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Rainfall Runoff and Storm Surge Flooding at Exmouth, Western Australia, in 1999

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SUMMARY

Exmouth is located on the eastern side of Cape Range on the North West Cape Peninsula on Western Australia's north west coast. On 22 March 1999 near midday, Cyclone Vance crossed the Pilbara coast between Onslow and Exmouth recording the then highest wind speed ever recorded on mainland Australia, with wind gusts of up to 267 km/hour.

The resulting storm surge at Exmouth together with rainfall runoff from the catchments extending from Cape Range inland of Exmouth resulted in extensive areas being inundated. Based on recorded debris levels in creeks taken following Cyclone Vance, peak flow estimates from Cape Range were found to be far in excess of previous design estimates for the area.

On 13 May 1999, flooding occurred again as significant rainfall and surface runoff followed heavy overnight rainfall. Both events in 1999 resulted in the most significant flooding experienced in the history of the town since its establishment in the 1960's.

This paper describes the geomorphology of the area, the severity of the combined storm surge and rainfall runoff event of March 1999 and the May 1999 event, and details the development of a conceptual flood management strategy for the town.

1. INTRODUCTION

Exmouth is located on the east side of Cape Range on the North West Cape Peninsula, on Western Australia's north west coast (Figure 1). The town itself has grown since its establishment in the 1960's associated with the Harold Holt Comunications Base at North West Cape, north of the town.

The town is often subject to cyclonic activity, and it is common for rainfall associated with these events to result in significant surface runoff. Present townsite develpment has been located on higher ground to avoid inundation risk from the creeks and immediate floodplains.

The townsite is situated on the coastal plain where natural discharge of runoff from the Cape to Exmouth Gulf is obstructed by coastal dunes. This situation contrasts with a typical river discharging to an estuary, for which a floodplain map is determined mostly by conveyance, rather than storage effects.

On 22 March 1999 near midday, areas of Exmouth were subject to gale force winds and flooding as a result of rainfall and storm surge associated with Tropical Cyclone Vance.

On 13 May 1999, flooding in Exmouth occurred again as significant rainfall and surface runoff followed heavy overnight rainfall.

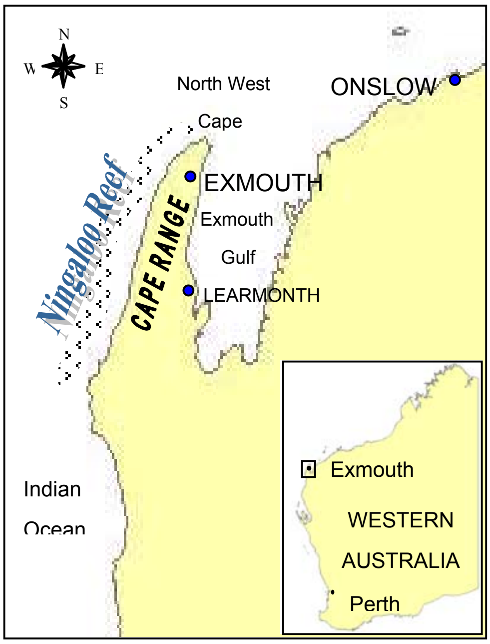

Figure 1: Exmouth location map

2. GEOMORPHOLOGY & HYDROGEOLOGY

Wyrwoll (1993) describes the geomorphology of the coast at Exmouth as comprising of washout plains from Cape Range. From a geomorphological point of view the coast dunes are an aeolion deposit which obstructs the runoff from the Cape. These dunes have been breached periodically during flood flows but commonly result in deltaic deposition behind the dunes.

Beneath the Cape Range Peninsula, a fresh to brackish groundwater lens exists in confined and semi-confined limestone aquifers. The depth of this groundwater lens is greater than 150 m in the centre of Cape Range

(Figure 2) as the mound rises to only a few metres Australian Height Datum (mAHD), and the divide is at approximately 150 mAHD (Colman, 1994).

The presence of a fresh groundwater lens suggests that the groundwater is readily recharged by infiltration of rainfall and runoff. This may be a result of direct infiltration through permeable river beds (there are unconfirmed reports of surface flows in drainage lines being completely lost to infiltration), and/or infiltration of rainfall in drainage areas in the centre of the Range.

The groundwater flow direction is towards the coast from the centre of the mound. Relatively steep groundwater gradients occur near the crest of the range, but gradients are virtually flat on the coastal plain. This reflects the lower permeability of limestone beneath Cape Range, and its higher permeability beneath the coastal plain.

3. CATCHMENT AND CLIMATE

Exmouth has a semi-tropical climate with average summer maximum temperatures of 38°C and average winter maximum temperatures of 24°C. The average annual rainfall for Exmouth town is 270mm with an average of 27 rain days per year, much of it being in May and June, or associated with cyclonic activity.

Six main creeks flow eastwards from Cape Range to the Gulf of Exmouth through the existing townsite and residential areas located south of the townsite (Figure 2). The largest of these catchments are the LIA (Light Industrial Area) Creek catchment (13.4 km^2) and the Market St catchment (18.6 km^2). The total area of the six catchments is 45.4 km^2.

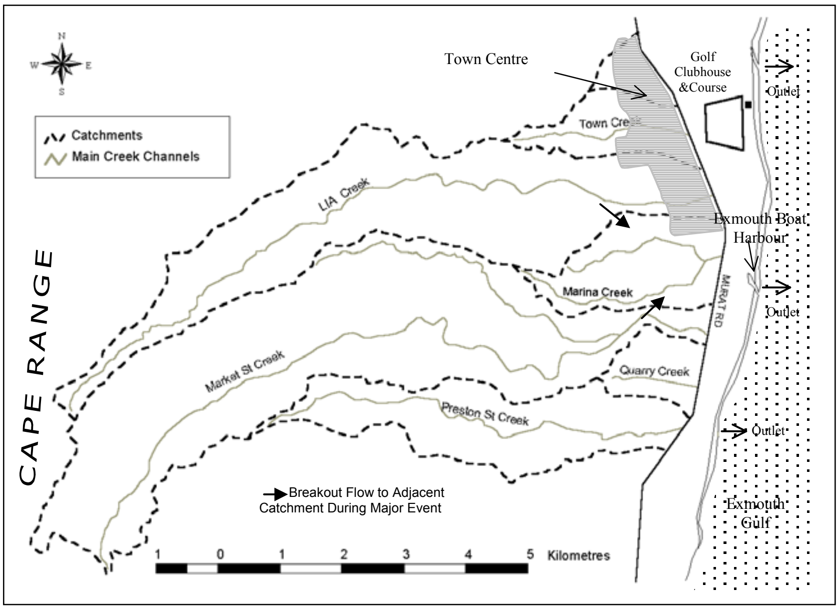

Figure 2 Catchment Map

The Krait St catchment (not shown in Figure 2) is located on high ground at the northern end of the main town centre is not considered by the Shire to be a flood risk.

4. FLOOD HISTORY & CYCLONE VANCE

No official record of flood history is available for the Shire of Exmouth, however anecdotal evidence provided by Kerry Graham (Chief Executive Officer, Shire of Exmouth) indicates the two events in 1999 as the most significant flooding events experienced in the history of the town since its establishment.

The first flood event of 1999 occurred on 22 March 1999 due to rainfall associated with Tropical Cyclone Vance. Flood damage to the town was minor compared to the wind damage caused by Cyclone Vance. Much of the area flooded is occupied by the town's golf course and currently undeveloped land.

In January 1999, prior to these flood events, a large bushfire destroyed large areas of vegetation on Cape Range. This fire is considered to have been a major factor in contributing to high runoff rates, resulting in catchments having minimal ability to retard flow during the rainfall events which followed in March and May 1999.

On 22 March 1999, Tropical Cyclone Vance (Category 5 Cyclone) crossed the Exmouth coast with peak wind gusts of up to 267 km/hour, setting a record for the highest wind speed ever recorded on mainland Australia. While no Bureau of Meteorology rainfall data was available for Exmouth for this event, based on records from local residents and those recorded at nearby Learmonth (Figure 1), approximately 150 mm of rain fell during the 10 hour period between 9am and 7pm on 22 March 1999. Based on this rainfall intensity (15 mm/hr), Tropical Cyclone Vance rainfall represented a 1 in 20 year average recurrence interval (ARI) event. Rainfall totals for 1 to 3 days showed reducing ARI (Figure 3). Shorter duration intensity data was not available.

Flooding in Exmouth occurred generally in the area between Murat Rd and the coast (Figure 2) due to a combination of storm surge and stormwater runoff. Flood debris along the eastern side of the coastal dunes

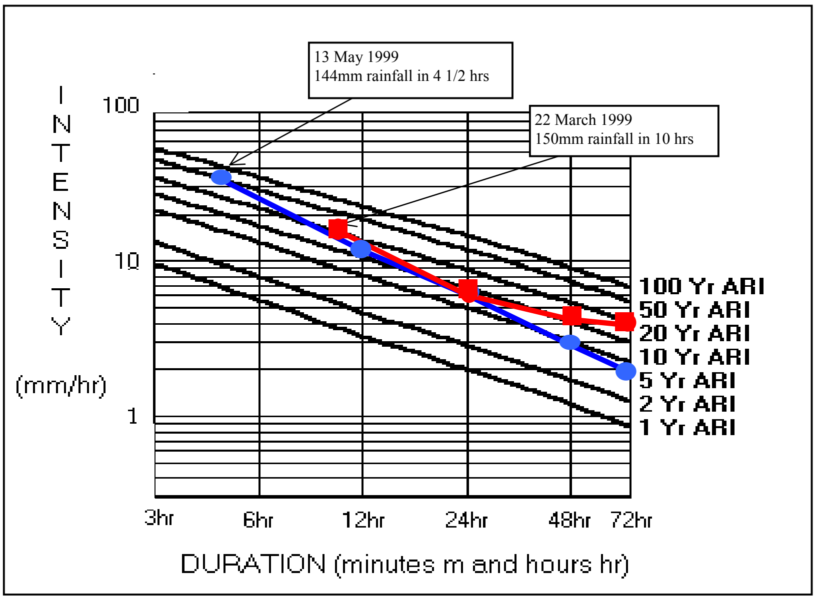

Figure 3: Exmouth IFD Curve

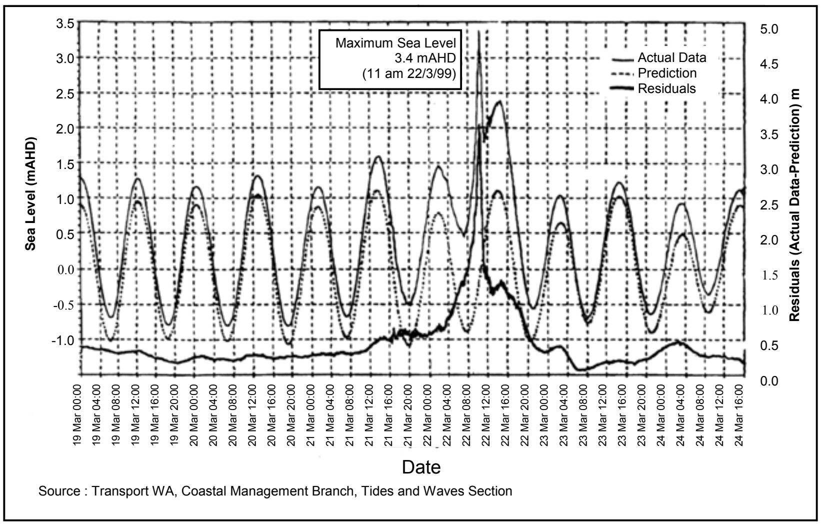

Figure 4: Exmouth Tides, Cyclone Vance March 1999

indicates a peak flood level of approximately 4.5 mAHD indicating approximately 3.6 Mm^3 of water ponded in the area between the dunes and Murat Rd. Aerial photography taken by the Department of Land Administration (DOLA) two days following the event show little ponding remaining, suggesting most water infiltrated or flowed out into the Gulf of Exmouth within 48 hours. Anecdotal evidence confirms most of this water had flowed out to the Gulf of Exmouth by 6pm on the day of the cyclone.

Peak sea levels in the Gulf of Exmouth reached 3.4 mAHD at 11:00 am on 22 March 1999 (Figure 4). Storm surge entered from the main harbour located south of the town site as well as through a natural ocean outlet located north of the golf course (Figure 2).

Based on prevailing catchment conditions (including the January 1999 bushfire), a volumetric runoff coefficient of 70% was estimated. The volume of runoff generated by the 150 mm rainfall on 22 March was estimated as 4.8 Mm^3, which exceeds the estimate of 3.6 Mm^3 available storage to 4.5 mAHD behind the coastal sand dunes. Surface runoff, rather than storm surge, was therefore considered the major factor contributing to inundation during and following Cyclone Vance.

5. MAY 13 1999 FLOOD EVENT

Based on rainfall records taken by local residents and the Bureau of Meteorology's Learmonth station 144mm of rainfall was estimated to have fallen in Exmouth between 2:30am and 7:00am on 13 May 1999. Based on the intensity for this period (32mm/hr), this event was estimated as a 1 in 50 year ARI event (Figure 3).

Similar to the March event, flooding occurred generally in the area between Murat Rd and the coast (Figure 5). Although flooding in this area was observed to be not as extensive as in March, the damage associated with the passage of water to this location was greater due to higher flows and velocities.

Assuming a volumetric runoff coefficient of 70%, as for 22 March 1999, the volume of runoff generated by the 144mm over the catchment area of 45.4 km^2 is estimated as 4.6 Mm^3. This volume is approximately 5% less than the total volume of stormwater runoff generated during Cyclone Vance.

Based on anecdotal data, floodwaters behind the dunes for the May event reached a level of approximately 3.5 mAHD. The greater amount of flooding behind the coastal dunes for Cyclone Vance is considered due to a combination of additional storm surge inflow and elevated sea levels preventing earlier discharge of floodwaters into the Gulf of Exmouth.

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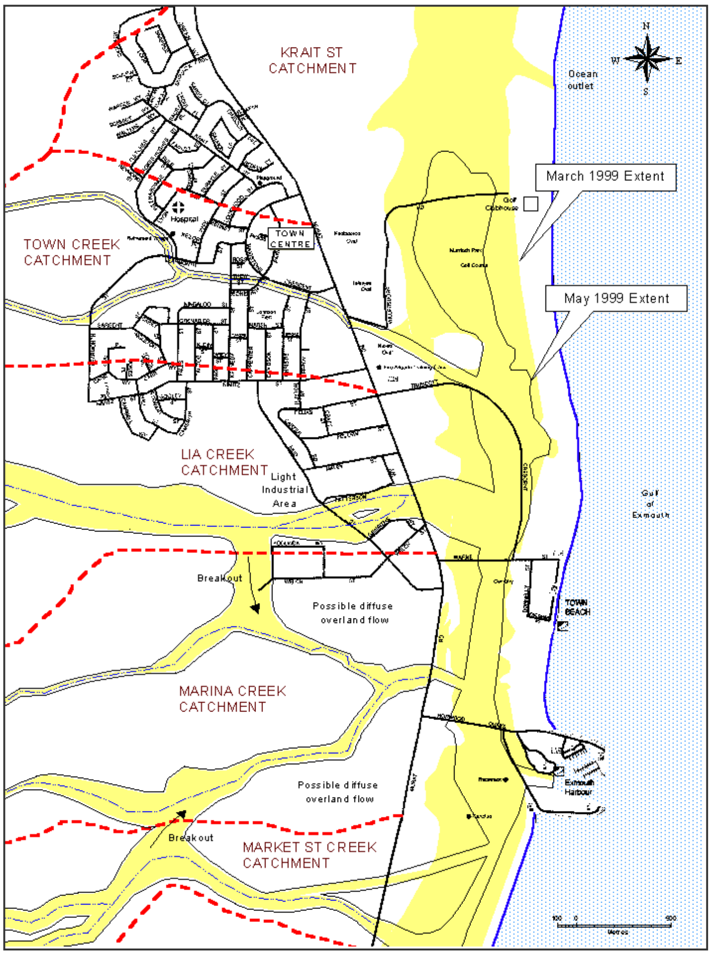

Figure 5 : Extent of Flooding for May & March 1999 Events

6. ESTIMATION OF FLOOD ARI'S

A field inspection was conducted from 15 to 17 November 1999 to record debris depths and collect data related to the 1999 floods. Debris depths within creek channels upstream of Murat Rd were assumed to represent flood depths for the more extreme May 13 event.

Flow rates and velocities for individual catchments were estimated using Manning's equation, with a channel roughness (Mannings n) of 0.03 based on field observation and Chow (1981). Velocities in the creeks were calculated to be in the order of 3 to 4 m/s, which was consistent with field observations of mobilised large limestone cobbles which indicated high velocities. Areas near Murat Rd where flow velocities decrease, resulted in cobble deposition.

The calculation of average recurrence intervals for the 13 May 1999 event flow estimates for each catchment were based on the Rational Method (IEAust, 1987) and comparing design flows and ARI's to the estimated May 1999 flows. On this basis the ARI of the 13 May 1999 flood was estimated to be in the order of 70 years. This result is consistent with the estimated ARI of the rainfall event of 1 in 50 years, and the additional runoff which could be expected from the catchment given the bushfire in January 1999.

The Flood Index Method (IEAust, 1987) was found to provide flows which were considerably smaller than the Rational Method (by a factor of 3) for similar ARI storms. These flows appear to be too small to be representative for the catchments considered given observed debris levels. If Flood Index Method estimates were considered appropriate the May 1999 event would have been an extreme event possibly in excess of 1 in 1000 years. This was considered too high an ARI given the estimated rainfall ARI.

7. DEVELOPMENT OF A FLOOD MANAGEMENT STRATEGY

The town of Exmouth is located on a floodplain where natural accumulation and deposition of runoff from Cape Range to the coast occurs. To date development of Exmouth has been deliberately away from the creek channels in order to avoid inundation of properties. This approach which has been applied since the town's establishment has paid dividends in preventing flood damage of properties during 1999. However proposals to extend future development to the area between Murat Rd and the Gulf of Exmouth have required a more detailed flood management strategy to be developed.

Proposed development in Exmouth include an Exmouth Marina Village earmarked for residential canal development, commercial mixed use development, and resort, with preliminary plans to include the concept of two flood compensating basins. Further industrial development in LIA Creek catchment near Murat Rd is also proposed.

Flood management considerations for Exmouth were divided into two broad categories of *Conveyance* and *Disposal*. No detailed hydraulic modelling was performed of the options due to budget constraints.

Conveyance refers to the provision of adequate flow paths and widths to enable the safe passage of surface water through the town where well defined existing flow paths currently exist. The existing conveyance system within the main town centre (Town Creek Catchment) performed well during both 1999 storms. The strategy for surface water conveyance is to provide 100 year ARI flood protection to developed areas via the continued use and maintenance of existing natural flow paths. This required the provision of additional bunds and consolidation of existing bunds, and the maintenance of floodway channels by the removal of accumulated sediments in creek channels adjacent to developed areas between large storm events.

Disposal refers to the provision of adequate capacity for disposal of surface water once it has passed the town. Existing flow paths downstream of Murat Rd are currently not well defined. The strategy for surface water disposal included three options; construction of detention basins, provision of additional ocean outlet capacity, and restricting floodplain development.

Opportunities for detention basins upstream of existing development are limited due to the large storage capacities which would be required to provide significant peak flow attenuation during flood events. Given the steep land immediately inland of town the opportunity for attenuating flows by storage are minimal. Preliminary plans for the Exmouth Marina Village located adjacent to the Exmouth Boat Harbour (Figure 3) include the concept of two compensating basins to be used for settlement of sediment during frequently occurring events prior to discharge to the Exmouth Boat Harbour. The storage capacity of the basins would only provide for frequent events, and events in excess of approximately a 1 year ARI event would require a spillway to discharge into canals of the Exmouth Boat Harbour.

Flow to the Exmouth Gulf currently occurs at three ocean outlets (Figure 3). They are generally efficient in terms of discharging stormwater as observed during May 1999 in which floodwaters quickly receded following the storm event. The provision of additional ocean outlets would require cutting through existing dune formations, considered likely to be environmentally unacceptable. Maintaining existing flow paths to the three existing ocean outlets is preferred in terms of stormwater disposal rather than the provision of additional ocean outlets.

The “do nothing” option involves allowing water to continue to pond in its current location and restrict developable land adjacent to the coast. This option is non preferred given the expected continued growth of Exmouth as a local and international tourist destination and the availability of engineering solutions.

Key elements of the recommended strategy are :

a). *Floodway Designation*: Designation of floodways in which development should not be permitted to occur without a detailed assessment of its impact including its obstructive effect on major flows, depth of flooding, velocity of flow, possible structural and potential flood damage, difficulty in evacuation during floods and its regional benefit.

b). *Flood Protection Bunds*: Establish new bunds and consolidate existing bunds as appropriate, especially adjacent to the LIA Creek catchment where 100 year flood protection is required.

c). *Maintenance*: Maintenance of flow channels by the removal of accumulated sediments in creek channels (particularly LIA Creek) adjacent to developed areas following large storm events. Sediment accumulation with time will reduce the capacity of the creek channel and raise upstream flood levels, increasing future risk of flooding.

d). *Opportunities for Catchment Storage*: Opportunities for the location of detention basins upstream of development in the catchments to contain flood flows are considered limited due to the large storage capacities which would be required to provide peak flow attenuation during significant flood events.

e). *Exmouth Marina Village*: Development of two compensating basins to be primarily used for the settlement of sediment during frequently occurring events prior to discharge to the Exmouth Boat Harbour. The capacity of the basins is for events smaller than typically a 1 year ARI event. The level and capacity of the basin spillways are critical to providing sufficient discharge of water to the Exmouth Boat Harbour during flood events without backwater effects.

f). *Additional Ocean Outlets*: Maintaining existing flood flow paths to the three existing ocean outlets is preferred in terms of surface water disposal rather than the provision of additional ocean outlets. The existing ocean outlets are generally efficient in terms of discharging stormwater, and additional ocean outlets should only be considered if monitoring of the flood management strategy performance indicates additional disposal capacity is required.

g). *Monitoring Strategy Performance*: Monitoring of the performance of the flood management strategy to be undertaken following significant storm events with revisions to be made as appropriate.

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8. CONCLUSION

A flood management strategy for Exmouth has been developed to provide 100 year flood protection to existing and proposed future development areas via the continued use and maintenance of existing floodways and natural flow paths to existing ocean outlets. This strategy details the designation of floodways and provision of additional bunds (including consolidation of existing bunds) to minimise flooding of properties adjacent to creek lines during storm events.

This study has not considered the impact of storm surge on flood levels and would require a more detailed study to determine joint probabilities of storm surge and flood flows.

9. ACKNOWLEDGEMENTS

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