Surface Hydrology for the Yannarie Salt Project

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Straits Salt Pty Ltd

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Contents

List of Tables

List of Figures

Appendices

1. Introduction

The surface hydrology along the hinterland has a complex inter-relationship between the watercourses, flood plain and an intricate maze of dunal ridges. To determine the volumetric flows at various outlets, a "top-down" approach was undertaken using a combination of topographic maps, aerial photos, satellite imagery, artificially generated digital ground elevation and some limited field surveys. Collectively these sources help formulate a robust picture of the overall hydrological model for the hinterland.

The investigation undertaken in this report examines the existing hydrological process bounded by the Yannarie River and Rouse Creek catchments including the flood plain west of the catchments. The determination of the volumetric flows discharging into the supra-tidal flats from the aforementioned catchments will serve as the basis for flood protection works required for the levee banks under extreme conditions such as the 100 year Average Recurrence Intervals (ARI) Storm. In addition, discharge generated by the more frequent events of up to 2 year ARI will be used to determine what impact the flood protection work has on the overall ecological values of the area.

The volumetric discharges are determined by a three step process. Firstly the flow regimes from the Yannarie and Rouse catchments are modelled using the runoff routing software "RORB". The hydrographs generated from the modelling are then fed into the flood plain as storages. Computer generated depth bands were used to establish the hydraulic heads required at the storage to drive the various outlets. These plots provided indicative levels in which flows from the outlets become active. Finally the hydrographs are routed through the storage using EXTRAN to determine the distribution of flow at the key outlets. This dynamic process takes into account the head differential to drive the outlets and thereby produces more consistant results.

2. Yannarie & Rouse Systems

2.1 General Description

The fresh water run-off discharging into the Yannarie basin mainly comes from the two watercourses, the Yannarie River and the Rouse Creek. These two waterways cross the North West Coastal Highway (NWCH) under two bridges.

The Yannarie River has a total catchment area of approximately 4300 km^2 and mainstream length of about 200 km. The defined channel of the Yannarie River terminates at about Yanrey Station. When the big flow eventuates, it discharges into a large floodplain and several adjacent smaller basins, spreads as a sheet flow into various claypan flats, or into small storages formed between the series of the sand dunes. Only excess run-off eventually finds its way to the supra-tidal flat through a number of natural channels. The volume of water retained in the various storages is eventually lost through evaporation and to a smaller extent via infiltration.

The Rouse Creek has a total catchment area of 1700 km^2 and mainstream length of 70 km. The defined channel of Rouse Creek ends approximatley 10 km downstream of the bridge on the NWCH. During a big flow event, some of the water has been reported to flow into the Ashburton, but most of it spreads as sheet flow and if there is sufficient discharge, some of the residual flow eventually make its way to the supra-tidal flat through natural channel outlets while a smaller proportion is directed into the Yannarie claypan, before discharging into the sea together with the water from the Yannarie.

2.2 Hydrology of the Yannarie and Rouse

In order to estimate the peak and volumetric discharges of the Yannarie River and Rouse Creek, the catchments were modelled using the run-off routing software called “RORB”.

The software is a general run-off routing program used to principally estimate flood hydrographs and volumetric run-offs. It subtracts losses from rainfall to produce rainfall excess and routes this excess rainfall as unit flow rate through catchment storage to produce the hydrograph.

The catchments of the Yannarie River and Rouse Creek were divided into sub-areas of the sub catchments and various reaches of the main streams. The rainfall on each sub-area is adjusted to allow for infiltration and other losses. The program routes the hydrograph from one sub-catchment to the other accumulatively by a linear or non-linear storage routing procedure, based on continuity and the storage function below:

$S=3600kQ^m$

Where:

S is the volumetric storage in m^3 detained in depressions such as basins and gullies.

Q is the outflow discharge in m^3/s at specified nodes

m is a dimensionless exponent (the value of 0.80 is used for m in this model.)

K is a dimensionless empirical coefficient.

Both these catchments are located in the Pilbara Region of Western Australia. For purposes of this modelling work, the recommended parameters and losses for the loamy soil for the North West of Western Australia, were adopted, as recommended by the Australian Rainfall and Run-off (1987) publication and Main Roads Western Australia's Technical Report No. 50 – Flood Estimation Procedures for Western Australia.

Details of the catchment area for the Yannarie River and Rouse Creek, the routing statements, and the computer model input statements are included in **Appendix A.**

2.3 Rainfall

In order to run the RORB model, an Intensity-Frequency-Duration (IFD) set of curves were prepared. These curves were derived using the sets of polynomials as recommended in chapter 2 of the Australian Rainfall and Run-off (1987) publication. The total 24-hour rainfall figure recorded at Nyang Station during the 24th March 1999 flood event (Tropical Cyclone Vance) was 135 mm.

The total 24 hour rainfall recorded during the March 2004 flood event (Tropical Cyclone Faye) was reported to be 382 mm. These figures were superimposed on the IFD curves in order to approximate their return periods or probability of excedence. It must be noted however that the rainfall records available are cumulative 24 hours rainfall figures. Information of the actual storm duration, movements of storm and the aerial distribution factors are not known and difficult to estimate with a high degree of confidence. In the absence of a more reliable record, these figures were checked against those read from the IFD curves for storm durations of 6 hours, 12 hours and 24 hours.

The Intensity Frequency Duration curves are included in Figure 1 below.

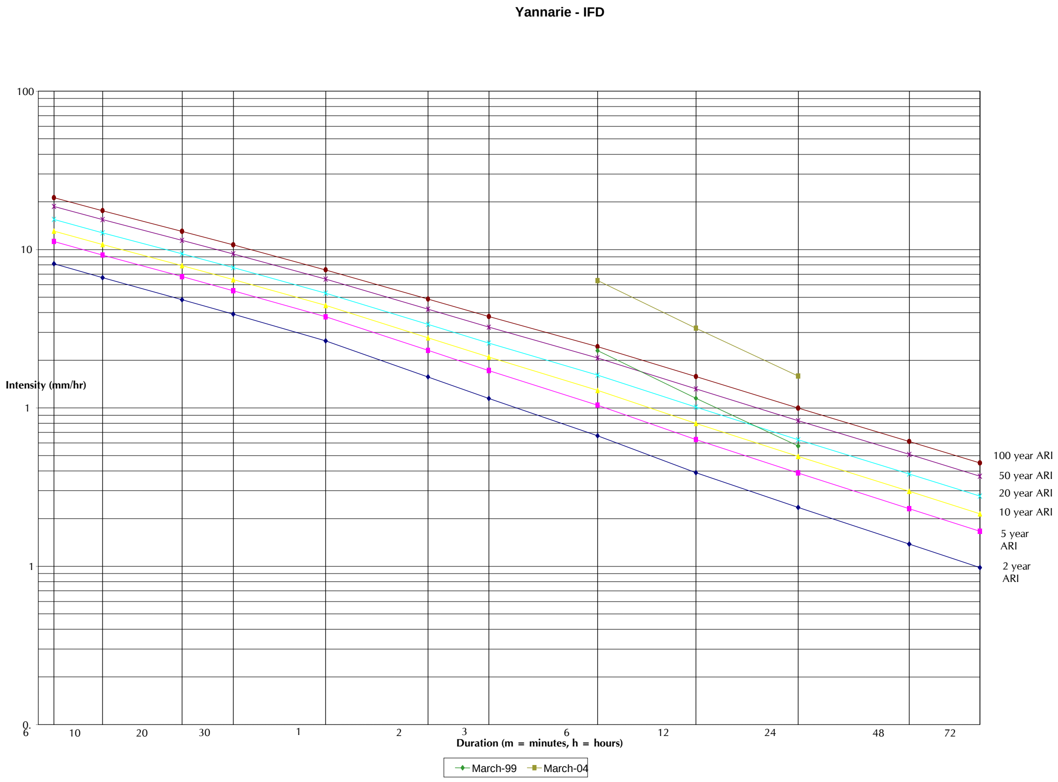


Figure 1: Intensity-Frequency-Duration curves for Yannarie

2.4 Hydrology

Peak flows for average recurrence intervals (ARI) of 1 in 5, 10, 20, 50 and 100 years were estimated using the RORB model. In addition, the model was also run to estimate the annual flow. The model shows no significant run-off in the Yannarie and Rouse resulting from the annual and 2-year ARI rainfall events. These modelling results are consistent with site observations. Generally, during the annual rainfall event no flow eventuates at the bridge sites. Annual events are usually generated by phenomena such as diurnal thunderstorms, the occasional scattered rainfall depressions or residual depressions dispersed from elsewhere. These more common rainfall events are usually very localised and cover small proportions of the catchment areas. They generate very little excess flows after surface losses.

The larger flood events, such as the 20 year ARI floods, are usually generated by cyclones either depositing rain directly over the catchments, or brought about by rain bearing depressions, which migrate from elsewhere.

The model was set up to estimate outflow at two locations for each of the catchments. The peak flows were first estimated at the bridges on the NWCH and then further downstream near Yanrey Station where it is estimated that the flow starts to spread and discharge into the various storage depressions before some of the excess flow eventually discharges into the sea if the water levels reach sufficient height to develop a hydraulic head.

For purposes of running the RORB model, the critical storm duration of the Yannarie River was approximated to be in the order of 24 hours and the 1 in 100 year total rainfall of 268 mm as read from the IFD curves was used. The critical storm duration for the catchment of the Rouse was about 12 hours. However, because the combined run-off of both catchments is required for the hydraulic analysis, both these catchments were modelled for storm durations of 24 hours. The temporal pattern used are those as recommended by the 1987 ARR publication. In reality, the temporal pattern can differ from the ARR depending whether the rainfall is a result of direct cyclonic activity or rain bearing depressions. Sometimes large flow events in catchments such as is the Yannarie are the results of the combination of more than one storm falling in the same catchment area, with quite different temporal patterns and aerial distribution.

The modelling results show that the peak flows upstream at the bridges were greater than the peak flow downstream near Yanrey Station for both the Yannarie and the Rouse systems. This reduction in peak flows is due to attenuation brought about by factors such as flatter slopes, the streams becoming less defined, shallower and wider flow, and the elongated nature of the last reaches of the waterways.

From the RORB modelling analysis of the catchments, the following results are summarised in Table 1 below.

Table 1: Estimated Peak Flows and Volumes

Yannarie River RORB Results								
	12 hour				24 hour			
Design Flow	Peak Flow Bridge (m3/s)	Volume (m3)	Peak Flow Yanrey (m3/s)	Volume (m3)	Peak Flow Bridge (m3/s)	Volume (m3)	Peak Flow Yanrey (m3/s)	Volume (m3)
Q5	0		0		0		0	
Q10	14	2.96E+06	13	3.39E+06	20	4.23E+06	19	4.96E+06
Q20	83	1.34E+07	78	1.58E+07	514	6.00E+07	484	7.16E+07
Q50	503	6.43E+07	483	7.66E+07	1714	1.06E+08	1620	1.92E+08
Q100	879	1.03E+08	851	1.24E+08	3000	2.56E+08	2848	3.06E+08

Rouse Creek RORB Results								
	12 hour				24 hour			
Design Flow	Peak Flow Bridge (m3/s)	Volume (m3)	Peak Flow Outlet (m3/s)	Volume (m3)	Peak Flow Bridge (m3/s)	Volume (m3)	Peak Flow Outlet (m3/s)	Volume (m3)
Q5	0		0		0		0	
Q10	18	1.48E+06	12	1.92E+06	27	2.04E+06	18	2.70E+06
Q20	110	6.31E+06	72	8.42E+06	577	2.76E+07	442	3.72E+07
Q50	405	2.97E+07	379	3.99E+07	1731	7.36E+07	1427	9.93E+07
Q100	701	4.76E+07	663	6.42E+07	3072	1.48E+08	3033	2.00E+08

The estimated 24 hour storm peak flow from the Yannarie at the NWCH for the 20, 50 and 100 year ARI are 500, 1600, and 3000 cubic metres per second respectively. Flow for the 1 in 10 year ARI appeared to have been under estimated by the RORB model. It is estimated that the 10-year real peak flow could be as high as 500 m^3/s and the 20 year ARI peak as much as 800 m^3/s. The modelling work indicated that the flows for the more frequent events are almost all taken up by the losses, which is consistent with site observations.

The estimated 24 hour peak flow of the Rouse at the NWCH for the 20, 50 and 100 year ARI are 400, 1500, and 3000 cubic metres per second respectively. Flow for the 10 year ARI is also shown as not significant. In the Rouse model, the flows for the 20, 50 and 100 year ARI tend to be over estimated. Nevertheless these figures have been conservatively adopted in the hydraulic analysis at the downstream end of the catchment.

RORB modelling shows that both catchments produced similar peak flows for the 24-hour, 100 year ARI storms, even though the Yannarie catchment is approximately 2.5 times that of Rouse. This 'anomoly' can be explained in terms of the catchment characteristics. As shown in Figure A1 in Appendix A, the Yannarie catchment is typically more elongated compared to Rouse. This greater runoff distance offsets the time of contribution of the subcatchments at the discharge outlet (ie. flows dissipated in the nearest subcatchments by the time the furthest subcatchment contributed). Subsequently a 'flatter' discharge hydrograph results. Conversely, for the concentric Rouse catchment, the time of contribution from the subcatchment is closer aligned, thus it reponds more rapidly (ie. narrower discharge hydrograph). Figures 2 and 3 show the hydrographs of the Yannarie and Rouse at the bridges on the NWCH and further downstream.

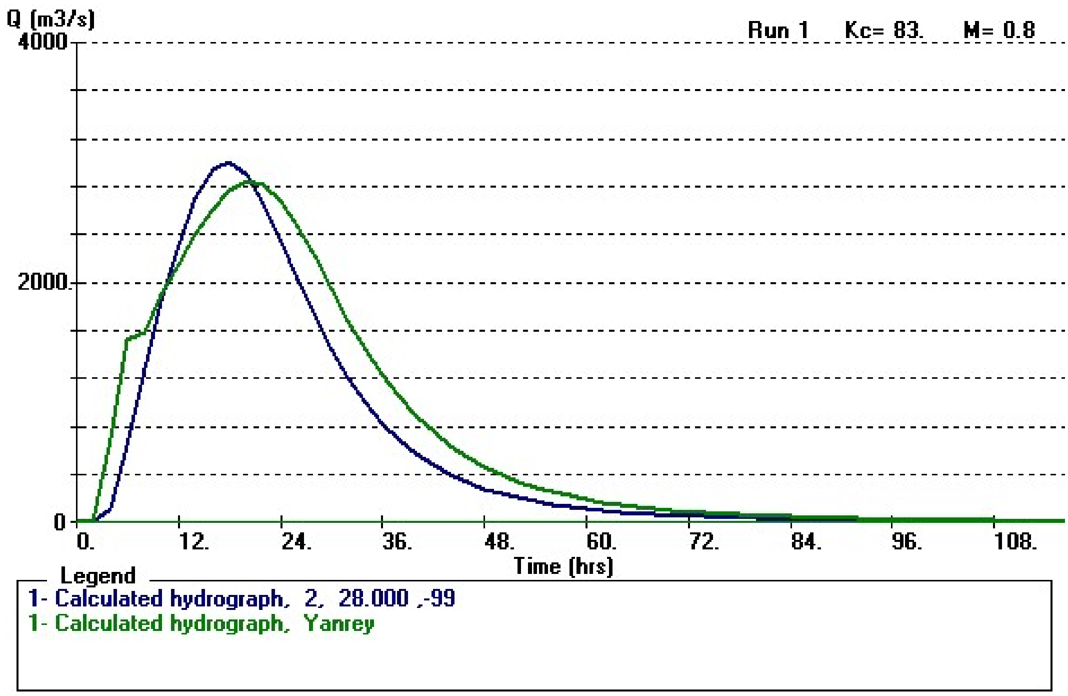


Figure 2: Yannarie 100-year 24-hour Hydrograph

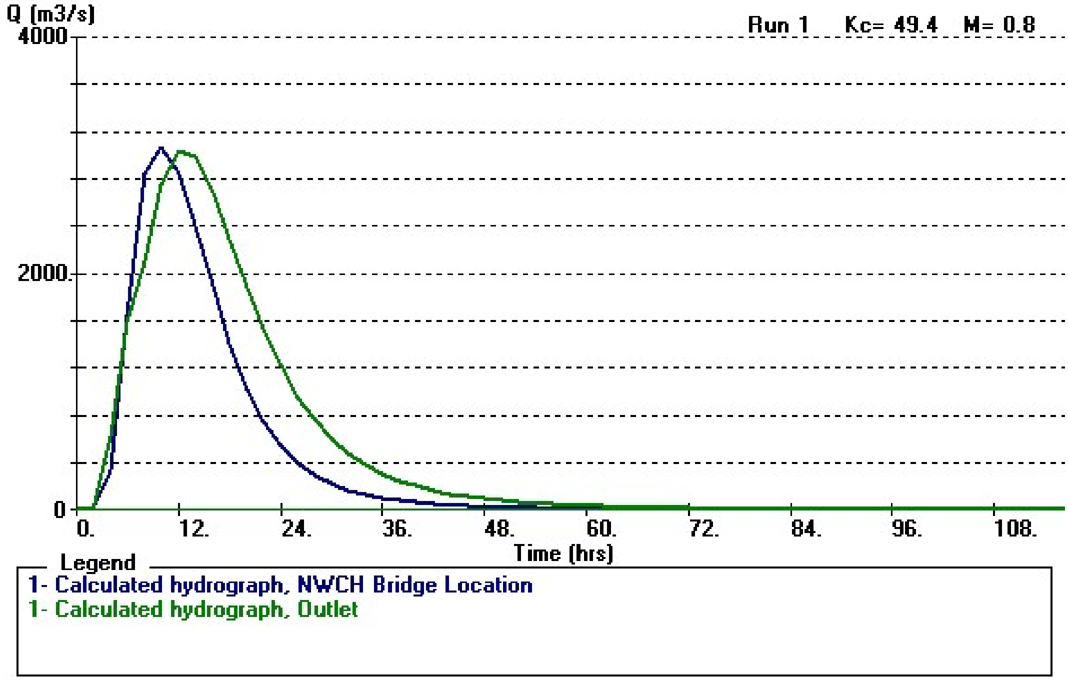


Figure 3: Rouse 100-year 24-hour hydrograph

The RORB modelling has been completed for the purpose of estimating flows at a regional scale for preliminary investigation. However, for detail design work it is recommended that the hydrological analysis be modelled more rigorously.

2.5 Hydraulics of the Yannarie and Rouse

In order to check the validity of the estimated peak flows obtained by the model, a hydraulic analysis was carried out to prepare the Stage & Discharge Curve at the bridges. A surface water hydraulic analysis was carried out at the Yannarie and Rouse Creek bridges on North West Coastal Highway using the computer program 'AFFLUX' developed by Main Roads WA. This program computes flow and velocities for various segments of the natural cross section of the open channel using the Manning's equation. When a bridge structure is inserted at this cross section, the program computes the backwater generated by the combined losses due to constriction, piers, abutments and other features such as skew and eccentricity.

In this analysis, firstly the stage discharge curves and velocities for the natural cross sections of the Yannarie River and Rouse Creek at the NWCH crossings were computed. Secondly using information obtained from Main Roads WA, the bridges over the Yannarie and the Rouse at the crossings were also hydraulically modelled and the backwater generated by the bridges and velocities under the bridges were also computed.

The stage discharge and backwater curves of the Yannarie and Rouse bridges at the NWCH are shown in Figure 4 and Figure 5 below.

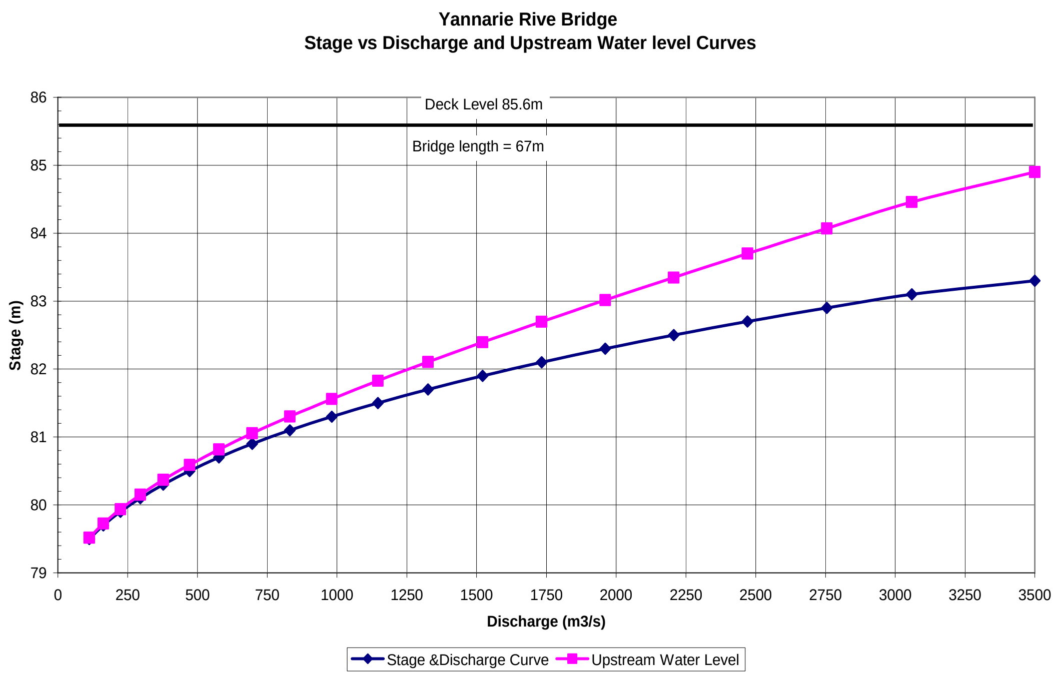


Figure 4: Stage discharge and backwater curves at Yannarie Bridge

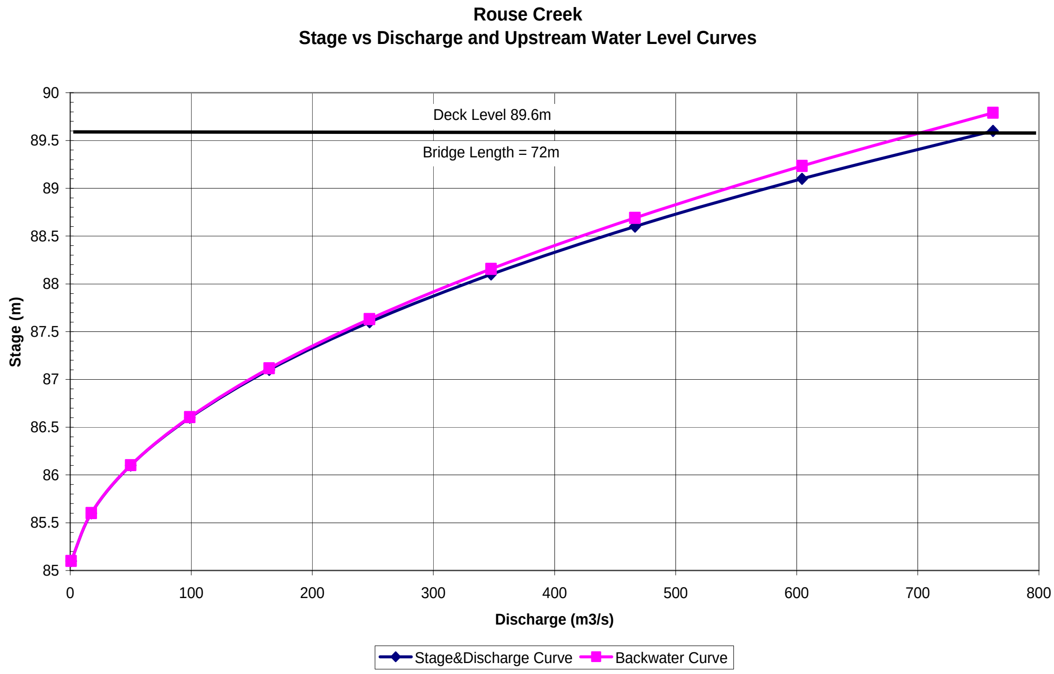


Figure 5: Stage discharge and backwater curves at Rouse Bridge

The opening of the 177m Yannarie bridge is in the order of 720m^2. At the stage height of 83.1mAHD the discharge is in the order of 3000m^3/s with a backwater 1.4m and an average velocity of approximately 4.3m/s under the bridge .

Figure 6: Yannarie Bridge

2.6 RORB Modelling for Yannarie and Rouse

During the March 2004 flood event, 360 mm of total rainfall was recorded over a period of 24 hours and during the flood event of March 1999 about 130 mm of total rainfall was recorded over a period of 24 hours. From the IFD curve, 360 mm of rainfall which caused the 2004 flood event has a return period of more than 1 in 100 years regardless of whether the storm duration was 6, 12 or 24 hours.

The total rainfall of 240 mm which caused the March 1999 flood event has a return period of between 20 to 100 year ARI, depending on whether the storm duration was, 24, 12 or 6 hours.

During the March 2004 flood event the upstream water level at the Yannarie was observed to be between 1.5 to 2.0 m below the bridge deck. The stage discharge curve of the Yannarie as shown in Figure 5 indicated that the peak is in the order of 2500 m^3/s and 3000 m^3/s. This estimated flow from the hydraulic analysis is consistent with the estimated 1 in 100 year ARI peak flow of 3000 m^3/s in the hydrological modelling of the catchment.

Similarly the bridge of the Rouse on the NWCH was observed to be flowing almost to full capacity during the 1999 and 2004 flood events. It was never overtopped. The stage discharge curve obtained from the hydraulic modelling of the Rouse as shown in Figure 6 indicated that the capacity of this bridge is in the order of 750 m^3/s. Both the results of the hydraulic analysis and anecdotal observations made during the two recent flood events indicated that the peak flows for the 50 year and 100 year flood events are either gross over estimations or that the catchment of the Rouse did not get the magnitude of the rainfall as recorded in Nayang Station in March 1999 and March 2004.

Regardless, for the final hydraulic analysis, the computed flows from the hydrological modelling of both catchments were conservatively adopted.

3. Storage and Discharge

3.1 Flood Plain Interaction

The existing watercourses and coastal outlets are inter-connected by a 200km^2 flood plain. Formation of this flood plain suggests it was the result of flows migrating from the hinterland "washing off" dunal ridges during major cyclonic events over the years. This rationale is supported by some small remant sand dunes (of approximatey 1-2m in height) that were evident along the 'terrace-like flood plain as shown in Figure 6. A satellite image taken shortly after Tropical Cyclone Vance (Refer to Figure B1 in Appendix B) was used to establish the following flow characteristics:

- Flows that breakout from Rouse Creek during major storm events spread both north and westwards. Flows travelling north are partly contained within the local dunal systems and partly makes its way out towards the supra-tidal flat via inter-dunal flows. Flows that are west bound appear to be partly contained by local depressions and channels with most continuing on to meet up with the Yannarie system.
- Flows that discharge from the Yannarie River are temporarily stored within the flood plain. This storage is contained by a series of interwoven sand dunes forming a "wall-like" structure along the boundaries, as evident in the Digital Evelation Model (DEM). Breaks in the dunal system create outlets in the storage area. Discharge from these outlets are predominantly head driven and thereby behave in a similar way to a bucket that consists of small outlet holes (orifices) at different elevations. Discharge through the orifices (ie outlets) therefore decreases with increasing elevation. This concept is shown on the satelite image where the intensity of flows at the outlets are reflected by the extent of the dispersion and tonality, namely the darker and wider the dispersion from the outlets, the more intense and greater the flow. Figure 7 is a conceptual representation of the storage system expressed using the "bucket theory".

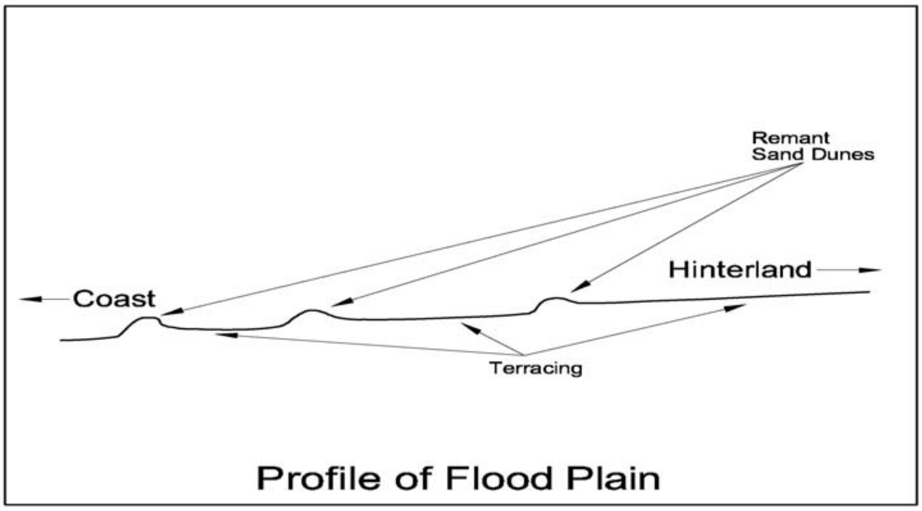


Figure 7: Flood Plain

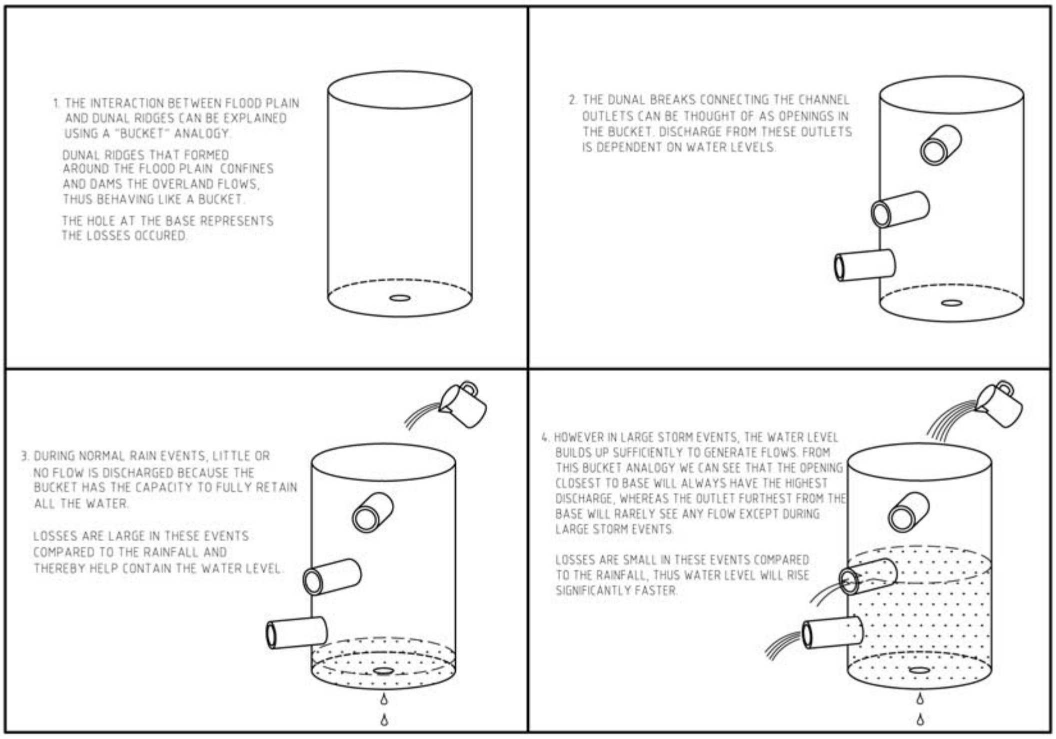


Figure 8: Bucket Concept

3.2 Determining the Storage Outlet Levels

The distribution of flows in the bucket concept is largely influenced by the outlet levels. To ascertain the minimum head required to drive flows through the individual outlets and thereby determine the invert levels at the storage, a plot of depth bands showing the wetted area for a range of incremental levels were completed (Refer to Figures C1-C7 in Appendix C). Simply put, the wetted area identifies the extent of the surface flows. In order for flows to travel from one point to the next, there must be continuity between two boundaries (ie. the wetted area must connect the storage to the outlet).

From these plots we observed that up to RL9.5 the wetted area does not extend to the boundary of the storage. Therefore it can be concluded that flows in the outlets for RL less than 10 (if any) are limited to local runoffs. At RL10 discharge from the Yannarie South outlet was triggered from the storage (ie. extent of wetted area connects storage to the outlet). At RL10.5 discharge from the Yannarie North outlet was found to have commeced. When the stage height reached RL11 flows from both the Rouse South and Rouse North outlets were triggered. Flows to the Rouse outlets were subjected to inter-dunal flows as indicated in Figure B1 in Appendix B.

3.3 Hydraulic Modelling for Peak Discharge

The bucket concept is modelled by routing the Yannarie River and Rouse Creek hydrographs through the storage to determine peak discharge for each of the four key outlets (Yannarie South, Yannarie North, Rouse South and Rouse North). The use of

EXTRAN allows for the dynamic effects of time and backwater conditions to be simulated, the outcome in which reflects the non-linear nature of discharge.

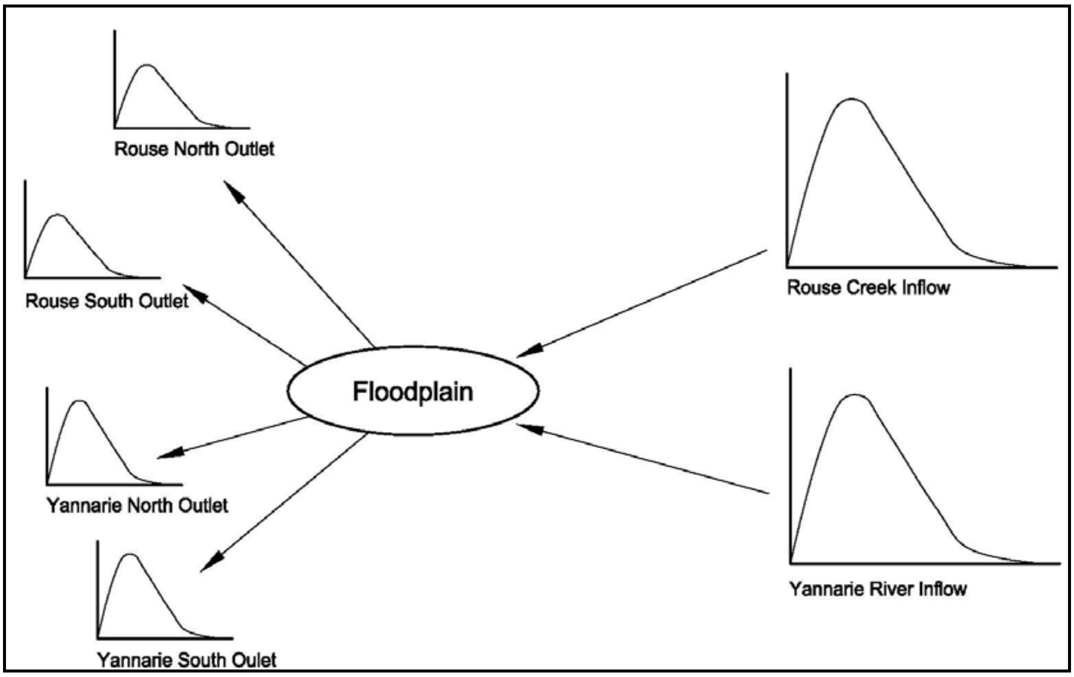


Figure 9: XP Model

Peak discharge for 20 and 100 year ARI were estimated using this hydraulic model. To approximate the flow distribution through these four outlets, the model was calibrated using Tropical Cyclone Vance (March 1999). This storm event was found to closely approximate a 20 year average recurrence interval by plotting against Intensity-Frequency-Duration curves. Knowing that discharge at the Rouse North outlet has dissipated to almost zero on the third day after the cyclone (as observed on the satellite image), the outlet inverts were adjusted iteratively to produce a similar outcome. Table 3 below shows outlet inverts established at the storage interface from the calibration.

Table 2: Outlet Invert Levels

Outlets	Invert RL (m, AHD)
Yannarie South	10.0m
Yannarie North	10.5m
Rouse South	10.7m
Rouse North	10.8m

Using the above invert levels peak discharges for a 100 year ARI was then modelled. Flow velocities and depths were estimated using Manning's formula to validate against the field data and anecdotal evidence.

Peak discharge for more frequent events (eg. up to 5 year ARI) was not modelled because no hydrographs could be generated from Yannarie River and Rouse Creek.

3.3.1 Input Parameters

The input parameters for EXTRAN modelling includes inflow hydrographs from the two watercourses, effective basin area, weir widths, invert levels and expected runoff losses. The lack of availability of actual surveyed data has limited some inputs to desk top extrapolations.

A series of hydrographs were generated using RORB. For major events, such as the 20 and 100 year ARI, the critical storm durations for Yannarie River and Rouse Creek were found to be 24 and 12 hours respectively. As this model considers the contribution from both watercourses in its analysis, the 24 hour critical storm durations were used. Table 4 below shows the peak inflow for the 20 and 100 year ARI storm events.

Table 3: Peak Inflow for 24-hour Storms

Catchment	24-hour Critical Storm	
	20-year	100-year
Yannarie River	500 m^3/s	3,000 m^3/s
Rouse Creek	400 m^3/s	3,000 m^3/s

Storages in EXTRAN are modelled as a nodal point which must be expressed as a flat surface. Typically an equivalent area for a constant sloping flood plain would be 50% of the total area. However as the flood plain is characterised by a terrace formation, an equivalent area of less than 50% is expected. Given the poorly defined nature of the terrace, a conservative estimate of 30% equivalent area was adopted in the model. This equates to approximately 70km^2 in area.

Discharges from the storage into the outlets are typically fed from multiple locations via inter-dunal flow (refer to Figure 9 below). To simplify this hydraulic process for modelling purposes, a channel width located downstream from the entry points is used to define the weir width. This will ensure that the weir in the model is a representation of the total flow that contributes to the outlet.

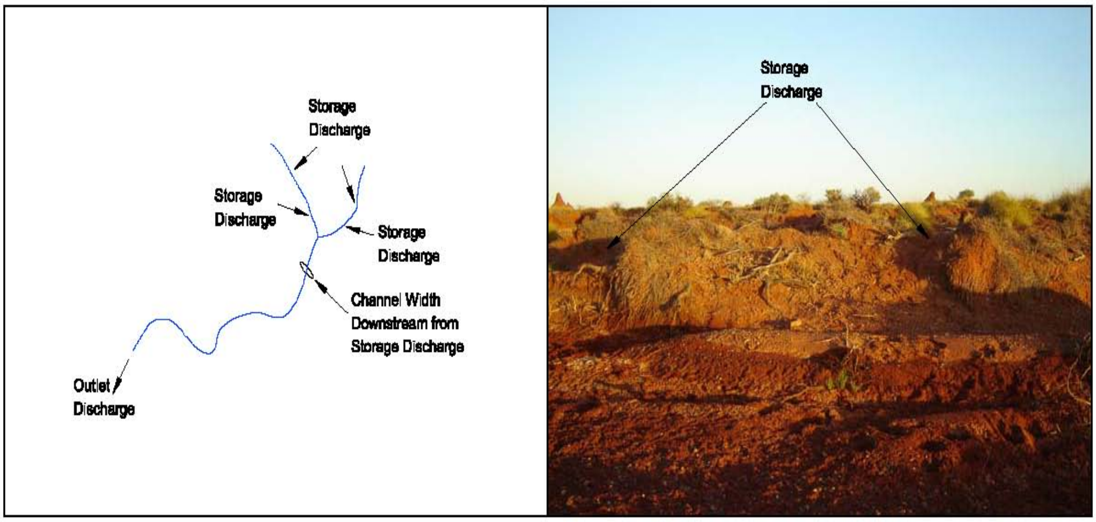


Figure 10: Locating channel width

The geological composition of the flood plain is dominated by alluvium and colluvium claypan of low permeability. The loses through infiltration from this soil type is expected to be minimal. Therefore the EXTRAN modelling has ignored losses from both infiltration and evaporation.

3.4 Discharge from Major Storms

Storages provided by the flood plain and dunal systems greatly influences discharge at the key outlets. Outflows have been conservatively estimated using EXTRAN on the assumption that inflows from the Yannarie River and Rouse Creek are fed directly into the flood plain as storage. In reality, only a portion of the flows from Rouse Creek ends up in the flood plain with most being captured by local depressions and inter-dunal flows north of the flood plain. The results generated from the model therefore have overestimated the discharges.

Table 4 below is a summary of the modelling outcomes:

Table 4: Outlet Discharge Summary

	20-Year			100-Year		
	Q (m^3/s)	H (m)	V (m/s)	Q (m^3/s)	H (m)	V (m/s)
Yannarie South	150	0.7	2.2	1010	2.2	4.5
Yannarie North	50	0.4	1.5	780	1.8	4.3
Rouse South	15	0.2	0.8	490	1.8	2.7
Rouse North	10	0.2	0.7	460	1.9	3.0

As expected, the above results indicate that Yannarie South is the dominant outlet. For intermediate storm events such as the 20-year ARI, over 65% of the total outflows is discharged via this outlet. The percentage is reduced to some 35% for 100-year ARI but is expected to increase to 80% for the lesser storms such as the 10-year ARI.

Peak discharge through the Yannarie North outlet accounts for approximately 25% of the total outflows for both the 20 and 100 year ARI storm events. The remaining Rouse South and Rouse North outlets, where flows take on a less direct path, each accounts for approximately 10% of the total outflows.

The storage head (ie. water level at the flood plain) for the 20 and 100 year ARI storms were estimated to be 1 and 3m respectively. This range is consistent with the anecdotal evidence obtained, where it was reported during Tropical Cyclone Faye (March 2004) that flooding near Yanrey Station was observed to be in excess of 2m. This further lends weight to the basis of the calibrated invert levels for the four main outlets.

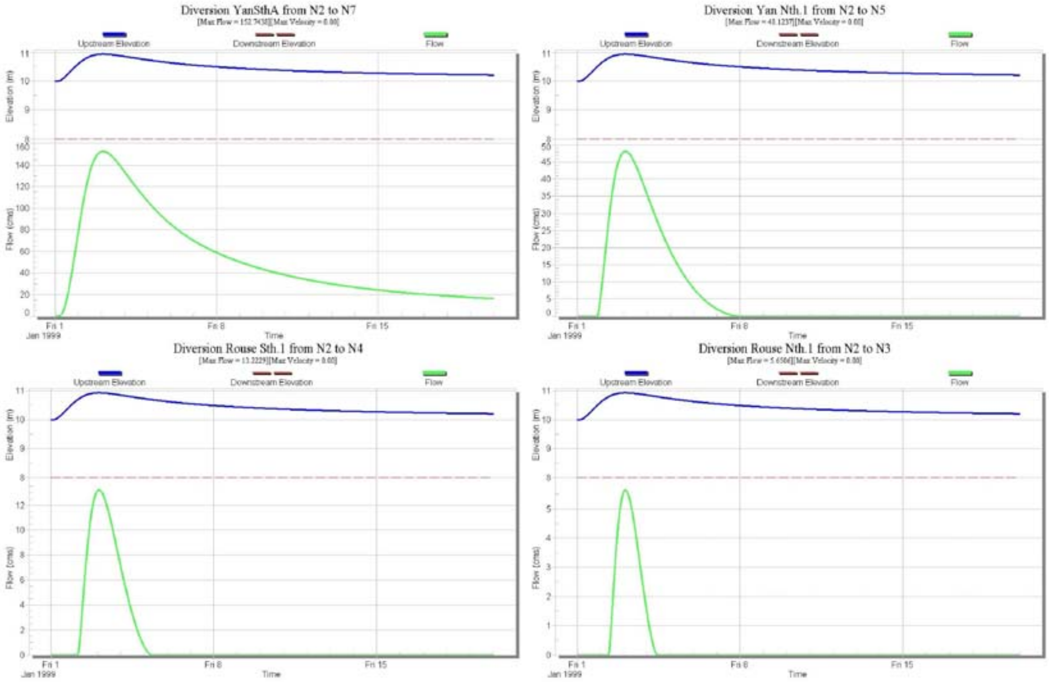


Figure 11: Discharge hydrographs for 20yr ARI

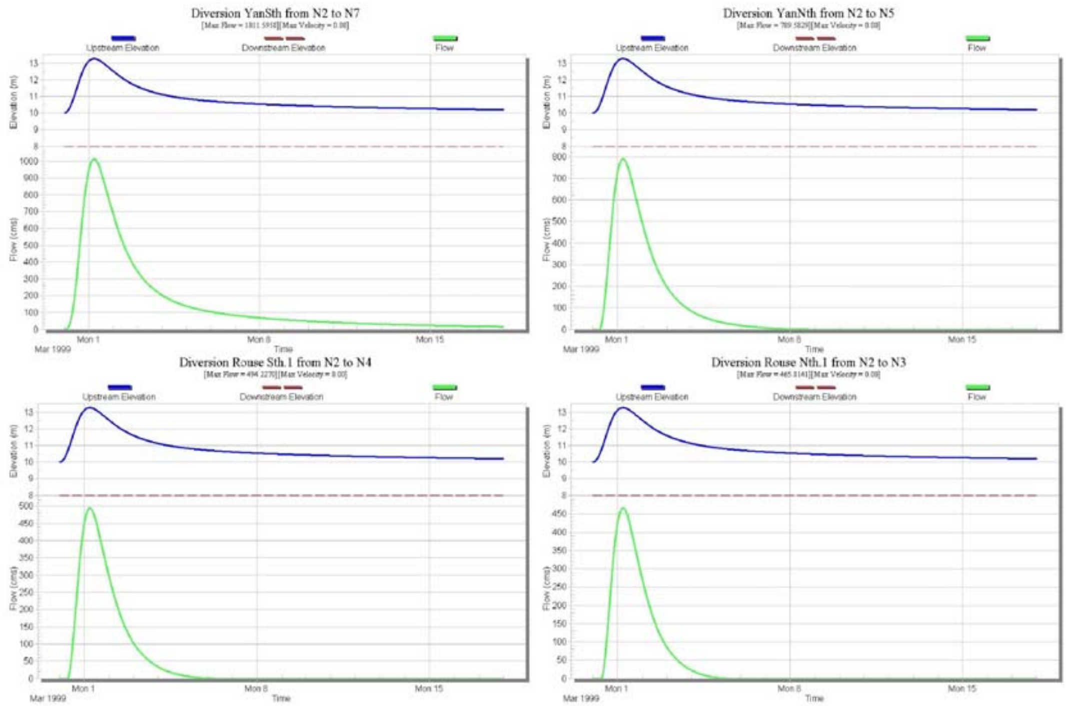


Figure 12: Discharge hydrographs for 100yr ARI

Hydraulic analysis using Manning's formula was carried out to validate the estimated peak flows. Depths and velocities were computed based on the corresponding weir geometry where the cross-sections were generally well defined. Using these as natural gauging stations, scouring and debris marks were checked on-site as evidence of flow depths from the most recent storm event.

Based on this approach, scour marks at approximately 2m and 1.5m were found in the Yannarie South and North outlets. Both of these would have been from the resulting flows of Tropical Cyclone Faye (100 year ARI). As show in Figure 12, these flows are wholly contained within the channel and is comparable to the values estimated in the hydraulic analysis detailed in Table 5.

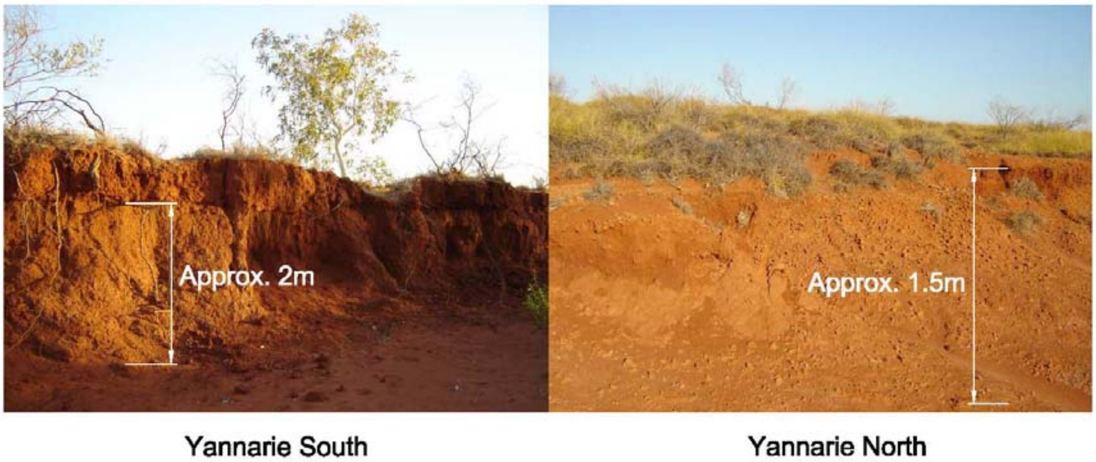


Figure 13: Evidence of scouring at Yannarie Outlets

Peak flows at the Yannarie South and North outlets are expected to exceed 4m/s for 100 year ARI storms. These kind of velocities are considered to be highly rapid, which under normal condition would cause severe erosion. Velocities for the Rouse outlets are less severe, though would still be considered to be high.

The formation of the rectangular channel is indicative of the frequent occurence of major storm events. The cementatious nature of the soil allow the highly vertical batters to remain stable under the extreme conditions noted in this region. The scour marks along the side batters serve as a reliable record of the likely peak flows and velocities of the of most recent events, thereby providing a basis for calibrating our hydraulic model.

3.5 Discharge from Minor Storms

The losses incurred from overland flows within the Yannarie and Rouse systems greatly limits the discharge at the outlets. Based on the recommended losses in ARR 1987, the systems failed to generate sufficient rainfall excess for the lesser storm events to produce any runoff. This suggests that these two systems are effectively disconnected from the outlet sub-catchments during the minor storms.

To estimated the peak flows for the 1 and 2 year ARI storms, the outlet subcatchments were modelled individually using RORB. The boundaries for these subcatchments were established using the wetted area principle as previously discussed (refer to Figures D1 in Appendix D).

Interogation of the daily rainfall data obtained from the Bureau of Meterology shows that the regional temporal pattern are mainly in clusters of one, two and three days. Because the data itself are not available in smaller increments (such as minutes or hours), it would be unreasonable to model the subcatchments for storms other than the 24, 48 and 72 hour durations.

The outcome based on an initial loss of 22mm and a continual loss of 5mm shows that the only flow generated in the modelling came from the Yannarie South outlet for the 2-year, 24 hour ARI storm. Table 5 below summarises the minor storm discharge.

Table 5: Peak Flows for Minor Storms Discharging into Supra Tidal Flat

	1 year, 24 hour		2 year, 24 hour	
	Peak Flow (m3/s)	**Volume (m3)**	**Peak Flow (m3/s)**	**Volume (m3)**
Yannarie Sth	0	0	0.3	15,000
Yannarie Nth	0	0	0	0
Rouse Sth	0	0	0	0
Rouse Nth	0	0	0	0

A broad historical assessment was made for the last 30 years (ie. between 1971 and 2000 inclusive). During this period, it is estimated that on a total of 10 occassions discharge from the Yannarie South Outlet was due to a 2-year, 24-hour ARI storm. Using the historical rainfall data, the estimated average volumetric discharge from these minor storms is approximately 17,000m^3. Given the distances across the supra-tidal flat ranges from 8-10km, this volume would conservatively equate to 25-30mm of inundated water (based on the same width as the channel outlet). However in reality dispersion would occur during discharge resulting in a much smaller inundation.

The above statistics is an indication of the infrequent and the random nature of minor storms in the Exmouth Gulf region. In addition, the volume discharged onto the supra-tidal flat by these minor storms can be considered as insignificant once evaporation has been accounted for. The average evaporation in Gulf region is approximate 9mm per day.

Table 6 below provides the estimated volumetric discharge for each of the 10 events.

Table 6: Discharge for Historical Minor Storms (2-yr, 24hr) at Yannarie South Outlet

Events	Discharge (m^3)
18/03/73	17,000
21/09/74	19,000
20/06/80	16,000
02/03/81	16,000
19/04/85	17,000
17/06/86	18,000
27/05/88	16,000
26/01/90	18,000
28/01/90	16,000
26/02/97	17,000

3.6 Flood Protection Work

The pond layout can have a significant impact on the yield capacity of the salt field. The principal design objective is to construct the levee walls as close to the hinterland as possible and thereby maximises the available area for harvesting. This optimisation however must be balanced with the need to protect the salt field from freshwater intrusion during the major storms.

Under the current proposed salt field layout, a condenser pond (Pond 8) has been designed to abut against the Yannarie North channel outlet (refer to Figure E1 in Appendix E). The resulting effect from this construction will see a build up in storage volume resulting from runoff that covers some 6 million square metres in area for 20 year ARI storms. For major storms, such as the 100 year ARI storms, flows will overtop the pond's levee wall and allow fresh water to enter the condenser pond.

To prevent this fresh water intrusion, a diversion weir is proposed to be constructed at a suitable location along the Yannarie North channel. The location of this diversion weir will need to ensure that flows can be diverted to other outlets and that these outlets have sufficient capacity to accomodate the increased flows for the major storm events.

Based on the initial desk top assessment, a location near the upper reaches of the Yannarie North channel is seen to have the necessary attributes to satisfy the above objectives. This proposed location is situated between the banks of two dunal ridges thus making it highly channelised (refer to Figure E2 in Appendix E). The narrow constriction created by the ridges would make it ideal for constructing the diversion weir.

The proposed diversion weir is to be 5m in height consisting of an outer core sourced from locally available material with an inner clay core (refer to Figure E3 in Appendix E). The weir height has been adopted to ensure that backwater conditions will not cause ovetopping for the 100 year ARI storms. Diverted flow will be encourage to take the path of least resistance towards the Rouse outlets. To faciliate the diverted flow, some minor earthwork is required at the 'choke point' north of the diversion weir (refer to Figure E2 in Appendix E).

Implementation of the diversion weir will result in ponding in the surrounding area upstream of the weir. The extent of ponding is dependent on the storm events. As discussed previously, discharges for minor storms (ie. up to 5-year ARI) are localised in nature. In contrast the larger storms are affected by the Yannarie and Rouse catchments.

Using volumetric approach, it was found that minor storm events are locally contained within a footprint of approximately 410,000m2 and 1,000,000m2 for the 2-year and 5-year ARI respectively (refer to Figure E4 and E5 in Appendix E). Storms greater the 5-year ARI will overtop at the 'choke point' and thereby result in runoffs migrating through the dunal systems to the Rouse channel outlets.

Table 7 below provides a summary of the storage volume as a result of the diversion weir.

Table 7: Volume and Water Level for Minor Storm Events in "Dam" Area Upstream of Diversion Weir

Event	Volume (m3)	Water Level (mAHD)
2 year ARI	423,000	9.0
5 year ARI	961,000	9.5

Diverting flows from the Yannarie North channel is expected to cause an increase in the peak discharge in the Rouse South and Rouse North channels. Initially flows from the Yannarie North channel will adopt the flow path shown in Figure E3 where it will discharge into the Rouse South channel during the minor storms. For larger storm events, backwater will build up from the narrowest point in the Rouse South channel and extend across the dunal system. When the backwater reaches approximately RL 10mAHD, sufficent hydraulic head will be created to push excess flows into the Rouse North channel.

Under the above condition Rouse South channel has a maximum discharge capacity (at the narrowest point) of 800m^3/s. Consequently for 20 year ARI storms, the diverted flow from the Yannarie North channel will be fully routed through to the Rouse South channel. However for the 100 year ARI storms, the diversion will cause an increase in the peak discharge for Rouse South and Rouse North channels from 490m^3/s to 800m^3/s and from 460m^3/s to 900m^3/s respectively.

Some ponding will also occur downstream of the diversion weir as a result of the blocked outlet by the pond's levee wall. The extent of this ponding is limited to within the Yannarie North channel.

4. Ashburton System

4.1 General Description

Based on the desk top assessment, the Ashburton River catchment is most likely to be the main source contributing to the discharge at the channel outlets that directly impact on the proposed northern pond extension. A Main Roads Western Australia (MRWA) report titled “Ashburton River Flooding, Feb 1997 – report on Flood Investigation” confirms that the Ashburton River is distinct and does not interconnect during major/extreme storm events with either the Yannarie or Rouse systems.

Based on findings in the MRWA report and the satellite imagery, it has been assessed that during a major storm event, flows breakout from the banks of the Ashburton approximately 20km from the supra-tidal flats. Similar to the Yannarie and Rouse, the breakout from the Ashburton is partially stored within the dunal system, partially lost through evaporation, with the balance traverses through inter-dunal systems and discharges at the channel outlets. This hydrological regime can be seen on Appendix B3.

4.2 Discharges onto the northern ponds

Discharge from the channels onto the supra-tidal flat requires modelling of the Ashburton system similar to that carried out for the Yannarie and Rouse. Due to the lack of data, this process has not been carried out. Instead a comparative review was completed using spectrum analysis of the satellite imagery to differentiate the intensities at the northern outlets. These values were then compared to the known base values estimated through the previously modelled Yannarie and Rouse systems to give a approximate order of flows.

Based on this approach, it was found that the northern outlets produces similar order of flows, that is for 20-year ARI storms the peak discharge would be in the order of 50-100m^3/s with the 100-year ARI storms producing a peak discharge in the order of 500-800m^3/s.

The estimated flows for the northern outlets were somewhat higher than expected given the greater energy required to drive these flows through the dunal system and into the dicharge channel outlets. However this may be a possibility based on the significantly larger Ashburton catchment that contributes to the flows.

It should be noted that comparative spectrum analysis has an inherent degree of error and can be substantial depending on the site conditions and the quality of the image. Therefore further modelling is recommended to ascertain a greater level of accuracy for flood protection work.

5. Fate of Discharge from the Yannarie South Channel.

In terms of understanding the relationship between the drainage systems in the hinterland and the supra tidal flat, it is necessary to understand that what water is available for discharge is the result of either a prolonged high intensity rainfall event generated by a local cyclone or the result of regional rainfall generated by a decaying cyclone or by local storms yielding high intensity rainfall.

The hydrological and hydraulic modelling completed shows that the 100 year ARI storms will discharge to the supra tidal flat. Smaller events, such as the 20 year ARI down to the 2 year ARI, will also discharge to the supra tidal flat but with greatly diminished volumes of water (of approximately one order in magnitude each time). Refer to Sections 3.4 and 3.5 for peak discharges.

Ultimate discharge to the supra tidal flat is the end result of surface runoff from the Yannarie and Rouse River systems being routed through the flood plain where some storage occurs, and some flow being diverted north through the dunal system where further storage occurs. This is a very complex surface hydrological system that converts 100 year ARI peak flow of approximately 3,000m^3/s in each of the river systems at the bridge on the North West Coastal Highway to a 1,000 m^3/sec peak flow at the mouth of the Yannarie South channel where it discharges to the supra tidal flat.

The performance of any single discharge event is dependent on a number of factors, key among which are the sediment load of the discharge, the depositional patterns of sediment resulting from the last discharge event, the degree of re-working of salt flat sediments by storm surges, and the simple relationship of the presence of water on the salt flat at the time of discharge and the depth of this water.

Discharge from the Yannarie South channel can be likened to a garden hose lying at the edge of a very large slab of concrete where the area of the slab of concrete is at least 50m square. Simulation of the 20 year ARI storms and less is provided by turning the hose on briefly for a few seconds then turning it off. Discharge is seen to spread out from the hose according to the roughness and slope of the concrete slab. The short time the hose is on means that little water is discharged to the slab and it travels a very short distance before flow stops. The same scenario applies to the larger 100 year ARI storms. Here, the hose is turned on for several minutes only this time, the tap is turned on slowly at first then gradually turned full on then slowly turned off. The distribution pattern of water across the concrete is identical except that the area covered is larger. What is important is that the leading edge of the sheet of water on the concrete slab is travelling at a very high velocity and depth at the hose outlet but both depth and velocity dissipate rapidly with increasing distance from the outlet.

If we simulate a storm surge, we have five fire fighting hoses lined up along the opposite side of the slab. They are all turned on together and their combined effect is to inundate the slab, meeting and combining with the discharge from our garden hose. The waters are mixed and flows become indistinguishable. When the hoses are turned off, flows stop, energy dissipates, (sea level returns to normal), and the slab dries out, ready for the next event.

An attempt to define the fate of discharge has been made by taking the Q_{100} peak flow data and converting it to a constant flow regime at a given distance across the supra tidal flat. At the mouth of the Yannarie South drainage channel, the geometry of discharge for the 100 year ARI storms is a stream of water 100 m wide, flowing 2.2 m deep and with a discharge velocity of 4.5 m/s. The potential flow was modelled (without considering the rising and falling limbs of the hydrograph) by developing a series of channels with increasing width with incremental increases in distance from the discharge datum. Each increase in channel width has been accompanied by a corresponding decrease in water depth with a calculated resultant flow velocity.

In simple terms, as the width of flow increases, the depth of flow and the velocity decreases. From the readily visible satelite image, the spread ratio for flows onto the supra tidal flat is approximately 1:0.8 (ie. 0.8m spread for every 1m run) where at approximately 2.1km from the discharge point, flow intersects with tidal surge. Table 8 below provides the indicative flow characteristics in the supra tidal flats using Manning's Equation.

Table 8: Flow Characteristics on Supra Tidal Flats

	Q_{peak}	V_{peak}	H_{peak}
2 yr	<1 m^3/s	< 0.1 m/s	< 0.01 m
20 yr	150 m^3/s	0.5 m/s	0.13 m
100 yr	1010 m^3/s	1.1 m/s	0.41 m

In addition to the dynamics of the discharge event, surface hollows and depressions exist across the salt flat. These will result in both the ponding of water and channelling of flows, according to the spatial relationship and interconnectedness of these features. Further, flows of dimensions such as less than 0.1m deep and flowing at 1m/s are subject to strong winds that can stop the discharge and cause it to travel down wind. In this scenario, southerly winds can blow the water back across the salt flat towards the mainland. This surface phenomenon has been observed at Lake Carey in the goldfields region of Western Australia.

For this flow to continue to the coast, it would require sustained discharge such as those from the 20 and 100 year ARI storms. Based on the discharge characteristics of the Yannarie South surface hydrology, there appears to be no direct hydrologic link between discharge from the mainland and the ecosystems of the project area mangrove zone for the minor storms of 2 year ARI or less.

The above analogy can be extended to other outlets driven by the Yannarie and Rouse systems. The context of this discussion has focussed on the Yannarie South channel as it generates the highest peak flow (ie. worst case scenario) but is equally applicable, to a lesser extent, to other channel outlets.

6. Conclusions

The hydrological and hydraulic modelling has found that discharge resulting from rainfall excess for minor storms (up to 2 year ARI) is limited to localised runoffs only. Of these channel outlets only the Yannarie South channel produced sufficient excess (from rainfall) to discharge into the supra tidal flats. Flows from the Yannarie and Rouse catchments do not generate sufficient volume during the minor storms to break the banks of the watercourses and are subsequently lost through evaporation. As demonstrated in the dispersion estimates, the flow depth and velocity for the minor storms are unlikely to have sufficient energy to reach the Gulf even if evaporative losses were ignored.

Conversely during a major storm, runoff overtops the banks and travel as overland flows along the flood plain. The dunal systems on the peripheral of the flood plain naturally dam the breakouts and act as a storage basin. When sufficient hydraulic head has built up, the storage is discharged into the outlets at various rates via inter-dunal flows.

For a 100 year ARI, peak flows from the Yannarie and Rouse are each estimated to be 3,000m^3/s. The storage attenuation at the flood plain has significantly reduced the discharge at the outlets. The modelling shows that Yannarie South is the most dominant with an estimated peak discharge of 1,010m^3/s. The remaining peak discharge for the Yannarie North, Rouse South and Rouse North are estimated to be 780, 490 and 460m^3/s respectively.

Discharges at the northern ponds were obtained using spectrum analysis. The method involves selecting a suitable bandwidth to differentiate the intensities at the outlets and compare these to the modelled values to ascertain an order of flow rate. Based on this process, it was assessed that the northern discharge outlets would produce similar flow rates to those at the Yannarie North and Rouse South outlets. These discharges will then be re-directed north by the northern pond's levee banks.

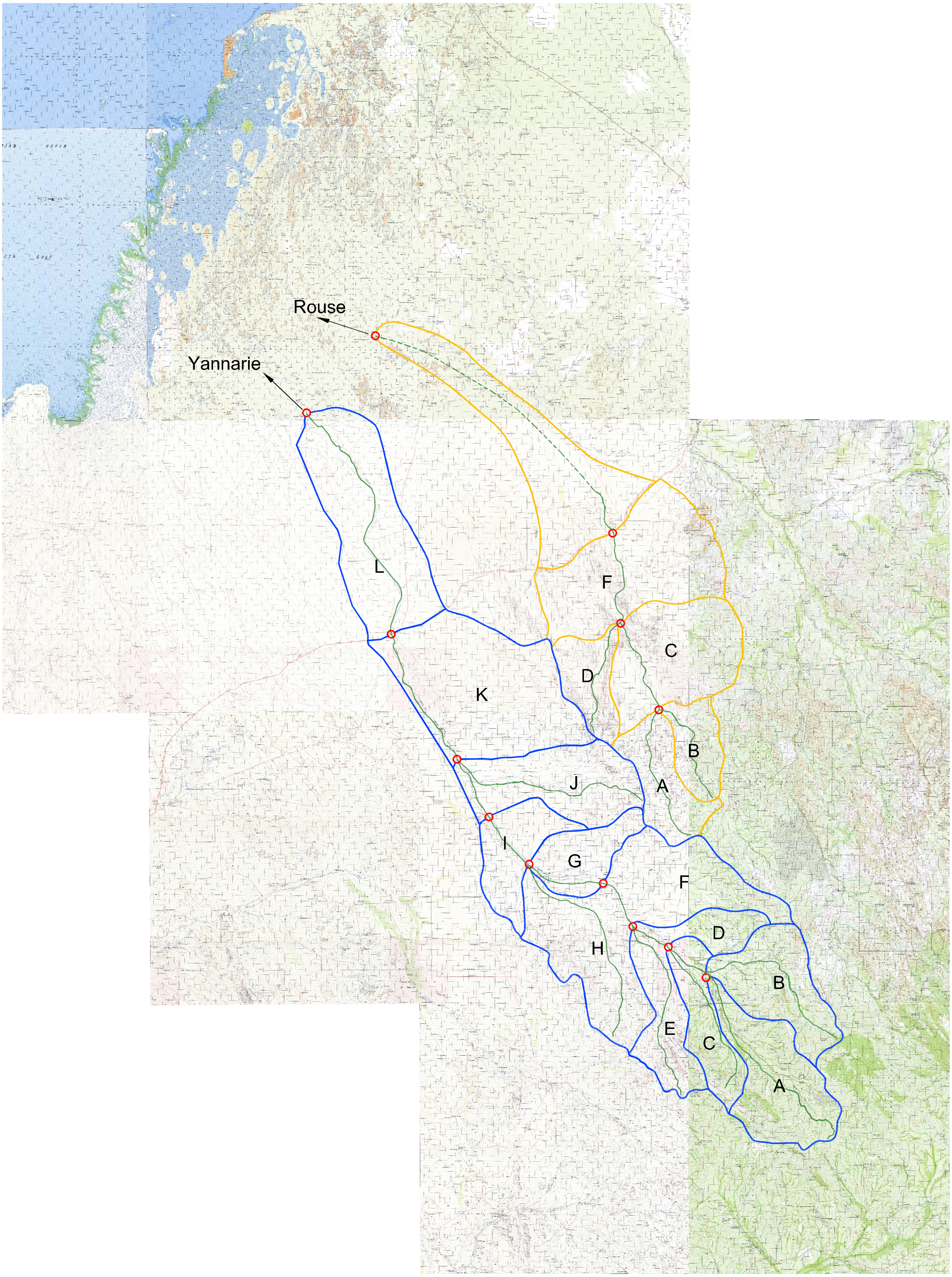
As part of this hydraulic investigation, a preliminary assessment of the inland flood protection work was also carried out. The optimisation in salt yield largely depends on the arrangement of the concentrator and crystalliser ponds. This may entail the construction of a levee bank close to the hinterland boundary that will subsequently block off the Yannarie South channel outlets. To prevent freshwater intrusion into the ponds, diversion weir at the upper reaches of the outlet channel is also recommended.

Based on the estimated peak discharge and local topography, a 5m high diversion weir will be required. Depending on the level of acceptable risks, it may be necessary to implement staged protection works. This staging work involves constructing additional diversion weirs at different reaches to avoid possible compromise resulting from inter-dunal flows.

The results obtained from the modelling have been completed using data sourced with varying degree of accuracy. Subsequently a conservative approach was adopted to ensure that the bounds of these accuracies have been accounted for this the analysis. It is therefore recommended field survey levels be obtained prior to detail design so that a more rigorous hydrological and hydraulic investigation be carried out to confirm these initial assessments.

Appendix A

RORB Modelling



DRN: R. Bargerbos Feb '05	**Exmouth Salt Feasibility**	PB 100 YEARS
CHKD: D. Luong Feb '05		
DATUM: N/A		
SCALE: N/A	CLIENT: Straits Salt Pty Ltd	Figure A1 2140169A

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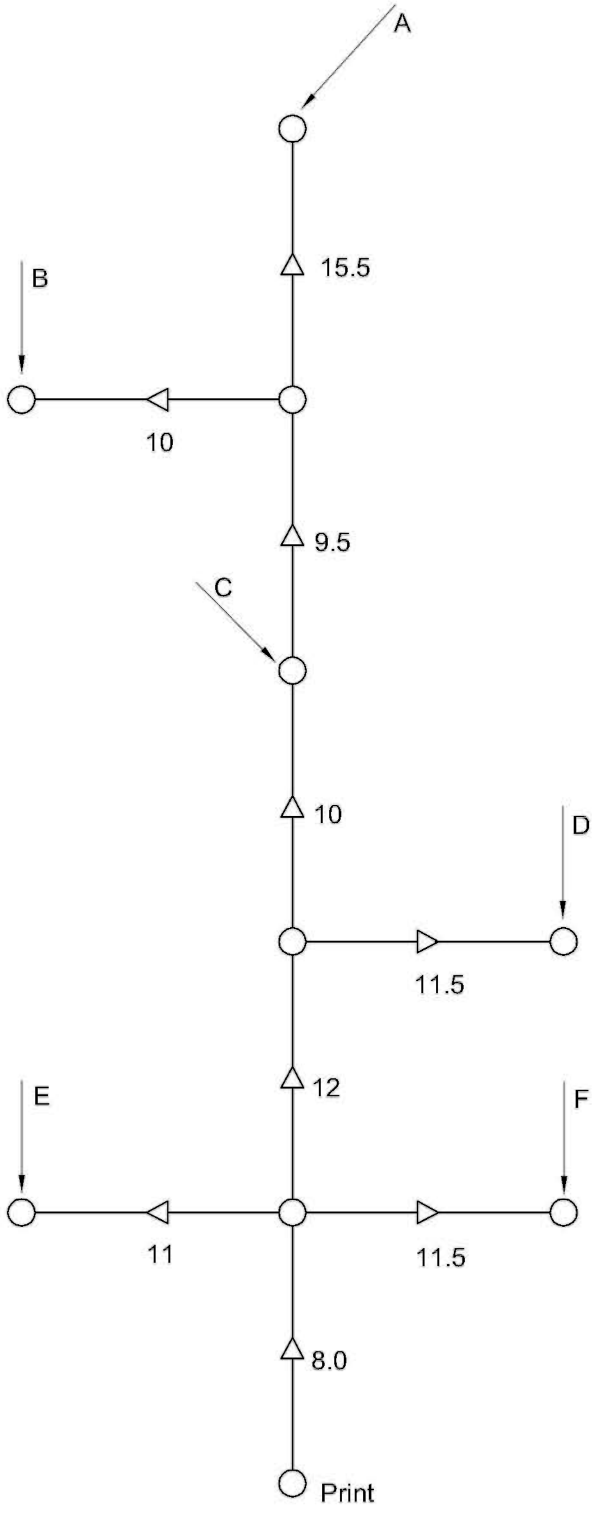

Sub-Catchment	Area (Km²)
A	215
B	151
C	437
D	175
E	355
F	310
TOTAL	1635

RORB Sub-Routines

Rain A	1
Store A	3
Rain B	1
Get A	4
Route B	5
Add C	2
Store C	3
Rain D	1
Get C	4
Route D	5
Store D	3
Rain E	1
Store E	3
Rain F	1
Get D	4
Get E	4
Route	F
Print	

DRN: R. Bargerbos Feb '05
CHKD: D. Luong Feb '05
DATUM: N/A
SCALE: Not to Scale

Exmouth Salf Feasibility

Rouse Creek Outlet

CLIENT:
Straits Salt Pty Ltd

100 YEARS®

Figure A2
2140169A

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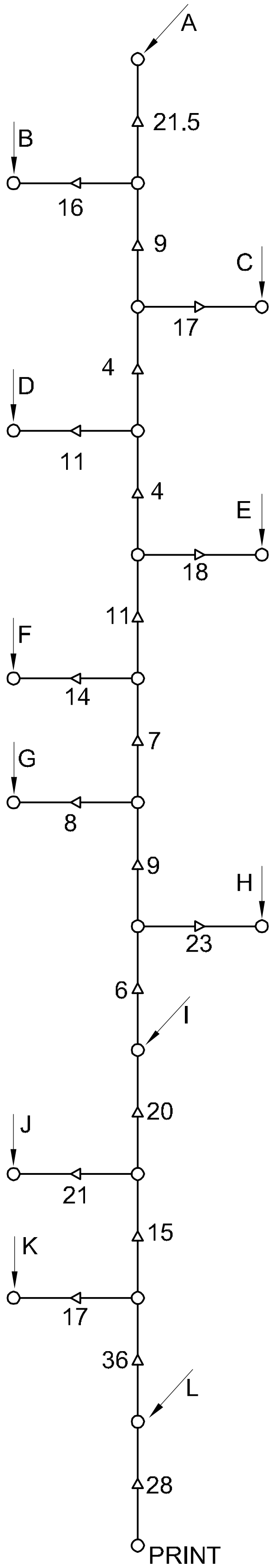

Sub-Catchment	Area (Km²)
A	378
B	318
C	176
D	145
E	227
F	363
G	186
H	405
I	218
J	378
K	797
L	705
TOTAL	4296

RORB Sub-Routines

Rain A	1
Store A	3
Rain B	1
Get A	4
Route B	5
Store B	3
Rain C	1
Get B	4
Route C	5
Store C	3
Rain D	1
Get C	4
Route D	5
Store D	3
Rain E	1
Get D	4
Route E	5
Store E	3
Rain F	1
Get E	4
Route F	5
Store F	3
Rain G	1
Get F	4
Route G	5
Store G	3
Rain H	1
Get G	4
Route H	5
Add I	2
Store I	3
Rain J	1
Get I	4
Route J	5
Store J	3
Rain K	1
Get J	4
Route K	5
Add L	2
Print	

DRN: R. Bargerbos Feb '05
CHKD: D. Luong Feb '05
DATUM: N/A
SCALE: Not to Scale

Exmouth Salt Surface Hydrology

Yannarie River Outlet

CLIENT:
Straits Salt Pty Ltd

Figure A3
2140169A

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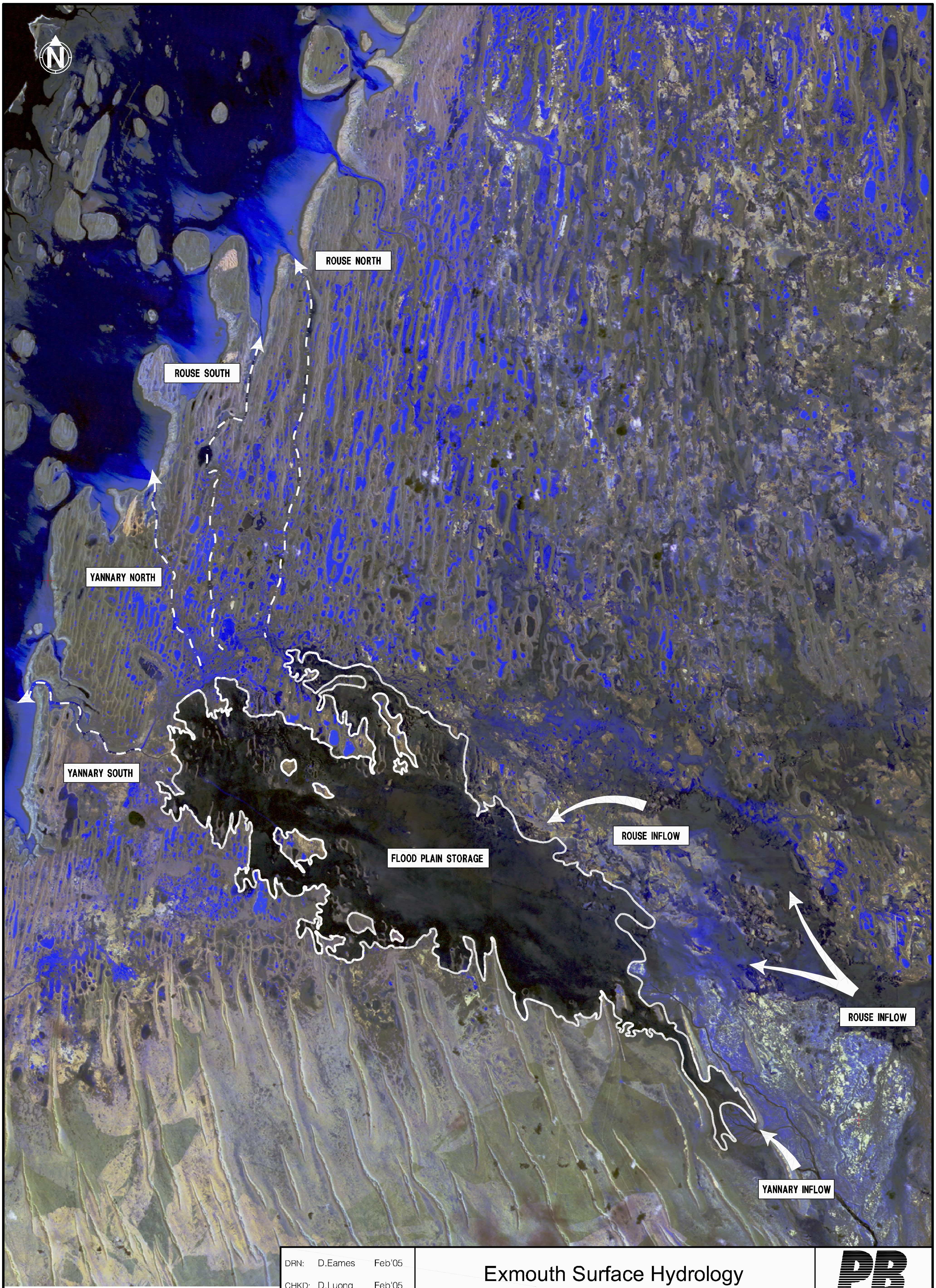
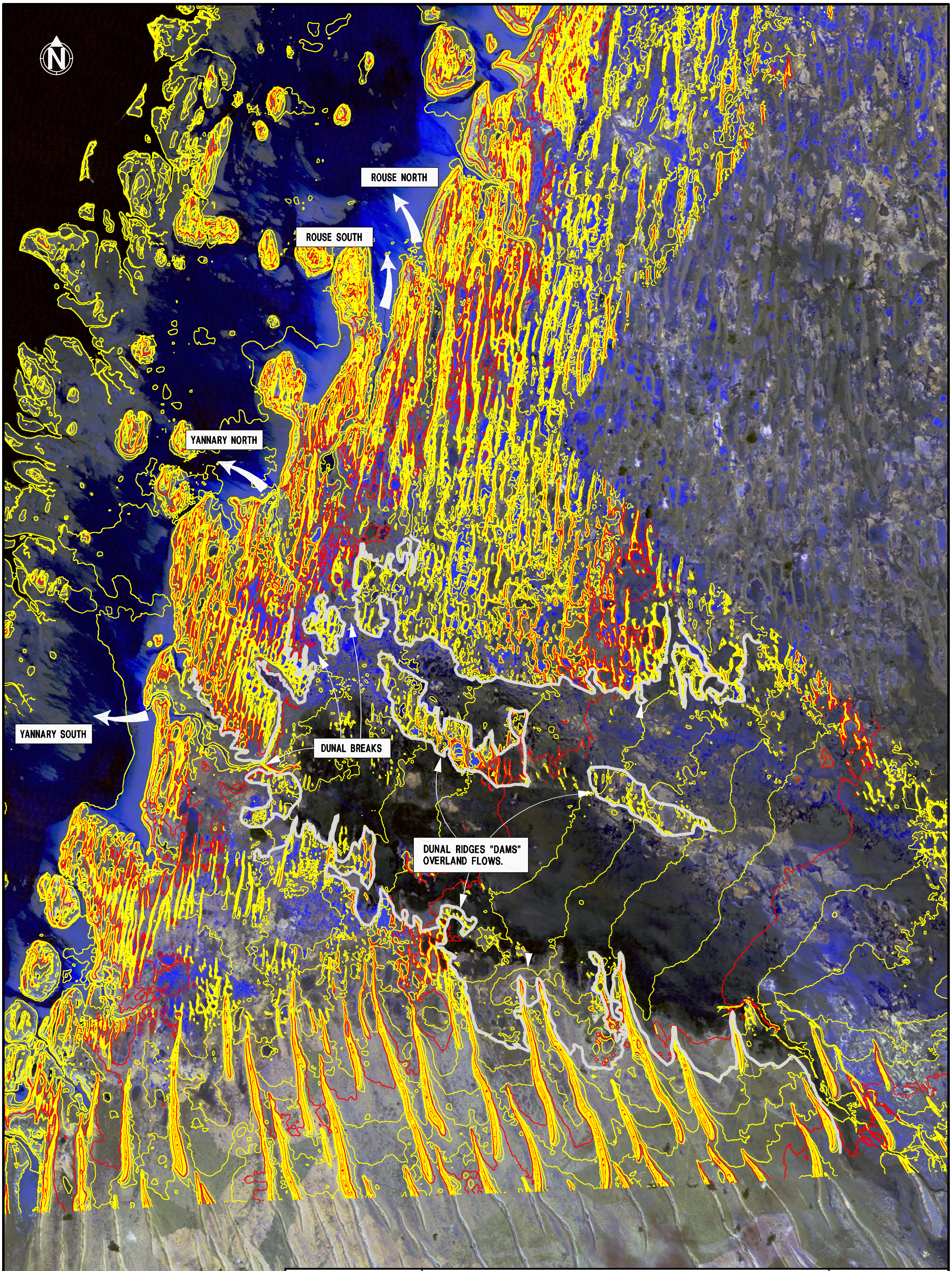
Appendix B

Surface Hydrology



DRN: D.Eames Feb'05	**Exmouth Surface Hydrology**	PB 100 YEARS
CHKD: D.Luong Feb'05	Yannarie and Rouse Hydrological Regime	
DATUM: MGA94	CLIENT:	Figure B1
SCALE: NTS	Straits Salt Pty Ltd	2140169A:PR_xxxxx:RevA



DRN:	D.Eames	Feb'05	
CHKD:	D.Luong	Feb'05	
DATUM:	MGA94		
SCALE:	NTS		

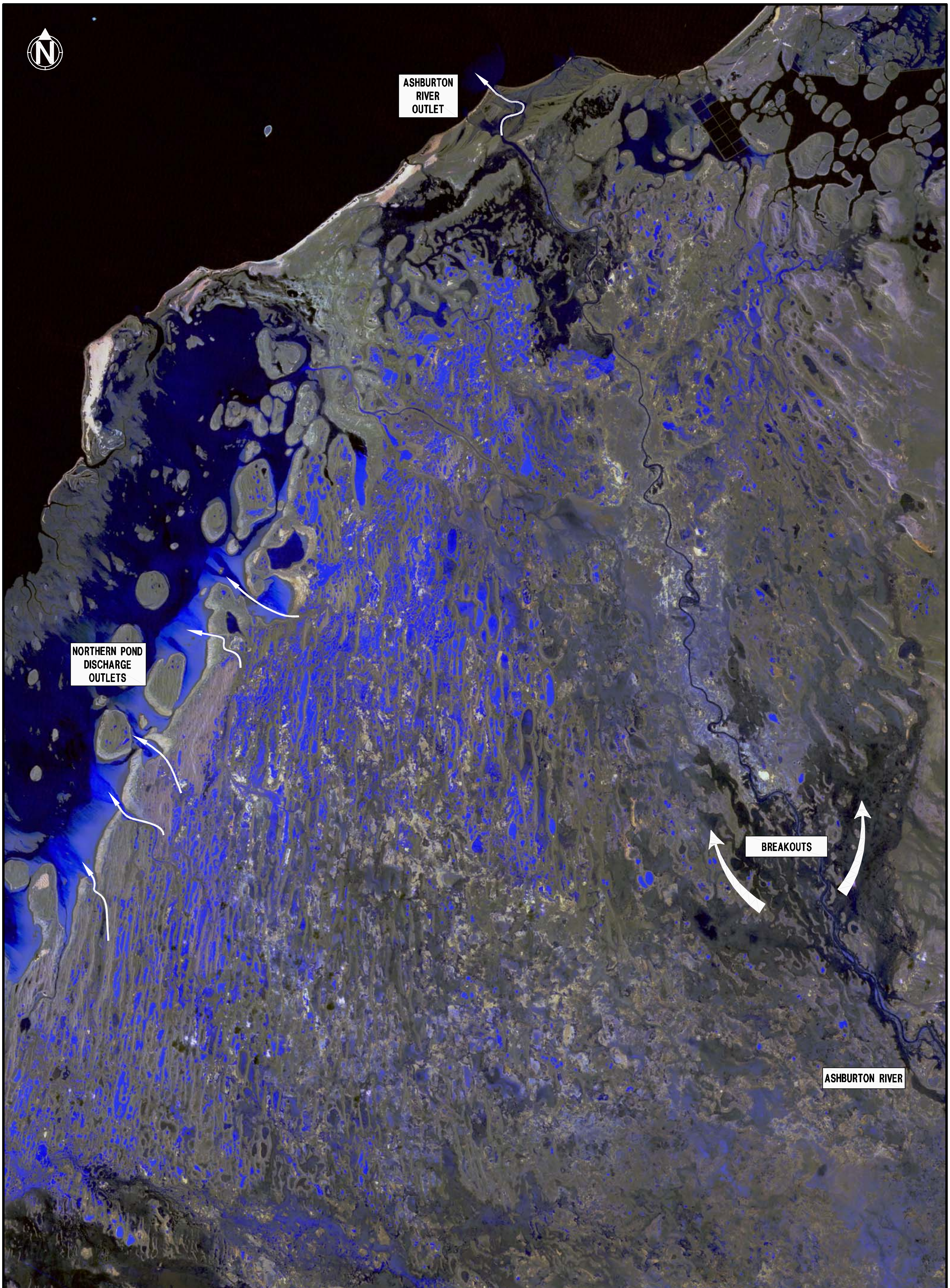
Exmouth Surface Hydrology

Discharge Outlets at Southern Ponds

CLIENT:
Straits Salt Pty Ltd

Figure B2

2140169A:PR_xxxxx:RevA



DRN: R.Bargerbos June '05 CHKD: D.Luong June '05 DATUM: MGA94 SCALE: NTS	**Exmouth Surface Hydrology** Hydrological Regime North of Yannarie CLIENT: Straits Salt Pty Ltd	PB 100 YEARS Figure B3 2140169A:PR_xxxxx:RevA

Appendix C

Depth Bands Analysis