GOVERNMENT OF WESTERN AUSTRALIA

HYDROLOGY OF THE ORD RIVER

WATER RESOURCE TECHNICAL SERIES

WATER AND RIVERS COMMISSION REPORT WRT 24

1999

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Cover Photograph: Lower Ord River

Hydrology of the Ord River

by
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Water and Rivers Commission
Surface Water Hydrology

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Summary

The Ord River is one of the major rivers of Western Australia, with significant resource management issues. This report is intended to provide some background information on the hydrology as well as the observed and potential impact of water resource development.

The Ord River has a catchment area of over 50,000 km^2 to the river mouth. The mean annual flow of the Ord River at the river mouth, without any water resource development was about 4,500 GL. However there has been significant water resource development of the Ord River, with two dams constructed in the early 1960s and early 1970s. These dams were the Kununurra Diversion Dam and the Ord River Dam.

With development of the first stage of the irrigation scheme on the Ord River the average annual river flow has reduced to about 3200 GL at the river mouth. This reduction is due to evaporation from Lake Argyle and water use for irrigation. With further irrigation development the average annual river flow reduces to about 2300 GL.

The major water quality issues of the Ord River are sedimentation of Lake Argyle, salt water interface in the lower Ord River, and in more recent times the pesticide levels in the Ord and Dunham Rivers downstream of Kununurra Diversion Dam.

The sediment load into the Ord River Dam is estimated to be about 24 Mt per year. Practically all of this sediment is captured in Lake Argyle. However due to the large storage volume in Lake Argyle the impact of this sediment load is marginal.

1. Introduction

The Ord River catchment is situated in the east Kimberley region of Western Australia and extends into north-western Northern Territory, between 127° 15'E and 130° 00'E and 15° 20' S and 18°40' S. It is drained by the 650 kilometre long Ord River which empties into Cambridge Gulf near Wyndham. The major tributaries of the Ord River are the Panton, Elvire, Nicholson, Negri, Wilson/Bow and Dunham Rivers.

The catchment area for the Ord River includes the towns of Kununurra (downstream of Lake Argyle), Warmun, and Halls Creek. The main industries within the Ord River catchment are diamond and gold mining, cattle grazing, agriculture, horticulture, aquaculture and tourism.

The Ord has been the scene of much change over the last three decades as a result of the construction of a diversion dam at the town of Kununurra and a large dam in a natural gorge, within the Carr Boyd Ranges, approx 50 kilometres upstream of the town. These dams have allowed for the construction of a major irrigation scheme around Kununurra.

A map of the downstream area of the Ord River is attached at the end of this report (Map 1).

2. Catchment Description

2.1 Climate

The Ord River catchment may be described as having a semi-arid to arid monsoonal climate which can be divided into two distinct seasons: a warm, dry season; and a hot, wet season. During the wet season, November through April, most of the rain comes from localised thunderstorms, but the most widespread heavy falls occur as a result of cyclonic disturbances. These cyclones, which are most frequent during January and February, often degenerate into tropical lows, delivering considerable amounts of rainfall in a short period of time. During the remainder of the year falls are light and sporadic, and several consecutive rainless months are not uncommon.

Temperatures during the day are high throughout the year, but particularly during the wet season, when maximums above 40°C are frequent. There are also marked seasonal variations in humidity, cloud cover and solar radiation.

2.2 Vegetation and soils

The Ord River catchment is composed of two distinct geological areas, loosely separated by the Great Northern Highway. The rough hilly country of the Durack Ranges, west of the highway, has thin soils and numerous granitic outcrops. East of Great Northern Highway slightly undulating plains composed of sandstone and marine sediments are the dominant landform. The soils of the catchment are strongly influenced by topography, with the various soils being derived from their respective geological formations. The ranges and plateaus have a stony skeletal soil, while deep sandy soils dominate the valley floors. The floodplains are dominated by grey and brown heavy cracking clay soils and in the *Eucalyptus* and *Acacia* woodlands deep reddish sandy soils are dominant.

The vegetation of the flat or slightly undulating plains within the Ord River catchment is primarily a grassland and grassland/savannah woodland complex dominated by perennial grass species (see Map 2). The rough hilly country within the catchment is only sparsely covered with spinifex and small trees. River gums, paperbarks and coolibahs are prevalent along the creeks and rivers, while the trees on the plains are predominantly small eucalypts such as bloodwoods and nutwood.

Over time, the vegetation has been altered by grazing and, in certain areas, the regeneration process. The introduction of exotic grass and shrub species has led to a dominance of exotic/naturalised grass species with few native grasses evident.

Because of the absence of 'dry' season growth, all plant cover available for soil protection at the onset of the wet season is a carry over from the previous wet season. One of the first impacts of overgrazing is the replacement of perennial grasses, which provide reasonable cover at this time, with annual species. Virtually all such annual species complete their life-cycle before the opening of the following wet season. Therefore, areas exhibiting a good ground cover at the end of one wet season can, even in the absence of grazing, be quite denuded by the start of the following wet, thus providing little soil protection. This has important implications for potential erosion resulting from the often intense thunderstorms that mark the opening of the wet season.

2.3 Landuse

Prior to the construction of the Kununurra Diversion Dam, in 1963, the catchment was mainly used for the running of cattle and for mining operations. Since the construction of the diversion dam and the Ord River Dam, in 1972, a portion of the Ord River flow is diverted into irrigation channels enabling large scale cultivation of the land around Kununurra.

3. Hydrology

3.1 Rainfall

The average annual rainfall within the Ord River catchment ranges from 780 mm in the north to 450 mm in the southern portion of the catchment. The variation in annual rainfall tends to increase with decreasing mean annual rainfall. This variation in annual rainfall is illustrated by the coefficient of variation (CV) for each rainfall station in Table 3-1. These coefficients of variation are low compared to other semi-arid areas of Australia, but higher than the south west of Western Australia.

The long term annual variation in rainfall at a number of rainfall gauging stations within the Ord River catchment are shown graphically in Appendix A.

Fig. 3-1 shows the long term variation in annual rainfall averaged over the entire catchment for the Ord River Dam. The highest rainfall years were 1922, 1926 and 1982. The low rainfall periods were 1911-1912, 1919-1920, 1928-1933, 1945-46, 1964-1965 and 1989-1990.

The long term mean annual rainfall averaged over the catchment of the Ord River Dam is 533 mm, with a coefficient of variation of 0.31. At the dam itself the mean annual rainfall is 632 mm with a coefficient of variation of 0.28.

Almost all rainfall occurs between November and April, the greatest falls being in January and February (see Fig. 3-2). The frequency and severity of the thunderstorms, which are the dominant climatic feature during the high rainfall months, produce a large variation in the monthly rainfall which is not evident in the dry months where only light, sporadic falls occur.

The extended periods of low rainfall that have been observed over the last 90 years in the lower Ord River area are outlined in Table 3-2.

Table 3-1: Summary of annual rainfall data

Station	Station N°	Lat.	Long.	Mean	Median	CV
Ivanhoe	M002013	15.42	128.41	763	724	0.29
Argyle Dam	-	16.07	128.45	632	615	0.28
Alice Downs	M002000	17.45	127.56	555	549	0.39
Ord River Station	M002024	17.23	128.55	506	498	0.34
Fox River Station	M002062	18.25	128.02	471	446	0.44

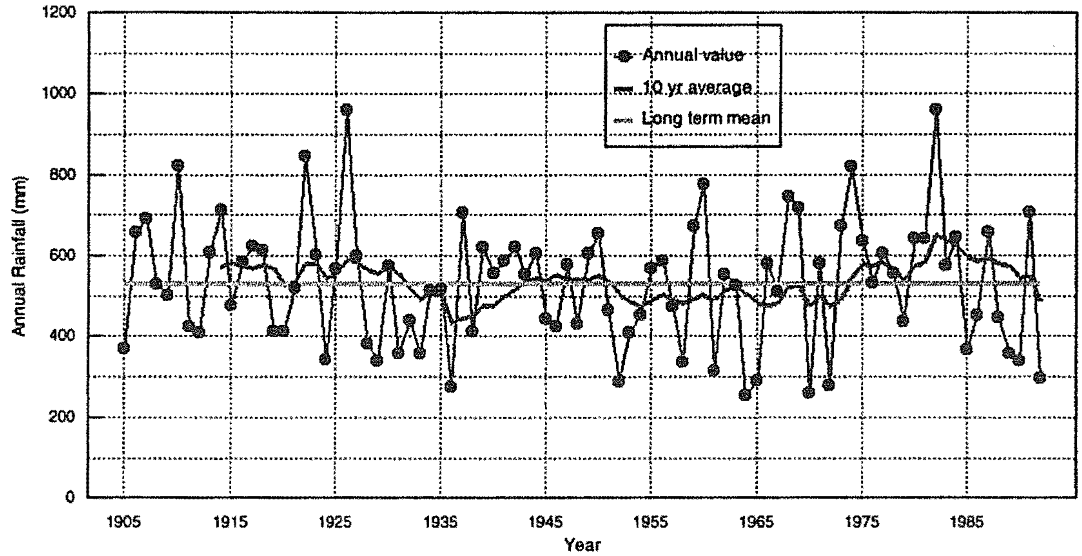

Figure 3-1: Annual variation in rainfall over the Ord River catchment to Lake Argyle

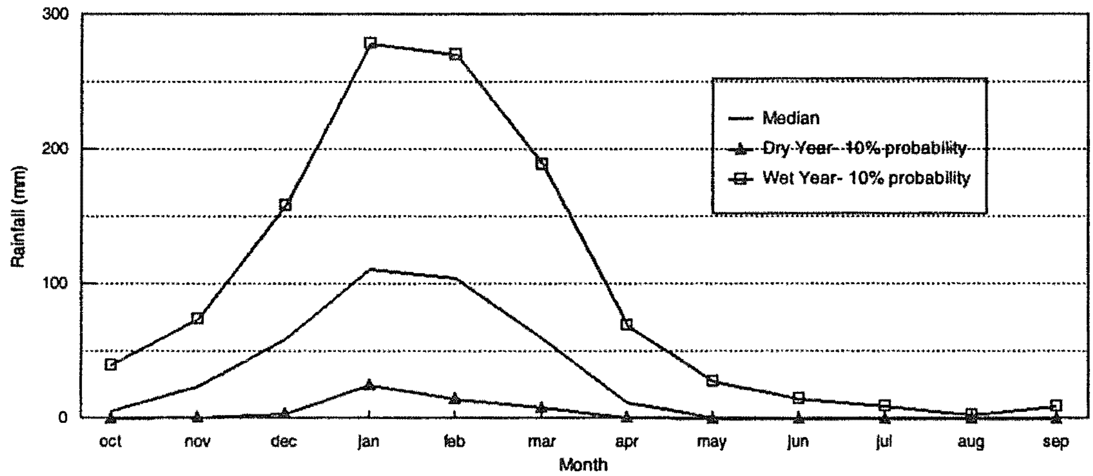

Figure 3-2: Seasonal variation in rainfall over the Ord River catchment to Lake Argyle

Table 3-2: Sequences of low rainfall in the lower Ord River catchment

Years	Duration (months)
1931-1934	47
1937-1939	24
1951-1954	37
1963-1966	35
1969-1972	35
1985-1986	24
1991-1992	37

3.2 Evaporation

Evaporation, as calculated by pan evaporation, for Kununurra averages almost 3000 mm per year, and is highest in September, October and November (see Figure 3-3). Evaporation for Lake Argyle averages only 2130 mm per year and is highest in January and October.

The main reason for the difference between the pan and lake evaporation is the difference in water temperature. The large mass of water in a lake such as Lake Argyle means that there is considerably less temperature fluctuation in the lake compared to the evaporation pan.

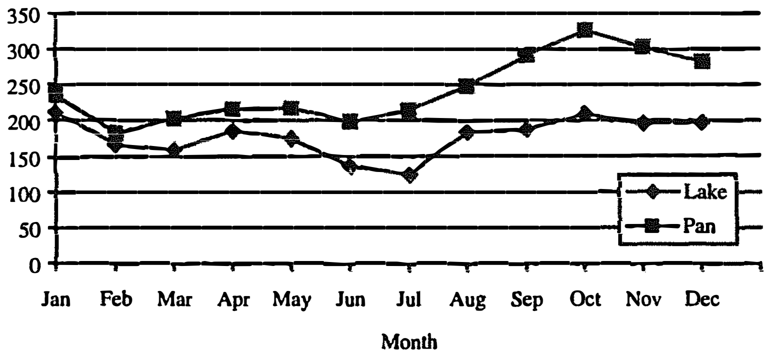

Figure 3-3: Monthly lake evaporation for Lake Argyle

3.3 Streamflow

The long term (1905-1990) average streamflow as inflow into the Ord River Dam is 3980 GL (± a standard error of 320 GL). This long term average is based on rainfall-runoff modelling, gauging station data and a reservoir water balance. A summary of the available gauging station data, within the Ord River catchment, is shown in Table 3-3 below, and graphically in Appendix A2.

Mean annual runoff varies from 61 to 106 mm for the major sub-catchments of the Ord River to Lake Argyle. The lower runoff rates are from the Negri and the headwaters of the Ord River. The Dunham River has a higher runoff rate than the Ord River, which is primarily due to the higher mean annual catchment rainfall.

The standard deviation and coefficient of variation for the streamflow into the Ord River Dam are 2930 GL and 0.74 respectively. The variation in annual streamflow, as defined by the coefficient of variation is relatively low, particularly when compared to other semi-arid areas of Australia.

The catchment runoff based on the average annual streamflow of 3980 GL and catchment area of 46,100 km^2 is 86 mm. This represents an annual runoff coefficient of approximately 16% of the catchment rainfall of 533 mm.

Based on historical measured, and modelled, streamflow data there is a 10% probability that the annual streamflow will be less than 1090 GL. Conversely there is also a 10% probability that the streamflow will be over 8200 GL.

The variation in annual streamflow for the Ord River at the Ord River Dam is shown in Fig. 3-4. The annual streamflow for the Ord River have positive skewness, which means that the data is not symmetric around the mean or median. The mean is biased toward the very large flows, however, these flows are greatly exceeded in number by flows of less than the mean.

The variation in monthly flow in the Ord River at the Ord River Dam is shown in Fig 3-5. The dominant month for streamflow for the Ord River are January, February and March. The monthly streamflows are highly skewed, particularly the low streamflow months.

Table 3-3 : Summary of annual streamflow data assuming no regulation

Sub-catchment	Gauging Station	Catchment Area (km^2)	Annual Flow Mean (GL)	Annual Flow Median (GL)	Mean Runoff (mm)	% of Total Mean
Ord River	809316	19,600	1,550	1,350	79	39
Negri River	809315	7,770	470	370	61	12
Wilson River	809322	2,570	270	250	106	6.5
non gauged area to ORD(1)		16,160	1,690(3)	1,410(3)	105	42
Ord River @ ORD(1)		46,100	3,980	3,040	86	100
Ord River @ KDD(2)		47,100	4,060(3)	3,100	86	
Dunham River	809321	1,600	190	150	120	
Dunham River at confluence with Ord		4,200	500(3)	390(3)	120	
Ord River @ Dunham River		51,300	4,560(3)	3,440(3)	89	

(1) Ord River Dam

(2) Kununurra Diversion Dam

(3) Estimated from total and sub-catchment data

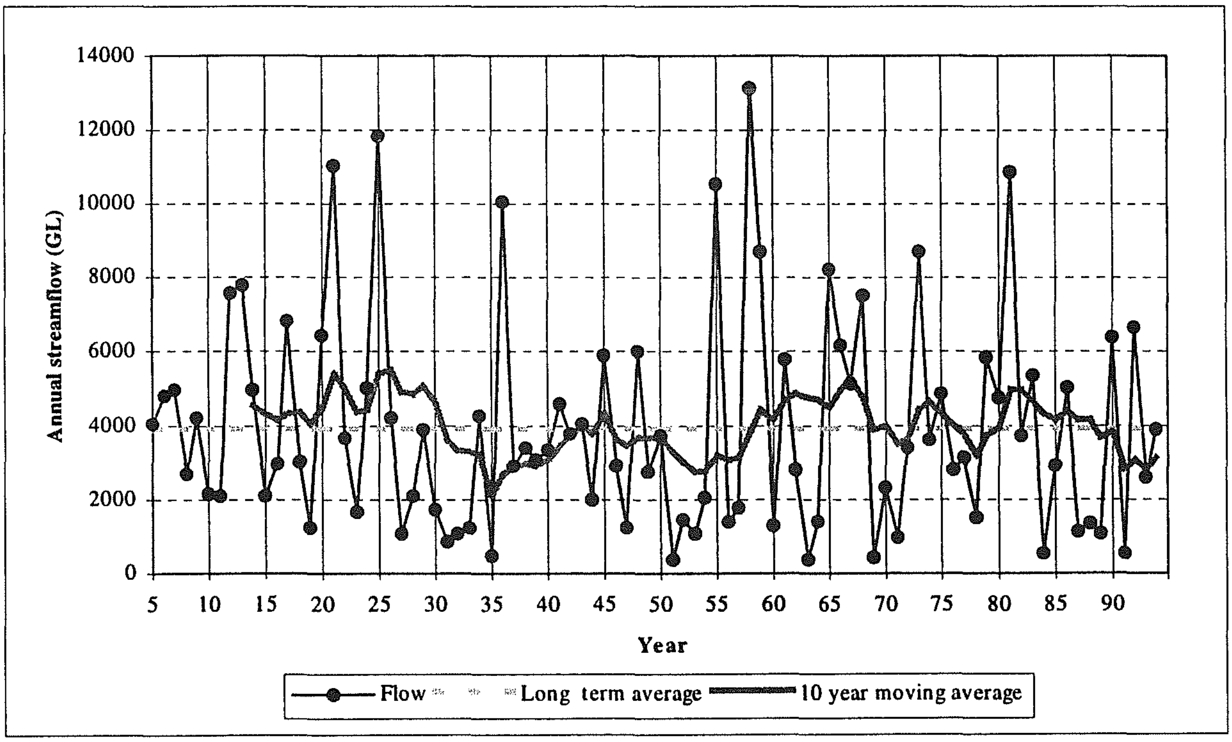

Figure 3-4 : Annual streamflow for the Ord River at the Ord River Dam

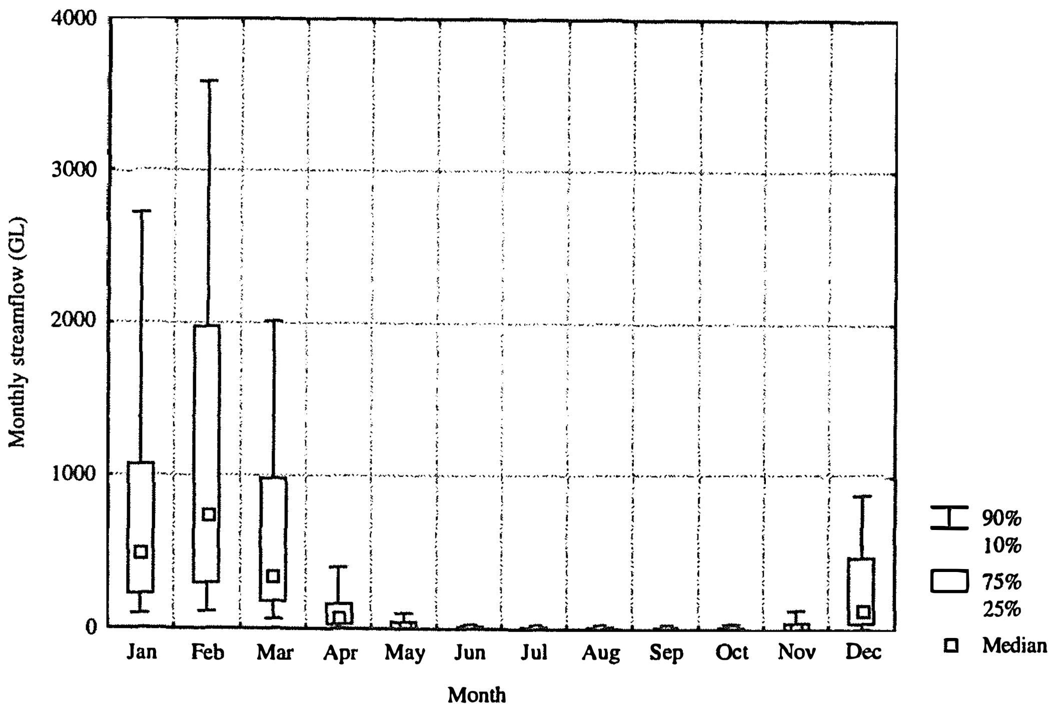

Figure 3-5 : Monthly streamflow variation for the Ord River at the Ord River Dam

3.4 Flood hydrology

The Ord River, and it's tributaries, is prone to serious flooding resulting from extreme tropical lows, cyclones and thunderstorm activity originating over the Timor Sea. For example, greater than 450mm of rainfall was recorded at Halls Creek over just three days (mean annual rainfall for Halls Creek is 530 mm) in January 1959. This rainfall caused widespread flooding throughout the catchment and resulted in one of the largest recorded flows for both the Ord River and the State.

The largest recorded flow on the Ord River of approximately 30,800 m^3s^{-1} (27.1m) was observed in February 1956 at the Coolibah Pocket streamflow gauging station. This gauging station, which was near the site of the present day dam wall of the Ord River Dam, was closed during the construction of the dam and is now inundated within Lake Argyle. Other major floods on the Ord River occurred in January 1959, March 1960, January 1966, December 1971 and February 1980 and 1993.

The construction of the two dams on the Ord River has greatly diminished the floodflows in the lower Ord. The Ord River Dam was designed to have extremely large flood storage within the reservoir. The relatively small capacity of the spillway is the mechanism behind this large flood storage, which is discharged slowly over a number of months. The combined flow through the valves at the dam wall and via the spillway has not exceeded 1,000 m^3s^{-1} since the dams construction in the early 1970's despite the fact that the estimated inflows to the dam have exceeded 10,000 m^3s^{-1} on occasions.

The floodflows in the lower Ord River, downstream of Kununurra, since the construction of the Ord River dams are dominated by the flows from the Dunham River, which enters the Ord River just downstream of Kununurra. This is despite the fact that the catchment area of the Dunham River is less than 10 % of the Ord River catchment.

The peak recorded flows for the Ord River and its tributaries plotted against catchment area are compared to the world peaks in Figure 3.6.

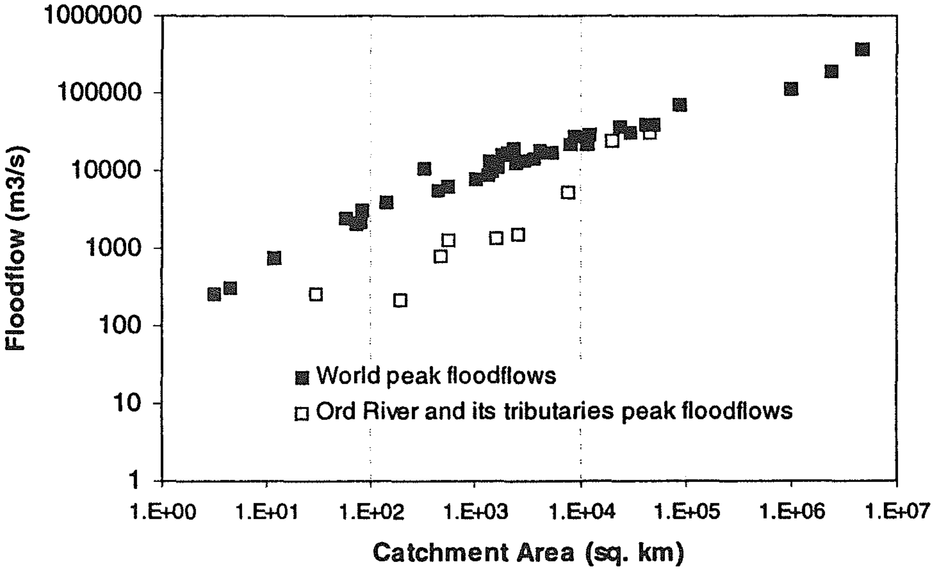

Figure 3-6 : Comparison of Ord River and World peak floodflows.

The peak floodflows for the smaller catchments are approximately one order of magnitude below the World peaks. However, the observed floodflows for the larger Ord River catchments approach the magnitude of the World envelope.

Runoff is dependent on a number of factors including rainfall volume and intensity, and the catchment geology, level of clearing and slope. The factor most likely to account for the World peak flows being an order of magnitude larger than the peak flows in the small Ord River catchments is the catchment slope. Slopes in the Ord River catchment are quite low by World standards, but as catchment area increases slope becomes less significant, hence the larger Ord River catchments approach the World peak flows.

The proximity of the floodflows for the larger Ord River catchments to the World peak flows suggests that the storage capacity of the soil and the rainfall volumes and intensities are similar to the conditions which produce the world peaks.

Figure 3-7 Ord River at Old Ord Homestead upstream of Lake Argyle

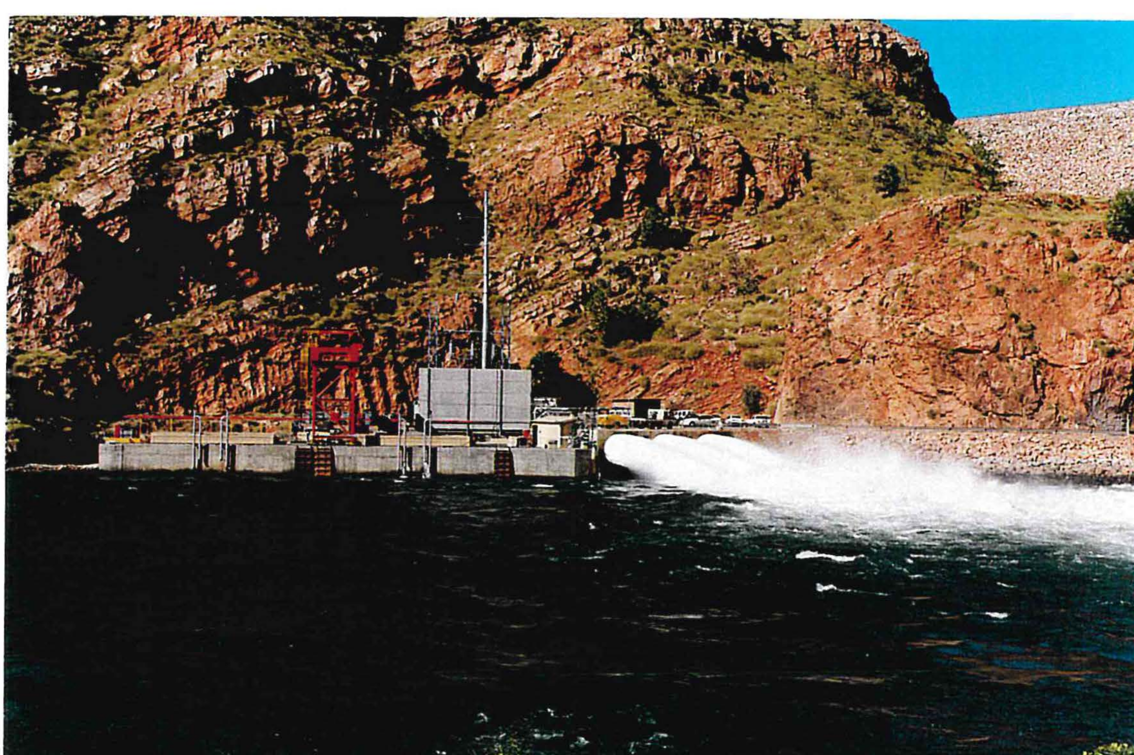

Figure 3-8 Water releases from Lake Argyle immediately downstream of Ord River Dam

Figure 3-9 *Irrigation channel in Ivanhoe Plains area of Ord Irrigation area*

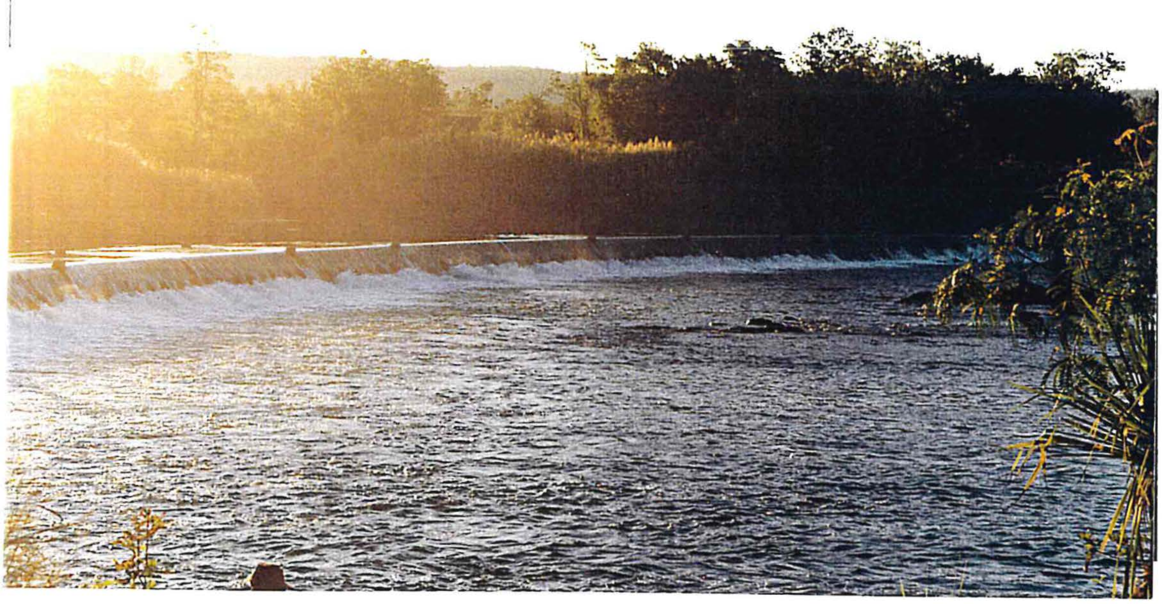

Figure 3-10 *Ivanhoe Crossing on the lower Ord River*

Figure 3-11 Riffle section of lower Ord River

Figure 3.12 Sediment plume stretching downstream from a channel draining a portion of the Ivanhoe Plain Irrigation area

Figure 3.13 Gorge in Carr Boyd Ranges downstream of the Ord River Dam

4. Water Quality

The major water quality issues were sedimentation of Lake Argyle due to the high sediment loads in the upper Ord River and salinity in the lower Ord River. Water quality issues, such as pesticides and nutrients, within the irrigation areas and their impact on the Dunham River and the lower Ord River are also becoming more important. This study will only look at the published data on water quality, consequently the impact of pesticides will not be discussed in any detail.

4.1 Sedimentation

Various studies and reports have indicated that pastoral activities following the settlement of the Ord River catchment in the late 1800s has resulted in widespread vegetation loss and accelerated soil erosion. This was first observed in the 1940s when exposed tree roots, soil pedestals and truncated soil profiles indicated that up to 30 centimetres of soil had been lost by sheet erosion in the synclinal basins east of the Halls Creek fault (Wasson *et al.* 1994). The largest and southern most of these basins is the Hardman Syncline, which stretches from just downstream of the Ord-Panton junction to the Ord-Negri junction. The other synclines in the Lake Argyle catchment are the Rosewood Syncline and the Argyle Syncline, which is largely submerged beneath the lake itself. As a result of the above observations the Ord River Catchment Regeneration Project (ORCRP) was designed to stabilise the most seriously eroded parts of these basins.

4.1.1 Catchment sediment loads

The total sediment load of the rivers in the Ord River basin follows a non-linear relationship with streamflow as shown in Figure 4-1 for the Ord River at Coolibah Pocket gauging station.

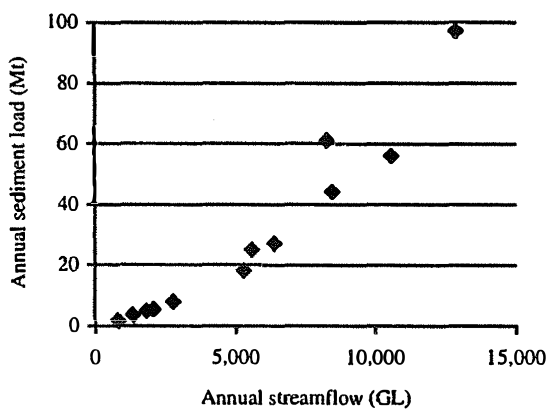

Figure 4-1 : Relationship between annual sediment load and streamflow for the Ord River (based on Kata, 1978)

All available sediment transport data from the Lake Argyle catchment has been analysed and converted to estimates of mean specific yields (Table 4-1)). This data clearly illustrates the dominance of the Ord River inflows on Lake Argyle sediment yields.

Tracer studies, using Nd isotopes, have established that about 60% of the sediment in Lake Argyle is derived from the Hardman Syncline, and about 34% is derived from the area between the Negri River and the lake (Wasson *et al.* 1994).

An approximate ^{137}Cs budget has been constructed (Wasson *et al.* 1994) to estimate the proportion of the sediment that comes from surface soils by means of sheet and rill erosion. A simple model, in combination with the budget, shows that only about 10% of the soil in the Lake was produced by surface erosion (Wasson *et al.* 1994). The remaining 90% results from channel erosion of subsurface soils in the gully networks within the catchment. These conclusions while plausible, must be treated as tentative because detailed depth profiles of ^{137}Cs in soils of the catchment have not been measured (Wasson *et al.* 1994).

Table 4-1 : Measured sediment loads for the major inflows of Lake Argyle (adapted from Wasson et al. 1994)

Catchment	Area (km^2)	Mean Annual Sediment Yield (Mt)	Mean Annual Specific Sediment Yield (t/km^2)
Ord River at Old Ord River Homestead	16,900	10.7 ± 3.6	550 ± 180
Negri River at Mistake Creek Homestead	7,800	0.7 ± 0.3	90 ± 40
Wilson-Bow River at Lake Argyle	6,600	≤ 0.9 ± 0.2	140 ± 30
Ord River at Lake Argyle	46,100	23.5 ± 4.7	510 ± 100

The removal of grasses by eating, trampling and death from drought bares the soil surface which rapidly seals as pores infill, thereby making the re-establishment of vegetation progressively more difficult. High rates of runoff resulting from this surface sealing leads to flow concentration in formerly shallow streamlines and on wash slopes, resulting in extensive and often deep gullies. Comparison of aerial photographs from the 1940s and 1980s suggest that there has been little, to no change in the gully networks within the catchment suggesting that the network is in a quasi-equilibrium state.

The revegetation strategy of the ORCRP was designed both to reduce sheet erosion, and to slow gully erosion by slowing runoff. Data from small catchments in the Northern Territory part of the Hardman Syncline shows that the vegetation cover is less important than drainage density as a control of sediment yield, at least where vegetation cover is competing with the grazing pressure of livestock. In areas of the revegetation on Ord River Station, where grazing has been controlled, high sheet and rill erosion rates have persisted due to the revegetation only being partially successful.

4.1.2 Reservoir sedimentation

At the time of the original dam design it was estimated that the average sediment load for the Ord River was 24 Mt per year. A recent survey (Wark 1987) indicated that approximately 380 Mm^3 of sediment had been deposited in Lake Argyle in the 16 years following construction. On an annual basis this represents a sediment transport rate of 24 Mt per year, similar to the earlier estimate. The mean particle size distribution of the suspended sediment is composed of 80% clay and silt, and only 20% sand size particles.

A sampling program quantifying the sediment load leaving the lake operated for two water years, from 1991 to 1993. The 1991/92 wet season was comparatively dry while the magnitude of a rainfall event during the 1992/93 wet was in the order of a 1 in 22 year recurrence event. This event resulted in the maximum measured sediment concentration in the outflows of 315 mg/l. Upstream values are not available for the peak of this event, but comparison can be made to the maximum concentrations so far measured in the Ord River. A summary of the results of this sampling program is shown in Table 4-2.

Based on the average overflow and releases since the Ord River Dam was constructed the average outflow of sediment from Lake Argyle is of the order 0.015 Mt or 0.06% of the sediment inflow to Lake Argyle.

Table 4-2 : Sediment load from Lake Argyle into Ord River (adapted from Clews, 1995)

Water Year	Sediment load (t)
1991/92	1,690
1992/93	23,210

By assuming the Wilson River sediment export rates for the Dunham River the average annual sediment load for the Ord River downstream of the Kununurra Diversion Dam has reduced from 24 Mt to about 0.6 Mt due to the construction of the two dams.

After 23 years the storage volume in the reservoir below the spillway level has been reduced by 3.3%. This has occurred through a 2.2 % reduction in the volume of the channel plus a 1% reduction from fines spread over the remainder of the Lake Argyle floor.

4.2 Salinity

Salinity in the upper catchment of the Ord River is low, averaging approximately 380 mg/L TSS. The derivation of this salinity is carbonate based. The composition of the salinity in the Ord River starts to change downstream of Carlton Crossing, where saltwater intrusion starts to become more dominant. Currently the relatively constant streamflow in the Ord River maintains the saltwater interface a significant distance downstream. Prior to the construction of the two dams the saltwater interface during the dry season probably extended further up the river than it does now. As further irrigation is developed there is the possibility that salt water intrusion will move further upstream due to the lower flows being released from the Kununurra Diversion Dam to the lower Ord River.

4.2.1 Lower Ord River salinity relationship

The relationship of salinity with distance upstream is shown in Figure 4-2. This data indicates that the tidal influence may be of a much larger significance than the flow, particularly in the first 25 km. At low tide the differences between low and high flows were up to 2,000 mg/L TSS.

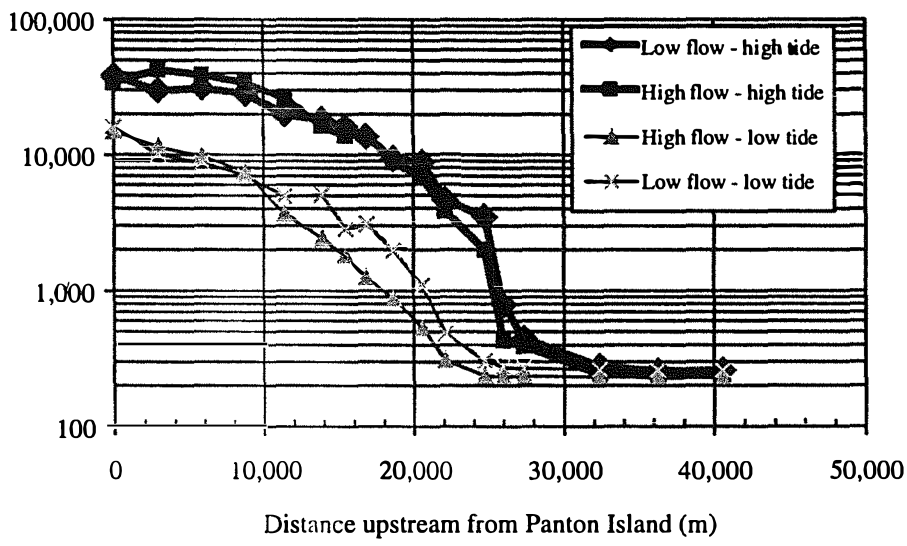

Figure 4-2 : Salinity variation under different flow and tidal conditions in the lower Ord River

(NB: Panton Island is located about 20 km upstream of the Ord River outlet into Cambridge Sound and marks the downstream extent of the Noogoora Burr Quarantine Area)

5. Water demand analysis

The various water demands on the Ord River are outlined in the following sections. The major demands described are:

- Irrigation;
- Hydropower;
- Environmental water; and
- In-stream needs.

5.1 Irrigation water demand

The water required to be released from Lake Argyle to meet the existing and proposed demand from the Ord River Irrigation Scheme is based on a number of assumptions of crop water demand and loss rates in the on-farm and water delivery systems. Currently only Stage I of the Ord River Irrigation Scheme has been developed. However planning for Stage II has progressed rapidly in recent years.

The water requirements for irrigated cropping are dependent on a number of factors, including climatic conditions, soil characteristics, irrigation designs and methods, and the type of crop under production (Sherrard, 1994). The water required for the production of a crop is defined as the crop water demand in this report. This crop water demand can be met by local rainfall (termed effective rainfall) or by irrigation. There are two loss factors incorporated into the water demand from the reservoir. These are the losses between the release point at the reservoir to the farm gate; and the losses within the farm itself. The losses within the farm can be from either the water distribution system or actual on-field losses.

5.1.1 Stage I

Stage I of the Ord River Irrigation Scheme comprises Ivanhoe and Packsaddle Plains and has a net irrigable area of 11,780 Ha (see Map 1).

5.1.1.1 Crop water demand

Stage I of the Ord River Irrigation Scheme is a mixture of crops, including Leucaena, and Sugarcane. The estimated water delivered to farm gate is expected to reach 200 GL by 2000. This assumes a crop water demand of 17.2 ML/Ha and an on-farm and in-field efficiency of 75%. The sugarcane water requirement at farm gate of 20 ML/ is slightly above the assumed crop water demand of 19.2 ML/Ha.

5.1.1.2 Efficiency

The assumptions for Stage I include a 75% on-farm and in-field efficiency and a 67% water delivery system efficiency. This results in an overall efficiency of 50%. Any increase in water releases for Stage I for increased crop water demand would be expected to include a component of efficiency gains from on-farm and water delivery systems.

5.1.1.3 Overall water requirement

The water demand from the Ord River Dam for Stage I is estimated at 300 GL, based on the above assumptions with respect to crop water demand and water efficiency. However if a much larger proportion of sugarcane is grown in Stage I and the sugarcane crop water demand is higher then currently estimated then the water required for Stage I in the longer term could be higher than 300 GL. A summary of the irrigation water requirements for Stage I is shown in Table 5-1.

Table 5-1 : Irrigation water requirements for Stage I

Component		Amount or rate
Crop water demand	ML/Ha	17.2
Effective rainfall	ML/Ha	4.2
Irrigation requirement	ML/Ha	13.0
Net irrigable area	Ha	11,780
On-farm & in-field efficiency	%	75
Water delivery at farm gate	GL	203
	ML/Ha	17.2
Delivery system efficiency	%	67
Water Required	GL	303
	ML/Ha	25.7

A sensitivity of the irrigation water requirement to variation in annual rainfall is shown in Table 5-2 for a crop water demand of 22.1 ML/Ha. This data is based on rainfall being 72% effective. This means that the crop can use 72% of rainfall on the irrigation field. As can be seen from Table 5-2 an approximate 30% reduction in annual rainfall leads to an increase in the required irrigation water of 13 %.

The range of water required to be released from storage for irrigation ranges from 260 to 340 GL. This is based on a number of assumptions with respect to the seasonal crop water demand and the above values should only be used as a guide.

Table 5-2 : Variation in irrigation water requirement with changes in annual rainfall for sugarcane

Percentile	Annual rainfall (mm)	Irrigation water requirement (ML/Ha)
10th	504	17.0
50th	724	15.4
Mean	763	15.0
90th	1074	13.0

5.1.2 Stage II - Weaber, Knox and Keep

The Weaber, Knox and Keep Plain (see Map 1) area consists of a net irrigable area of 32,000 Ha and would be serviced by a new main irrigation channel from Lake Kununurra.

5.1.2.1 Crop water demand

As a feasible upper limit to crop water demand, sugarcane is assumed for all this component of Stage II. In reality it would not be expected for all the Weaber, Knox and Keep Plain area to be developed for sugarcane.

Based on a sugarcane crop only, there have been a number of values used for crop water demand. Sherrard (1994) estimated the crop water demand for sugarcane at 19.2 ML/Ha. Ruprecht and McCosker (1996) used this value and 22.1 ML/Ha in the simulations of water availability for Stage II. Muchow et al, (1996) modelled sugarcane crop water demand based on the climatic conditions of Kununurra and estimated an upper limit of crop water demand to be 29.3 ML/Ha. This is considered an upper limit because:

- the model has not been validated with more specific climate data and with actual water balance data; and

- crop water demand was based on the best agricultural practice occurring throughout the region;

5.1.2.2 Efficiency

The water efficiency for the broadacre cropping would be expected to be 90% for the in-field and on-farm efficiency and 80% for the water delivery system efficiency to farm gate. The in-field and on-farm efficiency is based on tailwater return being incorporated into the irrigation system. Effective water management should ensure that the application of irrigation water matches the crop water requirements and minimises runoff and loss. The use of tailwater return systems which retain previously irrigated irrigation water for reuse are considered an integral part of effective water management.

5.1.2.3 Overall water requirement

The annual water required for the Weaber, Knox and Keep Plain component of Stage II is approximately 740 GL, based on the above crop water demand and water efficiency. However if higher crop water demands for sugarcane, such as 29.3 ML/Ha, were applied, irrigation requirements could be as high as 1000 GL.

A summary of the irrigation water requirements for the Weaber, Knox and Keep Plain component of Stage II are summarised in Table 5-3.

Table 5-3 : Irrigation water requirements for Stage II - Weaber, Knox and Keep Plain

Component		Amount or rate
Crop water demand	ML/Ha	22.1
Effective rainfall	ML/Ha	5.5
Irrigation requirement	ML/Ha	16.6
Net irrigable area	Ha	32,000
On-farm & in-field efficiency	%	90
Water delivery at farm gate	GL	590
	ML/Ha	18.4
Delivery system efficiency	%	80
Water Required	GL	738
	ML/Ha	23.1

The comparison between the irrigation water requirement and the effective rainfall is shown in Figure 5-1. The effective rainfall is assumed to be approximately 72% of the mean annual rainfall. This is considered a reasonable estimate given that the runoff to rainfall coefficient for the Ord River catchment is approximately 16%. This results in a loss rate of 84%, which is higher than the effective rainfall coefficient applied in these simulations.

The monthly crop water demand is based on the pan evaporation and a crop factor for sugarcane. As can be seen from Figure 5-1 most of the effective rain is in December to March. This is based on average conditions. There will be years when more water is required from irrigation due to lower than average rainfall.

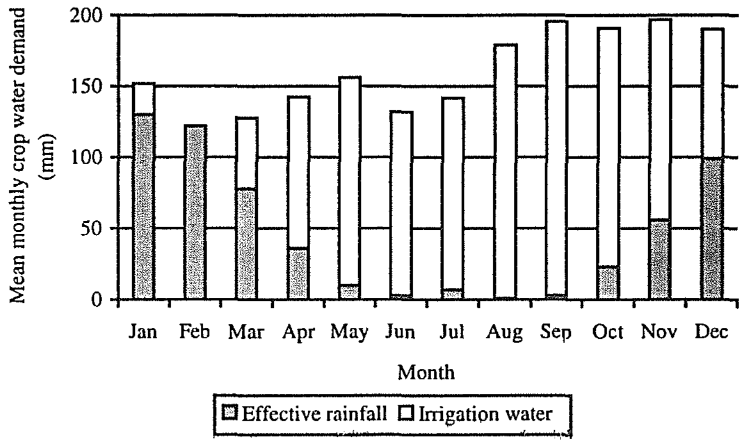

Figure 5-1 : Mean monthly crop water demand for sugarcane

5.1.3 Stage II - Carlton and Mantinea

The Carlton Plain, West Ivanhoe and Mantinea Flats component of Stage II analysis was based on a scenario of 1,800 Ha of Leucaena, 5,000 Ha of bananas and 2,000 Ha of tree crops.

5.1.3.1 Crop water demand

The crop water demand for the irrigation area downstream has been estimated based on Leucaena, Bananas, Tree crops and vegetable crops. The crop water demand has been estimated at 26.7 ML/Ha for Bananas, 16.1 ML/Ha for Tree crops and 20.5 ML/Ha for Leucaena. These values are consistent with Sherrard (1994).

5.1.3.2 Efficiency

An in-field and on-farm water efficiency of 75% has been assumed for the Leucaena and an 85% in-field and on-farm water efficiency has been assumed for the more intense horticulture crops. The water delivery efficiency has been assumed at 80% and 100% for Leucaena and horticulture respectively. This results in an overall delivery system efficiency of 95%.

5.1.3.3 Overall water requirement

The irrigation demand for Stage II for Carlton Plain and Mantinea Flats is considered to be 195 GL, based on the above crop water demand and water efficiency. A summary of the irrigation water requirements for the Carlton Plain and Mantinea Flats components of Stage II are summarised in Table 5-4.

Table 5-4 : Irrigation water requirements for Stage II - Carlton Plain and Mantinea Flats

Component		Leucaena	Bananas	Tree Crops	Total
Crop water demand	ML/Ha	20.5	26.8	16.1	23.1
Effective rainfall	ML/Ha	5.5	5.5	5.5	5.5
Irrigation requirement	ML/Ha	15.0	21.3	10.6	17.6
Net irrigable area	Ha	1,800	5,000	2,000	8,800
On-farm & in-field efficiency	%	75	85	85	83
Water delivery at farm gate	GL	36	125	25	186
	ML/Ha	20	25	12.5	21.2
Delivery system efficiency	%	80	100	100	95
Water Required	GL	45	125	25	195
	ML/Ha	25	25	12.5	22.2

5.2 Hydropower demand

The projected hydropower demand for the East Kimberley Region of Western Power is shown in Figure 5-2. The electricity demand is forecast to be approximately 65 GWhr by 2004 and to be slightly over 100 GWhr by 2020. Therefore for the short term town hydropower of 65 GWhr is used and for the longer term a value of 110 GWhr has been applied in the water availability analysis. The total electricity demand for Western Power and Argyle Diamond Mines Joint Venture (ADM) is set at 210 GWhrs for the next five to seven years. This means that the electricity supplied to Argyle Diamond Mines Joint Venture (ADM) will be approximately 145 GWhrs, depending on the amount of power supplied to the Western Power regional grid.

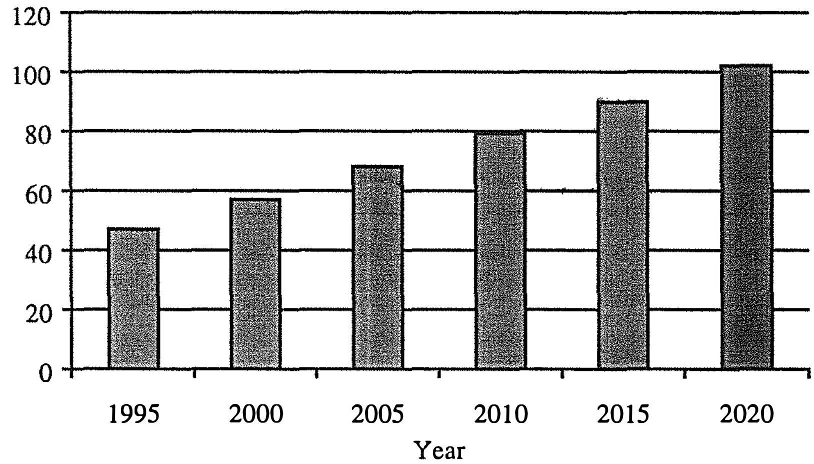

Figure 5-2 : Projected electricity requirements for East Kimberley Region of Western Power

5.3 Environmental water requirements

The water required to maintain ecological and geomorphological processes within the Ord River is currently uncertain. However a basic premise of techniques such as the Holistic Approach (Arthington *et al* 1992) is that the ecological integrity of the riverine system is a function of the natural flow regime. Arthington *et al,* (1992) also recommended a minimum monthly flow as a "hydrologically defined base flow". This is typically a percentile flow for each month. The 10, 20 and 30th percentile for the Ord River at Lake Argyle are shown in Table 5-5 compared to the 50 and 90th percentiles.

For this study the 20th percentile monthly flows have been used only as an indication of the impact of an environmental water provision on the water available for other uses such as irrigation and hydropower.

5.4 In-stream requirements

The in-stream requirements on the Ord River are varied and will not be discussed in any detail in this report. The in-stream requirements downstream of the Ord River Dam are based on the navigation requirements between Lake Kununurra and Ord River Dam. An in-stream water demand for downstream of the Ord River Dam was estimated at 1740 GL, based on a flow of 55 $m^3 s^{-1}$, for tour boats to navigate over the critical sections of river channel.

Downstream of Kununurra Diversion Dam the major in-stream water requirements are considered to be:

- irrigators pumping from the Ord River;
- navigation on the lower Ord River; and
- stock access across the Ord River.

Table 5-5 : Percentiles for the Ord River at Lake Argyle

Month	10th %ile (GL)	20th %ile (GL)	30th %ile (GL)	50th %ile (GL)	90th %ile (GL)
Jan	96.1	199.8	286.9	490.6	2725.8
Feb	113.6	221.1	378.3	739.5	3951.8
Mar	65.8	145.6	204.6	349.1	1995.8
Apr	4.1	18.8	35.5	69.8	397.8
May	0.0	2.5	6.4	12.5	104.1
Jun	0.0	0.0	0.8	2.5	22.9
Jul	0.0	0.0	0.1	0.5	9.0
Aug	0.0	0.0	0.0	0.1	2.2
Sep	0.0	0.0	0.0	0.0	0.7
Oct	0.0	0.0	0.0	0.0	36.2
Nov	0.0	0.2	3.7	11.4	128.0
Dec	10.4	27.0	53.0	133.9	772.1
SUM	290	615	960	1810	10146

6. Water availability analysis

6.1 Water balance analysis

The water availability analysis was based on the modelling approach outlined in Ruprecht (1995) and Ruprecht and McCosker (1996) for the hydropower project and Stage II irrigation respectively. The modelling is based on:

- demands for hydropower, environmental water provisions, in-stream, and irrigation;
- a monthly time-step;
- the overflow characteristics of the Ord River Dam; and
- the hydropower characteristics such as tailwater and power efficiency.

The definition of a failure is based on the number of months for which restrictions are necessary. The probability of failure is defined as:

$$p = n/N \qquad (1)$$

where p is the probability of failure;
n is the number of months during which restrictions are necessary; and
N is the total number of months in the time sequence.

The operating policy outlined in the section below has different restriction levels for irrigation, hydropower to Argyle Diamond Mine (ADM), and town hydropower. Consequently the probability of failure will vary for each user category.

The operating policy is based on four levels of restrictions. The priority of the users of water for the Ord River for this analysis was in descending order:

1. irrigation and environmental water provisions
2. hydropower for town supply
3. hydropower for ADM

The in-stream uses of the Ord River include navigation between Lake Kununurra and the Ord River Dam; navigation on the lower Ord River (downstream of the Kununurra Diversion Dam); stock access and watering along the lower Ord River. The in-stream uses downstream of the Ord River Dam are currently given similar priority of use as the hydropower for town supply. However it is uncertain whether this priority of use would be maintained with full development of the irrigation area.

The environmental water requirements, based on historical flows, have the most seasonal nature, greater than 90% of demand occurring in three months (Figure 6-1). The irrigation demand is also highly seasonal, decreasing during the wet season, November through April. This irrigation demand is an estimation of the demand for horticulture, cotton and sugar growing, based on current operating levels. Alternatively, the monthly demand of hydropower for town supply decreases slightly during the dry season. The town hydropower demand is much less seasonal than either irrigation demand or the environmental water requirements. The total hydropower demand to supply Western Power and ADM is assumed constant throughout the year.

6.2 Maximum divertible yields

A summary of scenarios for the maximum potential divertible yield from the Ord River system are outlined in Table 6-1. The scenarios in Table 6-1 are idealised scenarios and do not indicate any preferred water allocation.

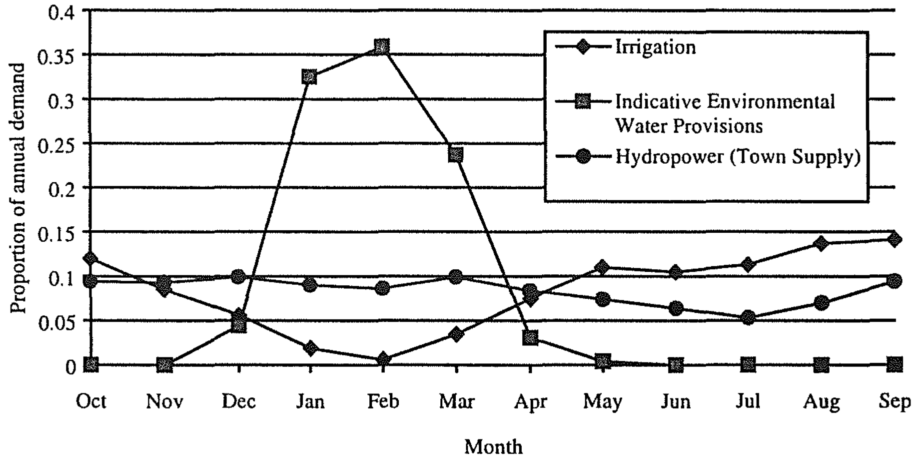

Figure 6-1 : Monthly demand for irrigation, environmental water and hydropower

Table 6-1 : Definition of maximum irrigation scenarios for water availability analysis for the Ord River

Scenario	Definition of scenario
I	Maximum Irrigation (winter-dominated monthly distribution)
	- no specific releases for in-stream use
	- no specific releases for environmental water
	- no specific releases for hydropower
II	Maximum Irrigation (winter-dominated monthly distribution)
	Environmental water releases(1) (20th percentile monthly flows - summer dominated monthly distribution)
	- no specific releases for in-stream use
	- no specific releases for hydropower
III	Maximum Irrigation (winter-dominated monthly distribution)
	Environmental water releases (20th percentile monthly flows - summer dominated monthly distribution)
	Town hydropower (65 GWhr)
	- no specific releases for in-stream use releases
IV	Maximum Irrigation (winter-dominated monthly distribution)
	Environmental water releases (20th percentile monthly flows - summer dominated monthly distribution)
	Town hydropower (110 GWhr)
	- no specific releases for in-stream use releases
V	Maximum Irrigation (winter-dominated monthly distribution)
	Environmental water releases (20th percentile monthly flows - summer dominated monthly distribution)
	Hydropower - ADM and town (210 GWhr)
	No in-stream use releases d/s ORD
	- no releases for in-stream use d/s KDD

(1) Assumes natural flow from Dunham River is available to meet environmental water requirements

(2) ORD = Ord River Dam; KDD = Kununurra Diversion Dam; ADM = Hydropower for Argyle Diamond Mine; town = hydropower for the East Kimberley Region of Western Power

The maximum divertible yields for the scenarios in Table 6-1 are shown in Figure 6-2. There is little change in maximum divertible yield for scenarios II to IV. The components of the releases from Lake Argyle to meet the water demands is shown in Figure 6-3. The additional releases for possible environmental water provisions are not very significant, as shown in Figure 6-3.

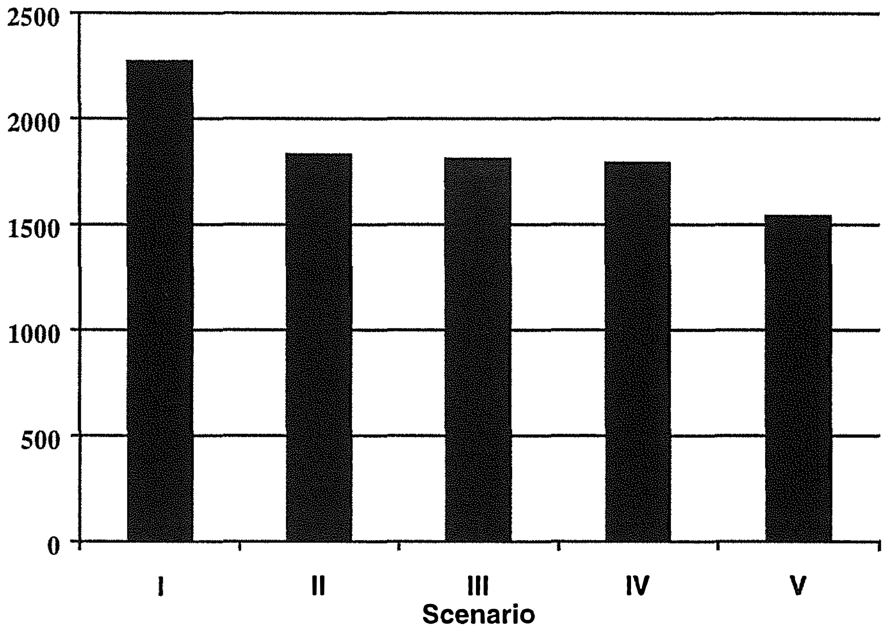

Figure 6-2 : Maximum divertible yields for the defined scenarios

Notes
(1) Divertible yield for irrigation given a 2% of months probability of failure
(2) Maximum feasible irrigation demand given current best estimate of crop water demand for sugarcane

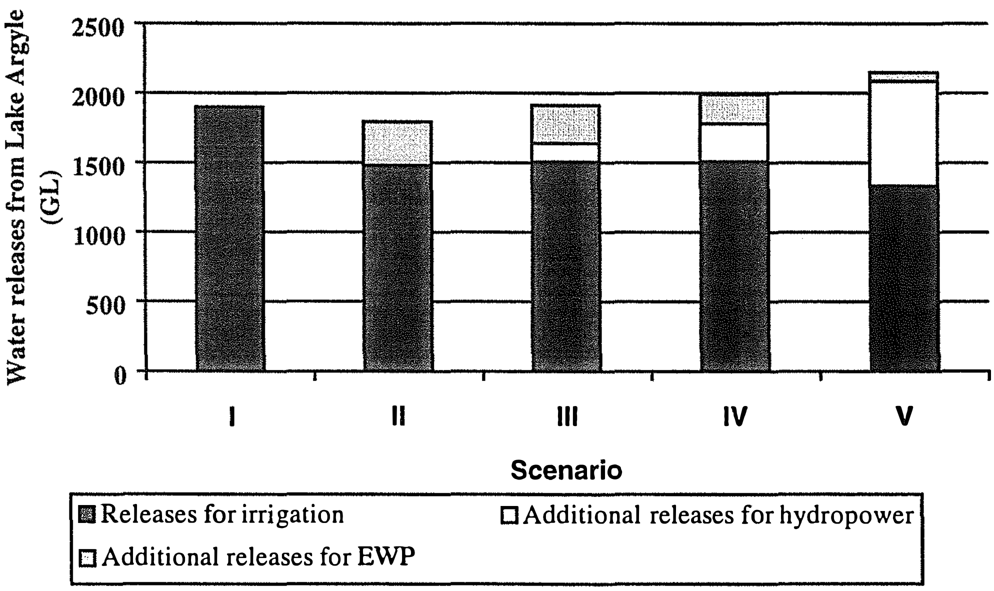

Figure 6-3 : Releases from Lake Argyle for the maximum divertible scenarios

Table 6-2 : Probability of restrictions for the maximum irrigation scenarios

Scenario	Probability of restrictions (%)							
	Hydropower				Irrigation			
	ADM		Town		25% reduction		75% reduction	
	Months	Years	Months	Years	Months	Years	Months	Years
I					2.0	6.9	1.7	4.6
II			3.6	9.2	1.9	4.6	1.4	4.6
III			3.7	9.2	1.9	4.6	1.4	4.6
IV			4.7	9.2	1.9	4.6	1.7	4.6
V	5.3	9.2	5.0	9.2	1.9	4.6	1.7	4.6

The probability of restrictions for the maximum divertible scenarios are shown in Table 6-2. The level of restrictions for town hydropower is significant for all scenarios incorporating hydropower.

6.3 Feasible divertible yields

Based on the maximum divertible yields a range of feasible divertible yields were analysed. Scenario Va is considered a reasonable upper limit to irrigation given current knowledge on environmental water requirements for the lower Ord River. Scenarios VIa and VIb incorporate expected irrigation demand scenarios with different hydropower demands. These hydropower demands are ADM and Western Power regional demands for Scenario VIa and just Western Power regional electricity demand for Scenario VIb. Scenario VII has the current demand patterns with the addition of the environmental water demand. These scenarios are outlined in Table 6-3 and the results in Figure 6-4.

Table 6-3 : Definition of the scenarios for feasible divertible yield

Scenario	Description
Va	1500 GL Irrigation (winter-dominated monthly distribution) Environmental water releases (20th percentile monthly flows - summer dominated monthly distribution) Hydropower - town and ADM (110 GWhr) - no releases for in-stream use d/s ORD or d/s KDD
VIa	1235 GL Irrigation (winter-dominated monthly distribution) Environmental water releases (20th percentile monthly flows - summer dominated monthly distribution) Hydropower - town and ADM (210 GWhr) - no releases for in-stream use d/s ORD or d/s KDD
VIb	1235 GL Irrigation (winter-dominated monthly distribution) Environmental water releases (20th percentile monthly flows - summer dominated monthly distribution) Hydropower - town (110 GWhr) - no releases for in-stream use d/s ORD or d/s KDD
VIc	1235 GL Irrigation (winter-dominated monthly distribution) Environmental water releases (20th percentile monthly flows - summer dominated monthly distribution) Hydropower - town (110 GWhr) - no releases for in-stream use releases d/s ORD - minimum in-stream use d/s KDD of 5 m^3/sec
VII	300 GL Irrigation (winter dominated monthly distribution) Environmental water releases (20th percentile monthly flows - summer dominated monthly distribution) Hydropower - town and ADM (210 GWhr) In-stream use releases d/s ORD (to meet a discharge rate of 55 m^3s^{-1}) - no releases for in-stream use d/s KDD

(1) Assumes natural flow from Dunham River is available to meet environmental water requirements

The feasible divertible yield figures are annual average values without restrictions. Actual irrigation demand will vary by ± 12% due to the variations in annual wet season rainfall on the irrigation areas. These higher demands in years of below average rainfall do not significantly affect the overall frequency of restrictions.

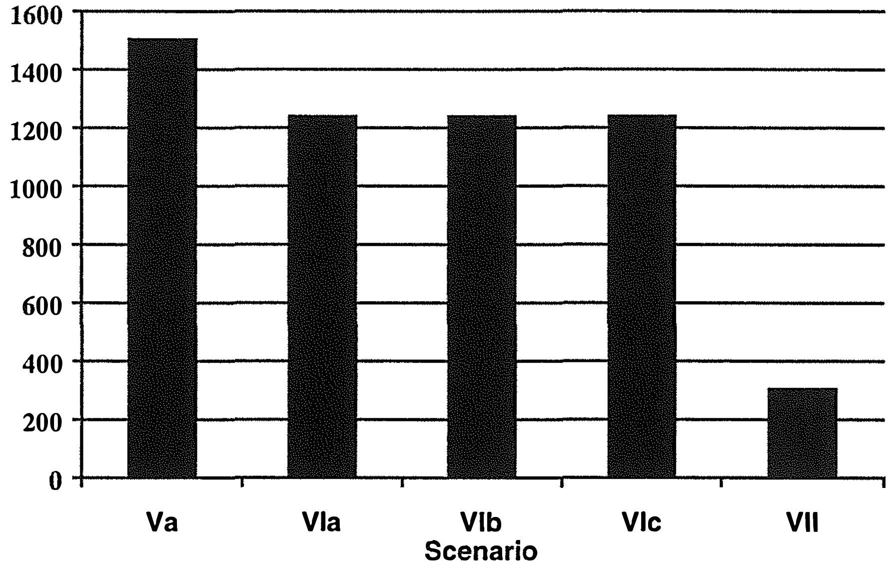

Figure 6-4 : Feasible divertible yields for the defined scenarios

The probability of restrictions for the divertible yield scenarios are shown in Table 6-4. The probability of restrictions for irrigation is less than 2% of months for all the feasible divertible yield scenarios. The probability of restrictions for hydropower ranges from 0.1 to 3.5% of months. However the probability of restrictions for ADM hydropower is 3.5 - 3.8% of months. The probability of restrictions for hydropower for the feasible divertible yields is significantly lower than for the maximum divertible yield scenarios (Table 6-2).

The sensitivity of the maximum potential divertible yield to a variation in the environmental water requirements, based on a monthly percentile is shown in Table 6-4.

The water balance components for the Ord River Dam are shown in Figure 6-5. The releases at the Ord River Dam are approximately 50% of the river inflow and 43% of the total inflow volume, while evaporation is 39% of the total inflow volume.

Table 6-4 : Probability of restrictions for the feasible divertible yield scenarios

Scenario	Probability of restrictions (%)							
	Hydropower				Irrigation			
	ADM		Town		25% reduction		75% reduction	
	Months	Years	Months	Years	Months	Years	Months	Years
Va			1.3	3.4	0.8	2.3	0.8	2.3
VIa	3.8	9.2	3.5	8.0	1.9	4.6	1.5	4.6
VIb			0.1	1.1	0.0	0.0	0.0	0.0
VIc			0.7	2.3	0.4	1.1	0.0	0.0
VII	3.5	9.2	2.8	5.7	1.3	3.4	0.8	2.3

Table 6-5 : Sensitivity of the maximum potential divertible yield with environmental water requirements

Environmental water requirements (1)	Max potential divertible yield (GL)
10 percentile	1700
20 percentile	1615
30 percentile	200

(1) Based on in-stream use releases d/s ORD, Hydropower - town and ADM, and no in-stream use releases d/s KDD

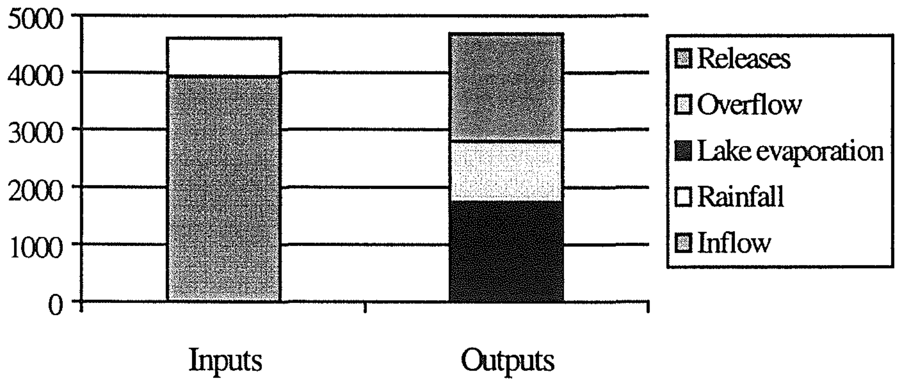

Figure 6-5 : Magnitude of water balance components for Lake Argyle

The long term variation in the water level in Lake Argyle and the overflow and draw, for both hydropower and irrigation, from Lake Argyle under full development of Stage I (Scenario VII) and Stage II (Scenario VIb) is illustrated in Figures 6-6 to 6-9.

Examination of Figures 6-6 and 6-8 illustrates that the draw for hydropower increases dramatically at low water levels within the Lake. This is due to the reduction in the head difference between the water levels upstream and downstream of the Ord River Dam.

The overflow volume from Lake Argyle was significant during a number of years under both scenarios despite assuming the characteristics for the current spillway, which was raised by 6 metres in 1992 and almost doubled the storage volume of the lake (Figure 6-7). The releases for hydropower and irrigation are more reliable under full development of Stage II (Scenario VIb) rather than the full development scenario for Stage I (Figures 6-8 and 6-9). Under Scenario VII restrictions on the releases for hydropower and irrigation occur for 3 out of 4 years during the 1930's and again prior to the large inflows during the 1954/1955 water year. During the same periods under scenario VIb, which is the full development of Stage II, the restrictions to irrigation are not evident and the restrictions on hydropower releases are far less significant.

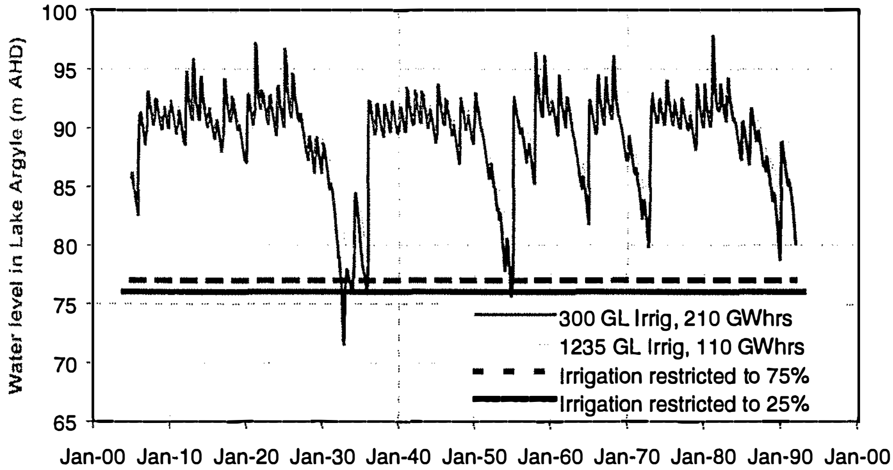

Figure 6-6 : Variation in water level in Lake Argyle

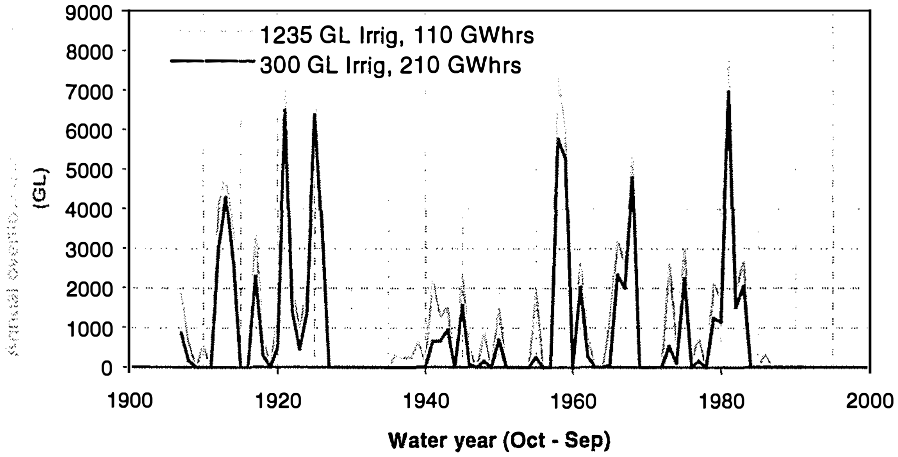

Figure 6-7 : Annual variation in the overflow volume from Lake Argyle.

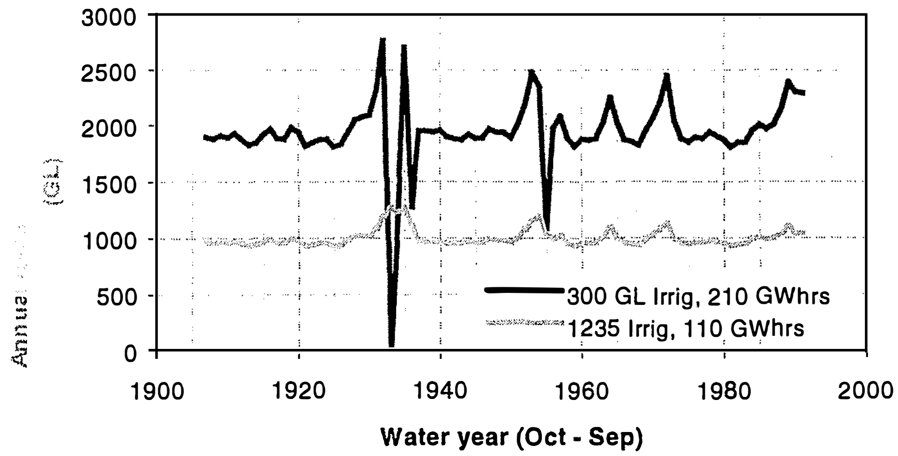

Figure 6-8 : Annual variation in the draw for hydropower from Lake Argyle.

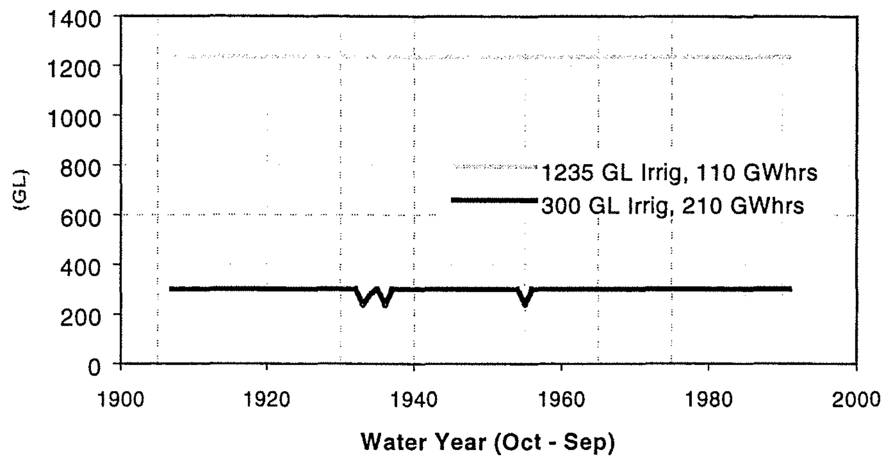

Figure 6-9 : Annual variation in the draw for irrigation from Lake Kununurra.

The diagrammatic representation of the outflows from Lake Argyle for Scenario VII, which is the full development of Stage I is shown in Figure 6-10. The hydropower releases are the major component of the outflows from Lake Argyle. The direct releases are only 45 GL, which is about 1.5% of the total releases from Lake Argyle.

With full development of Stage II of the Ord Irrigation Scheme, Scenario VIb, the hydropower releases are nearly halved due to the reduction in hydropower demand resulting from the closure of the Argyle Diamond Mine (see Figure 6-11). While the direct releases increase to nearly 18% of the total outflow from Lake Argyle.

The average annual inputs and exports from the Ord River at and downstream of Lake Kununurra is shown in Figure 6-12. The major input to the lower Ord River other than from releases from Lake Kununurra are the Dunham River, drainage return flows from Stage I irrigation and natural catchment inflows downstream of the confluence of the Ord and Dunham Rivers. The annual natural and drainage return inflows to the Lower Ord River exceed the amount of water extracted for irrigation of the West Ivanhoe, Carlton Plain and Mantinea Flat areas (Figure 6-12).

The basic inputs and outputs to Lake Argyle and Lake Kununurra and the natural catchment inflows between these two lakes is shown in Figure 6-13.

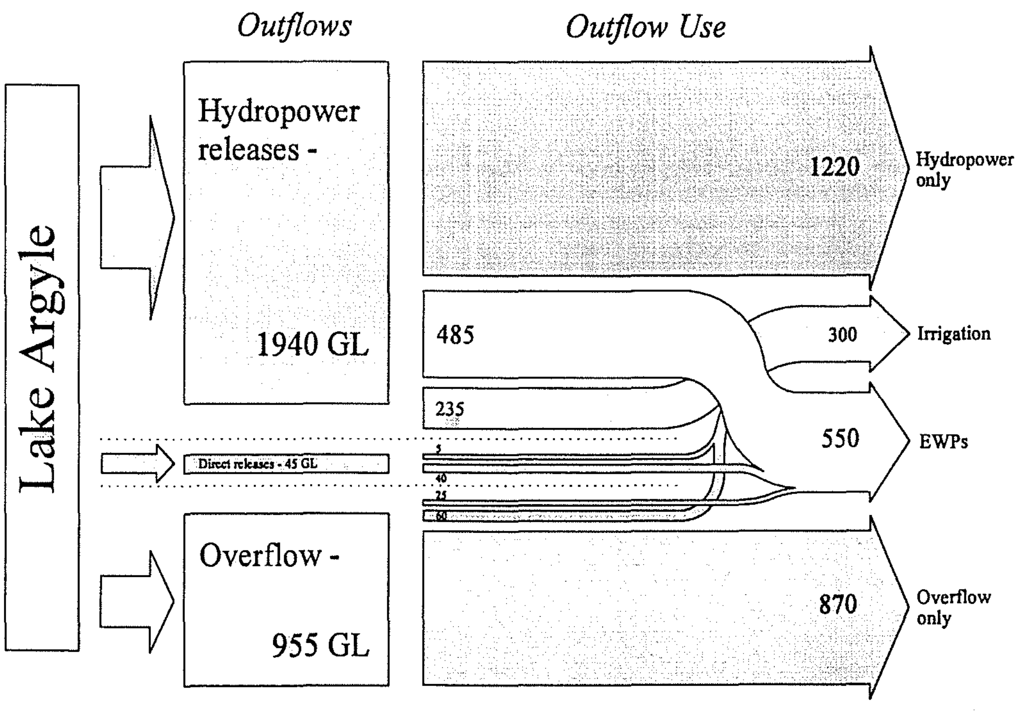

Figure 6-10 : Diagrammatic representation of outflows for Scenario VII

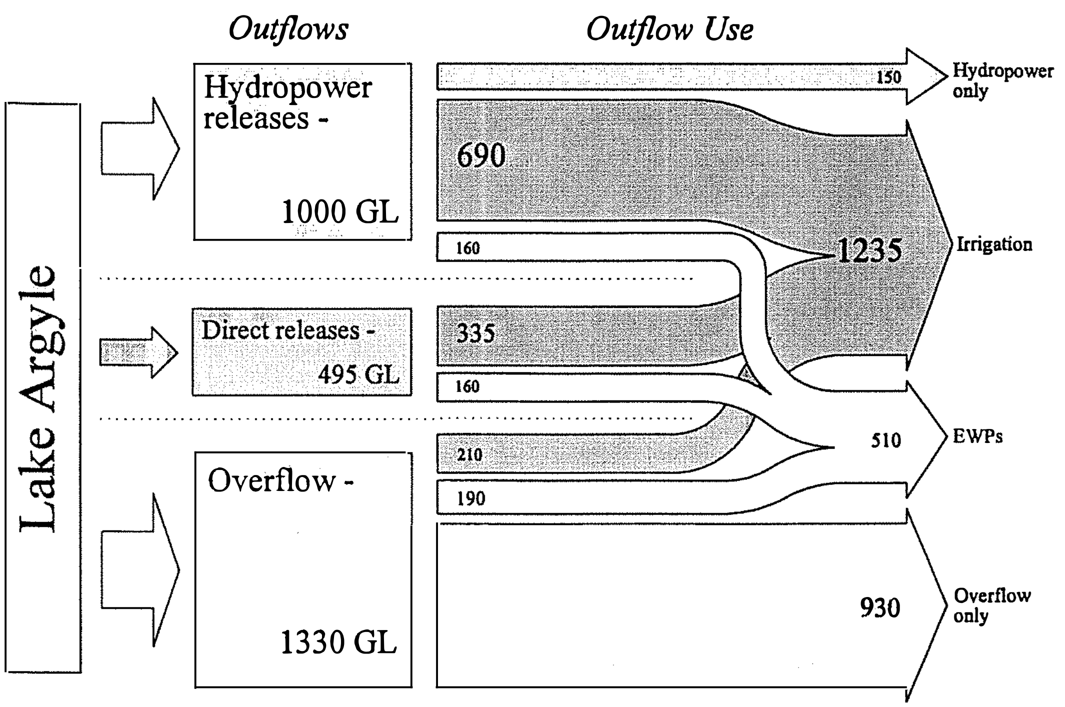

Figure 6-11: Diagrammatic representation of outflows for Scenario VIb

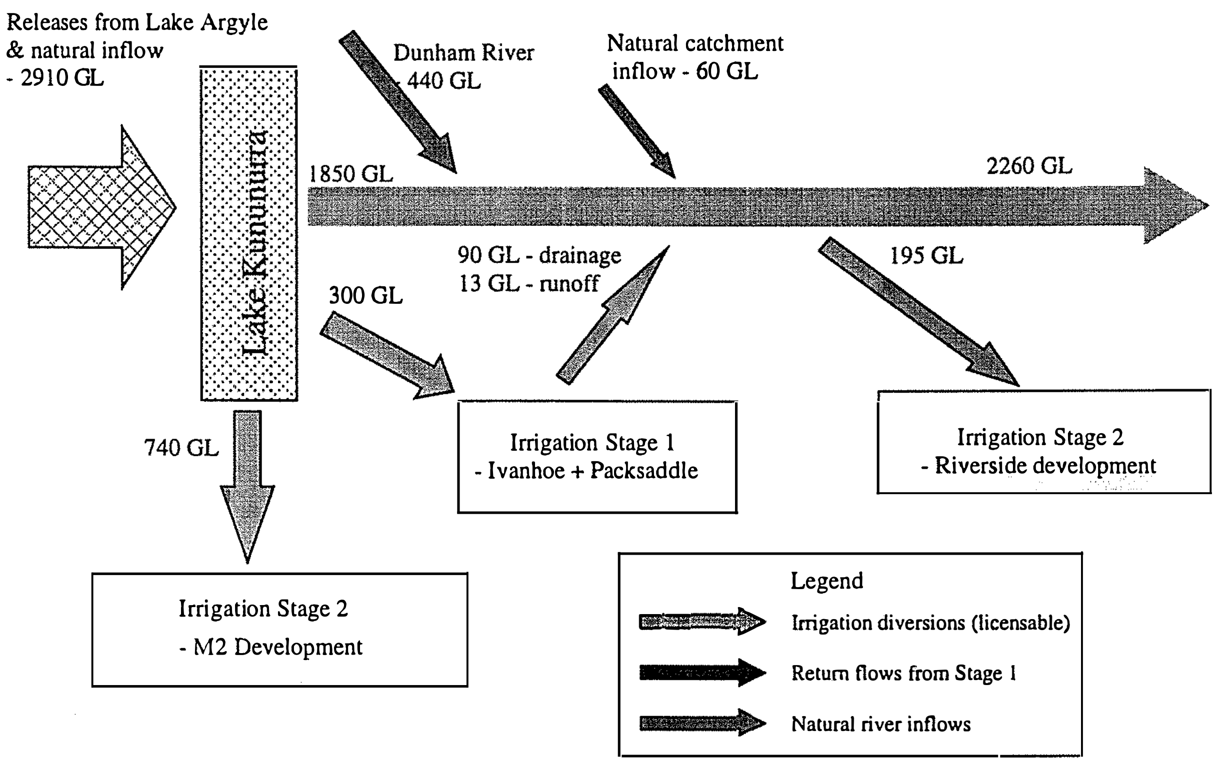

Figure 6-12: Diagrammatic representation of average annual flows from Lake Kununurra and lower Ord River for Scenario VIa

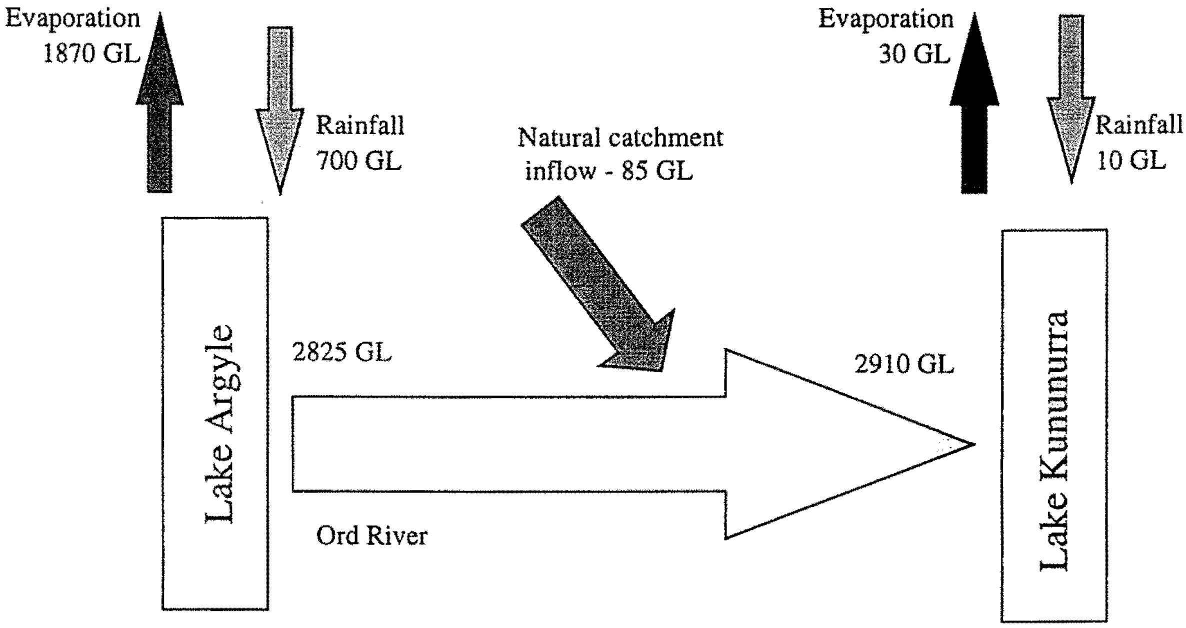

Figure 6-13: Diagrammatic representation of flows between Lake Argyle and Lake Kununurra

6.4 Impact of development on river flow

6.4.1 Observed impact

The flow of water in the Ord River has changed significantly over the last 30 years due to the construction of the Kununurra Diversion and Ord River Dams. The hydropower development and the potential significant increase in irrigation water demand will both have significant future impacts on the hydrology of the Ord River.

The variation in streamflow downstream of the Ord River Dam, but upstream of the Kununurra Diversion Dam for 1972 to 1989 is shown in Figure 6-14. The mean annual flow for the period of record shown in Figure 6-14 is 4060 GL for the natural pre-regulation river flow (no dam). Since construction of the dam the streamflow down the Ord River can be estimated from the releases and the overflow volume. The overflow from Lake Argyle re-enters the Ord River some distance downstream of the dam at the Spillway Creek confluence. The river flow at the Spillway Creek confluence averaged 2660 GL for the 1972 to 1989 period. Between the dam wall and the Spillway Creek confluence the releases account for almost the entire flow. The major difference in the two sequences is the reduction of the high flows in the regulated flows over the 18 years from 1972. The overflow characteristics of the Ord River Dam and the evaporation loss from Lake Argyle are considered to cause the lack of higher flows and the lower average flow respectively.

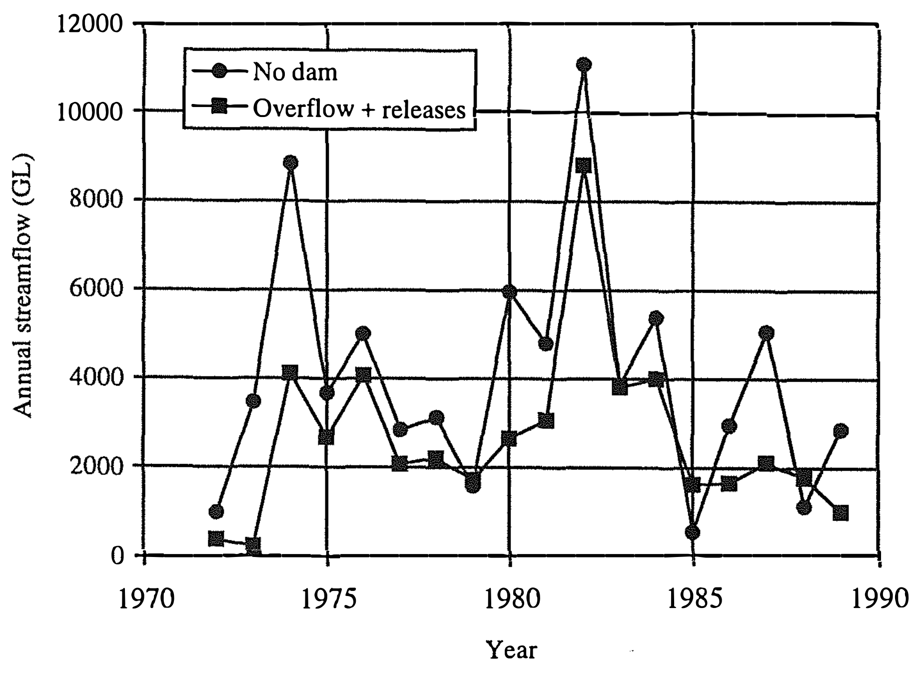

Figure 6-14: Variation in annual streamflow downstream of the Ord River Dam

The magnitude and the duration of the flow have changed significantly on a monthly, and seasonal, basis in the Ord River due to the construction of the two dams. Prior to the construction of the dams the flow would cease during the dry season. The continuous releases from the dams has led to the Ord River, downstream of the Ord River Dam, flowing consistently throughout the year, but the high and low flows have been dampened. This has led to a reduction in the streamflow variability downstream of the dams.

6.4.2 Potential impact

The potential variation in the median, low flow and a high flow for the Ord River due to various levels of development compared to no river regulation is shown in Table 6-6.

The median annual flow for the Ord River is slightly below 4000 GL downstream of the Dunham River assuming no river regulation. Given the current situation with approximately 300 GL irrigation the median annual flow downstream of the Dunham River confluence reduces to 2270 GL, a 34% reduction. With an increase in the irrigation demand to 1235 GL the reduction in median annual flow of the Ord River at the Dunham River confluence reduces by an additional 33%. However the median annual flow at this point is still over 1000 GL.

Table 6-6 : Identification of variation in annual flow for specific scenarios and at specific locations.

Location	Dry year 10th percentile (GL)	Median year 50th percentile (GL)	Wet year 90th percentile (GL)
Natural flow			
• Ord River @ ORD(1)	971	3040	7741
• Ord River @ KDD(2)	1113 (4)	3097	8047
• Ord River @ Dunham River(3)	1233	3440	8887
VII - 300 GL + 210 GWhrs			
• Ord River @ ORD	1929	2168	4733
• Ord River @ KDD	1655	1929	4565
• Ord River @ Dunham River	1774	2272	5397
VIb - 1235 GL + 110 GWhrs			
• Ord River @ ORD	1652	1834	5050
• Ord River @ KDD	640	782	4071
• Ord River @ Dunham River	758	1126	4911

(1) @ ORD denotes just downstream of confluence of Ord River and Spillway Creek
(2) @ KDD denotes just downstream of Kununurra Diversion Dam
(3) @ Dunham River denotes just downstream of the Dunham River
(4) Data is reported to 4 significant figures for maintaining consistency with upstream and downstream values and does not imply a high level of accuracy

The regulatory effect of the reservoirs on the annual streamflow downstream of the Dunham River confluence is illustrated by the reduction in the variability of streamflow following development (Figure 6-15). Although the irrigation demand increases fourfold at full development the variation in the flows in the Ord River streamflow downstream of the Dunham confluence is greater under the current development scenario (Figure 6-15). The streamflow in the Ord River downstream of the Dunham confluence under the current development scenario (300 GL irrigation and 210 GWhours hydropower) decreases but is much less variable than the natural flow situation. When fully developed (1235 GL irrigation and 110 GWhours hydropower) the streamflow is further decreased, however, there is an increase in the high flow variability toward a more natural level (Figure 6-15).

The variation in the median and 10th percentile annual streamflow with distance downstream from Kununurra Diversion Dam is illustrated in Figures 6-16 and 6-17. These plots illustrate that the irrigation demand in the Lower Ord has a relatively small effect on streamflow in the lower Ord River compared to the effect of the increased demand for the M2 area of Stage 2 which includes the Weaber/Knox and Keep Plain areas. At full development (1235 GL irrigation and 110 GWhours hydropower) the median streamflow in the lower Ord River is approximately 32% of the natural flow and around 46% of the streamflow at the current level of development (300 GL irrigation and 210 GWhours hydropower) (Figure 6-16). The median annual streamflow at the current level development is almost 70 % of the estimated median streamflow prior to the regulation of the two reservoirs.

The two intermediate development scenarios shown in Figure 6-16 are for the full development of the Weaber, Knox and Keep Plain areas (M2 areas) with either no or partial development of the lower Ord River irrigations areas. During these scenarios the lower Ord River flows were maintained at the levels estimated for the full development scenario. This was necessary due to the indicative environmental water releases not releasing water during the dry season to meet the social and tourism demands.

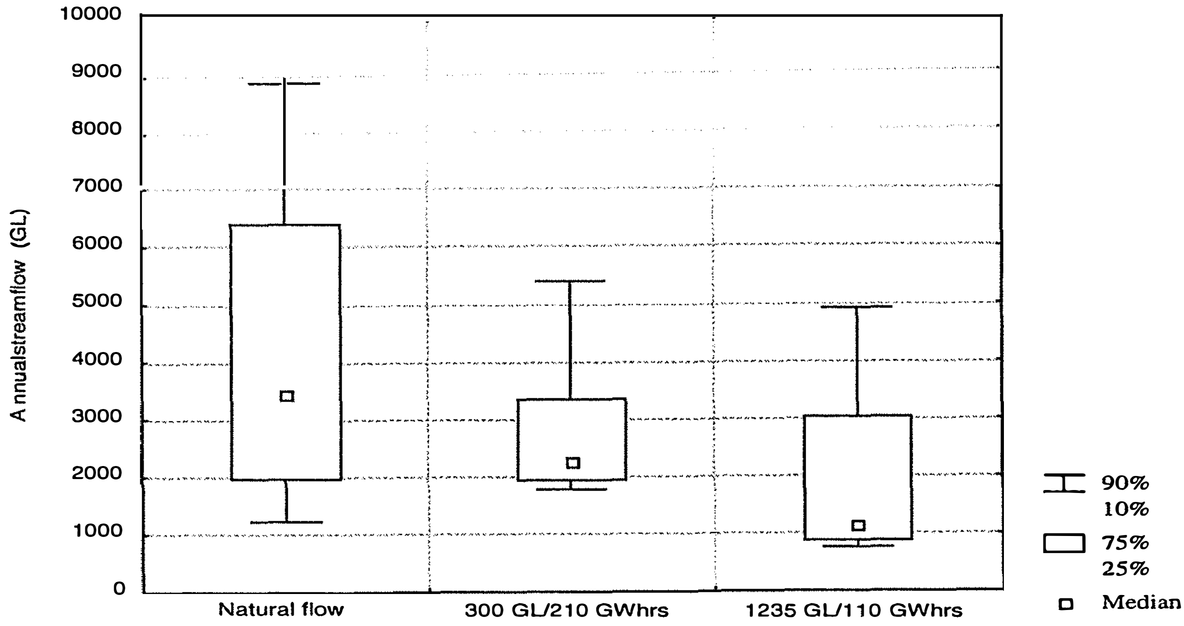

Figure 6-15: Variation in annual streamflow for the Ord River at the Dunham River confluence

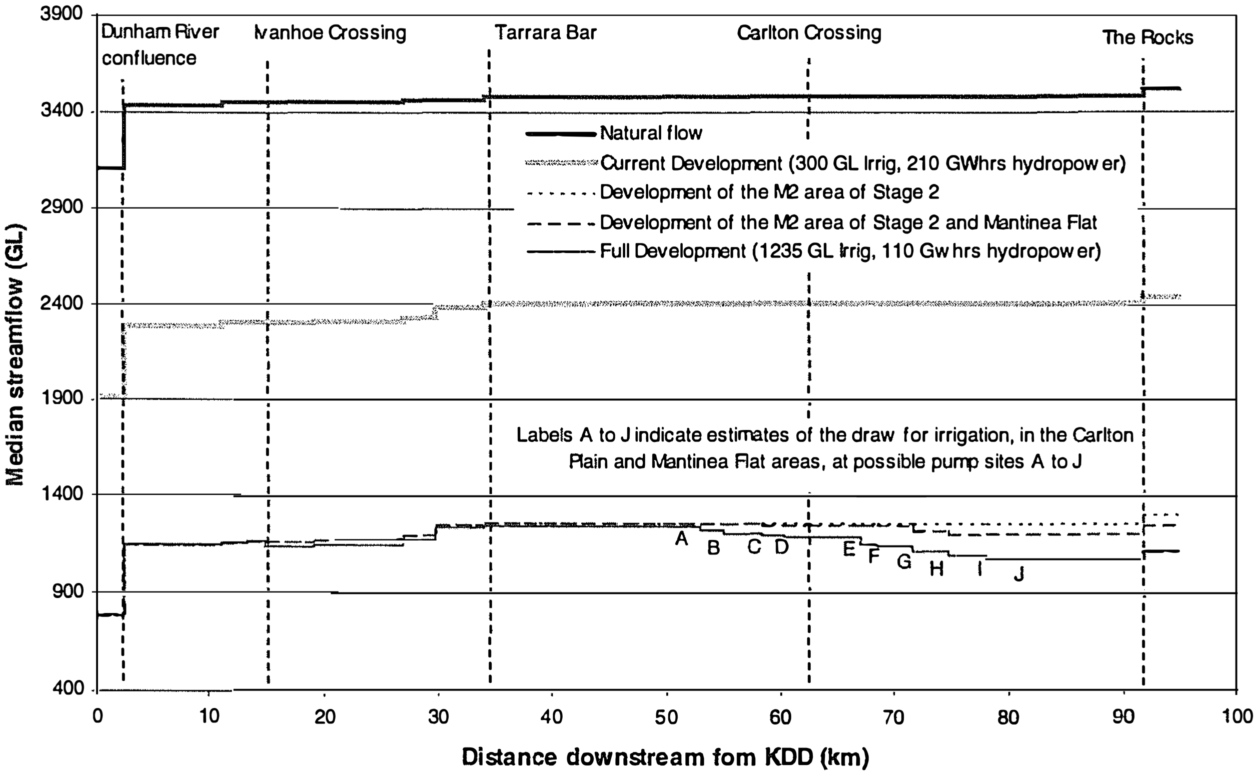

Figure 6-16 : Variation in the median annual streamflow in the Ord River downstream of KDD.

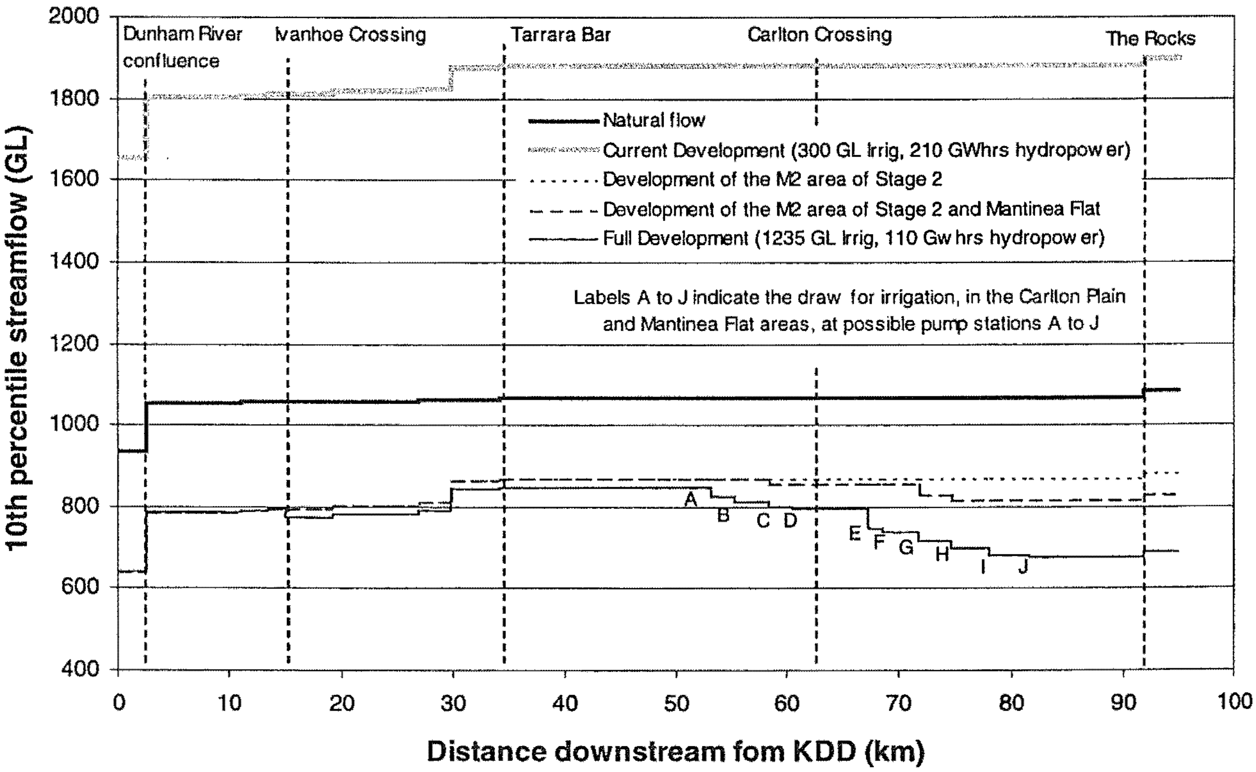

Figure 6-17 : Variation in the tenth percentile annual streamflow in the Ord River downstream of KDD.

During a relatively dry year (10 th percentile) the total annual streamflow at full development would be approximately 64 % of the total natural flow prior to any development. The streamflow at full development would only be around 36% of the streamflow in the lower Ord River at the current level of development, which is almost twice the natural streamflow during dry years (Figure 6-17).

The seasonal variation in streamflow in the Ord River downstream of the Kununurra Diversion Dam (Figure 6-18) highlights the higher flows expected during the dry, winter months with irrigation and hydropower development. Very wet (90th percentile) seasons the attenuation through the two reservoirs is likely to shift the peak flows from January - March to February – April (Figure 6-18).

The variation in streamflow downstream of Kununurra Diversion Dam during a typical low flow month is illustrated in Figures 6.19 and 6.20. These figures illustrate that during low natural streamflow months the streamflow downstream of the Carlton / Mantinea Irrigation area is approximately 10% of river flows under the current level of development when the M2 irrigation areas of Stage 2, Weaber, Knox and Keep Plain, become operational. Prior to the construction of the Ord River Dam and the Kununurra Diversion Dam the streamflow down the lower Ord River during August had a median of around 0.1 GL and there was no flow in the lower Ord at greater than a ten percentile level.

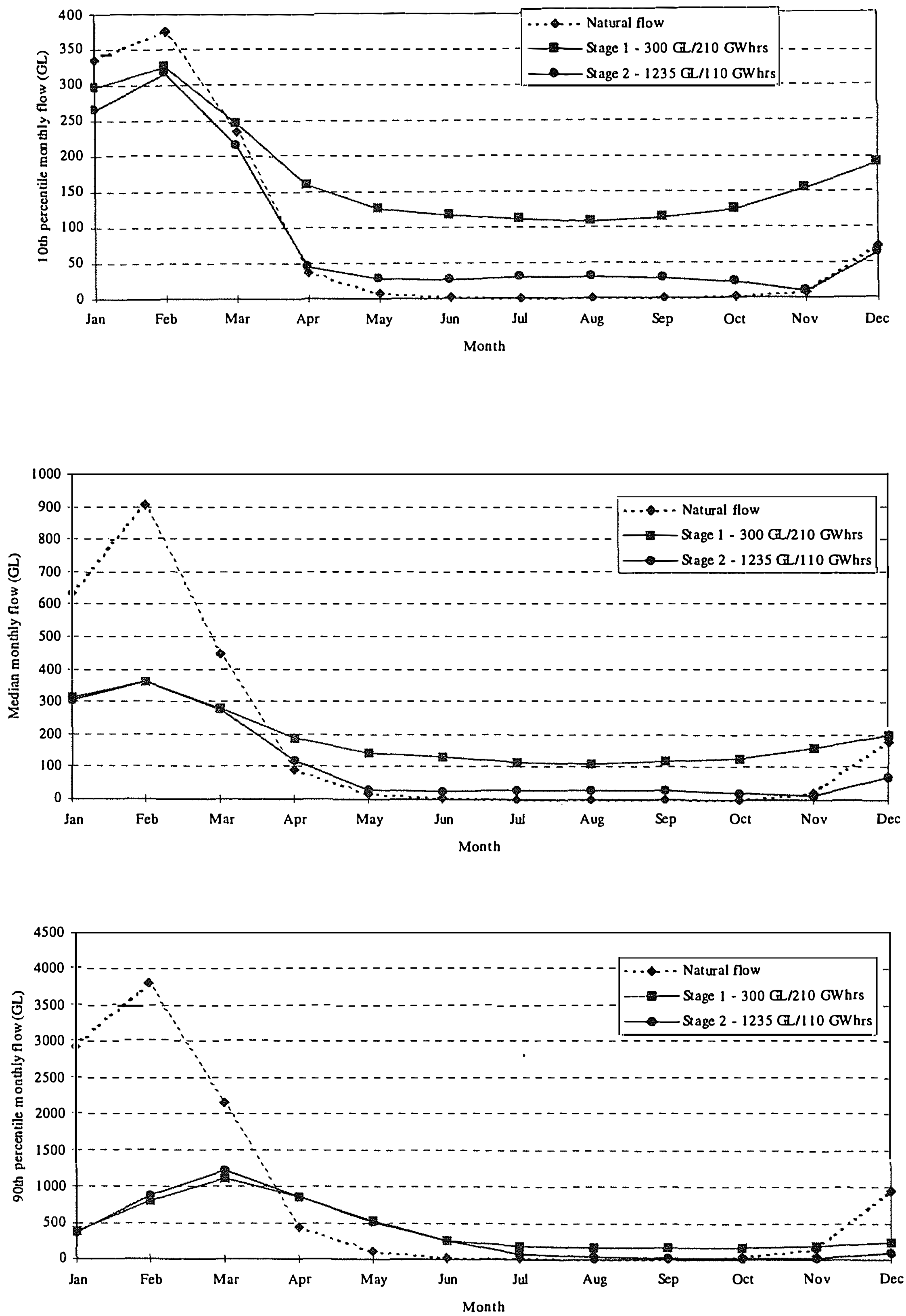

Figure 6-18 : Seasonal variation in streamflow for the Ord River at the Dunham River confluence.

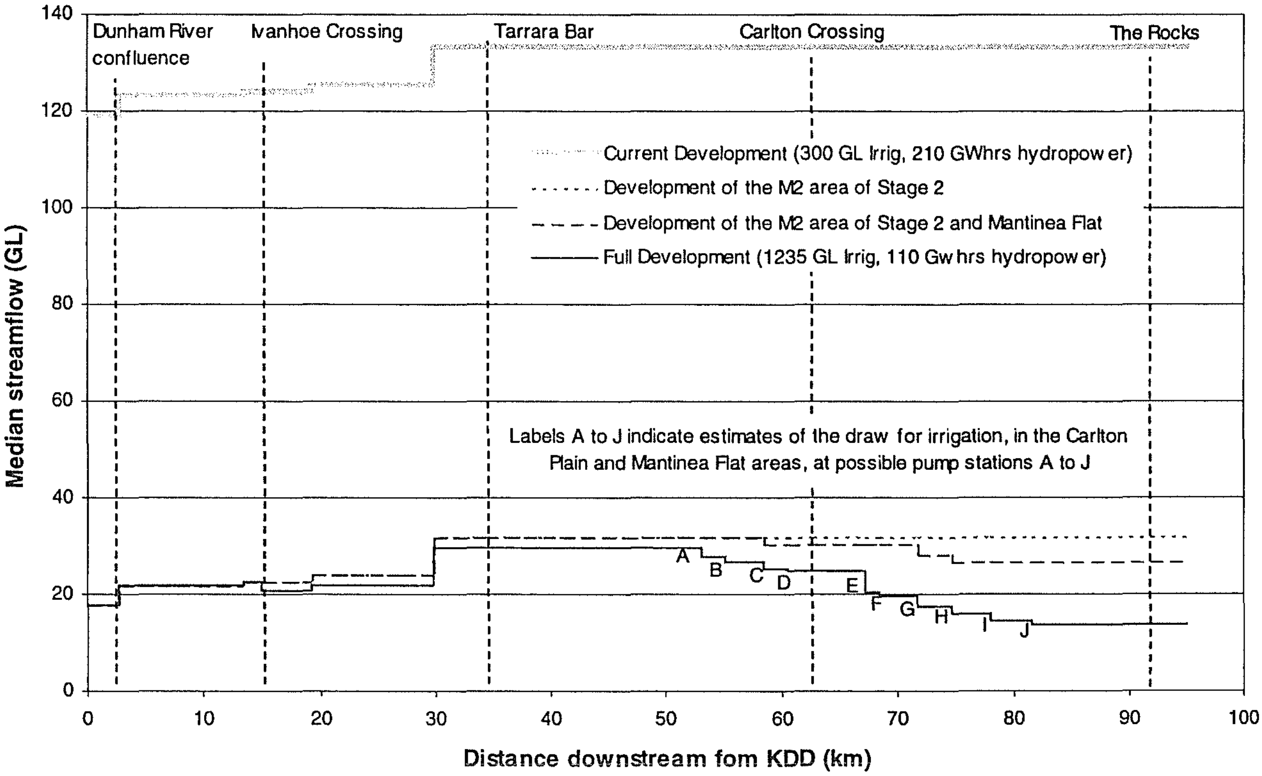

Figure 6-19 : Variation in the median August streamflow on the Ord River downstream of KDD

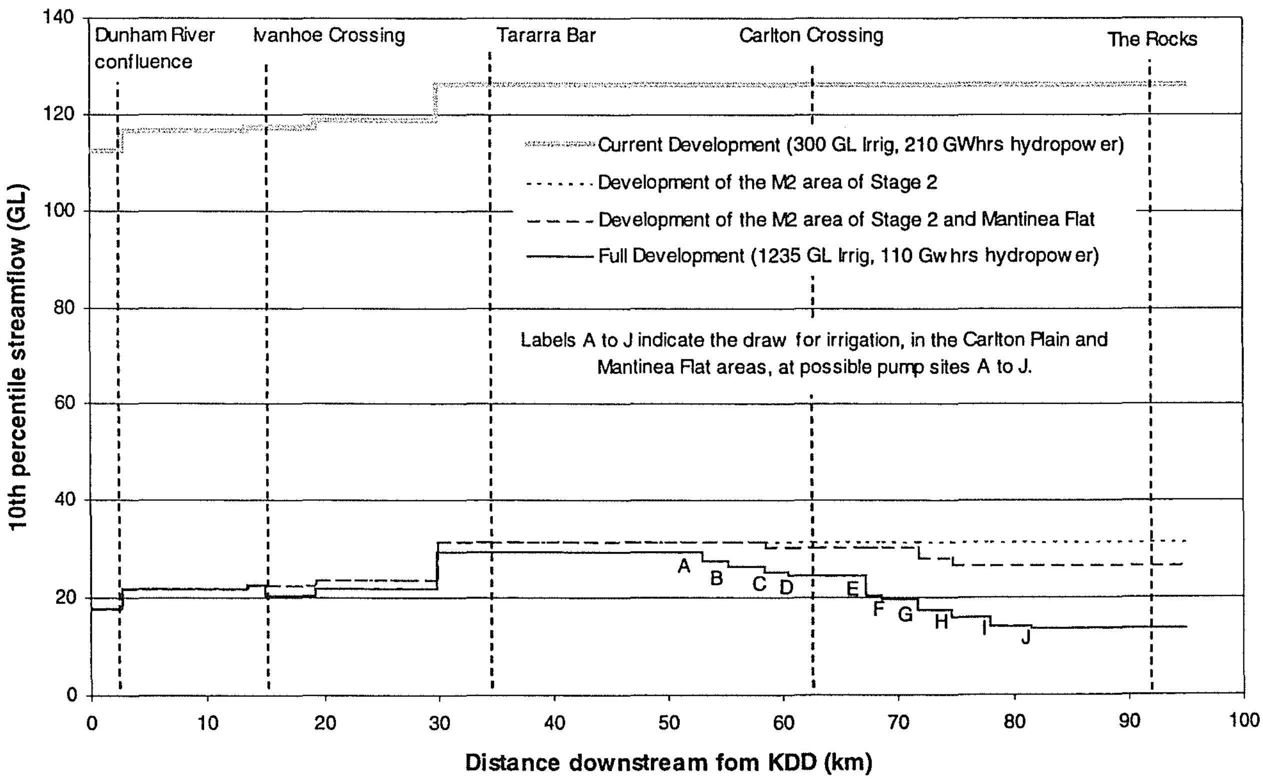

Figure 6-20 : Variation in the tenth percentile streamflow on the Ord River downstream of KDD.

The estimated average monthly flows for both Stage 1 and Stage 2 irrigation developments of the Ord River are reduced compared to the natural pre-regulation flow at Carlton Crossing on the lower Ord River (Figure 6-21). These reductions occur in January, February, March and December. Lake Argyle stores the wet season inflows and then water is released for irrigation in the dry season and more uniformly throughout the year for hydropower resulting in higher dry season flows at Carlton Crossing. The changes in the irrigation and hydropower demands at full development slightly increase the wet season flows and reduce the dry season flows. The flow changes at Carlton Crossing following full development result in a slightly better approximation of the pre-regulation seasonal flow regime.

The estimated changes in average river height at the deepest point on the Carlton Crossing cross-section mimic the changes in streamflow at the various levels of development (Figure 6-22). An additional 5 m^3s^{-1} released from the Diversion Dam to aid navigation in the lower Ord had little effect on the downstream water level. The greatest effect on water level at Carlton Crossing was estimated to be an increase of less than 0.15 metres during October. The level at Carlton Crossing was estimated to be less than 1 metre deep between August and November, inclusive

The small increase in streamflow and river height shown in Figure 6.21 and Figure 6-22 in the wet season is due to the indicative environmental water flows.

A preliminary analysis was carried out to understand the impact of reduced river flows on the nutrient status of the lower Ord River. The basic assumptions in this analysis were:

1) The natural flow Indicative Total Phosphorus concentration from the Ord and Dunham Rivers upstream of irrigation areas was assumed to be 0.015mg/L. The nutrient data did not show a strong seasonal or flow related response

2) The Indicative Total Phosphorus concentration for the drainage from irrigation was assumed to be a constant 0.07 mg/L since the data available does not show a strong seasonal or flow related response.

3) Indicative Total Phosphorus concentration for natural flow from irrigation areas ranges from 0.07 mg/L to 0.15 mg/L depending on the flow volume for the month.

The assumptions and analysis were based on only one year of nutrient and sediment data.

With the current conditions there is little variation in Indicative Phosphorus concentration for an average year in the lower Ord River (Figure 6-23). This is due to the dilution effect of the dry season flows from the operations of the hydropower station. As the level of irrigation for the Keep, Weaber and Knox River Plains area increases and the hydropower demand decreases the dilution effect will also decrease. For the full development of Stage 2 with a minimum flow of 5 m^3s^{-1} downstream of KDD to aid navigation, there is an increase of the dry season indicative phosphorus concentration to nearly 0.03 mg/L. This increase occurs in the dry season when there is little dilution from the Dunham River and there is relatively high nutrient concentration levels discharging from the Stage I irrigation area into the lower Ord River. Without the minimum 5 m^3s^{-1} release from KDD the indicative phosphorus concentration is estimated to approach 0.035 mg/L late in the dry season.

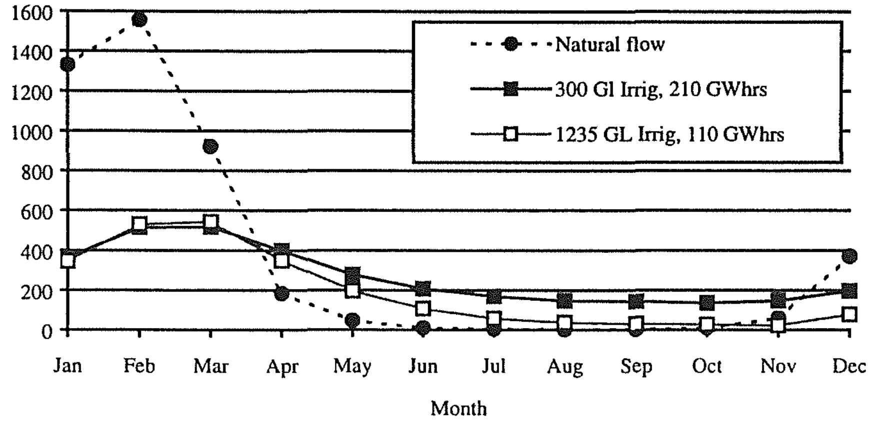

Figure 6-21 : Seasonal variation in flow at Carlton Crossing on the lower Ord River

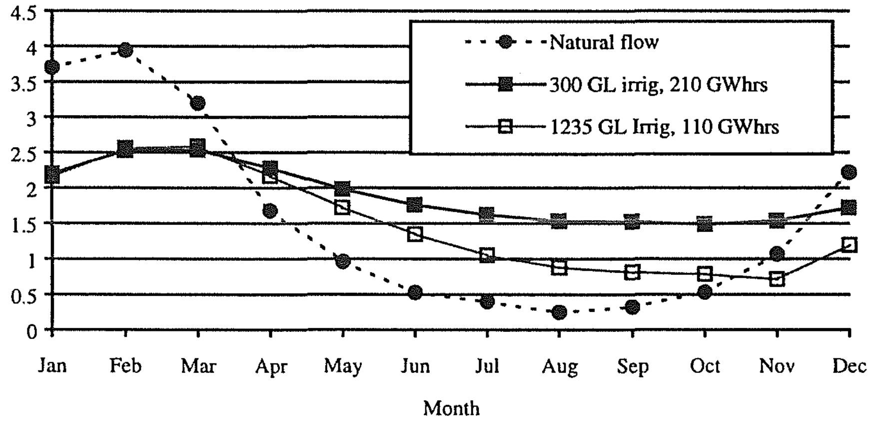

Figure 6-22 : Modelled seasonal variation in water depth at Carlton Crossing on the lower Ord River

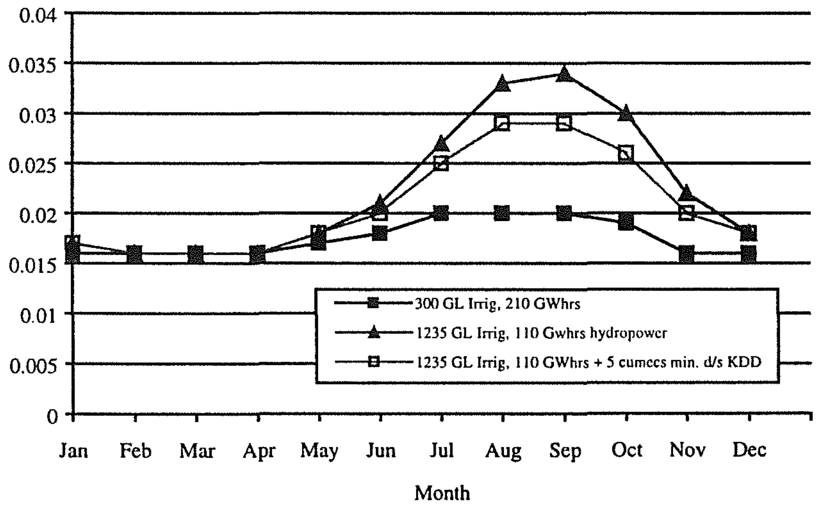

Figure 6-23 : Modelled seasonal variation in Total Phosphorus at Carlton Crossing on the lower Ord River

7. Water related investigations

Further hydrologic studies will depend on the requirements for the:

- licensing and associated operating strategy as part of the water allocation to the Water Corporation and Ord Irrigation Cooperative;
- future development of Stage II of the Ord River Irrigation Scheme (ORIS);
- more detailed investigations into the environmental water requirements and provisions for the water allocation; and
- investigations into the protection and enhancement for the Ord River catchment.

However further investigation is considered important in a number of key areas:

7.1 Stage I - Ord Irrigation Scheme

7.1.1 Licensing and operating strategy

The monitoring for the licensing of the Water Corporation and Ord River Irrigation Cooperative will probably include:

- Inflows to and outflows from Lake Argyle;
- Releases and draws from Lake Kununurra;
- Dunham River inflows to the Ord River; and
- Rainfall on irrigation areas.

Some of this monitoring is already being monitored by the Water Corporation or other agencies, such as the Bureau of Meteorology.

7.1.2 Overall water balance

Due to the uncertainty in the efficiencies of the water delivery and on-farm systems it is very important that the water balance for the existing irrigation areas is quantified. Some work is currently in progress into the water balance at farm level. There needs to be a supporting investigation into the water balance for the Ivanhoe Plain and Packsaddle Plain areas.

The monitoring required is:
Input

- Water delivery from Lake Kununurra to both Packsaddle and Ivanhoe Plains;
- Local rainfall on irrigation areas;
- Some broad indicator of the change in soil water/groundwater storage.

Output

- Ivanhoe Plain: Water monitoring at D2 and D4 drains (67% of the drainage area, see attached plan);
- Packsaddle Plain: Water monitoring at main drain entering Dunham River.

In conjunction with the water balance for Stage I a preliminary nutrient balance should be carried out. This may lead to a more detailed phosphorus and nitrogen budget for the Ord River.

There should also be a preliminary sediment sampling program for pesticides along some of the larger drains.

7.1.3 Environmental water

The water required to maintain a healthy river, particularly on the lower Ord River, needs to be evaluated. The hydrology of the Ord River has been significantly disturbed over the last 20 years and there is potential for further changes with additional irrigation development.

The hydrologic monitoring requirement for determining the environmental water requirements and provisions will include:

- water level, volume, and salinity for the Ord River at Carlton Crossing;
- water level and salinity at a number of key sites downstream of Carlton Crossing.

7.1.4 Preliminary salt balance

The overall salt balance for Ivanhoe and Packsaddle Plains irrigation areas should be undertaken. This should initially be a preliminary study to ascertain the relative magnitudes of the input, output and storage components of the salt balance.

7.2 Stage II - Ord Irrigation Scheme

7.2.1 Crop water demand - Sugarcane

The uncertainty in the appropriate crop water demand for sugarcane leads to uncertainty in the water required for irrigation. As the planning for Stage II of the Ord Irrigation Scheme (ORIS) progresses further investigations into the appropriate crop water demand are necessary.

7.2.2 Salinity variation - Lower Ord River

As more water is withdrawn from the Ord River for irrigation, particularly for Stage II of the ORIS then the dynamics of saltwater intrusion of the Ord River will need to be understood. This is particularly important for the Carlton Plain and Mantinea Flats component of ORIS Stage II.

The monitoring required is similar to that required for the environmental water requirements and provisions.

7.2.3 Keep River

As part of the investigation into the impact of Stage II irrigation the hydrology (including water quality) of the Keep River needs to be evaluated. This would require streamflow gauging stations on the major stream and tributaries. In particular stations are required on the Keep River, and Border and Knox Creeks. Additional gauging stations are required on smaller, representative catchments to identify the different flow regimes with different soil type.

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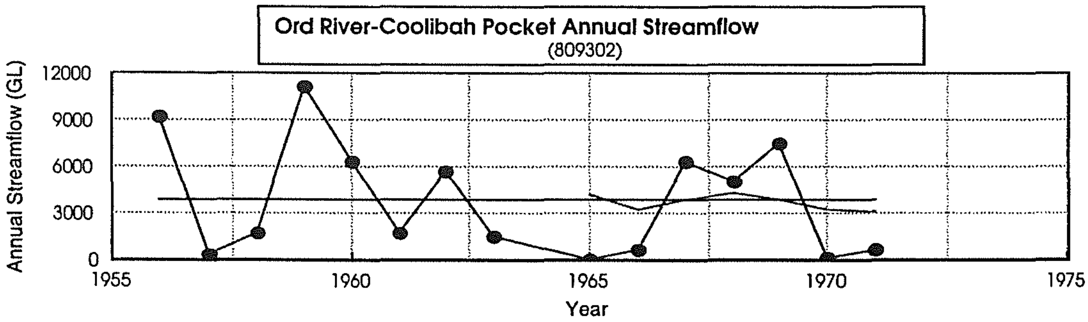
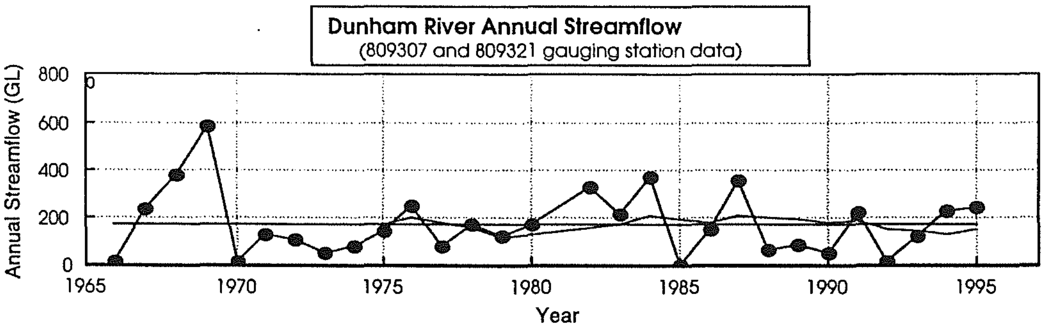
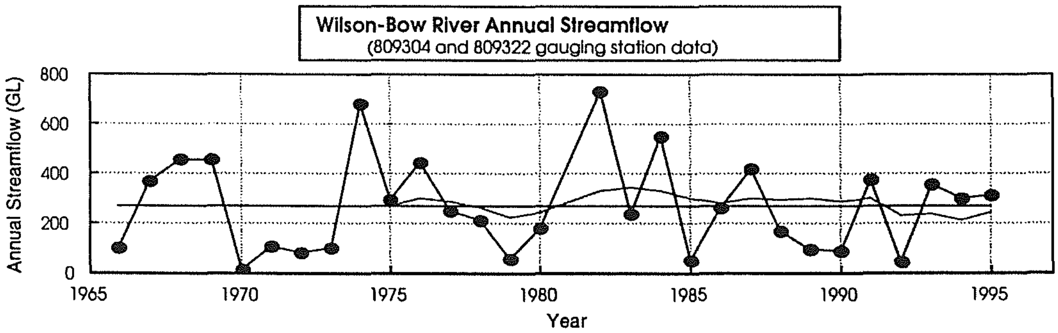
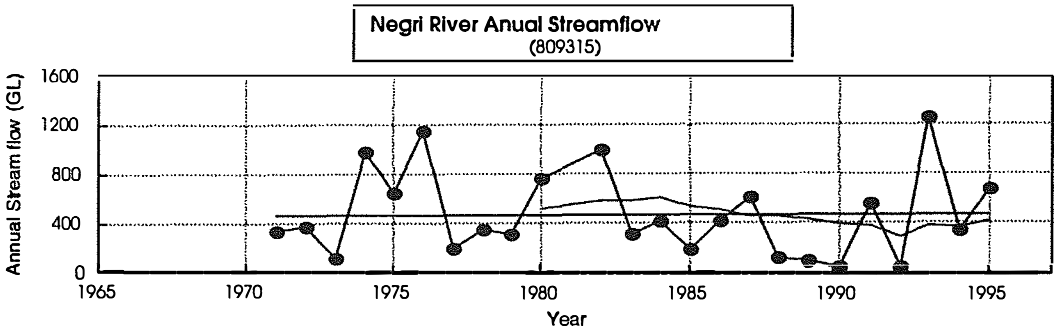
Appendix A

Streamflow at specific stations

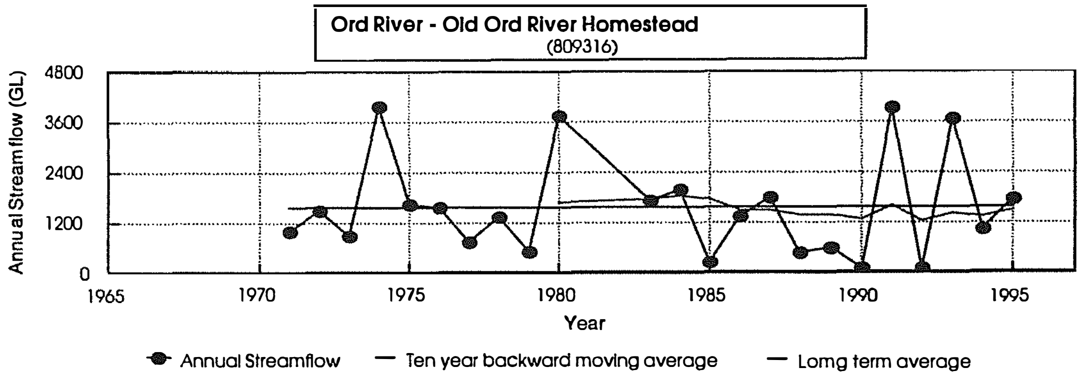








Negri River Anual Streamflow
(809315)
Annual Stream flow (GL)
1600
1200
800
400
0
1965
1970
1975
1980
1985
1990
1995
Year



Ord River - Old Ord River Homestead
(809316)
Annual Stream flow (GL)
4800
3600
2400
1200
0
1965
1970
1975
1980
1985
1990
1995
Year
Annual Streamflow
Ten year backward moving average
Lomg term average

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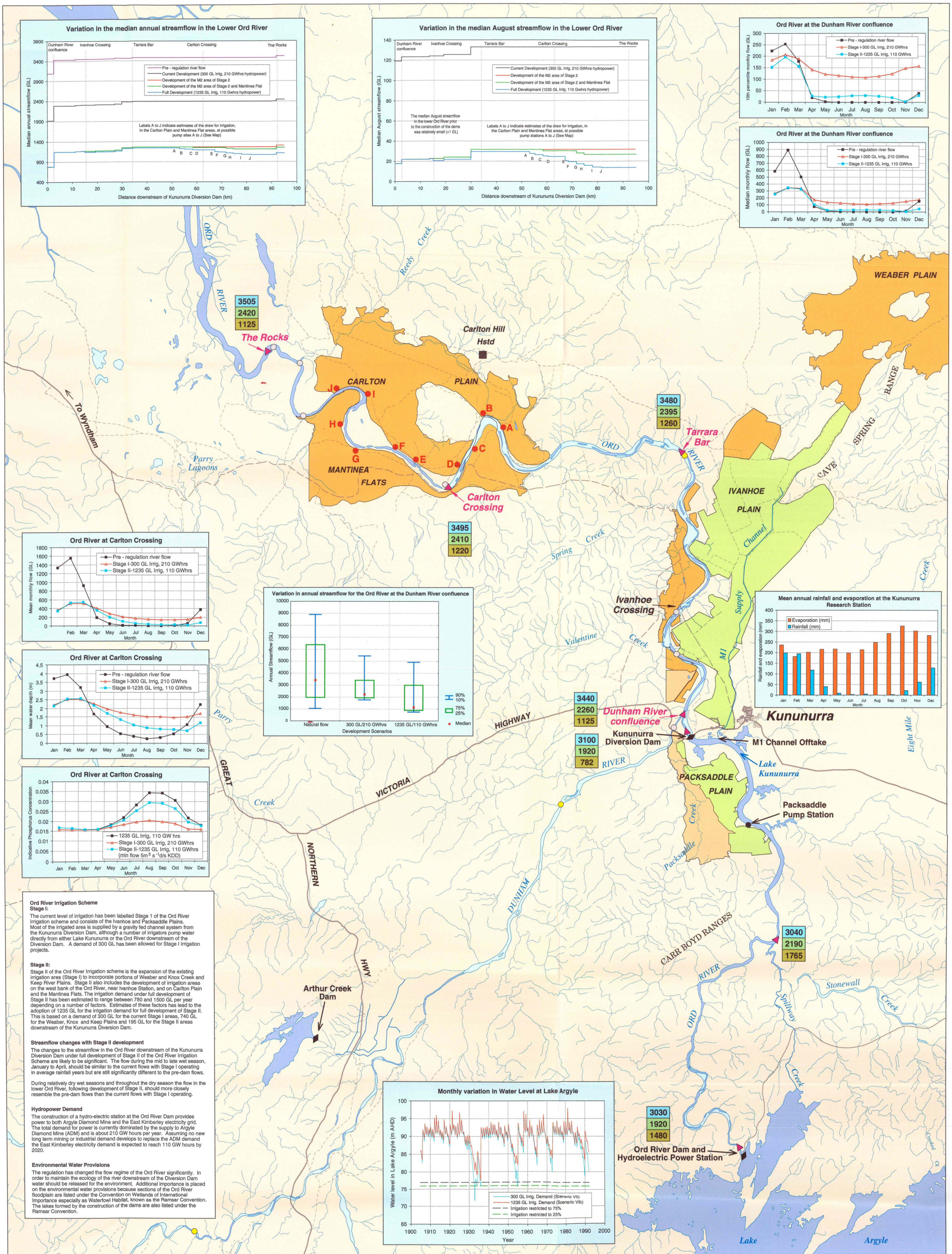

Current Irrigation Areas
Probable Irrigation Areas - Stage II
Other Possible Irrigation Areas
Major / minor roads
Streamlines
A Possible pump station sites
Key Streamflow Sites
WRC existing and proposed permanent flow gauging sites
WRC temporary flow and water quality gauging sites

Median Annual Streamflow (GL) - at key streamflow sites

3030 Natural
1920 Stage I Development - 300 GL/210 GWhrs
1480 Stage II Development - 1235 GL/110 GWhrs

5 0 5 10 15
kilometres

HYDROLOGY OF THE LOWER ORD RIVER

Produced by the Surface Water Hydrology Branch - February 1999

WATER AND RIVERS COMMISSION

Indicative pump stations taken from DNR (Qld) (April 1998)
Hydrography data taken from AUSLIG 1:250 000

This map should not be used for detailed planning purposes.