Government of Western Australia
Department of Water

Reservoir simulations in the Ord River catchment, Western Australia

Water availability under a range of possible demand scenarios

Looking after all our water needs

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Summary

The Ord River, located in the eastern part of the Kimberley Region of Western Australia, is one of the major rivers of Western Australia. It is highly regulated, mainly by the Ord River Dam which was built in 1972 and formed Lake Argyle. The Kununurra Diversion Dam, located 50 km downstream of the Ord River Dam, enables water to be diverted for extensive irrigation areas near the town of Kununurra.

A hydropower station is located at the Ord River Dam and generates power for nearby mining activities and to meet the needs of the regional population, including the towns of Kununurra and Wyndham. Additional irrigation water demand is expected from a second stage of irrigation, which is planned for the near future.

The Ord River system, from Lake Argyle to the confluence of the lower Ord and Dunham Rivers (downstream of the Kununurra Diversion Dam) has been simulated using the Danish Hydrologic Institute's MIKE BASIN water balance model. The model incorporates daily time series of catchment runoff, rainfall and evaporation from January 1906 to December 2004. A detailed environmental water provision (EWP) for the lower Ord River, water demand series for the Stage 1 and Stage 2 irrigation areas, and for hydropower, have also been incorporated into the model.

The model was used to prepare a recommended operating strategy for the current conditions (existing irrigation and hydropower demands) and for a range of possible future scenarios. The scenarios range from a combination of existing irrigation with moderate hydropower demands to increased levels of future irrigation and hydropower demands. The potential effects of raising the Ord River Dam spillway to increase storage in Lake Argyle and of a hydropower station at the Kununurra Diversion Dam were also evaluated.

Based on the model results, the evaporation from the lake surface accounted for a large component of loss from Lake Argyle in all scenarios modelled. For instance, under the existing irrigation and hydropower demand scenario, mean annual evaporation accounted for 26 per cent of the overall annual losses from the lake.

The large storage capacity of Lake Argyle buffers the system against isolated dry years. However, prolonged dry periods have a major impact on water supply reliability. Water release rules were established for all scenarios to ensure that irrigation targets (95 per cent annual reliability of supply and a minimum supply of 25 per cent of allocation) were met, while maximising the amount of power produced. A series of dry years in the early 1930s highlighted the effects of a drought period on the system.

1 Introduction

The Ord River catchment is located in the eastern part of the Kimberley Region of Western Australia. Major dams have been constructed on the river. These have enabled the development of a 15 000 ha (approximately) irrigation scheme at Kununurra (the Stage 1 Supply Area) and the generation of hydropower. There are plans to expand irrigation in the area (Stage 2 Supply Area – a total proposed area of approximately 32 000 ha in Western Australia and the Northern Territory), and additional hydropower generation may be required to support mining operations in the region.

The hydrology of the Ord River has been summarised in Ruprecht (1995) Ruprecht and Rodgers (1999) and Bari and Rodgers (2006).

At the time of publishing the *Ord river water management plan* (Department of Water 2007), a comprehensive assessment of ecological water requirements had been undertaken (Braimbridge & Malseed 2007) and revised hydrology of the Ord River system covering the period between 1906 and 2004 had been prepared (Bari & Rodgers 2006). The plan referred to a commitment to incorporate this updated information into future reservoir simulations.

This current round of reservoir simulations seeks to honour the plan's commitment, by incorporating our most up-to-date understanding of the hydrology and ecological water requirements of the Ord River. A MIKE BASIN model (Danish Hydrologic Institute 2005) for the Ord River has been developed and used to simulate the water balance within the lower Ord River system. The model encapsulates all demands (irrigation, hydropower and environmental) and applies reservoir operating rules to establish water availability at a daily time-step. Given the variety of competing water demands – irrigation, hydropower and the environment, and the possibility of additional irrigation allocations for the Stage 2 Supply Area, it has been important to assess the amount of water available under a range of demand scenarios.

2 Ord River catchment

2.1 Overview

The Ord River catchment covers an area of over 50 000 km^2 in the eastern part of the Kimberley Region of Western Australia. It is drained by the 650 km long Ord River, which flows into the Cambridge Gulf near Wyndham. The main tributaries of the Ord River include the Negri, Wilson and Bow rivers (upstream of the Ord River Dam), and the Dunham River, which joins the Ord River downstream of the Kununurra Diversion Dam near Kununurra (Figure 1).

The main industries within the Ord River catchment are agriculture, horticulture, tourism and mining. The construction of a diversion dam at the town of Kununurra in 1963 formed Lake Kununurra and enabled small scale irrigation development near the Kununurra townsite. The Ord River Dam was constructed in 1972 in the Carr Boyd Ranges approximately 50 km upstream of the town. The resulting reservoir, Lake Argyle, has a large storage capacity (10 700 GL at spillway level – 92.2 m AHD) and has resulted in an increase in both the reliability of supply and the area of cultivation. A hydropower station, built at the Ord River Dam in 1995–96, supplies over 90 per cent of the power to the towns of Wyndham and Kununurra, and to the Argyle diamond mine.

Since the construction of the Ord River Dam in the mid 1970s there has been a period of above average rainfall and irrigation restrictions have not been necessary. Inflows have also been well above average for the period of hydropower station operation (since the mid 1990s). However, analysis of the long-term rainfall series (from 1906 to 2004) shows that there have been periods of well below average rainfall (for instance during the 1930s). The risk posed by drought periods on water supply needs to be addressed in allocation planning for the reservoir and future irrigation developments (Figure 2). As such, a long-term hydrologic series (1906 to 2004) has been incorporated into modelling of the reservoir system. This series includes drought sequences as well as the recent high rainfall and inflow periods.

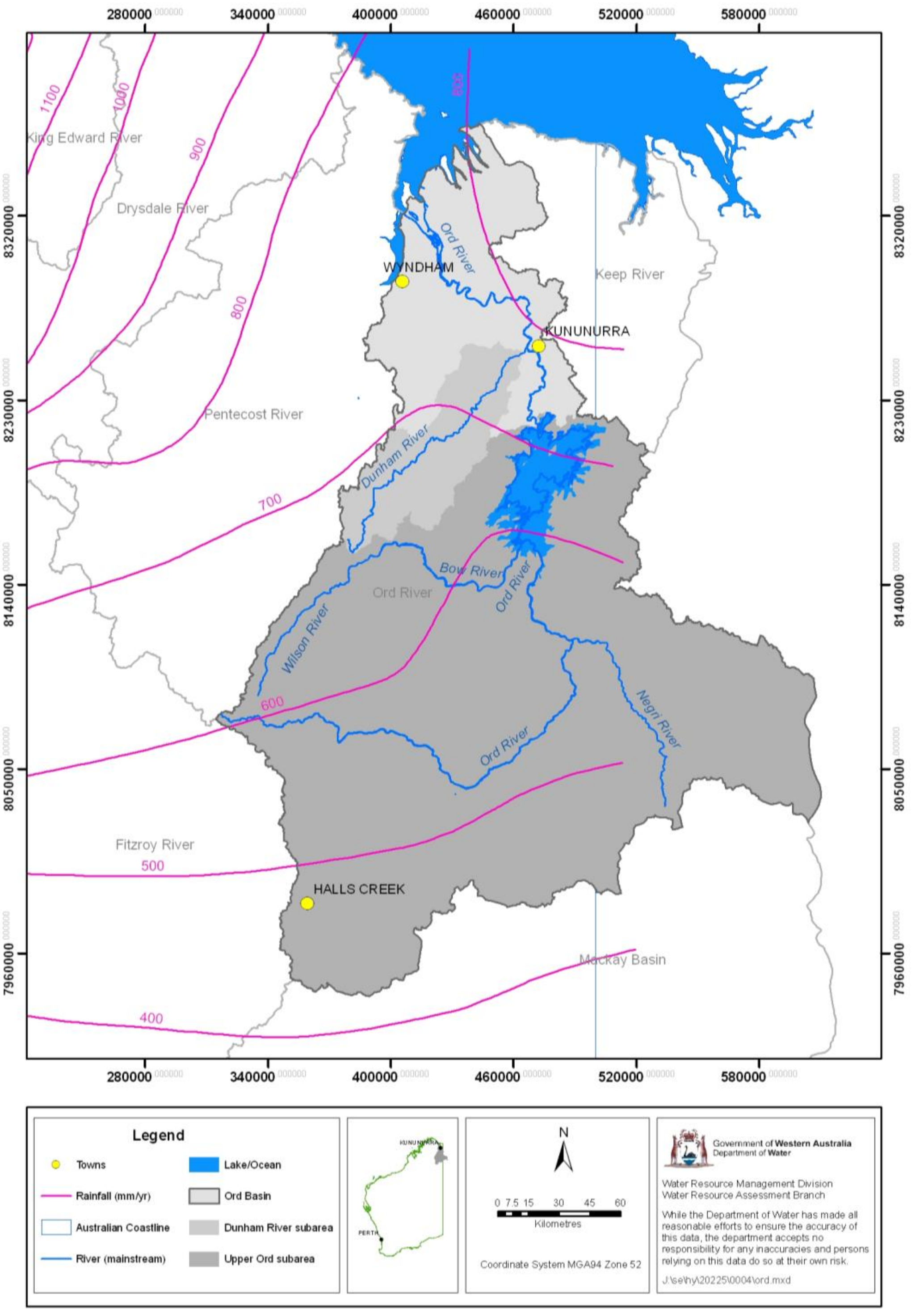

Figure 1 Ord River catchment with rainfall isohyets

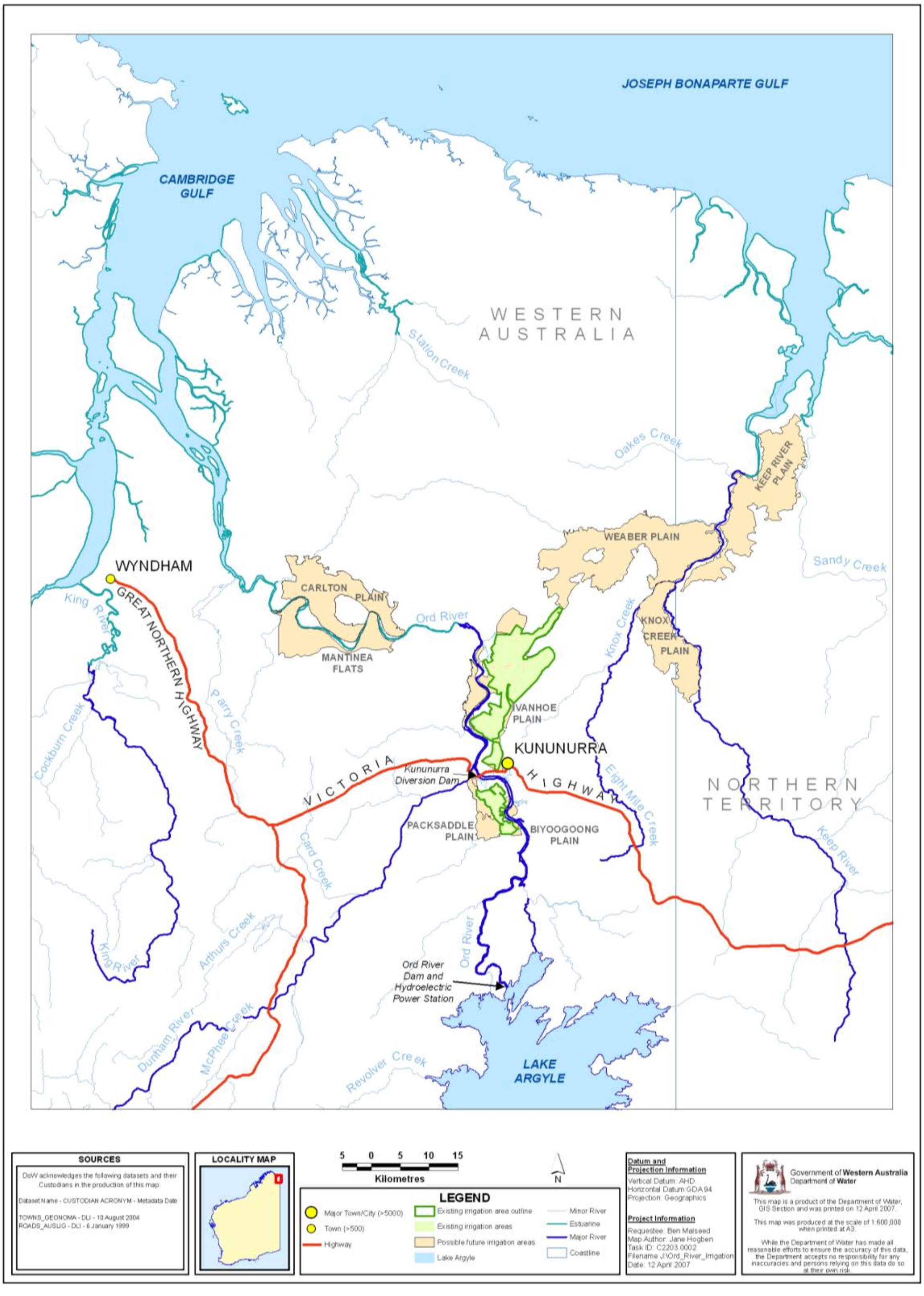

Figure 2 Lower Ord River hydrology and land use

2.2 Definition of a water year

Annual climate and streamflow figures and calculations throughout this report incorporate a water year that starts in November and carries through to the following October. This accounts for consecutive wet season months (between November and April). The water year will be described by the calendar year in which it ends, and which contains 10 of the 12 months. For instance, the water year from 1 November 1906 to 31 October 1907 will be described as 1907.

2.3 Climate

The Ord River catchment experiences a semi-arid to arid monsoonal climate with two distinct seasons, a warm dry season, and a hot wet season. Mean annual rainfall ranges from 780 mm in the north to 450 mm in the south (Figure 1). Rainfall is highly seasonal, with over 90 per cent of annual rainfall occurring during the wet season (November to March, Figure 3). Wet season rainfall develops from thunderstorm activity (resulting in localised rainfall) and cyclonic disturbances (resulting in widespread heavy falls). Thunderstorms are the dominant climatic feature in high rainfall months, and their frequency and severity produces large variations in monthly rainfall during the wet season. During the remainder of the year rainfall is light and sporadic, and it is not uncommon to have several consecutive months without rainfall.

Annual rainfall (1907–2004) at Lake Argyle ranges from (302 to 1637 mm and has a mean of 693 mm (Figure 4). The annual rainfall at Lake Kununurra varies from 355 to 1441 mm with a mean of 770 mm (Figure 5). This rainfall data has been taken from LUCICAT hydrologic modelling of the catchment (see Bari & Rodgers 2006).

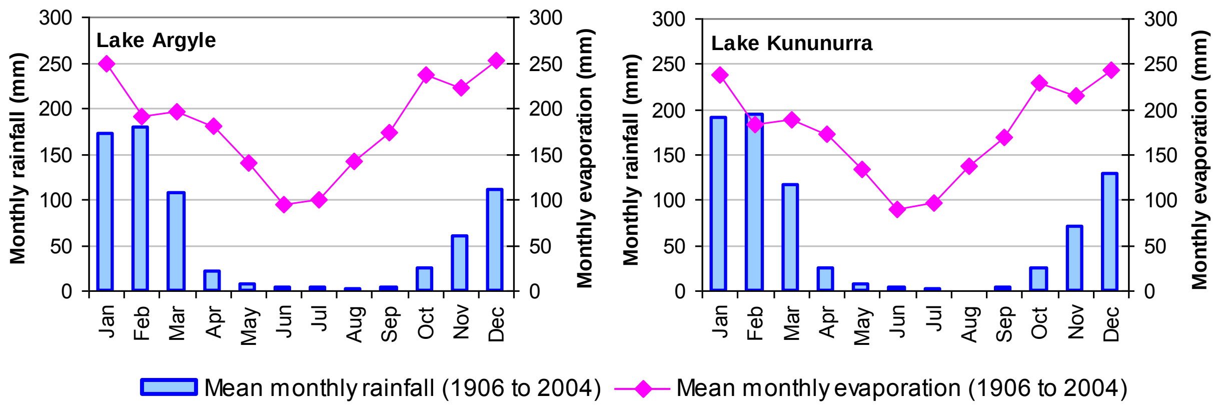

Figure 3 Mean monthly rainfall and evaporation at Lake Argyle and Lake Kununurra

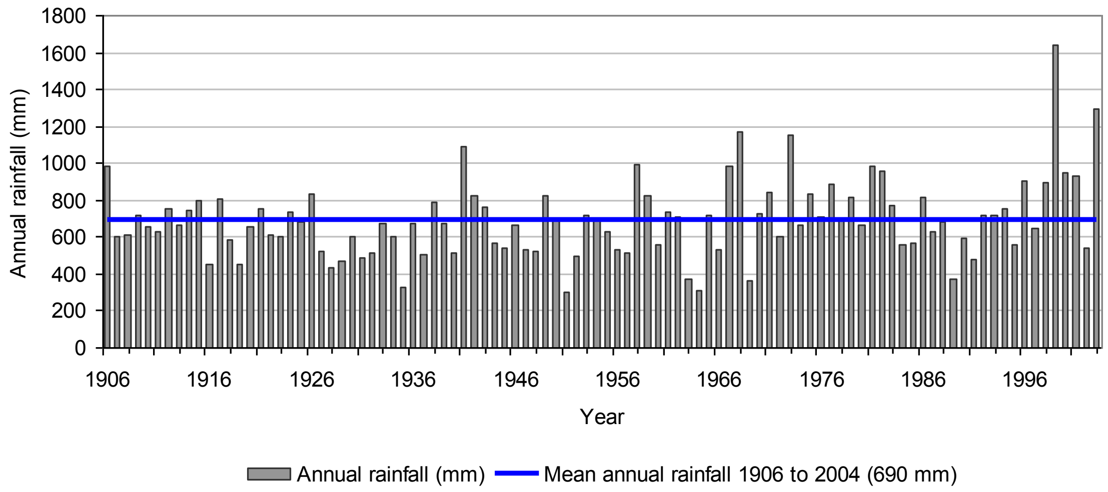

Figure 4 Annual rainfall at Lake Argyle (water year)

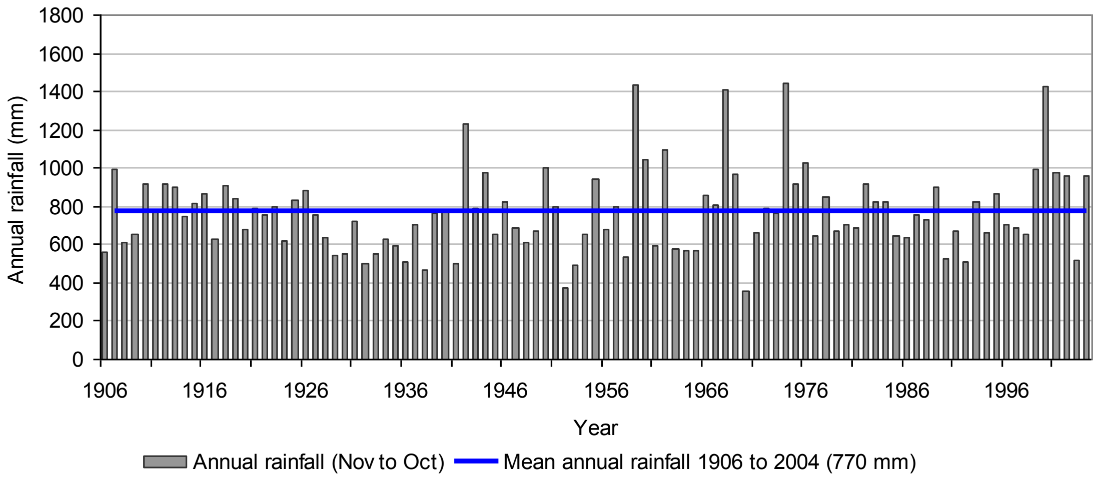

Figure 5 Annual rainfall at Lake Kununurra (water year)

Mean monthly evaporation exceeds rainfall for all months at both sites, with the exception of Lake Kununurra in February (Figure 3). Mean annual potential evaporation (1907 to 2004) was slightly higher at Lake Argyle than Lake Kununurra – 2179 mm compared with 2101 mm.

2.4 Streamflow

The long-term average streamflow (as inflow into Lake Argyle from 1907 to 2004) is 4278 GL. This average is based on observed, modelled and derived flow data from 1907 to 2004 (the derivation of this series is described in Section 2.5). There is a 10 per cent probability of annual flow exceeding 8331 GL, and conversely a 10 per cent probability of annual flow being less than 1090 GL.

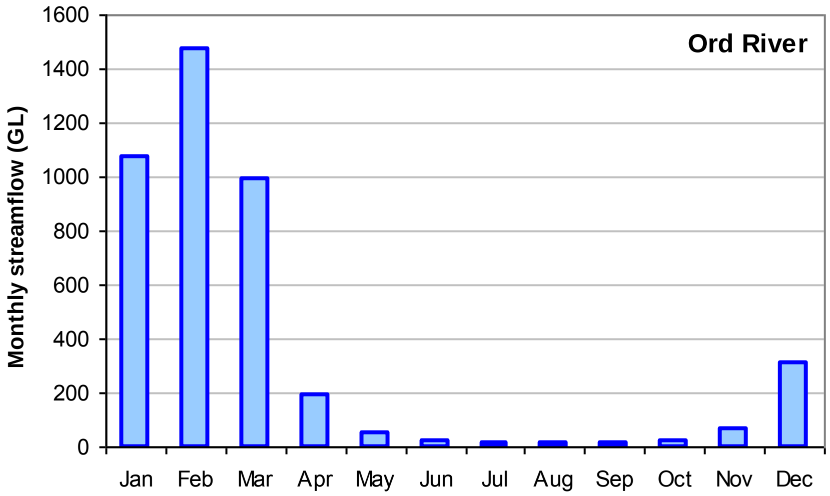

Figure 6 Mean monthly streamflow from the Ord River at the Ord River Dam

As with rainfall, streamflow is highly seasonal in the Ord River, and its tributaries, with over 90 per cent of streamflow occurring between November and March on average (Figure 6).

The Dunham River joins the Ord River 400 m downstream of the Kununurra Diversion Dam. It has a smaller catchment area than that of the Ord River Dam (4273 km^2 compared with 46 950 km^2)[1]. However, its catchment area is approximately four times larger than the unregulated portion of the catchment of Lake Kununurra, downstream of Lake Argyle (1008 km^2). Consequently, it is an important source of flow variability in the lower Ord River, with a mean annual flow of 505 GL. The Dunham River has a higher mean annual catchment runoff than the Ord River Dam catchment (118 mm compared with 91 mm). There is also greater interannual variability in streamflow on the Dunham River than the Ord River, with a coefficient of variation of 0.94 compared with 0.78. It has been noted in previous studies that there is a relatively low interannual variability in streamflow on the Ord River compared with other semi-arid regions of Australia. However, the variability is still much higher than that seen in the south-west of Western Australia (Ruprecht & Rodgers 1999).

2.5 Development of the updated hydrology series

Reservoir simulations for the 1994 Water Supply Agreement for the Ord River Dam hydropower station incorporated a monthly reservoir inflow dataset developed from a combination of recorded streamflow (1955–1971), reservoir operating records (1972–1992) and estimates of streamflow from catchment rainfall (pre-1955). While the dataset was sufficient at the time of use, it is now outdated (extending from 1906

[1] Catchment areas are consistent with the LUCICAT hydrologic modelling, not with the current management subareas. Runoff depths in the Ord River Dam catchment were scaled to ensure that the flow volumes from the previous monthly inflow sequence were maintained.

to 1991) and limits the simulation of a daily water balance for the system. Hence a daily hydrologic dataset (1906–2004) was developed, extending and improving on the previous monthly dataset by incorporating a 99-year daily streamflow series (from January 1906 to December 2004) from hydrologic modelling of the Ord River catchment using the LUCICAT model (Bari & Rodgers 2006).

In order to ensure consistency with the 1994 Water Supply Agreement water release rules for the Ord River Dam hydropower station, daily flows for the reservoir simulations were derived by disaggregating flows from the monthly dataset (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 incorporates the recent period of higher inflows (from 1992 to 2004).

The period of higher inflows is illustrated in Figure 7 and Figure 8. Mean annual inflow (water year) to Lake Argyle was much higher from 1992 to 2004 compared with 1907 to 1991 (6242 GL to 3978 GL). Similarly, mean annual streamflow in the Dunham River from 1992 to 2004 was much higher than from 1906 to 1991 (904 GL and 444 GL respectively).

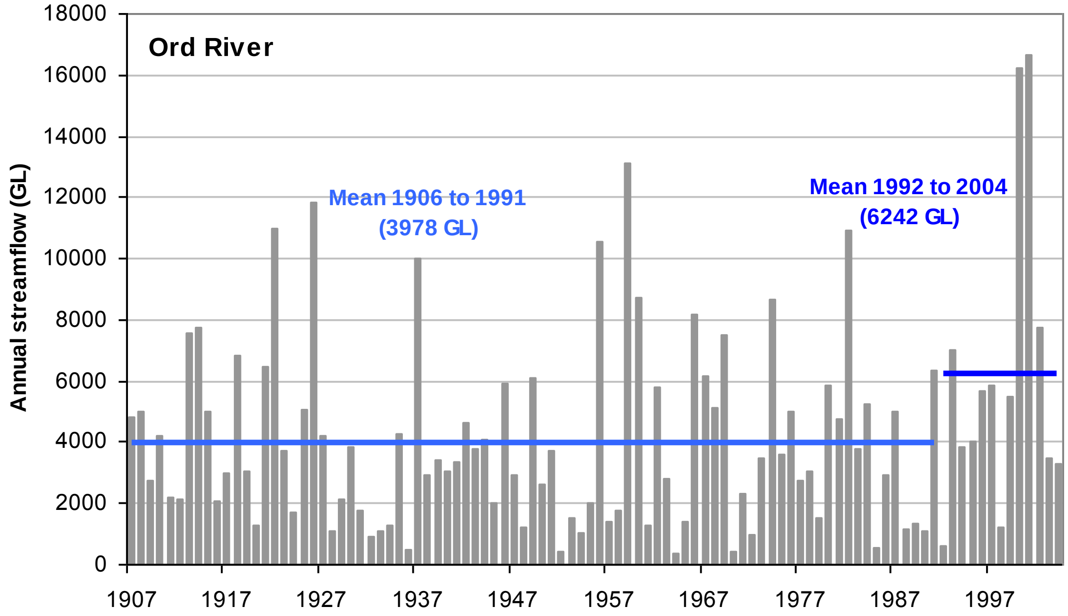

Figure 7 Annual inflow from the Ord River at the Ord River Dam (water year)

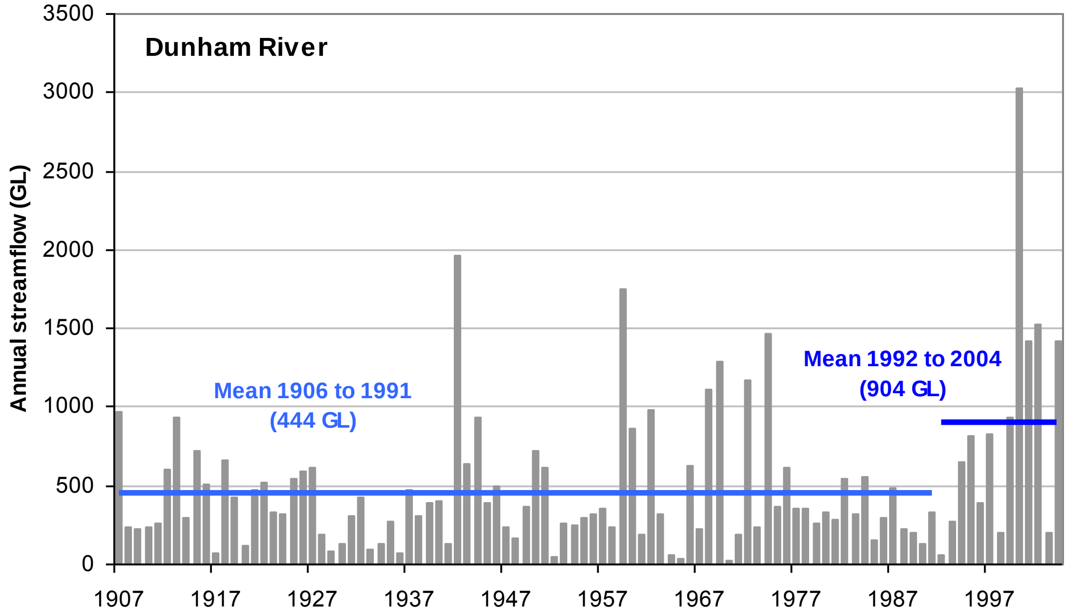

Figure 8 Annual streamflow from the Dunham River at the confluence of the Dunham and Ord rivers (water year)

3 Method

3.1 Overview of the project

Reservoir simulations were undertaken to define operating rules for releases from the Ord River Dam and to assess the impact of proposed development scenarios. Water balance simulations have been conducted on numerous previous occasions (Department of Water 2007; Ruprecht & Rodgers 1999 and Ruprecht 1995) to establish water availability in the Ord River catchment. This study incorporates the improved understanding of the hydrology of the Ord River, revised environmental water provision, and increased knowledge of potential future water and electricity demands.

The main components of this study are:

- incorporation of the most recent hydrological modelling data into the historical streamflow dataset (as described in Section 2.5)
- simulation of the existing development scenario (current demands and hydrology)
- simulation of a range of possible future demand scenarios.

3.2 MIKE BASIN model

MIKE BASIN is a water resource management tool developed by the Danish Hydrologic Institute. It has been used to simulate the Ord River system from Lake Argyle to the area downstream of the Kununurra Diversion Dam and Dunham River confluence. MIKE BASIN is a network model with rivers, tributaries and water users represented by a series of branches and nodes.

The model is simple and versatile, with an Arc GIS user interface and the ability to alter various aspects of the model coding to fit individual requirements. A water balance is calculated for each node in the model for each time step. The model allows priorities and restriction policies to be specified for each demand. User defined operating rules specify restriction levels and the portion of demand supplied.

Modifications were made to the standard MIKE BASIN package to enable key hydropower station characteristics to be simulated. Two lookup tables were used to provide power generation information for various flow rates and water levels in the reservoir. These lookup tables were supplied by the operators of the station as a Microsoft Excel spreadsheet which the model called during the simulation procedure (Appendix D).

There were also modifications made to enable irrigation and environmental water to be released from Lake Kununurra whilst specifying the restriction policies based on water levels in Lake Argyle. This was achieved by adjusting demands based on the level in Lake Argyle and the addition of dummy water demand nodes connected to the Ord River Dam, which supplement the supply from Lake Kununurra. As with the power generation information, the irrigation and environmental water demands were input via a Microsoft Excel spreadsheet.

A range of scenarios were simulated for the Ord River catchment. Some of these required special calculations, such as rules based on accumulated power generation to date, or the addition of a hydropower station at the Kununurra Diversion Dam. Such modifications were made to the model within a macro, utilising the Visual Basic programming language of the model. These modifications could be turned on and off as each scenario required.

3.3 MIKE BASIN data preparation and model setup

The basic input requirements for the MIKE BASIN model include time series of catchment runoff, rainfall and evaporation (expressed as a water depth over the surface area of the storages) and physical descriptions of features within the basin. Further input requirements for scenario simulations, such as demand series and operating rules are described in Section 4.

The Ord River catchment area, to the confluence of the Ord and Dunham rivers was divided into three subcatchments. These include the catchment upstream of Lake Argyle (46 950 km^2), the catchment between Lake Argyle and the Lake Kununurra dam wall (1008 km^2) and the Dunham River catchment (4273 km^2). The Ord River MIKE BASIN model schematic is shown in Figure 9, with catchment areas shaded in green (note that these are not to scale in the schematic).

The main stream of the Ord (above, between and below the dams) and Dunham rivers are represented by branches. Points of interest, such as the Ord River Dam, the Kununurra Diversion Dam, and the confluence between the Dunham and Ord Rivers are represented by nodes. Nodes are also located where environmental flows need to be accounted for, and for all water demands. In the case of the Ord River the key demand nodes are the Stage 1 and Stage 2 irrigation area demands, the Ord River Dam hydropower station and the potential Kununurra Diversion Dam hydropower station.

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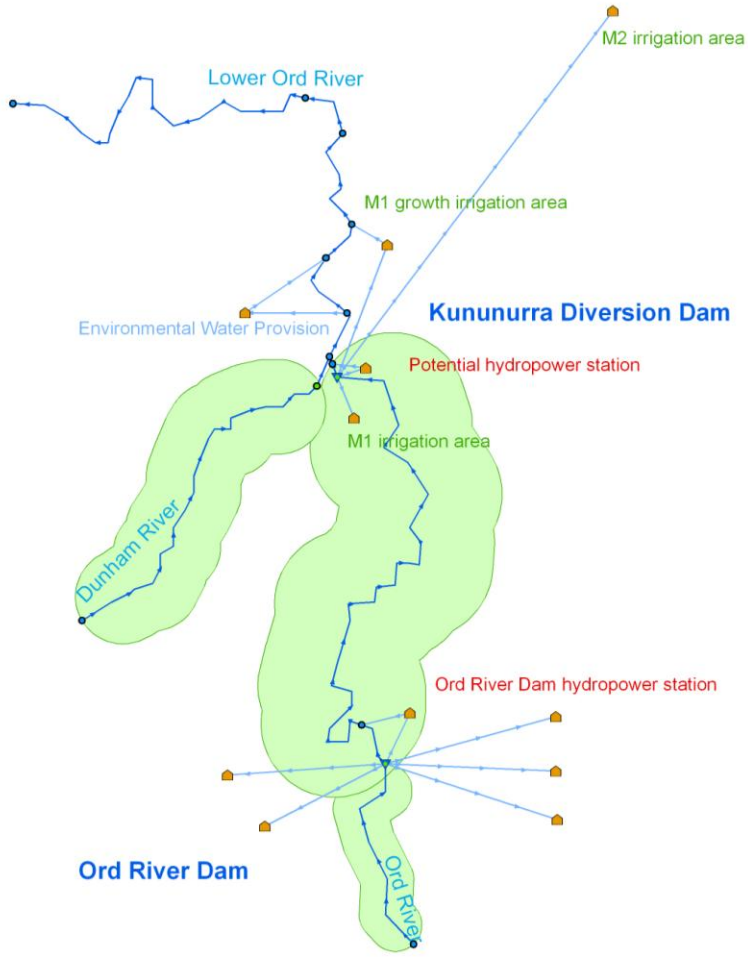

Figure 9 Ord River system – MIKE BASIN model schematic

Hydrologic features of the Ord River system are described by daily time series of runoff from the catchments of the Dunham River, Ord River Dam, and Kununurra Diversion Dam. These time series encompass almost 100 years of data (from 1906 to 2004) and have been taken from hydrologic modelling of the Ord River system using the LUCICAT model (Bari & Rodgers 2006), reservoir water balance data and gauging station data. The daily resolution of runoff data and the increased record length represent the main improvements between this and previous reservoir simulations. Previously hydrology series were based on a monthly time series from 1906 to 1992. The development of the updated hydrologic series is described further in Section 2.5.

Water management rules in the Ord River system are based on water levels in Lake Argyle. Hence, reservoir characteristics, such as storage capacity at various water levels and surface area (to establish evaporative losses over the reservoir) are particularly important. The relationship between storage volume and water level is described in the model by a level/area/volume table. The relationship between water level and storage volume for Lake Argyle is illustrated in Figure 10. The Kununurra Diversion Dam is operated to maintain a relatively constant water level and storage. Reservoir characteristics for Lake Kununurra (input to the model) and Lake Argyle are provided in Appendix B.

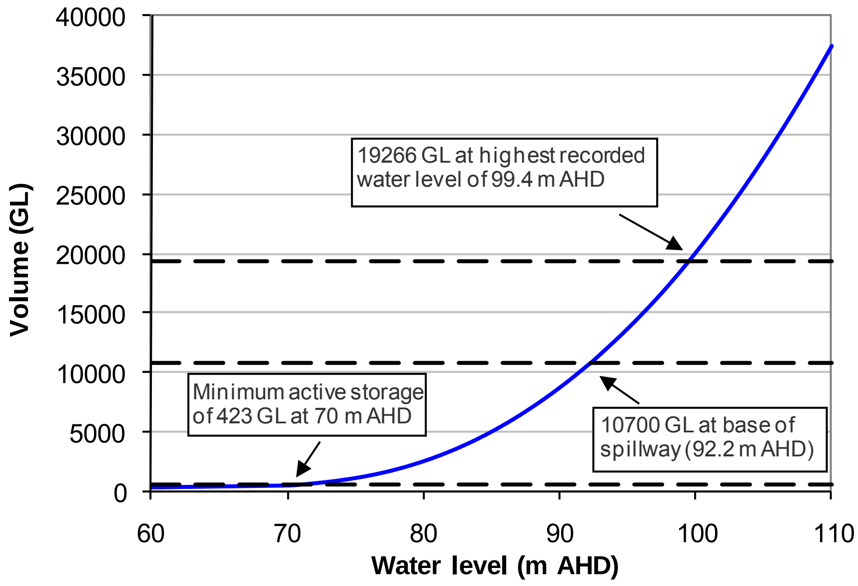

Figure 10 Lake Argyle water level/ storage volume curve

A sediment survey was recently conducted to determine the rate of sediment deposition in Lake Argyle and upstream reaches of the Ord and Bow rivers (Dixon & Palmer 2010). It was found that the rate of sedimentation was lower than estimated previously (Kata 1978; Wark 1987; Mauger & Hawkins 1994). However, sediment currently occupies 5 per cent of lake volume at full supply level. A recommendation of the sediment survey study was to explore the effect of sediment on the water level/storage relationship. If this work were undertaken it could be incorporated into future reservoir simulations.

Two daily time series were developed to represent the depths of rainfall and evaporation over the surface of Lakes Argyle and Kununurra. Rainfall and evaporation data for the reservoirs were derived from previous hydrologic modelling of the Ord River catchment (Bari & Rodgers 2006). There is an option in MIKE BASIN to include bottom seepage as a loss time series. However evaporative losses far outweigh seepage losses in the Kimberley Region of Western Australia, so seepage losses were not included in the model.

Monthly pan-to-lake coefficients were applied to the pan evaporation data applicable to both reservoirs. Temperature tends to fluctuate more in an evaporation pan than in a large water body (due to the regulating effect of the larger mass of water). Hence evaporation from water bodies tends to be less than pan evaporation measurements (Figure 11).

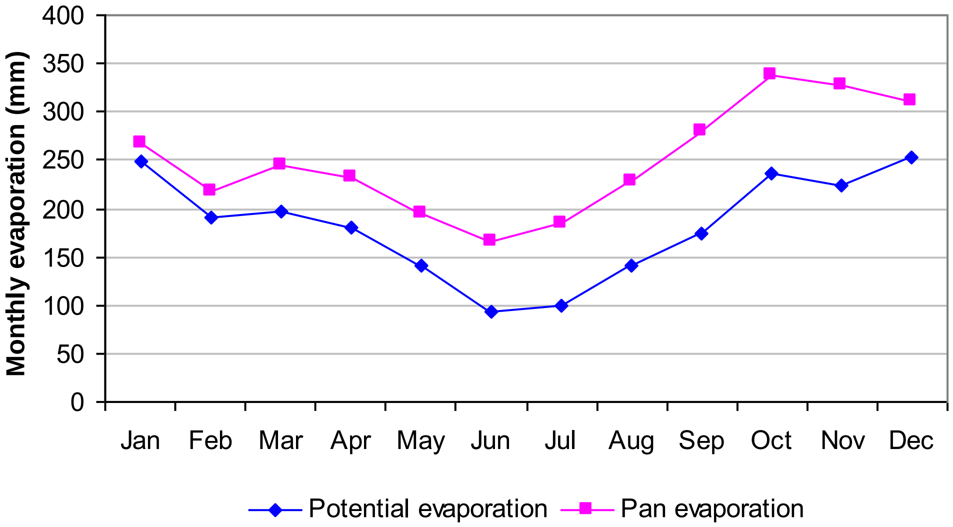

Figure 11 Comparison between monthly pan and potential evaporation at Lake Argyle

4 Water demand

4.1 Ecological water requirement for the lower Ord River

The ecological water requirement (EWR) for the lower Ord River has been designed to protect the ecological values of the lower Ord riverine environment, as developed since construction of the Ord River Dam. An ecological water requirement was included in previous modelling of the Ord River system (Department of Water 2007). However, it was revised in 2007 using the 'flow events methodology' developed by Stewardson (2001). This method is a more detailed approach to determining the EWR than used previously. A detailed description of the revised EWR and the method used to establish it is given in Braimbridge and Malseed (2007).

A number of wet and dry season flow requirements need to be maintained to meet the EWR. These include minimum base flow requirements for both the dry and wet seasons, and a range of wet season flow events of varying magnitude, frequency and duration (see Braimbridge and Malseed 2007 for a full description of flow requirements). The total annual flow required to meet the EWR is estimated at 1619 GL.

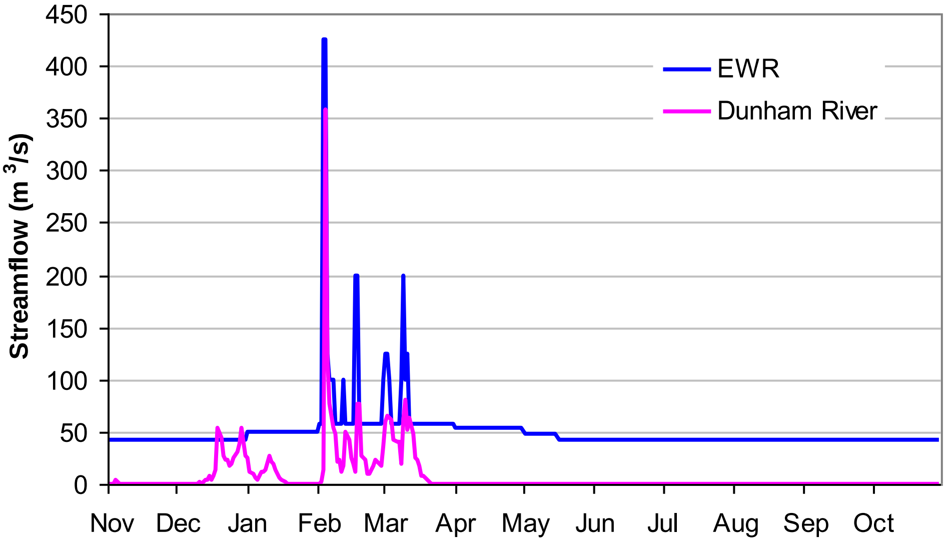

Figure 12 Example EWR demand series for the Lower Ord

The EWR is represented in the MIKE BASIN model as a daily water demand series for the Ord River downstream of the Kununurra Diversion Dam and the confluence with the Dunham River (one year of this series is illustrated in Figure 12). The Dunham River was identified as a source of many of the natural high flows on the lower Ord River. Consequently, the EWR demand time series was developed to align with the high flows on the Dunham River wherever possible. The EWR demand time series was input to the model as a daily time series for the entire period of modelling (1906–2004).

4.2 Hydropower demands

The hydropower station at the Ord River Dam began generating power in 1997 and provides electricity to Horizon Power (to supply the towns of Wyndham and Kununurra) and the Argyle diamond mine. The station currently supplies approximately 98 per cent of Horizon Power's demand and 90 per cent of the Argyle diamond mine demand, with the remaining power produced from diesel (Kununurra and Argyle diamond mine) and gas fired (Wyndham) power stations.

Monthly load records show that the Horizon Power demand is greatest in October and November (leading up to the wet season) (Figure 13). Future town demands mainly depend on population growth, which is linked to employment opportunities (such as the Argyle diamond mine and Stage 2 irrigation developments). For the purpose of modelling, the growth in Horizon Power demand was approximated at 3 per cent per year from 2005.

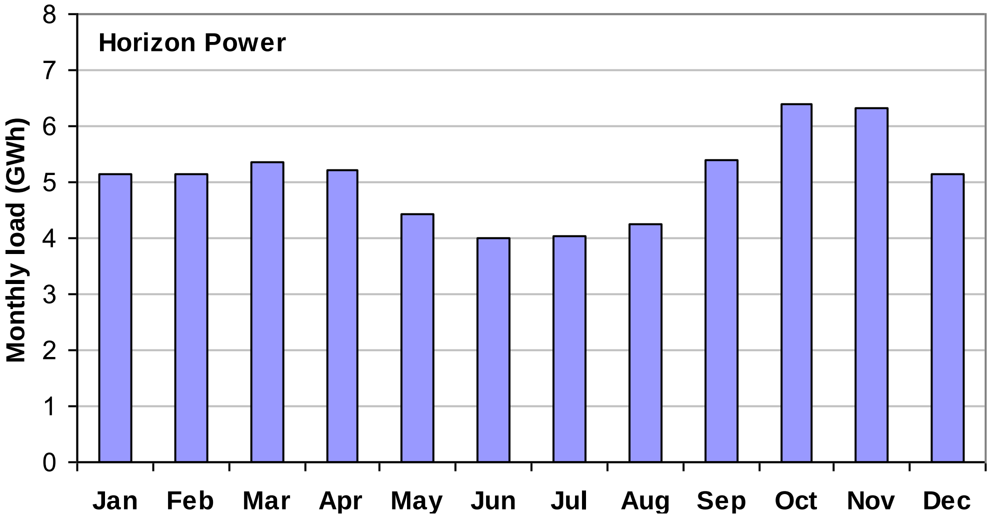

Figure 13 Horizon Power monthly electricity load 2005

The Argyle diamond mine uses approximately 70 per cent of the electricity supplied by the hydropower station. Future electricity demand depends on future mining activity. In particular, future underground operations would not only extend the life of the mine (to around 2018), but would also increase energy consumption at the mine due to the extra ventilation, refrigeration and ore handling requirements.

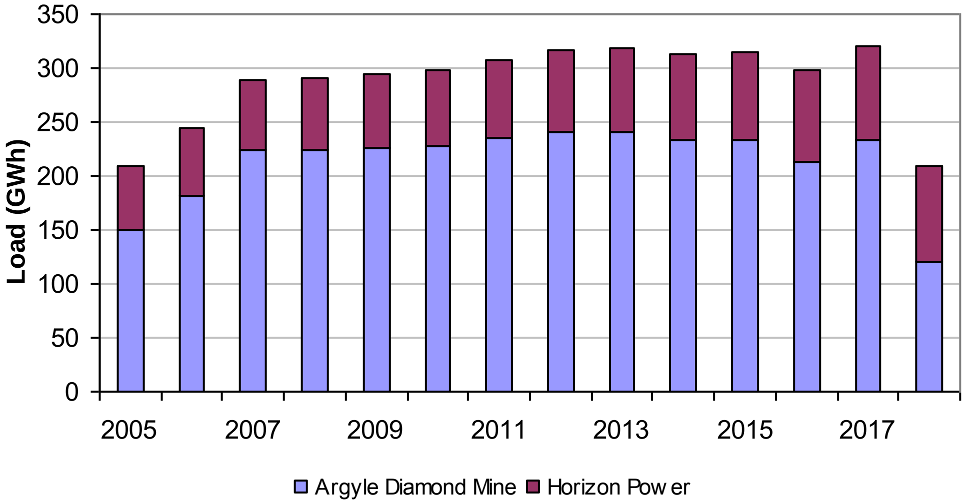

Figure 14 Forecast annual load for the Argyle diamond mine and Horizon Power (calendar year)

Figure 14 shows the forecast annual load for Horizon Power and the Argyle diamond mine, measured in 2005 and projected from 2006 to 2018. Load data for the reservoir simulations was taken from average hourly projections for each month in 2012 as this year represented a median load for the future period (between 2006 and 2017). The monthly load data used in the reservoir simulations is shown in Figure 15.

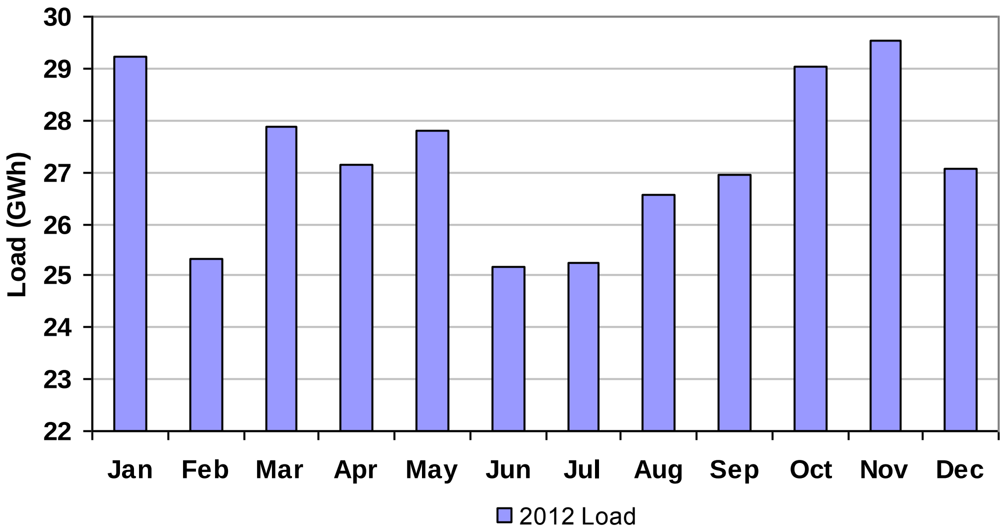

Figure 15 2012 load data input for the MIKE BASIN reservoir model

4.3 Irrigation demands

Separate monthly irrigation demand series were developed for the Stage 1 areas (existing and growth) and the potential Stage 2 development. These demands were represented in the MIKE BASIN model as demands on the Ord River Reservoir, as the restriction policies relate to the water level in Lake Argyle. As noted in Section 3.2, the model allowed for water to be diverted from Lake Kununurra with additional water required to meet demands extracted from Lake Argyle. This method was necessary as allocation rules were based on water levels in Lake Argyle, while the water is extracted downstream at (or below) the diversion dam.

Irrigation water requirements depend on a variety of factors including climate, soil characteristics, irrigation methods, delivery system design, and crop type. The water required to be released from Lake Argyle to meet existing and proposed demands for irrigation was based on a number of assumptions as to crop water demands, losses (both on-farm and within the water delivery system) and the proposed areas to be irrigated. It was assumed that crops could use approximately 72 per cent of rainfall over the irrigation area.

The areas under irrigation were derived from information supplied by the Ord Irrigation Co-operative. Crop water requirements were based on estimated data from the preliminary results of local field work by the Department of Agriculture (Sherrard 1994, updated 2001 (Department of Water 2007)) (Table 1).

Irrigation water requirements for the Stage 1 area were determined for a mixture of crops including bananas, leucaena, mangoes and sugar cane. Different on-farm and in-field losses were assumed for areas irrigated through furrows and sprinkler systems. Delivery efficiency was estimated to be 81 per cent, while the average efficiency of on-farm distribution and water use was 72 per cent. Similar efficiencies were established for the Stage 1 growth area, which was also a mixture of tree and annual crops. The combined mean annual water demand from the Stage 1 and Stage 1 growth irrigation areas was 350 GL.

Various scenarios for the Western Australian portion of the Stage 2 development area were explored by defining different areas of irrigation and altering the mix of crops within the area. For instance, a basic Stage 2 scenario was developed with a sugar cane crop with an average annual irrigation demand of 400 GL. The possibility of further expansion of the Stage 2 area was explored by various combinations of sugar cane and cotton crops with average annual irrigation demands of between 400 and 600 GL. The efficiency of on-farm distribution and water use was 80 per cent, while distribution efficiency was estimated to be 85 per cent.

The irrigation demand sequences represent our best knowledge of existing conditions, as well as a range of possible future conditions. Irrigation development scenarios for the Ord River district frequently change. Hence there is no way of predicting exact future irrigation water demands. By modelling a range of scenarios we can assess the sensitivity of the system to changing irrigation requirements.

Table 1 Crop water demands

	Bananas	Chickpea	Cotton	Beans	Honeydew	Hybrid Seeds	Leucaena	Mangoes	Pumpkin	Red Grapefruit	Rockmelon	Sandalwood	Sugar cane	Sweet Corn	Watermelon
	ML/ha	ML/ha	ML/ha	ML/ha	ML/ha	ML/ha	ML/ha	ML/ha	ML/ha	ML/ha	ML/ha	ML/ha	ML/ha	ML/ha	ML/ha
January	2.1	0.0	0.0	0.0	0.0	0.0	1.5	1.1	0.0	1.5	0.0	0.0	1.7	0.0	0.0
February	1.7	0.0	0.0	0.0	0.0	0.0	1.5	0.7	0.0	1.3	0.0	0.0	1.4	0.0	0.0
March	1.7	0.0	0.3	0.0	0.0	0.0	1.5	0.6	0.0	1.1	0.0	0.0	1.5	0.0	0.0
April	2.1	1.1	0.7	0.7	0.8	1.1	1.5	0.7	0.8	1.0	0.8	1.0	1.6	1.2	0.8
May	1.9	0.8	0.3	1.5	0.6	0.8	1.5	0.2	1.4	1.0	0.6	1.0	1.8	0.6	1.4
June	1.4	1.1	0.8	1.4	0.8	0.9	0.8	0.0	1.5	1.0	0.8	1.0	1.5	1.8	1.5
July	1.5	1.1	1.4	0.8	0.8	1.5	1.1	0.6	1.5	0.0	0.8	1.0	1.6	0.6	1.5
August	1.7	1.1	1.8	0.0	0.8	1.0	1.1	1.4	1.0	1.6	0.8	1.0	2.0	0.6	1.0
September	2.4	0.0	1.8	0.0	0.2	0.0	1.5	1.6	0.0	1.9	0.2	0.0	2.3	0.4	0.0
October	2.5	0.0	0.5	0.0	0.0	0.0	1.5	1.8	0.0	2.0	0.0	0.0	2.2	0.0	0.0
November	2.4	0.0	0.0	0.0	0.0	0.0	1.5	1.5	0.0	1.8	0.0	0.0	2.3	0.0	0.0
December	2.7	0.0	0.0	0.0	0.0	0.0	1.5	1.4	0.0	1.8	0.0	0.0	2.2	0.0	0.0

Source: Sherrard 1994, Department of Water 2007

4.4 Application of demand scenarios

The various water demands within the lower Ord River include irrigation, hydropower, environmental water and in-stream needs. With the exception of in-stream needs, all demands have been explicitly incorporated in scenario modelling for the lower Ord River. In-stream demands, such as requirements for navigation between Lake Kununurra and the Ord River Dam, can be varied and are discussed further in the *Ord River management plan* (Department of Water 2007).

The use of a revised environmental water requirement for the lower Ord River is one of the major improvements between this and previous reservoir simulations. The method used to incorporate this demand into the scenario modelling is described further in Section 5.1.

The impact of varying irrigation and hydropower demands on the lower Ord River was explored through the reservoir modelling. Hydropower demands (included as monthly power generation targets) remained constant for most scenarios, with the exception of some future 'low power demand' scenarios. Irrigation demands were incorporated as Stage 1, Stage 1 growth and Stage 2 monthly demand series. Both Stage 1 series remained constant throughout the simulations. However, Stage 2 demands were varied, in both quantity (representing the area irrigated) and seasonality (varying with crop mix).

Operational and supply targets for the Ord River Dam were considered in application of the demand scenarios. A minimum operating level for Lake Argyle was set to 70 m AHD. This ensures that the reservoir is not run dry during drought periods. There are also minimum supply and reliability targets for irrigation supply. In the driest year supply should be no less than 25 per cent of demand, and full irrigation supply must be met in 95 per cent of years.

Allocation rules were established as monthly restriction policies for irrigation, hydropower and environmental water demands. These restriction policies define levels in Lake Argyle at which water supplies are constrained. They are different for all demands, and for each scenario modelled. Multi-level restriction policies were developed in an iterative manner, by assessing how well each scenario simulation met reservoir operating targets and water supply requirements. Hydropower restriction policies were developed to optimise power generation while ensuring that reservoir operating and irrigation supply targets were maintained. Restriction policies for five allocation scenarios are included in Appendix A.

5 Results

Reservoir simulations were undertaken to explore the effects of the revised environmental water requirement (EWR) and a range of irrigation and hydropower demands on water availability, to establish rules for current and possible future demand scenarios, and to evaluate a number of different operating strategies for the reservoir.

Simulations were also conducted to assess the effects of changing features within the reservoir system, such as raising the spillway for the Ord River Dam, or including an additional hydropower station at the Kununurra Diversion Dam.

A number of different targets guided the development of operating rules for Lake Argyle. Irrigation targets included a minimum supply of 25 per cent of allocation and the full irrigation demand being met in 95 per cent of years. Hydropower targets were based on the existing commitment to allow 210 GWh of power to be produced each year. Targets for ecological water were assessed by a scientific panel and are discussed in Section 5.1. A minimum operating level of 70 m AHD in Lake Argyle was set to ensure that the reservoir was not run dry during drought sequences.

Reservoir simulation results are discussed for a range of scenarios, in terms of meeting operating targets and supply reliabilities. The impacts of five allocation scenarios (from current irrigation entitlements and moderate power demand to full irrigation entitlements and high power demand) on streamflow in the lower Ord River are also discussed.

5.1 Incorporating the revised environmental water requirement for the lower Ord

Reservoir simulations conducted prior to 2006 incorporated an ‘interim EWR’ which was based on maintaining 45 to 40 m^3/s flows in the lower Ord River (flows were to be reduced by 10 m^3/s during drought years, defined by a water level in Lake Argyle below 76 m AHD). The refined EWR for the lower Ord adopted in this study (discussed in Section 4.1) incorporates differing wet season and dry season minimum baseflows, and a range of wet season flow events of varying magnitude and duration.

Reservoir simulations were undertaken to determine water availability when the refined EWR regime was implemented. With an annual irrigation demand of around 750 GL (350 GL in Stage 1 and 400 GL in Stage 2), irrigation was restricted in 5 per cent of years, with a minimum supply of 10 per cent in the most severe year, and the water level in Lake Argyle was drawn down to a minimum of 67.5 m AHD. While the full irrigation supply was met in 95 per cent of years, the minimum supply was 15 per cent below the target minimum of 25 per cent. The minimum water level in Lake Argyle was also well below the 70 m AHD operating level. The minimum water level and minimum irrigation supply are indicators of the ability of the system to cope with very dry periods. In this case, extensive draw on the reservoir meant that there was not enough water retained in the reservoir to buffer against drought years. This simulation highlighted the possibility of adopting an environmental water provision (EWP) less than the EWR during drought periods.

A number of EWP options were considered by the scientific panel. These options detailed restrictions to be placed on the EWR in the driest 10 per cent of years. They covered a range of scenarios, including reductions to baseflow provisions, as well as reductions to the magnitude of wet season flow events. The EWP options are summarised in Table 2.

Table 2 Environmental water provision options

Option	Drought restriction description
1	Reduction of the EWR by 12%
2	Reduction of the EWR by 23%
3	Wet season baseflow requirements removed
4	Wet season peaks removed
5	Wet season peaks removed Wet and dry season baseflow reduced by 12% (an additional option which reduced dry season flows by 23% was also modelled)
6	Wet season peaks of 425 m^3/s and 300 m^3/s removed Remaining flows reduced by 23%
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

Maintaining flow variability in the lower Ord River was one of the priorities expressed by the scientific panel. Minimum dry season flow was also an important requirement to prevent oxygen depletion in river pools on the lower Ord River. Another consideration in determining an EWP was the economic and social effect on the community of maintaining the EWP regime in preference to other uses, such as irrigation and hydropower.

The final EWP option adopted was a combination of options 6 and 7. This EWP retains flow variability under drought restrictions, while meeting reservoir operation targets and irrigation supply reliability. Drought restrictions include a 23 per cent reduction in the EWR from January to March, and a two-step reduction (12 to 23 per cent) during the rest of the year. Wet season peaks are also reduced under drought restrictions.

There are a number of contributions to flow (and hence the EWP) for the lower Ord River. These include surplus inflow to Lake Kununurra (hydropower releases, Lake Argyle overflow and catchment inflow between the reservoirs) and inflow from the Dunham River. The Dunham River provides much of the flow variability (including many of the wet season flow events) necessary to maintain the EWP.

The amount of water released from storage specifically to maintain the EWP varies between allocation scenarios (between 47 and 890 GL/year on average) (Appendix C). In cases where there is limited demand for power, or releases for power are heavily restricted, there tends to be more need for specific EWP releases. This is also the case for scenarios where the full irrigation entitlement (including the Stage 2 irrigation area) is supplied, as more water is diverted from Lake Kununurra for irrigation.

5.2 Irrigation and electricity allocation scenarios with existing reservoir characteristics

Many scenarios were modelled and the results for five that represent the range of options considered are outlined in Table 3. These scenarios represent a range of allocation options, from existing irrigation and moderate hydropower demand (the recent past), to high future irrigation and high power demands. All scenarios listed incorporate the revised EWP for the lower Ord River.

Table 3 Definition of allocation scenarios

Scenario	Definition of scenario
I	The recent past • Stage 1 irrigation demand of 350 GL • moderate hydropower demand of 210 GWh • specific releases to meet the revised EWP
II	Current entitlements • Stage 1 irrigation demand of 350 GL • high power demand of 327 GWh, minimum hydropower guarantee above a level of 78 m AHD in Lake Argyle • specific releases to meet the revised EWP
III	Licensed to allocation limits • Stage 1 and 2 (Western Australian) irrigation demand totalling 750 GL annually • high power demand of 327 GWh • specific releases to meet the revised EWP
IV	Current entitlements, enhanced hydropower rules • Stage 1 irrigation demand of 350 GL • high power demand of 327 GWh, no minimum guarantee for power • specific releases to meet the revised EWP
V	Licensed to allocation limits, Horizon Power (town) demand only • Stage 1 and 2 (Western Australian) irrigation demand totalling 750 GL annually • low power demand equivalent to projected 2018 demand for Kununurra townsite • Specific releases to meet the revised EWP

There was very little difference between scenarios in variability of annual flow downstream of the two reservoirs (Figure 16). However, prior to regulation (the two dams) there was much greater interannual variability in streamflow. This larger variability is also shown in Table 4, where the natural flow (pre-regulation) has the least flow in a dry year (10th percentile) and almost twice the flow of any development scenario in a median and wet year.

Development scenarios with an additional irrigation allocation for the Stage 2 area (scenarios III and V) had slightly less median annual flow at the Dunham River confluence (due to the additional diversions from Lake Kununurra for irrigation supply) (Figure 16).

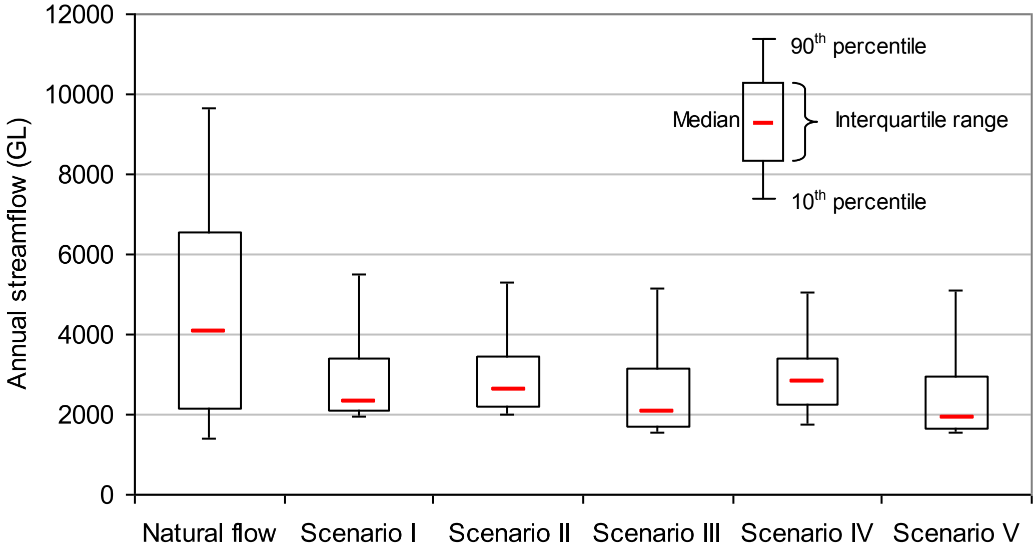

Figure 16 Variation in annual streamflow for the Ord River at the Dunham River confluence

Table 4 Variation in annual streamflow at the Dunham River confluence

Scenario	**Dry year 10th percentile GL**	**Median year 50th percentile GL**	**Wet year 90th percentile GL**
Natural flow	1390	4050	9670
I	1940	2280	5500
II	2000	2580	5290
III	1570	2070	5130
IV	1770	2800	5050
V	1570	1880	5120

Prior to regulation the lower Ord River would cease to flow during the dry season. The river is now perennial, with fairly consistent flow during the dry season as a result of the releases through the hydropower station. The flood storage available within Lake Argyle has resulted in significantly less monthly variability in flows in the Lower Ord River. The median and 90th percentile flows between December and March are much higher for the pre-development (‘natural’) scenario than for the various development scenarios (Figure 17).

Since regulation, flow has been more sustained and more consistent throughout the year. Median and 10th percentile monthly flow downstream of the Dunham River confluence are slightly higher for Scenario II (current irrigation entitlements) than for Scenario III (additional 400 GL of water diverted to the Stage 2 irrigation area) in all months.

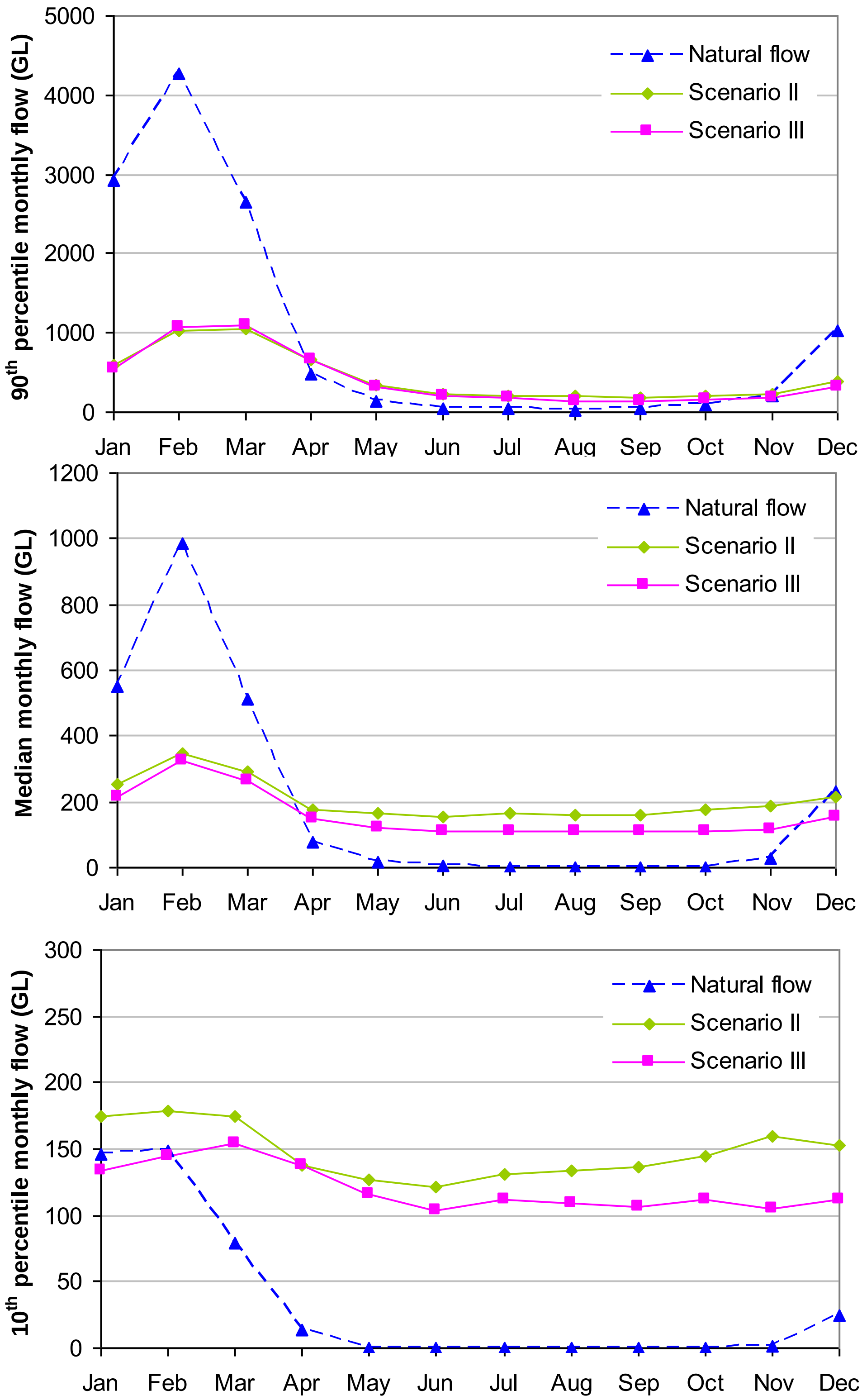

Figure 17 Seasonal variation in streamflow for the Ord River at the Dunham River confluence

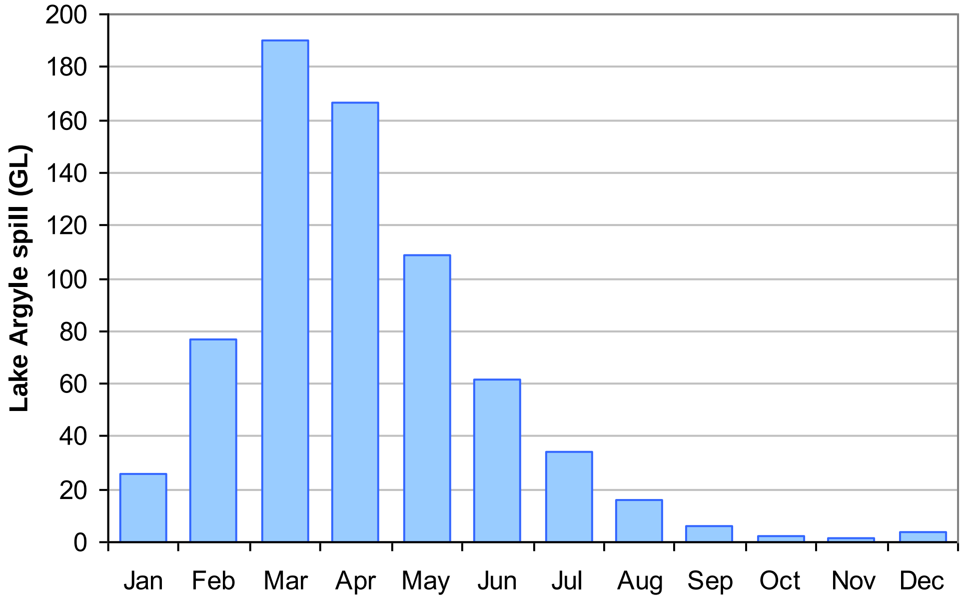

Figure 18 Mean monthly spill from Lake Argyle for Scenario II

Lake Argyle reservoir spills between 54 and 71 per cent of years (water years) under the five allocation scenarios. The mean annual spill (in years when it occurs) ranges from 1126 GL to 1576 GL for the five scenarios. The recent period has been wetter than the historical average. From 1990 to 2004 there have been between 9 and 11 years where the reservoir has spilled (depending on scenario). For the last 4 years simulated, the reservoir spilled for the entire year across all scenarios. Figure 18 shows the mean monthly spill from Lake Argyle under Scenario II (current conditions), illustrating that the greatest spill tends to occur late in the wet season and into early in the dry season (i.e. February to June).

As mentioned previously, Lake Argyle has a large flood storage, and the configuration of the spillway means that this can be discharged over several months of the dry season. The large storage also buffers the system against isolated dry years. However, prolonged dry periods (such as a period in the 1930s) and continual drawdown on the reservoir result in very low storage and inflows, and so water restrictions are needed. Comparison between annual inflow and average water level in Lake Argyle for Scenario II (Figure 19) shows this effect of drought periods. For instance, annual inflow was very low in 1992, but this was an isolated occurrence and water level in the reservoir remained high. A prolonged period of lower than average inflow years during the 1930s resulted in a substantial drawdown of the water in Lake Argyle. The dry sequence in the 1930s was critical to establishing satisfactory operating rules for each scenario. Operating rules that could maintain the minimum storage and irrigation supply criteria during this time were usually adopted.

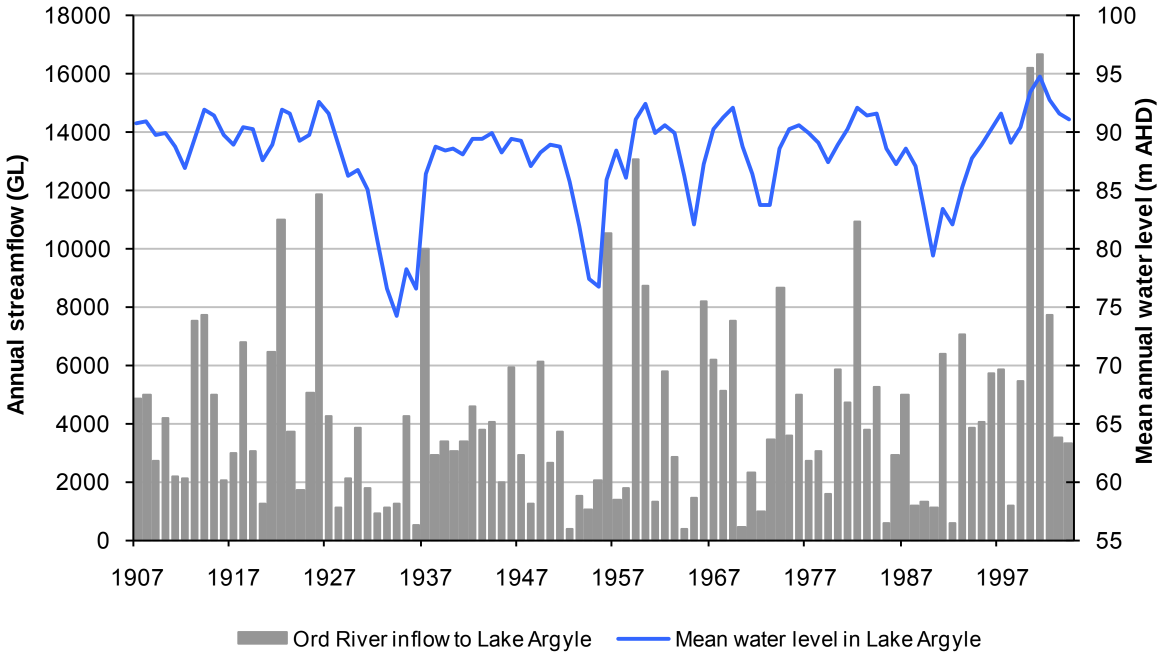

Figure 19 Comparison of inflow to Lake Argyle and water levels under the current irrigation scenario (Scenario II)

Comparison of mean monthly water levels in Lake Argyle for scenarios I and IV shows that there is little variability in water level between the scenarios over the simulation period. However, it is the water level in the driest years that can have a big effect on operating rules.

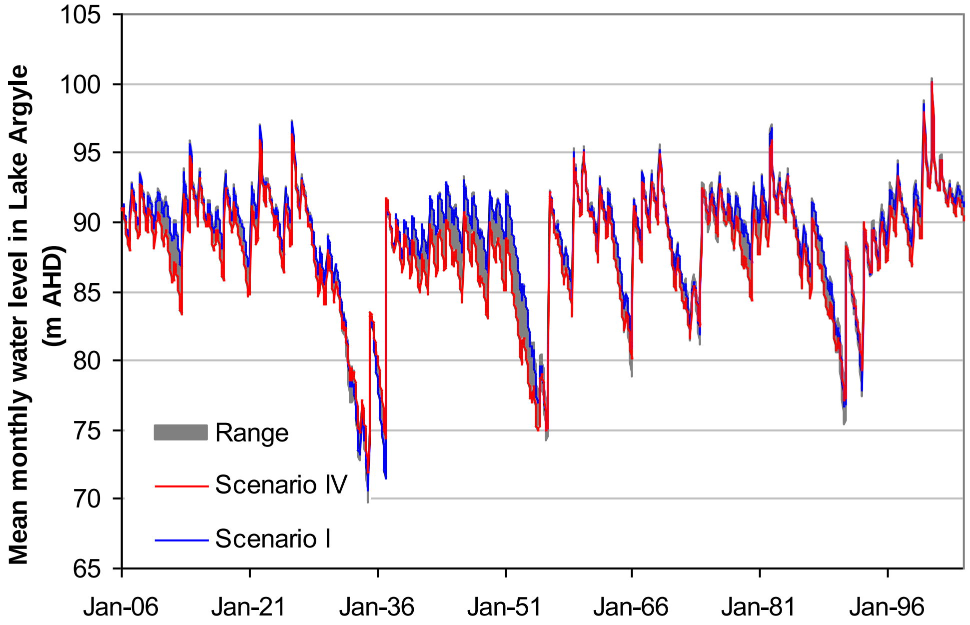

Figure 20 Variation in water level in Lake Argyle for five allocation scenarios (mean monthly)

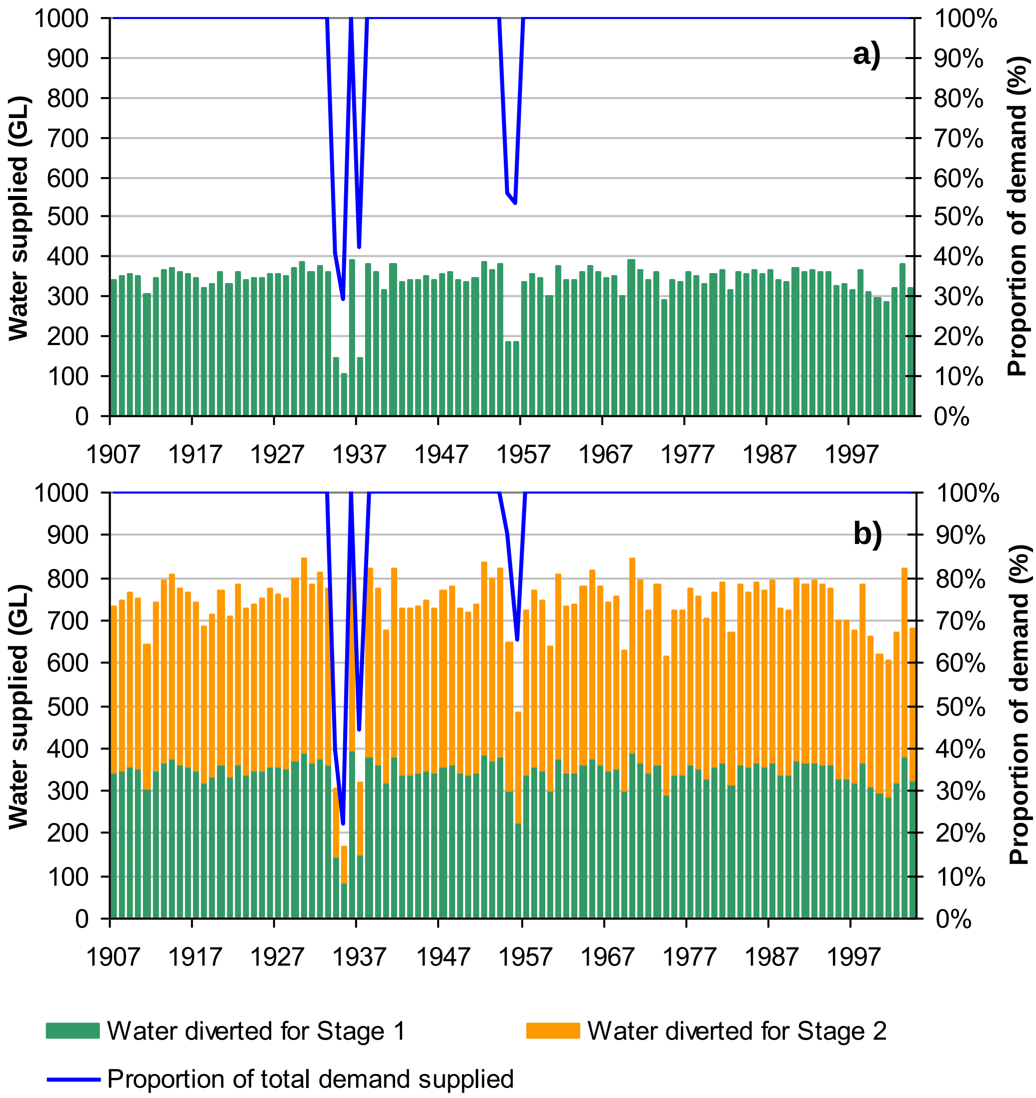

Figure 21 Irrigation supplied for current and future irrigation demand scenarios. a) scenario II, b) scenario III

Irrigation supply and demand is illustrated in Figure 21. There is variability in annual irrigation demand due to the effect of rainfall over the irrigation areas. However, mean annual demand is 350 GL for the Stage 1 irrigation area, and 400 GL for the Stage 2 irrigation area.

Table 5 Annual irrigation supply and reliability under the five allocation scenarios (water years)

Scenario	Irrigation supply reliability %	Proportion of demand supplied in the driest year %
I	96.3	29.5
II	95.3	28.3
III	95.3	22.9
IV	95.0	40.0
V	97.4	29.3

The results summarised in Table 5 and Figure 21 illustrate that the full irrigation demand is supplied in 95 per cent of years. For Scenario III, which incorporates the full scale development in the Stage 2 irrigation area, approximately 23 per cent of irrigation demand was supplied in the driest year. This is slightly less than the target of 25 per cent but was considered acceptable. However, it highlights the fact that supplying an additional irrigation demand of 400 GL, and supplying 210 GWh of power per year approaches the limits on the storage of the system.

Hydropower restrictions occur under each scenario to varying degrees. Under Scenario I, hydropower is restricted to a 210 GWh/yr rate when Lake Argyle is not spilling (i.e. water level below 92.2 m AHD). Hence restrictions occur frequently (there are 97.4 per cent of years with some days restricted, and 82.1 per cent of days overall are restricted to this rate) (Table 6). However, restrictions to meet the Wyndham and Kununurra town demand rate of 89 GWh/yr occur far less frequently (only when levels in Lake Argyle are between 78 and 76 m AHD).

Table 6 Frequency and severity of hydropower restrictions for five allocation scenarios

	Proportion of years with hydropower restrictions to a 210 GWh/yr rate[3] %	**Proportion of days with hydropower restrictions to a 210 GWh/yr rate[3]** %	**Proportion of years with hydropower restrictions to an 89 GWh/yr rate[2]** %	**Proportion of days with hydropower restrictions to an 89 GWh/yr rate[2]** %	**Proportion of years with hydropower restrictions to a 0 GWh/yr rate** %	**Proportion of days with hydropower restrictions to a 0 GWh/yr rate** %
I	97.4	82.1	9.8	2.1	6.7	2.3
II	78.0	47.4	10.8	2.5	9.8	3.1
III	0.0	0.0	88.2	57.6	8.8	2.6
IV	33.2	8.0	37.3	18.3	7.7	2.0
V	NA[1]	NA[1]	NA[1]	NA[1]	5.7	1.9

[1] power demand equals the 89 GWh/yr rate under Scenario V

[2] 89 GWh/y is the projected Kununurra and Wyndham power demand for 2018

[3] 210 GWh/yr is the guaranteed annual power guaranteed under the 1994 Water Supply Agreement

Figure 22 shows that the hydropower station has more control over water releases for power generation under Scenario I than under Scenario III. However, the figure also shows that power generation can occur from releases for other downstream uses (such as irrigation and environmental water provisions). Under release rules for Scenario III, releases for hydropower generation are restricted to 89 GWh/yr in 88.2 per cent of years (57.6 per cent of days in the simulation period). However, actual power production under this scenario is comparable to Scenario I due to the power produced from other releases (Figure 23).

Scenarios I and III are two ends of the hydropower restriction rule spectrum. Scenario I is based on maintaining 210 GWh/yr hydropower production at the discretion of the power station. Scenario III gives irrigation releases (Stage 1 and 2 areas) priority, and has a more severe restriction policy on hydropower releases (power releases are restricted to the 210 GWh/yr rate, then 89 GWh/yr rate). However, hydropower production between these scenarios tends to be similar due to the ability of the hydropower station to generate power from irrigation and environmental water releases.

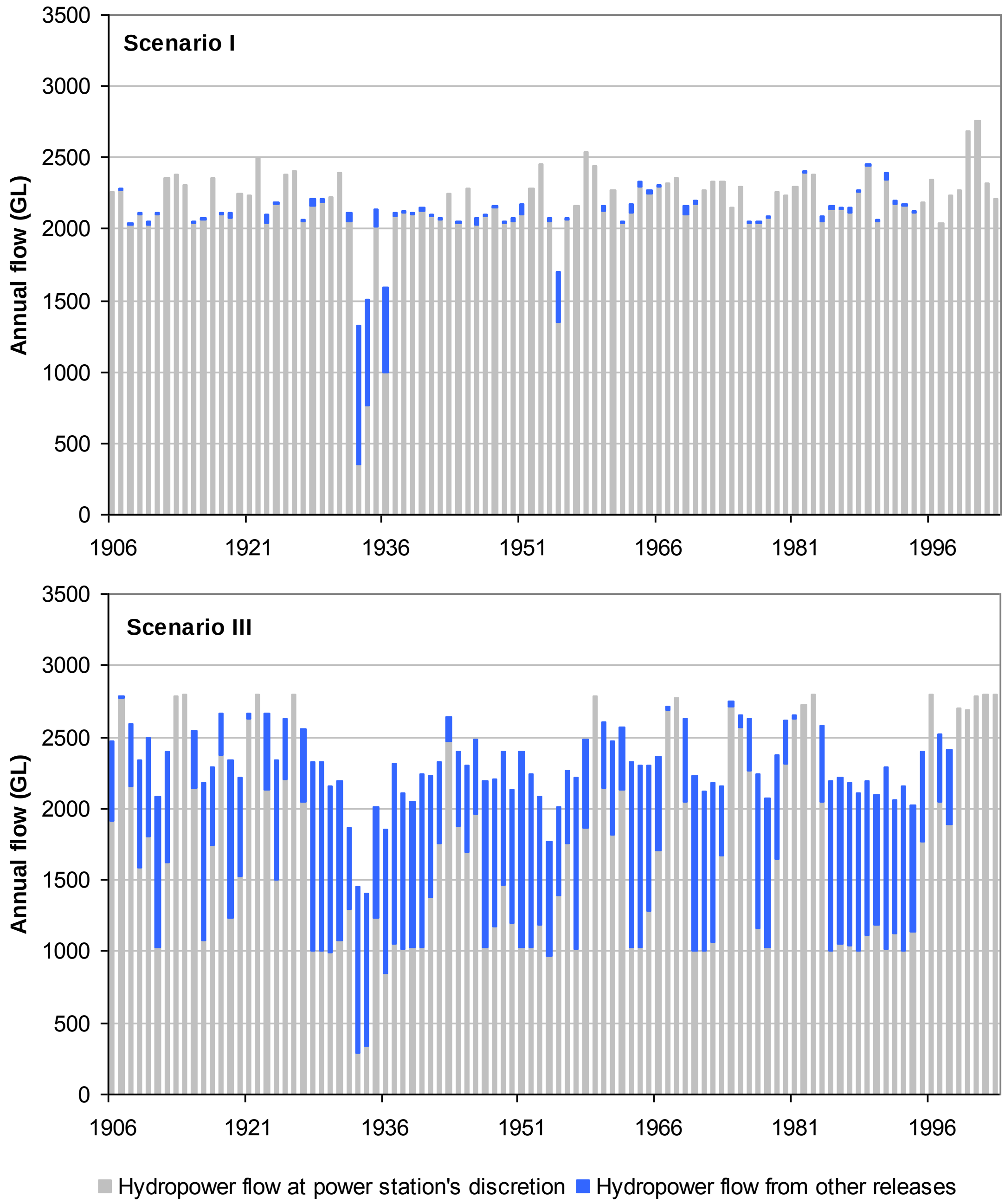

Figure 22 Contribution to releases through the hydropower station at Lake Argyle for scenarios I and III (financial years)

Hydropower restrictions may be more severe under Scenario III than Scenario I (releases at the discretion of hydropower generation is restricted in 57.6 per cent of days simulated). However, hydropower releases are less restricted under this scenario at higher lake levels. Where Scenario I restricts power to the 210 GWh/yr rate below 92.2 m AHD in Lake Argyle, Scenario III has a first level of restrictions (to 210 GWh/yr rate) at 91.45 m AHD in April. As a result more power is produced when lake levels are relatively high (as shown in Figure 23). Less power is produced under Scenario III at reasonably low levels in Lake Argyle.

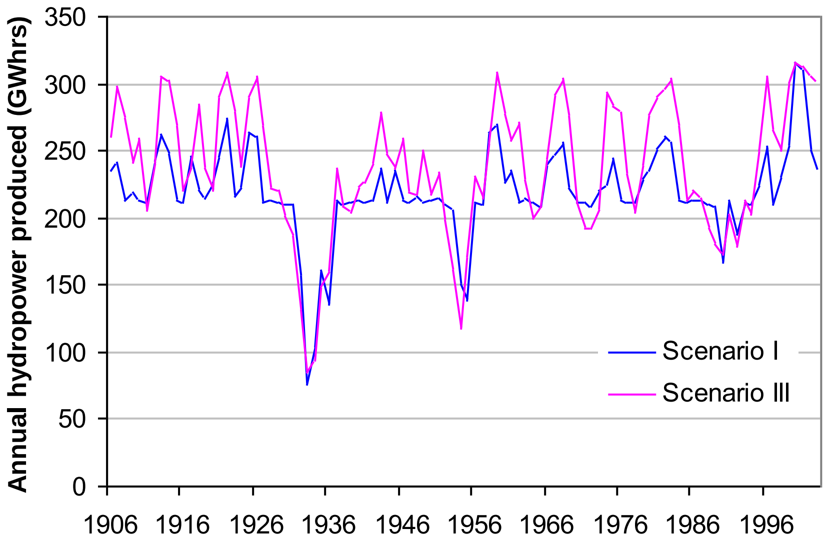

Figure 23 Annual hydropower production (financial year) for scenarios I and III

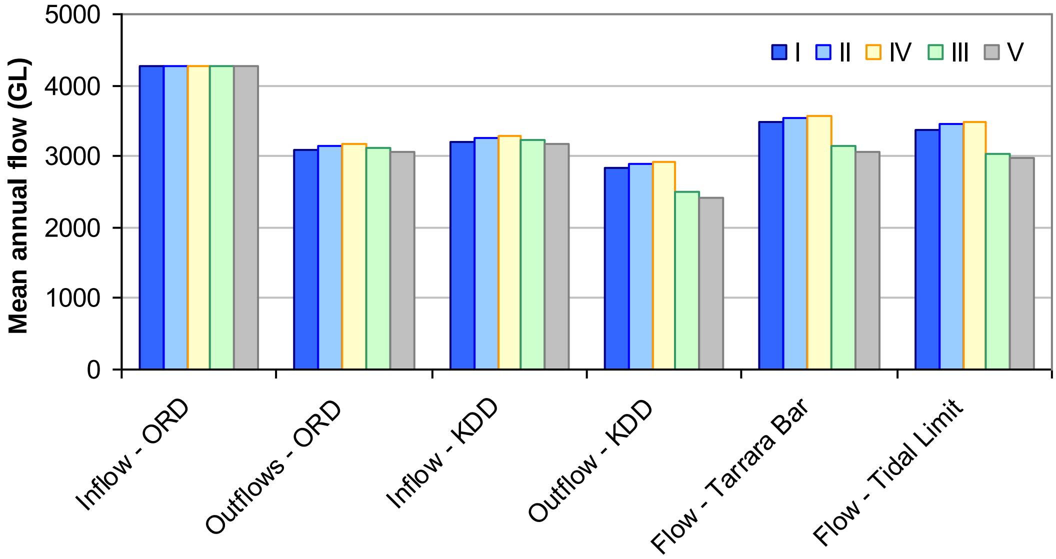

Figure 24 Mean annual (water year) Ord River flows for five scenarios

Mean annual flow at a range of locations along the lower Ord River, for five allocation scenarios is illustrated in Figure 24. Evaporation losses account for much of the difference between inflows and outflows from Lake Argyle. For instance, outflows from Lake Argyle are lower in the case of scenarios I and V. Both scenarios have lower power demand below the spillway level than the other three scenarios. As less water is released at high lake levels, more water is retained in the reservoir; these scenarios have higher evaporation losses than the others.

Inflow to Lake Kununurra corresponds to outflows from Lake Argyle with the addition of runoff from the catchment between Lake Argyle and the Kununurra Diversion Dam (this runoff is constant throughout all scenarios).

Flow at Tarrara Bar is lowest for scenarios III and V. Higher irrigation demands for these scenarios mean that more water (an extra 400 GL on average) is diverted from Lake Kununurra. Slightly more water is diverted for Scenario V as irrigation restrictions occur less frequently under this scenario.

There is less flow at the tidal limit than Tarrara Bar for scenarios III and IV (around 95 GL less). This is due to an additional 115 GL of extractions, which is offset a little by catchment inflows along this reach of the lower Ord River.

Figure 25 illustrates the components of mean annual flow at Tarrara Bar for the allocation scenarios (excluding the low power demand Scenario V). Surplus hydropower release is a large constituent of the flow at Tarrara Bar for all scenarios. Under Scenario III, surplus hydropower releases are substantially less than any other scenario. In this case releases for the EWP form a greater component of the flow at Tarrara Bar.

Under the current (350 GL/yr) irrigation scenarios (I, II and IV) releases to meet the EWP are required in some years (particularly in drought sequences such as the 1930s). These releases generally represent a small portion of total flow at Tarrara Bar. Despite the varying components to flow at Tarrara Bar for the four scenarios included in Figure 25, the total quantity of mean annual flow at Tarrara Bar is similar in all scenarios.

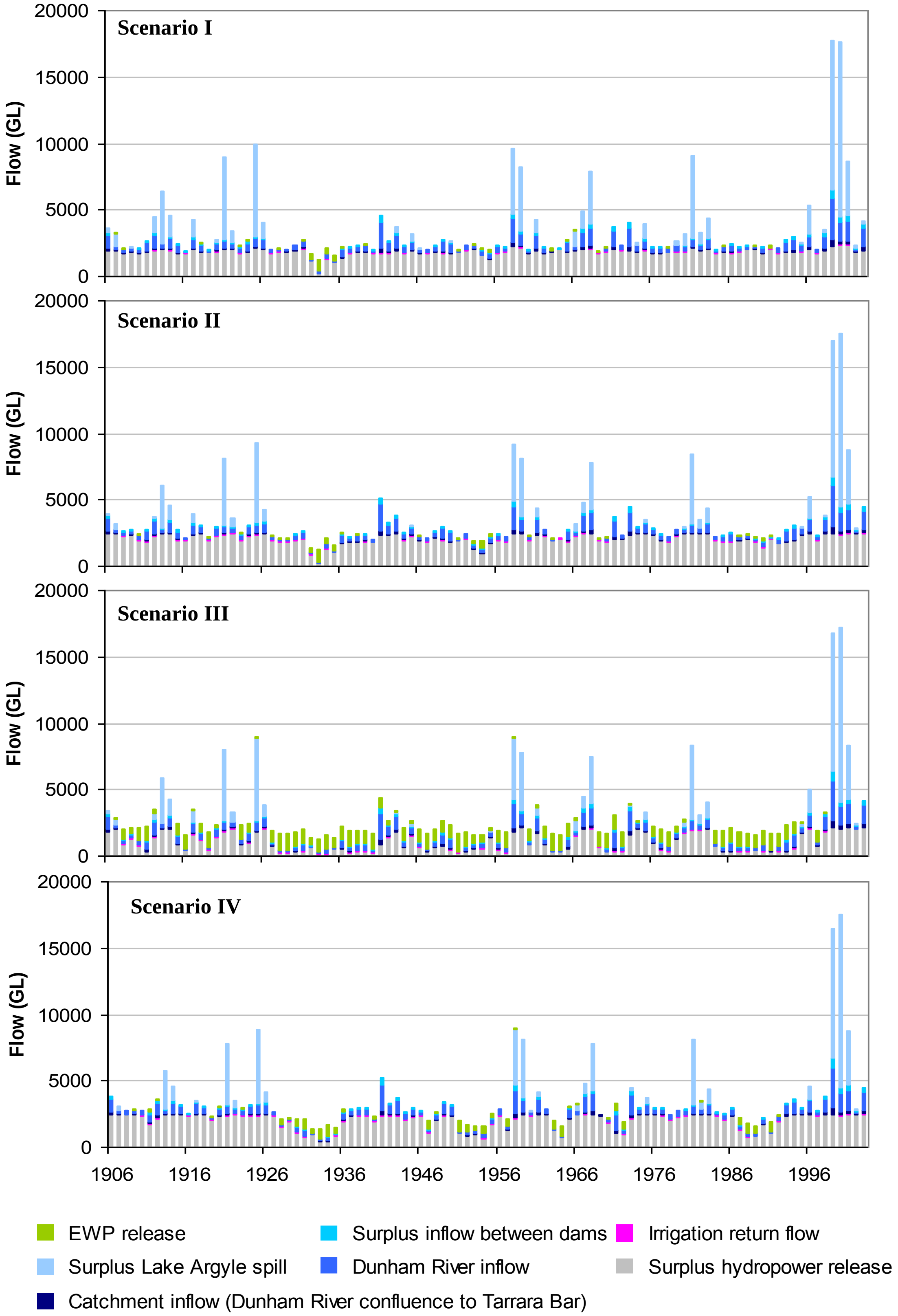

Figure 25 Components of annual flow at Tarrara Bar for scenarios I to IV

5.3 Impact of raising the Ord River Dam spillway

Simulations were also undertaken to assess water availability if the Ord River Dam spillway was raised by 0.5, 1.0 and 2.0 m. Increasing the spillway height effectively increases the storage capacity of the reservoir, which may make the reservoir more resilient during drought periods, but also increases evaporative losses from the surface of Lake Argyle. Increasing the spillway height may also lead to increased periods of inundation for some areas around the reservoir. The implications of this increased inundation have not been considered in further detail within this study.

Allocation Scenario III (high irrigation and power demands) was simulated for each of the three spillway increases. The spillway rating table within the model was adapted for each height increase. Reservoir operating rules for this scenario, established with the existing spillway height of 92.2 m AHD, were adopted for all spillway simulations.

As spillway height increased, so too did minimum lake storage level (in the driest sequence of years) and mean annual evaporation (Table 7). The minimum storage level highlights the resilience of the reservoir to drought periods. For instance, at the existing spillway height of 92.2 m AHD, the minimum volume of water stored over the simulation period was 413 GL (69.3 m AHD). With a 2.0 m increase in the spillway height, this minimum storage level increased by 334 GL (to 73 m AHD). The spillway height increases both the storage volume and surface area at the full supply level (spillway level). This has resulted in an increase in the mean annual evaporation. As the spillway height increases, the mean spill from the reservoir decreases as the reservoir is capable of storing larger volumes before the spillway flows.

Table 7 Effect of raising the Lake Argyle spillway for Scenario III (licensed to allocation limits and high power demand)

Increase m	Spillway level m AHD	Lake Argyle volume at spillway level GL	Minimum storage GL	Mean annual evaporation GL	Mean annual spill GL
	92.2	10 700	413	1151	742
0.5	92.7	11 222	502	1213	618
1.0	93.2	11 745	523	1240	565
2.0	94.2	12 803	747	1318	423

Target water levels and irrigation supply reliabilities were exceeded for all Scenario III simulations with raised spillway levels investigated. This indicates that raising the spillway may result in additional water availability. Simulations with additional irrigation allocation (of approximately 133 GL under a mix of 50 per cent cotton, 50 per cent sugar) were possible when the spillway level was increased by 1.0 to 2.0 m. With a spillway level increase of 2.0 m there may also be opportunity to increase environmental water provisions in drought years.

5.4 Impact of incorporating an additional hydropower station at the Kununurra Diversion Dam

There is potential to construct a hydropower station at the Kununurra Diversion Dam to supplement the supply from the existing station at the Ord River Dam. This additional hydropower station would generate power from Kununurra Diversion Dam releases. The station was incorporated into the model and releases from the diversion dam up to the limit of the station were used to generate power. No water was released specifically for hydropower generation at the diversion dam station. The proportion of water released from Lake Argyle that is not diverted for irrigation also passes through the Kununurra Diversion Dam and would enable power to be generated from both Lake Argyle and Kununurra Diversion Dam releases. This is an efficient use of the resource, and means that more power can be generated overall from Lake Argyle releases.

The impact of an additional hydropower station on water availability was explored under Scenario II (current conditions) and Scenario III (licensed to allocation limits, high irrigation and power demand).

Table 8 Comparison between Scenario II and Scenario III with and without an additional hydropower station at the Kununurra Diversion Dam

	Scenario II (current conditions)		**Scenario III (high irrigation and power demand)**	
	Existing conditions	**With additional hydropower station**	**Existing conditions**	**With additional hydropower station**
Min. water level in Lake Argyle (m AHD)	69.85	70.00	69.31	69.71
Mean hydropower production (GWhrs)	243.1	306.7	238.4	289.6
Mean releases for hydropower production (GL/yr)	2387	2188	1511	1457
Mean releases to meet EWP (GL/yr)	54	75	642	575
Mean spill (GL/yr)	699	839	742	858

A summary of the most important results for scenarios II and III with and without the additional hydropower station is shown in Table 8. More water was retained in storage for both scenarios with the additional hydropower station, as evident in the higher minimum water levels, and higher mean annual spill volumes. Mean annual power produced was also higher for both scenarios with the additional station, while the average volume of water released from Lake Argyle for hydropower production was lower.

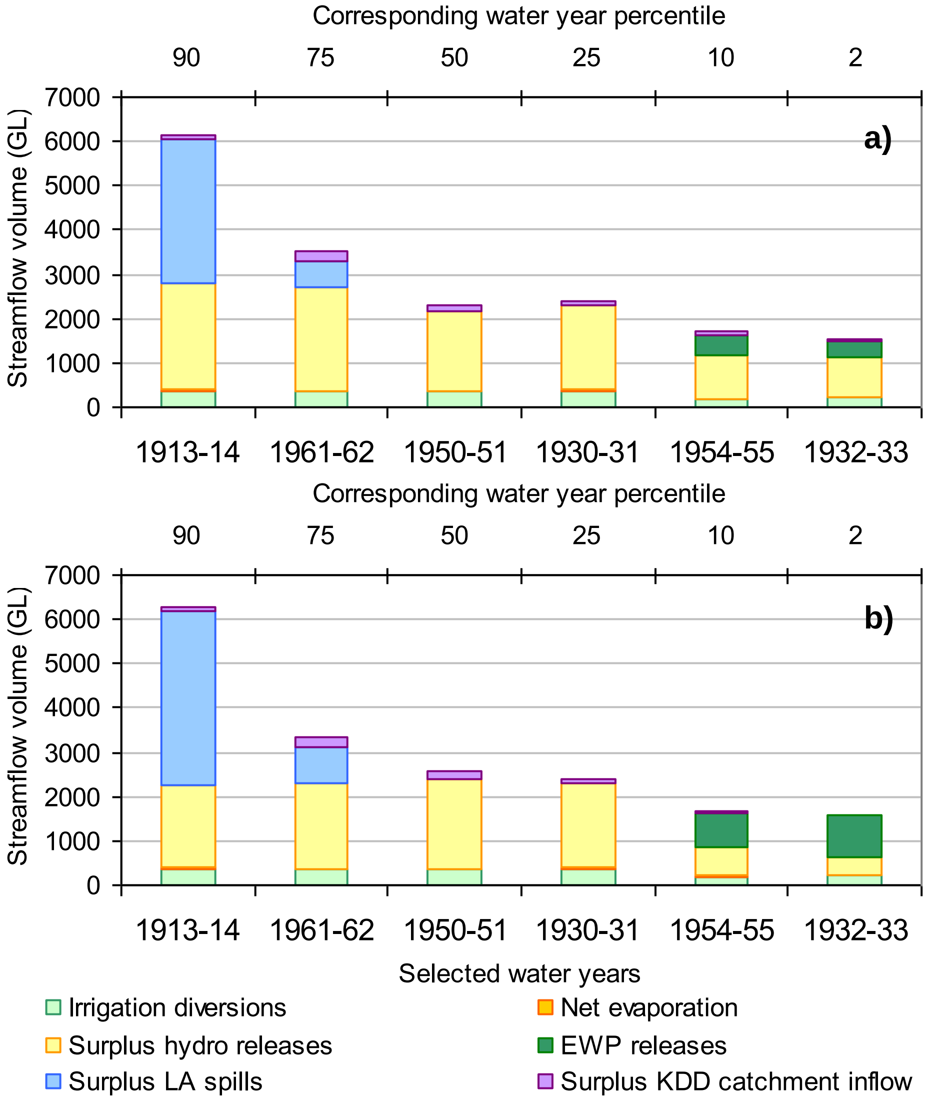

Figure 26 Components of releases from the Kununurra Diversion Dam, for the current situation (Scenario II) without (a) and with (b) an additional hydropower station at the Kununurra Diversion Dam

Under the current scenario, with the additional power station, more water is released to meet environmental flows in the lower Ord River in drought years (10th and 2nd percentile years) (Figure 26). Less water is released (overall) to generate power, while there is more spill from Lake Argyle in wet years (90th and 75th percentile years).

6 Concluding discussion

The hydrological dataset used in the modelling extends to 2004. It is recommended that this dataset is reviewed and updated as further information becomes available. This may involve assembling additional data from gauging stations along the Dunham River, and calculating Lake Argyle inflows via a reverse water balance of the reservoir. There is also scope to refine our understanding of current and projected future water demands, including crop demand, water delivery efficiencies and hydropower demand in the region.

Very dry years and, in particular, sequences of very dry years, have a large effect on the amount of water that can be allocated from Lake Argyle. Drought sequences affect the reliability of water supply. There is enough storage in the reservoir to buffer the system against isolated dry years (for instance 1985 and 1992). However, over a series of dry years (for instance the early 1930s) the water level in the reservoir will be continually drawn down, diminishing the available water, and management of the demands is necessary to ensure security of supply.

Evaporation is a large component of the Lake Argyle water balance. It is often commented that wet season inflows are so substantial there could be no shortage of water in Lake Argyle. However, evaporation outweighs rainfall in most months. The mean annual evaporation from Lake Argyle for the current situation (Scenario II) was 1132 GL, 26 per cent of the overall annual output from the lake.

Annual streamflow downstream of the Kununurra Diversion Dam reduces with increasing levels of development. For instance, from pre-dam to the current level of development, mean annual streamflow has reduced from an average 4397 GL to 2897 GL. This reduction is due to the effect of evaporation over the storages (as mentioned above) and diversions from Lake Kununurra for irrigation. Streamflow downstream of the diversion dam is further decreased with development of the Stage 2 irrigation area, as up to a further 400 GL could be diverted from Lake Kununurra for irrigation.

The reservoir simulations show that release rules can be developed to support hydropower generation and the existing and future irrigation development. However the additional irrigation allocation puts the system under greater pressure during drought periods. With extra water diverted from Lake Kununurra for increased irrigation and modified water release rules for hydropower, more water is required to be released to meet the environmental water provisions for the lower Ord River.

Physical alterations to the reservoir system, such as raising the level of the Ord River Dam spillway, or adding a hydropower station at the Kununurra Diversion Dam, do increase the versatility of the water resource. An additional hydropower station at the Kununurra Diversion Dam would enable more power to be generated from existing Lake Argyle releases, consequently more water would be retained in storage. Raising the spillway level would significantly increase the storage in Lake Argyle. Both options would help the system buffer against dry years and may make more water available for consumptive use.

Appendices

Appendix A — Operating rules

Table A.1 Scenario I water release rules – current irrigation and moderate hydropower demand

Month	Power						Irrigation				Environmental water provision			
	1st level		2nd level		3rd level		1st Level		2nd level		1st level		2nd level	
	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	32.30
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	32.30
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	32.30
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	32.30
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	32.30
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	32.30
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	32.30

Table A.2 Scenario II water release rules – current irrigation and hydropower demand

Month	Power						Irrigation				Environmental water provision			
	1st level		2nd level		3rd level		1st Level		2nd level		1st level		2nd level	
	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	32.30
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	32.30
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	32.30
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	32.30
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	32.30
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	32.30
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	32.30

Table A.3 Scenario III water release rules- high irrigation and hydropower demand

Month	Power						Irrigation				Environmental water provision			
	1st level		2nd level		3rd level		1st level		2nd level		1st level		2nd level	
	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	32.30
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	32.30
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	32.30
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	32.30
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	32.30
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	32.30
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	32.30

Table A.4 Scenario IV water release rules – moderate irrigation and high hydropower demand – enhanced operating rules

Month	Power						Irrigation				Environmental water provision			
	1st level		2nd level		3rd level		1st level		2nd level		1st level		2nd level	
	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	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	32.30
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	32.30
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	32.30
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	32.30
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	32.30
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	32.30
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	32.30

Table A.5 Scenario V water release rules – high irrigation and low power demand

Month	Power						Irrigation				Environmental water provision			
	1st level		2nd level		3rd level		1st level		2nd level		1st level		2nd level	
	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	32.30
Jul	-	-	-	8.00	76.00	0.00	78.40	50	73.50	0	82.30	37.00	76.20	32.30
Aug	-	-	-	8.39	76.00	0.00	77.70	50	73.50	0	81.70	37.00	75.30	32.30
Sep	-	-	-	10.98	76.00	0.00	76.80	50	73.50	0	81.10	37.00	74.30	32.30
Oct	-	-	-	12.62	76.00	0.00	76.00	50	73.50	0	80.50	37.00	73.10	32.30
Nov	-	-	-	12.89	76.00	0.00	75.70	50	73.50	0	80.00	37.00	75.70	32.30
Dec	-	-	-	10.18	76.00	0.00	75.30	50	73.50	0	79.50	37.00	75.30	32.30

Appendix B — Reservoir characteristics

Table B.1 Ord River Dam spillway characteristics

Water level m AHD	Spill m^3/s
90.21	0.00
90.76	0.06
91.44	0.49
91.82	1.08
92.03	2.00
92.19	4.53
92.45	22.51
93.00	124.00
93.52	258.78
94.01	362.39
94.50	424.77
95.00	472.00
96.00	588.00
97.00	711.00
98.00	848.00
99.00	996.00
100.00	1162.00
101.00	1337.00
102.00	1518.00
103.00	1702.00
104.00	1901.00
105.00	2108.00
106.00	2417.00
107.00	2870.00
108.00	4640.00
109.00	8080.00
110.00	13550.00

Table B.2 Relationship between water level, surface area and volume in Lake Argyle

Water level m AHD	Surface area km^2	Volume $10^6\ m^3$	Comment
42.95	0.0	0	
70.00	82.0	423	Minimum operating level
71.00	97.0	513	
72.00	116.0	619	
73.00	137.0	745	
74.00	162.0	894	
75.00	191.0	1071	
76.00	226.0	1279	
77.00	264.0	1523	
78.00	304.0	1808	
79.00	345.0	2132	
80.00	386.0	2497	
81.00	430.0	2905	
82.00	475.0	3358	
83.00	522.0	3857	
84.00	571.0	4403	
85.00	619.0	4998	
86.00	669.0	5642	
86.23	681.0	5797	Full supply level to December 1994
87.00	719.0	6336	
88.00	767.0	7080	
89.00	815.0	7871	
90.00	864.0	8710	
91.00	915.0	9600	
92.00	968.0	10541	
92.20	978.6	10700	Full supply level since December 1994
93.00	1021.0	11535	
94.00	1074.0	12583	
95.00	1126.0	13683	
96.00	1182.0	14837	
97.00	1243.0	16048	
98.00	1309.0	17324	
99.00	1376.0	18667	
100.00	1438.0	20074	
101.00	1499.0	21543	
102.00	1559.0	23073	
103.00	1619.0	24662	
104.00	1678.0	26311	
105.00	1737.0	28018	
106.00	1797.0	29785	
107.00	1857.0	31612	
108.00	1917.0	33499	
109.00	1974.0	35444	
110.00	2030.0	37446	

Table B.3 Lake Argyle spillway characteristics – spillway raised

Water Level m AHD	Spillway raised 2.0 m m^3/s	Spillway raised 1.0 m m^3/s	Spillway raised 0.5 m m^3/s
90.20	0.0	0.0	0.0
90.80	0.1	0.1	0.1
91.40	0.5	0.5	0.5
91.80	1.1	1.1	1.1
92.00	2.0	2.0	2.0
92.20	4.5	4.5	4.5
92.40	6.0	6.0	6.0
92.70	6.0	6.0	6.0
93.00	6.0	6.0	60.0
93.20	6.0	6.0	110.0
93.50	6.0	90.0	200.0
94.00	6.0	240.0	362.4
94.20	6.0	310.0	390.0
94.50	180.0	424.8	424.8
95.00	472.0	472.0	472.0
96.00	588.0	588.0	588.0
97.00	711.0	711.0	711.0
98.00	848.0	848.0	848.0
99.00	996.0	996.0	996.0
100.00	1162.0	1162.0	1162.0
101.00	1337.0	1337.0	1337.0
102.00	1518.0	1518.0	1518.0
103.00	1702.0	1702.0	1702.0
104.00	1901.0	1901.0	1901.0
105.00	2108.0	2108.0	2108.0
106.00	2417.0	2417.0	2417.0
107.00	2870.0	2870.0	2870.0
108.00	4640.0	4640.0	4640.0
109.00	8080.0	8080.0	8080.0
110.00	13550.0	13550.0	13550.0

Table B.4 Relationship between water level, surface area and volume in Lake Kununurra

Water level m AHD	Surface area km^2	Volume $10^6\ m^3$
24.00	0.0	0.0
25.00	0.1	0.3
26.00	0.3	0.9
27.00	0.6	1.7
28.00	1.0	3.0
29.00	1.5	4.7
30.00	2.3	6.8
31.00	3.1	9.3
32.00	4.0	12.1
33.00	5.0	15.4
34.00	6.0	19.4
35.00	7.0	24.2
36.00	8.0	30.4
37.00	9.0	38.6
38.00	10.0	49.0
39.00	11.2	60.8
40.00	12.5	73.4
41.00	13.8	87.0
42.00	15.0	105.4

Appendix C — Reservoir water balance

Table C.1 Mean annual water balance for the two reservoirs (water year)

Item	Units	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						
Input						
Stream inflow	GL/yr	4278	4278	4278	4278	4278
Output						
Net evaporation	GL/yr	1190	1132	1151	1106	1207
Releases via outlet works	GL/yr	2205	2445	2382	2507	1932
To meet hydropower demand		2155	2387	1511	2354	648
To meet irrigation demand		3	4	229	3	394
To meet EWP needs		47	54	642	149	890
Spillage	GL/yr	874	699	742	660	1126
Change in storage	GL/yr	9	2	3	5	13
Total outflow from Lake Argyle		3080	3145	3124	3167	3058
At Kununurra Diversion Dam/Lake Kununurra						
Input						
Inflow from KDD catchment	GL/yr	119	119	119	119	119
Lake Argyle Spillage	GL/yr	874	699	742	660	1126
Releases via Ord River Dam outlet works	GL/yr	2205	2445	2382	2507	1932
Output						
Net evaporation	GL/yr	20	20	20	20	20
Diversions	GL/yr					
To meet Stage 1 irrigation demand		342	340	341	343	344
To meet Stage 2 irrigation demand		0	0	390	0	393
Releases under the gates of the Kununurra Diversion Dam	GL/yr	2830	2897	2486	2917	2415
Surplus Lake Argyle spillage		854	679	722	640	1035
Surplus inflows from KDD catchment		118	118	118	118	118
Surplus hydropower station releases		1810	2046	1005	2010	373
Specific EWP releases from Lake Argyle		47	54	642	149	890
Change in storage	GL/yr	7	7	5	6	5

Appendix D — Power generation data

Table D.1 Lookup table for power production as a function of water level and hydropower station flow

Power MW	Lake level m AHD																		
Station flow m^3/s	60	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	103	110
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.4	0.0	2.7	3.1	3.5	4.0	4.4	4.8	5.2	5.5	5.1	5.3	5.6	5.8	6.0	6.3	6.4	6.5	6.5	-9998
24.4	0.0	4.3	4.7	5.2	5.7	6.2	6.6	7.0	7.5	6.9	7.3	7.6	7.9	8.2	8.5	8.7	8.9	8.9	-9998
28.5	0.0	5.4	6.0	6.6	7.1	7.6	8.2	8.7	9.2	8.5	9.0	9.4	9.8	10.1	10.5	10.7	10.9	10.9	-9998
32.6	0.0	6.5	7.1	7.7	8.4	9.0	9.6	10.2	10.8	10.0	10.6	11.0	11.5	11.9	12.3	12.7	12.9	12.9	-9998
35.3	0.0	7.2	7.9	8.5	9.2	9.9	10.6	11.3	12.0	11.1	11.7	12.2	12.7	13.2	13.7	14.0	14.3	14.2	-9998
36.6	0.0	7.2	8.2	8.9	9.6	10.4	11.1	11.8	12.6	11.6	12.2	12.8	13.3	13.8	14.3	14.7	14.9	14.9	-9998
36.7	0.0	7.2	8.2	8.9	9.7	10.4	11.1	11.9	12.6	11.6	12.2	12.8	13.3	13.9	14.3	14.7	15.0	14.9	-9998
37.7	0.0	7.2	8.2	9.3	10.0	10.8	11.5	12.3	13.0	12.1	12.7	13.3	13.8	14.4	14.9	15.2	15.5	15.5	-9998
38.7	0.0	7.2	8.2	9.3	10.4	11.1	11.9	12.6	13.4	12.4	13.1	13.7	14.3	14.8	15.3	15.7	16.0	15.9	-9998
39.5	0.0	7.2	8.2	9.3	10.4	11.5	12.2	12.9	13.8	12.7	13.4	14.0	14.6	15.2	15.7	16.1	16.4	16.3	-9998
40.4	0.0	7.2	8.2	9.3	10.4	11.5	12.6	13.3	14.1	13.0	13.7	14.4	15.0	15.5	16.1	16.5	16.8	16.7	-9998
40.7	0.0	7.2	8.2	9.3	10.4	11.5	12.6	13.5	14.2	13.2	13.9	14.5	15.1	15.7	16.2	16.6	16.9	16.9	-9998
41.8	0.0	7.2	8.2	9.3	10.4	11.5	12.6	13.7	14.6	13.5	14.2	14.8	15.4	16.0	16.6	17.0	17.3	17.3	-9998
43.3	0.0	7.2	8.2	9.3	10.4	11.5	12.6	13.7	14.8	13.7	14.4	15.1	15.7	16.3	16.9	17.3	17.6	17.6	-9998
44.8	0.0	7.2	8.2	9.3	10.4	11.5	12.6	13.7	14.8	13.7	14.4	15.1	15.7	16.3	16.9	17.3	17.6	17.6	-9998
45.2	0.0	7.2	8.2	9.3	10.4	11.5	12.6	13.7	14.8	13.9	14.7	15.3	16.0	16.6	17.1	17.5	17.9	17.9	-9998
45.6	0.0	7.3	8.2	9.3	10.4	11.5	12.6	13.7	14.8	14.1	14.9	15.6	16.2	16.8	17.3	17.8	18.2	18.2	-9998
46.1	0.0	7.5	8.4	9.3	10.4	11.5	12.6	13.7	14.8	14.3	15.1	15.8	16.5	17.1	17.6	18.1	18.4	18.5	-9998
46.5	0.0	7.7	8.5	9.4	10.4	11.5	12.6	13.7	14.8	14.5	15.3	16.0	16.7	17.3	17.8	18.3	18.7	18.8	-9998
46.9	0.0	7.8	8.7	9.5	10.5	11.5	12.6	13.7	14.8	14.7	15.4	16.2	16.9	17.5	18.1	18.5	18.9	19.1	-9998
47.5	0.0	8.0	8.9	9.7	10.8	11.7	12.6	13.7	14.8	15.0	15.7	16.5	17.2	17.9	18.4	18.9	19.3	19.5	-9998
48.2	0.0	8.2	9.1	10.0	11.0	12.0	12.8	13.7	14.8	15.3	16.0	16.8	17.5	18.2	18.8	19.3	19.7	19.9	-9998
48.8	0.0	8.4	9.3	10.3	11.3	12.2	13.1	14.0	14.8	15.5	16.4	17.1	17.8	18.5	19.1	19.6	20.0	20.3	-9998
48.9	0.0	8.4	9.4	10.3	11.3	12.2	13.1	14.0	14.9	15.6	16.4	17.1	17.9	18.6	19.3	19.7	20.2	20.4	-9998
52.9	0.0	9.6	10.7	11.8	12.8	13.8	14.7	15.6	16.5	17.4	18.2	19.1	19.9	20.6	21.4	22.0	22.7	23.0	-9998
57.0	0.0	10.7	11.9	13.0	14.1	15.1	16.2	17.2	18.2	19.2	20.1	21.0	21.8	22.7	23.5	24.3	25.0	25.4	-9998
61.1	0.0	11.8	13.0	14.1	15.3	16.5	17.6	18.7	19.8	20.9	21.9	22.9	23.9	24.8	25.6	26.4	27.2	27.6	-9998

Power MW	Lake level m AHD																	
Station flow m^3/s	60	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	103	110
65.2	0.0	12.9	14.1	15.3	16.5	17.8	19.0	20.2	21.5	22.6	23.8	24.9	25.9	26.9	27.8	28.6	29.4	29.8	-9998
69.2	0.0	13.8	15.1	16.5	17.8	19.1	20.5	21.8	23.1	24.4	25.7	26.8	28.0	29.1	30.1	31.1	31.9	32.3	-9998
70.1	0.0	14.0	15.4	16.7	18.1	19.5	20.8	22.2	23.6	24.9	26.1	27.3	28.5	29.6	30.7	31.6	32.4	32.9	-9998
72.6	0.0	14.0	16.0	17.4	18.9	20.3	21.8	23.1	24.6	26.0	27.2	28.5	29.7	31.0	32.0	33.1	34.0	34.5	-9998
73.3	0.0	14.0	16.0	17.6	19.1	20.5	22.0	23.5	24.9	26.2	27.6	28.9	30.1	31.4	32.5	33.6	34.5	35.0	-9998
74.8	0.0	14.0	16.0	18.1	19.6	21.1	22.6	24.1	25.5	26.9	28.3	29.6	31.0	32.2	33.4	34.5	35.4	36.0	-9998
76.8	0.0	14.0	16.0	18.1	20.2	21.8	23.3	24.8	26.3	27.8	29.2	30.6	32.0	33.3	34.6	35.7	36.8	37.3	-9998
77.4	0.0	14.0	16.0	18.1	20.2	22.0	23.6	25.1	26.6	28.0	29.5	30.9	32.3	33.7	34.9	36.1	37.2	37.7	-9998
77.8	0.0	14.0	16.0	18.1	20.2	22.2	23.7	25.2	26.7	28.2	29.7	31.1	32.5	33.9	35.2	36.5	37.5	38.0	-9998
78.4	0.0	14.0	16.0	18.1	20.2	22.4	24.0	25.5	27.0	28.4	30.0	31.3	32.8	34.2	35.5	36.9	37.9	38.0	-9998
78.6	0.0	14.0	16.0	18.1	20.2	22.4	24.0	25.5	27.1	28.5	30.0	31.4	32.9	34.3	35.7	37.0	38.0	38.0	-9998
80.3	0.0	14.0	16.0	18.1	20.2	22.4	24.6	26.1	27.7	29.1	30.7	32.2	33.6	35.1	36.5	37.8	38.0	38.0	-9998
80.6	0.0	14.0	16.0	18.1	20.2	22.4	24.6	26.3	27.8	29.3	30.8	32.3	33.8	35.3	36.7	38.0	38.0	38.0	-9998
81.5	0.0	14.0	16.0	18.1	20.2	22.4	24.6	26.6	28.1	29.6	31.2	32.7	34.2	35.7	37.1	38.0	38.0	38.0	-9998
82.3	0.0	14.0	16.0	18.1	20.2	22.4	24.6	26.8	28.4	29.9	31.5	33.1	34.6	36.1	37.5	38.0	38.0	38.0	-9998
83.5	0.0	14.0	16.0	18.1	20.2	22.4	24.6	26.8	28.8	30.4	32.0	33.5	35.1	36.6	38.0	38.0	38.0	38.0	-9998
84.4	0.0	14.0	16.0	18.1	20.2	22.4	24.6	26.8	29.0	30.7	32.2	33.8	35.4	37.0	38.0	38.0	38.0	38.0	-9998
85.3	0.0	14.0	16.0	18.1	20.2	22.4	24.6	26.8	29.0	30.9	32.5	34.1	35.7	37.3	38.0	38.0	38.0	38.0	-9998
85.5	0.0	14.0	16.0	18.1	20.2	22.4	24.6	26.8	29.0	31.0	32.6	34.2	35.8	37.3	38.0	38.0	38.0	38.0	-9998
86.1	0.0	14.0	16.0	18.1	20.2	22.4	24.6	26.8	29.0	31.2	32.6	34.3	35.9	37.5	38.0	38.0	38.0	38.0	-9998
86.8	0.0	14.0	16.0	18.1	20.2	22.4	24.6	26.8	29.0	31.2	32.8	34.6	36.1	37.7	38.0	38.0	38.0	38.0	-9998
88.1	0.0	14.0	16.0	18.1	20.2	22.4	24.6	26.8	29.0	31.2	33.2	35.0	36.5	38.0	38.0	38.0	38.0	38.0	-9998
88.3	0.0	14.0	16.0	18.1	20.2	22.4	24.6	26.8	29.0	31.2	33.2	35.0	36.5	38.0	38.0	38.0	38.0	38.0	-9998
89.6	0.0	14.0	16.0	18.1	20.2	22.4	24.6	26.8	29.0	31.2	33.2	35.2	36.8	38.0	38.0	38.0	38.0	38.0	-9998
89.7	0.0	14.0	16.0	18.1	20.2	22.4	24.6	26.8	29.0	31.2	33.2	35.2	36.8	38.0	38.0	38.0	38.0	38.0	-9998
90.6	0.0	14.0	16.0	18.1	20.2	22.4	24.6	26.8	29.0	31.2	33.2	35.2	36.8	38.0	38.0	38.0	38.0	38.0	-9998
93.7	0.0	14.0	16.0	18.1	20.2	22.4	24.6	26.8	29.0	31.2	33.2	35.2	36.8	38.0	38.0	38.0	38.0	38.0	-9998
110.0	0.0	14.0	16.0	18.1	20.2	22.4	24.6	26.8	29.0	31.2	33.2	35.2	36.8	38.0	38.0	38.0	38.0	38.0	-9998

Table D.2 Lookup table for hydropower station flow as a function of water level and power production

Flow m^3/s	Lake level m AHD																		
Power MW	**60**	**72**	**74**	**76**	**78**	**80**	**82**	**84**	**86**	**88**	**90**	**92**	**94**	**96**	**98**	**100**	**102**	**103**	**110**
0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
3.0	-9998	20.9	20.1	18.6	17.1	15.9	13.7	12.2	12.2	9.7	9.5	8.9	8.9	8.9	8.2	8.0	8.0	8.1	8.2
4.0	-9998	23.6	22.5	21.5	20.4	19.4	18.3	16.3	16.2	13.0	12.6	11.9	11.9	11.9	10.9	10.7	10.6	10.8	11.0
5.0	-9998	27.0	25.2	23.9	22.8	21.7	20.8	20.4	20.3	16.2	15.8	14.9	14.9	14.9	13.6	13.4	13.3	13.5	13.7
6.0	-9998	30.6	28.5	26.7	25.2	24.0	23.0	21.7	21.1	19.4	18.9	17.9	17.9	17.9	16.4	16.1	16.0	16.2	16.5
7.0	-9998	34.5	32.1	30.0	28.2	26.6	25.4	24.3	23.3	22.7	22.1	20.8	20.8	20.8	19.1	18.8	18.6	18.9	19.2
7.2	-9998	35.3	32.8	30.7	28.8	27.2	25.9	24.8	23.7	23.3	22.7	21.4	21.4	21.4	19.6	19.3	19.1	19.4	19.8
7.2	-9998	45.2	32.8	30.7	28.8	27.2	25.9	24.8	23.7	23.3	22.7	21.4	21.4	21.4	19.6	19.3	19.1	19.4	19.8
8.0	-9998	47.4	35.9	33.5	31.4	29.6	28.0	26.8	25.7	25.9	25.2	23.8	23.8	23.8	21.8	21.4	21.3	21.6	22.0
8.2	-9998	48.1	36.6	34.2	32.1	30.2	28.6	27.3	26.1	26.6	25.9	24.4	24.4	24.4	22.4	22.0	21.8	22.2	22.5
8.2	-9998	48.1	45.6	34.2	32.1	30.2	28.6	27.3	26.1	26.6	25.9	24.4	24.4	24.4	22.4	22.0	21.8	22.2	22.5
9.0	-9998	50.9	47.8	36.9	34.6	32.6	30.9	29.3	28.0	29.2	28.4	26.8	26.8	26.8	24.6	24.1	23.9	24.3	24.7
9.3	-9998	51.8	48.6	37.7	35.4	33.4	31.6	30.0	28.7	30.0	29.2	27.6	27.6	27.6	25.3	24.8	24.6	25.0	25.4
9.3	-9998	51.8	48.6	46.1	35.4	33.4	31.6	30.0	28.7	30.0	29.2	27.6	27.6	27.6	25.3	24.8	24.6	25.0	25.4
10.0	-9998	54.4	50.8	48.0	37.6	35.6	33.7	32.0	30.5	32.4	31.6	29.8	29.8	29.8	27.3	26.8	26.6	27.0	27.5
10.4	-9998	55.6	51.9	48.9	38.7	36.5	34.6	32.9	31.4	33.6	32.7	30.8	30.8	30.8	28.2	27.7	27.5	28.0	28.4
10.4	-9998	55.6	51.9	48.9	46.5	36.5	34.6	32.9	31.4	33.6	32.7	30.8	30.8	30.8	28.2	27.7	27.5	28.0	28.4
11.0	-9998	58.0	54.0	50.6	48.1	38.2	36.3	34.6	33.0	35.7	34.7	32.7	32.7	32.7	30.0	29.5	29.2	29.7	30.2
11.5	-9998	59.7	55.5	52.0	49.3	39.5	37.5	35.7	34.1	37.1	36.2	34.1	34.1	34.1	31.3	30.7	30.5	31.0	31.5
11.5	-9998	59.7	55.5	52.0	49.3	46.9	37.5	35.7	34.1	37.1	36.2	34.1	34.1	34.1	31.3	30.7	30.5	31.0	31.5
12.0	-9998	61.8	57.4	53.7	50.7	48.3	38.8	36.9	35.4	38.9	37.9	35.7	35.7	35.7	32.7	32.2	31.9	32.4	33.0
12.6	-9998	64.1	59.5	55.6	52.3	49.8	40.4	38.1	36.6	40.7	39.7	37.4	37.4	37.4	34.3	33.7	33.4	34.0	34.5
12.6	-9998	64.1	59.5	55.6	52.3	49.8	47.5	38.1	36.6	40.7	39.7	37.4	37.4	37.4	34.3	33.7	33.4	34.0	34.5
13.0	-9998	65.9	61.2	57.1	53.6	50.9	48.6	39.1	37.6	42.1	41.0	38.7	38.7	38.7	35.5	34.8	34.6	35.1	35.7
13.7	-9998	68.8	63.8	59.5	55.8	52.8	50.3	41.8	39.1	44.4	43.2	40.7	40.7	40.7	37.3	36.7	36.4	37.0	37.6
13.7	-9998	68.8	63.8	59.5	55.8	52.8	50.3	48.2	39.1	44.4	43.2	40.7	40.7	40.7	37.3	36.7	36.4	37.0	37.6
14.0	-9998	70.1	65.0	60.6	56.8	53.7	51.1	48.9	40.0	45.4	44.2	41.7	41.7	41.7	38.2	37.5	37.2	37.8	38.5
14.0	-9998	70.1	65.1	60.7	56.8	53.8	51.2	49.0	40.0	45.4	44.2	41.7	41.7	41.7	38.2	37.6	37.3	37.9	38.5
14.8	-9998	-9998	68.2	63.6	59.5	56.1	53.3	50.9	43.3	47.1	45.5	44.1	44.1	44.1	40.4	39.7	39.4	40.0	40.7
14.8	-9998	-9998	68.2	63.8	59.5	56.1	53.3	50.9	48.8	47.1	45.5	44.1	44.1	44.1	40.4	39.7	39.4	40.0	40.7

Flow m^3/s	Lake level m AHD																		
Power MW	**60**	**72**	**74**	**76**	**78**	**80**	**82**	**84**	**86**	**88**	**90**	**92**	**94**	**96**	**98**	**100**	**102**	**103**	**110**
15.0	-9998	-9998	68.9	64.2	60.1	56.6	53.8	51.4	49.2	47.5	45.8	44.6	44.6	44.6	40.9	40.2	39.9	40.5	41.2
16.0	-9998	-9998	72.6	67.8	63.4	59.6	56.5	53.9	51.6	49.7	47.9	46.5	45.3	44.4	43.6	42.9	42.5	43.2	43.2
17.0	-9998	-9998	-9998	71.2	66.8	62.7	59.3	56.5	54.1	52.0	50.2	48.5	47.1	45.8	45.0	44.3	43.9	44.2	44.2
18.0	-9998	-9998	-9998	74.5	70.0	65.8	62.2	59.1	56.5	54.3	52.4	50.7	49.1	47.6	46.6	45.9	45.4	45.3	45.3
18.1	-9998	-9998	-9998	74.8	70.2	66.1	62.4	59.3	56.7	54.5	52.6	50.8	49.3	47.8	46.7	46.1	45.5	45.4	45.4
19.0	-9998	-9998	-9998	-9998	73.1	68.9	65.1	61.8	59.0	56.7	54.7	52.8	51.2	49.6	48.4	47.6	46.9	46.7	46.7
20.0	-9998	-9998	-9998	-9998	76.1	71.9	68.0	64.5	61.5	59.0	56.9	55.0	53.2	51.7	50.3	49.4	48.5	48.2	48.2
20.2	-9998	-9998	-9998	-9998	76.8	72.5	68.6	65.1	62.0	59.5	57.4	55.4	53.7	52.1	50.7	49.7	48.9	48.5	48.5
21.0	-9998	-9998	-9998	-9998	-9998	74.7	70.7	67.1	64.0	61.3	59.1	57.1	55.3	53.7	52.2	51.1	50.2	49.7	49.7
22.0	-9998	-9998	-9998	-9998	-9998	77.3	73.4	69.7	66.5	63.6	61.2	59.2	57.3	55.7	54.2	52.9	51.8	51.4	51.4
22.4	-9998	-9998	-9998	-9998	-9998	78.4	74.4	70.8	67.5	64.6	62.1	60.0	58.2	56.5	55.0	53.7	52.5	52.0	52.0
23.0	-9998	-9998	-9998	-9998	-9998	-9998	75.9	72.2	68.9	65.9	63.4	61.2	59.4	57.7	56.1	54.7	53.5	53.0	53.0
24.0	-9998	-9998	-9998	-9998	-9998	-9998	78.5	74.7	71.3	68.2	65.6	63.3	61.4	59.6	58.0	56.6	55.3	54.7	54.7
24.6	-9998	-9998	-9998	-9998	-9998	-9998	80.3	76.2	72.8	69.7	66.9	64.6	62.6	60.8	59.2	57.7	56.4	55.8	55.8
25.0	-9998	-9998	-9998	-9998	-9998	-9998	-9998	77.2	73.6	70.5	67.8	65.4	63.4	61.5	59.9	58.4	57.0	56.5	56.5
26.0	-9998	-9998	-9998	-9998	-9998	-9998	-9998	79.8	76.0	72.8	70.0	67.5	65.3	63.4	61.8	60.2	58.8	58.2	58.2
26.8	-9998	-9998	-9998	-9998	-9998	-9998	-9998	82.3	78.0	74.7	71.8	69.2	67.0	65.0	63.3	61.8	60.3	59.7	59.7
27.0	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	78.4	75.0	72.1	69.5	67.3	65.3	63.7	62.1	60.6	60.0	60.0
28.0	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	81.1	77.3	74.3	71.6	69.3	67.2	65.5	63.9	62.4	61.8	61.8
29.0	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	84.3	79.8	76.4	73.6	71.2	69.1	67.3	65.7	64.2	63.6	63.6
29.0	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	84.4	79.8	76.4	73.6	71.2	69.1	67.3	65.7	64.3	63.6	63.6
30.0	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	82.4	78.5	75.6	73.1	71.0	69.1	67.5	66.0	65.3	65.3
31.0	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	85.6	80.8	77.6	74.9	72.8	70.8	69.2	67.8	67.1	67.1
31.2	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	86.1	81.2	77.9	75.2	73.1	71.1	69.5	68.0	67.4	67.4
32.0	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	83.6	79.7	76.8	74.6	72.5	70.9	69.4	68.8	68.8
33.0	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	87.3	82.1	78.8	76.3	74.2	72.5	71.1	70.4	70.4
33.2	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	88.3	82.7	79.2	76.7	74.5	72.9	71.4	70.8	70.8
34.0	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	85.0	80.9	78.0	75.8	74.1	72.6	72.0	72.0
35.0	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	88.7	83.3	79.9	77.5	75.6	74.1	73.5	73.5
35.2	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	89.7	83.9	80.3	77.9	75.9	74.4	73.8	73.8
36.0	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	86.4	82.0	79.3	77.2	75.6	75.0	75.0
37.0	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	90.4	84.6	81.2	78.8	77.0	76.4	76.4

Flow m³/s	Lake level m AHD																		
	60	**72**	**74**	**76**	**78**	**80**	**82**	**84**	**86**	**88**	**90**	**92**	**94**	**96**	**98**	**100**	**102**	**103**	**110**
37.1	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	90.6	84.8	81.4	78.9	77.1	76.5	76.5
41.0	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	88.1	83.5	80.6	78.6	77.8	77.8
41.0	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998	-9998

Table D.3 Target monthly power generation (2012) – representing a high power demand

	Target power production (2012)
	MW
January	39.3
February	37.7
March	37.4
April	37.7
May	37.4
June	34.9
July	33.9
August	35.7
September	37.4
October	39.0
November	41.0
December	36.4

Table D.4 Target monthly power generation (2018) – representing low (town only) power demand

	Target power production (2018 – town only)
	MW
January	10.1
February	11.2
March	10.6
April	10.6
May	8.8
June	8.1
July	8.0
August	8.4
September	11.0
October	12.6
November	12.9
December	10.2

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