Goose Creek discharges to the Ord Estuary about 20 km downstream of the Carlton-Mantinea subarea. At times of local flooding and high water levels in Wild Goose Creek lagoon, additional outlets from the lagoon become active, discharging to the estuary between 5 and 20 km downstream of the Carlton-Mantinea subarea. These extra outlets often occur in channels that normally flow into the lagoon, but reverse direction when water levels in the lagoon are especially high.

Parry Creek also enters from the south, about 22 km downstream of the Carlton-Mantinea subarea. It drains a larger catchment of 717 km^2 and includes most of the Parry Lagoons Nature Reserve and its upstream hinterland. The Parry Creek catchment is large enough to generate sufficient flows in its lower reaches to cause regular flooding of the south-western parts of the lower Ord River floodplain. That is, most of the inundation during wet seasons in this area is the result of local heavy rains in the Parry Creek catchment and is independent of Ord River flows. The exception, of course, is when the Ord is in major flood and breaks out upstream (see Figure 12).

Northern floodplain drainage

Collins Creek and its tributary Reedy Creek contribute from the north. They drain 525 km^2, including most of House Roof Hill and areas to the north-east. Again, local flooding is expected in parts of the northern floodplain after heavy rains in the catchments of these creeks. In major Ord River floods, the lower reaches of Collins Creek and the northern floodplain are inundated by flows that discharge over the Ord's northern levee bank just upstream from the outlet of the Tarrara-Carlton subarea (see above). Most of these flood flows drain around the back (north) of House Roof Hill and return to the (flooded) estuary via a greatly enlarged Collins Creek.

2.6 Ord River flooding in recent years

While Ord River flooding has been significantly reduced by construction of the Ord River Dam (DoW 2006), serious flooding still occurs on the lower Ord floodplain, albeit at a much reduced frequency. Since the 1999–2000 wet season four major floods have breached the natural levee banks of the lower Ord River. Proposals to develop irrigated agriculture on the Carlton Plain and Mantinea Flats were formulated before these recent floods occurred. A major review of the flooding risks to these areas should be undertaken before any developments proceed.

3 Current and projected water demands

Commercial water use of the Ord River and its tributaries is dominated by hydro-electricity generation at the Ord River Dam power station and the irrigation demands in the ORIA. Smaller demands also exist to service private irrigation developments and mining and mineral processing in the Ord River catchment.

Section 3.1 describes the electricity demands on the east Kimberley electricity grid. The subsequent sections describe the water demands by subarea.

3.1 Hydro-electricity demand

Figure 13 shows the recorded and projected electricity demands on the east Kimberley electricity grid. The power stations that supply this electricity grid are Pacific Hydro's Ord River Dam power station and diesel power stations at the Argyle Diamond Mine, Kununurra and Wyndham. Pacific Hydro's station has generated more than 90 per cent of the electricity supplied to the grid since 1996. The Argyle Diamond Mine's diesel station is expected to meet much of the growth in demand as underground operations progress at the mine site. However, there are financial, economic and environmental benefits associated with the increasing electricity load being met by the Ord hydropower station.

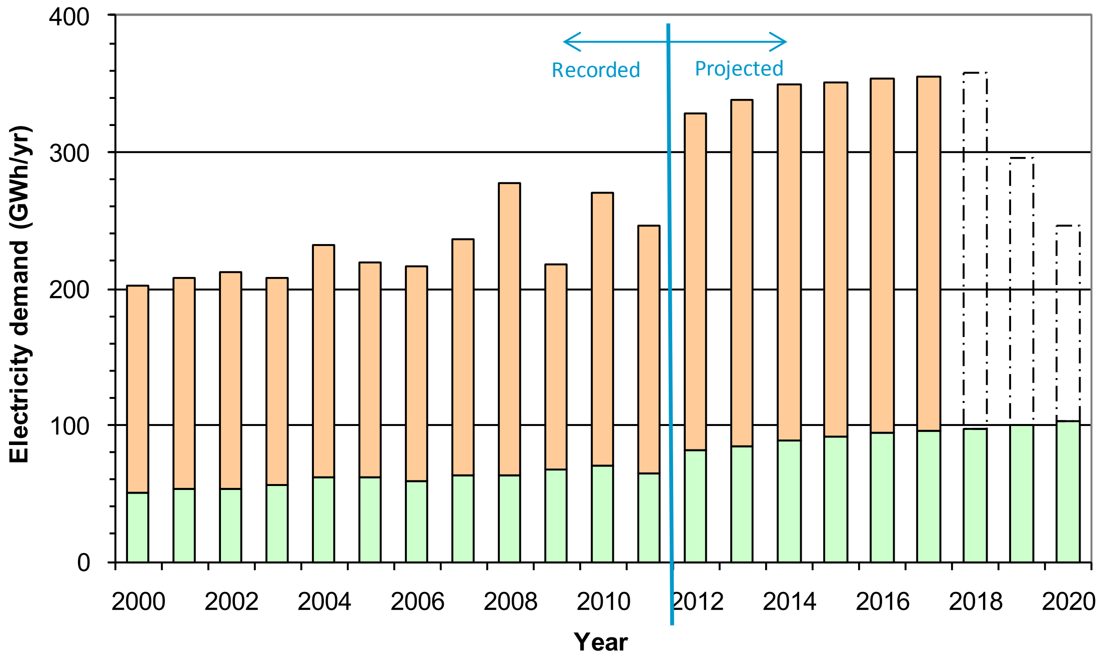


Figure 13 Recorded and projected loads on the east Kimberley electricity grid

The total electricity supplied to the east Kimberley grid to 2006 was normally in the range of 200 to 220 GWh/yr. Demand grew in 2007 and 2008 as the Argyle Diamond Mine's underground operations geared up, before reducing in 2009 when the mine cut back operations after the global financial crisis. Projected annual demand for 2010 is similar to that recorded in 2008 and is expected to grow strongly during the next few years (until 2013) when the mine's underground operations reach their maximum. Notional growth of three per cent a year has been projected in Horizon Power's demand from 2010.

The original 1994 Water Supply Agreement for the power station provided for the generation of at least 210 GWh/yr while water levels in Lake Argyle were greater than 78 m AHD (i.e. in all but drought years). The projected demand between 2010 and 2018 is well above this guaranteed minimum.

The amount of water needed to generate 1 GWh of electricity is a function of the water level in Lake Argyle and the turbine efficiencies of the station at that level. At typical lake levels (87–90 m AHD) about 10 GL must be released through the turbines to generate 1 GWh of electricity. At low lake levels (just above 78 m AHD) more than 12 GL is required. At high levels (more than 91 m AHD) only about 9 GL is required. As such, to generate the 210 GWh annual commitment at mid lake levels, about 2100 GL must be released each year. At low levels more than 2500 GL must be released.

The Argyle Diamond Mine has made no commitments to mine beyond 2018, although possible ways to extend the life of the mine are being explored. Therefore the electricity demand on the east Kimberley grid beyond 2018 is uncertain, although it is expected to decrease significantly from the high levels expected between 2013 and 2018. A possible exception to this would be if a new, large electricity demand developed within 100 to 150 km of existing electricity infrastructure.

3.2 Main Ord subarea

Water demand in the Main Ord subarea is dominated by irrigated agriculture.

Table 9 summarises the current and likely future range of irrigation water demands in this subarea. The different development areas are ranked in order of existing, current and likely future expansion (see also sections 1.2.7 and 1.2.8).

The current irrigation demand is used to supply land established under Stage 1 of the ORIA. This includes all farms supplied by the Ord Irrigation Cooperative (OIC) and 'self-supplied' irrigators who pump direct from the Ord River and Lake Kununurra. Increased demand is expected to occur in the next few years as the first 8000 ha of the 30 000 ha M2 supply area is developed (see Section 1.2.6). Further demand increases are expected as new areas near Stage 1 (West Bank and new Packsaddle areas) are established and the remaining parts of the M2 supply area are progressively developed.

The range of future water demands in Table 9 reflect the range of crops possible to be grown in each area. If crops with relatively low water demands are grown throughout (when all areas are developed) the aggregate demand for the Main Ord subarea could be a low 660 GL/yr. In contrast, if significant areas of high-water-demand crops are grown (e.g. sugarcane or bananas), then aggregate water demand could reach around 950 GL/yr.

Table 9 Range of possible future irrigation demands in the Main Ord subarea

Development area	Nominal gross farmland area (ha)	Range of possible future irrigation water demand† (GL/yr)	Range of on-farm demand (ML/farm area)
Stage 1	16 500††	250–350	12 – 17
M2 – OIEP	7 400	80–120	10 – 13
Ord West Bank	1 000	16–25	15 – 22
M2 – Knox Plain (in WA)	5 000	60–110	10 – 20
M2 – Sorby Hills (mining) area	3 000	30–65	10 – 20
East Bank, other miscellaneous	200	2– 5	10 – 20
New Packsaddle	800	8–12	10 –13
M2 – Northern Territory	14 000	160–200	10 –13
Cockatoo Sands	6 000‡	50–65	8 – 10
Total	**53 900**	**656–952**	

† At the point of diversion from the Ord River
‡ Most cockatoo sands lie outside the Main Ord subarea. The area to be supplied from the Ord is not yet clear
†† Area includes an extra 500 ha for double cropping

The background to the estimated range of potential demands (Table 9) is discussed in the following sections.

3.2.1 Stage 1 areas

Ord Irrigation Cooperative

The OIC holds a water licence to divert 335 GL/yr from the Ord River at Lake Kununurra. The OIC's water entitlement, granted initially in 2004, provided for expected growth in water demand on two fronts:

- irrigation development within its water service provision area (The OIC now supplies several extra locations – principally a new development known locally as Green's location. By early 2010, it had issued 97 per cent of the on-farm entitlements allowed under its licence.)
- a larger area of irrigated sugarcane, which was expected to reach 60 per cent of the irrigated area by 2009.

However, the local sugar mill closed in November 2007, with the result that sugarcane is no longer grown on a broad-acre scale in the district. Plantations of tropical trees, established to provide host species for Indian sandalwood, have been replacing sugarcane and now form the major crop type in the district. Table 10 documents this major change in the crop types being irrigated in recent years. The data are based on grower records that the Department of Agriculture and Food Western Australia (DAFWA) has collated.

Table 10 Land irrigated between 2002–03 and 2008–09 in Ord Stage 1 areas

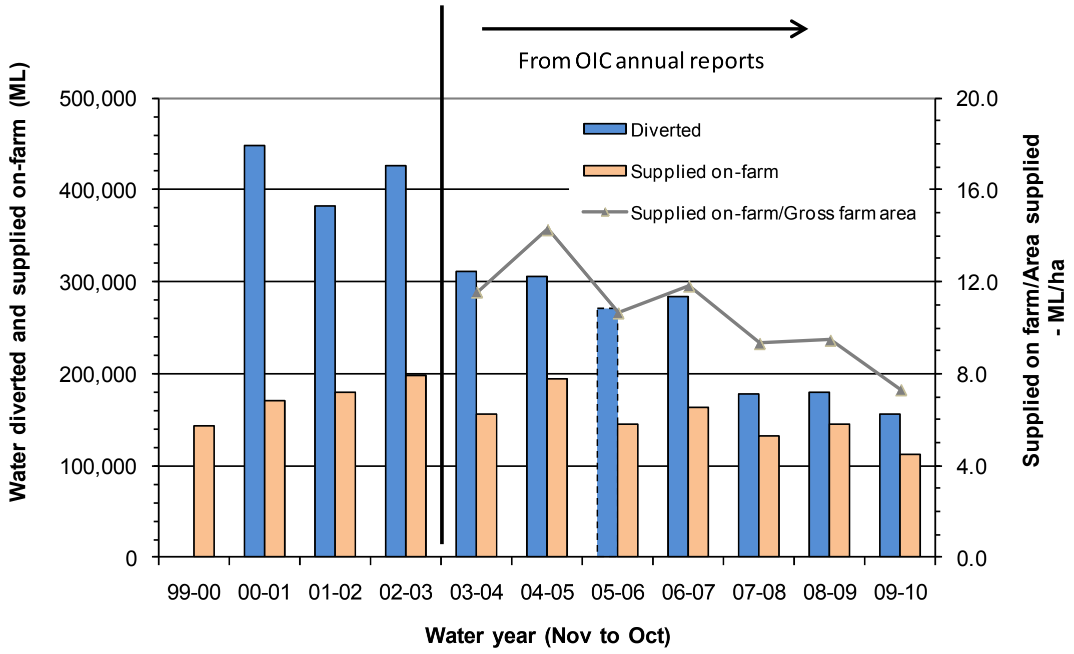
	02–03	03–04	04–05	05–06	06–07	07–08	08–09
Wet season field crop							
Hay (tonnes)	402	478	679	830	376	436	400
Dry season field crop							
Cotton	20	17	40	25	15	2	2
Sugar cane	4180	4031	4132	3489	3491	10	10
Rice							
Chickpea	270	421	553	298	546	546	548
Other	375	457	364	270	155	760	910
Chia				200	550	750	1068
Total field crops (incl. hay)	**5247**	**5404**	**5768**	**5112**	**5133**	**2504**	**2942**
Horticulture							
Rockmelons	731	476	472	442	480	438	280
Honeydews	275	163	167	168	180	198	158
Watermelons	419	326	223	198	144	164	157
Jarrahdale	142	98	132	150	75	285	130
Butternuts	239	138	165	167	125	255	234
Jap pumpkins	179	151	175	186	106	249	45
Mangoes	547	647	717	720	689	741	579
Banana	113	66	28				
Citrus		186	262	256	235	248	248
Other	370	169	91	125	85	158	244
Total horticulture	**3015**	**2420**	**2432**	**2411**	**2119**	**2736**	**2074**
Forestry							
Sandalwood	1010	1553	1729	2448	3046	4126	4667
Total forestry	**1010**	**1553**	**1729**	**2448**	**3046**	**4126**	**4667**
Other							
Leucaena/irrigated pasture	900	1175	975	925	925		
Sorghum grain and forage	1238	686	651	674	961	1041	743
Other	584	775	744	494	1521	3467	3049
Total other	**2722**	**2636**	**2370**	**2093**	**3407**	**4508**	**3792**
TOTAL	**11 994**	**12 012**	**12 298**	**12 064**	**13 705**	**13 874**	**13 475**

Source: DAFWA

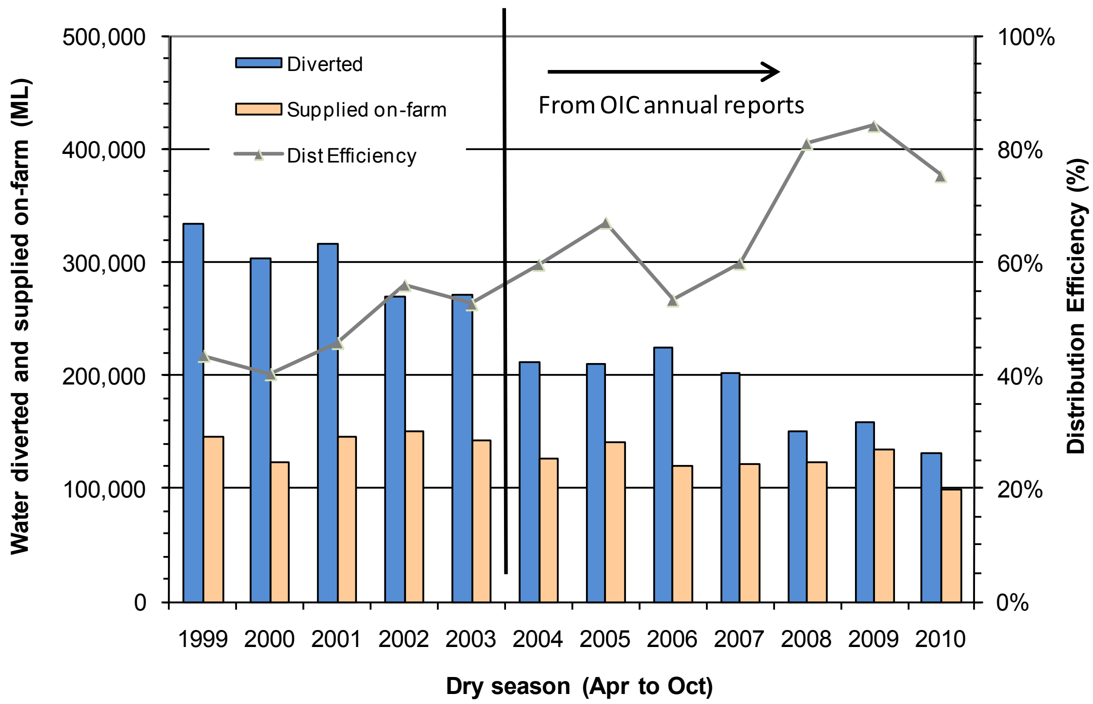
The move from sugarcane to sandalwood plantations in recent years has reduced water demand in the short term. While the water supplied to these plantations can be high in the first years after planting, over a full sandalwood rotation the average crop water demand is significantly less than sugarcane.

Figure 14 presents recent trends in the water diverted and supplied on-farm.

The figure shows a strong declining trend in the water diverted from the Ord River but a much smaller decline in the water supplied on-farm. The OIC has achieved major improvements in distribution efficiency in recent years, with the target distribution efficiency of 80 per cent being achieved in the dry seasons of 2008 and 2009 (Figure 14b). These gains have been made possible by the OIC progressively automating its water distribution systems. The OIC should be praised for reaching its targets and should be able to continue to achieve them in future years.



(a) For water years (November to October)



(b) For dry seasons (April to October)

Figure 14 Water diverted and supplied on-farm by the Ord Irrigation Cooperative

The declining trend in water delivered on-farm is clearly apparent when expressed as the volume supplied per unit area of farmland supplied (Figure 14a), and reflects the move away from sugarcane since 2007. The smaller decline in the gross water supplied on-farm is a result of the increased area now supplied by the OIC and the (relatively) high water application rates to sandalwood plantations in their early years

In combination, these trends have resulted in the OIC diverting less than 200 GL/yr in 2008, 2009 and 2010; or less than 60 per cent of its current entitlement. If current trends in water use are confirmed in the next few years, additional irrigation water from within the current allocations should become available.

Self-supplied irrigation

Many landowners adjacent to the Ord River (mainly small landholdings <10 ha) have established their own pumps and pipes to divert water directly from Lake Kununurra or the downstream river. These self-supplied users are mostly small-scale irrigators, although some diversions are for public and commercial purposes. As at May 2011, 85 self-supplied licences were issued and the total licensed entitlement granted was 11.9 GL/yr. Little further growth in this demand is expected. DoW (2006) made provision for demand to grow to 15 GL/yr.

3.2.2 Ord Irrigation Expansion Project – first phase of the M2 supply area

The ORIA expansion under the OIEP comprises 7400 ha of mainly Aquitaine clay soil on the Weaber Plain to the north-east of Kununurra. The project represents the first phase of the greater (30 000 ha) M2 supply area development. As shown in Figure 1, the area (now known as the Goomig farmlands) abuts the existing Ord Stage 1 developments. Water is to be supplied via the existing M1 and a new M2 channel. The M1 channel is to be used for the first 17 km (to Stock Route Road) with the new M2 channel extending a further 20 km. At the start of the Goomig farmlands, the M2 channel bifurcates into the M2N and M2S channels to supply the 17 individual lots in the development. The M2S channel has been designed with sufficient capacity to supply the subsequent phases of the M2 supply area development.

In November 2011, LandCorp sought “requests for proposals” to develop the 17 lots in the Goomig farmlands. Applicants (potential irrigators) are to complete their proposals by 28 February 2012 and are to include an outline their farm development plans and identify the crops they propose to irrigate. Depending on the crops proposed, aggregate water demand is expected to be between 80 and 120 GL/yr. Under current project scheduling, the first water is expected to be supplied to the new lots late in the 2014 dry season, with most lots being irrigated in 2015.

3.2.3 The Ord West Bank area

The Ord West Bank comprises about 1700 ha of mixed and levee soils, of which approximately 1000 ha would be suitable for a wide range of high-value horticultural crops (see Figure 2). Pressurised irrigation application methods are expected to be used and should deliver water to the crop root zone with few losses. Given the good quality levee soils, perennial tree crops (citrus, mangoes, sandalwood) are likely to be extensively grown in the area. In addition, renewed interest in growing bananas on these soils has emerged. As a result, on-farm water demand is likely to be larger than the district average for this area.

Table 9 lists an on-farm range of 15 to 22 ML/ha. Combined with efficient water distribution, the area's water demand is expected to between 16 and 25 GL/yr. LandCorp sought "expressions of interest" from the private sector to develop this area at the same time as the Goomig land release (November 2011). A "preferred proponent" is to be selected to firm up their development proposal, seek the remaining approvals and ultimately implement the development.

3.2.4 Further development of the M2 supply area

The M2 supply area development originally envisaged more than 30 000 ha of irrigated farmland on the Weaber, Knox Creek and Keep River plains.

Subject to meeting the initial environmental conditions (set by the governments of Western Australia and the Northern Territory in 2002) and any additional conditions set by the Australian Government under the *Environmental Protection and Biodiversity Conservation Act 1999*, a further 8000 ha (Western Australia) and 14 000 ha (Northern Territory) may be developed.

Knox Creek area in Western Australia (5000 ha)

The Knox Creek area comprises about 5000 ha of developable farmland located adjacent to the Western Australian border and to the east and south of the OIEP (see Figure 2). Supplying this area would require extension of the M2S channel about 10 to 15 km to the Knox Plain, bypassing about 3000 ha of potentially irrigable land in the Weaber Plain area's east. This area overlies known lead and silver deposits and will not be irrigated until mining is completed or the mining tenement is surrendered (see Sorby Hills area below). Subject to final designs, a pump station is needed to lift water from the extended M2S channel to supply the upper parts of the Knox Plain area. The M1 channel does not have the capacity to supply the additional water for the Knox Plain development. Hence the initial 17 km section of the M2 channel and a new M2 offtake structure at Lake Kununurra will also need to be constructed. In addition, the development will require a balancing storage to be built in the distribution system. This is to deal with water that has already been diverted from the river but is not needed immediately when rain has fallen over the supply area. Distribution efficiencies approaching 90 per cent should be achieved with a balancing storage.

Field crops likely to be grown at a broad acre scale include chickpeas, sorghum, chia, cotton, and rice. It is possible that sugarcane may be grown in the area once again: while this is unlikely at a large-enough scale to support a raw sugar industry in the district, it may be grown as a food source for overseas feedlots and exported without being refined into sugar. It is expected that a range of horticultural crops will be grown, but not at a broad acre scale.

Given the wide variety of possible crops, on-farm water demand could range from 10 to 20 ML/gross farm ha. Water demand at the point of diversion could therefore range between 60 to 110 GL/yr (Table 9).

Similarly to the Ord West Bank area, LandCorp sought 'expressions of interest' to select a preferred proponent to develop this area in November 2011.

Sorby Hills mining area

There is potential to mine lead and silver deposits beneath the eastern end of the Weaber Plain. Located close to the Northern Territory/Western Australia border and to the east of the OIEP, these deposits are being investigated to determine whether mining is economically and environmentally feasible. If proven to be so, the current indications are that mining would continue for less than 10 years and that irrigation could proceed after mine rehabilitation. As such, a further 3000 ha of irrigation land could be developed in this area in about a decade.

The development would build on the infrastructure constructed to service the OIEP and Knox Creek areas. The range of soils, likely crop types and water demands would be similar. Expected demand ranges between 30 and 65 GL/yr (Table 9).

Northern Territory

The M2 and M2S channels are being constructed with the capacity to supply a gross area of 14 000 ha of irrigated farmland in the Northern Territory at some future time.

However, many impediments need to be overcome before development can proceed in the territory. Some are summarised in Table 2. In addition, extensive negotiations and approvals will be required with the Northern Territory and Australian governments. Complementary legislation in both jurisdictions will be necessary to enable both sides of the border to be managed under the same administrative arrangements.

The expected long-term demand is between 160 and 200 GL/yr (Table 9). This assumes a range of on-farm water demands from 10 to 13 ML/ha. The upper limit of demand implies that significant areas of perennial tree crops could be grown within the 14 000 ha.

The upper limits of demand in the Knox and eastern Weaber areas (20 ML/ha) imply that up to 8000 ha of the M2 area could be used to grow sugarcane. It is considered highly unlikely that a further 14 000 ha would also be grown in the territory.

3.2.5 New Packsaddle Plain land and miscellaneous areas near existing lots

The land potentially available for new development on the Packsaddle Plain comprises up to 1380 ha (excluding creek lines and the Packsaddle freehold land in the area's south). Scattered pockets of levee and complex clay soils occur through the area and may prove suitable for irrigating a range of horticultural and broad acre crops. Further agronomic work and soil surveying is required to confirm the optimum locations for farming areas and crop types. The most cost-effective means to supply water to new Packsaddle Plain areas will also require investigation.

Water demand will depend on what areas are ultimately developed and the crop types grown. Given the scattered pockets and variable soils of the area, 800 ha is considered an upper limit of the area likely to be developed. The water demand is therefore likely to be in the range 8–12 GL/yr (Table 9).

There is also the potential to develop small areas of additional land adjacent to current Stage 1 lots. These will require further investigation and approval, including native title clearance. Water demand from these areas is unlikely to exceed a further 5 GL/yr (Table 9).

3.2.6 Other areas of potential development

The areas of potential development described above are based on surveys of irrigable soils carried out many decades ago when the original ORIA was being planned and designed. Given improvements in irrigation technology and soil science since, a wider range of soils could be irrigable today. DAFWA has recently mapped soils known locally as Cockatoo Sands (DAFWA 2010) and is evaluating their suitability for irrigation. Investigations are continuing. Other non-agricultural aspects will need to be resolved before the Cockatoo Sands can be developed. Because areas with Cockatoo Sands were not part of the Ord Final Agreement negotiations, native title and Aboriginal heritage matters have not been cleared. Consequently, developments based on Cockatoo Sands are highly unlikely to be developed during the period covered by the allocation plan (DoW 2012).

At present DAFWA considers these soils could be used to grow crops during the wet season: this would complement the existing businesses that grow dry season crops on the heavy clay soils in Stage 1 areas. While the wet season demand for this style of irrigation is currently uncertain, it is expected to be less than what is typical for dry season crops, given the wet season’s shorter duration and that rainfall during this time will supply some of the crop water demand. The maximum irrigation demand will occur during a dry ‘wet’ season, when frequent watering will be required because of the sandy nature of the soil. The length of each crop’s growing season will also be critical to its specific demand. Irrigation demand from the Ord River would also be reduced significantly if local groundwater beneath the Cockatoo Sands could be used to supplement the irrigation supply. DAFWA is investigating this potential.

Given the above, including current uncertainties, it is highly unlikely that demand based on wet season irrigation would exceed 8 to 10 ML/ha. Assuming 6000 ha of the Cockatoo Sands are close enough to the Ord River for water to be supplied to the area economically, potential water demand would be between 50 and 65 GL/yr (Table 9).

3.3 Tarrara-Carlton and Carlton-Mantinea subareas

In DoW (2006), the likely down-river water demands were based on development scenarios proposed by the Ord Development Council and the Department of Agriculture in 2000. The land associated with these scenarios informed the land negotiations that ultimately led to the Ord Final Agreement. The areas of native title extinguished by the agreement also reflected negotiations with pastoralists who held leases over land needed for Stage 2 developments (primarily over land that is to become the M2 supply area). The agreement provided for more than 15 000 ha of land, primarily on the Carlton Plain (northern side) of the lower Ord River, to be transferred from pastoral lease to freehold.

The down-river demand projections were revised in 2011 in response to new proposals to further expand sandalwood plantations in these (now) freehold-titled areas (see below).

3.3.1 Tarrara-Carlton

Water demand in this subarea is expected to be zero during the life of the allocation plan (DoW 2012). Opportunities for development are limited along this reach. The Ord Final Agreement makes little provision for any development and the soils and topography are not favourable for irrigation. While there is potential to supply the levee soils of the East Mantinea development from the lower part of this river reach, the area is better supplied from the Carlton-Mantinea subarea (see below and Chapter 4). While there are some Cockatoo Sands that could be supplied from this subarea, as noted above this is not expected to occur during the period covered by the allocation plan.

3.3.2 Carlton-Mantinea

The soils on the river's northern side in the Carlton-Mantinea subarea range from fertile loams (levee soils) to black soil cracking clays and reflect the range of soils of the greater Ord River floodplain. These potentially irrigable soils occupy more than 12 000 ha of the Carlton Plains area and extend to the north and west of House Roof Hill. About 1000 ha are known to be highly saline and are thus unlikely to be developed. About half the 12 000 ha comprises loaming soils, 40 per cent of which overlie saline sodic layers. The remaining half consists of clay or mixed soils. More than 80 per cent of these clayey soils also overlie saline sodic layers. Efficient irrigation practices and drainage management will be essential for successful irrigation in all areas with underlying saline and sodic soils.

Two areas of potential development have been identified on the river's south side: East Mantinea (1000 ha of levee soils), which is considered suitable for high-value horticultural crops; and Mantinea West (3000 ha), which consists of complex mixed clay soils suitable for a range of broad acre, citrus and some horticultural crops.

Previous water demand projections for the total subarea in DoW (2006) did not exceed 148 GL/yr (Table A5.5, Appendix 5, DoW 2006), based on an irrigation area of 9500 ha. This demand was (then) not expected to develop for many years.

As a result of sandalwood plantations expanding in the region and more than 15 000 ha of freehold land being granted in the subarea, proposals have been received for developing more than 8000 ha on the river's northern side alone within the next five years. If the 4000 ha of land development on the river's south side proceeds, the total area of irrigation development in the subarea could reach 12 000 ha in five to 10 years.

The projected increased area of irrigation is partly offset by changes in crop types and improvements in water application efficiencies. Given these changes, the upper limit of potential demand in the Carlton-Mantinea subarea is now assessed as 155 GL/yr.

3.4 Dunham River subarea

The current water demand in the Dunham River subarea (4270 km^2) is dominated by the irrigation development at Kingston Rest on the Arthur Creek, a tributary of the Dunham River. The initial irrigation development and associated Arthur Creek Dam was established under the provisions of the *Irrigation (Dunham River) Agreement Act 1968*. This Act was repealed in 2003 and rights to Arthur Creek water are now managed under the *Rights in Water and Irrigation Act 1914*.

The Kingston Rest irrigation development has been refurbished in recent years. The current owners hold a licence to divert 17.4 GL/yr and have established 1450 ha of sandalwood plantations to 2011. Plans are for a further 440 ha to be established in 2012 reaching an ultimate development of about 2 400 ha.

Mining tenements have been issued over much of the Dunham River subarea, although no major mining activities are occurring at present. Future mining proposals may require water for activities such as dust suppression and mineral processing. Small quantities of potable water would also be needed. While groundwater usually meets part or all of these demands, surface water might also be used, especially if small creeks and tributaries can be harvested near the mine site. Surface water demands of this type do not normally exceed 5 GL/yr and are unlikely to be any larger in this subarea, especially during the life of the allocation plan (DoW 2012).

3.5 Upper Ord subarea

Current licensed water entitlements in the Upper Ord subarea total 9 GL/yr. These licences support mining and mineral processing at the Argyle Diamond Mine. Future surface water demand in this subarea will continue to be dominated by the needs of the mining industry.

As indicated for the Dunham River subarea, surface water demands for new mining ventures are rarely greater than 5 GL/yr, unless the developments are major operations such as the Argyle Diamond Mine.

A potential growth in surface water demand of 5 GL/yr for mining purposes is considered appropriate for this subarea. New mining developments with water demands greater than 5 GL/yr would require comprehensive environmental assessment and approval before they could proceed. The environmental approval of such a large mining project might trigger a review of the allocation limit for this subarea if surface water were to be the source.

4 Ecological water for the Lower Ord

Construction of the Ord River Dam in the early 1970s greatly changed the flow regime of the lower Ord River.

Before the Ord River Dam was built, the Ord River flooded regularly, inundating large areas every two to three wet seasons. In the dry season the river dried out to a series of disconnected pools.

After the dam was built, wet season floods were reduced by a factor of about 10 and scouring of the river and its banks was much reduced. Flows in the lower Ord River became permanent during the dry season, as surplus water – stored in Lake Argyle from the previous wet season – was gradually released downstream over the dry season.

The changed flood regime has significantly influenced the environment of the lower Ord River. In 1999 Western Australia's EPA stated that after almost 30 years of regulation, the new flow regime had led to a modified riverine environment with significant values worthy of protection (EPA 1999).

The Department of Water then began work to develop an environmental water regime for the lower Ord to maintain its riverine environment (as it had established in response to the modified flows that had occurred since the Ord River Dam was built).

This has been a two-step process. The first step was to develop an environmental water regime designed to maintain the riverine environment at a low level of risk. Such a regime is termed the ecological water requirement (EWR) and focuses on the needs of the environment – without considering other competing water needs. It is developed using the best ecological and related scientific information available. This chapter discusses this first step.

The second step was to develop an environmental water provision (EWP) based on the EWR, but which also reflected commitments made to provide water to meet other demands. The EWP is the water regime that must be maintained in the environment when water allocations made for other purposes are fully realised. Development of the EWP is discussed in Chapter 6 and appendices B and C.

The department has updated and improved the EWR and EWP regimes for the lower Ord River over time, using research and investigation on riverine ecological processes in the region, as described below.

4.1 Interim environmental flow regime

In 2006 the Department of Water adopted an interim environmental flow regime to be maintained in the lower Ord River of:

- 45 m^3/s between the Kununurra Diversion Dam and House Roof Hill
- 40 m^3/s from House Roof Hill to the Ord Estuary.

and in an estimated five per cent of years (under drought conditions), when water levels in Lake Argyle fall below 76 m AHD:

- 35 m^3/s between the Kununurra Diversion Dam and House Roof Hill

- 30 m^3/s from House Roof Hill to the Ord Estuary.

The interim environmental flow regime approach was proposed in 2000 by a scientific panel of experts in river ecology and hydrology, set up to advise the department in accord with the EPA's advice (EPA 1999). The approach uses the river channel's wetted perimeter during the dry season as a surrogate measure of aquatic habitat. Flow rates that did not change the dry season wetted perimeter by more than 10 per cent from typical post-dam values (post-1960s) were considered acceptable.

4.2 Comprehensive ecological water requirement

Six years of research and investigation into the riverine ecology of the Ord and its neighbouring catchments (Trayler et al. 2006) enabled the Department of Water to update the interim environmental flow regime in 2007 with a comprehensive EWR for the lower Ord River (Braimbridge & Malseed 2007).

The EWR is made up of:

- a dry season baseflow component of 42 m^3/s from the Kununurra Diversion Dam to House Roof Hill and 37 m^3/s downstream of House Roof Hill which provides a minimum continuous flow throughout the year that varies depending on the season
- a wet season baseflow component between January and the middle of May
- a series of target wet season peaks that are required annually or inter-annually (every two, four or 20 years).

4.2.1 Method

The comprehensive EWR is based on the Flow Events Methodology (FEM) developed by Stewardson 2001. Central to the FEM is the premise that river-system integrity is related to variability of flow within and between years.

The method recognises that different components or parts of the flow regime such as low, high, bankfull and overbank flows are all important to the health of the river and have different ecological functions.

With the help of a scientific panel (see Braimbridge & Malseed 2007 for membership details), the department identified components (called flow-ecology linkages) of the flow regime considered necessary to maintain the lower Ord River's ecological health. Twenty-two flow-ecology linkages (Table 11, adapted from Table 12, Trayler et al. 2006) were identified to maintain:

- populations of fish and macroinvertebrates
- vegetation community structure and composition
- water quality
- channel geomorphology
- ecosystem processes in the lower Ord.

Hydraulic factors considered necessary to support each objective were also identified, as were the related flow characteristics necessary to support them.

The flow required to meet each flow-ecology linkage has been estimated using a hydraulic model of the lower Ord in combination with the River Analysis Package (RAP). RAP is a software package that supports the estimation of ecological flow requirements of rivers.

Based on the flow-ecology linkages the threshold flows (when habitats become available or ecosystem processes are maintained) were identified. This enabled prediction of the magnitude of flow required to inundate or maintain ecosystem processes or different habitat types such as vegetation, backwaters and refuge pools in the lower Ord.

For example, one of the flow-ecology linkages relating to maintaining fish communities requires the inundation of river benches to a depth of 1 m during the wet season to make this habitat available for fish (for feeding and spawning). Using the RAP software, the department estimated that flows of at least 125 m^3/s were required to inundate river benches to 1 m (see Figure 15).

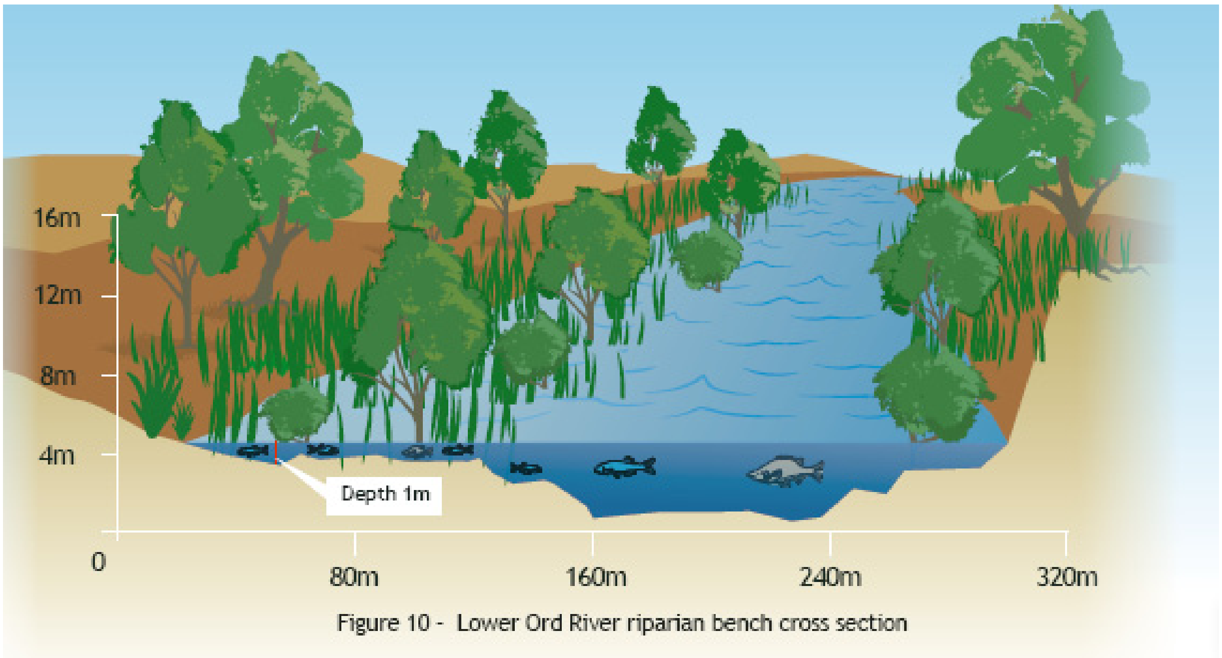


Figure 15 Lower Ord: conceptual example of flow-ecology linkages

This approach was applied to three distinct geomorphologic reaches of the lower Ord River: reach 1 below Kununurra Diversion Dam to Tarrara Bar; reach 2 from Tarrara Bar to a distance 73 km downstream of the diversion dam; and reach 3 which is the tidal-dominant reach (see Figure 16). [Note that reach 2 was subsequently divided into two; at the end of the Tarrara- Carlton subarea, 56 km downstream of the diversion dam (see Appendix B –section B2)].

The frequency and duration of the required flows were then determined using a daily flow regime for the lower Ord for the period 1974 to 2005. This period covers the flows experienced by the lower Ord River environment since the Lake Argyle spillway first overflowed (Figure 17).

Table 11 Environmental objectives and flow considerations

Objectives	No.	Flow-ecology linkage	Reach	Flow considerations			
				Flow component	**Season/ timing**	**Hydraulic factors/constraints**	**Time-series**
Fish							
Maintain species richness and composition of fish communities	1a	Shallow backwater habitat inundated and available for small-bodied fish and juveniles of large-bodied fish	1,2	Low flows	Dry season	Area of channel with zero velocity and depth 20–85 cm (average 45 cm)	Event frequency (minimum magnitude)
	1b	Shallow macrophyte habitat inundated and available for small-bodied fish and juveniles of large-bodied fish	1,2	Low flows	Dry season	Area of channel with depth 0.45–2 m	Event frequency (minimum magnitude)
	1c	Deep pool habitat available for large-bodied fish	1,2	Low flows	Dry season	Area of channel depth 3–4 m	Event frequency (minimum magnitude)
	1d	Deep backwater habitat inundated and available for large-bodied fish as habitat and possible spawning site	1,2	High flow	Wet season	Area of channel with velocity <20 cm/s and depth <2 m	Event frequency (minimum magnitude)
	1e	Riparian bench flooded and available for large-bodied fish as habitat and possible spawning site	1,2,3	High flow	Wet season	Area of inundated channel with gradient <0.1 and depth <1 m	High-flow spells
	1f	Passage over in-stream obstacles by migratory species	1,2,3	High flow	Wet season – extending through April	Depth over shallowest point 0.5–1 m	Low-flow spells
	1g	Flow sufficient to oxygenate pools and avoid fish kills	1,2	Low flows	Dry season	Pool velocity >0.08 m/sec	Low-flow spells
Macroinvertebrates							
Maintain species richness and composition of macroinvertebrate communities	2a	Submerged macrophyte habitat inundated and available for a range of macroinvertebrate species	1,2	Low flows	Dry season	Area of channel with velocity <0.3 cm/s and depth 45–90 cm	Event frequency (minimum magnitude)
	2b	Gravel runs and rapids inundated and available for a range of macroinvertebrate species	1,2	Low flows	Dry season	Area of channel with depth >16 cm. NB. minimum width to ensure lateral coverage also important	Event frequency (minimum magnitude)
	2c	Emergent macrophytes inundated and available for a range of macroinvertebrate species	1,2	Low flows	Dry season	Area of channel with depth 0.3–2.5 m (average 1.3 m)	Event frequency (minimum magnitude)
	2d	Permanent flows so that pools do not become isolated	1,2,3	Low flows	Dry season	Pool velocity >0.08 m/s	Low-flow spells

Objectives	No.	Flow-ecology linkage	Reach	Flow considerations			
				Flow component	**Season/ timing**	**Hydraulic factors/constraints**	**Time-series**
Ecosystem processes and connectivity							
Maintain connectivity and in-stream algal production	3a	Permanent flows maintaining shallow areas for algal production	1,2,3	Low flows	Dry season	Area of inundated channel with depth <50 cm	Flow duration
	3b	Lower riparian bench (damp zone) inundated to maintain algal production	1,2	High flow	Wet season	Area of inundated channel with depth <50 cm	Flow duration
	3c	Wet season baseflow	1,2,3	Low flows	Wet season	Area of inundated channel	Flow duration, magnitude
Maintain riparian inputs to river	4a	Seasonal inundation of mid-bank	1,2,3	Freshers	Wet season	Flood higher terrace to 0.25 m for short duration (~2–3 days)	Flow duration, magnitude
Maintain connectivity with Parry Lagoon floodplain	5a	Wetland inundation	2,3	Overbank flows	Wet season	Area of floodplain inundated	Event frequency (peak /duration)
Geomorphology							
Discourage excessive build-up of fine sediments, organics and associated in-channel vegetation	6a	Flows to provide sufficient power to scour sediment and vegetation build-up	1,2,3	Active channel flows	~ 3-yearly	Stream power sufficient to mobilise finer sediments (< 500 μm diameter)	Magnitude, duration
Water quality							
Prevent deoxygenation of pools	7a	Sufficient water exchange in pools to ensure dissolved oxygen levels do not reduce to anoxia	1,2	Low flows	Dry season	Pool velocity >0.08 m/s	Percent time exceeded
Riparian vegetation							
Maintain diversity of the damp zone and aquatic vegetation by reducing terrestrialisation, weed invasion and simplification of the vegetation structure	8a	Seasonal inundation of lower riparian terrace	1,2,3	High flow	Wet season	Area of inundated channel with gradient <0.1 and depth <1 m	Flow duration, magnitude
	8b	Manage dominance of emergent species through the provision of flows with sufficient power to scour vegetation	1,2,3	Active channel flows	~ 3-yearly	Stream power sufficient to scour vegetation	Flow duration, magnitude
Retain dryer elements of ‘old’ riparian zone	8c	Encourage *Eucalyptus* and other dryland species to persist on the mid-banks behind the damp zone. Seasonal higher flow pulses may encourage this	1,2,3	Freshers	Wet season (Feb–April)	Flood higher terrace to 0.25 m for short duration (~2–3 days)	Flow duration, magnitude
	8d	Irregular high-magnitude flood flows, equivalent to those observed in the 2000 wet season	1,2,3	Bankfull	Every 20 years	Stage height at least equivalent to the 2000 wet season flood	Magnitude, frequency

The expert panel provided advice throughout the process of determining the EWR. The panel had direct input into identifying flow-ecology linkages and reviewing the outcomes of the flow modelling (estimation of the flows required to meet each flow-ecology linkage).

The outcome of the process was an EWR that incorporates wet and dry season flows for each of the three reaches. The flow regime pieces together the flows required to satisfy all of the 22 flow-ecology linkages (see Braimbridge & Malseed 2007 for details).

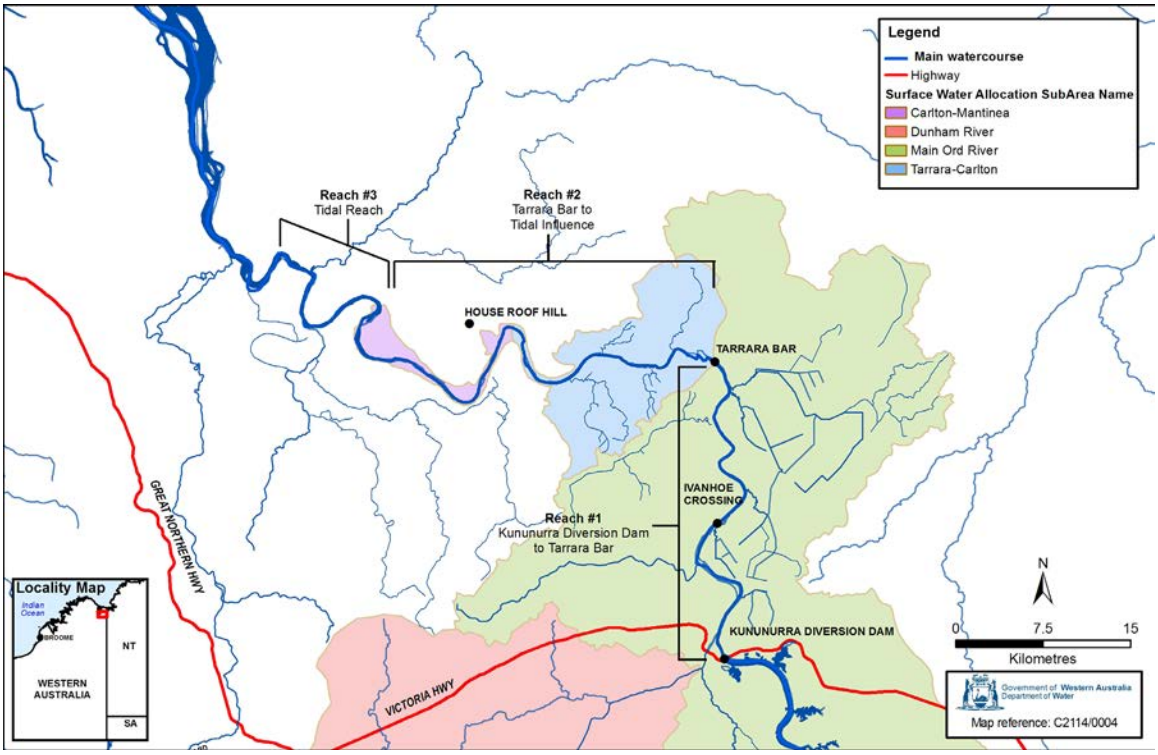


Figure 16 Lower Ord River ecological reaches

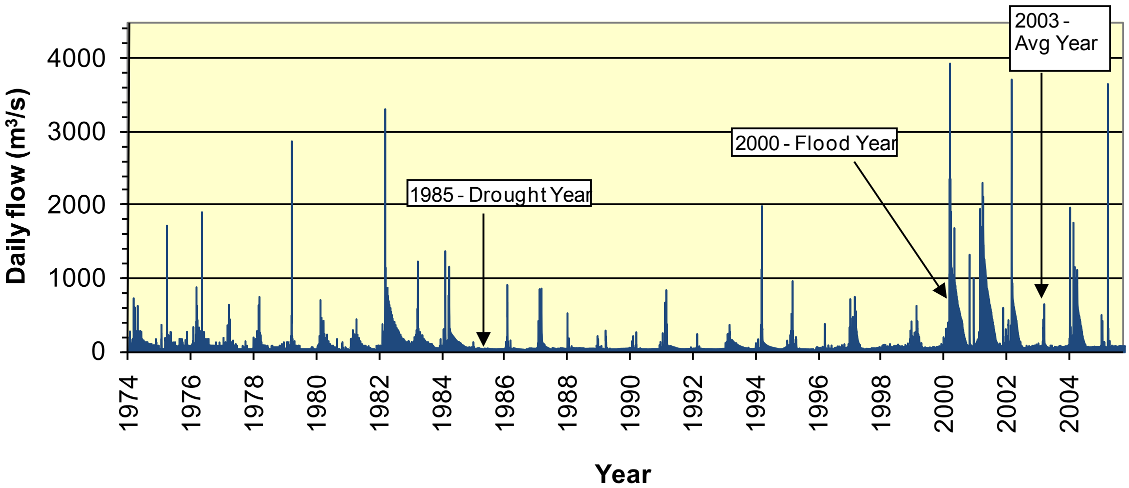


Figure 17 Historic (1974–2005) hydrograph of the lower Ord River post-Ord River Dam

4.2.2 Dry season ecological water requirements

Table 12 lists each dry season flow requirement against the relevant river reach and flow-ecology linkage.

The dry season flows were typically set as a minimum requirement. The exception is flow-ecology linkages that relate to the inundation of submerged and emergent macrophyte habitat. The flow regime outlined for these flow-ecology linkages limit the reduction in dry season flows from one year to the next, rather than providing for absolute minimum flow.

The dry season minimum flow thresholds were then ranked, and a dry season minimum of 42 m^3/s identified. Maintaining a flow of 42 m^3/s or higher in the dry season will satisfy most of the dry season flow-ecology linkages in reaches 1 and 2.

Table 12 Dry season flow requirements that meet flow-ecology linkages

Flow requirement	Flow-ecology linkage(s) met
Reaches 1 and 2	
Minimum of 42 m^3/s	Shallow backwater habitat inundated and available for small-bodied fish and juveniles of large-bodied fish
Minimum of 37 m^3/s	Deep pool habitat available for large-bodied fish
Minimum of 35 m^3/s	Flow sufficient to oxygenate pools and avoid fish kills Permanent flows so pools do not become isolated Sufficient water exchange in pools to ensure dissolved oxygen levels do not reduce to anoxia
Minimum of 25 m^3/s	Gravel runs and rapids inundated and available for a range of macroinvertebrate species
Minimum of 10 m^3/s	Permanent flows maintaining shallow areas for algal production
Limited rate of change from one dry season to the next (effective when mean discharge for the previous Oct/Nov is above 70 m^3/s)	Shallow macrophyte habitat inundated and available for small-bodied fish and juveniles of large-bodied fish Submerged macrophyte habitat inundated and available for a range of macroinvertebrate species Emergent macrophyte habitat inundated and available for a range of macroinvertebrate species
Reach 3	
Minimum of 10 m^3/s	Permanent flows maintaining shallow areas for algal production

4.2.3 Wet season ecological water requirements

Wet season flow requirements include a baseflow component (a minimum flow that should be maintained) and a series of target peak flows to satisfy specific flow linkages (Table 13).

Table 13 Wet season flow requirements that meet flow-ecology linkages

Flow requirement(s)†	**Flow-ecology linkage(s) met**
Regular flow of at least: • 50 m^3/s in January • 57 m^3/s in February and March • 53 m^3/s in April • 48 m^3/s from 1 to 15 May	• Wet season baseflow
Flows greater than 100 m^3/s for a minimum 18 days per year in reach 2	• Lower riparian bench (damp zone) inundated to maintain algal production
In four years out of five wet seasons: • four spells above 125 m^3/s with a total duration of at least 10 days in reach 1 • two spells above 200 m^3/s with a total duration of at least five days in reach 2 • one spell above 300 m^3/s with a minimum duration of two days in reach 3	• Deepwater backwater habitat inundated and available for large-bodied fish as habitat and possible spawning site • Riparian bench flooded and available for large-bodied fish as habitat and possible spawning site • Seasonal inundation of lower riparian terrace

In two out of three wet seasons:
• one spell above 425 m^3/s with a minimum duration of two days in reach 1
• minimum of:
  – 20 m^3/s in reach 2
  – 10 m^3/s in reach 3
	• Passage over in-stream obstacles by migratory species

High-flow event of at least • 750 m^3/s every two years in reach 1 • 1400 m^3/s every four years in reach 2	• Seasonal inundation of mid-bank • Encourage *Eucalyptus* and other dryland species to persist on the mid-bank behind the damp zone. Seasonal pulses of higher flows may encourage this.
Flood event with peak mean daily flow of 3700–4000 m^3/s every 27–35 years	• Wetland inundation • Flows to provide sufficient power to scour sediments and vegetation build-up • Manage dominance of emergent species through provision of flows with sufficient power to scour vegetation • Irregular high-magnitude flood flows, equivalent to those observed in the 2000 wet season

† The flow rate applies to all reaches unless specified otherwise

The maintenance of wet season flow-ecology relationships requires a number of events of varying magnitude, duration and frequency. These include components expected to occur each wet season, and others that are expected less frequently (from once in two years to once in 27 to 35 years).

The EWR for the lower Ord is summarised in a conceptual hydrograph (Figure 18). This includes all the events and components of events expected throughout the year. The resultant recommended flow regime has a dry season minimum, wet season peak flows and a wet season baseflow. Larger, less frequent flood events that contribute to the EWR were also identified (see Braimbridge & Malseed 2007 for details).

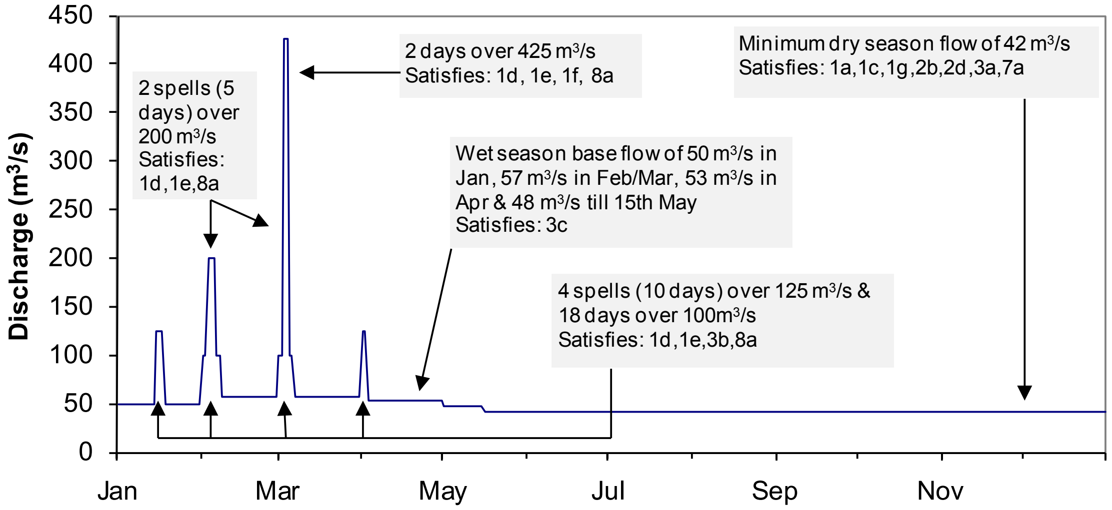


Figure 18 Lower Ord River environmental water requirement – as a composite flow regime

5 Social, recreational and cultural water

Visitors to the Ord region use lakes Argyle and Kununurra and the lower Ord River for recreation and tourism activities. Locals strongly identify with the Ord River, driven in part by its role in their livelihoods, whether through the agricultural, tourism or service sectors of the economy.

The Miriuwung Gajerrong people have a particularly strong attachment to the Ord River through their Dreaming and continue to hunt and fish along the lower Ord watercourse (where access permits).

The Ord River's social values are not limited to within the region: the river has considerable status with people who have visited and developed an affinity with the east Kimberley.

However, tourists, recreational fishers and Miriuwung Gajerrong elders, for example, hold different values and seek different experiences from the river. While often compatible, their respective desired flow regimes are not always the same. Tension also exists between the needs of water for ecological (Chapter 4) and social and cultural purposes (this chapter).

5.1 Social and recreational water needs

Water-based recreation on lakes Argyle and Kununurra and the lower Ord River has become important to the local economy (Table 9, DoW 2006).

The water-based recreation occurring downstream of the Kununurra Diversion Dam is only possible because of the continuous dry season flows in the lower Ord River since regulation. Between 1974 (after Lake Argyle first filled) and 2000, typical dry season flows have been around 50 m^3/s. Since 2000, as electricity demand has increased, dry season flow has increased and is now typically 60 to 70 m^3/s (when Lake Argyle is not spilling). These flow rates are sufficient for small boats to navigate down the lower Ord to Cambridge Gulf (under most conditions). As a result, recreational fishing along the lower Ord has become popular with both locals and visitors (supported by commercial tour operators).

As more water is diverted to supply new irrigation areas, dry season flows in the lower Ord will decrease – assuming other factors (e.g. power station release rules, the EWR) remain unchanged. As such, social and recreational needs for water are partly in conflict with further irrigation expansion.

In 2000 the local community discussed the importance of maintaining enough flow in the lower Ord to retain these recreational values. At this time, planning was well advanced to develop a raw sugar industry based on irrigating 30 000 ha of new farmland across the whole of the M2 supply area. This would have required an annual water entitlement of about 690 GL/yr. Provision was being made for a new peak diversion rate of 39 m^3/s. Hence, in 2000 there was a high likelihood of having lower flows during the dry season within five years.

A wide range of community views were expressed at a workshop held in June 2000 about what was an acceptable flow for recreational purposes along the lower Ord (Table 8, DoW 2006). Some felt that a minimal depth of 0.6 m should be maintained downstream of Tarrara Bar at all times to facilitate boat passage through to Cambridge Gulf. Many others considered making provision for average flows was sufficient, recognising that permanent or continuous (boat) passage might not be achievable if other (economic) benefits (from the expansion of irrigation) were also to be achieved.

5.2 Water to support traditional laws and customs

5.2.1 Aboriginal cultural values

The Miriuwung Gajerrong people's cultural values associated with the lower Ord River were documented by Barber and Lumley (2003) and reported in *Ord River water management plan* (DoW 2006). The key elements have been summarised below:

> Aboriginal people in the region have a strong association with the river and do not separate water from country. They have a responsibility for looking after their country through their 'conception spirit' that defines a group's location and extent. The Aboriginal belief system is centred on the Dreaming, which started when the land was flooded and continues to the present. The Dreaming are events that created the soils, water, places and culture and define timeframes. Aboriginal people learn about the Dreaming throughout their lifetime and many of the spatial and temporal cues to their stories and songs have been affected by irrigation development and changes to the hydrology of the river. While the Dreaming is less visible since irrigation development, the culture remains and Aboriginal people also attribute values to today's environment. Specific issues that arise in relation to river management are accessibility, predictability of flow, estuarine crocodile movement and water quality. Aboriginal people in the region take a long-term view of planning and want a role in management.
>
> At the community workshop in 2000, representatives of traditional owners indicated that access to the river for fishing and ceremonial activities were important to Miriuwung and Gajerrong people, and suggested short periods of 'dry out' and 'wash out'. Subsequent discussions with traditional owners confirmed that having access to the river so they can pursue their traditional activities associated with the river, was important to the Miriuwung and Gajerrong people.

The Miriuwung Gajerrong people's rights to exercise their traditional laws and customs in relation to the lower Ord River were recognised by the Federal Court of Australia in 2003 and 2006, as described below.

5.2.2 Aboriginal native title rights to water

The Miriuwung Gajerrong people hold native title rights to land and waters over extensive areas to the west and north of Lake Argyle (Figure 19). The native title rights are primarily in areas downstream of Lake Argyle and the Kununurra Diversion Dam, in the Main Ord, Tarrara-Carlton and Carlton-Mantinea subareas. Numerous other native title claims have been lodged with the Federal Court in the Upper Ord subarea (Figure 19).

The Miriuwung Gajerrong people's native title rights in relation to water stem from consent determinations of the Federal Court. These are known as the Miriuwung Gajerrong No. 1 (9 Dec 2003) and Miriuwung Gajerrong No. 4 (24 Nov 2006) determinations and specify the nature and extent of their native title rights. Schedules to each determination define the areas over which each determination was made, and the areas where native title rights were found to exist or not exist across these areas (see Figure 19).

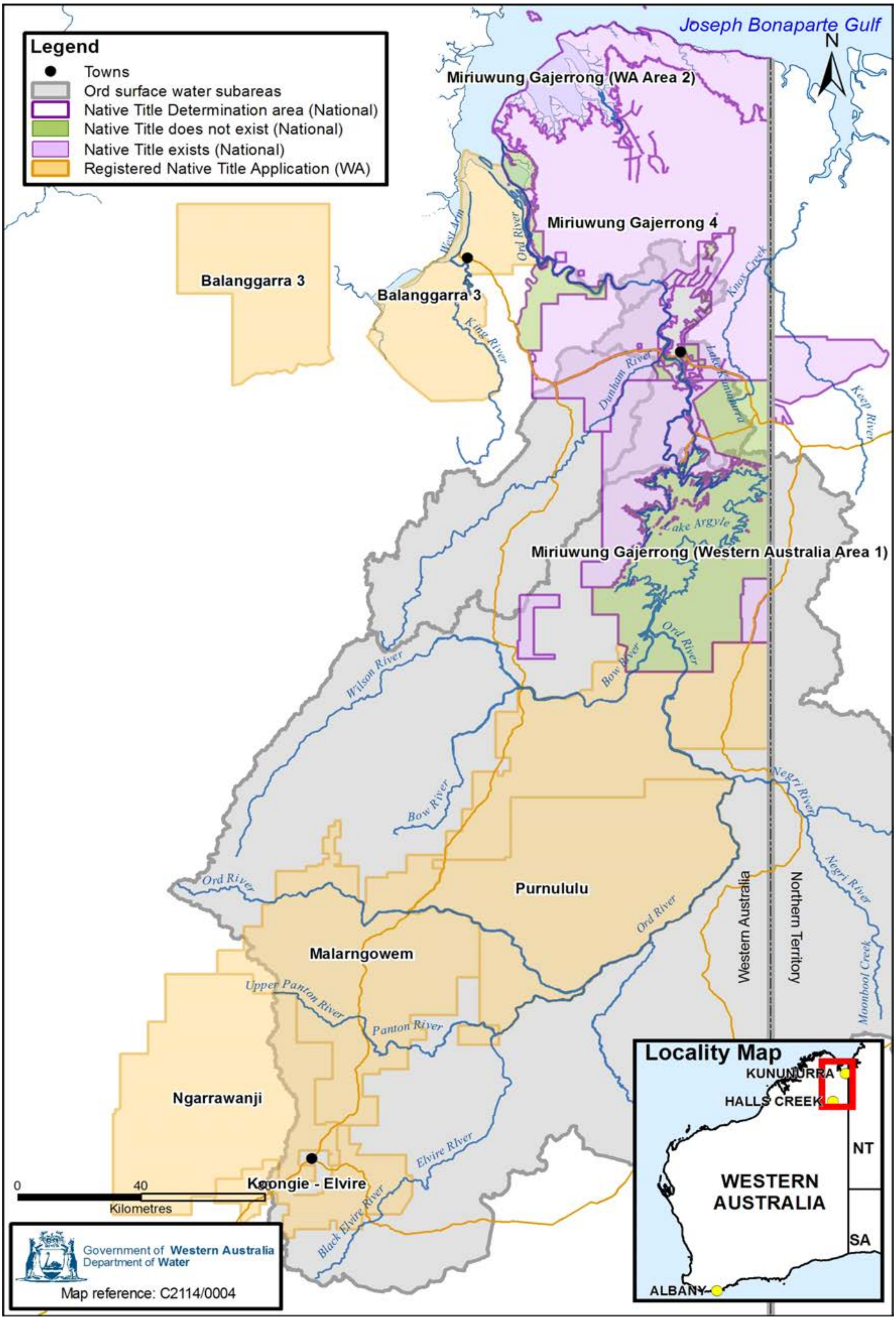


Figure 19 Native title determinations and applications in the north-eastern Kimberley

Appendix A includes key text from each determination that defines native title rights in relation to water that are relevant to this plan.

The Miriuwung Gajerrong people have rights to occupy, use and enjoy the land and waters in areas of native title, in accordance with their traditional laws and customs. This includes rights to enter and remain on the land and waters with native title, and to take water, fish and flora from these areas (Appendix A).

The rights in relation to 'waters', however, are not exclusive and are for uses related to traditional laws and customs.

The Miriuwung Gajerrong No. 1 determination established native title rights over unallocated Crown lands along the lower Ord River watercourse, downstream of the Kununurra Diversion Dam to near Tarrara Bar, where the land tenure along the watercourse changed to pastoral lease. The Miriuwung Gajerrong No. 4 determination defined native title over the downstream pastoral lease, extending the native title rights to the waters of the lower Ord, down to and including its tidal reach.

However, the Miriuwung Gajerrong No. 1 determined that above the Kununurra Diversion Dam, native title did not exist over lakes Kununurra and Argyle, or the Ord River between the Ord River Dam and Lake Kununurra. It also established that no native title existed along the reserve created to construct the spillway from Lake Argyle and transmit water from the spillway to Lake Kununurra.

The construction and operation of the two dams has substantially altered the downstream flow regime and affected the Miriuwung Gajerrong people's opportunity to enjoy their traditional and customary rights to the lower Ord River. Despite modifications to the flow regime, many of the Miriuwung Gajerrong people's cultural and spiritual values, held in relation to the river, remain.

An important consideration in managing flows in the lower Ord River is the Miriuwung Gajerrong people's interests in seeking to realise their native title rights along the lower Ord River. These are considered further in the following section, in terms of balancing the competing needs of in-stream (non-consumptive) demands on the lower Ord.

5.3 Balancing in-stream water needs

Most in-stream water needs are complementary. Releases from the hydropower station enable tour boats to navigate up to the Ord River Dam from Lake Kununurra if flows exceed 50 m^3/s. Hydropower releases, in excess of irrigation diversions from Lake Kununurra, are released downstream and contribute to meeting the EWR of the lower Ord. These flows also help recreational fishers to boat down the lower Ord to Cambridge Gulf.

Two situations arise when in-stream needs are not complementary. Firstly, as noted in Section 5.1, dry season flows in the lower Ord River will reduce as irrigation demand increases. Hence, boat navigation on the lower Ord will become more difficult more often in the future. However, there will be time for boat owners to adapt to these changing circumstances as irrigation demands are expected to grow gradually over many years.

Secondly, Miriuwung Gajerrong elders wish to see periods of ‘dry out’ during the dry season. These would be to promote learning of their pre-dam Dreamtime stories of the Ord River and carry out traditional ceremonial activities. However, maintaining a strong continuous flow between pools is a key aspect of the ecological demands of the lower Ord (see Chapter 4). The obligation to generate power is also a key factor that drives continuous flows in the lower Ord. Any extended ‘dry out’ period would limit electricity generation.

Providing ‘dry out’ periods, even for relatively short periods, will clearly be a challenge.

Nevertheless, since the early 1990s several short periods of low flow (usually of two to five days’ duration) have occurred in the lower Ord River towards the end of the dry season. Most were associated with maintenance and inspection work on the Kununurra Diversion Dam and other manmade structures downstream. In one case, in 2002, low flows were maintained over three days to investigate their ecological impact (see Appendix 3, DoW 2006).

The need to inspect these structures will occur regularly in the future. These are the times the Miriuwung Gajerrong people could best realise their native title rights in the lower Ord River. Given the Miriuwung Gajerrong No. 1 and No. 4 determinations and the Ord Final Agreement, the traditional owners expect to be involved in resource management decisions that affect their country. Consequently, the Miriuwung Gajerrong people should be involved in planning future low-flow periods so they can use such times to promote learning of pre-dam Dreamtime stories and plan their traditional ceremonial activities.

Planning ‘dry out’ periods at times of infrastructure maintenance will require coordination, as many competing interests need to be considered and arrangements negotiated and agreed.

While relatively rapid declines in flow rate will be required for maintenance, ‘dry out’ and power generation reasons, these should be limited to the extent possible. This will minimise the risk of adverse effects on the aquatic biota (observed during the 2002 low-flow trial). Such future low-flow periods should be infrequent, so that additional pressures on the river ecology are minimised. Except for emergencies, they should be separated by at least two years so that the riverine environment has time to recover.

6 Reservoir simulations

6.1 Balancing competing water needs

Chapter 3 describes the projected demands for water in the Ord River catchment in the short to medium term. Chapter 4 describes the ecological water needs of the lower Ord River, while Chapter 5 describes the in-stream water needs. The growing irrigation and hydropower demands, and the need to protect the downstream river ecology and balance competing in-stream interests, mean that difficult water allocation decisions are required. That is, not all water demands and environmental needs will be able to be met in all years. This chapter describes the reservoir simulations undertaken to determine how best to allocate water under a range of likely demand scenarios.

The challenge is to allocate Ord River water in a way that meets each demand to the extent possible, consistent with the outcomes and objectives of the allocation plan (DoW 2012).

In terms of balancing competing demands on the Ord River resource, the objective is to establish release regimes from Lake Argyle that are designed to achieve the following:

a) fully meet the licensed entitlements in 95 per cent of years
b) meet the monthly wet and dry season environmental flow targets at the Tarrara Bar gauging station (tables Table 12 and Table 13) in all years except during periods of drought
c) accept some reduction in the environmental flow targets during drought periods, consistent with advice from the panel of aquatic ecologists advising the department
d) maximise hydropower generation at the Ord River Dam power station, within the constraints of meeting conditions (a) to (c).

This hierarchy of criteria guided the reservoir simulations undertaken to establish how best to allocate and manage the water resources of the Ord River, given the available storage and highly variable nature of streamflow in this region.

6.2 Reservoir modelling

The Department of Water used the Danish Hydrologic Institute's MIKE BASIN computer package to simulate the behaviour the Ord storages and river system over a wide range of hydrologic conditions. The model simulated the operating rules of the Ord River Dam and power station and Kununurra Diversion Dam, performed water balance calculations for lake Argyles and Kununurra, and determined the resulting flows in the Ord River just below the confluence with the Dunham River. (The model also has the capacity to simulate hydropower generation at the Kununurra Diversion Dam but this is not explored here.) Details of the model structure and methodology are included in a technical report on Ord reservoir simulations from 2007 (Smith & Rodgers 2010). Some of the other key aspects are discussed in the following paragraphs.

Reservoir behaviour was simulated by performing a series of daily water balance calculations. These calculations determined the change in storage for given inflows and outflows each day. Because reservoir evaporation and rainfall are often significant components of the water balance, calculations of the evaporation losses from, and direct rainfall on, the reservoirs' water surfaces needed to be accurately computed. Hence the relationships between the water stored, the surface area and the water elevation of lakes Argyle and Kununurra were key inputs to the reservoir simulation model.

Given the multiple reservoirs and water demands of the Ord River system, it was important the simulations included all linkages (natural and manmade) between each reservoir and each demand. It was also important that water allocations and restriction policies that applied to each demand could be adjusted between simulation runs. Methods of allocating the water resource, particularly through times of drought, were explored by adjusting the demands and restriction policies between simulations. The various restriction policies, defined as different functions of (low) water shortage, were particularly important because they effectively established the relative priority of each allocation.

Inflows to the Ord River Dam are unregulated and highly variable. The reservoir simulations were performed over 98 years to ensure a full range of inflow conditions was considered. This enabled the reliability of allocations to be assessed and the severity of restrictions, when applicable, to be estimated.

6.2.1 Purposes of simulating the Ord River reservoirs and river system

The department undertook the Ord River system simulations to determine if the revised EWR (Chapter 4) could be met in full, given the allocation commitments in DoW (2006), and if not, what EWP options would be acceptable.

The desired EWP was to meet the EWR in full. However, initial simulations indicated that insufficient water was available to meet irrigation supply and power generation commitments while providing the EWR regime fully in all years. Similar to the approach taken in DoW (2006), a water provision for the environment, less than the EWR regime, proved necessary during drought periods.

In addition to the determination of EWPs for the Ord River, reservoir simulations were conducted to investigate a range of water allocation scenarios (for both irrigation and hydropower). The impact of changes to the existing infrastructure, such as raising the Ord River reservoir spillway and an additional power station at the Kununurra Diversion Dam, was also explored but is not reported here.

6.2.2 Criteria used in reservoir simulations

An iterative approach was used to explore different allocations and restriction policies by simulation. A range of EWP options was also developed and discussed with the scientific panel that advised the department on the EWR regime (see Appendix A). For each EWP option, the restriction policies for hydropower and irrigation were adjusted, in sequence, to ensure the EWP flow regime in the lower Ord River was maintained. That is, the hydropower release rules were adjusted first to achieve the following criteria wherever possible:

- reliable supply of irrigation water (full allocation supplied in 95 per cent of years)
- a minimum supply of 25 per cent of allocation in the driest year
- water levels in Lake Argyle always above 70 m AHD (never run dry).

If these criteria could not be met, then the irrigation restriction policy was adjusted and the simulations repeated. If the criteria were still unable to be met, a further environmental flow option was considered and evaluated (as discussed in Appendix B).

Figure 20 illustrates the iterative approach to simulations used to develop restriction policy for each demand. The resulting EWP regime is described in Appendix C. Further details of the model inputs, outputs and post-processing of results are given in Appendix D.

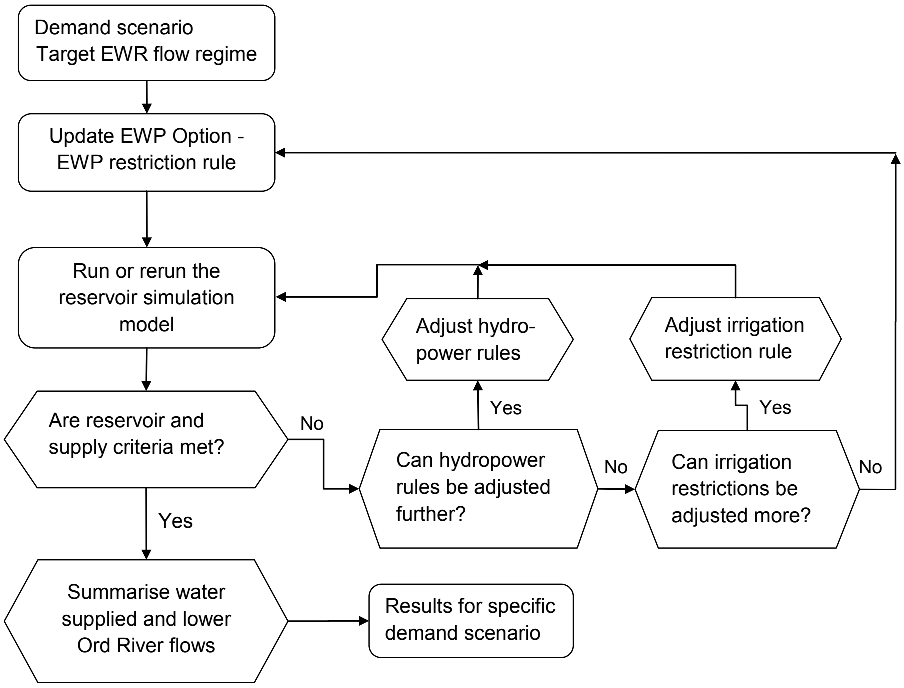


Figure 20 Iterative simulation approach to defining restriction policies for each demand

The water demand scenarios studied are described in the following section. The tables of Appendix D list the restriction policies developed for each scenario (by applying the simulation criteria and methodology described above).

6.3 Water demand scenarios

The potential future water and power demands of Chapter 3 were used to formulate three future demand scenarios on the Ord River water resource. All three future scenarios could arise the foreseeable future. For comparison, two other scenarios were formulated to reflect the recent past and the current licensed situation (likely to develop within the next two years). Table 14 lists the scenarios studied.

Table 14 Demand scenarios

Scenario	Definition of demand scenarios used in the reservoir simulation model
I	*The recent past* • Stage 1 irrigation demands, averaging 350 GL/yr (upstream of Tarrara Bar) • The recent past (moderate) hydropower demand of 210 GWh/yr • Specific releases to meet the environmental flow regime of Chapter 4
II	*Current licensed situation* • Stage 1 irrigation demands, averaging 350 GL (upstream of Tarrara Bar) • High power demand of 327 GWh/yr, with a minimum hydropower guarantee of 210 GWh/yr above a water level of 78 m AHD in Lake Argyle • Specific releases to meet the environmental flow regime of Chapter 4
III	*Licensed to allocation limits*† • Irrigation demands totalling an average of 750 GL/yr – the allocation limit of DoW (2006) upstream from Tarrara Bar. These reflect Stage 1 and new irrigation demands (expected to develop mainly in the M2 supply area) • High power demand of 327 GWh/yr • Specific releases to meet the environmental flow regime of Chapter 4
IV	*Current licensed entitlements, enhanced hydropower rules* • Stage 1 irrigation demand of 350 GL • High power demand of 327 GWh/yr, no minimum guarantee for hydropower • Specific releases to meet the environmental flow regime of Chapter 4
V	*Licensed to allocation limits*†*, low power demand (town only)* • Irrigation demands totalling an average of 750 GL/yr – the allocation limit of DoW (2006) upstream from Tarrara Bar. These reflect Stage 1 and new irrigation demands (expected to develop mainly in the M2 supply area) • Low power demand of 89 GWh/yr, equivalent to the projected Kununurra town power demand in 2018 (as projected in 2010) • Specific releases to meet the environmental flow regime of Chapter 4

† Note under this scenario an additional 115 GL is diverted from the Ord River downstream of House Roof Hill

Scenarios I and II reflect the recent past and near future respectively.

6.3.1 *Scenario I* (the recent past)

Scenario I has irrigation demands for Stage 1 areas of 350 GL/yr, as in DoW (2006), and a hydro-electricity demand on the Ord Dam power station of 210 GWh/yr. The electricity demand is based on the guaranteed minimum of 210 GWh/yr specified in the 1994 Water Supply Agreement for the power station. This is similar to the electricity demand on the power station in the recent past (to 2006, see Section 3.1). The environmental water demands of *scenario I* are based on the recommendations of Braimbridge and Malseed (2007), as described in Chapter 4. The same environmental demand was used in all scenarios.

6.3.2 *Scenario II* (the current licensed situation)

Scenario II has the same irrigation demands (Stage 1 allocations) and environmental water demands as *scenario I*. However, *scenario II* includes an electricity demand of

327 GWh/yr that reflects the rapidly growing electricity demand in the region (see Section 3.1). Note that the existing power station is not capable of meeting all of this high demand. It was included to determine the maximum electricity that could be generated given the power station's capacity and the need to meet the other water allocation objectives of the allocation plan (DoW 2012). This required limiting the electricity generated to the guaranteed minimum of 210 GWh/yr when water levels in Lake Argyle fell below mid levels (between 90.8 and 88.0 m AHD, depending on the month). The simulation model was used to determine the actual water levels for each month at which the 210 GWh/yr limit first applies. Note also that the 210 GWh/yr is not guaranteed when water levels fall below 78 m AHD. Below 78 m, electricity generation is restricted further: firstly to the town electricity demand (of 89 GWh/yr) down to 76 m AHD, then to zero when water levels fall below 76 m.

6.3.3 *Scenario III* (licensed to allocation limits)

Scenario III represents the situation when licensed diversions from the Ord River (between Lake Kununurra and Tarrara Bar) reach the allocation limit of DoW 2006. This is an average demand of 750 GL/yr; the same Stage 1 demand (350 GL/yr) as *scenarios I and II*, plus an additional average of 400 GL/yr for new developments (primarily to supply the M2 supply area – see Appendix B). It has the same hydropower demand of 327 GWh/yr as *scenario II.* However, more frequent hydropower restrictions are necessary to provide for the larger irrigation demand.

6.3.4 *Scenario IV* (current entitlements, enhanced hydropower rules)

Scenario IV represents the current situation with respect to licensed water entitlements (similar to *scenarios I and II)* and the high hydropower demands of *scenarios II and III*. However in this scenario (*scenario IV)* the water release rules for the power station have been optimised so that the long-term-average amount of electricity generated is larger than under *scenario II,* while still meeting the other water resource objectives (of maintaining high irrigation reliabilities and acceptable environmental flows). While *scenario IV* has the same environmental water demands as the other four scenarios, different restriction rules were developed for this scenario (see Section 7.1).

6.3.5 *Scenario V* (licensed to allocation limits, low power demand, town demand only)

Scenario V represents irrigation expansion to the allocation limits of DoW (2006) and a low future power demand (implying closure of the Argyle Diamond Mine). As the mine closure is not expected before 2018 (see Figure 13), this scenario represents a possible future in the medium term. (Note that the drop in electricity demand after the mine closes is not likely to be as severe as implied in the scenario. Pacific Hydro would seek to supply other industrial/mining customers in the region if financially viable to do so.) The irrigation demands are the same as *scenario III.* Importantly, the environmental flow demands remain the same as all the other scenarios. As there will be fewer hydropower releases under this lower power demand scenario, *scenario V* will require additional releases to be made specifically from Lake Argyle to meet the downstream environmental demand (see results in Section 7.2).

6.3.6 Demands expected in the next five to 10 years

The actual demands likely to occur during the next decade depend on the degree and speed with which irrigation expansion proceeds and the projected increases in electricity demand are realised. *Scenarios II to VI* reflect the full range likely to develop.

Given state government commitments to establish 8000 ha of new irrigation land on the Weaber Plain by the dry season of 2012 (OIEP – the first phase of the M2 development), and revised projections of electricity demand on the Ord River Dam power station (Chapter 4), the flow regime most likely to occur in the next three to five years will lie between those of *scenarios II and III*. Depending on the crops planned to be grown, the additional water entitlements expected to be granted are likely to be in the range of 80 to 120 GL/yr. As a result, the expected flow regime in the lower Ord (when the new area is using its full allocation) is likely to be closer to *scenario II* than *scenario III* (by linear interpolation about 25 per cent of the difference).

Further expansion of irrigation is possible but unlikely during the time the electricity demand from the Argyle Diamond Mine is predicted to be high (to 2018). It is difficult to be prescriptive beyond 2018. Decisions to extend the life of the mine's underground operation for a further five-plus years could be made around 2015–16 when further expansion of the area serviced for irrigation could be well advanced. In this situation the expected flow regime for the lower Ord River would move closer to *scenario III*, depending on the scale of the irrigation expansion being undertaken.

At some future time (probably beyond the life of DoW 2012) the full irrigation entitlement is likely to be granted (*scenario III*). While hydropower generation would be slightly constrained under this scenario, the electricity able to be generated would still be well above currently projected electricity demands on the power station after the Argyle Diamond Mine has ceased operations (*scenario V*).

Scenario VI represents optimal allocations for irrigation, hydropower generation and the environment, under current irrigation entitlements. The power station water release rules under the approach (termed 'enhanced' rules) provide benefits to all parties (see sections 7.3 and 7.4). However, the Water Corporation and Pacific Hydro must agree before they can be introduced. If the 'enhanced rules' approach were adopted, flows in the lower Ord are likely to lie between those of *scenarios III and IV*. The closer the additional entitlements granted for further irrigation are to 400 GL/yr, the closer the lower Ord flow regime will be to that of *scenario III.*

The following section describes the main water balance results from simulating reservoir operations under the five scenarios of Table 14. Chapter 7 provides more detail on the environmental flows achieved, irrigation water supplied and electricity generated over the 98 years simulated. Smith and Rodgers (2010) detail the restriction policies used in the reservoir simulations of each scenario.

6.4 Water balances of lakes Argyle and Kununurra

6.4.1 Long-term average water balances

Table 15 presents the water balance figures for lakes Argyle and Kununurra, averaged over the period of simulation (1906–07 to 2003–04) for the five scenarios. The long-term water balance results for Lake Argyle demonstrate the following main points:

- Catchment inflows are the same in all scenarios.
- Net evaporation (evaporation minus rainfall) accounts for between 26 to 28 per cent of mean annual inflow to Lake Argyle. Net evaporation loss is higher when demand is lower (*scenarios I and V* compared with *scenarios II, III and IV*). As more water is retained in storage, the evaporating surface of Lake Argyle is higher, which leads to the larger net evaporation.
- When irrigation and power demands are higher (*scenarios II, III and IV* compared with *scenarios I and V*), the average releases via the outlet works are higher and Lake Argyle spillage lower. This is as expected.
- Hydropower releases dominate the long-term average releases made via the Ord River outlet works in four of the five scenarios.
- Hydropower releases substantially meet the irrigation demands and needs of the lower Ord River environment. Under *scenario I* (the recent past) for instance, an average of 2205 GL/yr is released to meet hydropower demands. This is well in excess of the (current/recent past) irrigation demand of 350 GL/yr. Only a long-term average of 28 GL/yr is specifically released to meet irrigation demands (during drought periods of very low storage). Similarly, only a long-term average release of 157 GL/yr is specifically needed to meet environmental flows (during drought periods). In contrast, under *scenario III* (licensed to allocation limits), more water is released to meet irrigation demands and environmental needs, and less is released specifically for hydropower. Nevertheless, hydropower remains the major component of releases in all scenarios except *scenario V* – the low power demand scenario).
- If hydropower demand is low (*scenario V*), extra releases are necessary to meet irrigation demand (605 GL/yr) and the downstream environment (1139 GL/yr).

The long-term water balance results for Lake Kununurra demonstrate the following:

- Inputs to Lake Kununurra consist of runoff from the catchment between the dams (the Kununurra Diversion Dam catchment), spillage from Lake Argyle and releases from Lake Argyle via the Ord River Dam outlet works.
- Releases via the Ord River Dam outlet works are the largest input, representing more than 60 per cent of the total in all scenarios.
- Outputs are dominated by releases under the gates for the Kununurra Diversion Dam to the lower Ord River, rather than diversions for irrigation. This is the case for all scenarios, including those when irrigation demand is high (*scenarios II and V*).

- Irrigation diversions represent more than 97 per cent of the irrigation demands simulated, reflecting the target of ensuring high reliability for the allocations in the simulations.
- Releases to the lower Ord River are dominated by surplus hydropower releases, rather than specific releases made for downstream environmental needs, except when power demand is low (*scenario v*).
- Net evaporation loss from Lake Kununurra is a small component of the water balance, unlike Lake Argyle.

Figure 21 presents the long-term average annual inflows to and outflows from lakes Argyle and Kununurra. The significant net evaporation losses from Lake Argyle (inflows minus outflows) are clearly apparent. The losses range from 1100 to 1200 GL/yr depending on the scenario. Net evaporation is larger the lower the demand, as levels in Lake Argyle are marginally higher under lower demand, and result in a larger evaporating surface.

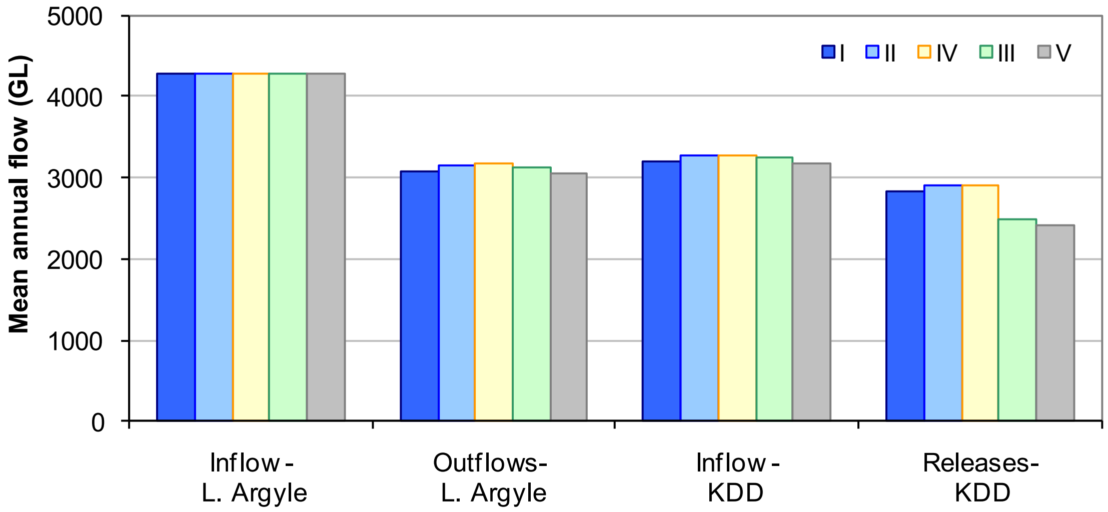


Figure 21 Mean annual Ord River flows for the five scenarios (as described in Table 14)

The inflows to the Kununurra Diversion Dam are slightly higher than the outflows from Lake Argyle because of the 1000 km^2 of additional contributing catchment. The differences between inflows to and releases from the diversion dam reflect the differences in the water diverted for irrigation between the scenarios.

Table 15 Ord River mean annual flows from Lake Argyle to the Kununurra Diversion Dam

	Scenario				
	I	II	III	IV	V
Irrigation allocation (GL/yr)	350	350	750	350	750
Hydropower demand (GWh/yr)	210	327	327	327	89
At Ord River Dam/Lake Argyle (GL/yr)					
Input					
Stream inflow	4278	4278	4278	4278	4278
Output					
Net evaporation	1190	1132	1151	1106	1207
Releases via outlet works (total)	2205	2445	2382	2507	1932
Releases made specifically to meet					
• *hydropower demand*	*2020*	*2282*	*1135*	*2153*	*188*
• *irrigation demand*	*28*	*24*	*434*	*65*	*605*
• *lower Ord environmental needs*	*157*	*140*	*814*	*288*	*1139*
Spillage	874	699	742	660	1126
Total outflow from Lake Argyle	3080	3145	3124	3167	3058
Change in storage	9	2	3	5	13
At Kununurra Diversion Dam / Lake Kununurra (GL/yr)					
Input					
Inflow from KDD catchment	119	119	119	119	119
Lake Argyle Spillage	874	699	742	660	1126
Releases via Ord River dam outlet works	2205	2445	2382	2507	1932
Output					
Net evaporation	20	20	20	20	20
Diversions					
• supplied to meet M1 irrigation demand	342	340	341	343	344
• supplied to meet M2 irrigation demand	0	0	390	0	393
Releases under the diversion dam gates (total)	2830	2897	2486	2917	2415
Contributions to the releases					
• *surplus Lake Argyle spillage*	*865*	*693*	*734*	*654*	*1076*
• *surplus inflows from KDD catchment*	*117*	*117*	*112*	*116*	*109*
• *surplus hydropower station releases*	*1691*	*1949*	*835*	*1861*	*106*
• *specific EWP releases from Lake Argyle*	*156*	*138*	*806*	*286*	*1124*
Change in storage	7	7	5	6	5

6.4.2 Storage level changes in Lake Argyle

Figure 22 shows the water levels in Lake Argyle under scenarios I and IV over the 98 years simulated. Also shown is the full range between scenarios. Variations between years are far greater than variations between scenarios. The annual inflow series (Figure 6) to the Ord River Dam is the dominant variable affecting Lake Argyle's storage behaviour (Figure 22). The very large inflows in the three wet seasons from 1999 to 2000 resulted in the highest storage levels simulated. The four occasions of lowest storage occurred after prolonged periods of below-average inflows during the early to mid 1930s, the early to mid 1950s, and the late 1980s to early 1990s.

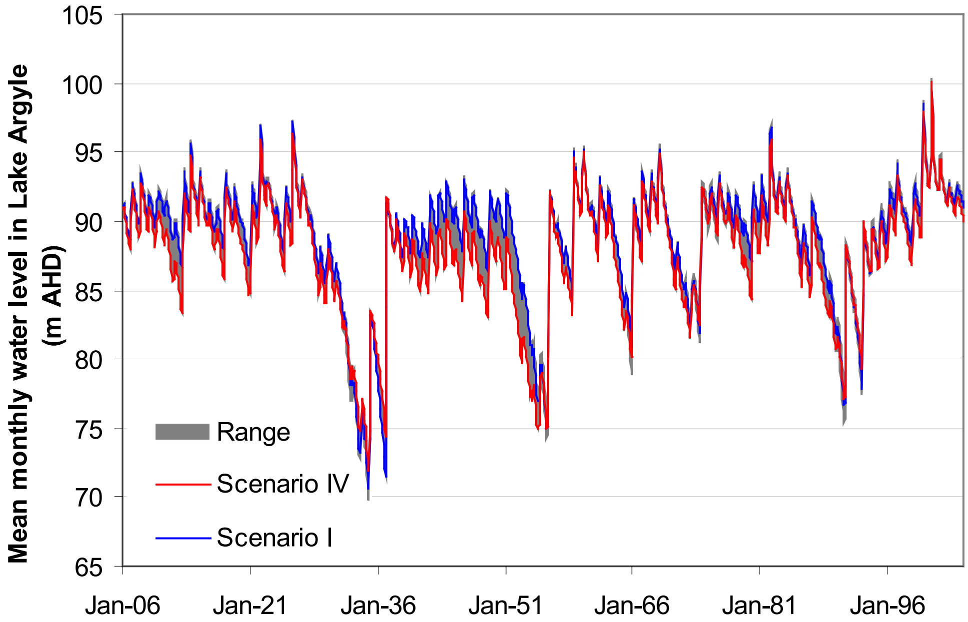


Figure 22 Range of mean monthly water levels in Lake Argyle

Minimum storage levels were similar under each scenario and occurred at similar times, with the lowest levels all occurring in January 1935. That is, the operating rules and restriction policies developed for each demand scenario (see Chapter 7) ensured the Ord River resource and the storage range of Lake Argyle were fully used over the whole simulation period.

6.4.3 Annual water balances from selected years

Given the changes in storage levels between years, large differences in the components of annual water balances are to be expected. Again these differences are larger between years than between scenarios.

Figure 23 and Figure 24 present annual water balance figures for lakes Argyle and Kununurra in selected years under *scenario III*. This 'licensed to allocation limits' scenario reflects the highest irrigation allocation possible under the both the current (DoW 2012) and former (DoW 2006) allocation plans and the projected high electricity demand. The water balance results for *scenario III* therefore reflect how the resource is to be managed when under the greatest demand pressure.

Six water years (Nov–Oct) were chosen from the 98 simulated to represent the wide range of inflow and initial reservoir storage conditions encountered over the simulation period. The output contributions to each water balance were presented in bar chart form and compared with the input total (line graph). Also included (for comparison) was a bar chart of the long-term average (mean) contributions from Table 15.[2] The bar charts were ordered in terms of their (nominal) inflow rankings, ranging from very wet years (90th percentile) to very dry years (2nd percentile). The nominal yearly percentiles are listed on the upper x axis, and the actual water year on the lower x axis.

Note that the inflows to and outflows from Lake Argyle (Figure 23) are not necessarily equal over each year. Any difference reflects a change in reservoir storage from the start to the end of the water year. For example in 1961–62 (at the nominal 75th percentile), inflows exceeded outflows, with a consequent increase in Lake Argyle's storage over the year. However, in 1930–31 (at the nominal 25th percentile) outflows exceeded inflows, and Lake Argyle's storage decreased over the year.

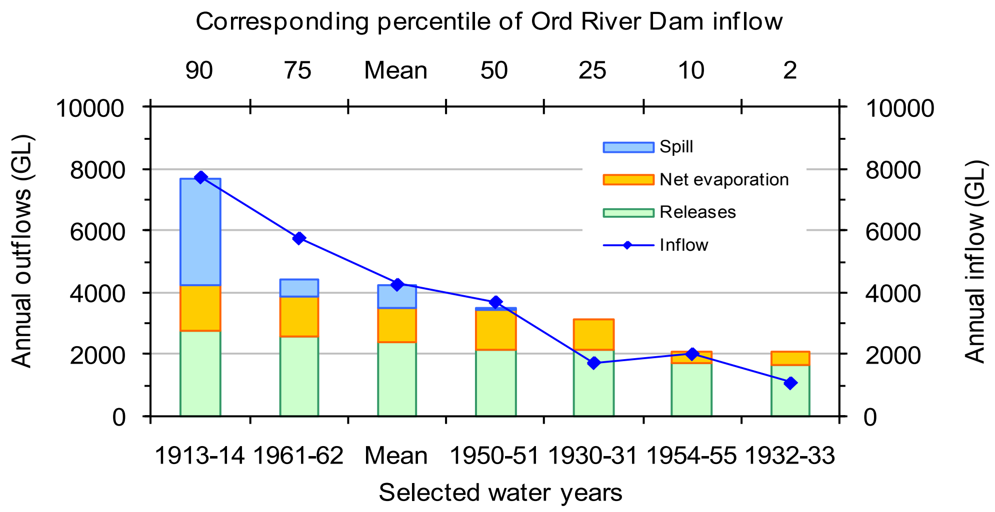


Figure 23 Lake Argyle annual water balances for selected years under scenario III

Spillage from Lake Argyle only occurs in years when inflows are above the median (see Figure 23). Net evaporation and releases from Lake Argyle reduce as inflows (and storage) fall. The reduction of releases with storage (and inflows) is a function of the restriction policies described in Chapter 6.

Unlike Lake Argyle, the water level (and storage) in Lake Kununurra is kept fairly constant (this enables water to be supplied by gravity to most Stage 1 areas). Consequently, Lake Kununurra's annual inflows equal annual outflows (Figure 24). In years when annual inflows are above the median, Lake Kununurra outflows are also dominated by releases of surplus spillage and surplus hydropower releases from Lake Argyle, although some releases (under *scenario III*) are necessary for the downstream environment. Diversions for irrigation from Lake Kununurra average about 750 GL/yr (for *scenario III*), although individual years are influenced by rainfall

[2] The average contributions to the long-term water balance do not represent any one year. Hence the mean year has no specific water year label and no storage at the end of the 'mean' year can be defined.

over the irrigation area. For scenarios with current irrigation demands (*scenarios I, II and IV)*, surplus spillage and hydropower releases are sufficient to meet downstream environmental needs.

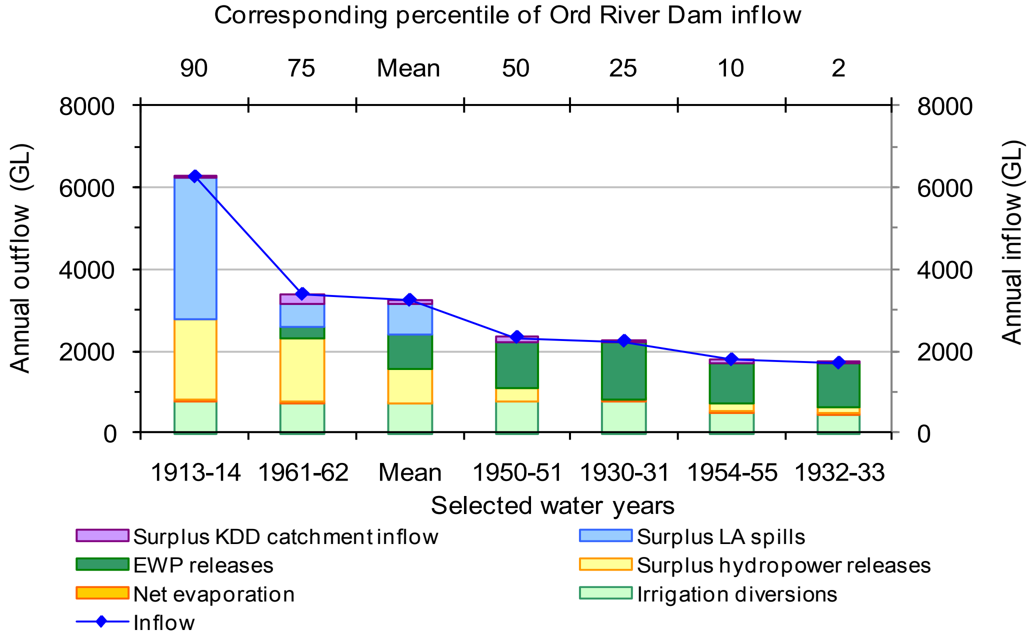


Figure 24 Lake Kununurra annual water balances for selected years under scenario III

In years with lower inflows, surplus hydropower releases decrease and additional releases become necessary to meet the downstream environmental needs. In very dry years (when the storage in Lake Argyle is very low), restrictions limit the amounts diverted for irrigation and released downstream to the environment (Figure 24– see 1954–55 and 1932–33)

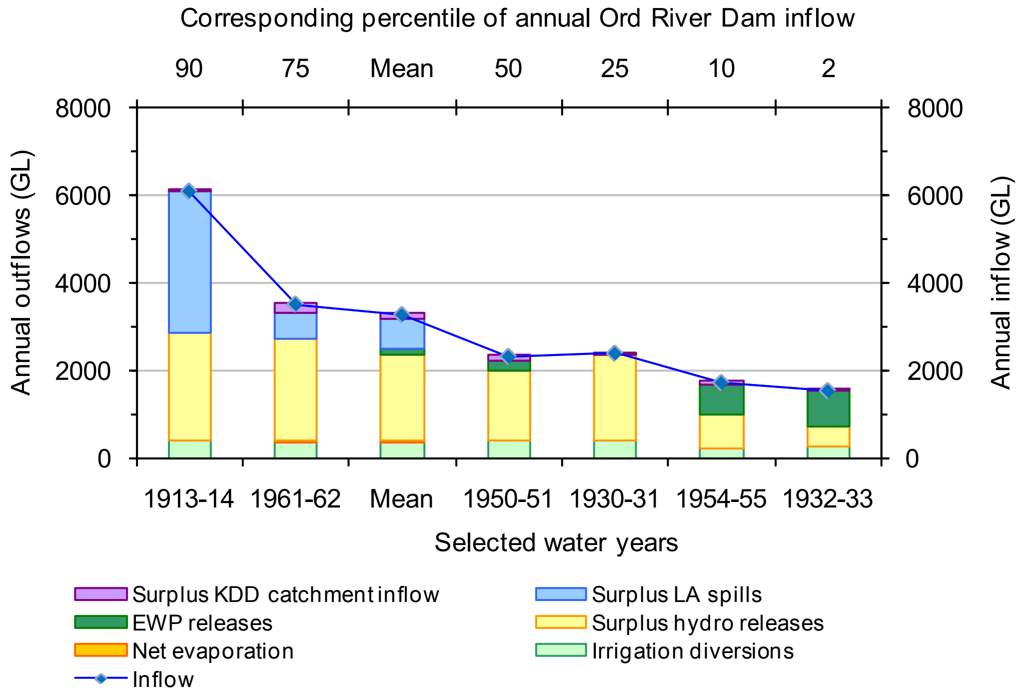


Figure 25 Lake Kununurra annual water balances for selected years under scenario II

In comparison, Figure 25 shows typical annual water balance figures for Lake Kununurra under *scenario II* (the current licensed situation). The overall water balance figures are similar to *scenario III* (Figure 24), except in relation to the amounts diverted for irrigation and released to meet the downstream environmental needs. Given the lower irrigation demand of *scenario II*, less water is diverted for irrigation and surplus hydropower releases become larger. As a result, less water needs to be specifically released from Lake Kununurra (and Lake Argyle) to meet the downstream environmental needs. Under *scenario II* specific environmental releases only become necessary in the very dry years of 1954–55 and 1932–33.

The following chapter describes the results of the reservoir simulations in terms of the water provided for the downstream environment, the water diverted from Lake Kununurra for irrigation, and the water used to generate hydro-electricity at the Ord River Dam power station. Also discussed are the allocation options and restriction policies evaluated for best operating the Ord River and Kununurra Diversion dams to meet the five demand scenarios.

7 Water for the environment, irrigation, and power generation

Chapter 3 discussed the commercial demands on the Ord River water resource, while Chapter 4 described a water regime for maintaining its riverine environment downstream of the Kununurra Diversion Dam. Given these competing demands, Chapter 6 outlined an approach to simulate the Ord River storage and river system under a range of likely future demand scenarios. The simulations have enabled the Department of Water to develop appropriate ways to manage the competing demands across the full range of likely future inflows.

This chapter describes the simulation results from the perspective of the water maintained in the lower Ord River for the environment, as well as that provided for irrigation and used for hydro-electricity generation.

7.1 Environmental water during times of drought

As described in Chapter 4, in 2007 the department completed a comprehensive EWR for the lower Ord to update the interim environmental flow regime used in DoW (2006).

Initial reservoir simulation runs indicated there was insufficient water to meet the target irrigation reliabilities, power generation commitments and fully meet the new comprehensive EWR in all years.

The challenge was to develop operating rules and restriction policies for drought periods, such as those experienced in the area in the 1930s and 1950s, to meet the objectives of the new allocation plan (DoW 2012).

To address this dilemma, restriction options were developed to limit the demand on Lake Argyle when water levels reached critically low levels (Section 6.2; Appendix A). The restriction policies were established for each water demand scenario and defined as functions of Lake Argyle levels for each month of the year.

Appendix A describes the development and evaluation of the eight EWP restriction policy options studied. The policy options were applied to the EWR and simulated under a selected range of the demand scenarios.

The assessment involved determining the degree to which the various components of the EWR were met, and then assessing the ecological changes likely to occur if the various restriction options were applied. The same scientific panel that advised the department on the EWR (Section 4.2.1) also participated in the EWP's development (see Appendix A).

The adopted EWP (option 6-7) was preferred because it retains more flow variability in the wet season and limits the time that flows fall below the dry season EWR of 42 m^3/s during drought times.

The scientific panel emphasised the ecological importance of retaining wet season variability and minimising the duration of low flows through drought periods.

7.1.1 The lower Ord River - Dunham River confluence to House Roof Hill

Table 16 presents the continuous environmental flow regime to be maintained in the lower Ord River between the Dunham River confluence and House Roof Hill (approximately 56 km downstream of the Kununurra Diversion Dam). Table 17 presents target wet season high flow events. Together, the tables define the target flow regime expected in this reach of the river under normal and Class 1 and Class 2 (drought) restrictions; the restriction classes being specified by the different water level trigger in Lake Argyle for each month of the year.

Table 16 Continuous environmental flows for the lower Ord River (to House Roof Hill)

	No restrictions		Class 1 restrictions		Class 2 restrictions	
Month	**When water level is > (m AHD)**	**Continuous (base) flow rate m^3/s**	**Water level trigger (m AHD)**	**Flows restricted to (m^3/s)**	**Water level trigger (m AHD)**	**Flows restricted to (m^3/s)**
Jan	79.2	50.0	79.2	38.5	79.2	38.5
Feb	82.0	57.0	82.0	43.9	82.0	43.9
Mar	83.4	57.0	83.4	43.9	83.4	43.9
Apr	83.7	53.0	83.7	46.6	81.0	40.8
May†	83.2	48.0	83.2	42.2	79.4	37.0
Jun	82.8	42.0	82.8	37.0	76.8	32.3
Jul	82.3	42.0	82.3	37.0	76.2	32.3
Aug	81.7	42.0	81.7	37.0	75.3	32.3
Sep	81.1	42.0	81.1	37.0	74.3	32.3
Oct	80.5	42.0	80.5	37.0	73.1	32.3
Nov	80.0	42.0	80.0	37.0	75.7	32.3
Dec	79.5	42.0	79.5	37.0	75.3	32.3

† *The flow rate reduces to 42.0 m^3/s in mid May*

Table 17 Target wet season high-flow events for the lower Ord River

Number of flow events over the wet season	Total target duration (days)	Daily discharge† (non-drought times) (m^3/s)	Daily discharge§ (when in drought) (m^3/s)
1 separate event	2	≥ 425	Not required
2 separate events	5	≥ 200	≥ 154
4 separate events	10	≥ 125	≥ 96
Events not applicable	18	≥ 100	≥ 77

† *when Lake Argyle levels are >82.0 m AHD in February, >83.4 m AHD in March and >83.7 m AHD in April*

§ *when Lake Argyle levels are <82.0 m AHD in February, <83.4 m AHD in March and <83.7 m AHD in April*

When restrictions do not apply (when storage levels in Lake Argyle are above restriction levels), flows in the lower Ord River are to be the same as the regime developed in Chapter 4. Table 16 defines two levels of restrictions for the continuous or baseflow component of the regime.

In the months of April to December, the environmental flows are reduced by 12 and 23 per cent under Class 1 and Class 2 restrictions respectively. In the wet season months of January to March, Class 1 and Class 2 restrictions are the same, reducing the flows by 23 per cent. A similar approach is used to reduce the high-flow events in the wet season months specified in Table 17.

Note that the 425 m^3/s peak event is not required during wet season when restriction apply. The remaining wet season peak flows are required at their restricted levels..

Wet season high-flow events in the lower Ord River are generated primarily by runoff from the catchment downstream of the Ord River Dam (principally the Dunham River catchment). Section 7.2.4 details Dunham River's dominant contribution to wet season high flows in the lower Ord. Hence, as discussed further in section 8.1, top-up releases from storage in Lake Kununurra are only required occasionally to achieve the peak events of Table 17.

The same trigger levels for restrictions apply to all future scenarios, except *scenario IV*. As the hydropower release rules of *Scenario IV* (current licensed entitlements, enhanced hydropower rules) are significantly different to the other scenarios (see Section 7.4), minor adjustments have been necessary to establish environmental water restriction levels for *Scenario IV* that meet the objectives of the allocation plan (DoW 2012) (see Appendix B).

7.1.2 The lower Ord River from House Roof Hill to the tidal limit

Studies undertaken by the department have found the aquatic habitat in the lower Ord River downstream of House Roof Hill is less sensitive to changes in (dry season) flows than the river upstream of House Roof Hill (see Appendix 3, DoW 2006). As such, an interim environmental flow of 40 m^3/s was adopted for downstream of House Roof Hill, compared with 42 m^3/s for the upstream reaches to the Dunham River confluence.

In developing comprehensive EWRs for the lower Ord River, Braimbridge and Malseed (2007) recommended a dry season flow rate of 42 m^3/s be maintained in the two reaches below the Kununurra Diversion Dam (see Figure 16).

This flow rate was selected to ensure sufficient local backwater habitats were maintained to protect small fish, and the juveniles of larger fish, in the fresh reaches of the lower Ord River. A review (in 2008) of the location of these backwater habitats indicated that most occurred upstream of House Roof Hill (reach 1 and the upper part of reach 2, see Figure 16).Hence a reduction in dry season flow from 42 to 37 m^3/s downstream of House Roof Hill should not significantly reduce shallow backwater habitat in the lower Ord River, which was considered acceptable.

The 5 m^3/s reduction in dry season environmental flows downstream of House Roof Hill was also considered acceptable in DoW (2006) and enabled 115 GL/yr to be set as the allocation limit for the Carlton-Mantinea subarea in the 2006 and 2012 plans.

7.2 Regulated flows in the lower Ord River

This section describes the resulting (simulated) flows expected to occur in the lower Ord River under the demand scenarios described in Chapter 6 and the environmental flow regimes of Table 16 and Table 17. The likely ecological changes resulting from these flow regimes are described in Chapter 8.

7.2.1 Annual flow characteristics

Table 18 lists the long-term average flows in the (regulated) lower Ord River at Tarrara Bar and the tidal limit for the five modelled scenarios.

The table also presents estimates of the average contributions to Ord River flow at each location. It should be read in conjunction with Table 15, which provides similar long-term average flows in the Ord River at the Ord River Dam and Kununurra Diversion Dam.

Table 18 Average annual flows of the (regulated) lower Ord River (1906–07 to 2003–04)

	Scenario				
	I	II	III	IV	V
Scenario demands					
Irrigation allocation (GL/yr)	350	350	750	350	750
Hydropower demand (GWh/yr)	210	327	327	327	89
Flow in the Ord River at Tarrara Bar (GL/yr)	3478	3545	3134	3565	3064
The contribution from:					
• Kununurra Diversion Dam releases	2830	2897	2486	2917	2415
• the Dunham River	505	505	505	505	505
• other local runoff (irrigation areas, and local creeks upstream of Tarrara Bar)	92	92	92	92	92
• Stage 1 irrigation return flows	51	51	51	51	52
Flow in the Ord River at the start of the tidal reach (GL/yr)	3499	3566	3041	3586	2970
The contribution from:					
• Kununurra Diversion Dam releases	2830	2897	2486	2917	2415
• the Dunham River	505	505	505	505	505
• other local runoff (irrigation areas and local creeks upstream of the tidal limit)	113	113	113	113	113
• Stage 1 irrigation return flows	51	51	51	51	52
• water abstracted for irrigation	-0	-0	-115	-0	-115

Figure 26 graphs the long-term average flows in the Ord River for the five scenarios at four locations downstream of Lake Argyle (using data in Table 15 and Table 18): namely, inflows to the Kununurra Diversion Dam, just downstream of the diversion dam, at Tarrara bar, and at the tidal limit.

The graph demonstrates the following main points:

- the average flows in the lower Ord River will remain around 3000 to 3600 GL/yr under likely future demands expected over the next 10 years
- the diversions of water from Lake Kununurra are apparent, especially under the higher irrigation demands of *Scenarios III and V*
- additional inflows enter downstream of the Kununurra Diversion Dam (mainly from the Dunham River catchment)
- only relatively small differences in average flows in the lower Ord River occur between the five scenarios, despite hydropower and irrigation demands being quite different (maximum difference being 17% between *Scenarios II and V*)

Flows remain similar in the lower Ord River between *Scenarios III and V* mostly because additional releases are necessary to maintain its environmental regime – if releases are not being made for hydropower generation at the Ord River Dam.

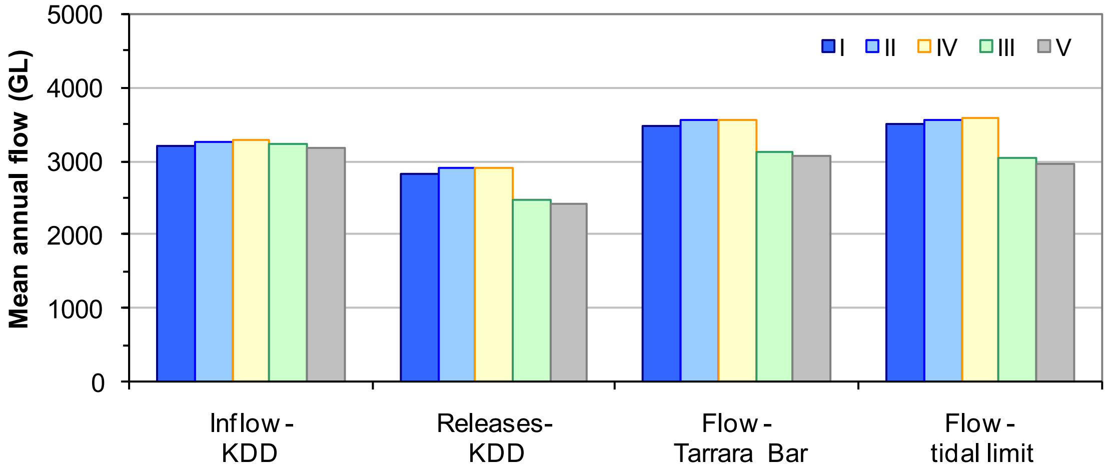


Figure 26 Average flows in the Ord River from Kununurra Diversion Dam to the tidal limit (1906–07 to 2003–04)

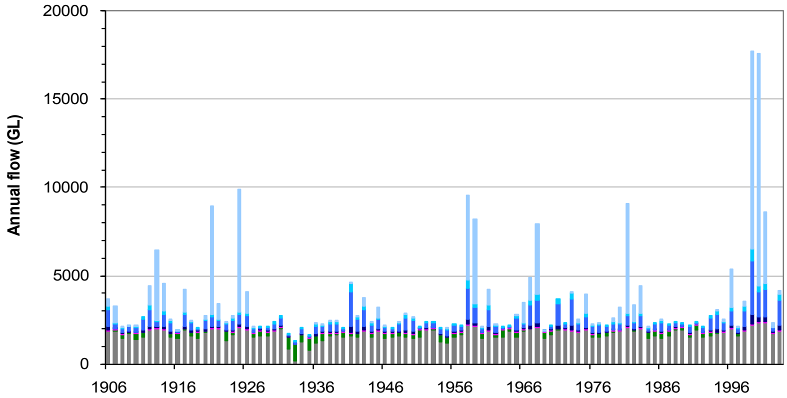
7.2.2 Annual flow contributions

In terms of the components contributing to the annual average flow in the lower Ord River, Table 15 demonstrates the following:

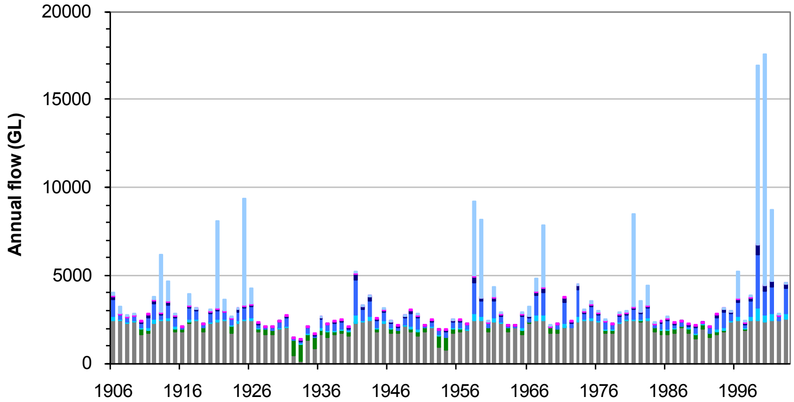
- the dominant component under all scenarios is the releases through the gates of the Kununurra Diversion Dam
- the Dunham River contributes between 15 and 20 per cent of the total, depending on the scenario and location
- the local runoff downstream of the Dunham River contributes about three to four per cent of the total and is similar to the 115 GL diverted downstream of House Roof Hill under *Scenarios III and V.*

Figure 27 and Figure 28 plot the annual flows at Tarrara Bar as simulated under the five demand scenarios. The contributions made by different upstream water sources are also shown.

(a) *Scenario I* - Recent past- current irrigation, moderate power demand (210 GWh/yr)



(b) *Scenario II* - Current irrigation, high power demand, current release rules



(c) *Scenario III* - Irrigation licensed to limits – high power demand (enhanced rules)

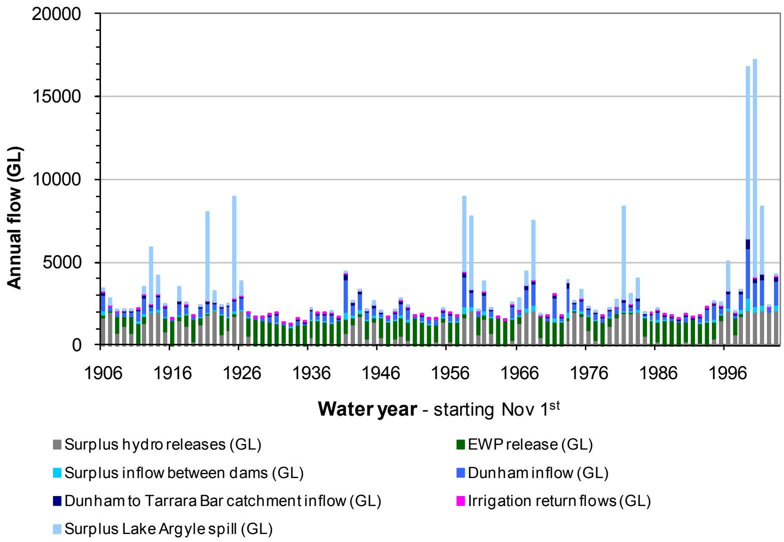
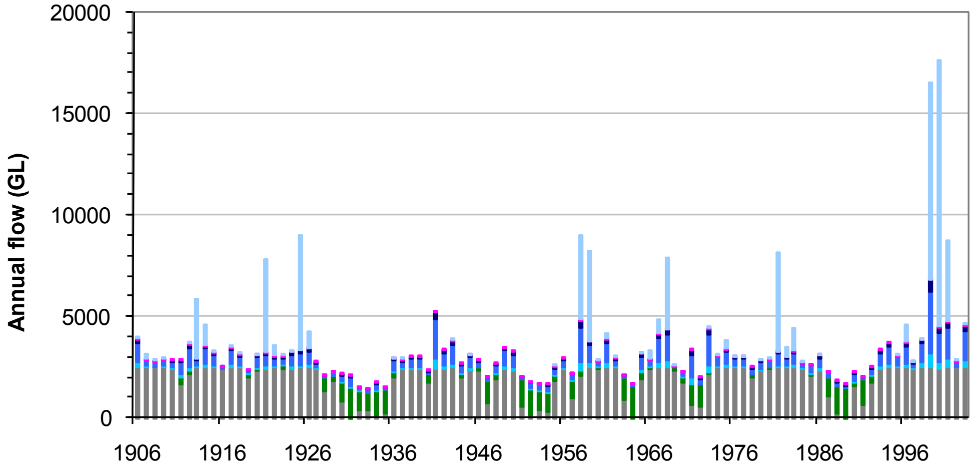


Figure 27 Annual flows in the lower Ord River at Tarrara Bar, Scenarios I to III

(a) *Scenario IV* - Current irrigation, high power demand (enhanced release rules)



(b) *Scenario V*- Irrigation licensed to limits, low power demand

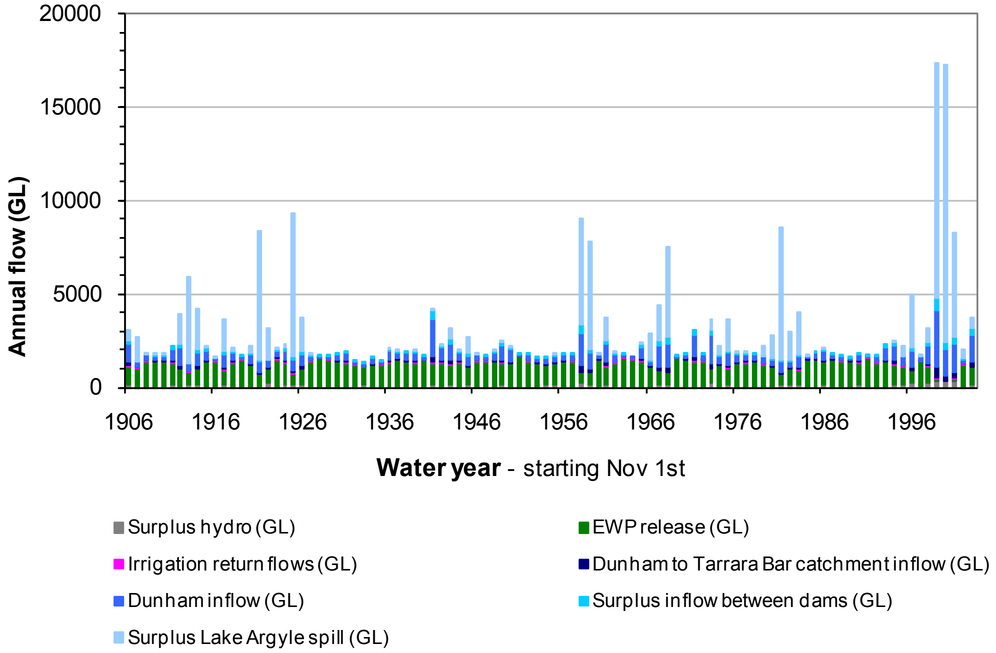


Figure 28 Annual flows in the lower Ord River at Tarrara Bar, Scenarios IV and V

In wet years, the dominant contributions are from Lake Argyle spillage and Dunham River flows. In years without Lake Argyle spillage, flows are dominated by surplus hydropower releases under current irrigation demands (*Scenarios I, II and IV*). Specific releases to meet downstream environmental demand under these scenarios only occur during drought periods, when storage is low and restrictions apply to all demands. Overall, releases specifically made for the environment make a minor contribution (Figure 27 and Figure 28), because hydropower releases are usually enough to meet the downstream demand under these scenarios.

However, specific environmental releases are necessary more often when the irrigation demand increases (*Scenario III*) and if enhanced hydropower rules are introduced (*Scenario IV*).

7.2.3 Seasonal and monthly flow patterns

The changes in lower Ord flows following regulation and between demand scenarios are more apparent when comparing seasonal and monthly flow characteristics. Table 19 presents the long-term average annual, wet season and dry season flow volumes, as well as the average dry season flow rate of the lower Ord River at Tarrara Bar under the five scenarios. Flows under pre-regulation conditions are included for comparison. Figure 29 shows the average monthly flow volumes at Tarrara Bar.

Table 19 Wet and dry season flows at Tarrara Bar – pre-regulation and the five scenarios

Scenario	Allocation case	Mean annual flow GL	Wet season flow GL	Dry season flow GL	Average dry season flow rate† m^3/s
	Before Ord River Dam regulation	4991	4841	150	6
I	The recent past	3478	2329	1149	56
II	Current licensed entitlements, high power demand	3523	2274	1249	66
III	Licensed to allocation limits, high power demand	3173	2100	1072	55
IV	Current licensed entitlements, enhanced power station rules	3546	2267	1279	69
V	Licensed to allocation limits, town power demand	3122	2089	1034	50

† Calculated as the average flow rate over five consecutive months of lowest flows each year. This measure was adopted to exclude high nominally 'dry season' flows caused by a late finish or early start to the wet season.

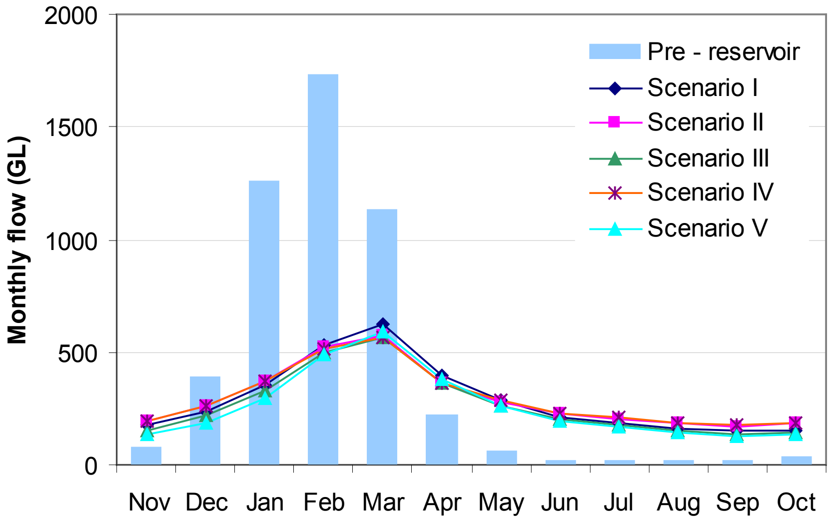


Figure 29 Mean monthly flow at Tarrara Bar for the period 1906 to 2004, for pre-dam conditions and the five allocation scenarios

Table 19 and Figure 29 demonstrate the major effect of regulation on the seasonal pattern of flow in the Ord River and confirm the earlier simulation results presented in DoW 2006.

The results also show that the average dry season flow between the scenarios ranges from 50 to 66 m^3/s at Tarrara Bar. The difference between scenarios is more apparent when comparing the distribution of the 98 dry season flows (Figure 30).

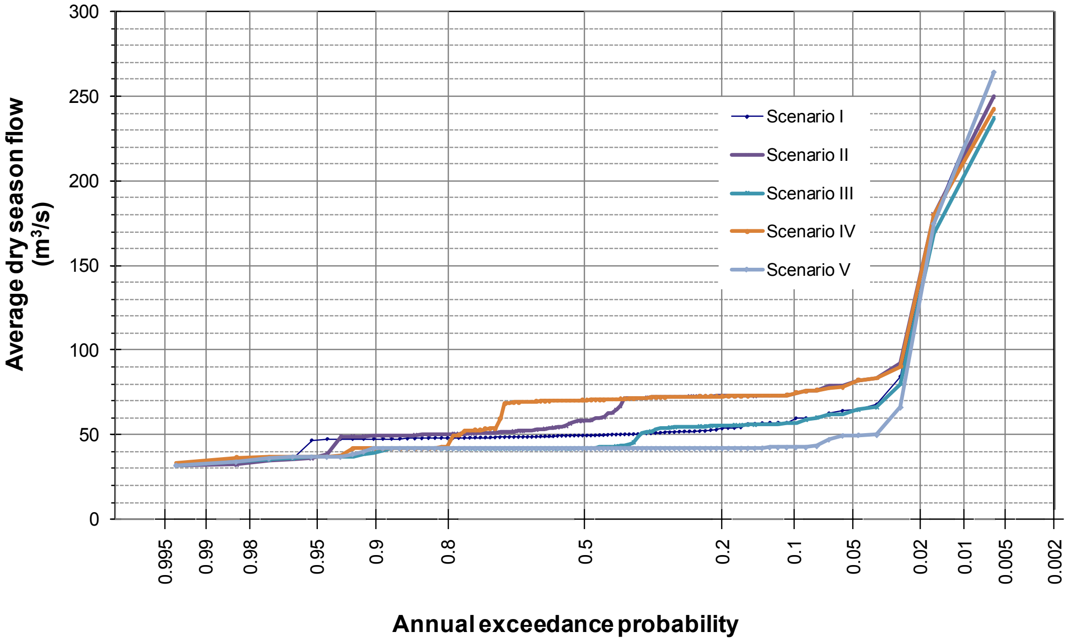


Figure 30 Distribution of dry season flows in the lower Ord River at Tarrara Bar

Dry season flow rates vary from the minimums required in severe drought years (32 m^3/s) to more than 200 m^3/s, when flows are influenced by continued spillage from Lake Argyle well into the dry season. In 90 per cent of years (between exceedance probabilities of 0.95 and 0.05), dry season flows range from 37 up to 80 m^3/s depending on the demand scenario.

Figure 30 shows how the various hydropower station release rules developed for each demand scenarios affect the resulting flows in the lower Ord River. In the high power station demand and current irrigation scenarios, flows can exceed 70 m^3/s in more than 40 per cent of years. These rates occur when power station releases are limited only by the station's capacity. However, when the storage in Lake Argyle reaches critical levels, power generation releases (made independently from other releases) must be limited to ensure that other demands can meet their overall target reliabilities in future years. This is reflected in the distributions of Figure 30 by the point where sharp declines in dry season flows start. The distributions then decline to 42 m^3/s (37–32 m^3/s in drought years) – the required dry season environmental flow rates. The differences between scenarios are clear.

Note that all the dry season flows are contained well within the flood levees of the lower Ord River and changes in aquatic habitats were considered within the limits of acceptable change (Appendix 3, DoW 2006). As described further in section 8.1, the scientific expert panel accepted the dry season environmental provisions adopted by the department for each scenario.

7.2.4 Daily flows during the wet season

Wet season inflows to Lake Kununurra are a combination of regulated releases from Lake Argyle and the natural runoff generated from rain that falls in catchment between the dams. As irrigation demand is usually low, wet season releases into the lower Ord at the Kununurra Diversion Dam reflect runoff from the catchment between the dams, spillage from Lake Argyle and the regulated releases from the outlet works of the Ord River Dam.

Additional tributaries which enter the lower Ord below the Kununurra Diversion Dam contribute extra runoff during the wet season (section 2.5).

In consequence, the daily fluctuations of flows in the lower Ord are dominated by the unregulated runoff from the catchments downstream of the Ord River Dam, with the regulated releases from Lake Argyle providing a relatively stable component to the overall flow.

The Dunham River's contribution

The Dunham River is the largest single tributary downstream of the Ord River Dam (section 2.5.1). Post-regulation, the Dunham River catchment generates virtually all the wet season flow peaks of the lower Ord. .

Figure 31 and Figure 32 illustrate the Dunham River contribution to daily flows in the lower Ord in two recent wet seasons. The figures show how the natural flows of the Dunham River are particularly important to meeting the wet season EWR regime of the lower Ord (Figure 18, page 46). For this reason, developments in the Dunham River catchment that significantly reduce peak flows and the daily variability of Dunham River flows will not be permitted (DoW, 2012).

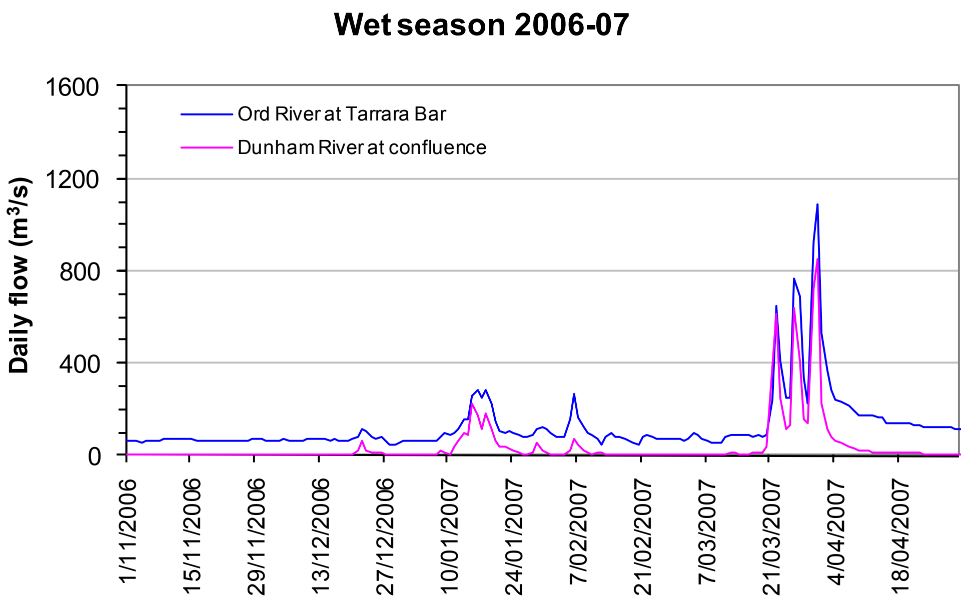


Figure 31 Ord River (Tarrara Bar) and Dunham River daily flows – 2005–06 wet season.

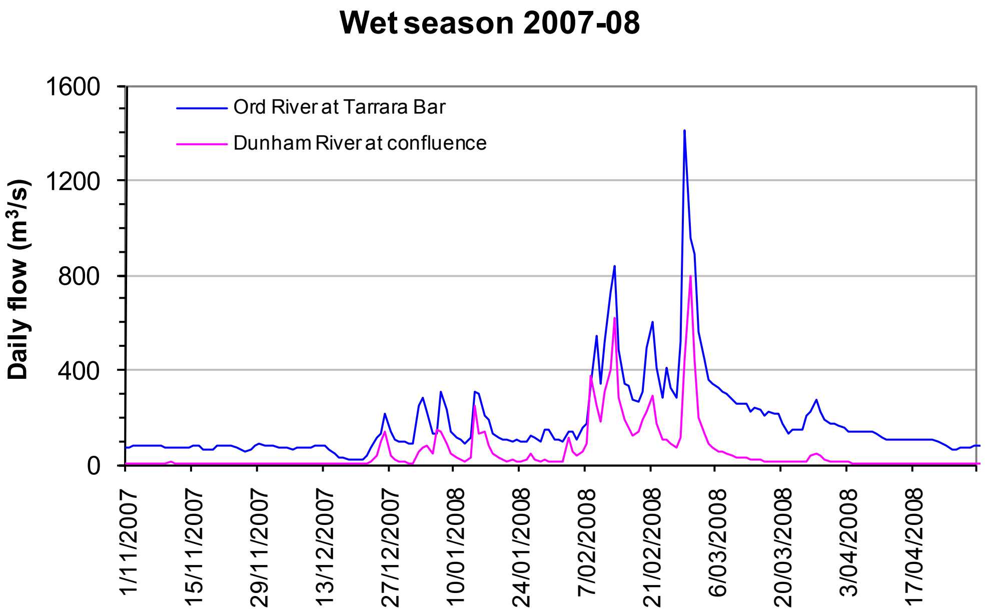


Figure 32 Ord River (Tarrara Bar) and Dunham River daily flows – 2006–07 wet season

Peak flows in the lower Ord usually occur within 24 to 48 hours of heavy rain falling in the Dunham River catchment. When Lake Argyle is not spilling, the contribution from the catchment upstream of the Ord River Dam is, of course, small; usually no more than 90 m^3/s, the maximum flow rate through the power station.

The Dunham River dominates peak flows in the lower Ord River even when Lake Argyle is spilling. Peak discharges down Lake Argyle's spillway channel are typically less than a twentieth of the peak of incoming floods; a result of the narrow and deep design of the spillway channel and the large flood storage capacity of Lake Argyle. Peak discharges from Lake Argyle are now much smaller than Dunham River peaks (Rodgers & Ruprecht, 2000; DoW 2006) despite the Ord River Dam catchment being ten times larger than the Dunham catchment. Moreover, their respective peak flows rarely coincide. Unlike the rapidly responding Dunham River, spillway flows peak towards the end of the wet season when lake levels are at their highest.

A consequence is that the target wet season flow events of Table 17 (page 67) will largely be generated from the unregulated flows downstream of the Ord River Dam.

Annual flood series post-regulation

In DoW (2006) we estimated likely changes in flood flows expected on the lower Ord River as a result of further irrigation development (Section 9.1.2, DoW 2006). While the differences were considered insignificant, the updated hydrology and reservoir simulations have enabled better estimates to be made.

Figure 33 shows the distributions of the annual maximum daily flows in the lower Ord for each of the five scenarios modelled. Each distribution was derived by selecting the peak daily flow in each water-year from the 98 years simulated and ranking the annual peaks to determine the exceedance probability for each value. As expected, the five resulting distributions are very similar and difficult to distinguish in Figure 33.

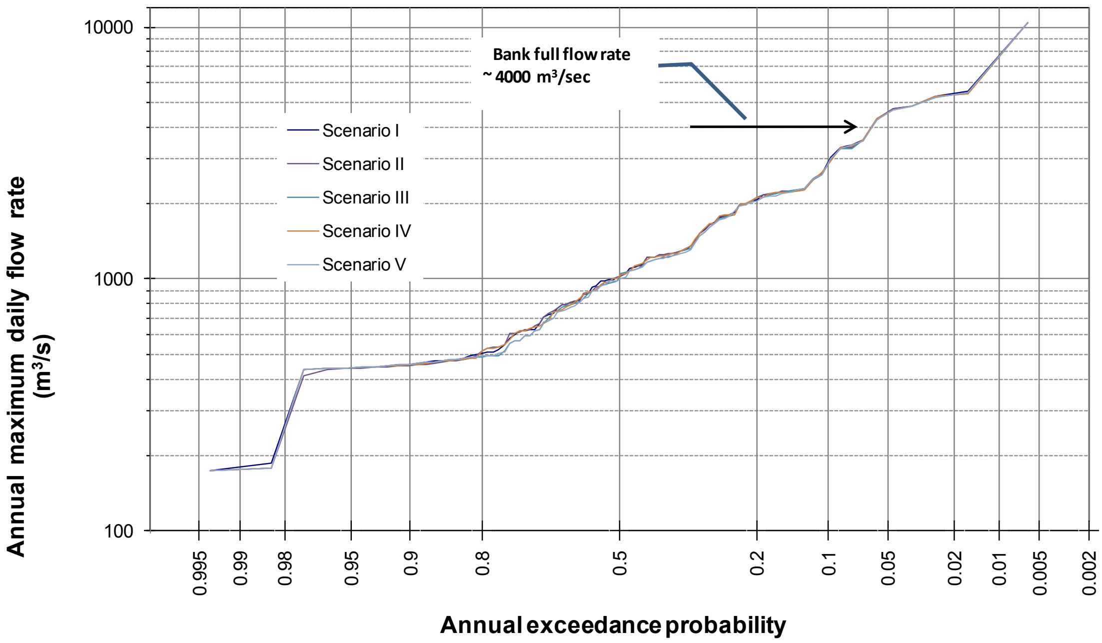


Figure 33 Annual maximum daily flow in the Ord River at the tidal limit (post-regulation)

The small variations in the lower Ord flood distributions that do occur (in the 500 to 800 m^3/s range –Figure 33) are the result of variations in spillway flows from Lake Argyle between scenarios at the time peak flows occur in the lower Ord. At these times spillway flow rates are typically in the zero to 200 m^3/s range, reflecting less than 25% when the lower Ord flows is peaking in the 500 to 800 m^3/s range. At lower peak flows, there is no spillage. At higher peak flows, the spillway contribution is proportionately smaller and very small about 1000 m^3/s .

No significant differences are apparent at or above bankfull conditions. As such, increased irrigation or the changed hydropower demands of the five scenarios should not significantly affect how often the Ord River floodplain Ramsar site is flooded.

7.3 The supply of irrigation water and its reliability

The monthly irrigation demands used in the reservoir simulations took into account the variation in monthly rainfall over the irrigation areas each year (Smith & Rodgers 2010). Therefore irrigation demands varied between years (see Figure 34), with higher demands occurring in years with dry 'wet' seasons and lower demands occurring in years with 'wet' wet seasons.

Figure 34 also shows the difference in demands between *scenarios II* (average 350 GL/yr) *and III* (average 750 GL/yr).

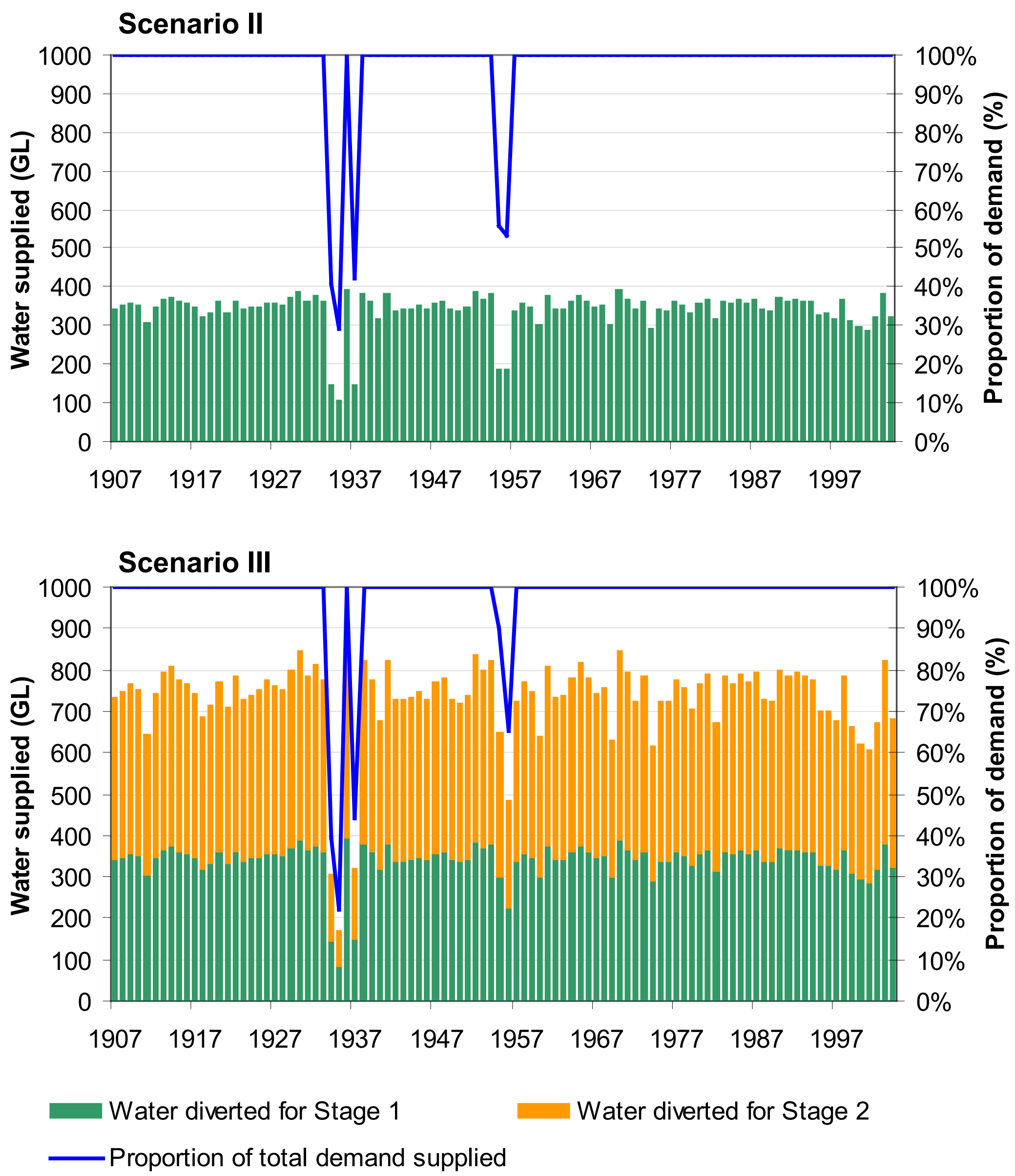


Figure 34 Irrigation water supply and reliability for scenarios II and III

The proportion of the irrigation demand supplied in each irrigation year is also shown. This is expressed as a percentage of the year's demand (see right axis) to clearly show the years when irrigation restrictions applied. For *scenarios II and III* this only occurred during the 1930s and the 1950s. The other scenarios showed similar results.

Table 20 presents the average water supplied, the probability of not having restrictions (reliability) and the severity of the most extreme year of restrictions for the five different scenarios.

Table 20 Irrigation supplied and reliability of supply for the five demand scenarios

Scenario	Average irrigation demand	Average water supplied		Probability of not having restrictions†	Proportion of demand supplied in the driest year
	GL/yr	GL/yr	% of demand	%	%
I	350	342	97.7%	96.3	29.5
II	350	340	97.1%	95.3	28.3
III	750	731	97.5%	95.3	22.9
IV	350	343	98.0%	95.3	36.1
V	750	737	98.3%	97.4	29.3

† *The probability in any one year that the annual water supplied would equal the annual water demand*

The key points of Table 20 are the following:

- The average water supplied exceeds 97 per cent of the demand under all scenarios, emphasising the high reliability of supplies dependent on Lake Argyle
- The probability of not having irrigation restrictions in any one year is 95 per cent or greater for all scenarios
- Under *scenario III,* the severity of irrigation restrictions in the driest year is marginally lower than the target criteria of 25 per cent, although we considered 22.9% was acceptable

The optimised hydropower rules ('enhanced rules' – *scenario IV*) reduces the severity of irrigation restrictions relative to the other scenarios (only 36 per cent in the driest year).

The 'enhanced' rules of *scenario IV* draw less on Lake Argyle when water levels are already low, enabling restrictions in subsequent years (when low inflows continue) to be less severe. The benefits of the 'enhanced' water release rules from the power generation perspective are described further in the following section.

7.4 Power generation

Table 21 summarises the long-term average amounts of electricity generated by the Ord River Dam power station for the five scenarios studied. The table also presents the electricity generated when the station is only limited by its installed capacity, and when different classes of limits/restriction apply. Comparisons between the water release rules of the different scenarios are discussed here to explain the main differences in the electricity generated. Appendix D includes tables of the complete restriction policies/water release rules used in the reservoir simulations of each scenario. Note that the tables in Appendix D are not identical to those in Appendix A of the plan (DoW, 2012). The tables in Appendix A in the plan, reflect the water levels that trigger each restriction class at the start of each month and are calculated as the average of the previous month and the current month in the tables in Appendix D. The trigger levels determined for the start of each month are to be used for water licensing purposes.

For the high power demand projections (*scenarios II, III and IV*) the long-term average electricity generated ranges from 238.4 to 248.6 GWh/yr. This represents between 73 and 76 per cent of the region's projected electricity demand (327 GWh/yr, Figure 13). The diesel power station at the Argyle Diamond Mine will provide most of the shortfall, unless new power stations are constructed in the region.

The differences in the average electricity generated between scenarios is about 10 GWh/yr or 4 per cent of the average amount generated by the Ord power station. While the differences in averages between scenarios are relatively small, they become more apparent when restrictions apply (Table 21) and reflect the different release rules developed for each scenario (see Section 6.2).

Table 21 includes the percentage of the long-term average electricity generated and the percentage of time the different classes of restrictions apply under the five scenarios. These change markedly between scenarios. For example, in *scenario II* (current licensed situation), 57 per cent of the electricity is generated when the station is only limited by its capacity (unrestricted), and 38 per cent is generated when output is limited to the annual rate of 210 GWh/yr (Class 1 limits). This contrasts with s*cenario III* (licensed to allocation limits), whereby only 49.3 per cent is generated when unrestricted, and 48.2 per cent is generated from other releases when Class 2 restrictions apply. Additional electricity can be generated (above the amount allowed for hydropower generation alone) from the releases the Water Corporation makes to meet its downstream obligations. This is commonly the case when Class 2 restrictions apply.

7.4.1 High power demand Scenarios

Figure 35 outlines the hydropower restriction rules (or water release rules for the station) for the three high power demand scenarios (*scenarios II, III and IV*). The graphs of monthly water levels indicate the trigger levels at which each class of restriction begins. The labels between the respective trigger levels indicate the annual rate of generation (allowed to be made independently from other releases) while the water level is in that range.

The differences between the water release rules are clearly apparent. In *scenario II*, hydropower generation is limited to an annual rate of 210 GWh/yr (the Class 1 rate) when water levels fall below 90.8 m AHD in March. This is not reduced to the 89.4 GL/yr rate (the Class 2 rate) until the water level falls below 78 m AHD. In *scenario III* (when irrigation water entitlements are granted up to the allocation limit) hydropower (generated independently of other demands) is limited to 89.4 GWh/yr (Class 2 restriction rate) when water levels fall below 91.1 m AHD in March. This rate applies down to 76 m AHD. Below 76 m hydropower is limited to that which can be generated from other releases (which the Water Corporation makes to meet its downstream obligations).

The effects of these different release rules are shown in Figure 36. The figure presents the electricity generated each financial year for the three high power demand scenarios (*scenarios II, III and IV*). It also shows the main contributions made to the annual total. The contributions are the amount generated when the station is unrestricted (limited only by the station capacity) and when the three different restriction classes apply. Class 1 and 2 restrictions are further partitioned into those generated at the allowed generation rates (at Pacific Hydro's discretion) and those generated from releases made to meet the Water Corporation's downstream obligations (for irrigation and the environment).

As more water is allocated for irrigation (*scenario III* compared with *scenario II*) more electricity is generated from other releases (the additional water needed to supply the extra irrigation demand). Restrictions on power generation become necessary at higher levels in the reservoir (Figure 35) to ensure enough water is retained in storage so that irrigation restrictions in future years do not become too frequent. When the station can operate independently from other release requirements, the station's operator has flexibility to meet very short-term fluctuations in the electricity load. This flexibility will be reduced as more electricity is generated from releases that are made to meet downstream obligations.

Figure 36 also shows how the amount of electricity generated each financial year reduces during times of low storage (poor inflows), especially in the 1930s and mid 1950s. At these times, water levels in Lake Argyle decline below the trigger levels for Class 3 restrictions.

7.4.2 The 'enhanced' rules (*Scenario IV)*

The projected electricity loads on the station are much higher than originally expected (in 1994) and are likely to coincide with the expansion of irrigation in the ORIA (Chapter 3). Hence there is a clear need to optimise how water is released from Lake Argyle. Moreover, the constraints of the 1994 Water Supply Agreement for the power station are no longer the best way to manage the water resource.

The water release rules developed for *scenario IV* enable more electricity to be generated (on average) and reduce the draw on the reservoir at times of low storage – consequently reducing the severity of irrigation restrictions during severe droughts. Sufficient water is also available to adequately protect the riverine environment of the lower Ord during drought periods (Section 7.1).

For the current irrigation entitlements, the enhanced rules of *scenario IV* enable 248.6 GWh/yr to be generated on average. This contrasts with only 243.1 GWh/yr under *scenario II.* The generation of the additional 5.5 GWh/yr is because restrictions begin at lower levels in the reservoir under *scenario IV* than under *scenario II*. However, to ensure enough water is available in the future if levels decline further, restrictions on generation become more severe at lower levels. Class 1 limits/restrictions start between 2.8 and 3.5 m lower under *scenario IV* than under *scenario II*, depending on the month. However, Class 2 restrictions start 5.5 to 9 m higher under *scenario IV* than under *scenario II* (see Figure 35).

Table 21 The electricity generated by the Ord River Dam power station under the five scenarios (financial years)

	Scenario I		***Scenario II***		***Scenario III***		***Scenario IV***		***Scenario V***	
Electricity generation statistics	**The recent past**		**Current licensed situation**		**Licensed to allocation limits**		**Current licensed entitlements, enhanced hydropower rules**		**Licensed to allocation limits, low power demand (town only)**	
Long-term mean (over 98 years)	*219.3 GWh/yr*		*243.1 GWh/yr*		*238.4 GWh/yr*		*248.6 GWh/yr*		*89.4 GWh/yr*	
Contributions to the electricity gen'd	*% gen'd*	*% of time*	*% gen'd*	*% of time*	*% gen'd*	*% of time*	*% gen'd*	*% of time*	*% gen'd*	*% of time*
Limited only by station capacity	19.3%	13.5%	56.6%	46.2%	49.3%	38.9%	82.3%	71.7%	N/A	N/A
Class 1 limits/restrictions										
to the 210 GWh/yr rate	73.0%	76.1%	38.0%	44.2%	0.0%	0.0%	6.3%	8.0%	N/A	N/A
from other releases	6.1%	6.0%	3.5%	3.9%	0.0%	0.0%	0.6%	0.0%	N/A	N/A
Class 2 restrictions										
to the 89.4 GWh/yr (town) rate	0.5%	1.1%	0.4%	1.0%	1.7%	3.9%	0.8%	1.9%	19.2%	19.2%
from other releases	0.4%	1.0%	0.6%	1.6%	48.2%	54.6%	9.4%	16.3%	78.9%	78.9%
Class 3 restrictions										
from other releases	0.7%	2.3%	0.9%	3.1%	0.8%	2.6%	0.6%	2.0%	1.9%	1.9%
*Years when the amount gen'd is < 210 GWh **and** water levels are > 78 m*										
Number of years	4		5		18		13		N/A	N/A
Av. electricity gen'd	207.6	GWh/yr	208.0	GWh/yr	195.7	GWh/yr	167.8	GWh/yr	N/A	N/A
Water levels are < 78 m										
Number of years	9		10		8		8		8	
Av. electricity gen'd	141.8	GWh/yr	137.8	GWh/yr	135.3	GWh/yr	124.8	GWh/yr	89.3	GWh/yr

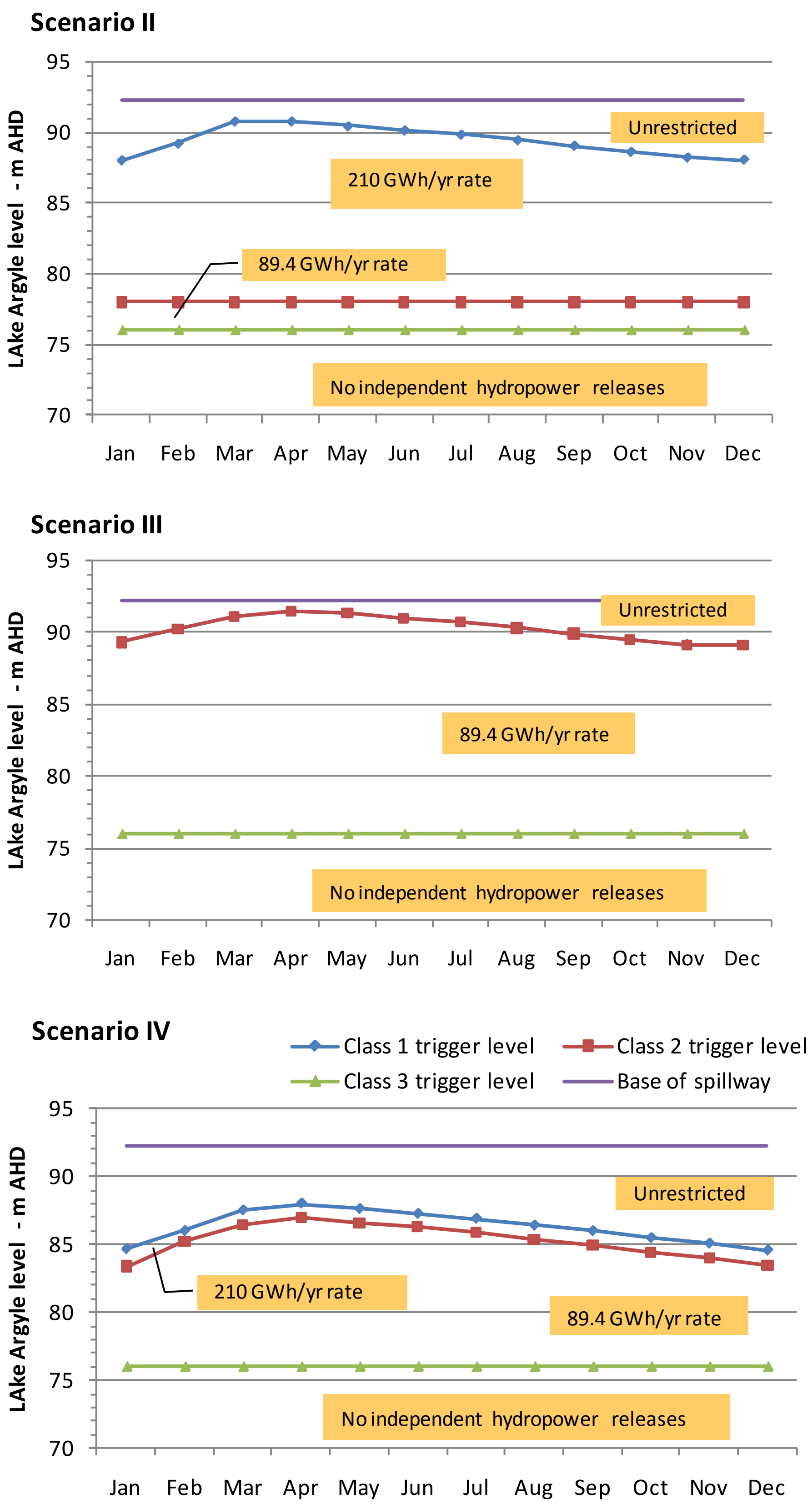


Figure 35 Hydropower restriction policies for scenarios II, III and IV

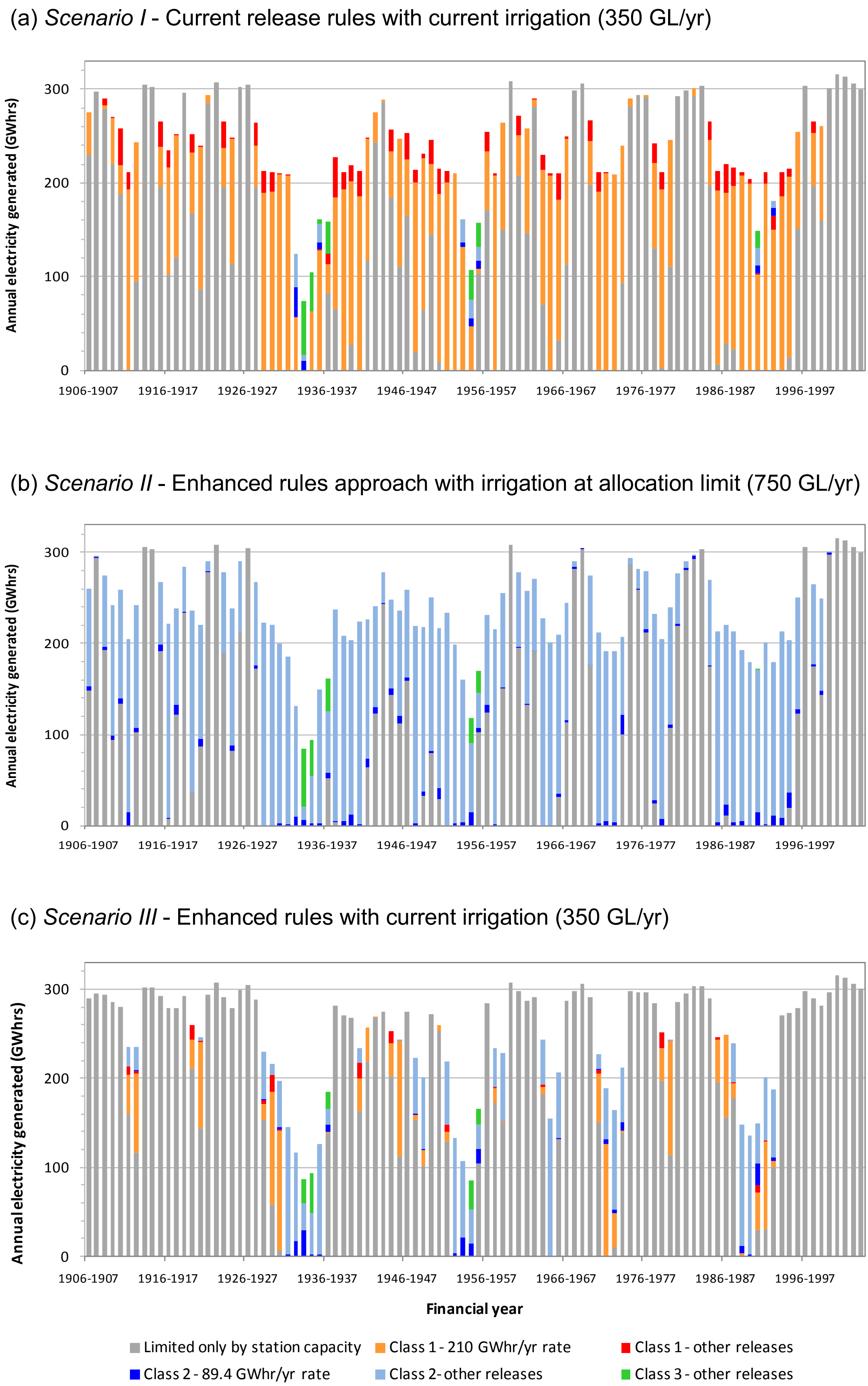


Figure 36 Annual amounts of electricity generated under scenarios II, III and IV

The differences between the annual amounts generated under *scenarios II* and *IV* are clearer when the distributions of the annual amounts generated are compared (see Figure 37). In years with high generation (greater than 290 GWh/yr – when Lake Argyle levels are above the spillway for most of the year) the amounts generated are similar. For years when between 210 and 290 GWh are generated, more electricity is generated under *scenario IV* (the 'enhanced' rules). It is only in 20 per cent of years when more electricity is generated under *scenario II* than *scenario IV*.

Note that under the rules of *scenario II*, 210 GWh/yr can be generated down to lake levels of 78 m AHD (Figure 35) – the minimum guarantee of the 1994 Water Supply Agreement. While this is not always fully achieved because of turbine constraints at low (pressure) heads (see Table 21), the effect of the rule is apparent in Figure 37. Between 210 to 215 GW/yr is generated in about 20 per cent of years (between exceedance probabilities of 15 to 35 per cent).

As water levels in Lake Argyle decline, more water must be passed through the station to generate the 210 GL/yr. The turbine efficiencies also decline at low heads. That is, extra water must be released at times when water levels are already low, just when the risk of triggering irrigation restrictions in the next year is high. Given the larger demands on the reservoir now, it is no longer wise management to allow the generation of 210 GWh/yr down to levels as low as 78 m AHD.

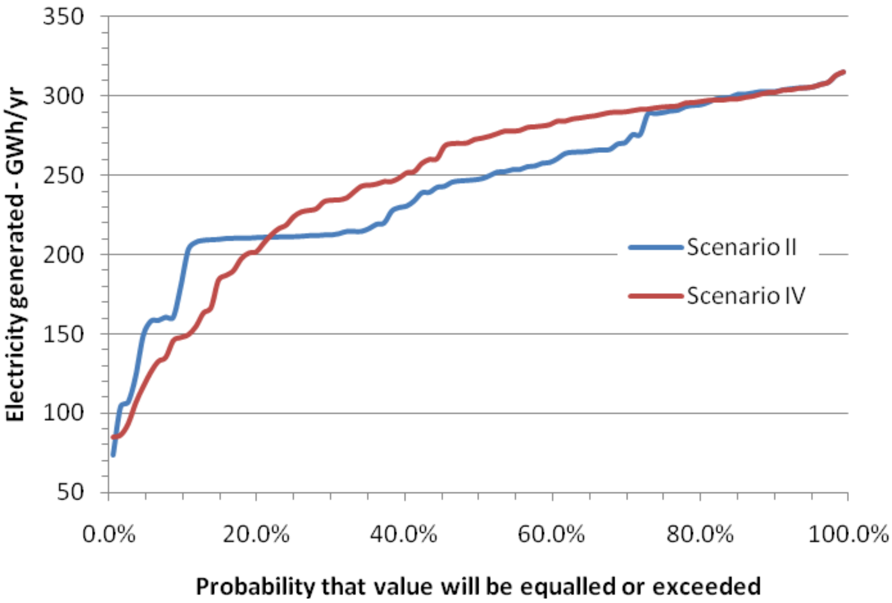


Figure 37 Distributions of the electricity generated under scenarios II and IV

By comparison, the enhanced rules limit the (independent) generation of electricity to the town demand rate (89.4 GWh/yr) when lake levels are between 76 and 87 m AHD (see Figure 35).

Figure 38 shows the advantage of the enhanced rules approach over setting rules that maintain the 210 GWh/yr rate to 78 m as water demand increases. The guaranteed minimum of the 1994 Water Supply Agreement cannot be met when water demand exceeds 520 GL/yr. The enhanced rules approach can be used up to a water demand of 650 GL/yr. For demand of more than 650 GL/yr, rules similar to those developed for *scenario III* become necessary.

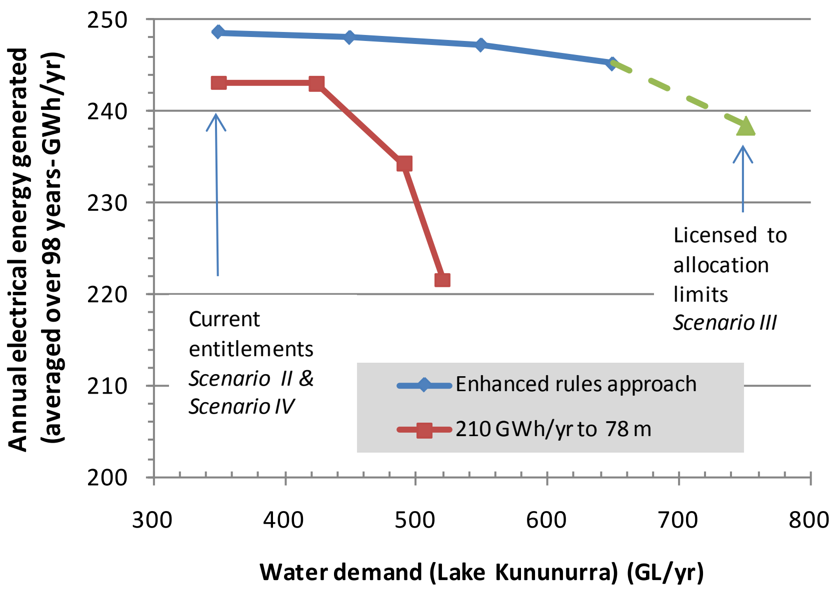


Figure 38 Electricity generated versus water demand and release rules approach

7.4.3 Water volumes released through the power station

(b) Scenario III – licensed to allocation limits

Figure 39 presents the volumes released through the power station each financial year under (a) *scenario I* (the recent past scenario), and (b) *scenario III* (licensed to allocation limits scenario – with high power and water demands).

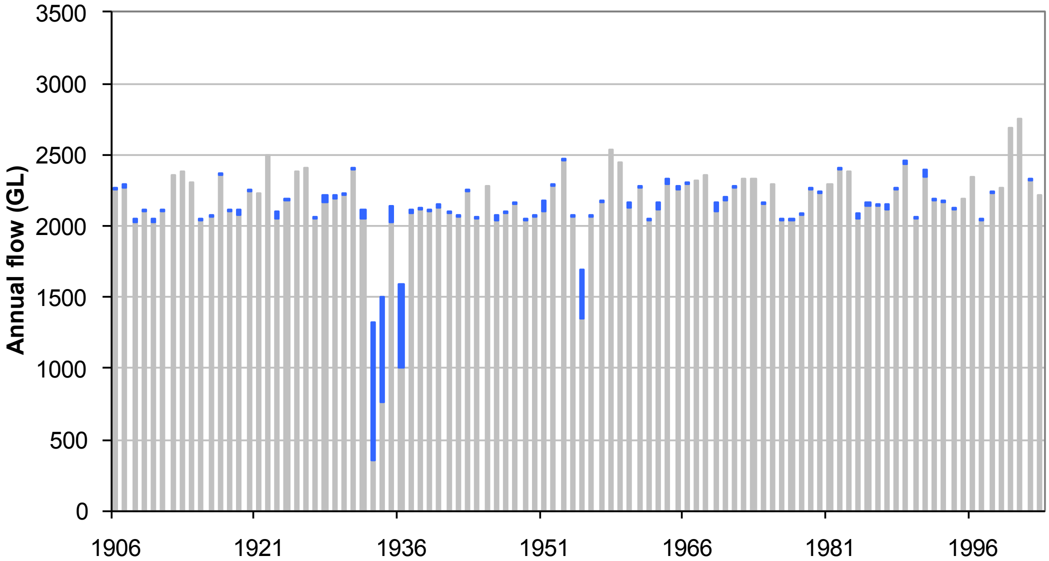
Under *scenario I*, an average of 2200 GL/yr is released through the power station. In most years, releases are greater than 2000 GL/yr and only fall below 2000 GL/yr in drought years. Releases are dominated by those made to generate the allowable power output at the time, and are greater than Water Corporation's downstream demands at the same time (termed times when hydropower limits dominate). The exceptions are in drought years when lake levels are below 78 m AHD, and power generation is restricted to rates below 210 GWh/yr. In these few years, releases needed to meet Water Corporation's downstream demands are commonly larger.

With expanded irrigation and high power demands (*scenario III*), an average of 2370 GL/yr is released through the power station. More than 2500 GL/yr are released in 35% of the financial years simulated; a consequence of the high power demand of *scenario III*.

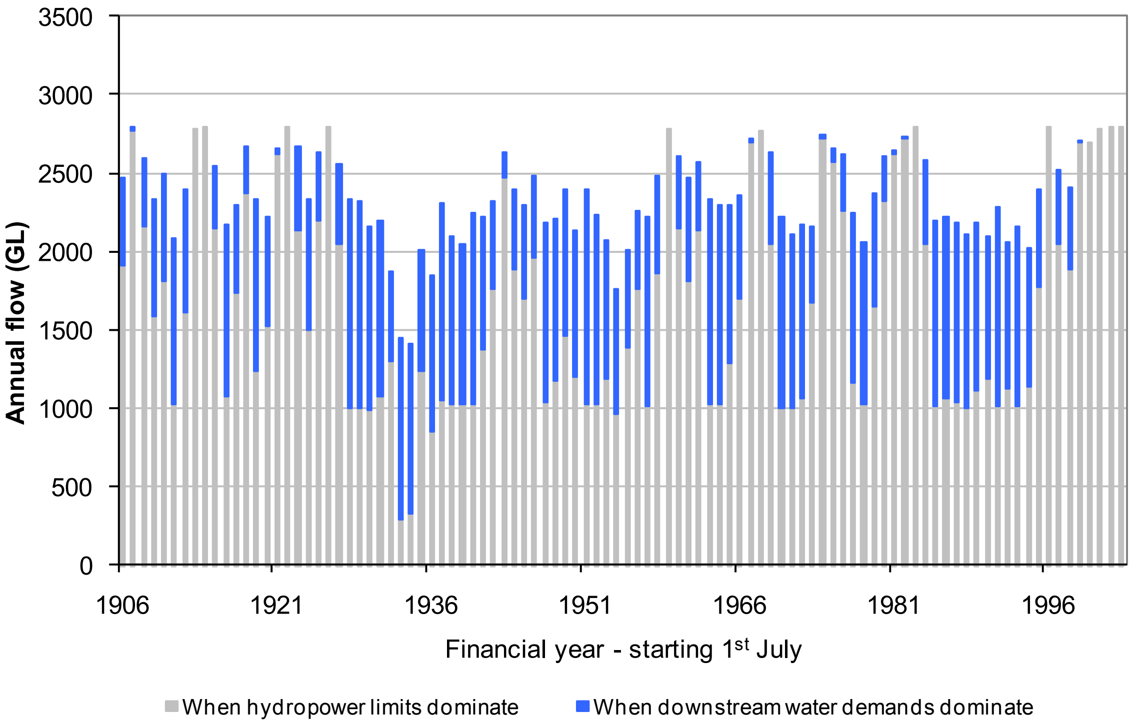
While more water is released through the power station under *scenario III* overall, (b) Scenario III – licensed to allocation limits

Figure 39 (b) shows a much higher proportion is released when Water Corporation's downstream demands dominate, compared with the recent past - (b) Scenario III – licensed to allocation limits

Figure 39 (a). Under *scenario III,* releases made to meet Water Corporation's downstream demands represent 29% of the total. This is only 2% under *scenario I*.



(a) Scenario I – the recent past



(b) Scenario III – licensed to allocation limits

Figure 39 Volumes of water released through the power station (scenarios I and III)

7.4.4 Potential of a 10MW power station at the Kununurra Diversion Dam

There is potential to generate additional hydro-electricity from a new 10 MW power station at the Kununurra Diversion Dam. The station would extract energy from flows being released from Lake Kununurra and the change in water level across the Kununurra Diversion Dam (about 14 m).

Simulations were undertaken to assess the electricity that might be generated if the existing Ord River Dam power station and the potential 10 MW station both contributed to the load of the east Kimberley electricity grid (see Section 3.1).

Table 22 summarises the amounts generated with and without the extra 10 MW hydropower station at the Kununurra Diversion Dam. Results are presented for:

- *scenario II* – 350 GL/yr of water demand, with high power demand (327 GWh/yr)
- *scenario III* – 750 GL/yr of water demand, with high power demand (327 GWh/yr).

Also shown are statistics on the water released and spilled from Lake Argyle and the severity of irrigation restrictions, with and without the extra power station.

Table 22 Benefits of a 10 MW power station at Kununurra Diversion Dam: scenario II and III

	Scenario II		***Scenario III***	
	350 GL/yr water demand – Power demand –327 GWh/yr		**750 GL/yr water demand – Power demand –327 GWh/y**	
Long-term average annual statistics	**Existing power station**	**With additional hydropower station**	**Existing power station**	**With additional hydropower station**
Electricity generated by a new 10 MW KDD station (GWh/yr)	0	80.2	0	65.2
Total electricity generated (GWh/yr)	243.1	306.7	238.4	289.6
Water released at Ord River Dam by Pacific Hydro for power generation (GL/yr)	2387	2188	1511	1457
Water released at the Ord River Dam for the lower Ord (GL/yr)	54	75	642	575
Spillage from Lake Argyle (GL/yr)	699	839	742	858
Average water supplied in the worst 5% of years with restrictions (% of demand)	70%	71%	54%	77%

Electricity generated by the 10 MW station at the Kununurra Diversion Dam is used to supply the east Kimberley electricity grid demand first. To the extent possible, the existing Ord River Dam power station then meets as much of the remaining electricity demand as possible. Smith and Rodgers (2010) provide further background on the two power station simulations.

The electricity generated by a new 10 MW station at Kununurra Diversion Dam is between 80.2 GWh/yr *(scenario II)* and 65.2 GWh/yr *(scenario III)*, depending on the water that is being diverted from Lake Kununurra.

Overall, the two power stations contribute on average 306.7 GWh/yr *(scenario II)* and 289.6 GWh/yr of renewable energy to the east Kimberley electricity grid. This represents between 89 and 94 per cent of the high demand expected to apply for much of the current decade.

While the new Kununurra Diversion Dam power station reduces the load on the existing power station at the Ord River Dam, the net increases in the energy generated remain significant. The net additional electricity generated averages more than:

- 60 GWh/yr under the current licensed situation (350 GL) – *scenario II*
- 50 GWh/yr if all water entitlements were granted (750 GL) – *scenario III.*

There are secondary benefits of reducing the electricity load of the existing power station at the Ord River Dam, especially as water demand increases. Table 22 shows that with both stations operating:

- less water is released from Lake Argyle for electricity generation, keeping more in storage for later supply
- the severity of water restrictions are lower, especially when the water demand is larger.

As such, a 10 MW hydro-electric power station at the Kununurra Diversion Dam is seen to be an effective use of renewable energy with clear benefits for water resource management.

7.5 Other scenarios

Smith and Rodgers (2010) give details of other scenarios simulated. These include cases that quantify the extra water entitlements that might become available if the base of Lake Argyle's spillway were raised up to 2 m. As separate approvals would be required before construction of such infrastructure, and go beyond the scope of the allocation plan (DoW 2012), the results are not reported here.

8 Ecological changes in the lower Ord

Section 7.2 describes the range of flows likely to occur in the lower Ord River – under the demand scenarios and reservoir simulations of outlined in Section 6.3. This chapter discusses the probable ecological effects of the different lower Ord flow regimes simulated.

8.1 Lower Ord flows and the EWR regime

The allocation limits and reservoir restriction policies in the allocation plan (DoW 2012) were developed to ensure the flow–ecology linkages that underpin the EWR regime could be fully met under all demand scenarios, except during drought periods.

Figure 40 shows the percentage of days that flows in the lower Ord River exceed, equal or fall below the EWR regime. The percentages are calculated over the whole simulation period (99 calendar years) and represent results for the five scenarios (Table 14) and related restriction policies (Appendix D).

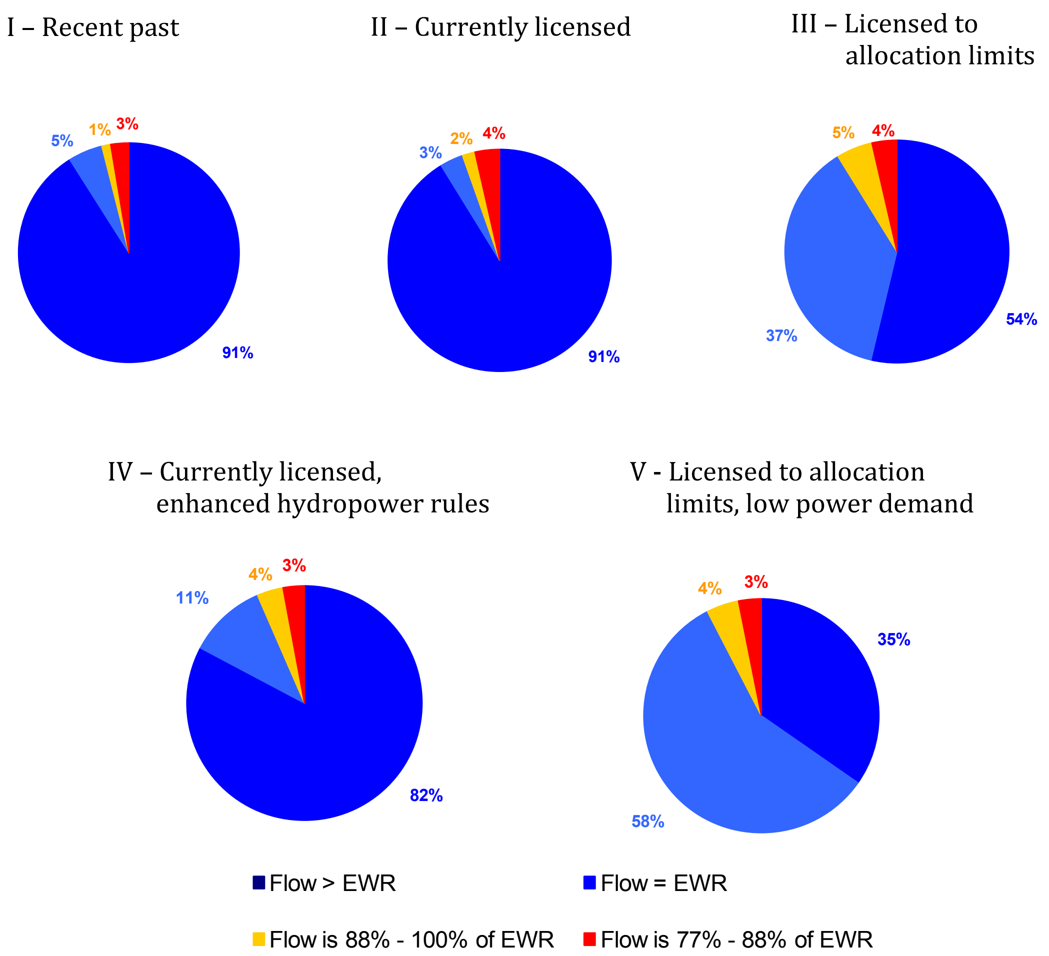


Figure 40 Proportion of days that lower Ord flows exceed, equal or fall below the EWR flow

8.1.1 Non-drought periods

Figure 40 shows that, under all demand scenarios, lower Ord flows equal or exceed the EWR regime 91 per cent or more of the time. As the EWR regime was developed to protect the modified riverine environment that has developed since regulation, ecological changes are expected to be minor when lower Ord flows either equal or exceed the EWR. Hence the riverine ecology should be very similar under the different demand scenarios and normal operating conditions (more than 90 per cent of the time).

The major difference between scenarios in these non-drought periods is the percentage of time the lower Ord River flows are greater than, compared with equal to, the EWR. When irrigation demands are high (*scenario III)*, or hydropower demands low *(scenario V),* dam operations are adjusted to ensure sufficient releases are made from Lake Argyle to meet the EWR for the lower Ord. Hence *scenarios III and V* have the highest proportion of flows equal to the EWR. Under current irrigation and moderate to high power demands *(scenarios I and II*) flows in the lower Ord are normally greater than the EWR.

Wet season flows

In non-drought periods, the wet season environmental water provision is (will be) met from a combination of the following:

- Hydropower releases combined with varying amounts of specific releases for the lower Ord environment depending on the scenario
- Unregulated runoff from catchments that contribute to the Ord River downstream of the Ord River Dam

Section 7.2.4 provides examples of the dominant role the unregulated tributaries (especially the Dunham River) play in meeting the high flow events of the EWR (Table 17). That is, flows at Tarrara Bar will normally meet those of Table 17 without additional releases being necessary from Lake Kununurra. However, if the target peak flows have not been met ’naturally’ in any one of the previous four wet seasons, then ‘top up’ releases are to be made from Lake Kununurra. The aim will be to release extra water from storage to add to ‘natural’ flow events in the Dunham River so that the peak targets are met. Since the EWR was established (2007), the high flow events have all been met by ‘natural’ runoff events.

Figure 41 shows results of hydraulic modelling of the lower Ord river at two cross-sections downstream of Tarrara Bar. Water levels are presented for flow rates between 4000 m^3/s (bank full conditions) and 100 m^3/s (the smallest high flow event of the wet season EWR). As river levels are affected by the tides in the Ord Estuary at these locations, the values graphed are averages over the tidal forcing at each location. At 4000 m^3/s the river is contained within its levee banks at cross-section 53664. For the same flow rate at cross section 77606, however, the river inundates areas to the north side of the river (the right bank) and is at the crest of the left bank levee. The frequency with which this now occurs (since regulation) is about once every 15 to 20 years, on average (DoW 2006).

Both cross-sections show that the water levels for flow rates of 100 m^3/s to 500 m^3/s (in the range of the high flow events of the composite EWR – Figure 18) occur at levels where riparian benches and side channels occur (shown more clearly in Figure 42). This is as expected, as we developed the EWR regime to ensure these benches were regularly inundated.

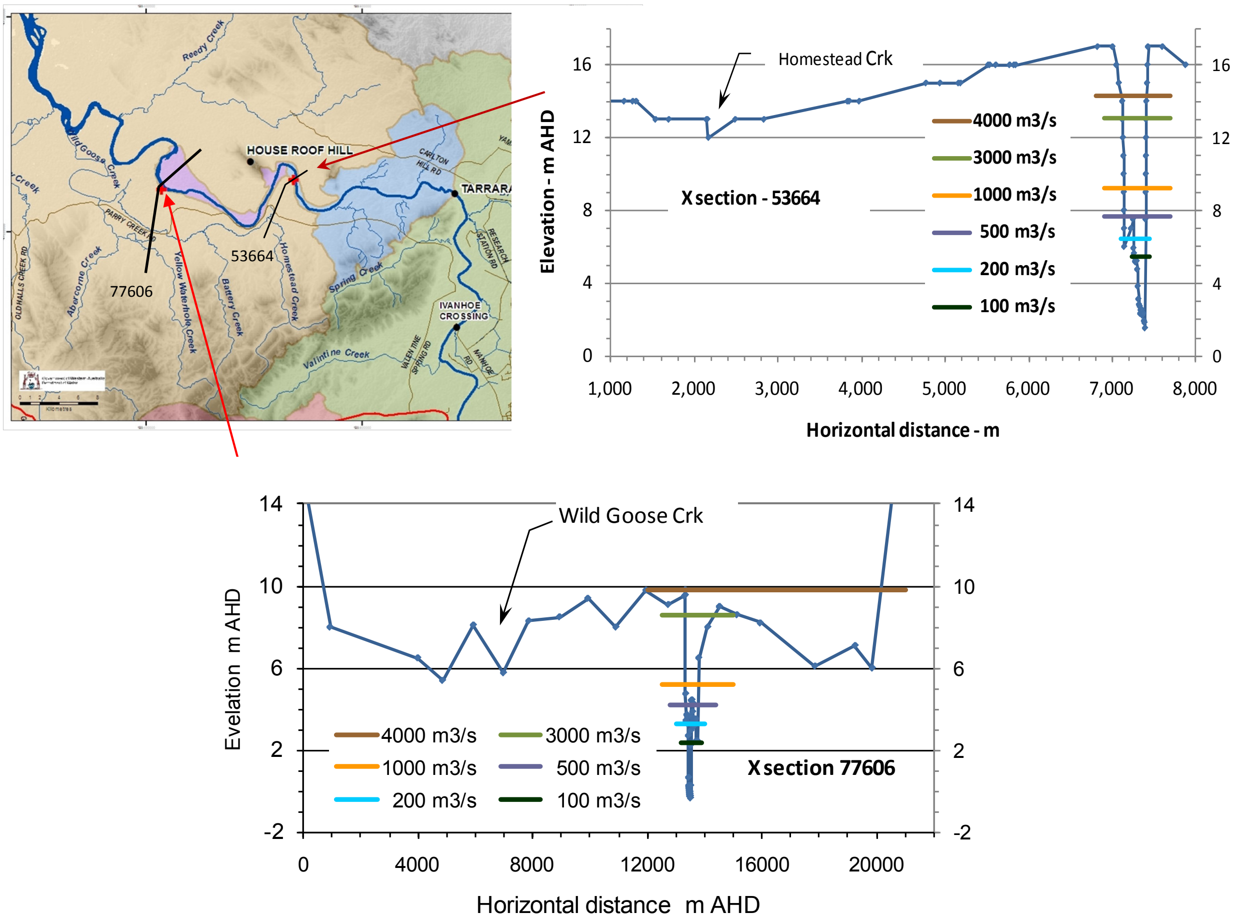


Figure 41 Wet season flow rates and levels at cross-sections 53664 and 77606

Dry season flows

Figure 42 shows detail of the main channel cross-sections at the same locations as Figure 41. It indicates the range of river levels can occur in the dry season, under the range of hydrologic conditions and scenarios simulated.

Flow rates of 100 to 200 m^3/s only occur in the dry season when Lake Argyle continues to spill well into June and July. Under *scenario II* (as currently licensed) river levels will be similar to those at a flow rate of 60 m^3/s. As irrigation areas expand and licensed water entitlements approach the allocation limit (*scenario III*), river levels will be similar to those at a flow rate of 42 m^3/s.

The dry season EWR of 42 m^3/s is effectively set by the need to provide sufficient backwater habitat for small bodied fish and juveniles of large bodied fish (Table 12).

Until irrigation demands increase, dry season flow rates and water levels in the lower Ord are likely to remain higher than 42 m^3/s. The current riverine environment has developed under higher dry season flow rates, especially since 1996 when the power station become fully operational. When the increased irrigation demand is realised, we might see some minor changes in the lower Ord's ecology. The changes will be the result of very minor changes in the availability of some habitats. However, based on the work completed to develop the EWR we consider that adequate habitat will be provided to maintain current ecosystems. These changes will be monitored (see DoW 2011, DoW 2012).

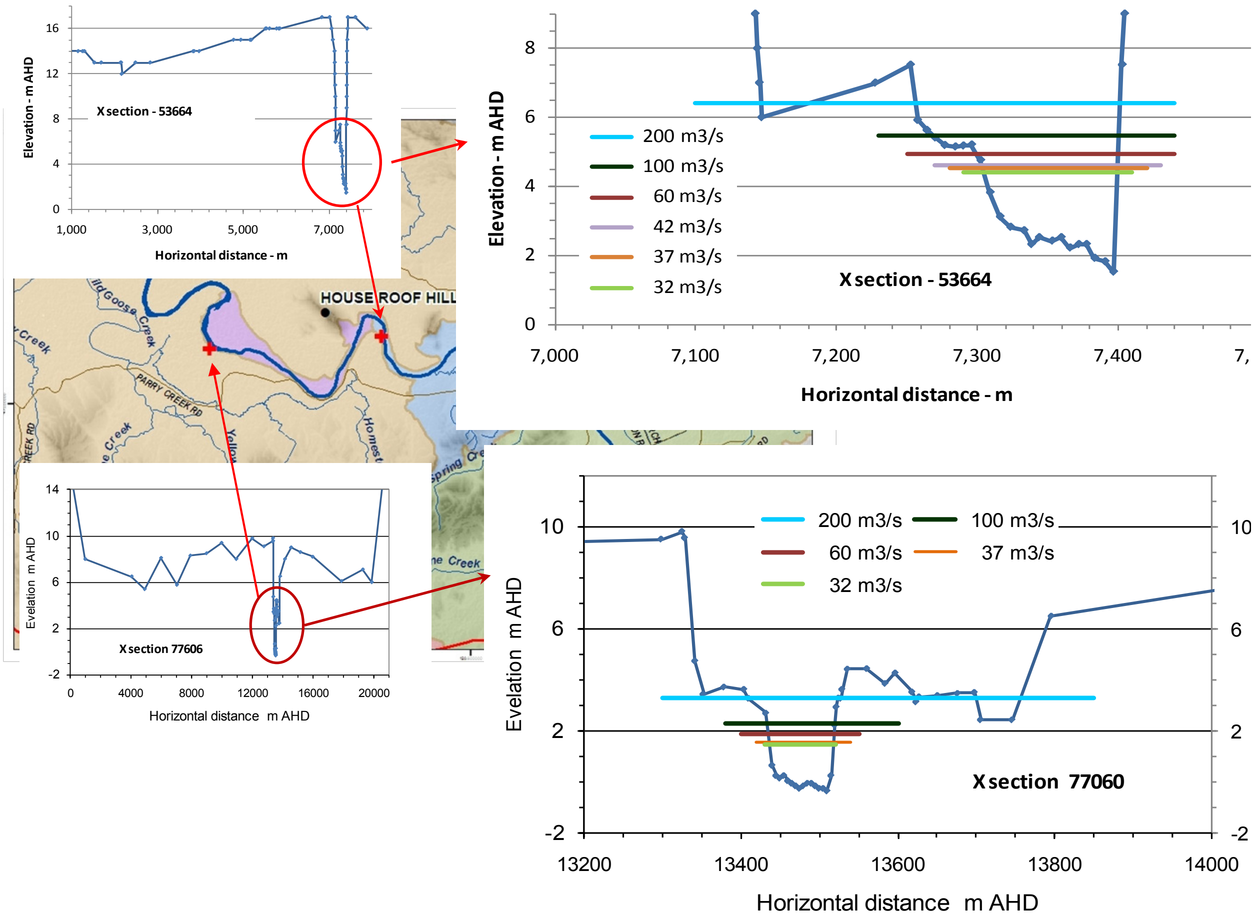


Figure 42 Dry season flow rates and levels at cross-section 53664 and 77060

Variations in flows between and within dry seasons

As described below, the riverine environment is considered sufficiently robust to adjust to these changes over time, especially if rapid reductions in dry season flow rates are minimised and changes between successive dry seasons are limited.

In areas of suitable habitat, extensive beds of submerged macrophytes (aquatic plants), have established in response to the current (relatively high and stable) dry season flows and reduced wet season scouring since regulation. These macrophyte beds are preferred habitat for *Macrobrachium* prawns and support small-bodied fish, thus forming an important part of the overall food web and contributing to species richness, abundance and aquatic fauna biomass in the lower Ord.

The macrophyte beds occur in relatively shallow water where adequate light penetrates the water column. The beds require waters with low velocity, generally less than 0.3 cm/s. (They can be scoured out by high velocity flows and take 12 months to fully recover.) The stable water depths that occur in the lower Ord during the dry season strongly influence the size (length) of the macrophytes. They commonly grow in water of 45 to 90 cm depth but can grow much longer (near to the surface) if water depths are greater (up to 2 m).

The growth pattern of the macrophyte beds is seasonal. The growth period is during the dry season, with maximum growth facilitated by low turbidity and greater light penetration and lower flow velocities. During the wet season the macrophytes die back to underground rhizomes and tubers. To maintain this habitat from one season to the next, at least part of the rhizomes from the previous dry season should be in a suitable depth range the following dry. That is, large changes in water level from one dry season to the next could mean the macrophytes' suitable depth range could shift beyond the extent of rhizomes from the previous season. Flow-ecology linkages were therefore developed to maintain some overlap in habitat from the end of one dry to the start of the next (flow-ecology linkages 1b, 2a and 2c, Braimbridge & Malseed 2007).

Reservoir simulation results were checked to ensure this criterion was met under the scenarios studied. In addition, the change in irrigation demands from *scenario II* to *scenario III* will occur over many years (five years or more) and should also not violate this EWR criterion.

Macrophytes can also be affected if rapid reductions in lower Ord flows occur over a day or so during the dry season (DoW 2006). Although likely to be a short-term impact if flows return to previous levels within days, situations where dry season flows reduce rapidly and remain low for extended periods (months) should be minimised. These situations can arise when water levels in Lake Argyle first trigger restrictions on hydropower generation. (Lower Ord flows could reduce from about 80 to 42 m^3/s within days under some circumstances.)

Fish may also be stranded in shallow backwaters if rapid changes in flow occur during the dry season.

The following approaches have been taken to minimise rapid changes in lower Ord flow rates during the dry season:

- The seasonal pattern of water levels in Lake Argyle that trigger hydropower restrictions have been selected to reflect the seasonal water level pattern. If inflows during the wet season are below average, hydropower restrictions are likely to be triggered during the wet – when Dunham River flows also contribute to the lower Ord.
- The trigger levels for Class 1 and Class 2 hydropower restrictions are separated by about 1 m (0.8–1.3 m) over the year so that power station

releases do not reduce suddenly (from unrestricted rates to Class 2 rates) in one step. (Note that *scenario III* is the exception to this approach, in that the trigger levels for both classes are the same. Under this scenario, however, rapid changes in lower Ord River flow rates are unlikely when hydropower restrictions are triggered. Before power station restrictions are triggered, most of the releases are diverted from Lake Kununurra. When Class 2 restrictions are triggered, additional environmental releases become necessary.

8.1.2 Drought periods

Minor differences occur between scenarios during times of drought.

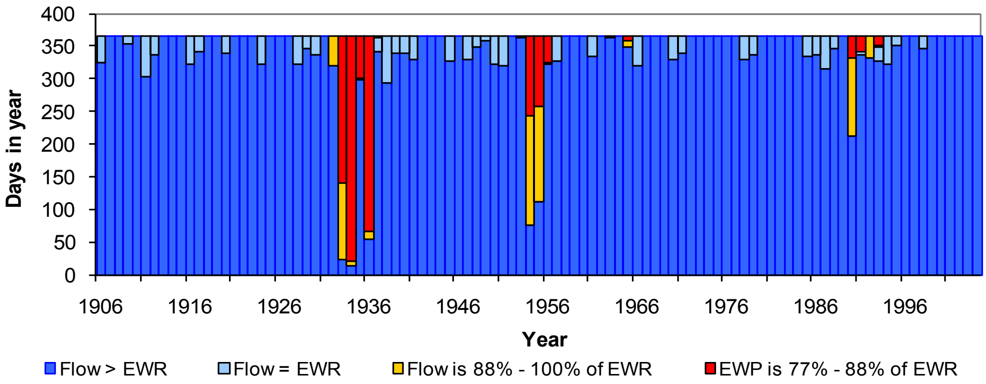
Under current licensed conditions (*scenario II*) flows are expected to fall below the EWR regime about six per cent of the time. When all water entitlements are granted (*scenario III*), lower Ord flows are expected to fall below the EWR regime about nine per cent of the time.

Figure 43 shows that lower Ord flows are simulated to be less than the EWR mainly during the critical drought periods of the 1930s and 1950s, with short periods occurring in the mid 1960s and late 1980s to early 1990s. The figure indicates the numbers of days in each year that lower Ord flows exceed, equal, and fall below the EWR regime for *scenarios II, III and IV*.

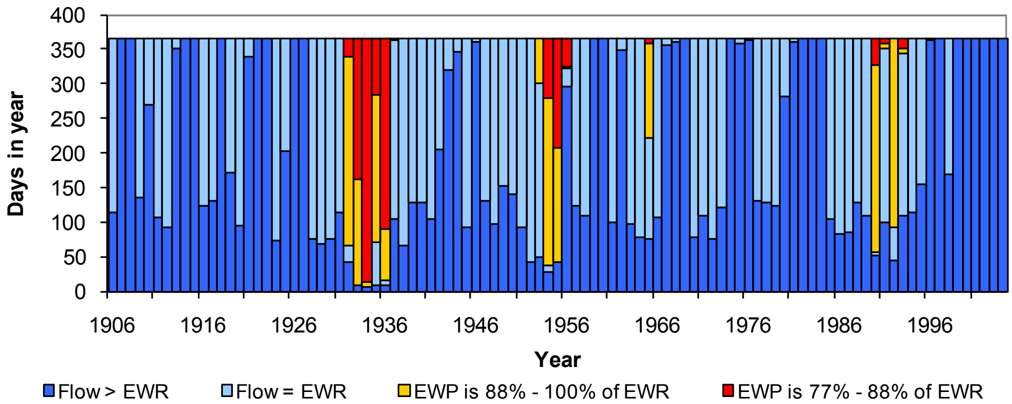
Differences in times when flows are less than the EWR regime are minor between scenarios and reflect the (small) differences in Lake Argyle water levels simulated for each scenario. As noted in Section 7.1, the EWP restriction policies are the same except for *scenario IV*.

The EWP restriction policies applied (tables C1 to C3, Appendix C) include two classes of restrictions: Class 1 where flows are reduced to 88 per cent of the EWR regime and Class 2 where flows are reduced to 76 per cent of the EWR regime. During the wet season, Class 1 and Class 2 restrictions are triggered at the same level (effectively reducing the baseflow component and target wet season peaks to 76 per cent of the EWR in one step). If restrictions are in place the largest annual wet season peak (425 m^3/s) is also not required. Figures Figure 40 and Figure 43 show the frequency at which the two classes of restriction apply.

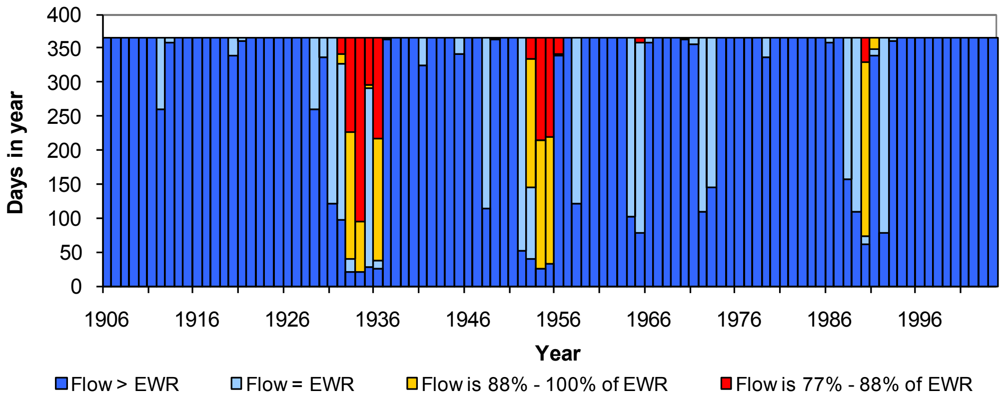
Note that while environmental water restrictions apply more frequently than irrigation restrictions, they are less severe (Figure 43 compared with Figure 33).



(a) Scenario II – currently licensed



(b) Scenario III – licensed to allocation limits



(c) Scenario IV – licensed to allocation limits, enhanced hydropower rules

Figure 43 Comparison of lower Ord flows with the EWR regime by year (scenarios II to IV)

8.2 Ecological impacts during times of drought

Several flow-ecology linkages, on which the EWR regime is based, cannot be fully met when the EWP restrictions apply. The ecological consequences of not maintaining all elements of the EWR regime during drought periods are discussed below.

Ecological features not fully maintained during restriction periods include the following:

- inundation of parts of shallow backwater habitat, used by small-bodied fish and juveniles of large-bodied fish
- inundation of areas of deep-water backwater habitat, available to large-bodied fish and possibly used as spawning sites during the wet season
- flooding of riparian benches, available to large-bodied fish as habitat and possible sites of spawning during the wet season
- seasonal inundation of lower riparian terraces
- permanent flows that exceed 35 m^3/s and provide connection between pools and contribute to dissolved oxygen levels in river pools.

Dry season shallow backwater habitat was considered likely to be most affected. Dry season flow rates reduce from 42 to 37 m^3/s under Class 1 and 32 m^3/s under Class 2 restrictions. Under these reduced flows, shallow backwater habitat may reduce to roughly 75 and 50 per cent under Class 1 and Class 2 restrictions respectively, of the amount present at the EWR flow rate. The maximum depth in remaining shallow backwaters is expected to be around 30 to 35 cm under Class 2 restrictions (about 70 per cent of the maximum depth at the EWR flow rate).

Thus while local backwater habitat is expected to significantly reduce during times of drought, it will not be eliminated altogether. Nevertheless, a consequence is that many of the smaller fish that prefer these backwaters will be forced into the deeper pools during the dry season. The larger pools represent the dominant form of the lower Ord's riverine environment – 85 per cent of the distance along the river between Kununurra Diversion Dam and the Ord Estuary at The Rocks (DoW 2006) – and will remain substantially unaffected (in size) during drought periods. The pools therefore represent major refugia for aquatic fauna during drought periods.

Predation pressures will, however, increase on smaller fish forced into the deeper pools (Storey 2003). Some reduction in juvenile numbers of large-bodied fish and small-bodied fish can therefore be expected during times of drought. However, given the pools will be largely unaffected and about 50 per cent of backwater habitat will remain, the changes would be expected to be small. Moreover, as the large pools act as major refugia for the species present, no lasting impacts are expected on fish biomass, species richness or abundance.

In assessing the suitability of the EWP restriction policy, the scientific panel was concerned about the risk of anoxia and fish kills during periods of low flow.

Monitoring and modelling of low flows during a trial in 2002 found that low flows, combined with extended periods of low wind speeds, could cause temperature stratification and reductions in dissolved oxygen in deep river pools. As a consequence, a dissolved oxygen monitoring program in selected river pools will be triggered when flows fall below 35 m^3/s – as detailed in DoW 2011. If anoxic conditions occur, flushing flows could be released from storage.

The following section discusses the likely effects on identified threatened species.

8.3 Risks to threatened species

8.3.1 The lower Ord River

There are 217 species of plants and vertebrate animal species (including 38 species of fish) known to occur in the lower Ord River (Figure 16).

The department conducted a search of threatened species records within 2 km of the lower Ord (Naturemap, DEC 2008; EPBC Protected Matters Search 2010).

This search identified species or species habitat likely to occur in the lower Ord that are listed under federal or state conservation legislation and/or relevant international agreements. A description of the conservation codes under the *Wildlife Conservation Act 1950* (WA) and the *Environmental Protection and Biodiversity Conservation Act 1999* (Cwlth) can be found in Appendix E. The results of the search are summarised in Table 23.

Of the species listed, only the freshwater sawfish (*Pristis microdon),* dwarf sawfish (*Pristis clavata*), Australian painted snipe *(Rostratule australis)* and freshwater whip ray (*Himantura chaophraya*) depend on the lower Ord's flow regime for part of their lifecycle.

The impact of altered flow on freshwater and dwarf sawfish and the freshwater whip ray is relatively unknown. The dwarf sawfish has only been the subject of one dedicated survey (Thorburn et al. 2007a), although it has been included in a number of broader surveys of sawfish, elasmobranchs or fish fauna in northern Australia (Field et al. 2008; Morgan et al. 2004; Stevens et al. 2008; Thorburn et al. 2004, 2004a).

Freshwater sawfish tend to move up rivers during flood periods (Allen 2000 pers. comm,, as cited in DEC 2009). It has a lifecycle in which the adults are found within the marine environment and the juveniles in fresh water. The Kununurra Diversion Dam largely prevents the freshwater sawfish and therefore probably the dwarf sawfish from inhabiting the Ord River upstream of the diversion dam. However, individuals of these species still may be present in the lower Ord downstream of the diversion dam.

Based on what is known of the habitat requirements and lifecycles of these threatened fish species, maintenance of deep pool habitat and connectivity between the reaches is considered of primary importance. Both of these requirements are covered by specific flow linkages in the EWR so that habitat requirements for these species will be maintained.

The maintenance of prey species and food webs that support prey species (e.g. mullet) are also important to maintain threatened fish species populations. The EWR includes specific objectives to maintain habitat and food webs (algal production and macroinvertebrate habitat) that support small-bodied fish populations. The monitoring program includes the establishment of a baseline for fish population size, structure and composition.

Although the Australian painted snipe can occur across Australia, the areas of most sensitivity to the species are those wetlands where the birds frequently occur and are known to breed. An apparent decline in Australian painted snipe numbers in the Kimberley region has been linked to overgrazing by cattle (Johnstone & Storr 1998).

The Department of Water used the ecological objectives of maintaining specific habitats and key ecological processes of the river system (Table 11) to guide the EWP for the lower Ord River. The key aims were to maintain the breeding, species richness and abundance of aquatic biota, including fish, in the lower Ord.

Table 23 Endangered species listed under state and federal legislation

Environmental Protection and Conservation Act 1999 (Cwlth)

Two species listed as endangered including the:

- red goshawk (*Erthrotriorchis radiatus*)
- northern quoll *(Dasyurus hallucatus)*

Three species listed as vulnerable including the:

- freshwater sawfish (*Pristis microdon)*
- dwarf sawfish or Queensland sawfish (*Pristis clavata*)
- Australian painted snipe *(Rostratule australis)*
- crested shrike-tit (northern)
- purple-crowned fairy-wren (western) (*Malurus coronatus coronatus*)
- Gouldian finch *(Erythrura gouldiae)*
- 25 migratory wetland species, one migratory marine species and 11 migratory bird species.

Wildlife Conservation Act 1950 (WA)

One species – the Australian painted snipe *(Rostratule australis)* listed as rare or likely to become extinct.

Two reptile species listed as marine.

One species of bird and one species of mammal listed as declared rare and threatened fauna.

One species of reptile listed as specially protected fauna.

Twenty-five bird species listed as priority fauna.

One species is also listed under the International Union for Conservation of Nature (IUCN) protected management categories – the freshwater whip ray (*Himantura chaophraya*) (Trayler et al. 2006:38).

Reducing dry season flows from 42 to 37 m^3/s downstream of House Roof Hill will mainly affect the extent of shallow backwater habitat used by small fish. The majority of shallow backwaters are upstream of House Roof Hill and we expect only minimal impact on the 10 backwaters downstream of House Roof Hill. The decrease in the required flow is considered acceptable during severe drought periods.

As we expect the EWP to be met 90 per cent or more of the time (Figure 40 and Figure 43), we do not consider the allocation limits of the plan (DoW 2012) to be a risk to threatened species. If changes in fish populations, including threatened species, do occur, we anticipate the ecological monitoring program will detect them so that corrective action can be taken.

8.4 Effects on Ramsar values

Lakes Argyle and Kununurra, as well as the lower Ord River floodplain and their associated wetlands, are listed as Wetlands of International Importance under the Ramsar Convention.

8.4.1 Lakes Argyle and Kununurra

Ramsar values

Lakes Argyle and Kununurra were listed under the Ramsar Convention because they:

- supported a large population of the vulnerable freshwater crocodile (*Crocodylus johnstoni)*, which is protected by the *Wildlife Conservation Act 1950* and the *Environment Protection and Biodiversity Conservation Act 1999*
- had at least 15 species of freshwater fishes (mainly catfishes, grunters and gudgeons), while four fishes (two catfish *Arius* spp., strawman *Quirichthys stramineus* and giant glassfish *Parambassis gulliveri)* are known in Western Australia only from the site and other parts of the Ord River system
- contained three species of freshwater turtle, with one of these, *Emydura australis,* being restricted to the Kimberley/Victoria River region
- were important dry season refuges for very large numbers of water birds – in August 1986, Lake Argyle supported more than 180 000 birds and in September 1978, Lake Kununurra supported 12 000 birds.

These values remain today (Hale & Morgan, 2010). At the time of listing (1990), the lakes were acknowledged as being manmade and operated as water supply storages, for the purpose of delivering a reliable water supply for irrigation. This original purpose remains today and dictates the day-to-day operation of the dams that form the lakes. That is, the Ramsar values were seen as compatible with dam operations.

The effect of different scenarios on the Ramsar values of the lakes

Lake Argyle

Although Lake Argyle’s water level varies widely, shallow water overlying a base of bare sediments often occurs around the lake’s southern shorelines. These areas have become important feeding habitat for migratory shorebirds (Hale & Morgan 2010).

Water levels usually fluctuate by about 2 to 3 m each year in response to common wet season inflows, average evaporation and releases for irrigation and hydro-electric power generation (*scenario I,* Figure 22). In wet seasons with major flood inflows, levels in Lake Argyle can increase by 10 m in six weeks (as occurred from mid February to late March 2011). Consequently shallow water around the southern shoreline is expected to occur in the late wet season and early dry season, even if the levels at which this happens varies between years.

In years of very low inflow, lake levels barely rise at all during the wet season. They can be drawn down by 3 to 4 m during the subsequent dry season (Figure). Over a series of years with below-average inflow, lake levels can drop 10 to 15 m before recovering in response to improved inflows. Shallow shoreline habitat would be expected to decline as lake levels decline over drought periods, especially given the manmade nature of the lake.

As noted in Section 6.4.2, the restriction policies established for each demand scenario (Appendix C) will ensure the range of future water levels in Lake Argyle, including during drought periods similar to the 1930s and 1950s, will be very similar (Figure). That is, we do not expect the shallow water shoreline habitat of Lake Argyle to be significantly different under the scenarios modelled, even though water levels change considerably from year to year.

Lake Kununurra

In contrast to Lake Argyle, the water level in Lake Kununurra is kept in a narrow range (about 0.5 m) to enable water to be readily diverted from the lake for irrigation. This stable water level has favoured the establishment of dense littoral vegetation, which in turn has provided important habitat for fish and waterbirds (Hale & Morgan 2010).

As the water level in Lake Kununurra will continue in the same stable range under all future scenarios, the lake's Ramsar values will not change.

8.4.2 The Ord River floodplain Ramsar site

The Ord River floodplain Ramsar site (Figure 44) can be divided into three relatively distinct wetland areas, based on geographical location and wetland type:

- *Parry Lagoons*, which include both the permanent (or near permanent) waterholes, such as Marglu Billabong, as well as the broader area of floodplain within the Parry Lagoons Nature Reserve that is subject to periodic inundation
- *Ord Estuary*, which includes the section of the Ord River that is under tidal influence from The Rocks to the boundary near Adolphus Island
- *False Mouths of the Ord*, which is the area of intertidal creeks and mudflats in the north of the site.

The False Mouths of the Ord drain directly into the outer (northern western) portion of Cambridge Gulf, distant from the Ord Estuary. The discussion below therefore focuses on the Parry Lagoons and wetlands, as well as the Ord Estuary and related tidal mudflats.

Ramsar values

The Ord River floodplain Ramsar site was listed under the Ramsar Convention because it:

- was Western Australia's best example of an extensive system of wetlands associated with the floodplain and estuary of a major tropical river

- supported a viable population of the (then) globally threatened saltwater crocodile (*Crocodylus porosus)* and the nationally vulnerable freshwater sawfish (*Microdon pristis)*
- had conditions that are suitable for use by more than 20 000 waterbirds at least several times within a 25-year period
- included the most biologically diverse, contiguous floodplain and mangrove system in Western Australia.

These characteristics remain today (Hale, 2008). The site's mangrove system is the largest, most species diverse and structurally complex mangrove system in the Kimberley. Large numbers of waterbirds from most waterbird families, particularly ducks and waders (shorebirds), use the site. In good rainfall years, Parry Lagoons and other seasonal wetlands constitute are a major breeding area for waterbirds in the Kimberley region.

The site was listed in 1990 after the hydrological regime of the lower Ord River had already been substantially altered by the construction of the Ord River Dam (in 1972). The ecological values of the lower Ord floodplain and estuary remained sufficiently high to justify the listing, even though these areas were still adjusting to the changed flood regime since regulation. That is, the wetland values of the lower Ord floodplain had been retained despite the lower Ord not flooding regularly since the early 1970s (Hale 2008).

The effect of future scenarios on the lower Ord floodplain and wetlands

The Parry Lagoons and wetlands of the lower Ord floodplain

Section 2.4 of DoW (2006) documented the changed flooding behaviour of the lower Ord River before and after regulation by the Ord River Dam. Section 2.5 described the consequent changes to the river and estuarine geomorphology and ecology. Sections 9.1.2, 9.3 and 9.4 indicated further changes, expected as a result of the addition diversions allowed under the plan, would be minor (DoW 2006).

The updated hydrology and reservoir simulations reported here enabled the 2006 conclusions to be checked. In addition, the new simulations enabled us to directly compare the resulting lower Ord flow regimes modelled under the five scenarios.

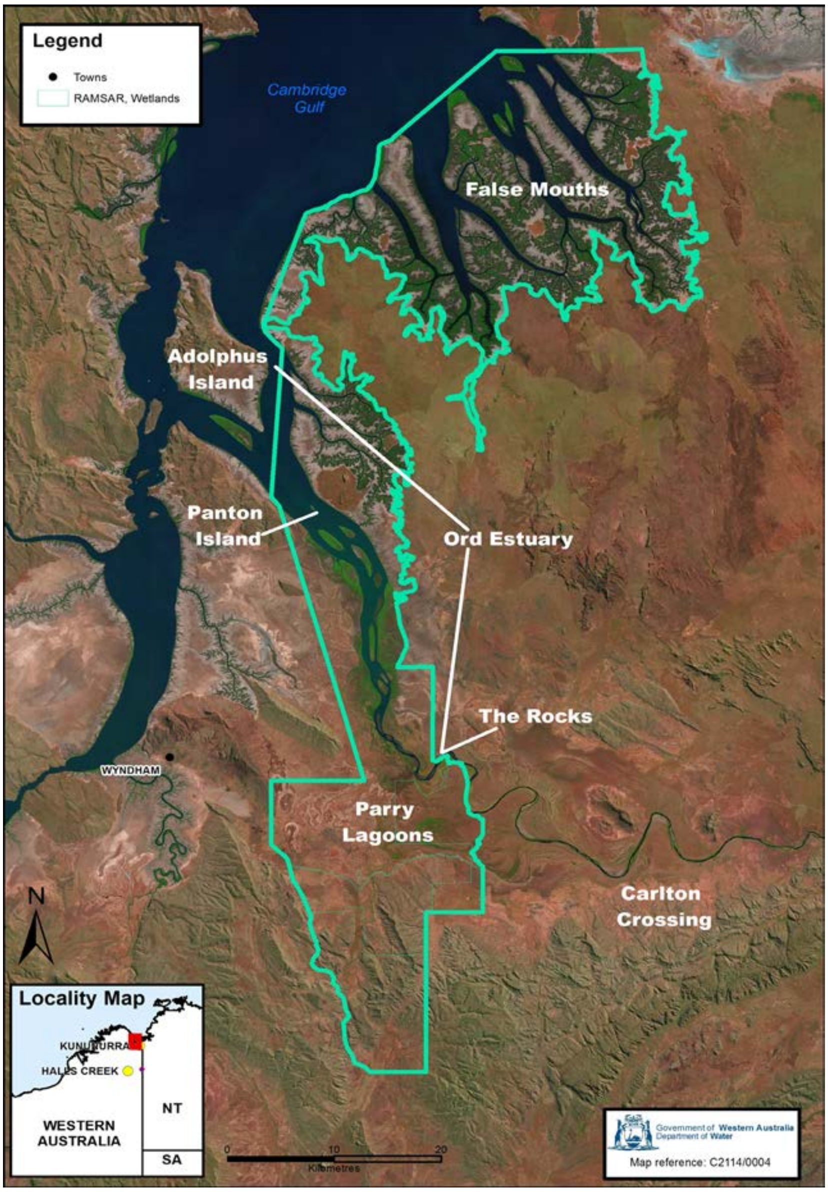


Figure 44 The lower Ord River floodplain Ramsar site (from Hale, 2008)

Floodplain inundation caused by Ord River flooding

There is no distinguishable difference in the magnitude and frequency of floods that exceed bankfull conditions (greater than 4000 m^3/s) in the lower Ord River under the five scenarios (see Section 7.2.4 and Figure 33). Post-regulation, the Ord River is now estimated to overtop its levee banks on average only about once every 15 to 20 years (annual probability of exceedance of 0.07 to 0.05).

As noted in DoW (2006) and recognised in the *Ecological characteristic description of the Ord River floodplain* (Hale 2008), the ecology of the Parry Lagoons and wetland areas is expected to continue to adapt to this reduction in power and frequency of Ord River flooding.

Floodplain inundation caused by local rainfall and runoff

Section 2.5.3 describes the local creeks that drain the adjacent hills and the lower Ord floodplain and discharge downstream into the Ord Estuary. On the southern floodplain in particular, runoff from the catchments of Parry and Wild Goose creeks is large enough to frequently inundate much of the Parry Lagoons and associated wetland areas, while flow in the main Ord watercourse remains contained within its flood levees. Flooding induced by local runoff occurs much more frequently than overbank flow from the main river and is now considered to drive wet season wetland ecology post-regulation.

The frequent local flooding is a consequence of the shallow soils and steep topography of the Livistonia Range, the rainfall intensities of the wet season, the size of the Wild Goose and Parry creek catchments (total of 1225 km^2) and the flat topography of the Parry Lagoons and adjacent wetland areas. On fluvial-geomorphic grounds Wild Goose and Parry creeks would be expected to overtop their banks and inundate parts of the floodplain at least once in every one to three years (Petts & Maddock 1994).

Given the frequency of local flooding, the wetlands of the lower Ord floodplain have regular hydrologic and ecological connection with the estuary. Clearly, the operation of the dams proposed under the different scenarios do not directly affect local flooding. The frequency and extent of these connections will therefore remain essentially unchanged under the five scenarios. Much more significant is the interaction between local flooding and spring tides in the estuary (see below).

It should be noted that moderate to high peaks in the lower Ord River will interact with local runoff to a small degree and prolong inundation of the lower Ord floodplain. To the extent that dam operations affect the frequency of moderate peak flows in the lower Ord, minor differences in inundation could be expected. Figure 33, however, shows very minor differences in the frequency of peak daily flows in the 500 to 800 m^3/s range. This reflects minor differences in spillage rates from Lake Argyle under the different scenarios. Different backwater impacts at these relatively moderate peak flow rates would be minor.

The Ord estuary and tidal mud flats

Section 7.2 details the characteristics of the annual, monthly, dry season and annual peak flows of the lower Ord River under the five scenarios. While the differences between scenarios are very small relative to the inflows to Cambridge Gulf (DoW 2006), concern remains about the possible impact on the Ramsar values of the Ord Estuary and associated tidal mud flats. This section argues that the provisions of the allocation plan (DoW 2012) will have no measurable impact on them.

The Ord River estuary is a large macro-tidal system with a tidal range of more than 7 m at spring tides. Figure 43 shows typical water levels along the lower Ord from the Kununurra Diversion Dam to the lower estuary for a typical dry season flow rate of 45 m^3/s. The insets represent recorded tidal levels at The Rocks and at Sphinx Rock over similar lunar cycles. The large tidal range is clear, especially during the spring tidal cycle. The rapid upstream and downstream movement of estuarine water can be inferred from the gradients of the water surface at spring tide and at the associated low tide of the spring tide cycle.

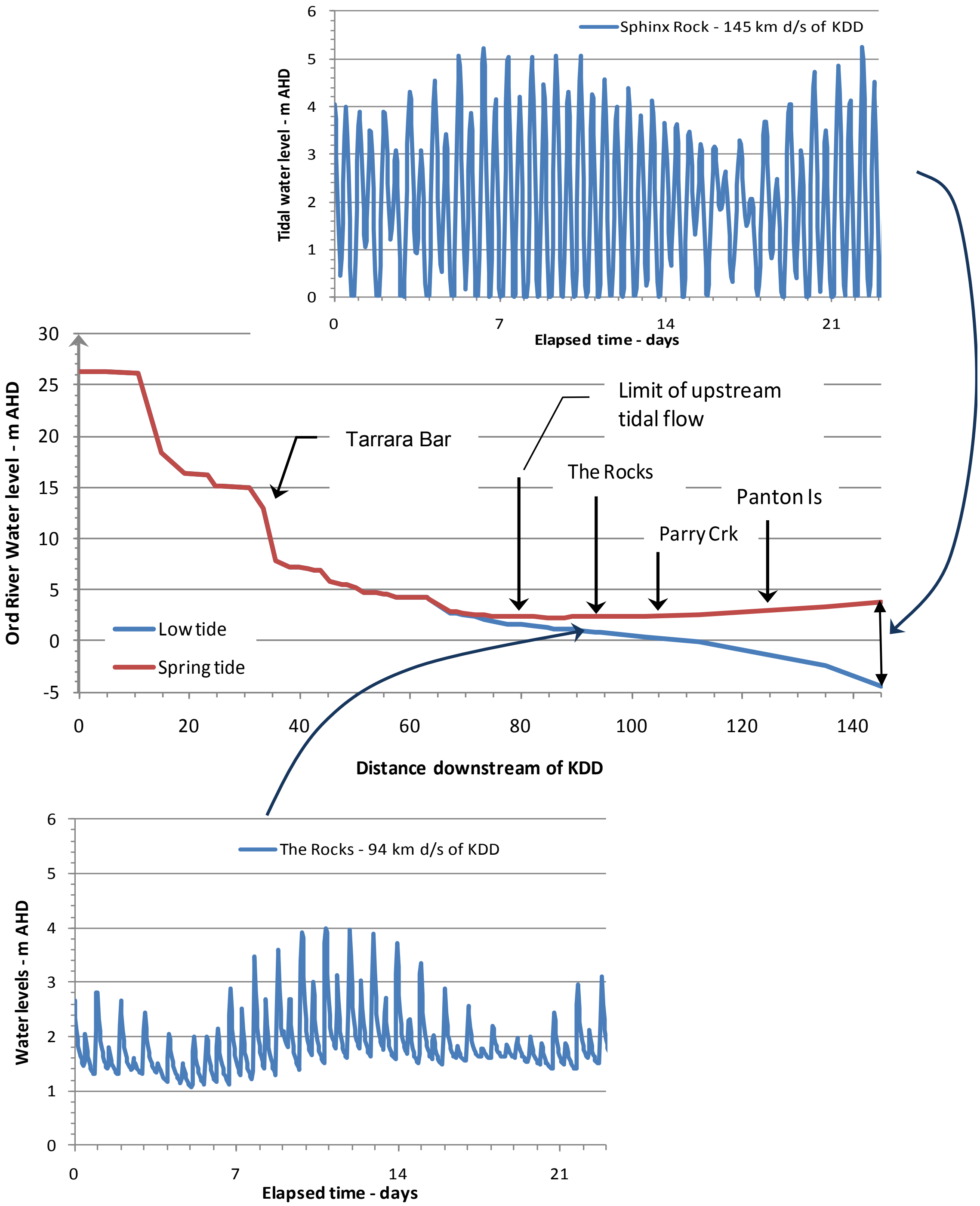


Figure 45 Water levels in the lower Ord from the Kununurra Diversion Dam to the estuary – for flow rate of 45 m^3/s

These tidal movements have enormous power and ensure the tidal zone is always well mixed (vertically). Monitoring of estuarine salinities in the mid 1990s indicated that salinities along the estuary can range from fresh to near seawater concentrations over one tidal cycle (see Figure 46 below).

Comprehensive field investigations and modelling of the hydrodynamic mixing and ecological processes of the estuarine reach were initiated in the early 2000s as part of the Ord Bonaparte Research Program (OBRP) (Parslow et al. 2003). More recent reports on follow-up modelling work (Robson et al. 2008) and descriptions of the estuarine ecological patterns and processes (Gehrke 2009) have distilled the knowledge gained from the OBRP studies.

The field work confirmed the critical role played by the following two factors:

- The power of the tidal cycle to drive estuarine mixing and sediment re-suspension.
- Runoff generated from the unregulated portion of the Ord River catchment (downstream of the Ord River Dam) in producing (occasional) large wet season floods that can flush saline water from the estuary for several months. Such flood events make the estuarine reach brackish, until tidal forcing re-establishes more saline water as river inflows decline during the dry season.

Both factors strongly drive the estuary's water quality and biological productivity.

The estuarine reach is considered a key transition zone between permanent fresh (riverine) areas and the more saline and tidal dominated estuary mouth. The reach has been called the high-energy brackish zone, where the highest sediment and nutrient concentrations occur. The strong tidal currents keep the water column well mixed and turbid, continually re-suspending sediments. Salinities are highly variable, ranging from less than 4 ppt to more than 28 ppt (Gehrke 2009).

Responses to high flows during the wet season

Estuarine salinities can be strongly influenced by the recent history of high Ord River inflows during the wet season (Gehrke 2009). While much smaller since regulation, high-flow events are still generated by runoff from the unregulated catchments downstream of the Ord River Dam. (The catchment area from the Ord River Dam to the tidal limit is 6240 km^2. A further 1750 km^2 drains into the estuarine reach – see Section 2.5.3.)

Inflows to the estuary with a daily peak flow rate of more than 800 m^3/s occur in most wet seasons. Peak daily flows of at least 1000 and 2000 m^3/s occur (on average) once every two years and five years respectively (annual exceedance probability of 0.5 and 0.2, Figure 33). Although flows of these sizes are contained within the river banks of the lower Ord, they contribute significantly to the variability of wet season salinities of the estuary, especially in its upper reaches. Larger, less frequent floods (especially those that exceed bankfull levels; that is, greater than 4000 m^3/s) are sufficient to flush marine water from most of the estuary.

One example occurred in late February 2002. Salinities as low as 5100 mg/L TSS were recorded 8 km downstream of Panton Island (138 km downstream of the Kununurra Diversion Dam) on 27 February 2002. This was five days after the Ord

River peaked at 5300 m^3/s on 22 February 2002 at Tarrara Bar. Salinities are usually 20 000 to 40 000 mg/L TSS in this part of the estuary (see Figure 46).

If the larger floods coincide with a spring tide cycle, extensive areas of the floodplain and mudflat areas become inundated and can remain so for many days. Water has often been observed to drain off the floodplain back to the river channel as the tide recedes.

Given the above, and recognising that inflow variability will not change significantly under the scenarios studied, the range of estuarine salinities during the wet season are also not expected to change significantly in the future.

Responses to changes in dry season flows

Some changes are expected in dry season inflows between scenarios (Figure 30; Table 19). However, the resultant estuarine salinities are not expected to change significantly for the reasons elaborated below.

Initial investigations of the saltwater/freshwater interface in the estuary were undertaken at the end of the 1994 dry season. The aim was to determine the upward extent of salty water at times of spring tide and low Ord River inflow.

Figure 46 (adapted from Ruprecht & Rodgers 1999) shows the variation in salinity along the estuarine reach for two successive times of spring tides (4 Nov and 3 Dec 1994). The tidal range at the Wyndham tide gauge was 7.4 and 7.2 m on 4 November and 3 December respectively. The range measured at the Collins/Reedy Creek confluence on 3 December was 2.3 m (4.2 m high tide to 1.9 m low tide). At the time inflows to the estuary were low (42 m^3/s – 4 Nov) or very low (12 m^3/s – 3 Dec). Wet season runoff had not yet begun that season, and inflows were governed by releases from Lake Kununurra. The releases were reduced from 40 to 10 m^3/s a week before 3 December 1994. This provided the most favourable conditions for estuarine water to extend upstream.

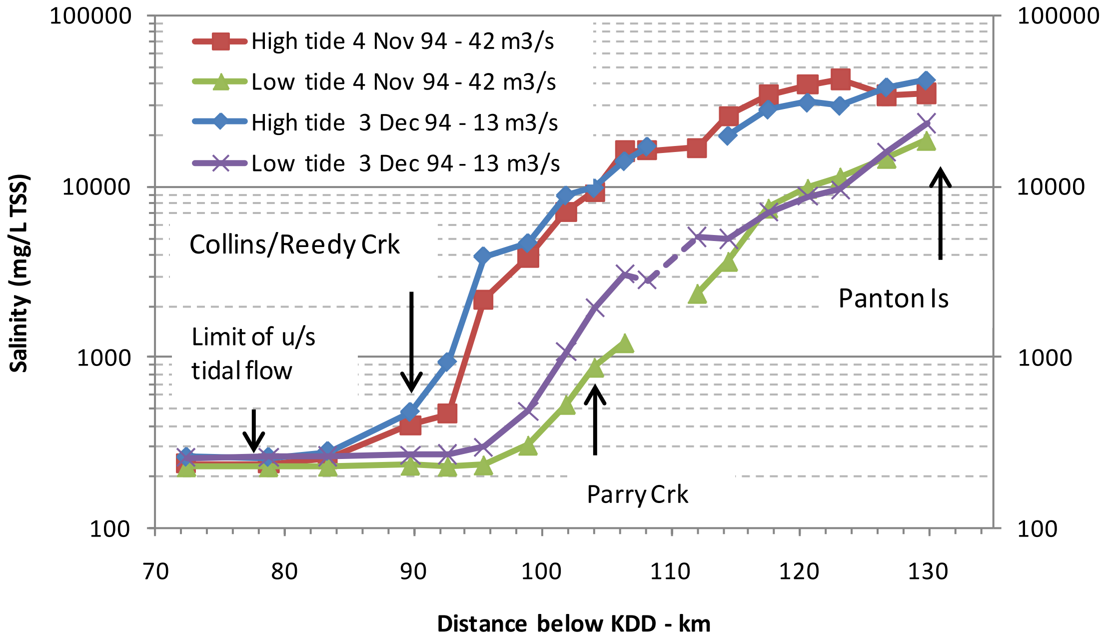


Figure 46 Ord Estuary salinities under different inflow and tidal conditions

The figure shows the transition from fresh water at 260 mg/L TSS (about 80 km downstream of the Kununurra Diversion Dam) to marine waters (about 33 000 to 40 000 mg/L TSS) near Panton Island a further 50 km downstream. The salinity differences at specific locations between high and low tides are much larger than differences caused by the reduction in inflow. Near the Parry Creek confluence, for example, the salinity was 9335 mg/L at high tide and 882 mg/L at low tide on 4 November 1994, when Ord River inflow was 42 m^3/s. A similar range, from 9798 to 1935 mg/L TSS, was recorded on 3 December 1994 when the inflow was only 13 m^3/s. (Note that flows as low as 13 m^3/s will no longer occur in the lower Ord because of the environmental flow regime.)

This is expected as fluxes of incoming estuarine salt and water each flood tide cycle are very much larger than the salt and water input from the river under typical dry season inflow rates (Figure 30). The following calculations were undertaken to demonstrate this point. Results of hydraulic modelling (Mike 11) were used to provide first-order estimates of salt and water loads over an incoming spring tide period at three different locations in the estuary (see Table 24). These were compared with the input of salt and water from the river for two dry season flow rates (70 and 45 m^3/s).

Table 24 shows that the river inputs are small percentages of the incoming tidal inputs each flood tide, especially in the lower reaches of the estuary.

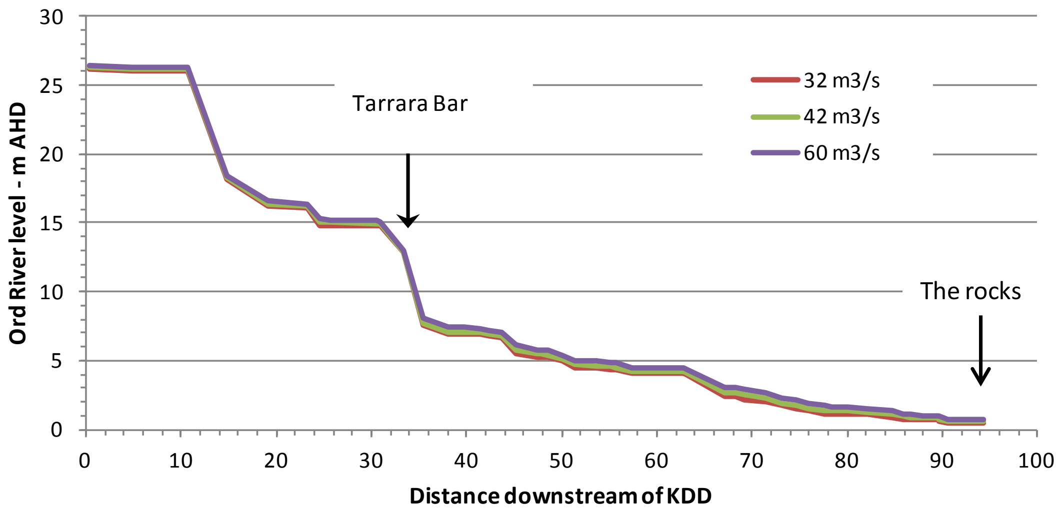
While the fresh/saline transmission zone can be expected to move in response to changes in dry season inflows, Figure 46 and Table 24 demonstrate that the movement each spring tidal cycle is much greater. The ecology of this transition zone is adapted to these large salinity ranges (Gehrke 2009).

Dry season flows are to remain predominantly in the range 32 to 60 m^3/s (see Figure 30). Figure 47 shows modelled water levels (to The Rocks) for these flow rates. The small water level differences with flow rate during the dry season are minor relative to the levels and flow rates driven by the tides.

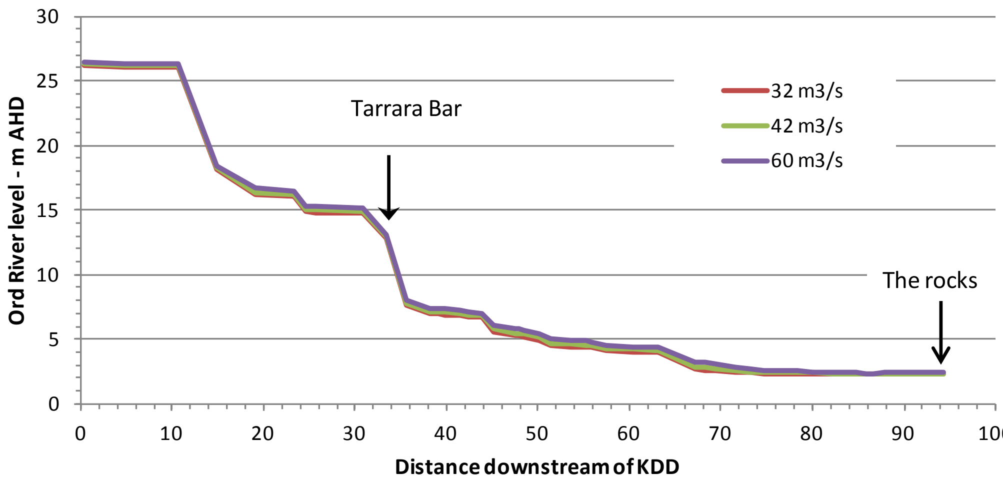
That is, changes in dry season flow rates expected under the five scenarios studied will have no significant impact on the range of salinities experienced in the Ord Estuary.

Table 24 Salt and water fluxes in the Ord Estuary over an incoming spring tide cycle

		Estuarine location		
	Units	**The Rocks – ~ 4 km d/s of Collins/Reedy Crk**	**Near Parry Creek**	**Near Panton Island**
Incoming tide				
Period	hrs	3.3	4.5	5.4
Max incoming flow rate	m^3/s	181	1631	16 435
Incoming tidal volume	m^3	1 269 970	14 564 685	127 722 028
Typical salinity	mg/L	1000	10 000	30 000
Incoming salt load	kg	1 269 970	145 646 849	3 831 660 838
River input (a)				
(a) at flow rate of	m^3/s	70	70	70
Input volume	m^3	161 096	159 676	168 393
as % of incoming tide	%	13%	1%	0%
inflow salinity	mg/L	200	200	200
salt load	kg	32 219	31 935	33 679
as % of incoming tidal salt load	%	2.5%	0.0%	0.0%
River input (b)				
at flow rate of	m^3/s	45	45	45
Input volume	m^3	103 562	102 649	108 252
as % of incoming tide	%	8.2%	0.7%	0.1%
salinity	kg/m^3	200	200	200
salt load	kg	20 712	20 530	21 650
as % of incoming tide	%	1.6%	0.0%	0.0%



(a) River levels for typical dry season flow rates – at low tide during a neap cycle



(b) River levels for typical dry season flow rates – at spring tide

Figure 47 Ord River levels at flow rates of 32, 42 and 60 m^3/s (to The Rocks)

Responses to changes in inflows over the annual cycle

DoW 2006 (Section 9.5) included estimates of Cambridge Gulf salinities over an annual cycle for a range of different river inflows (Figure 30, DoW 2006). While approximating salt and water mixing in the larger Cambridge Gulf embayment, the modelling helps us understand the factors that affect salinities at the lower end of the Ord Estuary.

Although based on the previous hydrology and reservoir simulations, as well as simple mixing assumptions, the Cambridge Gulf modelling demonstrated the following:

- salinities reduce in response to wet season inflows and gradually increase over the dry season to return to near starting salinities by the end of the dry season
- the degree of reduction depends on the magnitude of the wet season inflow
- variations in salinities between years was:
    - greatest before Ord River regulation
    - similar under ‘current conditions’ to conditions allowed under DoW 2006
- the additional diversions allowed under DoW 2006 increased salinities by about 1 ppt relative to salinities under the (then) current conditions (Table 18, DoW 2006).

While recognising the simplifications involved, the Cambridge salinity modelling clearly indicated that additional diversions allowed under the 2006 (and the 2012) plan would only have a marginal impact on the salinity of the lower Ord Estuary.

8.4.3 Limits of acceptable change in Ramsar areas

The department considers that only minor changes in the ecology of the Ramsar-listed areas will result from the lower Ord flow regimes expected under the allocation plan (sections 8.4.1 and 8.4.2 above). In fact it will be very difficult to attribute any ecological changes to specific water releases from Lake Argyle or water licensing decisions. The large natural variations in the hydrology, ecology and estuarine dynamics of the Ramsar areas are expected to mask any small changes that may occur.

Hale (2008) has argued against simply using a wider range than natural variability to define limits of acceptable change for the Ord River floodplain site, considering that:

> …changes in salinity as a result of water regulation may not result in changes to maximum and minimum values in the estuary, but significantly alter the distribution.

Large changes in salinity occur over a single tidal cycle and thus changes in salinities due to variations in dry season flows will be small (Section 8.4.2). Changes in lower Ord flows allowed under the allocation plan will not lead to any major differences in the distribution of salinities observed in the estuary.

Hale (2008) also argued that abiotic components based on hydrology, geomorphology and water quality can be used to establish short term ‘limits of acceptable change’ (Figure 47, Hale 2008). In taking this approach for hydrology, Hale proposed that connectivity between the Parry Lagoons and the estuary should occur every three to five years to maintain optimal ecological character. This is expected to occur from local rainfall and runoff from the catchments of Wild Goose Creek and Parry Creek, not from flooding of the Ord River (see Section 8.4.2).

A dry season salinity range of 30 to 35 ppt was set as a limit of acceptable change for estuarine salinity during the dry season (Table 17, Hale 2008). Although salinities along the estuarine reach are highly variable and strongly depend on location (Figure 46), dry season salinities in this range can be expected at the lower end of the estuary (near Panton Island and Sphinx Rock). Changes of about 1 ppt are considered an upper limit of possible increases due to the small changes in dry season inflows expected under the allocation plan (Table 24).

A dissolved oxygen concentration of at least 90 per cent of saturation has been set for estuarine waters (Table 17, Hale 2008). This estuarine water quality property will not be significantly affected by the management proposed in the allocation plan. The EWPs for the lower Ord River are designed to minimise the risk of having low dissolved oxygen in the incoming river water. The power of the tidal mixing also promotes dissolved oxygen entrainment. Estuarine dissolved oxygen levels will not be significantly affected by the proposed river management.

8.5 Monitoring of possible impacts

To check that the department's environmental provisions are meeting the stated objectives and that no unexpected impacts are occurring, an ongoing monitoring program has been developed. The monitoring program is outlined in the allocation plan (DoW 2012) and described in detail in the *Lower Ord River environmental water provisions monitoring program and management framework* (DoW 2011).

The Ord monitoring program specifies the different types of monitoring to be undertaken, the ecological and management triggers (the point when we predict changes in flow will cause rapid ecosystem changes), and the appropriate response for each management trigger and the responsible agency (e.g. Department of Water, OIC, Water Corporation).

Monitoring data will be assessed against the ecological triggers. If these triggers are repeatedly breached the EWP rules and operating strategy may need to be amended.

Appendices

Appendix A — Native title rights on the lower Ord River

Native title rights along the lower Ord River are held by the Miriuwung Gajerrong people as specified by the Federal Court of Australia in the consent determinations known as Miriuwung Gajerrong No.1 (9 December 2003) and Miriuwung Gajerrong No. 4 (24 November 2006). This appendix includes two tables of the key text relating to native title rights in relation to water in each determination

Table A1 Miriuwung Gajerrong No. 1 Determination – key aspects related to water

Para†	Key text from the paragraphs that relate to rights to water
9.2	..... non-exclusive rights to occupy, use and enjoy the land and waters in accordance with traditional laws and customs as follows: (a) the right of access to the land and waters; (b) the right to take fauna from the land and waters; (c) the right to take fish from the waters; (d) the right to take flora from the land and waters; (e) the right to take other natural resources of the land such as ochre, stones, soils, wood and resin; (f) the right to enter and remain on the land and waters; (g) the right to take water; (h) the right to engage in cultural activities on the land and waters, including to conduct ceremonies; and (i) the right to care for and maintain sites and areas that are of significance to the native title holders under their traditional laws and customs. These native title rights and interests do not confer possession, occupation, use and enjoyment of those land and waters on the native title holders to the exclusion of others.
11	There are no exclusive native title rights in or to flowing or subterranean water in the Determination Area.
14	The nature and extent of other interests in relation to the Native Title Area are the following, as they exist as at the date of the determination: (d) the interests of the holder of the licences described in paragraph (7) of Schedule 4 [includes licences granted under the *Rights in Water and Irrigation Act 1914* 7(g)] (k) the interest of the Crown, or any other person having responsibility from time to time for the operation or maintenance of the Ord Irrigation Project or any part of it, in the operation and maintenance of the 'Works' (as defined in the *Rights in Water and Irrigation Act 1914* (WA)) which form part of the Ord Irrigation Project as at the date of the determination;
15	The relationship between the native title rights and interests in the Native Title Area and the other rights and interests referred to in paragraph 14 (**other interests**) is that: (a) in relation to the other interests referred to in paragraph 14(a)–(f), (i)–(k), (m), (n) and (p) – the other interests, and the doing of any activity required or permitted to be done by or under the other interests, prevail over the native title rights and interests and any exercise of the native title rights and interests, but do not extinguish them, and the existence and exercise of the native title rights and interests does not prevent the doing of the activity; (b) in relation to the other interests referred to in paragraph 14(a)–(f), (i), (o) and (p) – to the extent that the other interests are inconsistent with the continued existence, enjoyment or exercise of the native title rights and interests, the native title continues to exist in its entirety, but the native title rights and interests have no effect in relation to the other interests to the extent of the inconsistency during the currency of those other interests. If those other interests are later removed or otherwise cease to operate, either wholly or partly, the native title rights and interests will again have full effect, wholly or partly as the case may be.

† Paragraph 9.1 defines areas where native title is held to the exclusion of others. The plan does not cover any such areas.

Table A2 Miriuwung Gajerrong No. 4 Determination – key aspects related to water

Para †	Key text from the paragraphs related to rights to water
9	.... they confer the following non-exclusive rights on the Native Title Holders, including the right to conduct activities necessary to give effect to them: (a) the right to access and move about the land; (b) the right to hunt and fish, to gather and use the resources of the land and waters such as food and medicinal plants and trees, timber, charcoal, ochre, stone and wax, and to have access to and use of water on or in the land and waters; (c) the right to live, being to enter and remain on the land, to camp and erect temporary shelters and other structures for that purpose, and to travel over and visit any part of the land and waters; (d) the right to light camp fires; (e) the right to do the following activities: (i) engage in cultural activities on the land; (ii) conduct ceremonies; (iii) hold meetings; (iv) teach the physical and spiritual attributes of places and areas of importance on or in the land and waters; (v) participate in cultural practices relating to birth and death, including burial rights; and (vi) record, conserve, maintain and curate sites and activities arising in subparagraphs (i) to (v) above; (f) the right to have access to, maintain and protect places and areas of importance on or in the land and waters, including rock art, engraving sites and stone arrangements; (g) the right to make decisions about the use and enjoyment of the land and waters by the Native Title Holders; and (h) the right to share or exchange subsistence and other traditional resources obtained on or from the land and waters.
10	The nature and extent of the native title rights and interests in relation to the flowing, tidal and underground waters of the Determination Area are that they confer on the Native Title Holders non-exclusive rights to: (a) hunt, gather and fish on, in and from the flowing, tidal and underground waters for personal, domestic, social, cultural, religious, spiritual, ceremonial or communal needs but not for commercial purposes; (b) take, use and enjoy the flowing, tidal and underground waters and natural resources and fish in such waters for personal, domestic, social, cultural, religious, spiritual, ceremonial or communal needs but not for commercial purposes.

† Paragraph 8 defines rights to other areas to the exclusion of others. These are generally small and are mainly offshore islands not in the plan area.

Appendix B — Environmental water during droughts

Not all water demands can be met in all years (Section 6.1). As described in Section 6.2 a reservoir simulation approach was used to evaluate a range of restriction policies to determine how to best share the resource through periods of drought. This included developing a policy to restrict environmental water releases during times of low storage in Lake Argyle, but only to the extent that the riverine environment would not be substantially affected during the drought and was capable of rapid recovery soon after the drought.

Under normal operations, releases for Lake Argyle storage are made to ensure the EWR regime is met in the lower Ord River. Flow rates less than the EWR regime were considered reasonable to consider during periods of shortage provided the likely impacts of the lower flows were minor and temporary. This appendix describes how different environmental water restriction policy options were assessed and the final EWP regime selected. Appendix C details the environmental water regime adopted and tables D1 to D5 of Appendix D list the water levels in Lake Argyle at which environmental water (and other) restrictions are triggered.

B.1 Kununurra Diversion Dam to House Roof Hill

The comprehensive EWR regime for the lower Ord (Chapter 4) includes:

- a continuous baseflow component that applies throughout the year
- wet season flow components that consist of:
  - a set of higher flow events, expected to be achieved for a specified number of days in four out of five wet seasons, and
  - infrequent inter-annual wet season flood events (to be met by Dunham River flows).

The infrequent inter-annual wet season flood events are not expected during times of drought and are therefore not discussed further here.

Table B1 summarises the environmental water restriction policy options studied to determine how to best share water between competing needs during periods of shortage (drought).

The eight EWP options formed input to multiple runs of reservoir simulations. These were carried out using the iteration strategy and simulation criteria described in Section 6.2. The simulation runs that produced satisfactory or near satisfactory water supply and reservoir criteria were then considered in more detail.

This was undertaken in two stages. Firstly, the simulated lower Ord flows were compared with the target EWR regime over the 99 (calendar) years studied. Secondly, the different periods and degrees of shortfall were assessed for their likely ecological consequences. The ecological assessment involved three rounds of consultation with the department's scientific panel of ecological experts. (The panel was established to help the department determine the EWR for the lower Ord and was therefore familiar with the process and the Ord River system. Many of the panel members had been involved in ecological and/or geomorphological investigations of the lower Ord since 2000.)

Table B1 Restriction policy options for environmental water and their supply implications

Option	Description of environmental water restriction policy during times of drought	Irrigation supply and reservoir operational implications
1	Reduction of the EWR by 12% in all components	Did not meet minimum supply and reservoir operational criteria
2	Reduction of the EWR by 23% in all components	Minimum supply and reservoir criteria substantially met
3	Extra wet season baseflows removed (wet and dry season baseflows set as the same)	Did not meet minimum supply and reservoir operational criteria
4	All wet season peaks removed	Did not meet minimum supply and reservoir operational criteria
5	All wet season peaks removed. Wet season baseflow and dry season flows reduced by 12% (an additional option of reducing dry season flows by 23% was also modelled in 5% of years)	Supply criteria were met but the minimum reservoir operating level was not (for *scenario III*)
6	Wet season peaks of 425 m^3/s and 300 m^3/s removed. Remaining flows reduced by 23% in 5% of years	Irrigation reliability met but supply restrictions severe and minimum reservoir level criterion not met
7	Wet season peaks of 425 m^3/s and 300 m^3/s removed. A two-step approach of reducing flows by 12%, and 23% in very dry years (5% of years)	Minimum supply and reservoir criteria substantially met
6–7	Combination of Option 6 and 7. A 23% reduction for January to March and a two-step reduction (12% to 23%) for rest of year	Minimum supply and reservoir criteria substantially met

The first four options did not meet the reservoir criteria (option 1), did not meet the EWR regime frequently enough (option 2), or were unsatisfactory from both a water supply and environmental perspective (options 3 and 4). The remaining four options substantially met most or all of the supply and reservoir criteria, and reflected the combinations of different environmental restrictions applied during the wet and dry seasons. Options 6 and 7 were developed following initial feedback from the scientific panel. Options 1 to 5 did not provide sufficient flow variability during the wet seasons of drought years.

B.1.1 Ecological implications of EWP options

In seeking a preferred EWP restriction policy, the ecological implications of all eight options were considered. This was done by reviewing which components of the EWR would be met or not met under each option. The implications of not meeting each component were then discussed with the expert panel.

Tables B2 and B3 present dry and wet season flow-ecology linkages either met or not met under each restriction option. The resulting wet season baseflows provided by a 12 and 23 per cent reduction are listed in Table B4.

The tables reflect the way the different options were defined and simulated.

Table B2 Dry season flow-ecological links – met/not met under the various EWP options

Flow-ecology linkage(s)	EWR flow requirement	EWP options †							
		1	2	3	4	5	6	7	6–7
1a	Minimum of 42 m^3/s in reach 1 and reach 2	✗	✗	✓	✓	✗(✗)	✓(✗)	✗(✗)	✗(✗)
1c	Minimum of 37 m^3/s in reach 1 and reach 2	✓	✗	✓	✓	✓(✗)	✓(✗)	✓(✗)	✓(✗)
1g, 2d, 7a	Trigger level of 35 m^3/s in reach 1 and reach 2 (start DO monitoring if flows fall below 35 m^3/s)	✓	✗	✓	✓	✓(✗)	✓(✗)	✓(✗)	✓(✗)
2b	Minimum of 25 m^3/s in reach 1 and reach 2	✓	✓	✓	✓	✓(✓)	✓(✓)	✓(✓)	✓(✓)
2d, 3a	Minimum of 10 m^3/s in reach 1, reach 2 and reach 3	✓	✓	✓	✓	✓(✓)	✓(✓)	✓(✓)	✓(✓)
1b, 2a, 2c	Limited rate of change from one dry season to the next (effective when mean discharge for the previous Oct/Nov was above 70 m^3/s)	✓	✓	✓	✓	✓(✓)	✓(✓)	✓(✓)	✓(✓)

† Flow-ecology link met (✓) or not met (✗). Where two responses are shown, the first response relates to the first restriction step. The response in brackets relates to the second restriction step.

The degree to which lower Ord flows are less than the desired EWR is not solely dependent on the EWP option. It is also dependent on the demand scenario simulated. Table B5 more clearly distinguishes the differences between the EWP options, under high irrigation and power demands (*scenario III)*. Table B5 lists the percentage of time that flows in the lower Ord are in the flow ranges specified. The flow ranges specified reflect the main flow-ecological links of the dry season EWR regime (Table 12).

Table B3 Wet season flow targets – met/not met for alternative EWP restriction options

Flow-ecology linkages	Flow requirements	EWP option †							
		1	2	3	4	5	6	7	6–7
3c	Minimum of 50 m³/s in January	✗	✗	✗	✓	✗(✗)	✓(✗)	✗(✗)	✗(✗)
	Minimum of 57 m³/s in February and March	✗	✗	✗	✓	✗(✗)	✓(✗	✗(✗)	✗(✗)
	Minimum of 53 m³/s in April	✗	✗	✗	✓	✗(✗)	✓(✗)	✗(✗)	✗(✗)
	Minimum of 48 m³/s from 1 to 15 May	✗	✗	✗	✓	✗(✗)	✓(✗)	✗(✗)	✗(✗)
3b	Flows greater than 100 m³/s for a minimum 18 days per year in reach 2	✗	✗	✓	✗	✗	✗	✗	✗
1d, 1e, 8a	Four spells above 125 m³/s with a total duration of at least 10 days in reach 1	✗	✗	✓	✗	✗	✗	✗	✗
	Two spells above 200 m³/s with a total duration of at least five days in reach 2	✗	✗	✓	✗	✗	✗	✗	✗
	One spell above 300 m³/s with a minimum duration of two days in reach 3	✓	✗	✓	✗	✗	✗	✗	✗
1f	One spell above 425 m³/s with a minimum duration of two days in reach 1	✗	✗	✓	✗	✗	✗	✗	✗
	Minimum of 20 m³/s in reach 2	✓	✓	✓	✓	✓	✓	✓	✓
	Minimum of 10 m³/s in reach 3	✓	✓	✓	✓	✓	✓	✓	✓
4a ,8c	High-flow event of at least 750 m³/s every two years in reach 1	NA	NA	NA	NA	NA	NA	NA	NA
	High-flow event of at least 1400 m³/s every four years in reach 2	NA	NA	NA	NA	NA	NA	NA	NA
5a, 6a, 8b, 8d	Flood event with peak mean daily flow of 3700–4000 m³/s every 27–35 years in reaches 1, 2 and 3	NA	NA	NA	NA	NA	NA	NA	NA

† Flow-ecology link met (✓) or not met (✗). Where two responses are shown, the first response relates to the first restriction step. The response in brackets relates to the second restriction step.

Table B4 Wet season baseflows under 12 and 23 per cent reductions

EWR wet season baseflows	12%	23%
Minimum of 50 m³/s in January	44	38
Minimum of 57 m³/s in February and March	50	43
Minimum of 53 m³/s in April	47	40
Minimum of 48 m³/s from 1 to 15 May	42	37

Table B5 Lower Ord flows under scenario III – options 5, 6, 7 and 6-7 (% of days in range)

Flow/flow range	Option 5	Option 6	Option 7	Option 6–7
Equal to 32 m³/s	2.1%	2.7%	1.5%	1.5%
Greater than 32 m³/s to less than or equal to 37 m³/s	12.1%	2.9%	7.6%	6.1%
Greater than 37 m³/s to less than 42 m³/s	12.3%	3.4%	8.2%	7.1%
Equal to 42 m³/s	67.0%	63.0%	63.1%	63.5%
Greater than 42 m³/s	6.5%	28.0%	19.6%	21.8%

Table B5 demonstrates the following points:

- under option 5 only 6.5 per cent of flows occur above the dry season target of 42 m^3/s, indicating very limited periods of high flow during the wet season
- option 6 has the smallest percentage of time with flows in the range of less than 42 m^3/s, a result of applying more severe restrictions in fewer years than the other options
- under option 7 the lowest flow of 32 m^3/s occurs for only 1.5 per cent the time, with the highest flows (greater than 42 m^3/s) occurring for a modest 19.6 per cent of the time
- option 6-7, being a refinement of option 7, had a similar period of lowest flows (1.5 per cent), but increased to 21.8 per cent for the period of high (wet season) flows above 42 m^3/s.

B.1.2 Identification of a preferred drought restriction option

From the ecological perspective options 6, 7 and 6-7 were considered acceptable. Options 7 and 6-7 have the lowest percentage of time with flows less than 37 m^3/s. The scientific panel considered that flow rates less than 35 m^3/s, if coinciding with low wind speeds over the river, could risk low levels of dissolved oxygen developing at depth in pools of the lower Ord River. Option 6, while having more flow at 32 m^3/s, had more flows at rates greater than 42 m^3/s, and hence more wet season variability: a characteristic the expert panel also considered important to the river's overall ecological health.

While options 5, 6, 7 and 6-7 substantially met most or all the irrigation and reservoir operational criteria, options 7 and 6-7 were preferable, especially under the high demands of *scenario III*. Option 6 produced the most severe irrigation restrictions. In the worst year of the 1930s drought, only 18 per cent of the irrigation entitlement could be supplied.

As option 5 was not favoured ecologically because of its low wet season flow variability, and option 6 produced excessively severe irrigation restrictions, the final choice was between options 7 and 6-7.

Option 6-7 was a refinement of option 7 that provided less flow below the dry season target of 42 m^3/s and more flow above 42 m^3/s (wet season flow variability). Hence, option 6-7 was adopted as the preferred EWP restriction policy and considered the best way to balance the competing needs of the environment and irrigation during times of water shortage.

B.2 Downstream of House Roof Hill

An additional 115 GL was allocated downstream of House Roof Hill for future irrigation developments on the Mantinea Flats and Carlton Plain area in DoW (2006).

The 115GL allocation is likely to be abstracted at an average rate of 5 m^3/s over a notional 38-week period of the year (e.g. mid March to early December – the actual areas and types of crops will dictate the seasonal pattern of demand). The dry season abstraction rate is to be limited to a maximum of 5 m^3/s.

Initial investigations for the interim EWP had shown that the river channel from about 56 km downstream of the Kununurra Diversion Dam, near House Roof Hill, became predominately U shaped, as opposed to the reach between the Kununurra Diversion Dam and House Roof Hill that contained benches with more gradual side slopes.

Because of the simpler channel morphology downstream of House Roof Hill, a 5 m^3/s reduction in flow rate was considered acceptable because sufficient aquatic habitat (as measured by the 'wetted perimeter') was still maintained along the reach (Appendix 3, DoW 2006).

A similar 5 m^3/s reduction was considered likely to be acceptable, but needed to be tested using the new flow-ecological linkage methodology. The following section describes the assessment of the ecological implications of maintaining 37 m^3/s downstream of House Roof Hill in this reach during the dry season.

B.2.1 Ecological risks of reducing flows by 5 m^3/s below House Roof Hill

The river consists predominantly of deep pools along the 20 km downstream of House Roof Hill to the tidal limit. A flow rate of 37 m^3/s will maintain this deep pool habitat over the dry season (Table 12) and thereby provide habitat for large-bodied fish (flow-ecological linkage 1c, Table 11). With the exception of shallow backwater habitat, a flow rate of 37 m^3/s is also sufficient to meet the other flow-ecology linkages of Table 12.

Impacts on backwater habitat

The 5 m^3/s reduction will primarily affect shallow backwater areas, a preferred habitat for small-bodied fish and juveniles of large-bodied fish. The RAP analysis (Table 12) indicated that 42 m^3/s is necessary to meet this flow-ecology linkage (1a, Table 11).

Nine backwater sites were used in determining the flow requirement for shallow backwaters in reach 2 (two of which were downstream of House Roof Hill).

Investigation of cross-section levels at these sites indicated an average 10 cm reduction in maximum backwater depth and a 16 per cent reduction in functional backwater habitat associated with the reduction of flows from 43 to 37 m^3/s (Table B6).

The majority of backwaters have a maximum (cross-sectional) depth of at least 20cm. Therefore while a 5 m^3/s reduction in flows may reduce the size and depth of shallow backwaters it should not result in the total loss of any existing backwater habitats.

Analysis of existing backwater habitat in reach 2 using aerial photographs taken in 2004–05 found there to be more backwater habitat available upstream of House Roof Hill than downstream (Table B7).

Sixty-three per cent of backwater habitat (by area) in reach 2 is upstream of House Roof Hill and therefore not affected by an additional allocation of water downstream of House Roof Hill.

Of the 12 backwaters downstream of House Roof Hill, two were located downstream of Mambi Island and were thus potentially affected by tidal influences. Field observations indicate that water levels in these backwaters may vary by up to 30 cm during spring tides.

Table B6 Discharge stage height relationship for shallow backwaters

Maximum depth (cm)	Mean discharge required (m^3/s)	Percentage of functional habitat available (% of cross-sectional area)
20	23	0
30	29	16
40	37	37
50	43	53
60	52	76
70	61	100

Consequently, it may be less likely these backwaters are adversely affected by a 5 m^3/s reduction in flows.

With most shallow backwaters (23) located upstream of House Roof Hill and only minimal impact expected on the 10 backwaters downstream of it, an allocation of 5 m^3/s downstream of House Roof Hill was considered acceptable.

Table B7 Backwaters in reach 2

	Number of backwaters	Average surface area (m^2)	Average length (m)	Estimated total area of backwaters (m^2)
Upstream of House Roof Hill	23	4400	180	101 000
Downstream of House Roof Hill	12	5000	240	60 000

Impacts during the wet season

Irrigation demand will be reduced during the wet season but there is still potential for reductions in flow. As a worst case scenario, a 5 m^3/s reduction in flow would impact wet season baseflows, as shown in Table B8.

Wet season irrigation demand is likely to be low from January to March, therefore demands of up to 5 m^3/s may potentially only impact on wet season baseflows during April and May.

Reducing baseflow by 5 m^3/s towards the end of the wet season is likely to reduce water depths by 5 to 10 cm downstream of House Roof Hill. This is likely to have a minimal impact on ecological values.

The reduction in flows is also expected to have no obvious impact on wet season peak flows in reach 2. The magnitude and short duration of such events which occur after high rainfall events (when irrigation demand is minimal) ensures that any impact would be negligible.

Table B8 Wet season baseflow below House Roof Hill

Month	Baseflow EWR (m^3/s)	Baseflow EWP (m^3/s)
January	50	45
February	57	52
March	57	52
April	53	48
May (1 to 15)	48	43

B.2.2 Environmental water below House Roof Hill in drought periods

Under the adopted EWP regime (Appendix C), the environmental flow regime to be met is reduced in two steps during drought periods (approximately 10 per cent of the time). The first step is a 12 per cent reduction of dry season flows to 37 m^3/s, followed by a second step of a 23.8 per cent reduction to 32 m^3/s in severe drought periods. During these severe drought periods, water supplied to irrigation may be reduced by up to 75 per cent (i.e. announced allocations would be around 25 per cent of the water entitlements granted, under worst case conditions).

During drought periods (first step of environmental water restrictions), an abstraction rate of 5 m^3/s downstream of House Roof Hill would reduce the dry season flow from 37 m^3/s to 32 m^3/s. This would result in reduced flows agreed acceptable during severe drought periods (second step restrictions). Although flows of 32 m^3/s will occur more frequently below House Roof Hill than upstream, deep pool habitat will not change significantly and monitoring of dissolved oxygen at depth in river pools is planned (see next section).

During severe drought periods (second step restrictions for environmental water), irrigation allocations downstream of House Roof Hill will also be restricted. However, because the soils of the down-river areas are predominantly suitable for permanent plantings, restrictions are planned to be less severe than in Stage 1 and M2 areas. Based on limiting restrictions in down-river areas to no more than 40 per cent of granted water entitlements during severe restrictions, the abstraction rate under severe drought conditions would not exceed 2 m^3/s.

Abstracting 2 m^3/s downstream of House Roof Hill would further reduce flows from 32 to 30 m^3/s. This is in line with the interim EWP from DoW (2006), which allocates 30 m^3/s downstream of House Roof Hill in the driest five per cent of years.

Contingency monitoring of dissolved oxygen

While the expert panel were willing to accept a further reduction in flows below House Roof Hill, given the relative abundance of shallow backwater habitat upstream of this point and the anticipated low frequency of such severe restrictions, its members remained concerned about the potential risk of anoxia downstream of (the eastern end of) House Roof Hill.

To address this concern, the department's monitoring requirements for lower Ord River will include contingency monitoring of dissolved oxygen levels in pools downstream of licensed abstractions when flow rates are planned to fall below 35 m^3/s. If low dissolved oxygen concentrations are recorded by the monitoring, additional releases from storage can be ordered at short notice.

Appendix C — The environmental water provision

C1 Description of EWP flow regime

Consistent with the EWR, the EWP regime consists of a continuous 'baseflow' component that applies throughout the year (Table C1) and a set of higher-flow events (Table C2) expected to be achieved for a specified numbers of days.

The EWP regime also involves avoiding short-term reductions in dry season flow rates and large reductions in flow from the end of the previous dry to the end of the early months of the following dry season.

The area downstream of House Roof Hill has reduced wet and dry season baseflow requirements compared with areas upstream of House Roof Hill.

The flow regime expected to be maintained in the lower Ord River in drought conditions is based on the implementation of option 7, which aims to maintain maximum variability under drought restrictions.

C2 Continuous 'baseflow' EWP regime

Table C1 summarises the continuous flow rates to be maintained throughout the year. Two classes of restrictions were adopted to apply to the full EWR regime, as shown in Table C1.

The required flow rates are a function of the month of the year and the class of restrictions applicable at the time. The water levels in Lake Argyle that define the different classes of restrictions are shown in Figure C1.

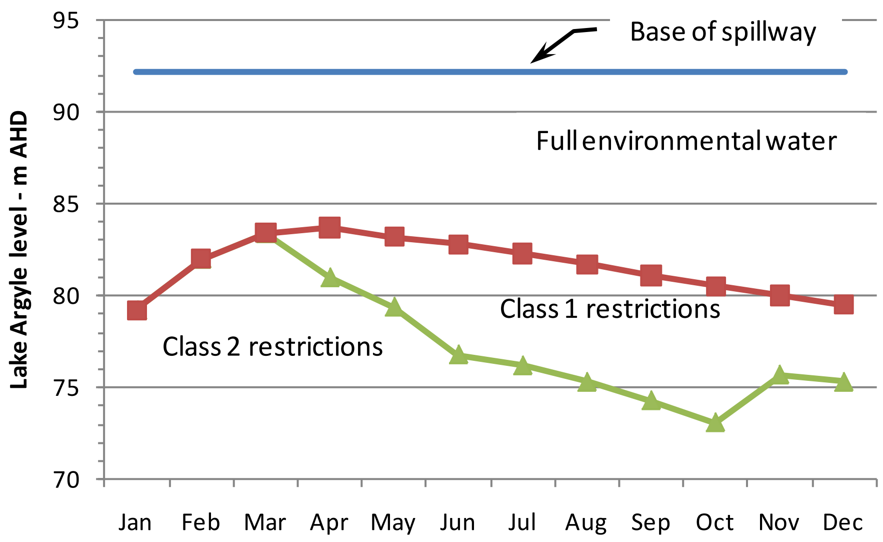


Figure C1 Lake Argyle levels at which EWP class 1 and class 2 restrictions apply

Table C1 Continuous 'baseflow' EWP regime for the lower Ord River

	The EWP regime when restrictions do not apply		**The EWP regime when class 1 restrictions apply**		**The EWP regime when class 2 restrictions apply**	
	When water in Lake Argyle is higher than	The (EWR) flow rates required	When water in Lake Argyle is in the range shown below	EWP flow rates required	When water in Lake Argyle falls below the levels shown below	EWP flow rates required
	m AHD	m^3/s	m AHD	m^3/s	m AHD	m^3/s
January	79.2	50	-	-	79.2	39
February	82.0	57	-	-	82.0	44
March	83.4	57	-	-	83.4	44
April	83.7	53	-	-	81.0	41
May	83.2	48*	83.2 to 79.4	37	79.4	32
June	82.8	42	82.8 to 76.8	37	76.8	32
July	82.3	42	82.3 to 76.2	37	76.2	32
August	81.7	42	81.7 to 75.3	37	75.3	32
September	81.1	42	81.1 to 74.3	37	74.3	32
October	80.5	42	80.5 to 73.1	37	73.1	32
November	80.0	42	80.0 to 75.7	37	75.7	32
December	79.5	42	79.5 to 75.3	37	75.3	32

** The May EWP flow requirement drops from 48 to 42 m^3/s on 15 May*

C3 The wet season high-flow regime

In addition to the continuous 'baseflow' component of the EWP, a set of higher flow events also form part of the regime that makes up the EWP. These higher flow events inundate and maintain local habitats (e.g. riparian benches) that are important for the health of the river's aquatic flora and fauna, as well as its riparian vegetation.

Table C2 presents the target flow rates and expected periods of inundation when restrictions do not apply. Table C3 defines the high-flow events expected when EWP restrictions apply during drought conditions.

As the target peak flow events of tables C2 and C3 are to be achieved in four out of five years, the Water Corporation will be required to carry out top-up releases from Lake Kununurra if flows at Tarrara Bar have not met the targets in one or more of the preceding four wet seasons.

Note that the target flow regime will be a combination of tables C2 and C3 if water levels change from drought to non-drought (or vice versa) during the course of a wet season.

Table C2 Wet season‡ high-flow regime expected when EWP restrictions do not apply†

Number of flow events over the wet season	Total target duration (days)	Duration remaining if (higher) flow targets have been met (days)	Average daily discharge (m^3/s)
Two separate events	5	3	≥ 200
Four separate events	10	5	≥ 125
Events not applicable	18	8	≥ 100

‡ The wet season is to be taken from 1 November to 30 April the following year. However, if heavy and early wet season rains generate high-flow events in October that meet the criteria, these can be included.

† When Lake Argyle levels are > 82.0 m AHD in February, > 83.4 m AHD in March and > 83.7 m AHD in April

Table C3 Wet season high-flow regime expected when EWP restrictions apply†

Number of flow events over the wet season	Total target duration (days)	Duration remaining if (higher) flow targets met (days)	Average daily discharge (m^3/s)
Two separate events	5	3	≥ 154
Four separate events	10	5	≥ 96
Events not applicable	18	8	≥ 77

† When Lake Argyle levels are < 82.0 m AHD in February, < 83.4 m AHD in March and < 83.7 m AHD in April

Appendix D — Reservoir modelling detail

Section 6.2 outlined the reservoir simulation model used to produce the results reported in this document. This appendix provides extra detail on the model inputs, outputs and the post-processing of the results. It should be read with the technical report on the reservoir simulations (Smith & Rodgers 2010).

D1 Model inputs, output and post-processing of results

As detailed in Section 2.2, long-term time-series (98 water years – 99 calendar years) of daily streamflow data formed the primary hydrologic input to the model. Three sets of inflows were used:

- inflows to the Ord River Dam from the upper Ord catchment
- inflows to the Kununurra Diversion Dam from the catchment between the dams
- inflows to the lower Ord River (downstream of the Kununurra Diversion Dam) from the Dunham River catchment.

Other key inputs include the following:

- Lake Argyle's storage/surface area/elevation relationships
- hydropower, irrigation and environmental water demands, respectively located at the power station, Lake Kununurra and below the Dunham River confluence
- turbine characteristics of the Ord power station (provided by Pacific Hydro in 2007)
- power station water release rules, and irrigation and environmental flow restriction policies (expressed as functions of the water level in Lake Argyle in each month).

D2 Model outputs

The model calculates the following outputs from Lake Argyle:

- releases from the Ord River Dam outlet works
- the electricity generated by the Ord River Dam power station
- Lake Argyle spillway flows
- net evaporation loss from Lake Argyle.

The model also calculates the following outputs from Lake Kununurra:

- water diverted to meet the three irrigation demands (Stage 1, Stage 1 growth, and the new M2 supply area)
- releases made to the lower Ord River, under the Kununurra Diversion Dam gates.

The model's output at the lower Ord River node (just downstream of the Dunham River confluence) was simply the flow in the Ord River (at the node), calculated as the sum of the Kununurra Diversion Dam releases and the input from the Dunham River catchment.

D4 Post-processing of results

The department also undertook additional post-processing of the simulation results to more clearly identify differences between runs and demonstrate the key factors causing the differences.

In relation to the power station release rules, the post-processing determined the amount of electricity generated when the power station water release rules:

- were only limited by the capacity of the (current) power station (unrestricted)
- limited generation to the minimum guaranteed in the original water supply agreement for the power station (210 GWh/yr)
- limited flows through the power station to releases required to meet the Water Corporation's downstream obligations (to supply irrigation and environmental needs)
- limited generation to the electricity demand from Kununurra and Wyndham.

The post-processing analysis also estimated contributions to (the simulated) flows in the lower Ord River. For example, the lower Ord flow at the point (node) just downstream of the Dunham River confluence was partitioned into the following contributions:

- surplus releases and spillage from Lake Argyle, in excess of those diverted from Lake Kununurra
- inflows from the catchment between the dams, in excess of the catchment inflows diverted from Lake Kununurra
- inflows from the Dunham River catchment.

Estimates were also made of extra inflows that enter downstream of the Dunham River confluence. These included contributions from the catchments described in Section 2.5 and drainage flows from the irrigated areas of Stage 1. This enabled estimation of Ord River flows at the subarea outlets of the Ord River catchment below the Ord River Dam.

D5 Restriction policies

Smith and Rodgers (2010) documented the restriction policies developed for each scenario and these are repeated here for convenience (see the following tables). They include the levels in Lake Argyle at which different restriction classes start, and the degree of restriction/supply applicable, until the next water level and restriction class begins.

Hydropower limits are expressed as a maximum megawatt output allowed to be generated independent of other releases from Lake Argyle. Irrigation restrictions are expressed as a percentage of the water demand allowed to be supplied. The EWP restriction policy is expressed as the continuous daily flow target, expressed in m^3/s, to be maintained in the lower Ord River.

The reservoir simulation calculations were performed each day. Hence the water levels were checked against the restriction policy triggers each day, and the appropriate restricted demands used in each daily water balance calculation.

Note that, in practice, not all the restriction policies will be implemented on a daily basis. However, the daily modelling approach enabled appropriate monthly trigger levels for each restriction class to be determined by simulation.

The Ord surface water allocation plan (DoW 2012) describes how the different restriction policies will be implemented in practice.

Table D1 Scenario I restriction policies – the recent past

Month	Power						Irrigation				EWP			
	Class 1		***Class 2***		***Class 3***		***Class1***		***Class 2***		***Class 1***		***Class 2***	
	Water level	Restricted target	Water level	Restricted target	Water level	Restricted target	Water level	Proportion supplied	Water level	Proportion supplied	Water level	Restricted flow	Water level	Restricted flow
	m AHD	MW	m AHD	MW	m AHD	MW	m AHD	%	m AHD	%	m AHD	m^3/s	m AHD	m^3/s
Jan	92.20	24.51	78.00	10.12	76.00	0.00	75.20	50	73.50	0	79.20	44.00	79.20	38.50
Feb	92.20	23.22	78.00	11.23	76.00	0.00	77.00	50	73.50	0	82.00	50.20	82.00	43.90
Mar	92.20	24.41	78.00	10.56	76.00	0.00	77.00	50	73.50	0	83.40	50.20	83.40	43.90
Apr	92.20	23.54	78.00	10.64	76.00	0.00	79.00	50	73.50	0	83.70	46.60	81.00	40.80
May	92.20	22.46	78.00	8.76	76.00	0.00	79.40	50	73.50	0	83.20	42.20	79.40	37.00
Jun	92.20	22.40	78.00	8.13	76.00	0.00	79.00	50	73.50	0	82.80	37.00	76.80	32.00
Jul	92.20	23.05	78.00	8.00	76.00	0.00	78.40	50	73.50	0	82.30	37.00	76.20	32.00
Aug	92.20	24.19	78.00	8.39	76.00	0.00	77.70	50	73.50	0	81.70	37.00	75.30	32.00
Sep	92.20	24.96	78.00	10.98	76.00	0.00	76.80	50	73.50	0	81.10	37.00	74.30	32.00
Oct	92.20	24.30	78.00	12.62	76.00	0.00	76.00	50	73.50	0	80.50	37.00	73.10	32.00
Nov	92.20	26.85	78.00	12.89	76.00	0.00	75.70	50	73.50	0	80.00	37.00	75.70	32.00
Dec	92.20	23.85	78.00	10.18	76.00	0.00	75.30	50	73.50	0	79.50	37.00	75.30	32.00

Table D2 Scenario II restriction policies – currently licensed

Month	Power						Irrigation				EWP			
	Class 1		***Class 2***		***Class 3***		***Class1***		***Class 2***		***Class 1***		***Class 2***	
	Water level	Restricted target	Water level	Restricted target	Water level	Restricted target	Water level	Proportion supplied	Water level	Proportion supplied	Water level	Restricted flow	Water level	Restricted flow
	m AHD	MW	m AHD	MW	m AHD	MW	m AHD	%	m AHD	%	m AHD	m^3/s	m AHD	m^3/s
Jan	88.00	24.51	78.00	10.12	76.00	0.00	74.90	50%	73.50	0%	79.20	44.00	79.20	38.50
Feb	89.20	23.22	78.00	11.23	76.00	0.00	77.00	50%	73.50	0%	82.00	50.20	82.00	43.90
Mar	90.80	24.41	78.00	10.56	76.00	0.00	77.00	50%	73.50	0%	83.40	50.20	83.40	43.90
Apr	90.80	23.54	78.00	10.64	76.00	0.00	79.00	50%	73.50	0%	83.70	46.60	81.00	40.80
May	90.45	22.46	78.00	8.76	76.00	0.00	79.40	50%	73.50	0%	83.20	42.20	79.40	37.00
Jun	90.15	22.40	78.00	8.13	76.00	0.00	78.80	50%	73.50	0%	82.80	37.00	76.80	32.00
Jul	89.85	23.05	78.00	8.00	76.00	0.00	78.00	50%	73.50	0%	82.30	37.00	76.20	32.00
Aug	89.45	24.19	78.00	8.39	76.00	0.00	77.40	50%	73.50	0%	81.70	37.00	75.30	32.00
Sep	89.05	24.96	78.00	10.98	76.00	0.00	76.70	50%	73.50	0%	81.10	37.00	74.30	32.00
Oct	88.61	24.30	78.00	12.62	76.00	0.00	75.90	50%	73.50	0%	80.50	37.00	73.10	32.00
Nov	88.20	26.85	78.00	12.89	76.00	0.00	75.40	50%	73.50	0%	80.00	37.00	75.70	32.00
Dec	88.05	23.85	78.00	10.18	76.00	0.00	75.00	50%	73.50	0%	79.50	37.00	75.30	32.00

Table D3 Scenario III restriction policies – licensed to allocation limits, high power demand

Month	Power						Irrigation				EWP			
	Class 1		***Class 2***		***Class 3***		***Class1***		***Class 2***		***Class 1***		***Class 2***	
	Water level	Restricted target	Water level	Restricted target	Water level	Restricted target	Water level	Proportion supplied	Water level	Proportion supplied	Water level	Restricted flow	Water level	Restricted flow
	m AHD	MW	m AHD	MW	m AHD	MW	m AHD	%	m AHD	%	m AHD	m^3/s	m AHD	m^3/s
Jan	89.30	24.51	89.30	10.12	76.00	0.00	75.20	50%	73.50	0%	79.20	44.00	79.20	38.50
Feb	90.20	23.22	90.20	11.23	76.00	0.00	77.00	50%	73.50	0%	82.00	50.20	82.00	43.90
Mar	91.10	24.41	91.10	10.56	76.00	0.00	77.00	50%	73.50	0%	83.40	50.20	83.40	43.90
Apr	91.45	23.54	91.45	10.64	76.00	0.00	79.00	50%	73.50	0%	83.70	46.60	81.00	40.80
May	91.30	22.46	91.30	8.76	76.00	0.00	79.40	50%	73.50	0%	83.20	42.20	79.40	37.00
Jun	91.00	22.40	91.00	8.13	76.00	0.00	79.00	50%	73.50	0%	82.80	37.00	76.80	32.00
Jul	90.70	23.05	90.70	8.00	76.00	0.00	78.40	50%	73.50	0%	82.30	37.00	76.20	32.00
Aug	90.30	24.19	90.30	8.39	76.00	0.00	77.70	50%	73.50	0%	81.70	37.00	75.30	32.00
Sep	89.90	24.96	89.90	10.98	76.00	0.00	76.80	50%	73.50	0%	81.10	37.00	74.30	32.00
Oct	89.50	24.30	89.50	12.62	76.00	0.00	76.00	50%	73.50	0%	80.50	37.00	73.10	32.00
Nov	89.15	26.85	89.15	12.89	76.00	0.00	75.70	50%	73.50	0%	80.00	37.00	75.70	32.00
Dec	89.10	23.85	89.10	10.18	76.00	0.00	75.30	50%	73.50	0%	79.50	37.00	75.30	32.00

Table D4 Scenario IV restriction policies – currently licensed, enhanced hydropower rules

Month	Power						Irrigation				EWP			
	Class 1		***Class 2***		***Class 3***		***Class1***		***Class 2***		***Class 1***		***Class 2***	
	Water level	Restricted target	Water level	Restricted target	Water level	Restricte d target	Water level	Proportion supplied	Water level	Proportion supplied	Water level	Restricted flow	Water level	Restricte d flow
	m AHD	MW	m AHD	MW	m AHD	MW	m AHD	%	m AHD	%	m AHD	m^3/s	m AHD	m^3/s
Jan	84.70	24.51	83.40	10.12	76.00	0.00	74.90	50%	73.80	0%	78.30	44.00	78.30	38.50
Feb	86.00	23.22	85.20	11.23	76.00	0.00	77.00	50%	73.80	0%	81.00	50.20	81.00	43.90
Mar	87.50	24.41	86.40	10.56	76.00	0.00	77.00	50%	73.80	0%	82.60	50.20	82.60	43.90
Apr	88.00	23.54	87.00	10.64	76.00	0.00	79.00	50%	73.80	0%	82.10	46.60	81.00	40.80
May	87.60	22.46	86.60	8.76	76.00	0.00	79.40	50%	73.80	0%	81.60	42.20	79.40	37.00
Jun	87.25	22.40	86.30	8.13	76.00	0.00	78.80	50%	73.80	0%	81.10	37.00	77.20	32.00
Jul	86.90	23.05	85.90	8.00	76.00	0.00	78.00	50%	73.80	0%	80.50	37.00	76.20	32.00
Aug	86.40	24.19	85.40	8.39	76.00	0.00	77.40	50%	73.80	0%	79.90	37.00	75.30	32.00
Sep	86.00	24.96	85.00	10.98	76.00	0.00	76.70	50%	73.80	0%	79.20	37.00	74.30	32.00
Oct	85.50	24.30	84.40	12.62	76.00	0.00	75.90	50%	73.80	0%	78.30	37.00	73.10	32.00
Nov	85.10	26.85	84.00	12.89	76.00	0.00	75.40	50%	73.80	0%	77.60	37.00	74.50	32.00
Dec	84.60	23.85	83.50	10.18	76.00	0.00	75.00	50%	73.80	0%	77.40	37.00	76.20	32.00

Table D5 Scenario V restriction policies – licensed to allocation limits, low power demand

Month	Power						Irrigation				EWP			
	Class 1		***Class 2***		***Class 3***		***Class1***		***Class 2***		***Class 1***		***Class 2***	
	Water level	Restricted target	Water level	Restricted target	Water level	Restricted target	Water level	Proportion supplied	Water level	Proportion supplied	Water level	Restricted flow	Water level	Restricted flow
	m AHD	MW	m AHD	MW	m AHD	MW	m AHD	%	m AHD	%	m AHD	m^3/s	m AHD	m^3/s
Jan	-	-	-	10.12	76.00	0.00	75.20	50%	73.50	0%	79.20	44.00	79.20	38.50
Feb	-	-	-	11.23	76.00	0.00	77.00	50%	73.50	0%	82.00	50.20	82.00	43.90
Mar	-	-	-	10.56	76.00	0.00	77.00	50%	73.50	0%	83.40	50.20	83.40	43.90
Apr	-	-	-	10.64	76.00	0.00	79.00	50%	73.50	0%	83.70	46.60	81.00	40.80
May	-	-	-	8.76	76.00	0.00	79.40	50%	73.50	0%	83.20	42.20	79.40	37.00
Jun	-	-	-	8.13	76.00	0.00	79.00	50%	73.50	0%	82.80	37.00	76.80	32.00
Jul	-	-	-	8.00	76.00	0.00	78.40	50%	73.50	0%	82.30	37.00	76.20	32.00
Aug	-	-	-	8.39	76.00	0.00	77.70	50%	73.50	0%	81.70	37.00	75.30	32.00
Sep	-	-	-	10.98	76.00	0.00	76.80	50%	73.50	0%	81.10	37.00	74.30	32.00
Oct	-	-	-	12.62	76.00	0.00	76.00	50%	73.50	0%	80.50	37.00	73.10	32.00
Nov	-	-	-	12.89	76.00	0.00	75.70	50%	73.50	0%	80.00	37.00	75.70	32.00
Dec	-	-	-	10.18	76.00	0.00	75.30	50%	73.50	0%	79.50	37.00	75.30	32.00

Appendix E — Conservation categories in federal and state conservation laws

Endangered fauna and ecological communities: *EPBC Act 1999*

Categories of threatened species

1) A native species is eligible to be included in the extinct category at a particular time if, at that time, there is no reasonable doubt that the last member of the species has died.
2) A native species is eligible to be included in the extinct in the wild category at a particular time if, at that time:
   a) it is known only to survive in cultivation, in captivity or as a naturalised population well outside its past range; or
   b) it has not been recorded in its known and/or expected habitat, at appropriate seasons, anywhere in its past range, despite exhaustive surveys over a time frame appropriate to its life cycle and form.
3) A native species is eligible to be included in the critically endangered category at a particular time if, at that time, it is facing an extremely high risk of extinction in the wild in the immediate future, as determined in accordance with the prescribed criteria.
4) A native species is eligible to be included in the endangered category at a particular time if, at that time:
   c) it is not critically endangered; and
   d) it is facing a very high risk of extinction in the wild in the near future, as determined in accordance with the prescribed criteria.
5) A native species is eligible to be included in the vulnerable category at a particular time if, at that time:
   e) it is not critically endangered or endangered; and
   f) it is facing a high risk of extinction in the wild in the medium-term future, as determined in accordance with the prescribed criteria.
6) A native species is eligible to be included in the conservation dependent category at a particular time if, at that time, the species is the focus of a specific conservation program, the cessation of which would result in the species becoming vulnerable, endangered or critically endangered within a period of 5 years.

Native species of marine fish

1) A native species of marine fish is eligible to be included in a category mentioned in a paragraph of subsection 178(1) at a particular time if, at that time, the species meets the prescribed criteria for that category.
2) A subsection of section 179 referring to a category (the ***relevant category***) does not apply to a native species of marine fish if regulations are in force for the

purposes of subsection (1) of this section prescribing criteria for the relevant category.

Listing of threatened ecological communities

1) The Minister must, by instrument published in the *Gazette*, establish a list of threatened ecological communities divided into the following categories:
   a) critically endangered;
   b) endangered;
   c) vulnerable.
2) Subject to subsection (3), the Minister must not include an ecological community in a particular category of the list, as first established, unless satisfied that the ecological community is eligible to be included in that category when the list is first published.
3) The list, as first established, must contain only the ecological communities listed in Schedule 2 to the *Endangered Species Protection Act 1992* immediately before the commencement of this Act, and they must be listed in the endangered category.
4) If the Minister is satisfied that an ecological community included in the endangered category of the list, as first established under subsection (3), is not eligible to be included in that or any other category, or is eligible to be included in another category, the Minister must, within 6 months after the commencement of this Act, amend the list accordingly in accordance with this Subdivision.
5) An instrument (other than an instrument establishing the list mentioned in subsection (3)) is a disallowable instrument for the purposes of section 46A of the *Acts Interpretation Act 1901*.

Critically endangered, endangered and vulnerable communities

1) An ecological community is eligible to be included in the ***critically endangered*** category at a particular time if, at that time, it is facing an extremely high risk of extinction in the wild in the immediate future, as determined in accordance with the prescribed criteria.
2) An ecological community is eligible to be included in the ***endangered*** category at a particular time if, at that time:
   a) it is not critically endangered; and
   b) it is facing a very high risk of extinction in the wild in the near future, as determined in accordance with the prescribed criteria.
3) An ecological community is eligible to be included in the ***vulnerable*** category at a particular time if, at that time:
   a) it is not critically endangered nor endangered; and
   b) it is facing a high risk of extinction in the wild in the medium-term future, as determined in accordance with the prescribed criteria.

Listing of key threatening processes

1) The Minister must, by instrument published in the *Gazette*, establish a list of threatening processes that are key threatening processes
2) The list, as first established, must contain only the key threatening processes contained in Schedule 3 to the *Endangered Species Protection Act 1992*, as in force immediately before the commencement of this Act.

Conservation codes under Western Australia's *Wildlife Conservation Act 1950*

Table E1 Conservation codes for gazetted fauna — the Wildlife Conservation Act 1950

Conservation code	Description
Schedule 1	…fauna that is rare or likely to become extinct, are declared to be fauna that is in need of special protection.
Schedule 2	…fauna that is presumed to be extinct, are declared to be fauna that is in need of special protection.
Schedule 3	…birds that are subject to an agreement between the governments of Australia and Japan relating to the protection of migratory birds and birds in danger of extinction, are declared to be fauna that is in need of special protection.
Schedule 4	…fauna that is in need of special protection, otherwise than for the reasons mentioned [in Schedule 1 – 3].

In addition to these species with a formal gazetted conservation status, the Department of Environment and Conservation also maintains a priority list of species that are restricted, vulnerable or too poorly known to be considered for gazetting (Table E2). These species have no special protection, but their presence would normally be considered. The taxon needs further survey and evaluation of conservation status before consideration can be given to declaration as threatened fauna.

Table E2 Conservation codes for priority fauna — Dept of Environment and Conservation

Conservation code	Description
Priority 1	Taxa with few, poorly known populations on threatened lands.
Priority 2	Taxa with few, poorly known populations on conservation lands. Taxa which are known from few specimens or sight records from one or a few localities on lands not under immediate threat of habitat destruction or degradation, e.g. national parks, conservation parks, nature reserves, state forest, vacant Crown land, water reserves, etc.
Priority 3	Taxa which are known from few specimens or sight records, some of which are on lands not under immediate threat of habitat destruction or degradation.
Priority 4	Rare taxa. Taxa which are considered to have been adequately surveyed and which, whilst being rare (in Australia), are not currently threatened by any identifiable factors. These taxa require monitoring every five to 10 years.

Shortened forms

COAG	Council of Australian Governments
DAFWA	Department of Agriculture and Food Western Australia
DoW	Department of Water
EPA	Environmental Protection Authority
EWP	Environmental water provision
EWR	Ecological water requirement
FEM	Flow Events Methodology
GCM	Global circulation models
IUCN	International Union for Conservation of Nature
LUCICAT	Land Use Change Incorporated Catchment (model)
NASY	Northern Australia Sustainable Yields (study)
OBRP	Ord Bonaparte Research Program
OEKDP	Ord-East Kimberley Development Project
OIC	Ord Irrigation Cooperative
OIEP	Ord Irrigation Expansion Project
ORIA	Ord River Irrigation Area
RAP	River Analysis Package
WRC	Water and Rivers Commission (former)

Glossary

Abstraction	Withdrawal of water from any surface water or groundwater source of supply.
Allocation limit	The annual volume of water set aside for use from a water resource. In the Ord area it is the total amount of water that can be licensed from a resource or subarea.
Annual announced allocation	The proportion of an annual water entitlement that is available in a given year.
Annual water entitlement	The amount of water specified on a licence issued under Section 5C of the *Rights in Water and Irrigation Act 1914* that can be taken between 1 April and 31 March the following year.
Argyle Diamonds	Argyle Diamonds Ltd, operators of the Argyle Diamonds Mine; a wholly owned subsidiary of Rio Tinto Ltd.
Consumptive use	Water used for consumptive purposes considered as a private benefit including irrigation, industry, urban and stock and domestic use.
Diversion (of water)	Taking water from a watercourse, usually by gravity
Environmental water requirement	The water regime needed to maintain the current ecological values (including assets, functions and processes) of water-dependent ecosystems consistent with the objectives of an environmental flow study.
Environmental water provision	The water regime resulting from the water allocation decision-making process taking into account ecological, social, cultural and economic impacts. They may meet in part, or in full, the ecological water requirements.
Fit-for-purpose water	Water of a quality suitable for the intended end purpose. It implies that the quality is not higher than needed.
Goomig farmlands	New farmland being established by the Western Australian Government under the Ord Irrigation Expansion Project. The area is located on the Weaber Plain to the north east of Stage 1 areas. It is to be supplied with water from Lake Kununurra via an upgraded existing M1 channel and a new M2 supply channel
In-situ water	Represents water that needs to be left in the system, including the water needed to maintain the integrity of the resource and ecological, social and cultural values.
Licence (or licensed entitlement)	A formal permit that entitles the licence holder to take water from a watercourse, wetland or underground source under the *Rights in Water and Irrigation Act 1914.*

Lower Ord River	The Ord River watercourse between the Kununurra Diversion Dam and the Ord River Estuary
Management area	A defined surface water area or groundwater area proclaimed under the *Rights in Water and Irrigation Act 1914.*
Macrophyte	An aquatic plant
Ord Final Agreement	A deed for the Compulsory Acquisition of Native Title Rights and Interests (Ord) between the State of Western Australia, the Miriuwung and Gajerrong People (MG), and private interests (Grantee Parties)
Over-allocation	Where the total volume of water allocated out of the resource (that could be abstracted at any time) is over the set allocation limit.
Over-use	Where the actual volume of water abstracted from the resource is over the set allocation limit.
Pacific Hydro	Pacific Hydro Limited, owners and operators of the Ord River Dam hydropower station
Regulated (river)	A river is regulated when its flow regime is significantly altered by the presence and operation of upstream water storages
Reliability	The frequency with which a water licence holder can access their full annual water entitlement.
Self-supply	Water users (individuals or organisations) who abstract water from a source for their own individual requirements.
Social value	An in-situ quality, attribute or use that is important for public benefit, welfare, state or health.
Social water requirement	The water regime needed to maintain social and cultural values.
Subarea	A subdivision, within a surface or groundwater area, defined to better manage water allocation. Subarea boundaries are not proclaimed and can therefore be amended without being gazetted.
SunWater	SunWater Corporation, a government trading enterprise owned by the Queensland Government and is currently the preferred water service provider for the new Goomig farmlands area. Subject to further negotiations and issuing the necessary licences, SunWater is expected to be the new water service provider for the new area.

References

Allen, GR 2000, Personal communication between the Department of Environment and Conservation (WA) and Department of Sustainability, Environment, Water, Population and Communities (Cwlth).

Braimbridge, MJ & Malseed, BE 2007, *Ecological water requirements for the lower Ord River*, Environmental water report series, report no. 4, Department of Water, Perth.

Barber, K & Rumley, H 2003, *Gunanurang: (Kununurra) Big River Aboriginal cultural values of the Ord River*, report to the Water and River Commission, June 2003.

Bari, M & Rodgers, S 2006, '*Generating a 100-year daily runoff series for the Ord River catchment using the LUCICAT model*', 30th Hydrology and Water Resources Symposium, 4–7 December 2006, Hobart, Tasmania.

CSIRO 2009, *Water in the Timor Sea Drainage Division*, a report to the Australian Government from the CSIRO Northern Australian Sustainable Yields project, CSIRO Water for a Healthy Country Flagship, Australia.

Department of Agriculture and Food Western Australia 2010, *Cockatoo Sands soil survey: assessment of potential irrigation areas, Kununurra area, east Kimberley,* Resource management technical report 364, Department of Agriculture and Food Western Australia, August 2010.

Davidson, BR & Graham-Taylor, S 1982, *Lessons from the Ord*, Centre for Independent Studies, Policy Monographs No 2. St Leonards, NSW.

Department of Water 2006, *Ord River water management plan*, Water resource allocation and planning series, report no. 15, Department of Water, Perth.

—2011, *Lower Ord River environmental water provisions monitoring program and management framework*, Environmental water report series, report no.19, Department of Water, Perth, June 2011.

—2012, *Ord surface water allocation plan: for public comment,* Department of Water, Perth.

Department of the Environment and Heritage 2010, *Nationally threatened species and ecological communities: Australian painted snipe* <http://www.environment.gov.au/biodiversity/threatened/publications/pubs/painted-snipe.pdf>.

—2010, *Rostratula australis — Australian painted snipe,* Australian Government, Canberra <http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=77037>.

Department of Sustainability, Environment, Water, Populations and Communities 2009, *Pristis microdon – freshwater sawfish*, Australian Government, Canberra <http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=66182>.

Department of Environment and Conservation 2009, *Western Australia Ramsar sites*, Department of Environment and Conservation, Government of Western Australia, Perth.

—2008, *Threatened and Priority Fauna database,* Government of Western Australia, Perth.

Dixon, RNM & Palmer DW 2010, *Lake Argyle sedimentation – 2006 survey,* Department of water, Salinity and land use impacts series, Report no, SLUI 42, January 2010

Environmental Protection Authority 1999, *Draft interim water allocation plan, Ord River*, *report and recommendations*, Bulletin 965, EPA, Perth, December 1999.

Field, IC, Charters, R, Buckworth, RC, Meekan MG & Bradshaw CJA 2008, *Distribution and abundance of* Glyphis *and sawfishes in northern Australia and their potential interactions with commercial fisheries*, Canberra: Commonwealth of Australia.

Gehrke, P 2009, *Ecological patterns and processes in the lower Ord River and estuary*, CSIRO May 2009, National Flagships Research for a Healthy Country.

Hale, J 2008, *Ecological character description of the Ord River floodplain Ramsar site*, report to the Department of Environment and Conservation, Perth, Western Australia

Hale, J & Morgan, D 2010, *Ecological character description for the lakes Argyle and Kununurra Ramsar Site*, report to the Department of Environment, Water, Heritage and the Arts, Canberra.

Johnstone, RE & Storr GM 1998, *Handbook of Western Australian birds, vol. 1: non-passerines (emu to dollarbird)*, Perth, Western Australia: West Australian Museum.

Le Page, JSH 1986, 'The Ord River Project', in *Building a state*, Water Authority of Western Australia, pp555–65.

Ord River Scientific Panel 2000, *Ord River Scientific Panel report to the Waters and Rivers Commission: recommendations for estimation of interim ecological water requirements for the lower Ord River*, Water and Rivers Commission, Perth, Western Australia.

Morgan, DL, Allen, MG, Bedford, P & Horstman, M 2004, *Fish fauna of the Fitzroy River in the Kimberley region of Western Australia – including the Bunuba, Gooniyandi, Ngarinyin, Nyikina and Walmajarri Aboriginal names,* records of the Western Australian Museum, 22:147–161.

Petts, GE & Maddock, I 1994, 'Flow allocation for in-river needs', in: Calow P & Petts, E (ed), *The rivers handbook, hydrological and ecological principles – volume 2,* Blackwell Science Ltd.

Parslow J, Margvelashvili N, Palmer D, Revill A, Robson B, Sakov P, Volkman J, Watson R, & Webster I 2003, *The response of the lower Ord River and estuary to management of catchment flows and sediments and nutrient loads: final science report, 2003*, CSIRO Marine Research/Land and Water Australia.

Petheram C, Rustomji P & Vleeshouwer J 2010, *Rainfall-runoff modelling across northern Australia*, a report to the Australian Government from the CSIRO Northern Australian Sustainable Yields project, Water for a Healthy Country.

Powell, JM 1998, *Watering the western third: water, land and community in Western Australia, 1826–1998*, Water and Rivers Commission.

Rodgers, S & Ruprecht, J 2000, *Impacts of river regulation on flooding in a sub-tropical river in Western Australia,* Technical report series, Water and Rivers Commission, Perth Western Australia.

Robson, BJ, Burford, MA, Gehrke, PC, Revill, AT, Webster, IT & Palmer, DW 2008, *Response to the lower Ord River and estuary to changes in flow and sediments and nutrient loads,* CSIRO, Water for a Healthy Country Flagship report, June 2008.

Ruprecht, JK & Rodgers, SJ 1999, *Hydrology of the Ord River: Western Australia,* Water resources technical series, WRT 24, Water and Rivers Commission, Perth, Western Australia.

Stevens,JD, McAuley, RB, Simpfendorfer CA & Pillans RD 2008, *Spatial distribution and habitat utilisation of sawfish (Pristis spp.) in relation to fishing in northern Australia*, a report to the Department of the Environment, Water, Heritage and the Arts [online], CSIRO and Western Australia Department of Fisheries, available from: <http://www.environment.gov.au/coasts/publications/pubs/sawfish-report.pdf>.

Smith, K & Rodgers, S 2010, *Reservoir simulations in the Ord River catchment*, Surface water hydrology series, report no. 33, Department of Water, Perth, May 2010.

State Solicitor's Office 2005, *The Ord Final Agreement – comprising the Deed for the compulsory acquisition of native title rights and interests (Ord),* executed on 6 October 2005 and Ord Final Agreement Variation # 2, 14 February 2006, State Solicitor's Office, Government of Western Australia.

Thorburn, DC, Morgan, DL, Rowland, AJ, Gill HS & Paling E 2007b, 'Life history notes of the critically endangered dwarf sawfish, *Pristis clavata*, Garman 1906 from the Kimberley region of Western Australia', in *Environmental Biology of Fishes*.

Thorburn, DC, Morgan, DL, Rowland, AJ & Gill H 2004. *Elasmobranchs in the Fitzroy River, Western Australia*, report to the Natural Heritage Trust.

Storey, AW 2003, Lower Ord River: fish habitat survey, unpublished report prepared for the Water and Rivers Commission, Western Australia.

Trayler, K, Malseed, B & Braimbridge M 2006, *Environmental values, flow related issues and objectives for the lower Ord River,* Environmental water report series, report no. EWR1, July 2006, Department of Water, Perth.

Trayler et al. 2003, *Productivity and water flow regulation in the Ord River of north-western Australia, Environmental Flows Initiative Project, final report on sampling*, May 2003.

Wark, R & Dixon, R (2012), *Controlling the deposition of sediment in Lake Argyle – A success story*, Paper submitted to the Organizing Committee, ICOLD for their 2012 Congress in Kyoto, Japan

Water and Rivers Commission 1999, *Draft interim water allocation plan, Ord River Western Australia, May 1999*, Water resource allocation and planning series, report no. 2, Water and Rivers Commission, Perth, Western Australia.

Wetland Research and Management 2008, *Lower Ord River: design of an environmental water provision monitoring and assessment program*, Department of Water, Perth.

Legislation

Government of Western Australia, *Rights in Water and Irrigation Act 1914*, Perth.

— 1950, *Wildlife Conservation Act 1950*, Perth.

— 1968, *Irrigation (Dunham River) Agreement Act 1968*, Perth (repealed 15 Dec 2003).

Australian Government, *Environmental Protection and Biodiversity Conservation Act 1999*, Canberra.

Department of **Water**
168 St Georges Terrace, Perth, Western Australia
PO Box K822 Perth Western Australia 6842
Phone: 08 6364 7600
Fax: 08 6364 7601
www.water.wa.gov.au
9482 100 0512