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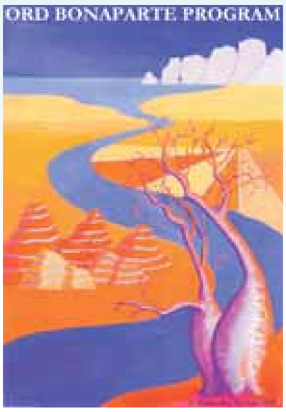
Modelling Surface Water in the Ord River Irrigation Area (ORIA)

Neil R. Viney



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CSIRO LAND and WATER

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

A water balance model, LASCAM, has been applied to the Ord River Irrigation Area (ORIA) to predict the discharge of surface water from the drainage network. For application of LASCAM, the ORIA was divided into a network of 49 subcatchments based on the topology of the drainage network. The resulting network includes five subcatchments located outside the irrigation area whose surface fluxes have the potential to flow into the ORIA drains. The model was calibrated simultaneously on six gauged drains to produce a single set of parameters that could be used to predict discharges from the remaining drains. The calibration results indicate that, despite some deficiencies in the available data, LASCAM is able to provide excellent predictions of discharges simultaneously across a diverse range of cropping systems and hydrological conditions. The calibrated model was applied to the entire ORIA to generate annual water balances for both Ivanhoe Plain and Packsaddle Plain. The water balances suggest that on Ivanhoe Plain 44% of input water (irrigation water, rainfall and external inflows) is discharged to the streams, while on Packsaddle Plain the runoff rate is 30% of applied water. The maximum predicted daily discharge from the ORIA in a 25-year simulation is 12 GL, while the predicted range in annual discharge is 234–356 GL.

THE STUDY AREA

Location

The Ord River Irrigation Area is in the East Kimberley region of northern Western Australia near the town of Kununurra. It comprises about 150 km^2 of irrigated horticulture and silviculture in the Ivanhoe and Packsaddle Plains. The ORIA is part of the Ord River catchment, which drains over 50000 km^2 of Western Australia and Northern Territory. The river discharges into Cambridge Gulf about 120 km downstream of the ORIA.

Climate

The region has an arid to semiarid monsoonal climate with two distinct seasons—a wet season (November to April) and a dry season (May to October). The mean annual rainfall (1965 to 2002) at the Kimberley Research Station within the ORIA is 822 mm. More than 95% of this falls during the wet season, mainly in localised thunderstorms or widespread cyclonic storms. During the dry season rainfall is light and sporadic. One-third of all dry seasons have rainless spells of at least five months duration. There is considerable inter-annual variability in rainfall, with annual totals over the last 38 years varying between 430 mm and 1528 mm. There has been a tendency for increased rainfall amounts in recent years with annual averages of 1005 mm over the last 10 years and 1115 mm over the last 5 years.

Air temperature is generally higher in the wet season than in the dry season. The average daily temperature range for January is 26 – 36ºC, while for July it is 15–30ºC. The mean annual pan evaporation at Kimberley Research Station is 2811 mm and the monthly averages range from 6.4 mm d^{-1} in March and June to 10.1 mm d^{-1} in October. Reflecting the increased rainfall trends, pan evaporation over the last 10 years has been about 10% lower than the long-term mean.

Vegetation

The natural vegetation of the floodplains of the Ord River catchment is primarily a grassland and grassland/savannah woodland complex dominated by perennial species (Ruprecht and Rodgers, 1999). River gums, paperbarks and coolibahs are prevalent along the creek lines, while small eucalypts dominate the plains. The upland parts of the catchment are sparsely covered with spinifex and small trees (Ruprecht and Rodgers, 1999).

Since large-scale irrigation began in 1963, the vegetation of Ivanhoe and Packsaddle Plains has changed considerably as cropping has gradually replaced native vegetation. Until production ceased in 1974 in the face of uncontrollable pest infestation, cotton was the principal crop in the ORIA. In the ensuing years, the principal crops were sunflower, seed crops and melons, while since the mid-1990s, sugar has become the dominant crop.

Irrigation supply and drainage

Irrigation water for the ORIA is delivered along a network of primary and secondary supply channels (Figure 1). The main supply channel for the Ivanhoe Plain is the M1, which draws water from Lake Kununurra. Since 1998, the M1 has supplied an annual average of 440 GL to the ORIA. In the Packsaddle Plain, the main supply channel is SP1, which also draws water from Lake Kununurra.

Tailwater is collected in a network of drainage channels (Figure 2). In the Ivanhoe Plain, most of the drainage discharges from the western edge of the irrigation area via natural stream lines into the Ord River. The exception is the water that drains through Cave Spring Gap along the D8 drain and discharges into the Keep River catchment. In the Packsaddle Plain, drains DP9 to DP12 discharge into Lake Kununurra, while drains DP1 to DP8 discharge into Packsaddle Creek, a tributary of the Dunham River, which joins the Ord River below the Kununurra Diversion Dam.

There is some potential for surface water flows originating outside the ORIA to contribute to ORIA drainage flows. To the east of Ivanhoe Plain, an area of about 84 km^2 drains westward towards the ORIA, while an area of 3 km^2 drains onto Packsaddle Plain from the south.

During the dry season, daily offtake rates into the M1 are relatively stable and for most days, range between 1100 ML and 1500 ML. In the wet season, daily offtake rates are much more variable (typically 600–1900 ML), and show significant response to rainfall events. Management issues can occasionally affect daily offtake volumes during the wet season. For example, the M1 is periodically drained for weed control. Secondly, the supply and drainage network on the Ivanhoe Plain is sometimes used to alleviate high water levels in Lake Kununurra.

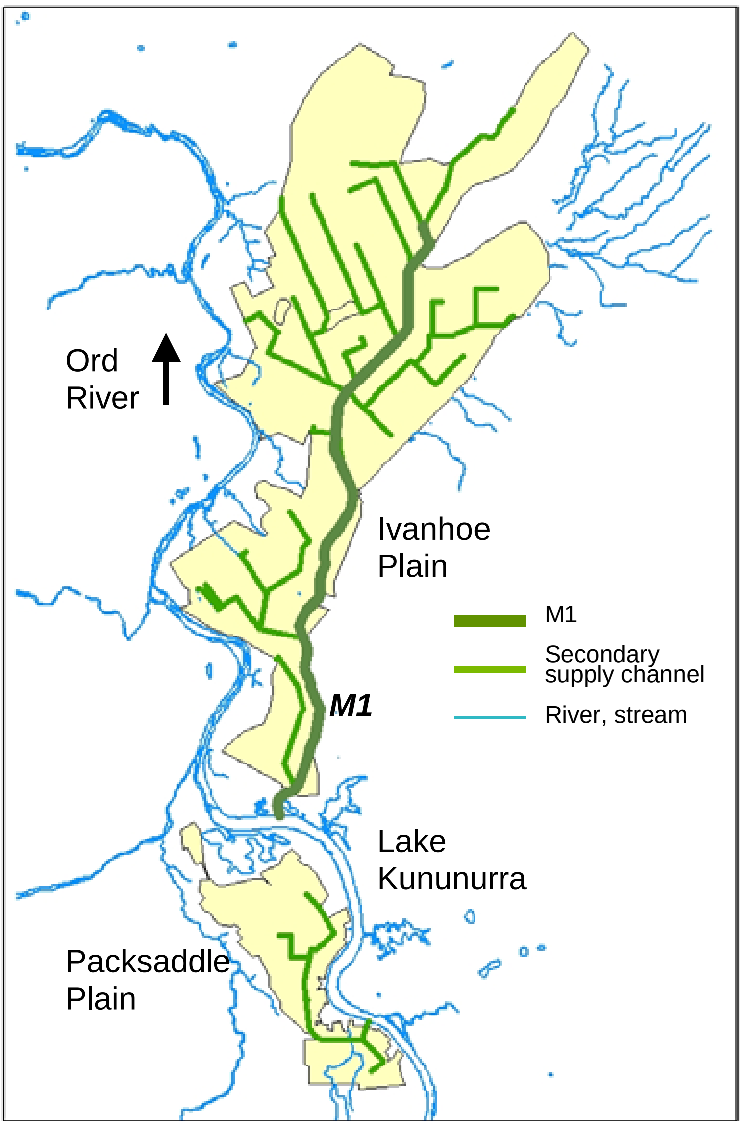

Figure 1: The network of irrigation supply channels

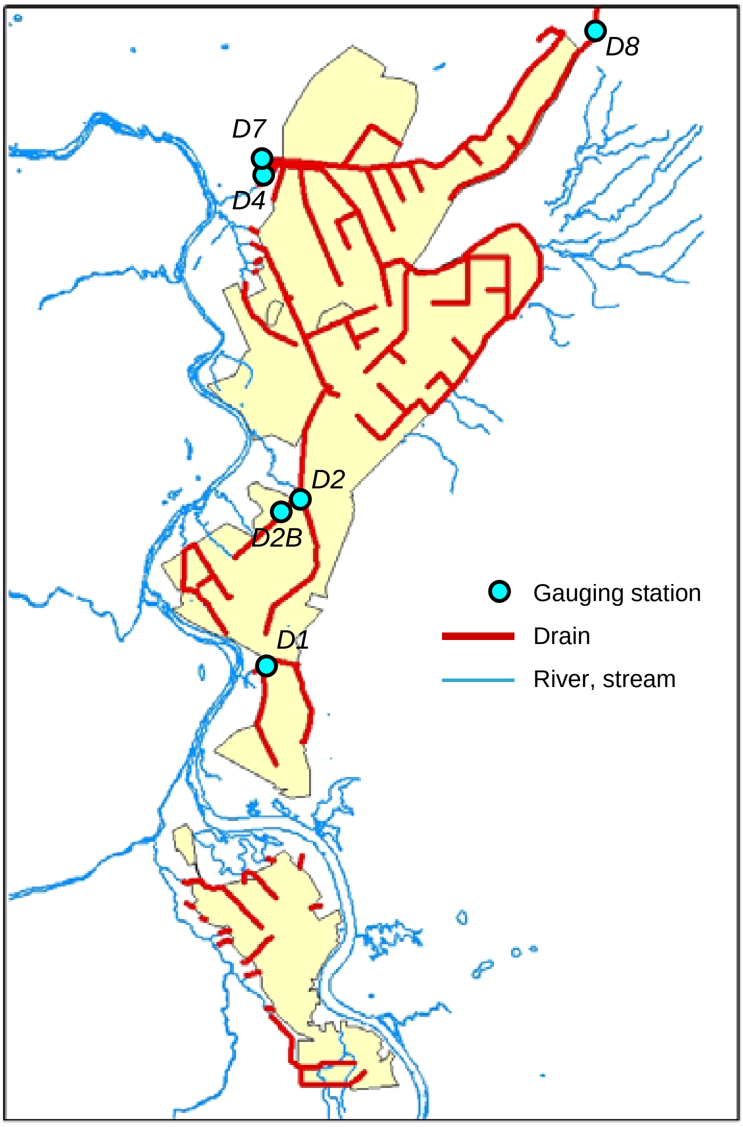

Figure 2: The network of drainage channels

THE HYDROLOGICAL MODEL

The hydrological model used to predict drainage flows in the ORIA is based on LASCAM (Sivapalan *et al.*, 1996). The LASCAM model was developed to predict the impact of climate and land use changes on fluxes of water, salt, sediment and nutrients in forested and agricultural catchments in Western Australia. It operates on a daily timestep and relies on calibration of model parameters against one or more observed records of streamflow and load.

Gridded topographic information is used to divide a catchment into a number of subcatchments and to delineate a stream network. LASCAM is applied separately to each of these subcatchments and the resulting flows are routed along the stream network. At the subcatchment scale, the model revolves about three inter-connected stores of soil water representing the near-stream perched aquifer (the A store), the deeper, regional groundwater (the B store) and the unsaturated zone (the F store). Streamflow is generated from infiltration-excess and saturation-excess overland runoff and from a baseflow discharge from the A store. The hydrological processes and the subcatchment properties influencing them are assumed to be lumped at the subcatchment scale, but are allowed to vary between subcatchments. A global set of model parameters is used (i.e. all subcatchments use the same parameter set). Routing is achieved through a simple, but efficient scheme in which bulk stream velocity is dependent on streamflow volume.

The inputs to the water balance component of the model are daily rainfall (distributed), pan evaporation and land use information (e.g. leaf area index, which is allowed to vary with time), while topographic data are needed to define the subcatchments and the stream network. For calibration purposes, measured streamflow records are also required at one or more points in the catchment's stream network. The outputs from the model, for each subcatchment and for the total catchment, are surface and subsurface runoff, actual evaporation, recharge to the permanent groundwater table, baseflow and measures of soil moisture.

DATA COLLECTION AND PREPARATION

Rainfall data

Daily rainfall data was available for several sites in and near the ORIA. Some sites with short or poor quality records were omitted from the study. The final set of rainfall stations consisted of six Bureau of Meteorology (BoM) stations and four Water and Rivers Commission (WRC) stations. The BoM gauges are manually read once daily, at 9 am and provide the total rainfall of the previous 24 hours. The WRC gauges record continuously, but for compatibility with the BoM sites, their data was accumulated to 24 hour totals to 9 am. The sites used in this study are listed in Table 1.

Table 1: Location and duration of rainfall data records. Station numbers beginning with "0" are BoM stations; those beginning with "5" are WRC stations.

Station Number	Station name	Northing (GMA)	Easting (GMA)	Duration	Complete-ness (%)
002005	Carlton Hill	8287770	449920	1965–	70
002013	Ivanhoe Station	8265210	465860	1965–99	61
002014	Kimberley Research Station	8269240	468830	1965–	100
002038	Kununurra Post Office	8256100	472000	1965–97	82
002052	Tropical Farm	8249280	471830	1980–	95
002056	Kununurra Aero	8255220	468940	1971–	89
502018	D2B drain	8265900	470500	1971–96	86
502032	Lake Kununurra	8255200	471900	1999–	100
502047	Block 68 outflow	8273100	477100	1999–	100
502052	Block 27 outflow	8264500	469200	1999–	100

Potential evaporation data

Pan evaporation data has been collected at the Kimberley Research Station since 1965. In this study, this data was used to establish seasonal patterns of pan evaporation for the ORIA. For the purposes of LASCAM simulation, pan evaporation was assumed equivalent to potential evaporation and was assumed constant in space across the ORIA.

Streamflow data

Flow rates in the drainage network have been recorded electronically only since 1998. This study uses data from the gauges listed in Table 2, all of which are maintained and operated by the Water Corporation. More recently, several flow gauges have been installed in the ORIA as part of the Ord-Bonaparte Program (OBP). At present the record duration of these gauges is insufficient for use in this study, but it is expected that their data will be used in later stages of this work. For compatibility with the rainfall records, all streamflow data was extracted as 24 hour totals to 9am.

Table 2: Location and duration of streamflow data records

Station Number	Station Name	Northing (GMA)	Easting (GMA)	Duration	Completeness (%)
809308	D1 drain	8259689	469428	1998–2001	100
809319	D2B drain	8265952	470562	1998–	99
809334	D4 drain	8278401	469854	1998–	89
809335	D7 drain	8278379	469800	1998–	100
809336	D2 drain	8266219	470762	1998–	93
809338	M1 supply channel	8254136	469745	1998–	94
809347	D8 drain	8282777	481246	2000–	100

Subcatchment disaggregation

The ORIA "catchment" was defined as comprising those areas that supply water to the drainage network. This includes those parts external to the ORIA, but whose surface flows can join the ORIA drainage network. Excluded from this definition of the catchment are the small Packsaddle land holdings fringing Lake Kununurra and the small Ivanhoe land holdings along the east bank of the Ord River to the southwest of drain D2A1. Many of these excluded holdings draw their water directly from the lake or river independently of the supply network. The total area of excluded small holdings is about 6 km^2.

The ORIA catchment is therefore not a catchment in the true sense of the word, but a collection of adjacent catchments, each with distinct discharge points.

Subcatchment disaggregation—the subdivision of the catchment into constituent subcatchments—is normally done automatically with the aid of digital elevation maps or manually using topographic maps. In the ORIA, however, topography plays little role in defining drainage patterns. Instead, the subcatchment network was defined in terms of the network of drainage channels. This involved using drainage maps and aerial photographs to assess the drainage direction and discharge points of each individual field.

This disaggregation yielded a network of 49 subcatchments, details of which appear in Table 3. Included among these subcatchments are several with negligible area that are used either as linking subcatchments or as dummy subcatchments to provide a convenient means of accumulating flows from different discharge points. For example, subcatchments 9 and 30, with notional areas of 0.01 km^2 and stream lengths (below the outlets of their tributaries) of 0.1 km, are included to coincide with gauging sites that occur just below confluences. Subcatchments 1, 2, 5, 6, 40 and 42 are dummy subcatchments used to accumulate flows from disparate discharge points. For example, the flow through subcatchment 6 is the total of all Ivanhoe Plain subcatchments that discharge to the Ord River (see Table 4). As such, it gives the sum of the discharges from drains D1 to D7, together with the discharge from several smaller, unnamed drains along the east bank of the Ord River.

Table 3: Spatial properties of the 49 subcatchments. The second column indicates the subcatchment into which the primary subcatchment discharges. An entry of 0 indicates a terminal subcatchment. The third column gives the distance of the subcatchment outlet above the notional catchment outlet. The fourth column gives the subcatchment area and the fifth column gives the total area of subcatchments draining through that subcatchment.

Subcat no.	Downstream subcat	Distance (km)	Local area (km^2)	Basin area (km^2)	Centroid northing	Centroid easting
1	0	0.0	0.01	236.73	8278000	468000
2	1	0.1	0.01	17.13	8282780	481250
3	2	0.2	10.37	10.37	8279350	478400
4	2	0.2	6.75	6.75	8278250	478750
5	1	0.1	0.01	219.59	8269000	468000
6	5	0.2	0.01	197.05	8270000	468000
7	6	0.3	0.75	9.08	8278650	471100
8	7	3.3	2.38	8.33	8278850	473450
9	8	4.2	0.01	5.95	8278350	473300
10	9	4.3	2.81	2.81	8277800	475200
11	9	4.3	3.13	3.13	8276700	474400
12	6	0.3	0.10	129.92	8278500	470250
13	12	1.4	8.56	8.56	8275250	471300
14	12	1.4	12.63	121.26	8275550	473150
15	14	7.6	1.00	1.00	8269000	477000
16	14	7.6	4.13	4.13	8271600	474400
17	14	7.6	3.56	103.50	8274000	476000
18	17	10.1	52.00	52.00	8277000	482000
19	17	10.1	0.95	0.95	8272750	476700
20	17	10.1	8.74	46.99	8274000	478000
21	20	14.2	14.25	14.25	8269800	474800
22	20	14.2	24.00	24.00	8275000	476000
23	6	0.3	1.13	1.13	8275900	469750
24	6	0.3	10.75	10.75	8272300	471700
25	6	0.3	1.00	1.00	8274200	469700
26	6	0.3	0.26	0.26	8273750	468250
27	6	0.3	1.19	4.75	8273250	469000
28	27	1.6	3.56	3.56	8271900	469950
29	6	0.3	4.94	4.94	8269900	470250
30	6	0.3	0.01	11.95	8266250	470700
31	30	0.4	8.56	8.56	8263200	470750
32	30	0.4	3.38	3.38	8266900	471450
33	6	0.3	2.97	4.94	8264050	469950
34	33	2.9	1.03	1.03	8263250	469000
35	33	2.9	0.94	0.94	8263000	468300
36	6	0.3	4.00	4.00	8265150	468800
37	6	0.3	5.38	5.38	8262150	467700
38	6	0.3	6.94	6.94	8257750	470250
39	6	0.3	2.00	2.00	8256400	468750
40	5	0.2	0.01	22.53	8251000	468000
41	40	0.3	5.19	5.19	8251000	470600
42	40	0.3	0.01	17.33	8250000	467000
43	42	0.4	1.31	2.87	8251000	468400
44	43	3.5	1.56	1.56	8249550	470450
45	42	0.4	3.38	3.38	8250100	468250
46	42	0.4	1.50	1.50	8248700	469800
47	42	0.4	2.19	2.19	8247250	470250
48	42	0.4	3.88	7.38	8244900	472100
49	48	1.7	3.50	3.50	8242500	472200

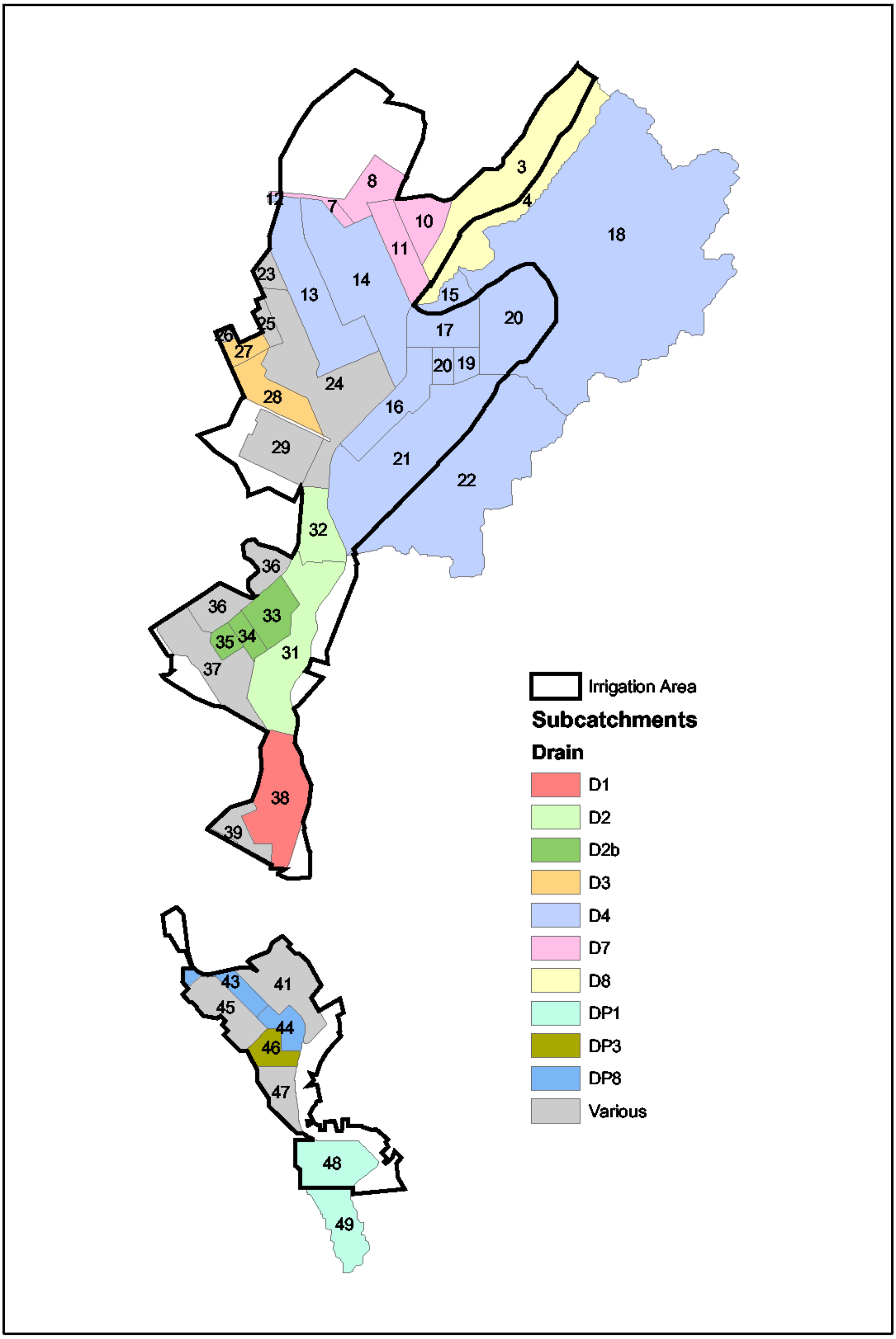

Figure 3: The subcatchment network

Table 4: Details of flow accumulation at the dummy subcatchments.

Subcat no.	Total discharge from…	Tributary subcatchments
1	ORIA	2–49
2	Ivanhoe Plain to Keep River	3–4
5	ORIA to Ord River	6–49
6	Ivanhoe Plain to Ord River	7–39
40	Packsaddle Plain	41–49
42	Packsaddle Plain to Packsaddle Creek	43–49

The arrangement of the subcatchment network is displayed in Figure 3 and shows that subcatchments 4, 15, 18, 22 and 49 are outside the irrigation area. The small linking and dummy subcatchments are not shown. Areas shown in white in Figure 3 are not modelled. Subcatchments 20 and 36 each comprise two discontiguous land areas.

Crop cover

LASCAM requires input values of annual average leaf area index (LAI) for each subcatchment. These annual LAI values are permitted to change with time. In the ORIA, subcatchment LAI was determined by establishing areal fractions for various crop types on each subcatchment and by assuming representative LAI values for each crop.

Table 5: Assumed annual average leaf area index for each crop.

Crop	Leaf area index
Native vegetation	1.0
Sugar cane	3.0
Sandalwood	2.5
Leucaena	2.0
Fruit trees	2.0
Cotton	1.5
Cucurbit	1.5
Hybrid seed	1.5
Vegetables	1.5

Table 6: Crop types (percentage of area) in each subcatchment

Subcat	Native	Sugar	Sandal- wood	Leucaena	Fruit	Cotton	Cucurbit	Seed	Vegetable
1	100	0	0	0	0	0	0	0	0
2	100	0	0	0	0	0	0	0	0
3	0	0	0	20	0	0	0	80	0
4	100	0	0	0	0	0	0	0	0
5	100	0	0	0	0	0	0	0	0
6	100	0	0	0	0	0	0	0	0
7	100	0	0	0	0	0	0	0	0
8	0	0	0	100	0	0	0	0	0
9	0	0	0	100	0	0	0	0	0
10	0	0	0	0	0	10	65	10	15
11	0	0	0	100	0	0	0	0	0
12	100	0	0	0	0	0	0	0	0
13	10	35	10	0	0	0	15	5	25
14	0	75	0	0	0	0	20	5	0
15	100	0	0	0	0	0	0	0	0
16	0	35	25	0	0	0	30	10	0
17	0	0	0	0	0	0	0	100	0
18	100	0	0	0	0	0	0	0	0
19	0	40	0	0	0	0	60	0	0
20	0	75	0	0	0	0	15	10	0
21	15	40	0	0	0	0	5	20	20
22	100	0	0	0	0	0	0	0	0
23	0	0	100	0	0	0	0	0	0
24	0	60	10	0	0	10	5	15	0
25	0	100	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	100	0
27	0	0	50	0	0	0	40	10	0
28	0	50	40	0	0	0	0	0	10
29	0	20	20	0	0	25	0	20	15
30	100	0	0	0	0	0	0	0	0
31	0	40	0	0	10	0	50	0	0
32	0	55	5	0	0	0	0	30	10
33	0	35	0	0	0	0	40	0	25
34	0	100	0	0	0	0	0	0	0
35	0	100	0	0	0	0	0	0	0
36	30	40	5	0	0	0	25	0	0
37	40	0	0	0	25	0	10	15	15
38	0	60	0	0	15	0	15	0	10
39	0	40	0	0	0	0	60	0	0
40	100	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	100	0	0
42	100	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	100	0	0
44	0	0	0	0	0	0	100	0	0
45	0	0	85	0	0	0	15	0	0
46	0	30	0	0	30	0	40	0	0
47	0	40	0	0	20	0	40	0	0
48	0	10	0	0	5	0	70	0	15
49	100	0	0	0	0	0	0	0	0

The LAI values in Table 5 represent annual averages. It is important to note that for some crops (e.g., cucurbits, seed, vegetables) the growing period lasts only during the dry season, so the actual LAI during the dry season will be greater than the annual averages in Table 5.

Crop fractions for each subcatchment (Table 6) were derived from expert knowledge and aerial photography. The only information available was for relatively recent times; little is known of the distribution of crops prior to the introduction of sugar cane. In the present study, this is not a major problem since the only streamflow data available for calibration and the only gauged M1 offtake rates are from 1998 onwards. However, it means that prediction of drainage flows under earlier crop distributions is troublesome, as is prediction of the dynamic aspects of water table rise.

Irrigation water supply

The offtake of water from Lake Kununurra into the M1 channel is gauged. This provides information on the gross amount of water supplied to the Ivanhoe Plain and how it might vary in time. However, there is no information on how the supply is distributed in space. That is, we don't know what proportion of the total offtake is directed into each of the secondary supply channels. As a consequence, it is difficult to obtain estimates of the amount of water applied to each subcatchment. Furthermore, there are no details on the route taken by discretionary releases for flood mitigation.

There appears to be no information at all on the offtake volume into the SP1 channel for irrigation of Packsaddle Creek. In this study, the SP1 offtake was assumed to be at the same areally-averaged rate as the M1 offtake. From Table 3, the modelled irrigated subcatchments of the Ivanhoe Plain and Packsaddle Plain (i.e. excluding the unirrigated external subcatchments) are 130 km^2 and 19 km^2, respectively. Given that the annual offtake into the M1 is 440 GL, we therefore assume an annual offtake into SP1 of 64 GL for irrigation of the modelled Packsaddle subcatchments. Note that with some irrigated parts of Packsaddle Plain not being modelled, the total actual offtake into SP1 may be greater than 64 GL.

Table 7: Assumed monthly crop water requirements

Crop	Dry season water use (ML/ha)	Wet season water use (ML/ha)
Native vegetation	0.0	0.0
Sugar cane	1.2	2.0
Sandalwood	1.0	2.0
Leucaena	1.0	2.0
Fruit trees	1.0	2.0
Cotton	1.2	0.0
Cucurbit	0.7	0.0
Hybrid seed	0.7	0.0
Vegetables	0.7	0.0

Estimates of the daily volume of irrigation water applied to each subcatchment were obtained from pro-rata scaling of estimates of crop water requirements for each crop. Recognising that some crops are irrigated all year round, while some are irrigated only during the dry season, separate crop water requirement data was used for each season (Table 7). The data in Table 7 was adapted from values published by Kinhill Engineers (1995), Nulsen and Sherrard (1999) and Ruprecht and Rodgers (1999).

CALIBRATION RESULTS

For the ORIA, LASCAM was calibrated against observed daily streamflows at the six gauged drains in Table 2 and Figure 2. Model calibration was done simultaneously for all six sites using a single global parameter set. Each model run covered the period 1989–2002, with the first nine years being used as a spin-up period and the last five (the only years with observed data) for calibration. Both vegetation cover and irrigation supply were assumed to be the same in the spin-up period as in the calibration period.

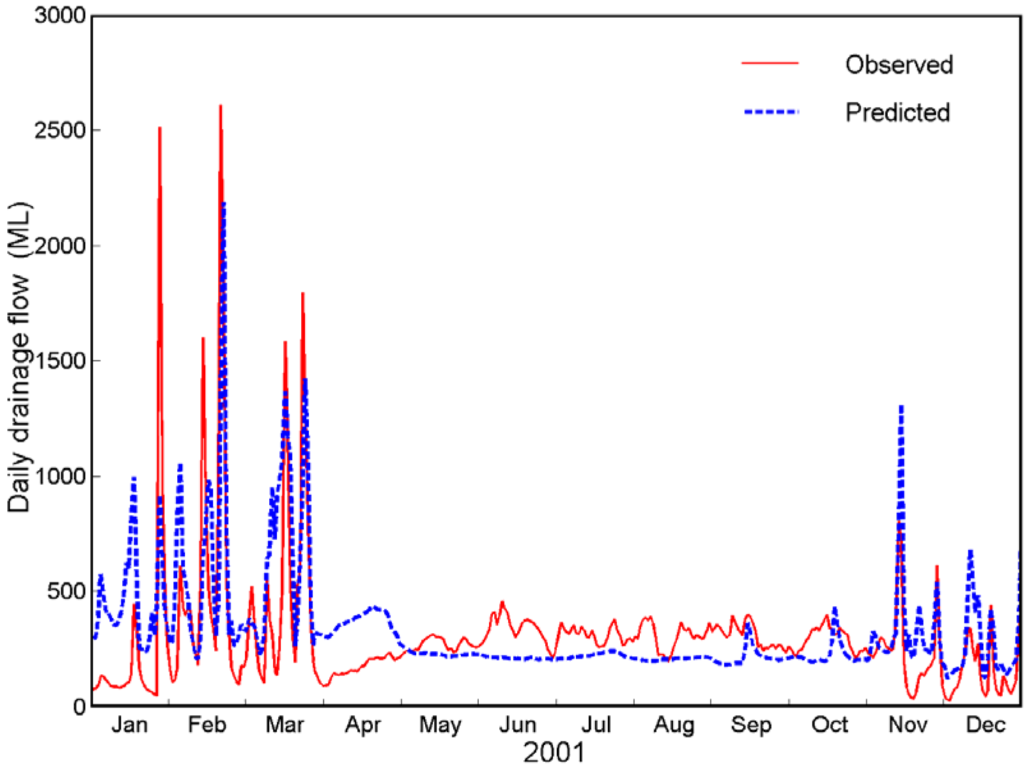

Figure 4: Observed and predicted streamflow for the D4 gauge, 2001.

An example of the model fit for daily predictions is shown in Figure 4 for the D4 drain, which has the largest catchment of all the drains in the ORIA. The quality of the fit is modest. It is particularly noticeable that the model overpredicts wet season baseflow and underpredicts some of the wet season peaks, especially at the beginning of the year. These traits are common to most of the gauged drains. Of much less concern is the inability to reproduce the small-scale structure of the observed dry season hydrograph. This structure results from short-term variability in irrigation demand in response to field drying after rain (or after the previous irrigation event). The model is not intended to predict this demand variability, so it is sufficient that its prediction is of an appropriate order of magnitude.

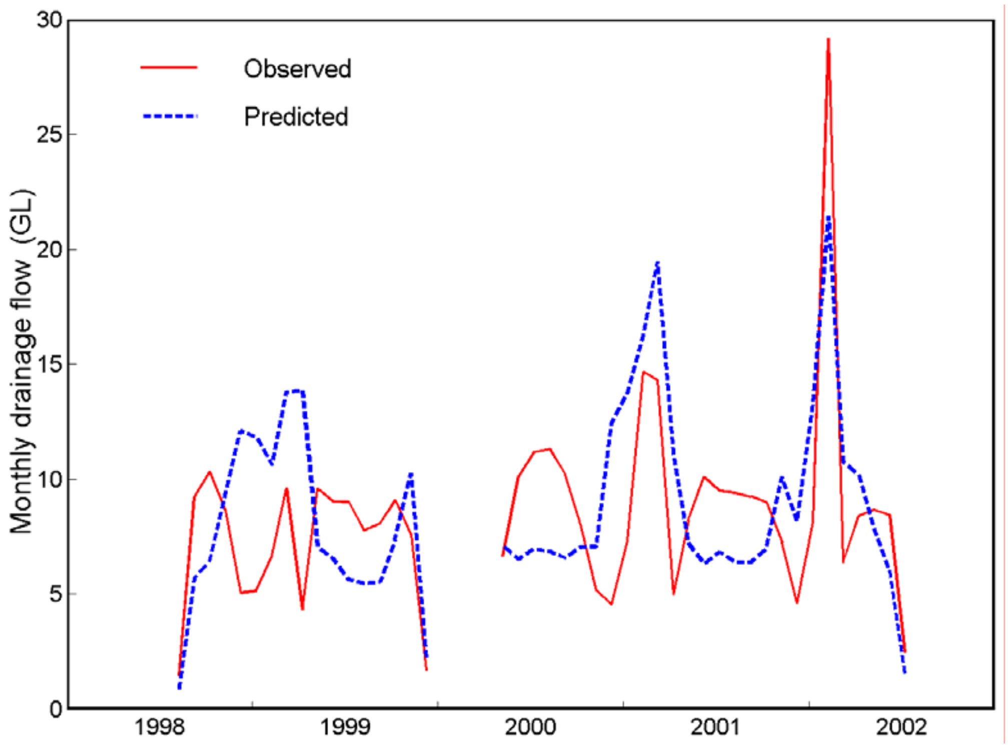

Figure 5: Observed and predicted monthly discharge from drain D4, 1998–2002

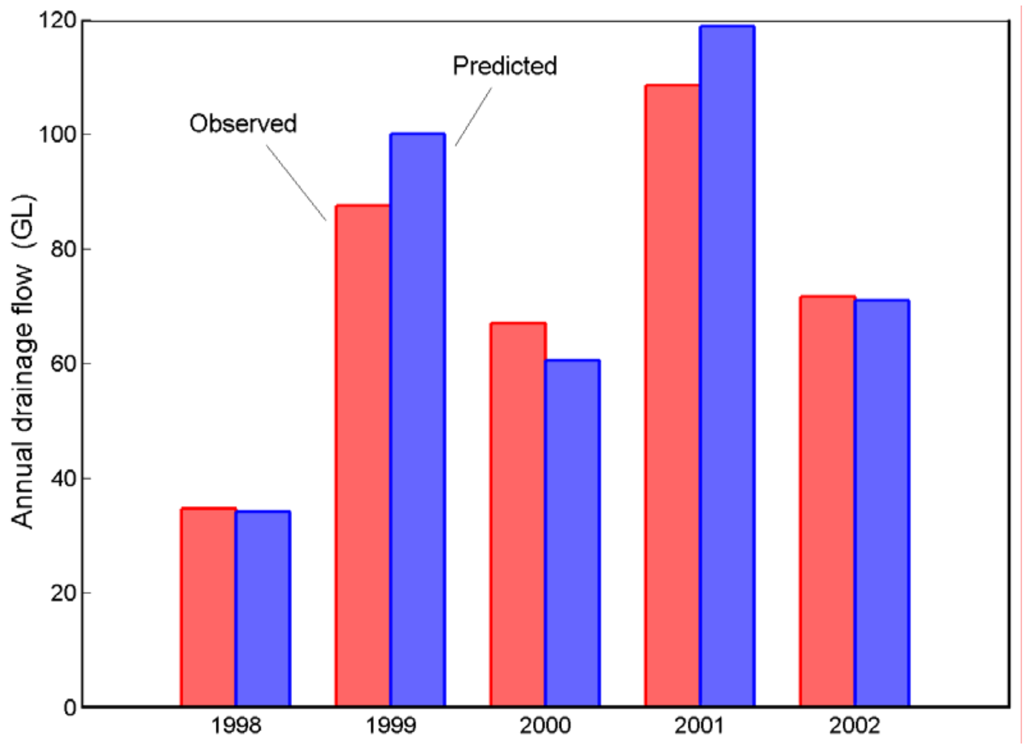

Figure 6: Observed and predicted annual discharge from drain D4, 1998–2002

When observations and predictions are accumulated and compared at monthly or annual timesteps, the quality of predictions appears better (Figures 5 and 6). The one shortcoming now is the substantial underprediction of the peak flow in February 2002. This peak was caused by a single event that produced more than 160 mm of streamflow, even in the D4 catchment which is almost 60% unirrigated. This was despite there being less than 180 mm recorded in the rain gauge at Kimberley Research Station during the storm event and no extra offtake into the M1. It is possible that uncertainty in the gauge rating for such a large event may have led to an error in estimating the observed flow. Figure 5 also indicates a tendency to underpredict dry season flows. This tendency is probably related, in part, to the variability in dry season demand, for which proportionally greater runoff might be expected from the demand peaks.

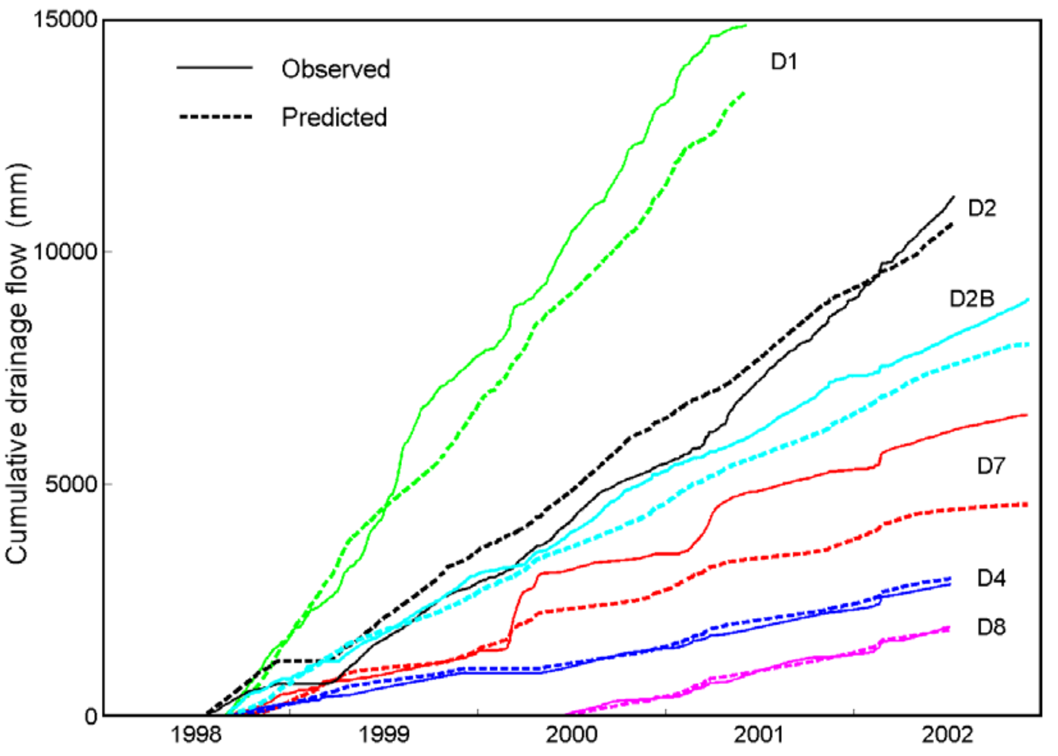

Figure 7: Observed and predicted cumulative discharge from the six gauged drains, 1998–2002. Note: the observed record for D1 ends in 2001; the observed record for D8 begins in 2000.

Comparisons of cumulative fluxes of observed and predicted flow are shown in Figure 7 and indicate that for most gauges, cumulative flows are well-predicted. The main exception is drain D7 which is underpredicted by nearly 30%. However, most of this underprediction is associated with two large, prolonged events in early 2000 and early 2001. The observed hydrographs during these two events show that elevated discharges were maintained at this gauge for much longer than is normal for peak events. It is possible that these discharge events were caused by release of water into the M1 to alleviate flooding in Lake Kununurra.

Given the uncertainties involved in estimating the spatial distribution of supplied irrigation and discretionary water, and that calibration was against daily flows only (not monthly or annual flows), the fact that the model is able to predict cumulative flows for a range of subcatchments with differing cropping systems and diverse average flow rates is extremely encouraging.

WATER BALANCE SIMULATIONS

The calibrated model has been shown to provide good predictions of drainage flow at six locations across the catchment. With this confidence in the model's ability to predict discharges from areas with such diverse cropping systems and flow rates, we may now apply the model to predict streamflows in all the subcatchments and in all drains. This will then allow the evaluation of an average annual surface water budget for the ORIA. To achieve this, the calibrated model was run over a 25 year period. This period used observed rainfall from 1978 to 2002, but is based on steady state conditions pertinent to the region's current vegetation cover. It is important to note that there is no intention to model the dynamic filling of the aquifers that is known to have occurred over this period; rather it is an attempt to develop predictions of average flows under current conditions. The historical rainfall is used only to provide a realistic interannual range of meteorological forcing.

The resulting average annual discharges from the main drains in the ORIA are given in Table 8. Note that in Table 8, drain D2 represents a combination of the flows at the gauging sites for D2 and D2B, since the D2 gauging site is upstream of the confluence with the flows from D2B. In general, comparison of Tables 6 and 8 show that subcatchments with large proportions of sugarcane tend to have the largest areally-averaged discharges (column 3 of Table 8). Drains D1, D2, D3, D6 and DP3 all have at least 30% of their catchments growing sugar. In contrast, subcatchments with large proportions of native vegetation (e.g., D4, D8, DP1) or dry season crops (e.g., D7, D8, DP8) tend to have the smallest discharges.

Table 8: Predicted mean annual discharge for selected drains.

Drain	**Predicted mean annual discharge**	
	(GL)	**(mm)**
D1	30	4356
D2	41	2411
D3	10	2041
D4	92	708
D6	22	2039
D7	8	864
D8	12	688
DP1	4	535
DP3	3	1816
DP8	2	687

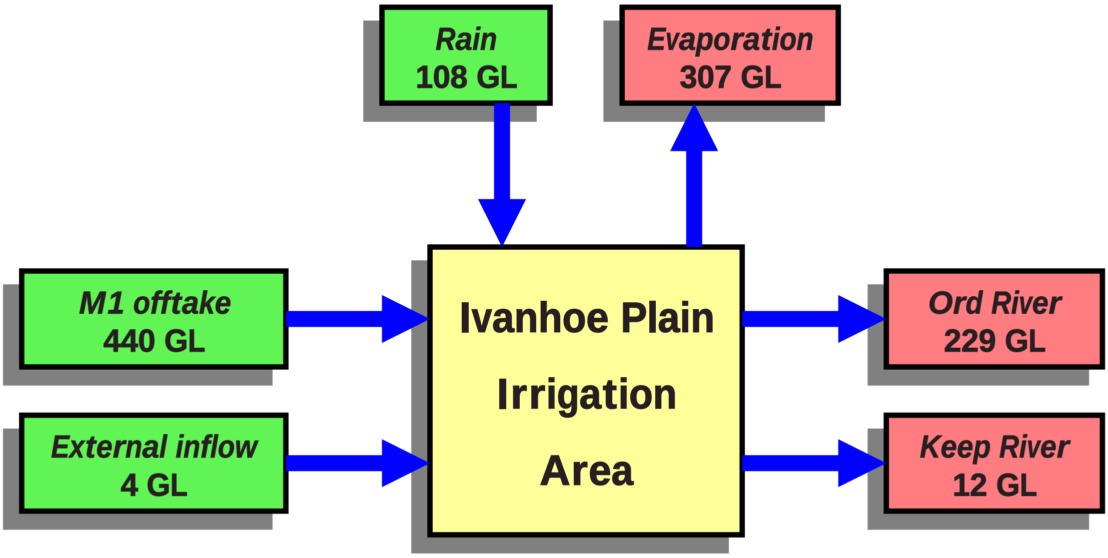

Figure 8: Predicted annual average water budget for Ivanhoe Plain

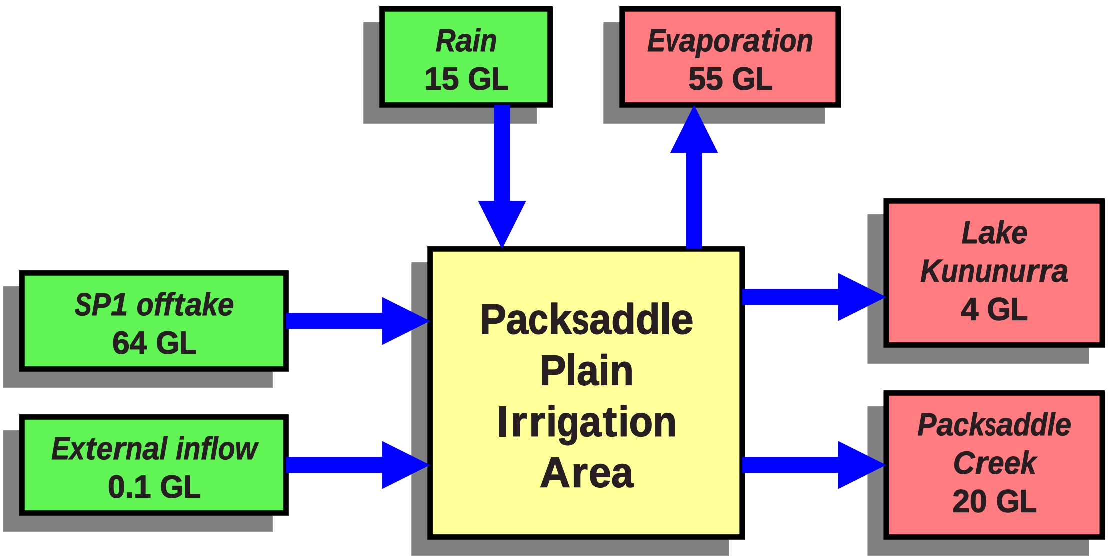

Figure 9: Predicted annual average water budget for Packsaddle Plain.

Predicted average annual water budgets for Ivanhoe Plain and Packsaddle Plain are shown in Figures 8 and 9. They suggest that the Ivanhoe Plain irrigation area receives an annual average of 440 GL from the M1, 108 GL from rainfall and 4 GL of flow from the external subcatchments. This external flow is highly variable, and reaches significant proportions only in years with extreme rainfall events, such as 2000, 2001 and 2002. The median external inflow is less than 1 GL. The total water input to the Ivanhoe Plain is dissipated in evaporation (307 GL) and surface water discharges to the Ord (229 GL) and Keep (12 GL) Rivers. The total surface water discharge thus represents 44% of the total input. This figure is commensurate with runoff percentages reported by Nulsen and Sherrard (1999) for single irrigation events at five small sugar cane plots on the Ivanhoe Plain, but is greater than the 30% runoff rate they reported for one field over a 12 month period.

The water budget for the Packsaddle Plain (Figure 9) is based on a highly uncertain value of irrigation supply. This supply, estimated at 64 GL, is augmented by 15 GL of rainfall and negligible external surface water inflow. From the area modelled, 4 GL of drainage water flows back to Lake Kununurra via drains DP9 to DP12, while 20 GL is discharged into Packsaddle Creek. The total surface discharge is thus 30% of total inputs. The smaller runoff rate reflects the relatively smaller proportion of sugar cane and the larger proportion of dry season horticulture in Packsaddle Plain.

Lateral groundwater fluxes are not included in the model, so in Figures 8 and 9, the evaporation term also includes a small amount of groundwater discharge to the rivers. Smith *et al.* (2003) have estimated this groundwater discharge to average 11 GL per year in the ORIA. However most of this is sourced from recharge from Lake Kununurra, which is not included as a source term in Figures 8 and 9, so the net effect of groundwater discharge on the water budgets of Ivanhoe and Packsaddle Plains is negligible.

The maximum predicted daily discharge from the entire ORIA in the 25-year simulation is 12 GL, which occurred in response to 230 mm of rain falling during a four-day storm event. The predicted range in monthly discharges is 16–68 GL and the predicted range in annual discharges is 234–356 GL.

DISCUSSION AND CONCLUSIONS

Model simulations

The LASCAM model has not previously been applied to predict discharges from an irrigation area. Some amendments to the model, especially concerning the way water is delivered to the catchment and to the streams, were necessary for this application. At first glance, the resulting daily calibration predictions appear modest, but this perception must be tempered by the nature of the prediction problem. Being an irrigation area, the catchment and its hydrological response are, to a large extent, controlled by human decision making at several levels. At one level, these decisions include those by the irrigators in determining when, what and how much to plant and when and how much to irrigate. At another level, the decisions of the supply managers in releasing and routing water, not just for irrigators, but also for network management purposes and for flood mitigation, are critical determinants of discharge hydrology. In the past, the impacts of these decision-making processes have been poorly documented, thus making them extremely difficult to incorporate into a hydrological model. Of particular difficulty for modelling is the problem of assessing the spatial distribution of irrigation delivery.

In the light of the foregoing concerns and the limited amount of observed flow data available for calibration, the model predictions are satisfactory. Indeed, the cumulative predictions (Figure 7) are extremely good. They indicate that the model is able to predict well across a diverse range of cropping and supply conditions, including some unirrigated areas. Furthermore, it is able to do so using a single set of model parameters and without any form of local tuning.

LASCAM is possibly not the ideal model for application to the ORIA—it is doubtful that such a model exists. However, it may well be the most appropriate existing model. Few other models would be able to handle the hydrological diversity of the ORIA as well as LASCAM. Furthermore, LASCAM includes algorithms for predicting discharges of salt, sediment and nutrients, which will be used in future stages of this project.

Simulations of the long-term water balance of the ORIA have shown that subcatchments with greater proportions of sugar cane tend to produce greater amounts of streamflow, while those with greater proportions of dry season crops produce less streamflow. Water budget analyses for the two plains have shown that about 44% of the total inflow to Ivanhoe Plain is discharged through the drainage network, while the Packsaddle Plain drains discharge 30% of total inflow. An annual average of 4 GL of surface water enters the ORIA from adjacent external areas.

Future work

As foreshadowed above, the next stage of this project will be to use LASCAM to predict salt, sediment and nutrient discharges from the ORIA. At present there is insufficient concentration data available to adequately calibrate these components of the model. This situation is expected to improve as the Ord Bonaparte Program's field monitoring program progresses.

A model of the entire Ord River catchment above Tarrara Bar, but excluding the ORIA, will also be developed. This model will be coupled with the ORIA model to enable prediction of the delivery of water, salt, sediment and nutrients to the river's estuary for use in models of estuary dynamics.

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