WATER AND RIVERS
COMMISSION

- Report to Environment Australia -

Ord River Historic Flows: Assessment of the Impacts of Regulation on Flooding.

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Background

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 Ord River has a catchment area of over 50,000 km^2 to the river mouth. The Ord River is regulated by the Ord River Dam (ORD) and the Kununurra Diversion Dam (KDD). The Kununurra Diversion Dam was completed in 1963 and the Ord River Dam, in 1972. Since 1972 the Ord River has been regulated with a catchment area above the Kununurra Diversion Dam of 47,100. The unregulated component of the Ord River to the river mouth is slightly more than 10% o of the total catchment area.

The lower Ord River (Fig. 1) has significant cultural and environmental significance including a Ramsar listed wetland, significant tourism and recreational use along the river, a number of sites of significance to the indigenous people of the area and a major irrigation development.

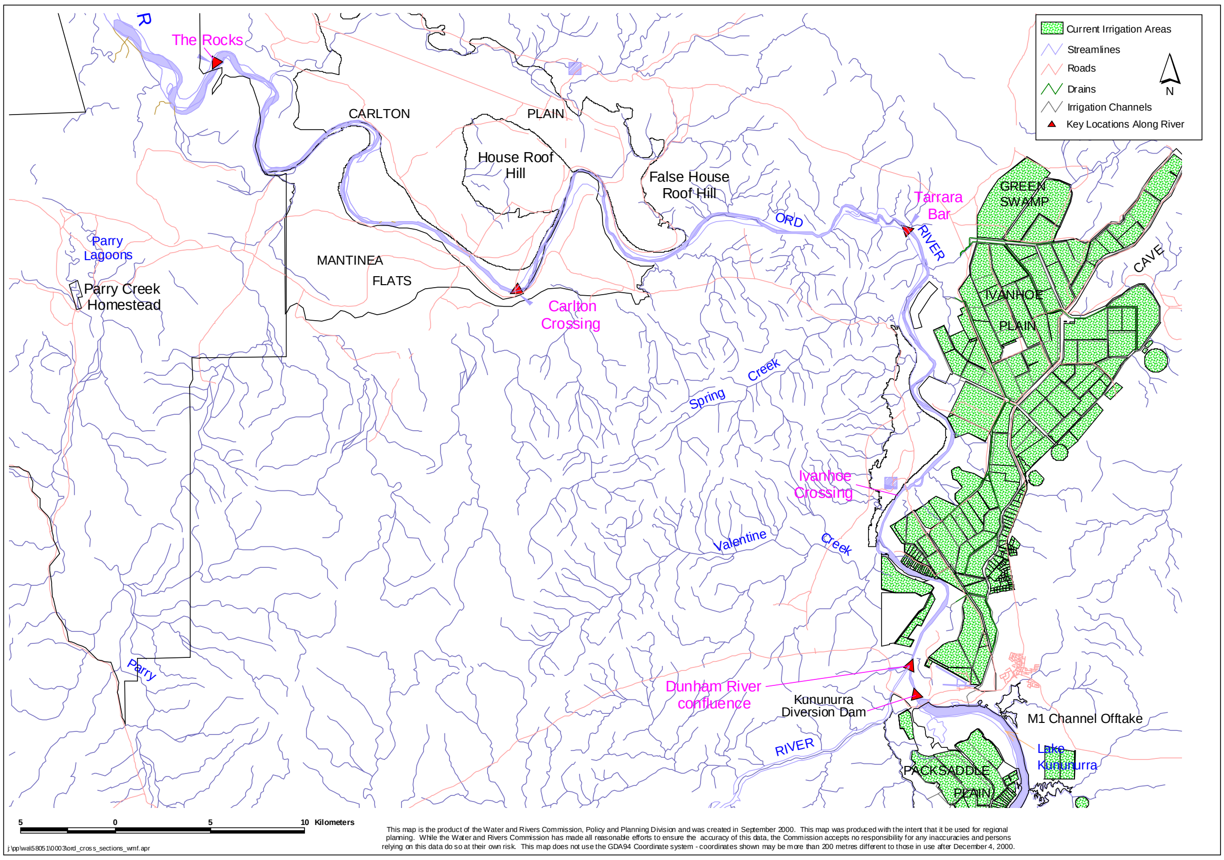

Figure 1 Map of the Lower Ord River catchment

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.

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. The variability of rainfall is relatively low compared to other semi-arid areas of Australia, but higher than the south west of Western Australia (Fig. 2).

Almost all rainfall occurs between November and April, the greatest falls being in January and February (Fig. 3). 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 that is not evident in the dry months where only light, sporadic falls occur.

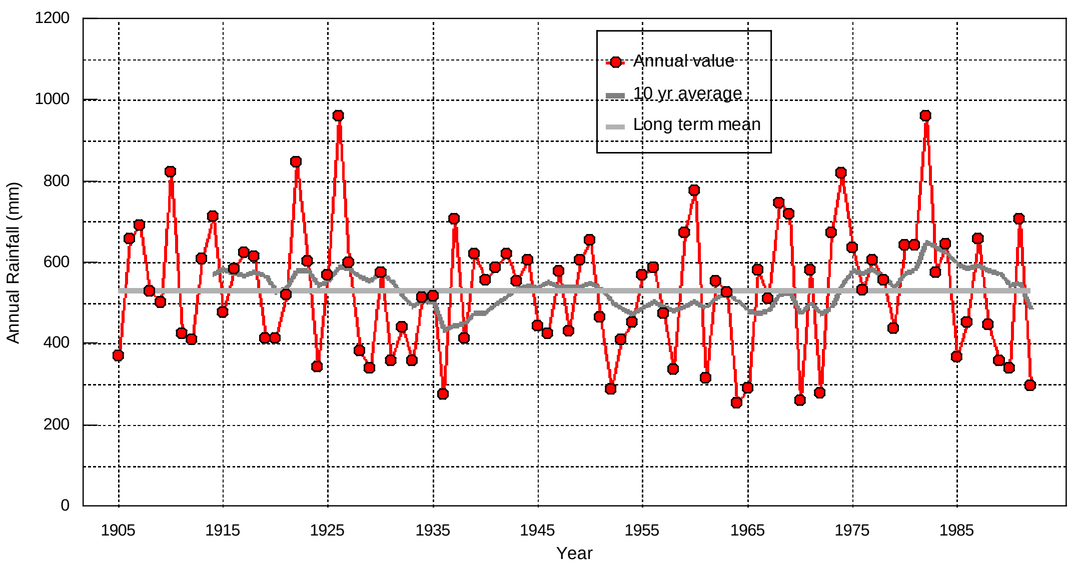

Figure 2 Annual variation in rainfall over the Ord River catchment to Lake Argyle

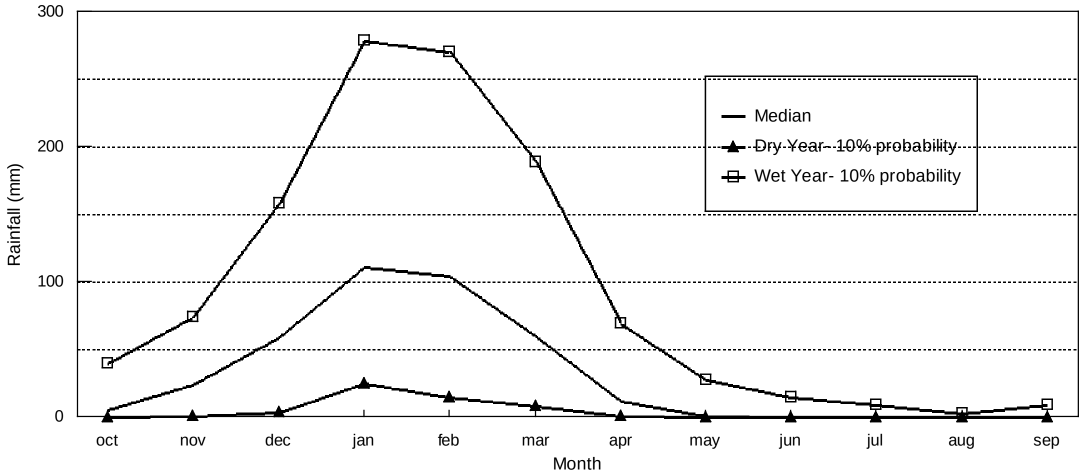

Figure 3 Seasonal variation in rainfall over the Ord River catchment to Lake Argyle

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 1.

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. 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 5. The dominant month for streamflow for the Ord River are January, February and March. The monthly streamflow are highly skewed, particularly the low streamflow months.

Table 1 Summary of annual streamflow data assuming no regulation

Sub-catchment	Gauging Station	Catchment Area (km^2)	Annual Mean Flow (GL)	Annual Median Flow (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

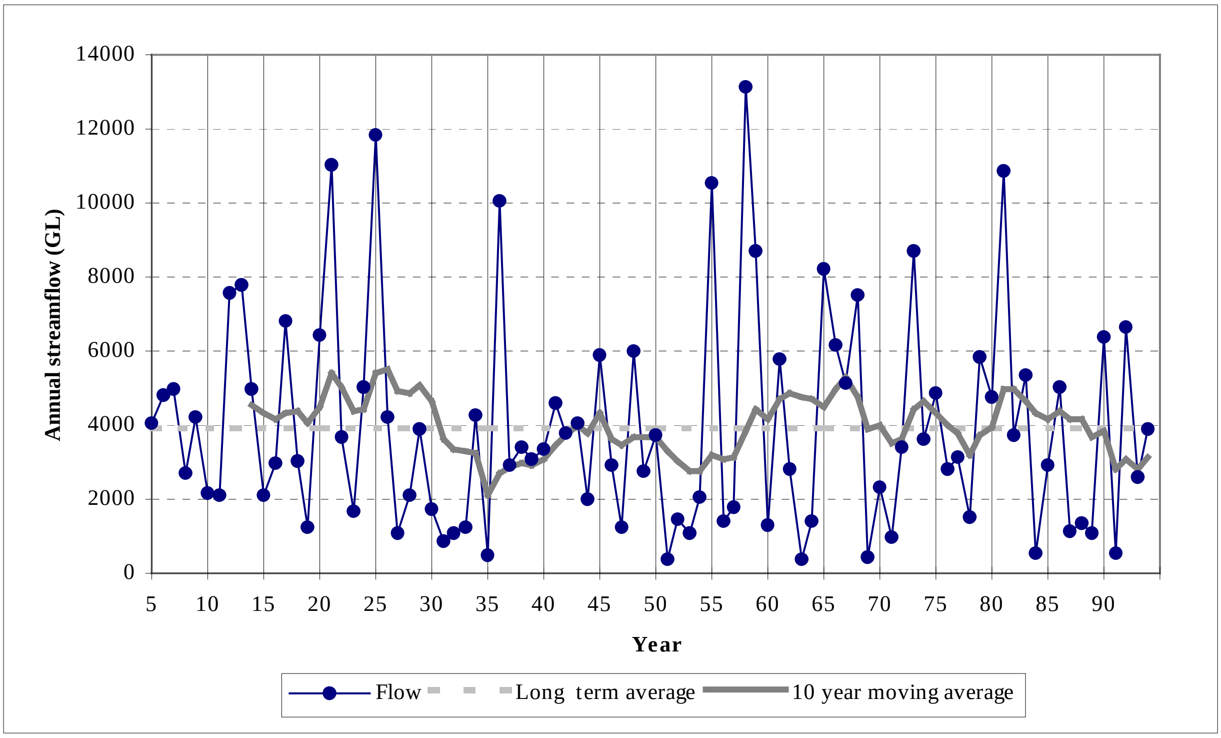

Figure 4 Annual streamflow for the Ord River at the Ord River Dam

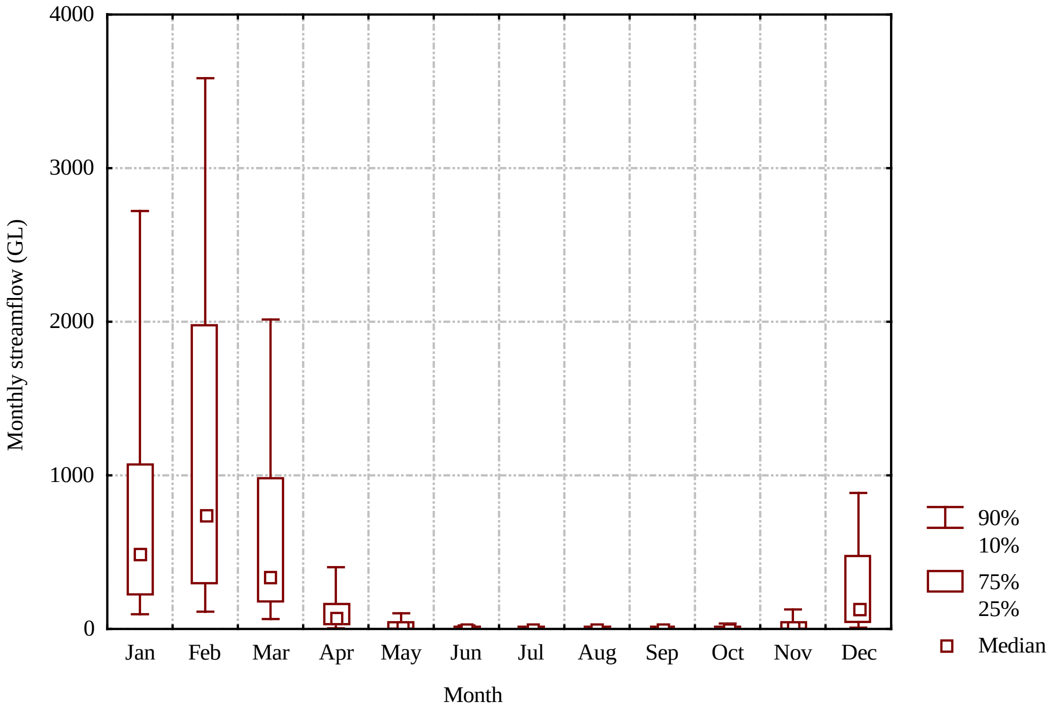

Figure 5 Monthly streamflow variation for the Ord River at the Ord River Dam

Impact of regulation on flooding

The Ord River, and it's tributaries, are prone to serious flooding resulting from extreme tropical lows, cyclones and thunderstorm activity originating over the Timor Sea. For example, greater than 450 mm 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} 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 peak recorded flows for the Ord River and its tributaries plotted against catchment area are compared to the world peaks in Figure 6.

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 flood 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.

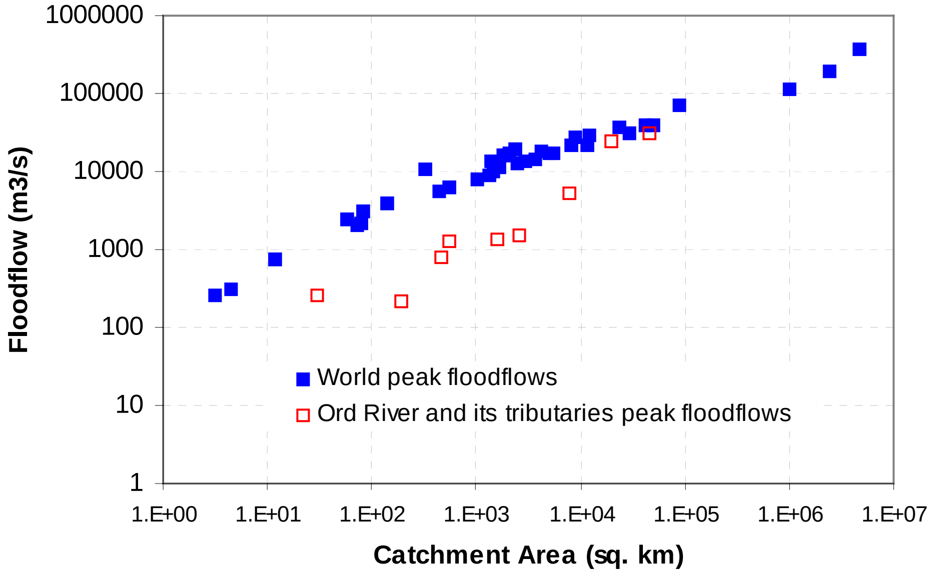

Figure 6 Comparison of Ord River and World peak floodflows.

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.

Flood frequency analysis

There are no streamflow gauging stations information in the Lower Ord River, below the KDD. Therefore, the flood frequency of flows in the Lower Ord River must be estimated from a combination of gauged flows on the Dunham River and the Ord River.

Prior to the construction of the ORD a gauging station operated for a period of 15 years (1955-1971) at a location near the present dam wall. Information from this station is used in the flood frequency analyses of natural (pre-dam) flows in the Lower Ord and for the inflows to the ORD. Since construction the inflows have been estimated using a simple water balance method on the water level in Lake Argyle. The largest inflows estimated from Lake Argyle water levels are significantly smaller (less than half) than the largest events recorded at the gauging station prior to the dams construction. The rainfall data indicates that that this may be due a lack of intense rainfall events since construction. While the total rainfall since construction has typically been above average there has not been the extreme events such as during the 1950's, which resulted in the largest flows recorded.

The results of a flood frequency analysis on the available gauged information and inflow estimates are shown in Table 2.

Table 2 Flood frequency results for Ord River and Dunham Rivers – pre-regulation

	Design Flow (m^3s^{-1})					
	50 % AEP[3]	20 % AEP	10 % AEP	5 % AEP	2 % AEP	1 % AEP
Ord River @ Ord River Dam [1]	4,420	10,800	17,100	24,800	37,800	50,000
Dunham @ Dunham Gorge[2]	390	790	1,210	1,780	2,890	4,100

1. Flood frequency results for the annual flow estimates for the Coolibah Pocket gauging station combined with the reservoir inflow estimates.
2. The Dunham Gorge streamflow gauging station monitors the flow from slightly less than half of the entire Dunham River catchment to the confluence with the Ord River.
3. Annual exceedence probability

The design flows entering the Ord River from the Dunham have been estimated by areally scaling the results from the flood frequency analysis performed on the gauged information according to the equation below.

$$q_{mouth} = q_{gauged} \text{ x } (A_{mouth} / A_{gauged})^{0.7}$$

Indicative 1 %, 10 % and 50 % probability flows for the tributaries in the Lower Ord River, downstream of KDD, were estimated by areally scaling (eq 1) the measured flows in the Dunham River. These estimated flows for the major tributaries downstream of the Dunham River confluence with the Ord is shown in Table 3.

Table 3 Indicative design flows in the Lower Ord tributaries

Tributary	Indicative design flow (m^3s^{-1})		
	50 % prob.	10 % prob.	1 % prob.
Valentine Creek	80	250	850
Spring Creek	40	120	400
Goose Hill Creek	120	370	1270
Parry Creek	160	500	1690
Reedy Creek	150	460	1550

A rainfall runoff model of the Ord and Dunham River systems was developed and design rainfall applied across the entire catchment to determine design flows in the lower Ord River. This approach assumes the flows above ORD, between ORD and KDD and in the Dunham River are almost fully dependent, but, does not assume the peaks from each will coincide. The outflow from KDD is highly dependent on the operation of the radial gates at the dam. This dependence on the operation of the gates at KDD on the outflow has not been accounted for during the runoff routing modelling. Instead the outflow from the KDD has been assumed to e equivalent to the KDD inflow (ie. there is no change in the storage in the KDD).

The results of the rainfall runoff modelling were verified by comparing the flood frequency results for the gauged site on the Dunham River and the inflows to the ORD. The estimated flow, on the Ord River at the confluence of Dunham River, with an annual exceedence probability (AEP) of 10 % was found to have reduced by approximately 80 % following regulation by the ORD. A similar percentage reduction was found for the 1 % AEP flow following regulation at the ORD. The ORD spillway characteristics are a limiting factor in peak discharges downstream of Lake Argyle.

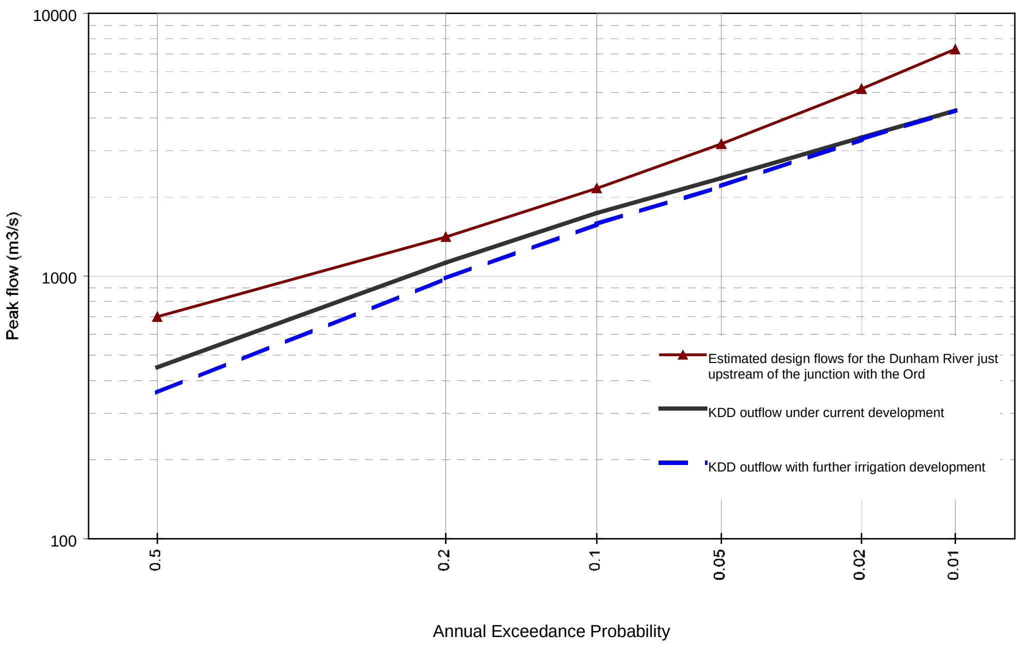

Figure 7   Flood frequency curves for the Dunham River and the outflow from KDD

The post regulation flood frequency for the outflows from the Ord River and Kununurra Diversion Dams were calculated using a joint probability approach (3). The underlying assumption of this method is that the inflows to the ORD and the antecedent water level in ORD are independent as are the flow from the ORD and from the KDD catchment below the main dam. It is likely that the assumption regarding the independence of the outflow from the ORD and the flow from the KDD catchment is to the most part valid because of the size disparity of the two catchments and the added attenuation of flows by Lake Argyle. It is unlikely that the outflow from KDD and the flow from the Dunham River are actually independent, therefore, a similar approach to estimating flows downstream of the Dunham has not been applied.

The joint probability approach provided estimates of the outflows from the KDD with probabilities of less than 5%. Outflow events from KDD with probabilities of greater than 5 % have been estimated using the results of water balance modelling on the system for a period of 87 years. Further irrigation development centred on the Ord River is estimated to have a relatively small effect on the design floodflows in the Lower Ord compared to the change from the pre-regulation flows.

Figure 7 shows that the design flows for the Dunham River are larger than the similar design flows from Lake Kununurra. During the flood frequency analysis the dependence of the outflow from the KDD on the operation of the radial gates at the KDD was not accounted for. Similar to in the runoff routing method described above, the outflow from KDD was assumed to be equivalent to the estimated inflow.

Effects of river regulation on floodplain inundation

In order to examine the effect of regulation on floodflows in the lower Ord River and its floodplain a Mike 11 hydraulic model was developed. The model network was based on the Ord River main channel only. The approximate location of overflow reaches and tributaries were included where deemed appropriate. Some 24 cross-sections along the Ord River and a further 2 cross-sections on the Dunham River were incorporated in the model. These cross-sections were extended to include the broader Ord River floodplain using the available 1:100 000 contours and spot height information.

The model network between Carlton Crossing and The Rocks is a relatively complex network of overbank flow channels (Figure 8). Although there is only a single flood relief channel on each side of the Ord River main channel, they are typically removed from the Ord River itself and are connected to the river by a complex system of overbank flow and flood storage areas.

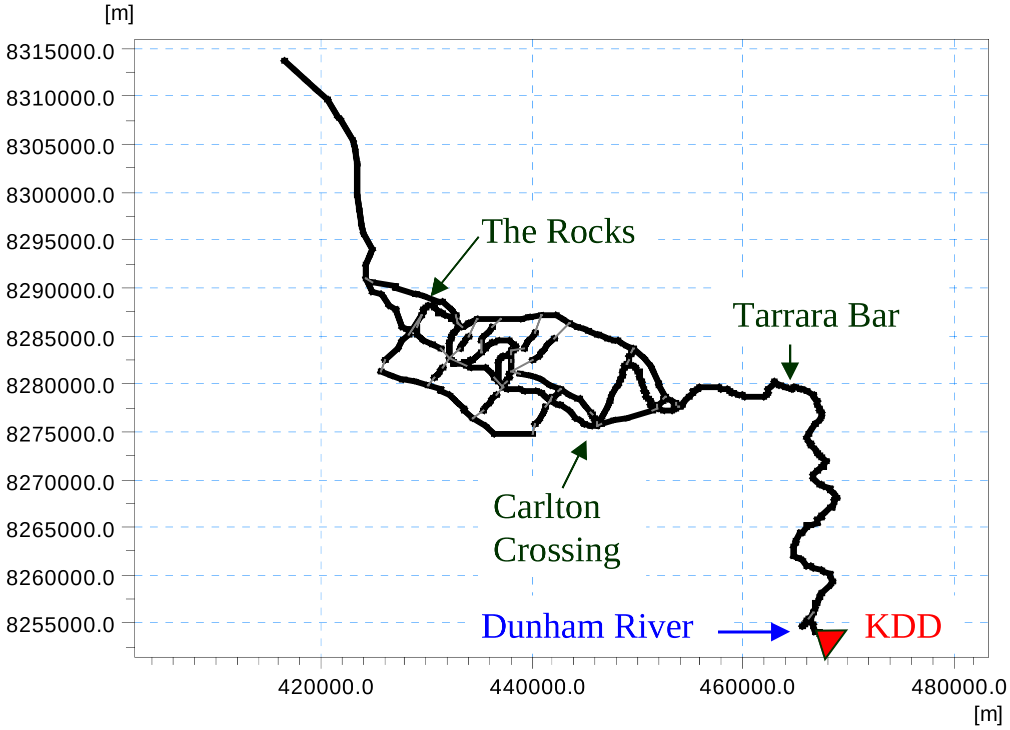

Figure 8. MIKE 11 – Model schematic for the Ord River

The model was calibrated using flow and tidal data and aerial photography available from an event during February / March 2000. The model was then used to compare the flood extent and duration of design flow estimates for the current level of regulation and the natural (pre-regulation) situations.

Extent of flooding - Event in 1999 / 2000

The rainfall during the 1999 / 2000 wet season (October-March) was wetter than the long term average throughout the Ord River catchment. In excess of 150 mm of rainfall was recorded at the Argyle Diamond Mine airport in the 24 hours to 0900 on the March 4th 2000 and greater than 100 mm was recorded at a number of other Bureau of Meteorology operated sites within the Ord River catchment.

As a result of the above average rainfall throughout the 1999/2000 wet season the streamflow in the Ord River both upstream and downstream of the dams was relatively large. The level in the ORD exceeded the previous highest level recorded since its construction in the early 1970's. The peak level recorded of 98.4 m AHD is more than 6 metres above than the full supply level of the dam and corresponded to 7,100 GL of water stored above the full supply level. The spillway characteristics for the Ord River Dam meant that there was still flow over the spillway at the beginning of October, despite less than 20 mm of rainfall received within the catchment during the previous 4 months.

At the peak, in March 2000, a total of approximately 900 m^3s^{-1} was flowing downstream of the Ord River Dam over the spillway. The release valves at the dam wall were closed because of the potential of the large head to cause them to fail. This concern was heightened as significant vibrations of the outlet works were observed as the level rose. This peak outflow is an order of magnitude less than the estimated peak daily inflow of approximately 13,000 m^3s^{-1}.

Prior to the construction of the ORD peak flows in excess of 30,000 m^3s^{-1} were estimated to be passing through the location of the ORD based on gauged information at Coolibah Pocket. The results of the flood frequency analysis on the inflow to ORD indicate that the March 2000 event has an approximate annual exceedance probability of 14 % (1in 7 ARI). However, based on the estimated inflows to ORD since 1972 the probability of the event is approximately 7% (1 in 14).

The flow in the lower Ord River peaked at approximately 5000 m^3s^{-1}, made up of 2700 m^3s^{-1} from the Dunham River and approximately 2000 m^3s^{-1} released from the Kununurra Diversion Dam and approximately 300 m^3s^{-1} from the catchment downstream of the Dunham River confluence. The releases from the KDD were made up of overflow from the ORD of approximately 300 m^3s^{-1}, flow generated between the two dams and additional releases from storage within the KDD.

The peak flow down the Ord River coincided with a large spring tide sequence. This resulted in the Ord River breaking out onto the floodplain in places. The high river levels combined with the incoming tide resulted in break-outs at the major creek confluence just upstream of The Rocks and numerous other sites further downstream (Figure 9). The high tides and the associated large tidal surges also resulted in increased levels at sites upstream of the direct tidal influence.

Unfortunately, the coarse nature of the contour information in this area of the Ord River system may result in inaccuracies in the model results at the local scale. This is evident when comparing the MIKE 11 results for the March 2000 event with an aerial photograph of the observed inundation of the meander loop in Figure 10. The MIKE 11 results indicate that the entire loop is inundated, while there are dark areas of vegetation above the flood level evident in the photograph.

Flood Inundation for 10% Annual Exceedence Probability (AEP)

The flood inundation maps (Figs 11 and 12) show a similar reach of the Ord River and extending further north than the map shown in Figure 1. The maximum flood extent for the post-regulation situation is significantly smaller than the extent of flooding of an event of similar AEP pre-regulation (Fig. 11). Unfortunately, the coarse nature of the contour information in this area of the Ord River system may result in inaccuracies in the model results at the local scale.

Numerous breakouts from the main Ord River channel and a far greater area of inundation was estimated for the 10 % AEP pre-regulation flow. The meander loops between Carlton Crossing and The Rocks were estimated to be entirely underwater with the landform data and a significant portion of the Mantinea Flats and Parry Lagoon areas to the south of the Ord and a large area on Carlton Plain, to the north, is also inundated.

In contrast, an event of 10 % AEP post-regulation is estimated to inundate only a small to moderate area in the vicinity of Parry Lagoons and the meander loops between Carlton Crossing and The Rocks. This inundation is driven as much by the high tides applied at the mouth as to the flow in the Ord River. The combination of large flows and high tides result in break outs from the main channel at sites downstream of The Rocks and at the creek confluence just upstream of this site on the northern bank. The post-regulation 10 % AEP event is not estimated to cause major flooding of the Mantinea Flats and Carlton Plain areas and the estimated areal extent of the inundation in the Parry Lagoons area was far greater pre-regulation.

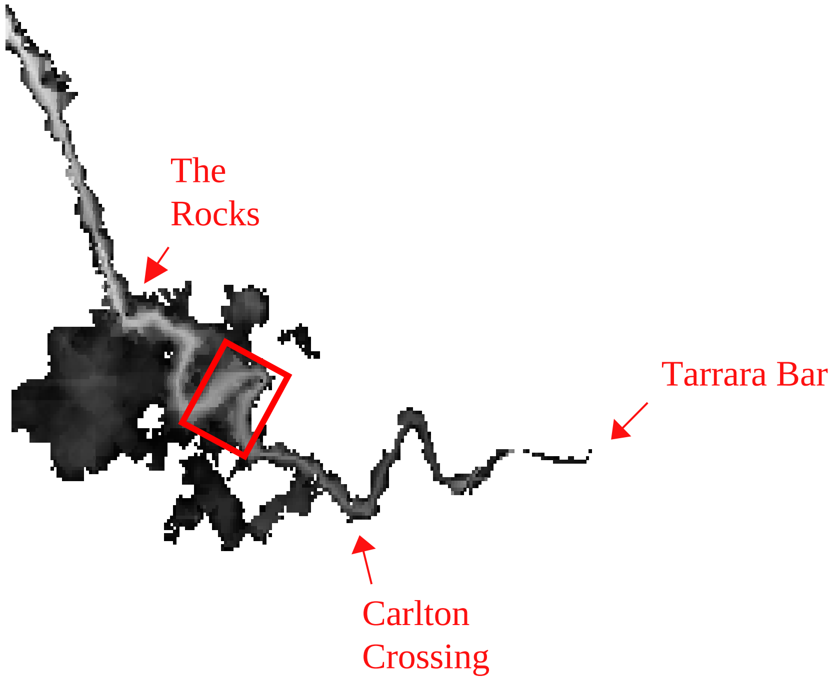

Figure 9. Flood inundation areas estimated for the March 2000 event.

Figure 10. Flood inundation of Mantinea Loop during the March 2000 event.

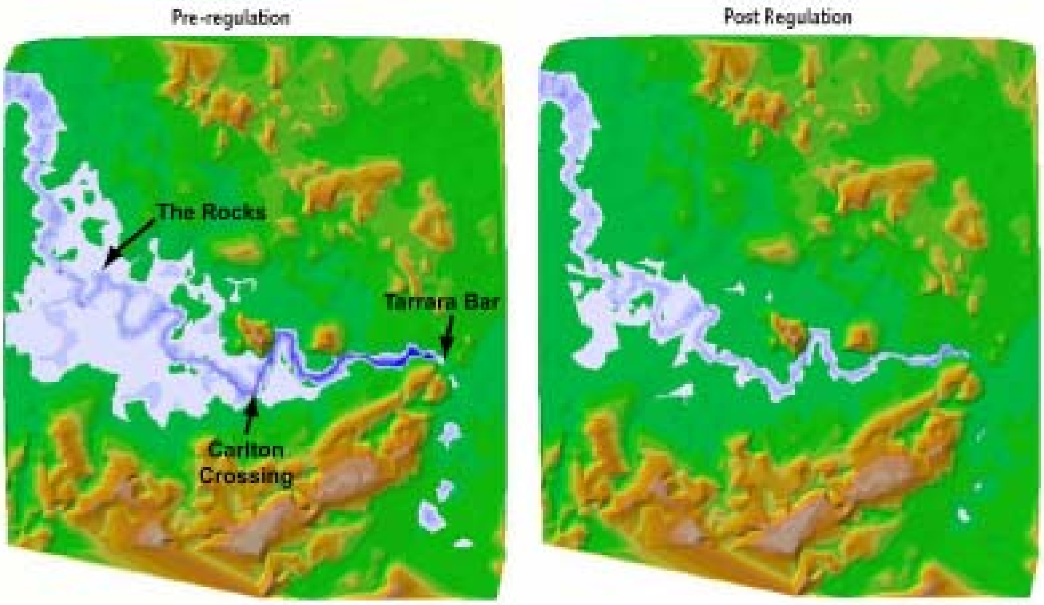

Figure 11. Flood inundation area maps for the pre and post-regulation 10 % AEP events (light shades indicate the area of inundation).

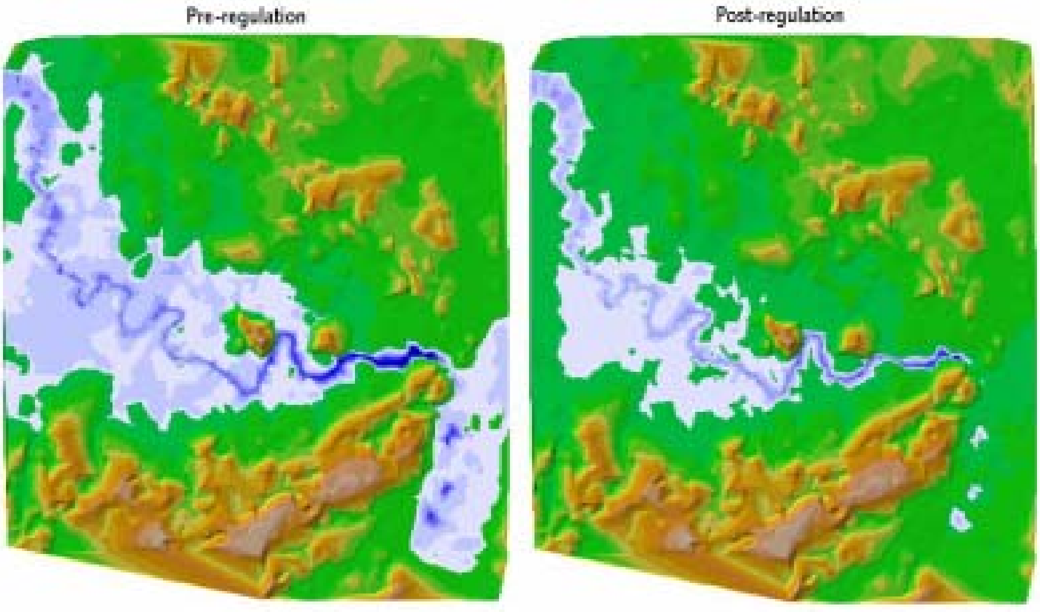

Figure 12. Flood inundation maps for the pre and post-regulation 1% AEP events (light shades indicate the area of inundation).

Flood Inundation for 1% Annual Exceedence Probability

The flood extent for the natural (pre-regulation) 1 % AEP flow is again significantly larger than the equivalent 1 % probability post-regulation flow (Fig. 12).

The pre-regulation 1 % AEP flow breaks out of the main Ord River channel and surrounds House Roof Hill to the north, flooding Carlton Plain. The entire southern floodplain, Mantinea Flats and Parry Lagoons, is flooded and much of the current irrigation area on Ivanhoe Plain is also inundated.

The areal extent of inundation for the post-regulation scenario includes many of the wetlands on the floodplain south of the main Ord River channel, in the general area of Mantinea Flats and Parry Lagoons. There is also some large areas of inundation within the Carlton Plain area. However, the post-regulation 1% AEP event is not estimated to flow around House Roof Hill to the north as was estimated pre-regulation. The indicative average depth of inundation has also been significantly reduced due to the construction of the dams.

Changes to frequency of floodplain inundation

The floodplain and floodplain flows are considered important for vegetation and in-stream biota. The implication of changing the flow regime in the floodplain zone needs further understanding for the lower Ord River.

The extremely large flood storage available within the ORD has resulted in a significant decrease in floodflows in the lower Ord River. The impact on floodplain inundation in the lower Ord River due to the river regulation is highly significant (Table 4). For example the probability of an event large enough to break out from the main river channel flood and lead to floodplain inundation at the Rocks location has reduced from 50 % AEP (1 -in - 2 year average recurrence interval event) to 1.5 % AEP (1 - in - 67 year average recurrence interval event).

Table 4. Estimated impact on floodplain inundation (% AEP)

Location	Pre-regulation	Post-regulation
Ord d/s Dunham	1	No longer reaches floodplain
Tarrara Bar	<1	No longer reaches floodplain
Carlton Crossing	33.3	0.33
The Rocks	50	1.5

Conclusion

The regulation of the Ord River has resulted in substantial changes to the flooding regime of the lower Ord River. These changes to the flooding regime have resulted in significant changes to the channel characteristics and sediment regime. The lack of the large flood pulses has resulted in the general loss of channel capacity with extensive deposition of sediments in various parts of the channel.

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