Exmouth Floodplain Management Study

FLOODPLAIN MANAGEMENT STRATEGY

- Final
- December 2007

Executive Summary

Sinclair Knight Merz was commissioned by the Western Australia Department of Water (DoW) to develop a floodplain management strategy for the Shire of Exmouth. The Shire of Exmouth has an existing Strategy based on flooding events in the recent past. This new investigation is based on detailed hydrologic and hydraulic modelling of the investigation area. It also covers the area to the north and south of the existing development to take in all areas currently planned for future development under Council and Department of Planning and Infrastructure (DPI) strategic land planning.

The objectives of the Floodplain Management Strategy were aligned with the Standing Committee on Agriculture and Resource Management Report 73 (SCARM73), "*Floodplain Management in Australia, Best Practice Principles and Guidelines*" (CSIRO, 2000). The objectives are:

1) Limit the impacts of existing flooding problems on the well-being of individuals to acceptable levels;
2) Limit the property impacts of existing flooding problems to acceptable levels;
3) Preserve, and enhance where possible, the natural function of the floodplain to convey flood waters and/or sustain flood dependent ecosystems;
4) Encourage the compatible planning and use of floodplains as a resource for the use of the whole community.

The scope of services requested to achieve these objectives were:

- Hydrologic modelling of the catchments of the Cape Range creeks including tide and storm surge analysis in the Exmouth Gulf;
- 10, 25, 100 and 500 year ARI floodplain modelling and mapping;
- Development of a floodplain management strategy;
- Flood damage assessment study;
- Assessment of flood management options that will increase Exmouth's flood protection; and
- Evaluation of possible water harvesting opportunities.

A review of earlier studies identified that two major flooding events have occurred in the recent past. These events were associated with severe Tropical Cyclone Vance in March 1999 and a major rainfall event in June 2002. These events have been used as the basis for floodplain planning by Council. Actual flood damage costs from these events were not recorded.

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A review of Council's existing floodplain planning showed that developments and flood mitigation measures were not aligned with the SCARM objectives. Two such examples are the Exmouth Marina Village (EMV) development and the Market Street bund separating the Market St Creek and Marina Creek.

Hydrologic and hydraulic modelling was performed for the investigation area. It was found that the EMV has caused a significant alteration to the existing flooding regime in the investigation area and that measures would be required to mitigate these impacts. It was found that the Light Industrial Area (LIA)was prone to shallow flooding as was the Town Centre area.

Council requested that a series of flood mitigation measures be tested including improvement to existing drainage floodways and opening/enlarging natural breakouts to Exmouth Gulf. It was found that opening/enlarging breakouts to Exmouth Gulf had negligible impacts on regional flood levels. It was found that improvements to the LIA drainage would reduce flood damages in the LIA and would mitigate flood damage on Murat Road caused by the EMV.

The existing Market Street bund was found to be too low to be an effective flood mitigation measure and no evidence could be found to support the quality of its design or construction. Therefore, it was not considered to be suitable as a flood mitigation measure. At the time of the study, Council was required to assess the EMV development. Without the bund, the EMV development level was too low and would be costly to elevate to the appropriate flood immunity. Therefore, Council requested that the Market Street bund be considered as part of the flood mitigation strategy and agreed that its design and construction requires a full and immediate review.

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The resulting Floodplain Management Strategy recommended the following.

Flood Mitigation Measure	Description	Discussion
Structural	LIA Creek Improvements	The improvement of drainage structures where LIA Creek crosses Reid Street and the extension and upgrade of floodway levees to contain the 100 year ARI flow in bank for conveyance to the east of Murat Road
	Replacement / Upgrading of Market Street bund	Engineering assessment of the Market Street bund for adequacy. Raising and extending the levee and potentially replacing/upgrading the existing structure to convey Market St Creek across Murat Road.
	Murat Road Causeways	• Initial work to upgrade the crossing of Market Street Creek over Murat Road to allow for the increased flow due to the Market Street bund. • The gradual replacement of floodways along Murat Road with culvert or bridge structures to increase accessibility along Murat Road to the town centre during flood events.
Non-Structural	Land Use Planning	Setting aside land under "floodway" designation in Council planning to avoid inappropriate development. Planning and management of land under "flood fringe" designation to avoid regional flooding impacts.
	Building Development Controls	Setting of minimum floor levels for future developments to ensure adequate 100 year ARI flood protection.
	Flood Emergency Response Planning	Planning for flood emergencies by ensuring plans are in place for evacuating isolated communities and avoiding damage or isolation of critical Council and emergency services infrastructure.
	Streamflow / rainfall gauging, data collection and ongoing review	Installation of streamflow and rainfall gauging to provide ongoing data. This will enable the findings of this study to be monitored and reviewed.

As part of the study, the Shire of Exmouth required that SKM also investigate the capacity to harvest some of the floodwaters to supplement the town water supply. Based on the intensity and infrequency of rainfall events in Exmouth and the high evaporation rates, it was deemed that it was not feasible to undertake harvesting and storage of surface water. The only likely method of harvesting water was through improving inflow to the regional groundwater aquifer.

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Contents

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Figures

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Government of Western Australia

Tables

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1. Background

Sinclair Knight Merz was commissioned by the Western Australia Department of Water (DoW) to develop a Floodplain Management Strategy (Strategy) for the Shire of Exmouth. The Shire of Exmouth has an existing Strategy based on past flooding events. This new investigation is based on detailed hydrologic and hydraulic modelling of the investigation area. It also covers the area to the north and south of the existing development to take in areas currently planned for future development under Council and Department of Planning and Infrastructure (DPI) strategic land planning

1.1 Study Objectives and Scope

The Standing Committee on Agriculture and Resource Management Report 73 (SCARM73), "*Floodplain Management in Australia, Best Practice Principles and Guidelines*" (CSIRO, 2000) sets out four principal objectives to floodplain management:.

1) Limit the impacts of existing flooding problems on the well-being of individuals to acceptable levels;
2) Limit the property impacts of existing flooding problems to acceptable levels;
3) Preserve, and enhance where possible, the natural function of the floodplain to convey flood waters and/or sustain flood dependent ecosystems;
4) Encourage the compatible planning and use of floodplains as a resource for the use of the whole community.

These objectives were adopted for this investigation. The scope of services requested to achieve these objectives were:

- Hydrology of the catchments of the Cape Range creeks including tide and storm surge analysis in the Exmouth Gulf;
- 10, 25, 100 and 500 year ARI floodplain modelling and mapping;
- Development of a floodplain management strategy;
- Flood damage assessment study;
- Assessment of flood management options that will increase Exmouth's flood protection; and
- Evaluation of possible water harvesting opportunities.

1.2 Investigation Area

This section gives a brief introduction and description of study area elements. The investigation area is shown in Figure 1-1 and Figure 1-2.

Exmouth Marina Village (EMV) – The Exmouth Marina Village is a recent development that is ongoing at the time of the development of this Strategy. The EMV is a canal development that is being constructed east of Murat Road, interfacing with the Exmouth Gulf at the existing Exmouth Boat Harbour. The canal is constructed in an area of land that was previously a depression and drainage path for all of the flow from the Market Street and Marina Creek catchments and a portion of the LIA Creek catchment.

The EMV passes the flow from these catchments via a spillway on the southernmost canal arm fronting Murat Road (Canal Arm 4) and a spillway to the north on Madaffari Drive.

The EMV has not experienced flooding as it was developed after the last major flooding events in 1999 and 2002.

Exmouth Boat Harbour – The boat harbour is a small harbour that services some local fishing vessels and provides permanent moorings to recreational and commercial craft. The harbour is at the mouth of the EMV canal development.

The boat harbour suffered damages in the 1999 and 2002 flood events. A fishing vessel was sunk in 1999 when a surge of floodwaters entered the harbour from upstream. It is believed that this surge was the result of the failure of an upstream embankment, possibly a road, which had been holding back floodwaters. Several fishing trawlers were also damaged whilst moored in the harbour during the June 2002 event.

Murat Road – Murat Road is the main road into Exmouth and provides the primary evacuation route for residents into and away from the town. The road is elevated above the water level that naturally ponds behind the eastern coastal dunes.

Murat Road is crossed by all of the drainage lines in the investigation area. The crossings are causeways with some minor culvert drainage structures to pass low flows.

Reid Street – Reid Street is an important road that leads from Murat Road, up into higher terrain behind the LIA and into the west of town. Reid Street has a number of causeway crossings of drainage lines that flow into the ponded area behind the coastal dunes.

McLeod Street Breakout – This breakout is to the south of the EMV and is known to have opened during the 2002 flood event as part of natural coastal processes. The breakout is being kept open through sand extraction activities managed by Council.

Northern Breakout – The Northern Breakout is an opening through the coastal dunes north of the townsite. It is the largest of the breakouts that drain the area that ponds behind the coastal dunes. The Northern Breakout is subject to coastal process of wind and waves that will close the breakout over time. With each significant flood event, the breakout is generally reformed.

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- Figure 1-1 Investigation Area North

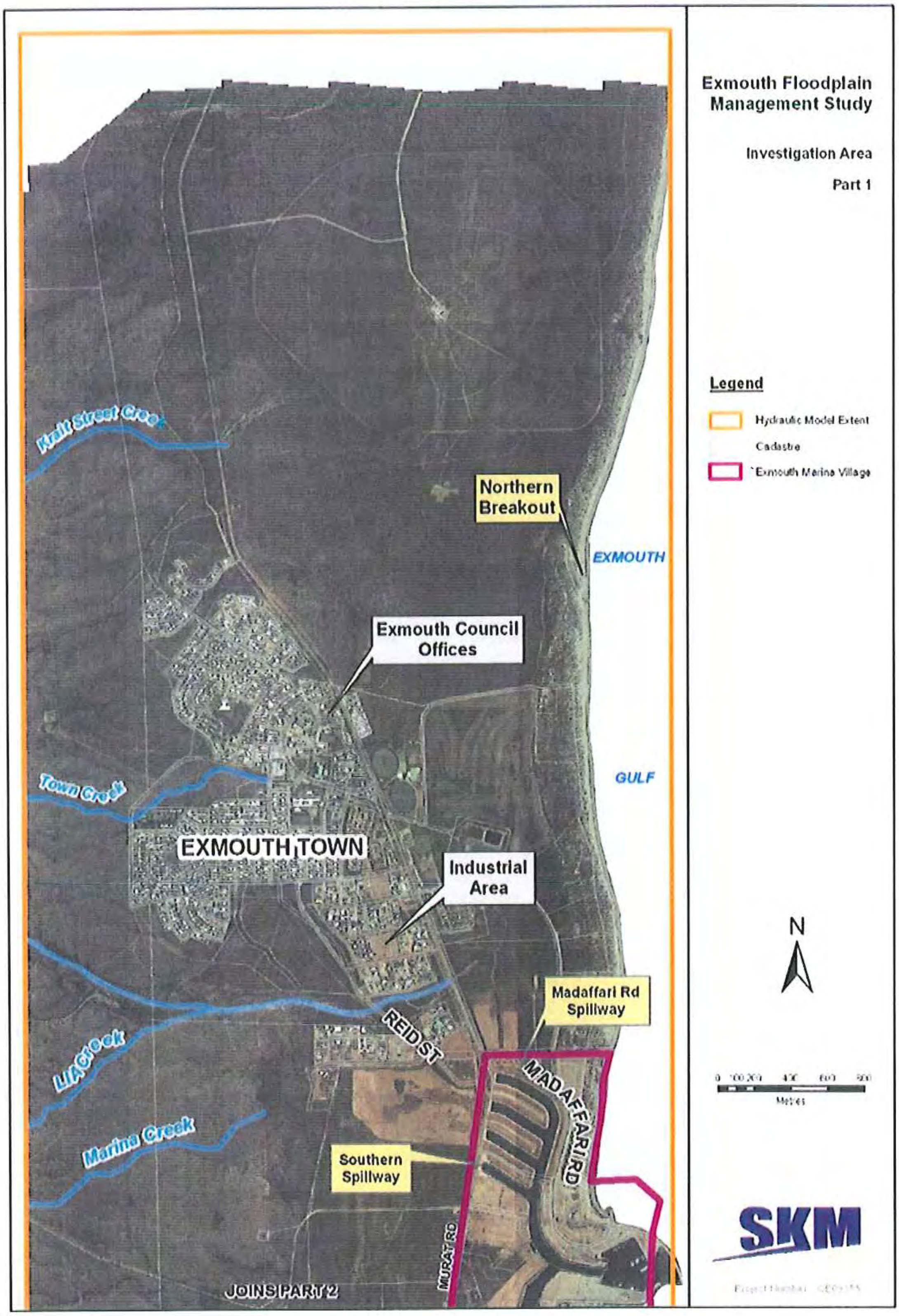

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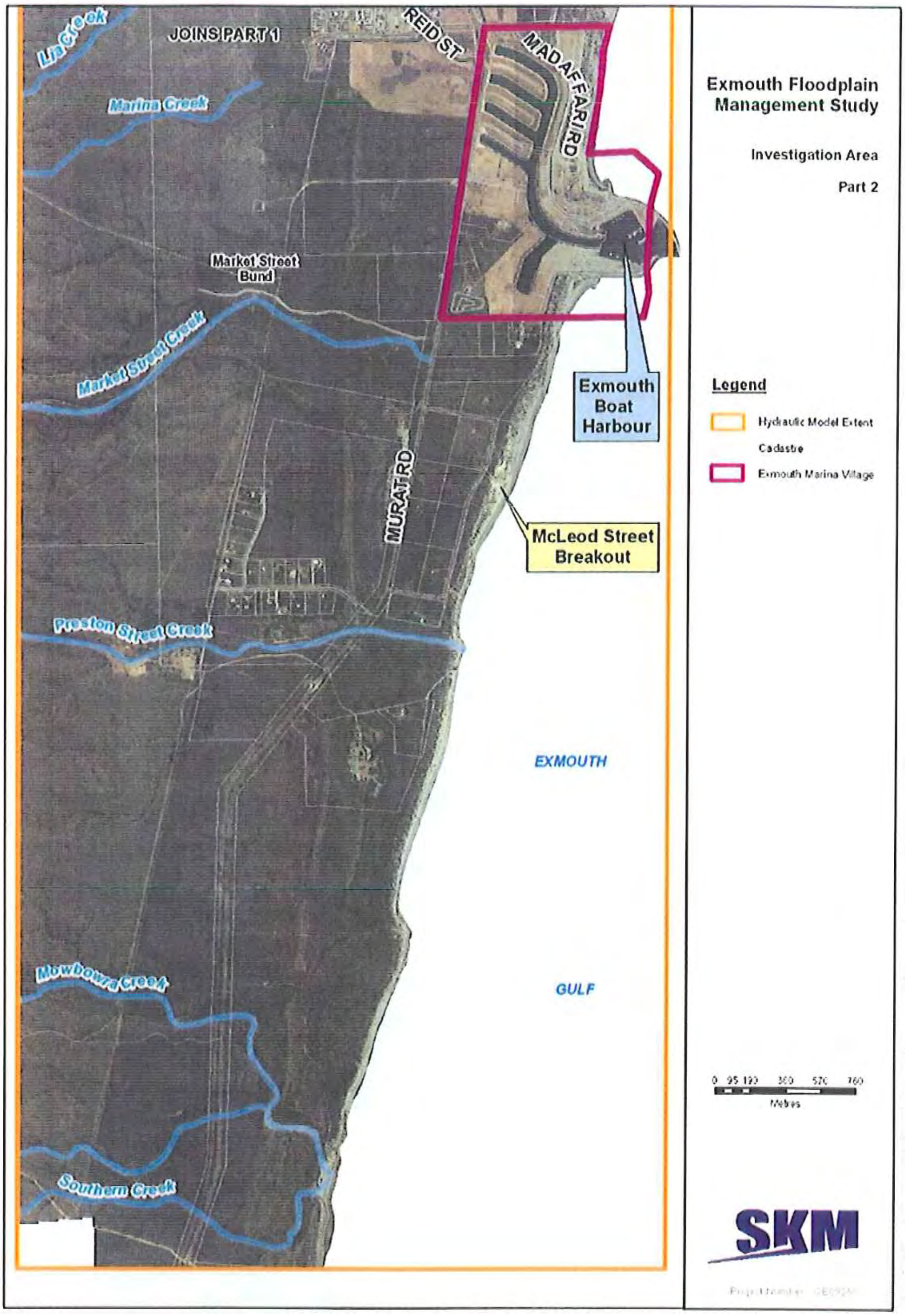
Figure 1-2 Investigation Area South



1.3 History of Flooding

Two recent flood events dominate the records of major flooding for Exmouth. These events occurred in March 1999 and June 2002. The March 1999 flood event was the result of severe Tropical Cyclone Vance which crossed the coast near Exmouth. This is discussed further in Section 3.1.1.

The second major flooding event occurred in June 2002. It was a significant rainfall event occurring in winter. The event caused widespread flooding through a longer, more drawn out rainfall event which included the wettest June day on record in Western Australia (BoM, 2002). More detail is provided in Section 3.1.2.

Both of the recorded flood events broke the banks of the drainage lines from the upstream catchments. Damage was focussed in the Light Industrial Area (LIA). The flooding in both instances damaged roads. Boats in the Exmouth Boat Harbour were damaged in both these events. During Cyclone Vance, an upstream embankment was breached by floodwaters and sent a surge of water into the boat harbour. There was only one report of residential impacts in the March 1999 event and this was in Preston Street where a resident reported that the Preston Creek bund was breached (JDA, 1999).

1.4 History of Floodplain Development

Development in the investigation area has generally been limited to the higher terrain away from the floodplain around the central business area. The town site has experienced some flooding from the Town Creek catchment but this has been limited and without extensive damages.

As development has expanded away from the Town Centre, it has encroached into the LIA Creek floodplain with the development of the Light Industrial Area. Flood mitigation measures have been put in place to pass LIA Creek flooding while avoiding flooding impacts on the industrial development.

The EMV has been developed on and adjacent to the drainage path that once flowed from the LIA Creek, Marina Creek and Market Street Creek catchments. The EMV has incorporated spillway structures to pass floods from these catchments and detailed hydraulic modelling has been done in this investigation to understand the impacts of the development.

A bund has been constructed on the floodplain between the Market Street Creek and Marina Creek catchments. The structure prevents flow from Market Street Creek from crossing into the Marina Creek catchment and flowing into the EMV. A discussion on the effectiveness and impacts of this measure is contained in Section 4.2.2.

1.5 Institutional Framework

The Department of Water is the State's lead floodplain management institution and provides guidance on floodplain management issues in Western Australia. It is the Department's responsibility to "*develop plans for and provide advice on flood management*". These activities are advisory only as the Department of Water is not an approving authority.

The DoW uses the following guideline principles to ensure proposed development in floodprone areas is acceptable with regard to major flooding:

- Proposed development has adequate flood protection from a 100 year ARI flood.
- Proposed development does not detrimentally impact on the existing flooding regime of the general area.

The DoW assists Council in guiding appropriate landuse planning and establishing building development controls to ensure developments conform to their guiding principles. DoW adopts risk based floodplain management principles as set out in documents such as *Floodplain Management in Australia – Best Practice Principles and Guidelines* (SCARM73, CSIRO, 2000).

2. Physical and Social Setting

The town of Exmouth is remote in the north west of Western Australia. The nearest communities are Carnarvon, 350km to the south, and Karratha, 570km to the north east. The area has a short European history. The economy of the area is driven by tourism, based on the natural assets of the nearby Cape Range and Ningaloo Marine Park.

2.1 Area History and Tourism

The town site of Exmouth was initially developed from the early 1940s. Most of the development seen today was built in the early 1960s, based on joint Australian and United States military interests in the area. Prior to that time there was limited settlement in the area that serviced pearling and sparse pastoral interests. A nomadic indigenous tribe was known to pass through the area frequently up to the early 1900s.

The major growth in Exmouth occurred with the establishment of the North West Cape Communications Station and development of a local prawning and pearling industry in the area.

There is limited European cultural heritage in the area due to its recent settlement however the area is rich in natural assets such as the Cape Range National Park and the nearby Ningaloo Marine Park and Ningaloo Reef.

2.2 Cape Range

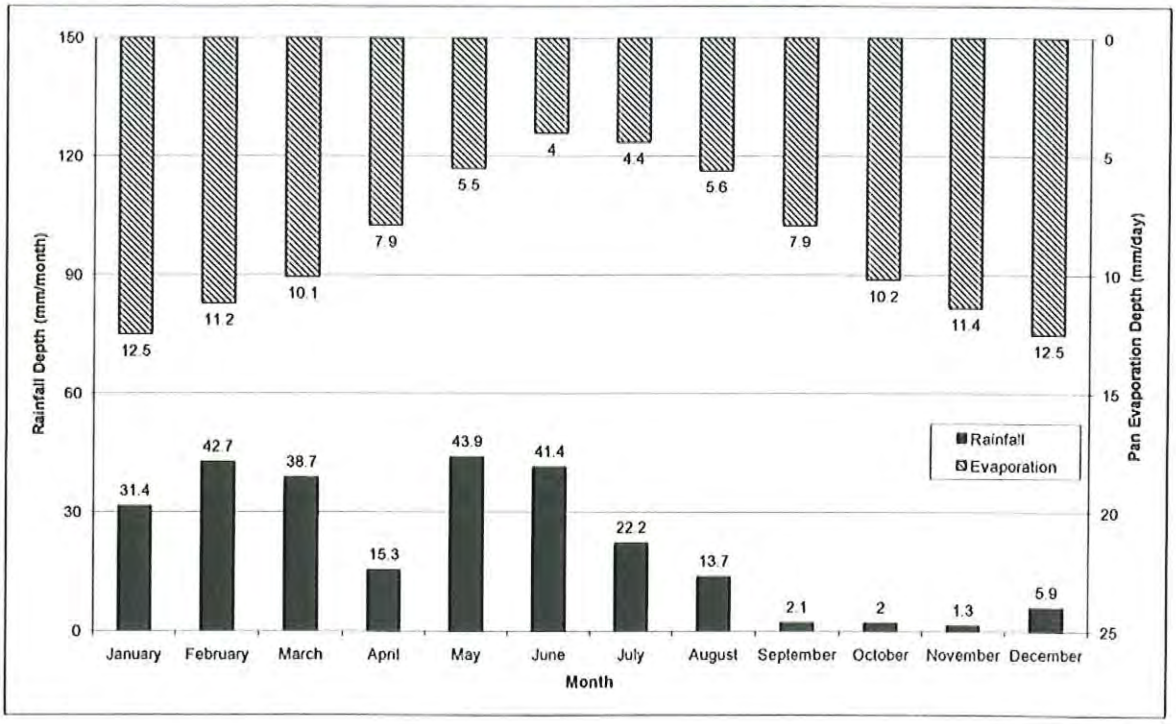
The catchments draining through the investigation area flow from Cape Range. The Cape Range National Park is approximately 40 kilometres from Exmouth on the west coast of the North West Cape and the eastern flanks of Cape Range drain to the Exmouth Gulf.

The Cape Range is rugged limestone with sparse vegetation that drains east to the coastal plans. Coastal dunes detain runoff to create ponded water behind the coastal dunes which help to sustain diverse, sparse vegetation communities in the lowland areas.

2.3 Climate

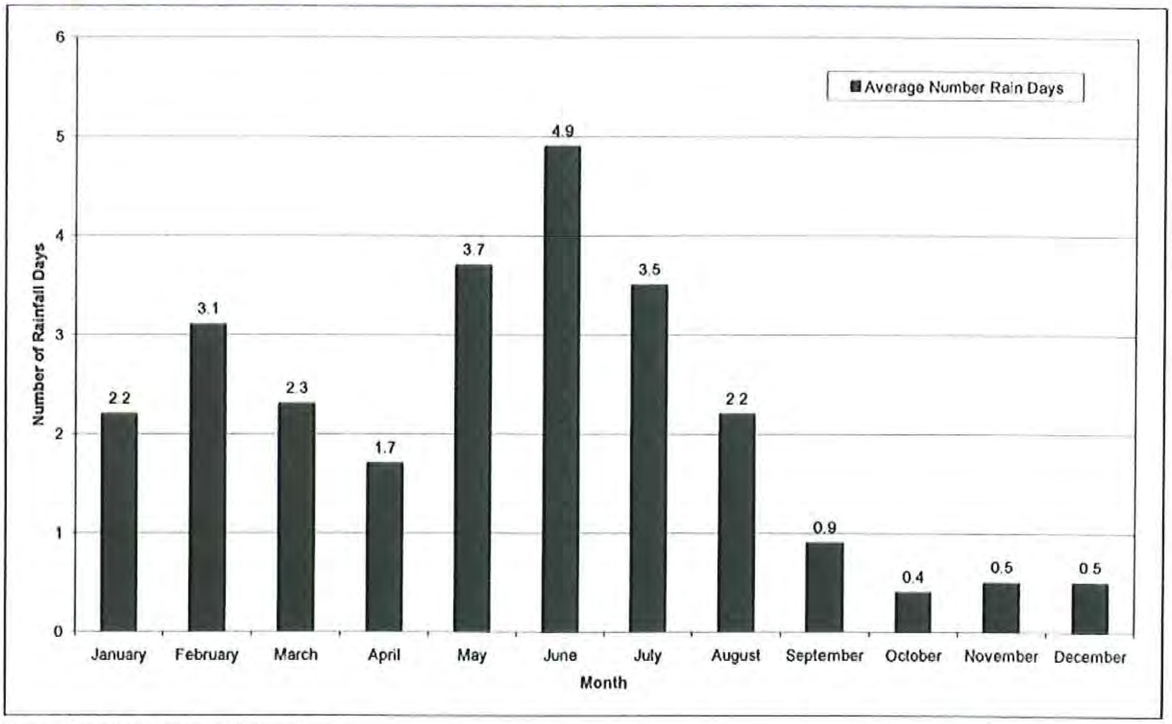
The climate of the region is characterised by very hot summers and temperate winters. Most of the rainfall occurs either during January to March or from May to July. During January to March rain is generally associated with thunderstorms and cyclonic low pressure systems. The area has a history of cyclones passing into the Exmouth Gulf and causing storm surge, high winds and rain. From May to July, tropical cloud bands often bring heavy rains from the northwest (BoM, 2007). Average annual rainfall is approximately 260mm with evaporation well exceeding this at over 3100mm. Figure 2-1 to Figure 2-3 show the average climatic data for the area on a monthly basis.

▪ Figure 2-1 Average Rainfall and Daily Evaporation by Month (Learmonth Airport)



Source: Australian Bureau of Meteorology

▪ Figure 2-2 Average Number of Rain Days by Month (Learmonth Airport)



Source: Australian Bureau of Meteorology

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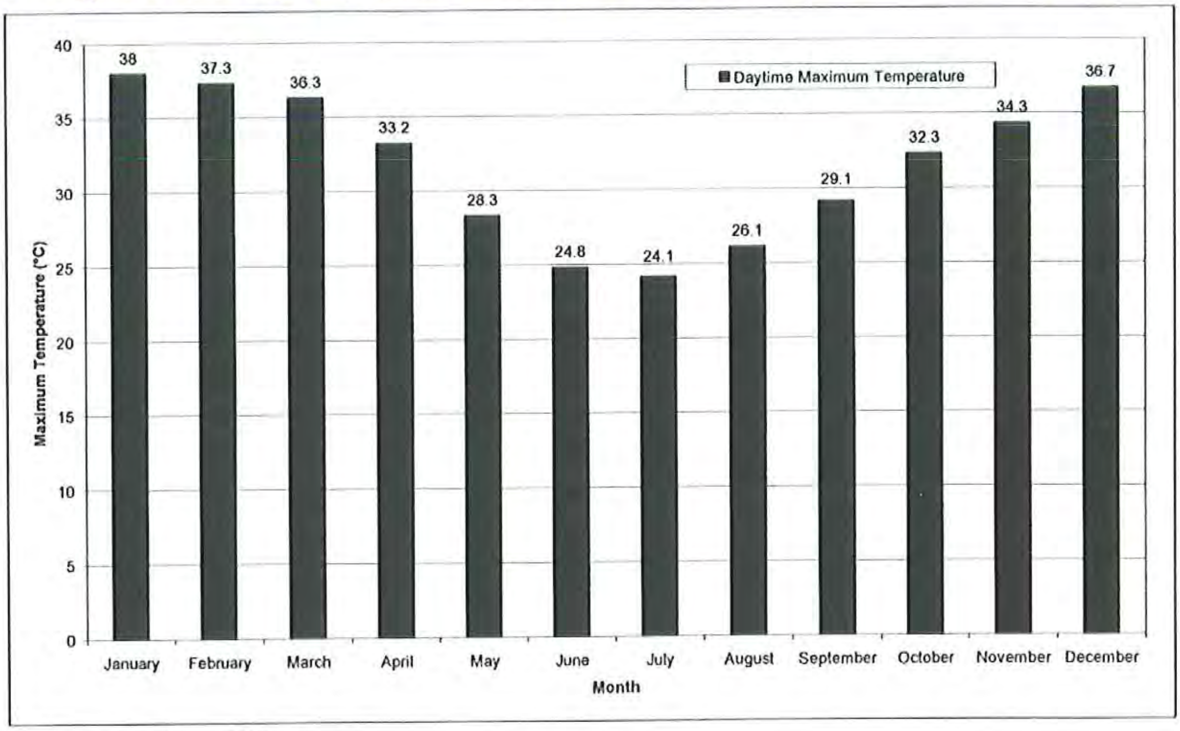
- Figure 2-3 Average Daytime Maximum Temperature by Month (Learmonth Airport)



Source: Australian Bureau of Meteorology

2.4 Living with Floods

The residents of Exmouth are familiar with flooding. However, with a large transient residential and tourist population, the awareness of Exmouth's flooding is assumed to be not high. The only access road to the town and its services is Murat Road. Murat Road has numerous causeway crossings along its length and these causeways flood during runoff events affecting vehicular and pedestrian access to the township. Flooding is normally short in duration and the community can manage, however, it creates risk as it isolates the population from emergency services.

In recent years, Exmouth has experienced two significant rainfall runoff events that have caused flooding. They occurred with Cyclone Vance in March 1999 and in a very large rainfall event of June 2002. The June 2002 event was a significant winter event with 304.6mm of rainfall recorded in 24 hours, which broke the previous single day June rainfall record for Western Australia by more than 30mm. The June 2002 event also exceeded the town's average annual rainfall in a single day.

Both the 1999 and 2002 rainfall events were large and an assessment of 24 hour regional rainfall data placed the 2002 event between 100 years and 200 years annual recurrence interval (ARI). The rainfall events caused extensive flooding behind the coastal dune system. This was exacerbated by high tide levels, particularly in the 1999 event, coincident with cyclonic storm surge.

Exmouth is the subject of extensive planned growth. New development must be conscious of the area's flooding potential and cognisant of the isolation that flooding may cause. This Floodplain Management Strategy, combined with detailed hydrologic and hydraulic modelling, is required to better understand the flooding issues and predict potential flooding impacts.

3. Hydrologic and Flooding Characteristics

The worst recorded flooding in the investigation area was attributed to cyclonic activity or deep low pressure systems impacting the western coast and Exmouth Gulf. In particular, two flooding events were referred to extensively during consultation in the community. These were the March 1999 Tropical Cyclone Vance and a major rainfall event in June 2002. Both events caused flooding and damage.

This Section describes the history of flooding in the study area and summarises the hydrologic and hydraulic modelling that has been undertaken to develop this Floodplain Management Strategy.

This report refers to a number of watercourses in the investigation area being (listed from north to south):

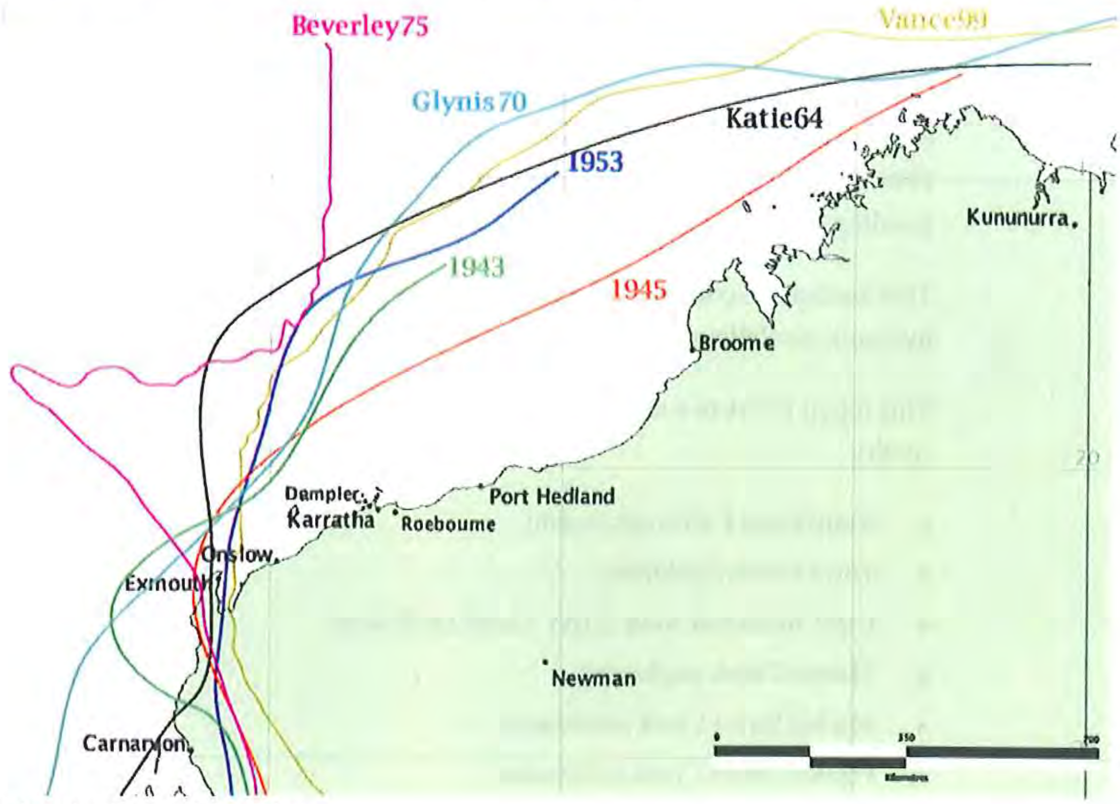
- Krait Street Creek catchment;
- Town Creek catchment
- Light Industrial Area (LIA) Creek catchment;
- Marina Creek catchment;
- Market Street Creek catchment;
- Preston Street Creek catchment;
- Mowbowra Creek catchment; and
- Unnamed southern catchment

Figure 1-1 and Figure 1-2 show the investigation area and locate the various watercourses within the area.

3.1 Historical Cyclonic and Flooding Events

The North West Cape and Exmouth Gulf is the most cyclone prone area of Australia. In March 1999, it experienced one of the most powerful cyclones in Australia's recorded history (BoM, 2000) with Cyclone Vance. Figure 3-1 shows a track of significant cyclones that have impacted on the Gulf area. The Bureau of Meteorology predicts that a cyclone can be expected in the Exmouth region every second or third year on average. However, the interval between cyclones varies greatly as climatic patterns take multi-decadal cycles.

- **Figure 3-1 Recorded Exmouth Gulf Cyclone Tracks**



Source: Australian Bureau of Meteorology

3.1.1 Severe Tropical Cyclone Vance – March 1999

Severe Tropical Cyclone Vance crossed onto the mainland at Exmouth on 22 March 1999. More than 10% of the buildings of the town suffered damage and the cyclone brought a damaging storm surge. A winds gust of 267km/hr was recorded at Learmonth Meteorological Office and this was the highest wind gust ever recorded on mainland Australia.

The majority of the damage relating to the cyclone resulted from wind damage and there is little record of major flooding damage. Rainfall from this event was approximately 207mm measured at the Learmonth gauge. A storm surge of 3.6m at Exmouth caused extensive beach erosion and stranded marine vessels. The cyclone produced a maximum storm surge of over 5.0m near Onslow.

3.1.2 June 2002 Flood Event

On 4 June 2002, Exmouth had the wettest June day on record for Western Australia with 304.6mm of rain recorded in 24 hours. The rainfall was generated by a deep low pressure system that was trapped in the Exmouth Gulf. The system was widespread and also provided rains as far south as Perth in the same 24 hours.

The rainfall event caused extensive inundation, especially in the coastal flats behind the dunes.

3.2 Consultation

The Exmouth community and Council were consulted as part of the development of this study and this Section outlines the discussions.

Previous investigations, as outlined in Section 4.1, also contain anecdotal evidence of the two major flood events and this information was collected soon after the events occurred. This information was referred to extensively to understand the flooding characteristics of the investigation area.

3.2.1 Exmouth Golf Course

Kerry Graham, former CEO of the Shire of Exmouth, toured the investigation area and described his experience through the two significant flood events of town. Mr Graham confirmed flood behaviour and was able to show a June 2002 flood mark in the golf course area. Mr Graham confirmed that the flood filled the ponded area behind the coastal dunes and discussed how the water levels dropped quite rapidly once the rainfall ceased. The flood mark supplied was used as part of the hydraulic model validation exercise discussed in a subsequent Section.

The Exmouth Golf Course holds photographs of the June 2002 flood event which were reviewed as part of the investigation.

3.2.2 Video of June 2002 Flood Event

A video was supplied by Council which films the progress of a four wheel drive vehicle in transit from the north of Exmouth to the south beyond the Exmouth Boat Harbour to the McLeod Street Breakout during the June 2002 flood event. The video provides numerous interesting pieces of validation data.

The video shows that a very small area of higher land remained free from flooding, believed to be on the corner of McLeod Street and Murat Road where a vehicle appears stranded. This point was validated to confirm that it was predicted to remain flood free in the June 2002 event.

The video captured the flow velocity and depth in the area of the petrol station on the corner of Murat Road and Maidstone Crescent and the station owner provided photographs to confirm this aspect.

3.2.3 Light Industrial Area Flooding

Properties through the LIA were inspected. Flood marks were still present through a workshop in Griffiths Way and this showed that the flooding was approximately 300mm deep through the area. The description of the flooding suggested that the hydraulic structures upstream of the LIA were not adequate to pass flooding and the water flowed onto Reid Street.

Once the water was on Reid Street, it was able to break from the banks of the LIA Creek and flow through the LIA.

3.2.4 Service Station on Murat Road

Photographs were provided at the intersection of Murat Road and Maidstone Crescent. The photography showed that the flooding through this intersection was a high velocity and this was confirmed through the video of the June 2002 event. The high velocities at this location were evident in the subsequent flood modelling.

3.2.5 Previous Investigations

The *Exmouth Flood Management Study* (JDA, 1999) provided anecdotal evidence and photography of the March 1999 event. The *Review of Exmouth Flood Management Study – Assessment of June 2002 Flood Event* (JDA, 2002) provided similar anecdotal evidence and photography of the June 2002 event. It also included a field assessment to photograph, survey and document flood debris levels throughout the town for the June 2002 event.

3.3 Catchment Response to Rainfall

Flood modelling was undertaken to better understand the catchment response to rainfall. This was done in two parts, by constructing a hydrologic model of the catchments to estimate the runoff from rainfall and then a hydraulic model to predict flow patterns and inundation from the runoff. The development of the hydrologic and hydraulic models was presented in detail in a separate report *Exmouth Floodplain Management Strategy – Flood Modelling Report* (SKM, 2007) and a summary is presented.

The hydrologic model predicted that the catchments are slow to respond to rainfall due to high initial losses and continuing losses in the upper catchment. This was due to the exposed, fractured limestone absorbing much of the rainfall unless the rainfall was intense enough to overwhelm its uptake. The lower catchment was more responsive, notably in areas where the limestone was covered with a thin soil layer.

Further details and mapping of the flooding behaviour is contained in Section 3.3.3.

3.3.1 Model Calibration

The hydrologic modelling could not be calibrated as there are no streamflow monitoring gauges in the area. It was necessary to use an iterative approach whereby the hydrologic model was developed on parameter values based on regional estimates and the resulting flows were tested in the hydraulic model. The flooding extent and inundation depths were then verified against recorded and anecdotal flood records to check for consistency. Parameters in the hydrologic model were then modified and the hydraulics tested again until a suitable calibration was achieved.

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A sensitivity analysis was undertaken to improve the confidence in the results of the hydraulic model. The sensitivity to numerous elements was tested including tidal boundary conditions, surface roughness and the elevation of the Northern Breakout. The sensitivity analysis showed that the inundation of the upper reaches of the model area was sensitive to the hydraulic roughness adopted. In the lower reaches, the hydraulics was dominated by the storage available behind the dunes. Making changes to tidal conditions, roughness or breakout elevation had little effect due to the large volume available for flood storage.

The validation successfully replicated the flooded extent of the investigation area for the June 2002 flood event. However, this cannot be considered to be a thorough calibration of the hydrology nor the hydraulics. The work completed here should be fully calibrated and validated once flow information and flood level data is collected for future flood events.

3.3.2 Design Rainfall and Runoff Estimation

Design storm rainfall depths (Table 3-1) were derived using the method of *Australian Rainfall and Runoff* (IEAust, 1998) and input to the hydrologic model discussed in the previous section. Design flows were developed for the 10, 25, 100 and 500 year ARI events. The one hour and three hour storms were found to be critical for the Creeks within the investigation area. Peak flow discharges are reported for the "Existing Case" at specific locations (Table 3-2).

- Table 3-1 Summary of Design Rainfall Depths (mm)

Duration (hours)	Event (1 in y ARI)			
	10	25	100	500
1	57	74	106	146
3	82	109	161	230

- Table 3-2 Summary of Design Flood Peak Discharges in the Investigation Area

Catchment	Peak Discharge (m^3/s)				Critical Storm
	Q10	Q25	Q100	Q500	
Krait St – Nth	2.0	8.7	23.9	43.3	1 hr
Krait St – Sth	22.1	52.9	124.0	200.7	1 hr
Town Creek	4.0	6.3	11.2	17.5	3 hr
LIA Creek	27.5	65.9	151.9	277.5	1 hr
Marina Creek	12.8	27.3	53.9	85.6	1 hr
Market Street Ck	44.3	112.1	271.8	473.8	1 hr
Preston Street Ck	4.3	10.8	26.1	45.3	3 hr
Mowbowra Creek	8.2	19.6	45.8	78.9	3 hr
Southern	28.3	69.6	159.1	274.9	1 hr

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3.3.3 Design Flood Inundation and Flow Behaviour

The design floods were modelled in a hydraulic model. Inundation extents and flow characteristics were developed for the 10, 25, 100 and 500 year ARI events. Numerous flow durations were considered and it was found that the 1 hour and 3 hour duration storms were critical at various locations in the investigation area. Therefore, both the 1 hour and 3 hour duration events were modelled and the results were interrogated to produce a single map that showed only the peak inundation from these two durations for each single event. Mapping of flood inundation and flow velocity are provided in Appendix A.

Two scenarios were modelled when establishing the initial hydraulic model. These were:

1) ***Existing Case*** – this scenario used the terrain data collected at the commencement of the study and included all cut and fill for development that had already been approved by Council. This scenario included the proposed flood mitigation around the EMV but excluded the Market Street bund and this is discussed later in Section 4.2.2.
2) ***Pre-Canals Case*** – this scenario was used to assess the flow behaviour prior to the construction of the canals of EMV. This used the terrain data captured at the commencement of the study and the area of EMV was replaced with survey data from prior to its construction. Areas of fill that had occurred since the 1999 flood event were removed and returned to an approximation of the pre-development terrain.

The hydraulic model found that flow would approach the investigation from the upland slopes with speed and intensity. It was generally contained in defined channels until it reached the lowlands behind the coastal dunes. Here it would pond and slowly discharge to the Exmouth Gulf via a number of breakouts through the coastal dune system.

The hydraulic modelling suggested that the amount of storage behind the coastal dune system was significant when compared to the quantity of floodwaters flowing off the catchment. The area behind the dunes was able to fill and cater for the volume of a large flood without impacting on the existing Exmouth townsite. Here it would remain stored unless a breakout was available. This was an important finding in the hydraulic modelling as it meant that this land is critical as it could be set aside as it provided a large detention area, thus buffering the townsite from flooding.

The hydraulic modelling found that the flow patterns of the investigation area had been greatly modified by recent development. The drainage of the LIA, Marina and Market Street Creeks previously flowed to the Exmouth Gulf via the Exmouth Boat Harbour after ponding behind the coastal dunes. This area has subsequently been developed into the canal estate of the EMV and has been engineered to reduce the flow into the canal system through a bund diverting the Market Street catchment and walls on the western face of each canal, facing Murat Road. The EMV canal system and a bund between the Market Street Creek and the Marina Creek catchments have been constructed subsequent to the large floods and have yet to be tested by major flooding.

Development in the Light Industrial Area was found to encroach onto the LIA Creek floodplain with the area experiencing shallow and rapid flooding. This is exacerbated by low capacity culverts on Reid Street, upstream of the LIA, which causes overtopping of roads and passing floodwaters down roads rather than inside defined floodway channels and protective bunding.

The outputs of the Existing Case hydraulic modelling for the 10, 25, 100 and 500 year ARI events are shown in Appendix A. The 100 year ARI inundation mapping for the Pre-Canal Case is also shown in Appendix A.

4. Effectiveness of Current Floodplain Management

Previous assessment of development on the floodplain in Exmouth has been based on historical flooding. Previous investigations had quantified the discharges of catchment flow around the townsite and in the LIA Creek and Market Street Creek catchments. Limited work has been done in areas to the north and south of this general area.

Regional scale hydraulic modelling of design flood events had not been done. Therefore, there was a limited understanding of how various elements of the floodplain interact.

This Section discusses previous floodplain management investigations and the flood mitigation measures that have arisen from those studies.

4.1 Previous Studies

Two investigations currently guide Council in floodplain development in Exmouth:

1) *Exmouth Flood Management Study* (JDA Consultant Hydrologists, 1999)
2) *Review of Exmouth Flood Management Study – Assessment of June 2002 Flood Event* (JDA Consultant Hydrologists, 2002)

4.1.1 Exmouth Flood Management Study (JDA, 1999)

This flood management study was triggered by the flooding impacts experienced by Cyclone Vance. The study objectives were to:

- Identify drainage catchments within the townsite;
- Document and map areas of the townsite inundated by surface water during Cyclone Vance;
- Estimate 100 year ARI rainfall, flow rates and potential inundation areas in the townsite;
- Develop flood management options;
- Assess flood risk within the townsite given existing drainage infrastructure and future development proposals; and
- Develop a recommended flood management strategy.

The study reported issues with the current drainage scheme along Preston Street where residences were flooded in the Cyclone Vance flood event. It also reported that the drainage along LIA Creek was inadequate and required further consideration to avoid flooding of the Light Industrial Area.

The study considered the then proposed development of the EMV and the expansion of the Light Industrial Area to the south of Welsh Street.

Flood mitigation options were proposed on the basis of anecdotal flood records projected onto a coarse terrain model. No regional hydraulic modelling was done to validate existing flood hazards or the benefits of the proposed measures.

Figure 4-1 is extracted from the JDA (1999) report showing the proposed flood mitigation measures. The Study investigated options for:

- Detention basins;
- Additional ocean outlets; and
- Constraints on floodplain development

The recommended strategy for the investigation is summarised below:

Floodway Designation

Designated floodways in accordance with Figure 4-1 with flood impact assessment required for development in the floodways.

Flood Protection Bunds

Flood protection bunds to:

1) Preston Street Creek catchment to protect residential properties of Preston Street
2) LIA Creek catchment along Griffiths Way to protect the Light Industrial Area
3) Marina Creek catchment in the area of Welsh Street and Koolinda Way to protect existing development
4) No additional bunding in Town Creek, Market Street Creek or Quarry Creek with natural breakout flows to continue.

Flood Channel Maintenance

Regular maintenance of existing channels with the removal of sediment deposited from large events.

Flood Detention Basins

Detention opportunities considered to be limited if the intention was to mitigate large floods. The EMV canal development proposed compensatory storage upstream of Murat Road for small rainfall runoff events.

Ocean Outlets

Maintenance of the existing ocean outlet recommended and additional outlets considered after maintenance of the strategy.

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Monitoring

The strategy was to be monitored subsequent to future flooding events.

Funding

Funding to be sought for clearing of creek channels in developed areas.

4.1.2 Review of Exmouth Flood Management Study – Assessment of June 2002 Flood Event (JDA, 2002)

This report arose after the June 2002 flood event which damaged boats in the Exmouth Boat Harbour and caused some minor property impacts. The scope of the works of the review was:

- A site inspection to identify the extent and severity of flooding for the June 2002 event, and recording of debris levels and their location;
- Comparison of the June 2002 event with previous significant flood events in March and May 1999;
- Comparison of the June 2002 event with the estimated 100 year ARI flood estimates in JDA (1999); and
- Based on the outcomes of the above analysis, review the recommended flood management strategy of JDA (1999)

The review found that the rainfall event of June 2002 approximated the 100 year ARI, 24 hour rainfall depth and the maximum 12 hour rainfall depth exceeded the 100 year ARI, 12 hour rainfall depth.

The June 2002 event occurred independently of a storm surge which increased discharge velocity through the Exmouth Boat Harbour that damaged moorings and vessels. The anecdotal evidence of flood behaviour and extent was recorded as being similar between the 1999 and 2002 events despite the 2002 event being almost twice the runoff volume. A new outlet to the Exmouth Gulf formed south of the Exmouth Boat Harbour during the event (McLeod Street Breakout).

The revised strategy extended designated floodways based on recorded flooded extents. It recommended that the new ocean breakout be maintained and advised that the proposed compensatory storage basins associated with the canal development had been deleted from the canal design planning.

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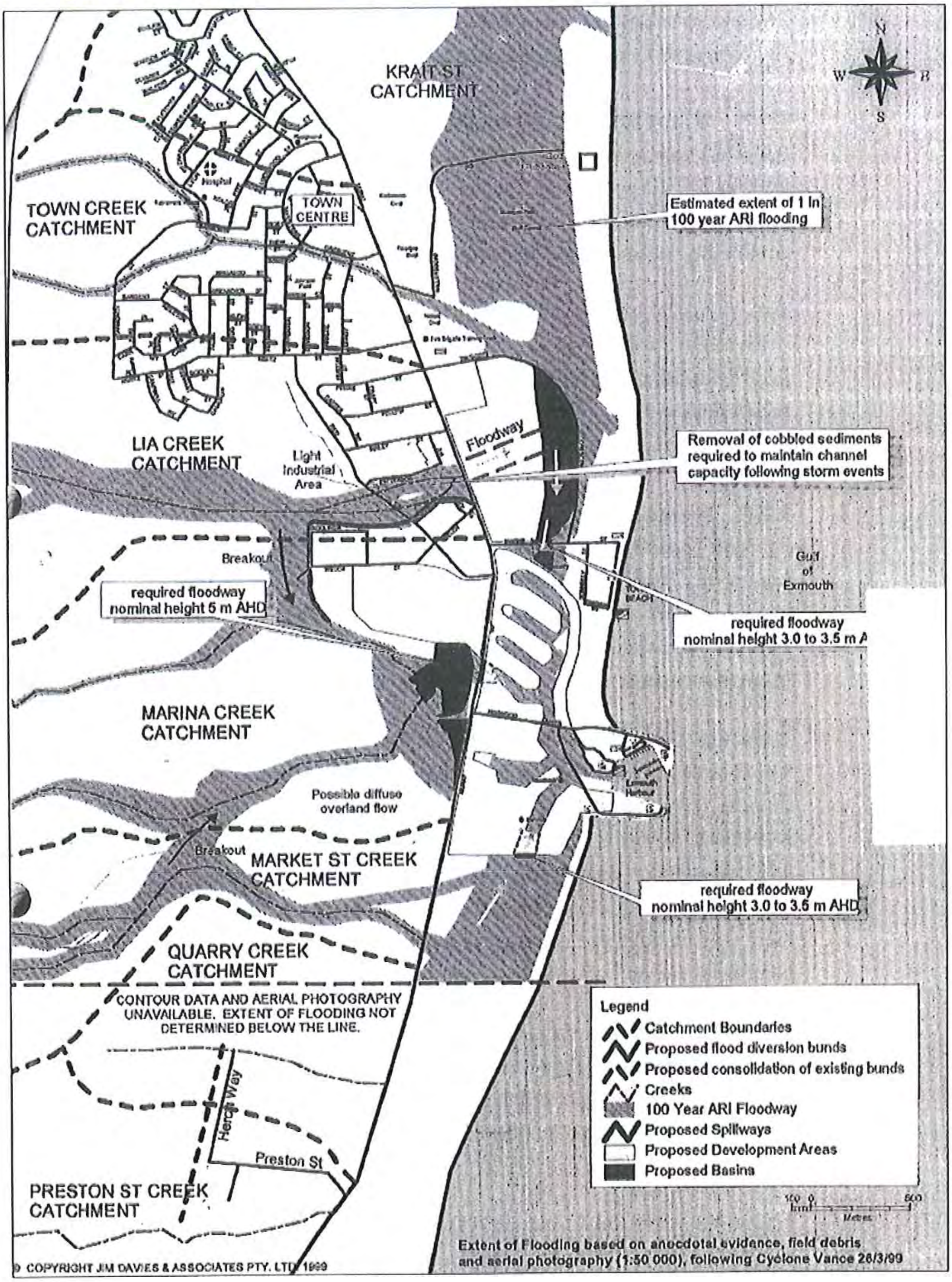
Figure 4-1 JDA (1999) Proposed Flood Management Measures



4.2 Existing Floodplain Development and Management Measures

The site investigation and hydraulic modelling identified existing floodplain development and flood mitigation measures that are considered worthwile and these are discussed below:

4.2.1 Murat Road Causeways

All of the catchments of the Cape Range drain across Murat Road via causeways. As discussed in Section 2.4, the permanent residents of Exmouth are familiar with the flooding in the area and are aware that runoff events cut Murat Road. However, this is possibly not the case with tourists or community members who frequent the area outside the rainfall season.

This investigation was undertaken to understand the limitations to development to the south and north of Exmouth townsite. As development extends to the north and south it will further isolate itself from the services of the town including emergency care. Therefore, development should be undertaken with awareness of this limitation and causeways may have to be replaced with bridges or culverts to lower the frequency and duration of road closure.

4.2.2 Market Street Bund

An earth levee was constructed on the ridge separating the Market Street Creek and Marina Creek catchments after the June 2002 flood event. This was constructed on the recommendation of Landcorp (pers. comm. Keith Woodward, ESC, 2006). The intent of the design appears to be to stop the interconnection of the Market Street and Marina Creeks in larger flow events and thus lessen the quantity of flow towards the EMV and through into the Exmouth Boat Harbour.

Initial runs of the hydraulic model found that the bund was very effective at diverting flow that would have otherwise passed into Marina Creek. However, the subsequent impact of this is to increase flow and the level of flooding south of the Exmouth Marina Village and around existing residences. It was also found that the bund was unlikely to cope with a 100 year ARI flood event as it was not high enough and would be overtopped. The quality of the material or the design / construction was not assessed and design information could not be supplied by Council. Therefore, there was a heightened risk that the failure could cause increased flooding problems downstream if a failure occurred.

Through discussions with the Department of Water and Council, it was decided that the bund was an unacceptable floodplain management practice due to the impact it would have on existing residential developments and the limited benefit that it provided existing flood affected areas. Therefore, it was agreed that the bund should be considered not to be in place in the "Existing Case" scenario.

Figure 4-2 shows the difference in flood levels caused by the Market Street bund. Areas in red show where flood levels have increased and the degree of increase is shown in the legend.

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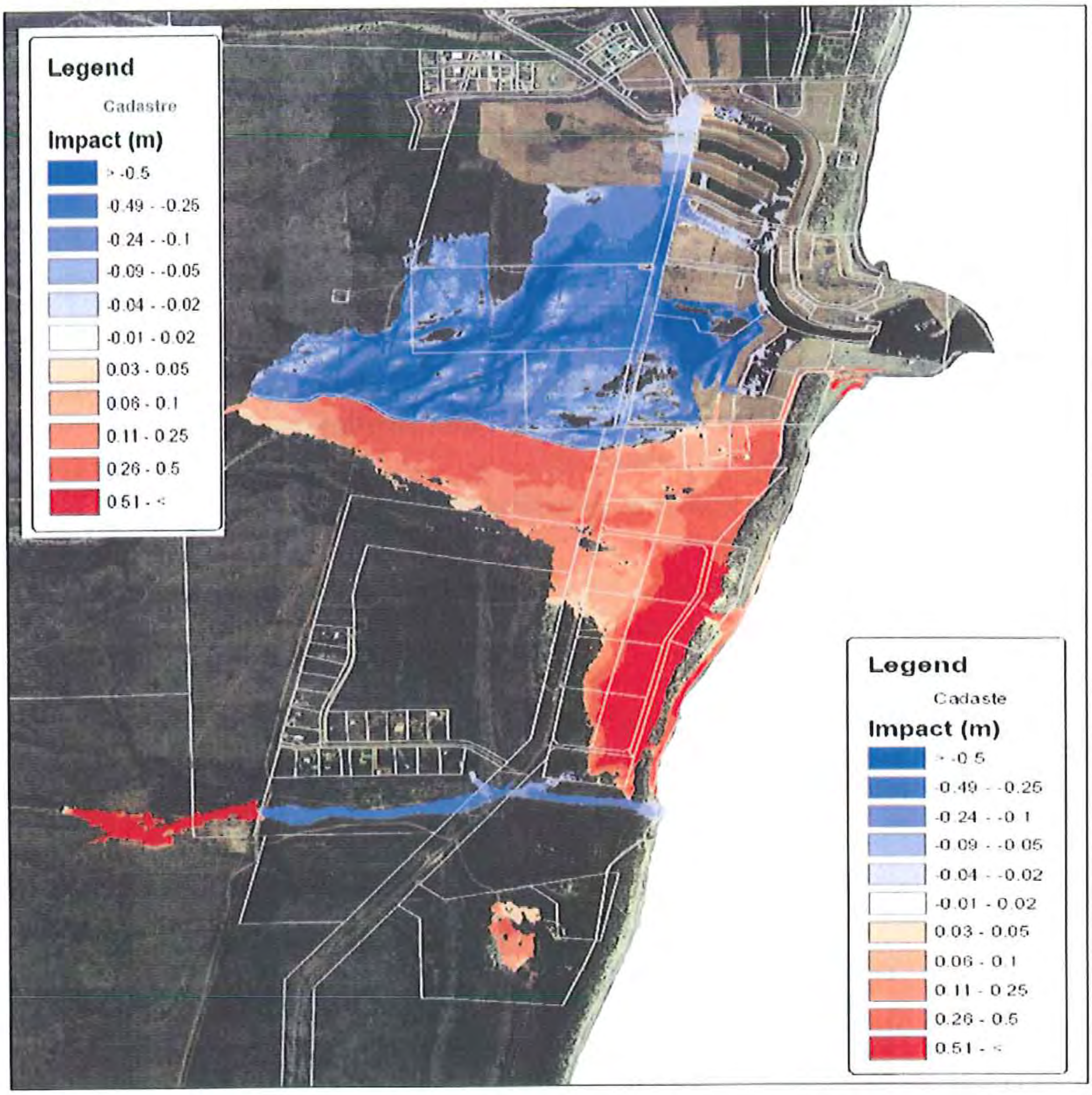
▪ Figure 4-2 Impact of the Market Street Bund on Q100 Flood Levels



The Figure shows that the bund dramatically reduced flood levels north of the structure and all the way through Marina Creek and to the EMV. The Figure shows that south of the EMV, the Market Street bund pushes flood levels up by more than 500mm and has increased flood levels at existing residences by 100 to 250mm.

During the course of the investigation, the residences affected by the bund were demolished and the land was subject to development conditions that would require the land to be filled. On this basis, the Market Street bund was considered as a flood mitigation measure in the "Developed Case" and this is discussed in Section 5.4.6.

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4.2.3 EMV Canal Development

EMV canal development has involved extensive filling of an area of floodplain storage behind the coastal dunes. The filling has occurred without providing compensatory storage for floodwaters and the canal spillways have not been designed to provide adequate conveyance to pass all of the flow previously passing through the original breakout into the Boat Harbour. The JDA (1999) discusses a southern spillway and upstream detention storage for the EMV however these measures have not been included in the development construction.

Hydraulic modelling found three key elements of the EMV development needed further consideration and mitigation:

1) EMV development forces floodwaters from the LIA Creek to flow south down Murat Road at high velocity where it previously passed directly across the road and flowed out of the Exmouth Boat Harbour;
2) EMV development increases flood levels south of Market Street and in areas of existing development; and
3) EMV development is not constructed to a level that will provide 100 year ARI flood immunity in the Existing Case – that is assuming the Market St bund will fail.

The EMV has resulted in a concentration of flood flows and higher peak discharges and water levels through the Exmouth Boat Harbour. Table 4-1 compares the peak discharge from the Q100 flood at various locations around EMV before and after development.

Table 4-1 Changes in 100 year ARI Peak Discharges Due to EMV Development

Location	Peak Discharge Pre-Canals (m^3/s)	Peak Discharge Existing Case (m^3/s)
Flow over Madaffari Drive to the Exmouth Boat Harbour	13.2	15.9
Exmouth Boat Harbour ocean outfall	142	218
Flow southward along Murat Road	N/A – flow crossed Murat Road	26.3

Prior to the EMV development, the floodwaters of LIA, Marina and Market Street Creeks and some of the floodwaters ponded from Town and Krait Street Creeks would pass through a main breakout to the Exmouth Gulf via the Exmouth Boat Harbour. Before it could pass through the Exmouth Boat Harbour, it would fill low-lying land behind the coastal dunes which provided flood detention storage, lessening the peak discharge.

The filling of the floodplain area has impacted on the flooding regime as now floodwaters must enter the canals before they can flow through the Exmouth Boat Harbour. There are only two points of ingress to the canals. These are:

1) A constructed spillway on Madaffari Drive; and
2) A constructed spillway on Murat Road

A third spillway proposed to the south of the canals in JDA (1999) does not appear to have been considered in the design and has contributed to higher flood levels south of the EMV.

The spillway on Madaffari Drive was found to be adequate to pass a flow discharge similar to the Pre-Canals scenario. Prior to development, water ponded north of Warne Street from the LIA and Town Creeks. It would flow generally across a broad length of Warne Street to the Exmouth Boat Harbour. However, the discharge was limited because the controlling elevations of the outlet to the Exmouth Gulf were high. With the constructed spillway, the flow is concentrated to a narrow spillway into the canals, passing a similar peak discharge.

It is important to note that the spillway will drain water ponded behind the dunes for the length up to the Northern Breakout. As discussed previously, this storage zone is very large and can hold almost the entire volume of the 100 year ARI flood event. The spillway has only a small capacity and thus, it is possible that it will flow for much longer than the causeways on Murat Road. Therefore, there is the potential to isolate the community of the new canal estate from town for a lengthy period if this road is the only point of egress from the residential area.

The flood modelling found that water breaks out from the LIA Creek and flows down Reid Street and through the Light Industrial Area. This water cannot enter the EMV without flowing south down Murat Road to the southern spillway. The 100 year ARI flood event will flow down approximately 500m of Murat Road at a high velocity and would cause damage and scour. In the lesser 10 year ARI event, it was still flowing with damaging depth and velocity. Therefore, consideration would need to be made to resolve this. Mitigation options were developed to limit the flooding out of the LIA Creek catchment and an assessment was made of how long Murat Road might be cut by flooding and how often and how long it would take to be repaired to a serviceable standard after flooding has subsided.

Figure 4-3 shows the impact predicted for the 100 year ARI flood event due to the EMV development.

The hydraulic modelling also showed that the EMV development level is too low if the Market Street bund failed during the 100 year ARI flood event. The southern area of the EMV is most susceptible to flooding and areas to the north have inadequate freeboard to the constructed levels.

To the south of the EMV, floodwaters from the Market Street catchment cannot flow into the EMV and Boat Harbour as they did in the Existing Case. A spillway proposed in the designs presented in JDA (1999) was not constructed. The flooding is forced to the south and it directly impacts on existing dwellings and land. This floodwater has no egress to the Gulf except through dune breakouts further south. The impact of this is well represented in the hydraulic modelling however it is likely that broader environmental impacts will occur due to this increased flow causing a change to the geomorphology of the dune breakouts south of the EMV. These impacts have not been assessed in this study.

All the three EMV development impacts required thorough assessment to undertsand how they could be managed and mitigated.

4.2.4 Filling of Floodplain North of EMV

Future development was planned for land north of EMV and east of Murat Road. Filling had commenced at the time of the study. As discussed previously, this is an area that was very important as it provides flood storage behind the coastal dunes. If this filling activity continues, it will remove floodplain storage and concentrate flows and increase peak discharges similar to what has been experienced at the mouth of the Exmouth Boat Harbour due to the EMV development.

4.2.5 Filling in the Marina Creek Floodplain

Fill was placed on the floodplain of a creek that forms a part of the Marina Creek floodplain, south of Welch Street. This area previously conveyed the flood flow of this small creek and breakout flow from the LIA Creek. Channel works may be required to give this channel definition and to convey the water more effectively to the Exmouth Boat Harbour. At the time of this study, the flows from Marina Creek will run into, and along, the edges of the fill. In the absence of any channel works, it is recommended that scour protection of the affected edges (particularly in the south west corner) is carried out to prevent the erosion of this imported fill.

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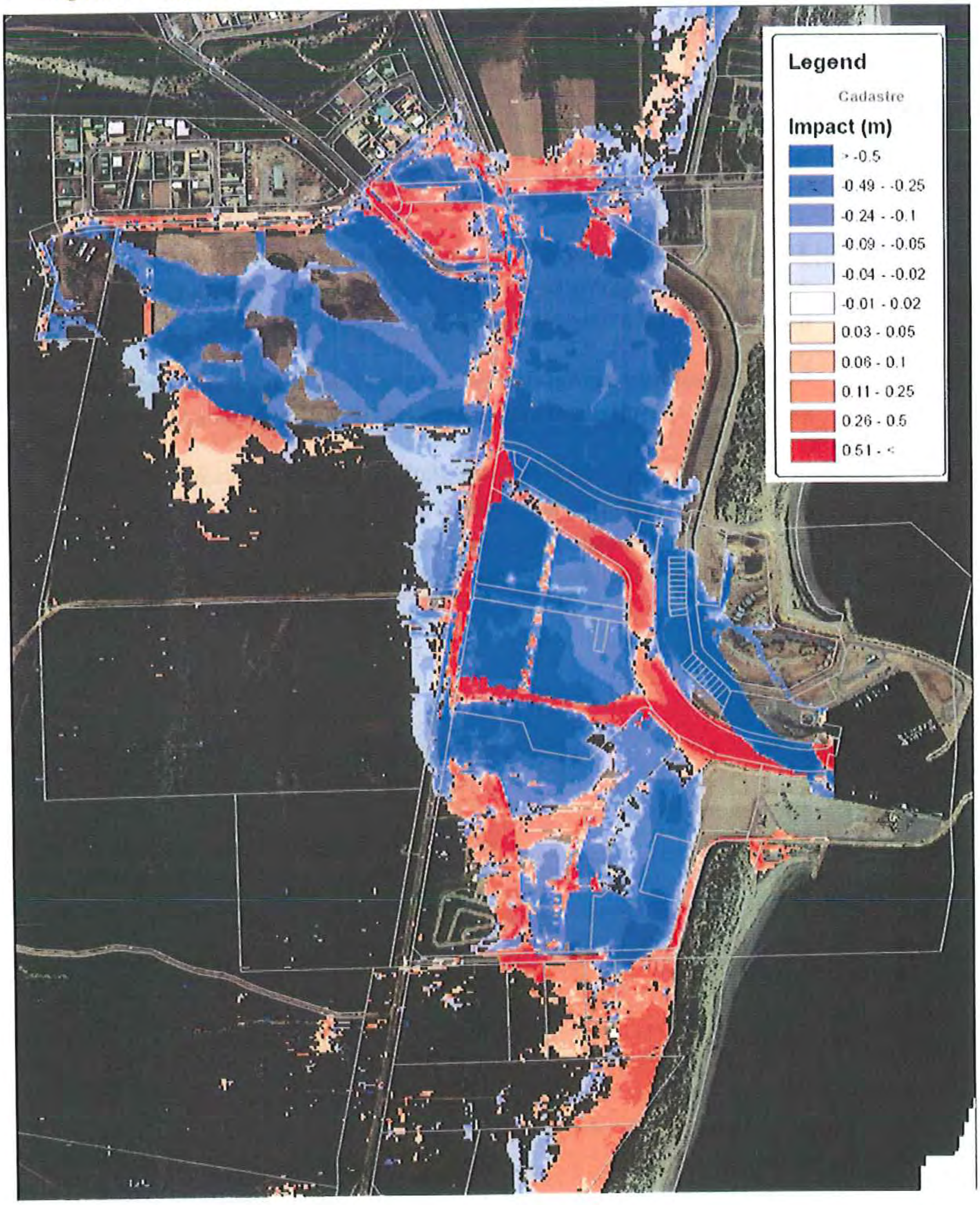
- **Figure 4-3 Impact of the EMV Development on Regional Q100 Flood Levels**



4.3 Summary of Findings

A review of the previous studies shows that the Council's current floodplain management planning was focussed on managing existing flooding problems. Council has previously focussed development on the higher land west of Murat Road and away from creeks and this had avoided flood damages from significant flood events. Current planning and ongoing development has begun to encroach on the natural flooding regime and thus flooding impacts are likely, as shown in the hydraulic modelling.

To date, floodplain management planning has been undertaken on the basis of anecdotal flood records of recent significant flood events. No hydraulic modelling has been done to validate the hydraulic impacts of development and quantify impacts at a regional scale.

Existing floodplain management practices has been founded on sound principles and objectives except for the development of the EMV and the Market Street bund.

In summary, Council has been successful in avoiding flood damages through controlled development however, as development pressure of the waterways and the floodplains increase, so will the level of assessment required to manage flood impacts increase. The EMV and Market Street bund are recent developments and have not been tested by floods.

5. Options for Floodplain Management

Floodplain management measures can be broadly categorised into four categories as described in SCARM73 and summarised in Table 5-1.

Table 5-1 Summary of Available Floodplain Management Measures

Floodplain Management Measure	Description	Appropriate for
Non-Structural Measures		
Land use planning	This non-structural measure was accepted as being the most cost effective through controlling development on flood prone land. Aspects of this measure includes: ▪ Incorporate land use planning for floodplain management into statutory planning instruments; ▪ Voluntary land acquisition in more hazardous flood areas ▪ Assess the cumulative regional impact of developing areas of floodplain rather than ad-hoc assessment of individual developments	Planning for future development and fixing existing problem areas where voluntary acquisition can occur.
Development and building controls	This non-structural measure encourages planning construction methods that reduce the likelihood of permanent damages to properties. Measures include: ▪ Appropriate siting of dwellings and planning for road corridors to support evacuation and flood mitigation; ▪ Encourage construction methods appropriate to flood prone lands; and ▪ Consider the introduction and certification of flood proofing of individual dwellings	Planning for future development and fixing existing flooding problems if dwellings can be flood proofed after initial construction.
Flood emergency response plans	Flood emergency response plans accept that there is a residual flood risk and plans for appropriate response and recovery. This measure requires the development of a flood emergency response plan complimentary to this floodplain management plan and with consideration of flood events up to the probable maximum flood.	Planning for existing and future development.
Structural measures		
	Structural measures need to be developed with consideration that, unless designed for the probable maximum flood, they may eventually be overwhelmed. When this occurs, they may exacerbate flooding problems rather than alleviate them. Structural measures need continuous maintenance and upkeep and, therefore, must be accepted as an asset by the Council and managed as such. Such measures include: ▪ Levees; ▪ Detention basins; and ▪ Diversion channels	Planning for future development and fixing existing flooding problems.

This Section outlines the objectives of the floodplain management plan and the methodology used to develop floodplain management options. It discusses the existing flood hazard and the relative effectiveness of the mitigation measures that have been considered.

5.1 Objectives for Floodplain Management

SCARM73 set out four principal objectives to floodplain management:

1) Limit the impacts of existing flooding problems on the well-being of individuals to acceptable levels;
2) Limit the property impacts of existing flooding problems to acceptable levels;
3) Preserve, and enhance where possible, the natural function of the floodplain to convey flood waters and/or sustain flood dependent ecosystems;
4) Encourage the compatible planning and use of floodplains as a resource for the use of the whole community.

These objectives were adopted for this investigation.

5.2 Assessment of Existing Flood Hazard

The development of floodplain management options was guided by SCARM73 and the Department of Water.

SCARM73 recommended that flood hazard should be considered as a function of flood depth and velocity as well as considering the ability to evacuate populated areas. Figure 5-1 schematises the SCARM73 flood hazard categories. The assessment of flood hazard by this method required that the flood depth and velocity be known throughout the investigation area and the combination of the results were assessed against the graph to give the relevant hazard category.

The following Table 5-2 described the typical flow conditions associated with each hazard category as defined by the SCARM73 report.

The WA Department of Water has provided their recommended floodplain development strategy which is shown on Figure 5-2.

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Figure 5-1 SCARM73 Flood Hazard Categories

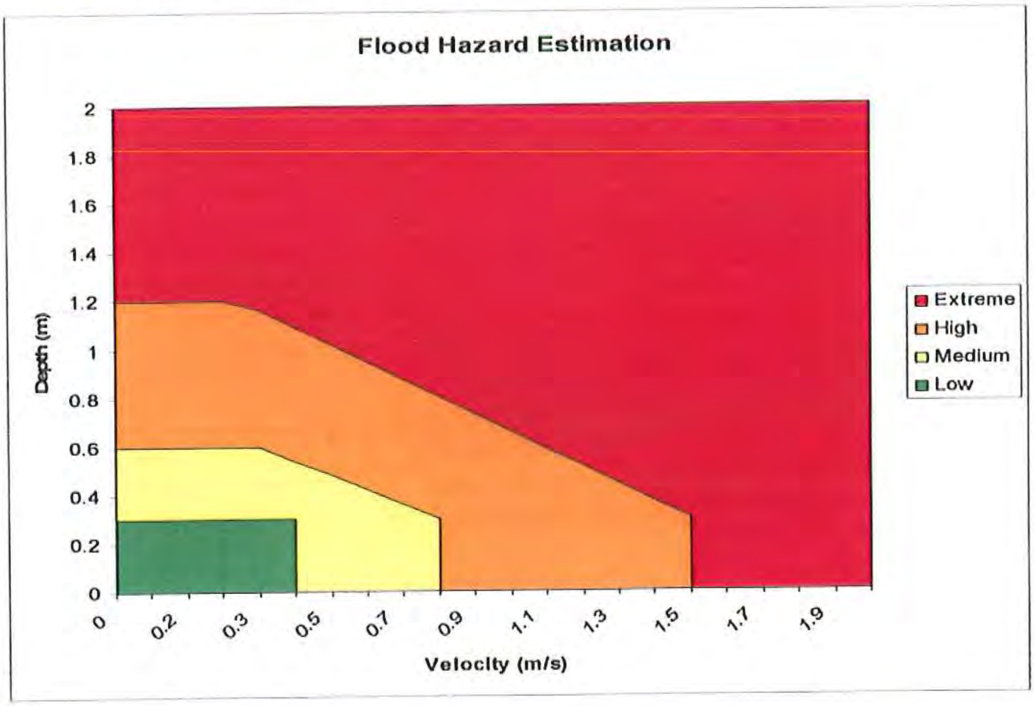

Table 5-2 SCARM73 Hazard Category Descriptions and Appropriate Land Uses

Hazard Category	Description	Appropriate Land Uses
Low	▪ No significant evacuation problems with short evacuation distances. ▪ Children and the elderly can wade safely. ▪ Evacuation is possible in a small sedan vehicle. ▪ There is ample time for flood warning and flood forecasting and evacuation.	▪ All including residential and commercial. ▪ Emergency services. ▪ Communication facilities.
Medium	▪ Fit adults can wade safely but children and adults may have difficulty. ▪ Evacuation distances are longer. ▪ Maximum flood depth and velocities are higher. ▪ Evacuation by small sedan type vehicle is possible in the early stages of flooding after which 4WD vehicles are suitable.	▪ Residential and commercial ▪ No emergency services.
High	▪ Fit adults can wade with difficulty. ▪ Flood depths are up to 1.0m and velocities exceeding 1.5m/s ▪ 4WDs and trucks are the only vehicles able to evacuate. ▪ Boats and helicopters may be required. ▪ Evacuation routes remain trafficable only up to the minimum time.	▪ Open space ▪ No residential. ▪ Commercial and industrial with acceptance of flood risk as a "business risk" ▪ Club houses with appropriate protection.
Extreme	▪ Boats and helicopters are required for evacuation. ▪ Wading is not an option. ▪ Flood depths exceed 1.0m and velocity exceeds 1.5m/s	▪ Open space ▪ Club houses with appropriate protection

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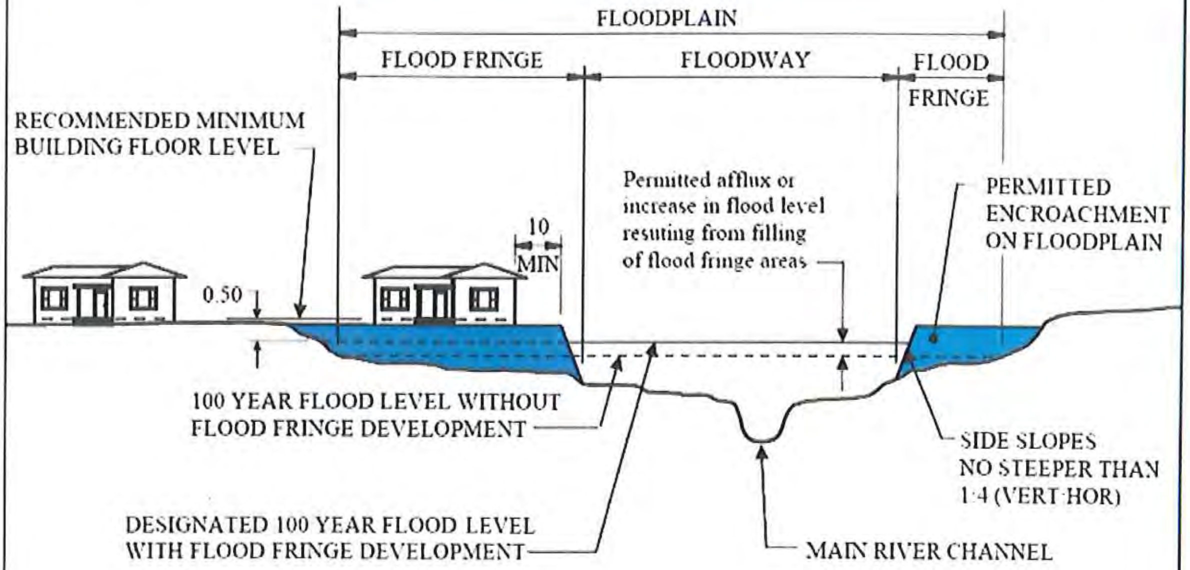
▪ Figure 5-2 Department of Water Recommended Floodplain Development Strategy



GENERAL NOTES

1. Development (ie. filling, building, etc) that is located *within the flood fringe* is considered acceptable with respect to major flooding. However, a minimum habitable floor level of 0.50 metre above the adjacent 100 year flood level is recommended to ensure adequate flood protection.

2. Development (ie. filling, building, etc) that is located *within the floodway* and is considered obstructive to major river flows is not acceptable as it will increase flood levels upstream.

A hydraulic assessment of the existing flood hazard was required to understand how flood risks affect the investigation area. This was needed before assessing options for floodplain management and flood mitigation.

The hydraulic model of the 100 year ARI flood event for the Existing Case was used as the basis of a flood hazard assessment and development of options for floodplain management. The model results were tested using the flood hazard estimation techniques outlined in SCARM73.

Flood hazard mapping was generated from the hydraulic modelling results using the project Geographic Information System (GIS). The GIS analysis is based on the results of 100 year ARI peak flood depth and velocity. This is a conservative analysis because it assumes that peak flood depth is coincident with the peak flood velocity. Experience with using this methodology has found that it does not exaggerate flood hazard and gives sound results.

The area of the EMV raised some concern because of its risk of isolation during flooding. The only road access was severed by a causeway and pedestrian access was limited due to floodwaters flowing southwards along Murat Road.

Appendix B contains the output from the flood hazard assessment.

5.3 Comparison of Existing Flood Hazard and Development Planning

Council's current land use planning was compared to the flood hazard mapping. It identified a number of conflicts between current planning and the existing flood hazard through the investigation area and is discussed in this Section.

5.3.1 Krait Street Creek Catchment

The Krait Street Creek catchment experiences flooding but the area currently has no planning for future development. Flood fringe areas and floodways should be defined for in this area before it experiences development pressures.

5.3.2 Town Creek Catchment

The hydraulic modelling results show that shallow flooding is expected through the Town Centre during a large flood event. Flood fringe areas can be suitable for commercial development if owners are willing to take the flooding risk as a business risk. The modelling shows that flooding can occur through areas designated as Town Centre and retailers and Council should make suitable plans for flood protection to protect town assets.

Flooding is expected to occur in an area of existing residential development downstream of Learmonth Street on Town Creek. This needs to be addressed in floodplain management. Downstream of this is an area of land designated as residential that was not developed at the time

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of this investigation. This area should be developed with caution and should be tested for regional flood impacts.

5.3.3 LIA Creek Catchment

Upstream of Reid Street, the high hazard areas are confined to areas proposed for public open space. There are also areas susceptible to inundation of low and medium hazard that are proposed for future urban. If this is to occur, these areas will require careful modelling to ensure that flood impacts are minimised.

Downstream of Reid Street the flood fringe covers the majority of the LIA. Although the floodway appears to cover some of the LIA, this land is not developed. Therefore, this land should be set aside for floodways and not developed.

Overall the LIA Creek catchment should be investigated to examine options to remove or mitigate the existing flood hazard.

5.3.4 Marina Creek Catchment

The Marina Creek catchment flow crosses over to interact with the LIA Creek catchment flow upstream of the existing LIA development. This results in low and medium hazard however the land is zoned for industrial use. Such development needs to be cognisant of the flooding risk and floodplain filling should only occur with careful consideration for regional flooding impacts.

The main channel of the Marina Creek catchment does not align with the area of zoned open space upstream of Murat Road. This area was also being filled at the time of this investigation, thus rendering it unsuitable for the development of a drainage corridor or a diversion. Therefore, a floodway designation should be provided for land zoned future urban upstream of Murat Road to allow for Marina Creek flow.

5.3.5 Market Street Creek Catchment

The Market Street Creek catchment breaks into a number of flow paths that should be taken into consideration in the planning of development in the areas zoned future urban upstream of Murat Road. The area of future urban should be hydraulically modelled to understand the amount of encroachment that can occur into the floodplains without causing regional flooding impacts. Once this is known, land should be defined as floodways.

The areas behind the coastal dunes, downstream of Murat Road, are zoned for long term future urban. Given the findings of this investigation it is more appropriate that this area be set aside for floodplain storage. As a minimum, the areas of high and extreme hazard should be set aside as floodways and filling should not be allowed. This will ensure that the natural function of the area is maintained and unnecessary damage to the coastal dunes and coastal processes does not occur. If development is to occur in the areas of low and medium hazard then it should only be done with consideration of the impacts on flood levels and with an understanding of broader environmental impacts.

5.3.6 Southern Investigation Area

The existing rural residential areas at the southern extent of the investigation area have housing developed in areas of low and medium hazard. The house floor levels of this area should be considered to ensure that they are immune from 100 year ARI flooding and, if not, measures should be taken to rectify this situation.

5.4 Development and Testing of Structural Mitigation Measures

Structural flood mitigation measures were tested in an attempt to alleviate flooding of existing properties. Some testing was done on the effectiveness of increasing the capacity of the natural breakouts. A summary of the structural measures tested are reported below:

- LIA Creek Improvements:
  - Improved drainage over/through Reid Street culverts to keep flooding in the LIA Creek and to avoid it flowing down Reid Street to Murat Road.
  - Flood mitigation bunding along LIA Creek between Reid Street and Murat Road and improved channel conveyance.
  - Constructed drainage along Reid Street table drain to manage flows overtopping onto Reid Street.
- Murat Road Drainage:
  - Culverts under Murat Road with capacity of the 10 year ARI flood event to manage floodwaters flowing down Reid Street and avoid damaging flow down Murat Road to the canal spillway.
- Widening of McLeod Street Breakout:
  - Lowering and widening this breakout to increase drainage of the ponded area south of the canal developments.
- Alteration of the Northern Breakout:
  - Testing of the sensitivity of the opening of the northern breakout on flood levels in the ponded area behind the coastal dunes.
- Development of a Warne Street Breakout:
  - Testing the impacts of opening a new breakout at Warne Street.
- Market Street Bund
  - A properly engineered levee preventing flow crossing from Market Street Creek to Marina Creek in the 100 year ARI flood event.

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5.4.1 LIA Creek Improvements

This mitigation option resulted in improved flooding conditions through the light industrial area by increasing the floodway capacity to the storage available east of Murat Road. Two separate tests were run. One test looked to reduce the flooding through LIA providing partial 100 year ARI flood immunity. The second assessment provided for full 100 year ARI flood protection for the LIA.

The impact of the two options is shown in Figure 5-3 and Figure 5-4

Figure 5-3 shows that the option provides benefit through the target area while increasing flooding in the floodways and in the ponded area. The areas of increased impact do not cause property impacts and serve only to make a minor rise in the ponded level east of Murat Road. Despite this, flooding still breaches the floodway and flows down Reid Street. Although flood levels were reduced along Murat Road, they were still deep and damaging.

Figure 5-4 was more beneficial and completely removes the flooding problems in the Light Industrial Area and along Murat Road. However, the works and associated costs to achieve this are greater than the previous option as it will include works on Reid Street to raise its approaches to the floodway and works on the floodway bunds plus a new bunding system west of the Light Industrial Area.

5.4.2 Murat Road Drainage

This mitigation option improved drainage out of the Light Industrial Area and delivered it to the EMV with less impact on Murat Road. This option was specifically focussed on drainage in smaller flood events to increase the serviceability of the Murat Road during floods. The impact of the option on the 10 year ARI flood event is shown in Figure 5-5.

The option was found to be effective in reducing the Q10 flooding down Murat Road however the terrain was not conducive to capturing the amount of flow required to make the option totally effective. The option would require the installation of large culverts under Murat Road and into the EMV and this would be an expensive undertaking given that it would now need to be retro-fitted.

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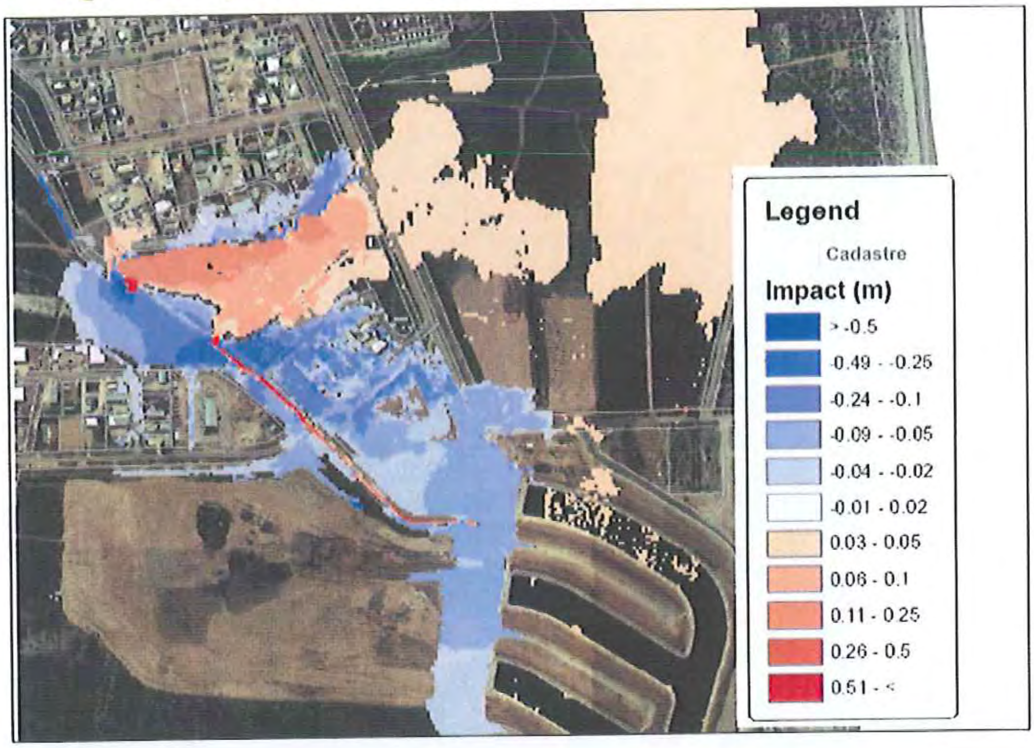
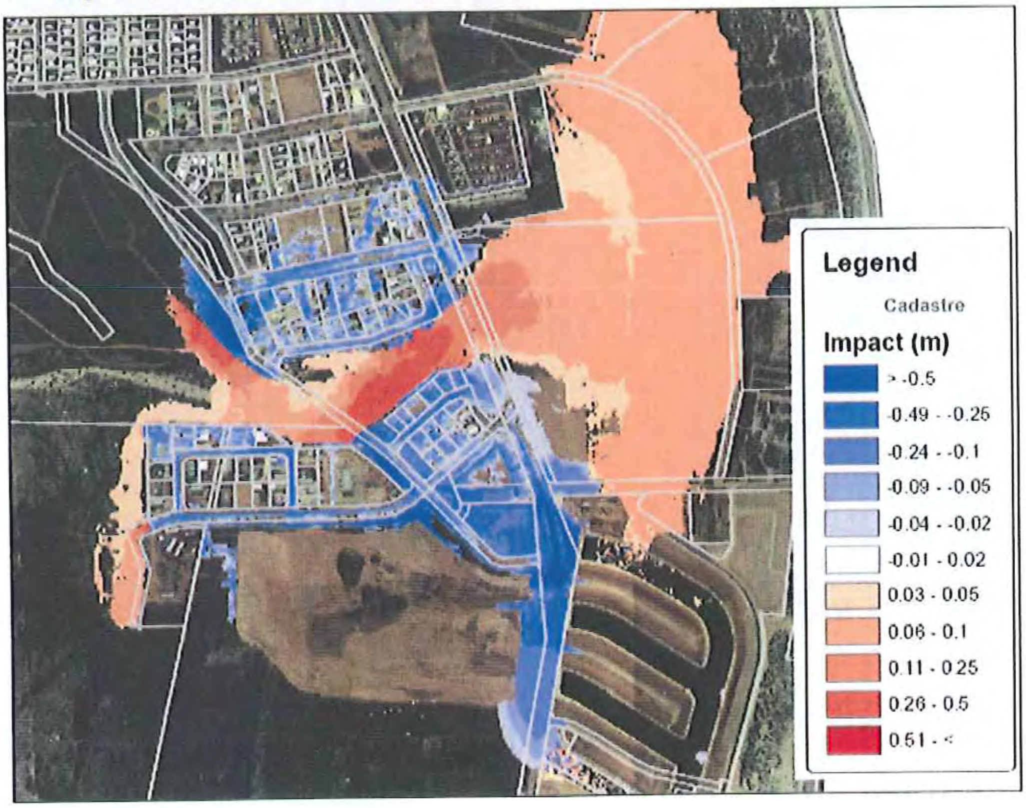
- Figure 5-3 Impact of LIA Mitigation Option – Partial 100 year ARI Flood Protection



- Figure 5-4 Impact of LIA Mitigation Option – Full 100 year ARI Flood Protection



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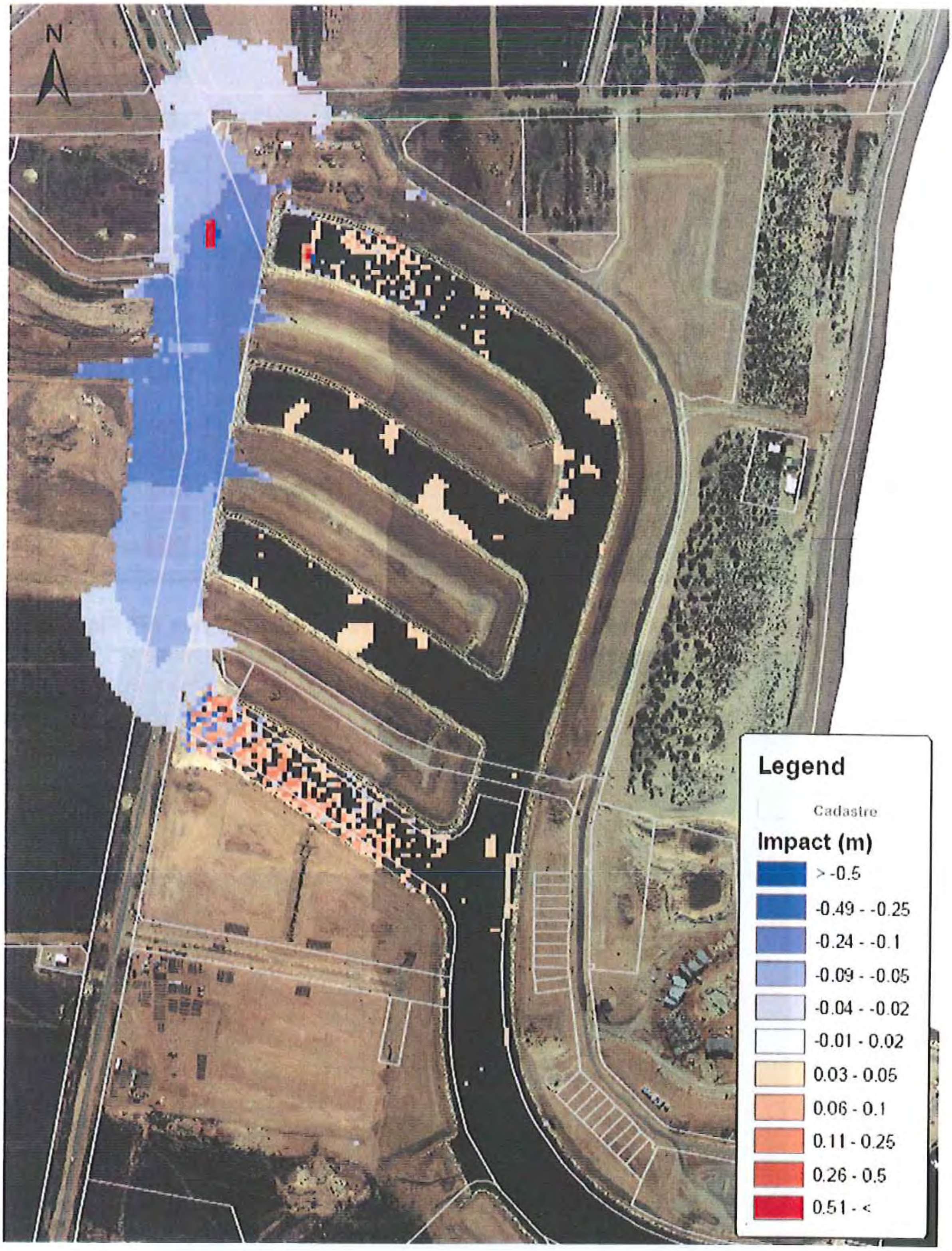
- **Figure 5-5 Impact of Murat Road Drainage on 10 year ARI flooding**



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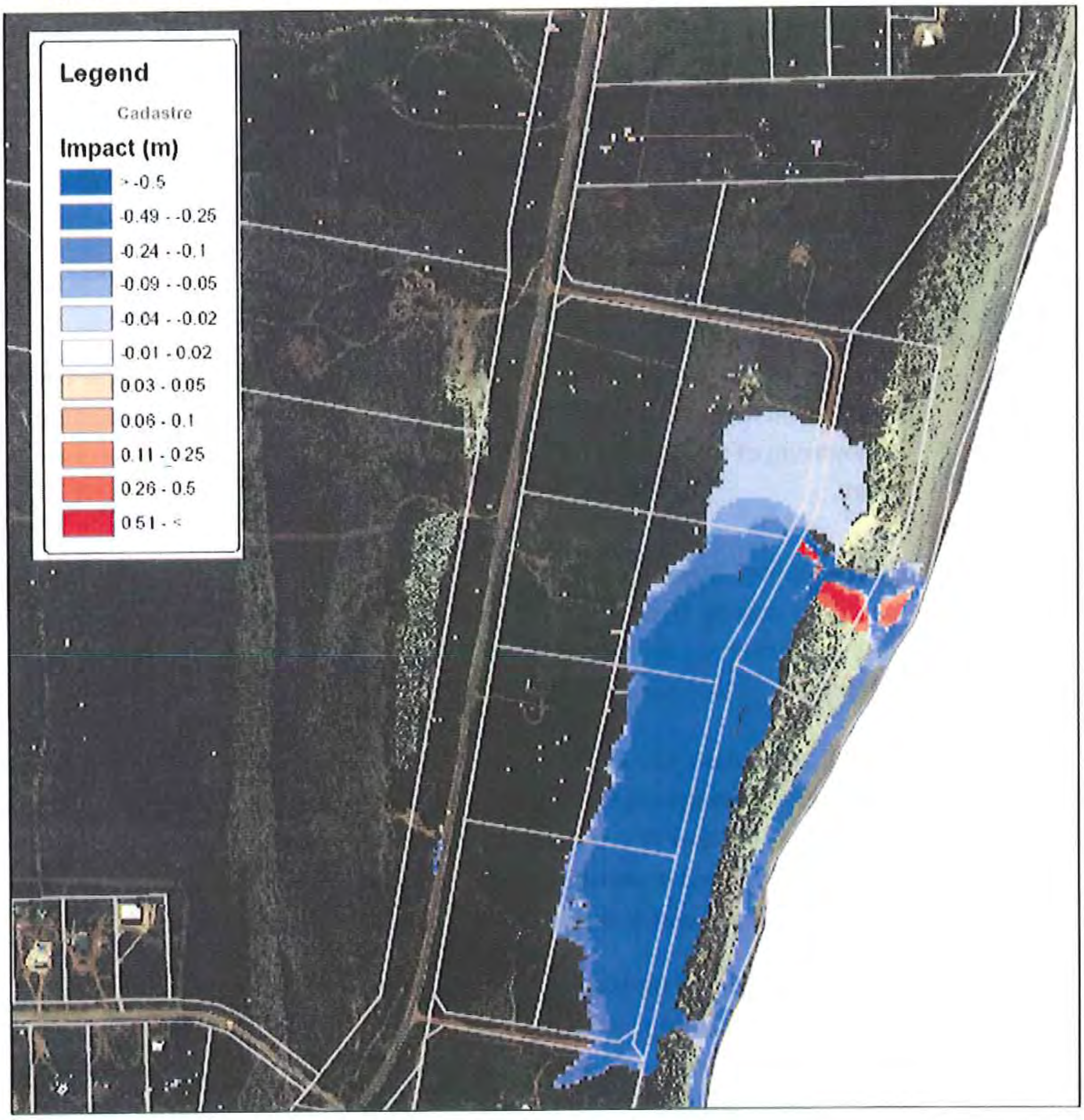
5.4.3 Widening of McLeod Street Breakout

This mitigation option increased the width of the existing McLeod Street breakout. The breakout width was doubled to 60m. The aim of the option was to provide additional drainage south of the EMV canal development and to mitigate existing flooding in the area. The modelling of the 100 year ARI flood event shows that the option would reduce flood levels generally but because of the size of the storage area, the extent of the inundation did not reduce significantly. It provided limited benefit for the costs involved in maintaining such an opening and benefit did not extend to existing residences affected by the EMV canal development. Figure 5-6 shows the impact of the widening on the regional flood levels.

▪ Figure 5-6 Impact of Widening McLeod Street Breakout on 100 year ARI flooding



5.4.4 Alteration of the Northern Breakout

This option was not tested specifically as a flood mitigation measure. It was assessed during the sensitivity analysis of the hydraulic model to see how the regional flooding responded to changes in the level of the breakout. The modelling found that the flood levels were sensitive to the northern breakout trigger level but this did not affect the inundation extent greatly. The ponded area takes the flow from the LIA, Town and Krait Creek catchments but the volume available in the area was so large that it could store the volume of large floods. Therefore, the operation of the Northern Breakout did not have a great affect on flood levels.

Figure 5-7 shows the impact of altering the northern breakout so that it is completely blocked. Despite the blockage, no properties are affected and the impacts do not extend as far south as EMV.

5.4.5 Development of a Warne Street Breakout

This option tested the construction of a new breakout at Warne Street. The proposed breakout was set to a width equivalent to the road reserve and the level was set at the same level as the Madaffari Drive spillway.

Figure 5-8 shows the impact of the mitigation option. It was found that the option had little improvement to regional flood levels beyond an area that is currently zoned for recreational use. The lowering of flood levels was less than 50mm in this area and in most cases, little more than 20mm.

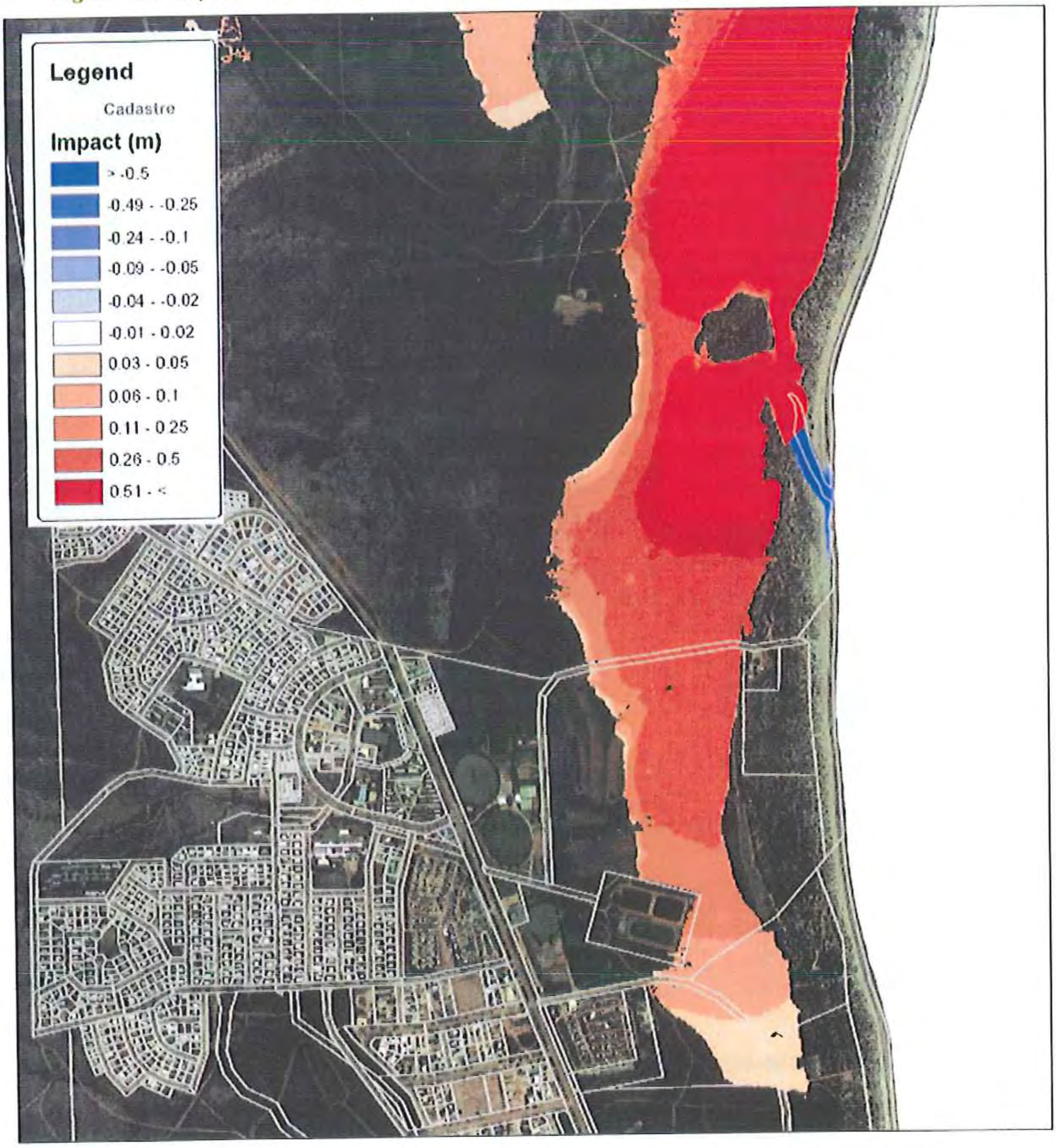
5.4.6 Market Street Bund

There is an existing levee aimed at preventing Market Street Creek overflowing into the Marina Creek catchment and thus reducing the flow into the EMV. This levee was assessed as being inappropriate as discussed in Section 4.2.2.

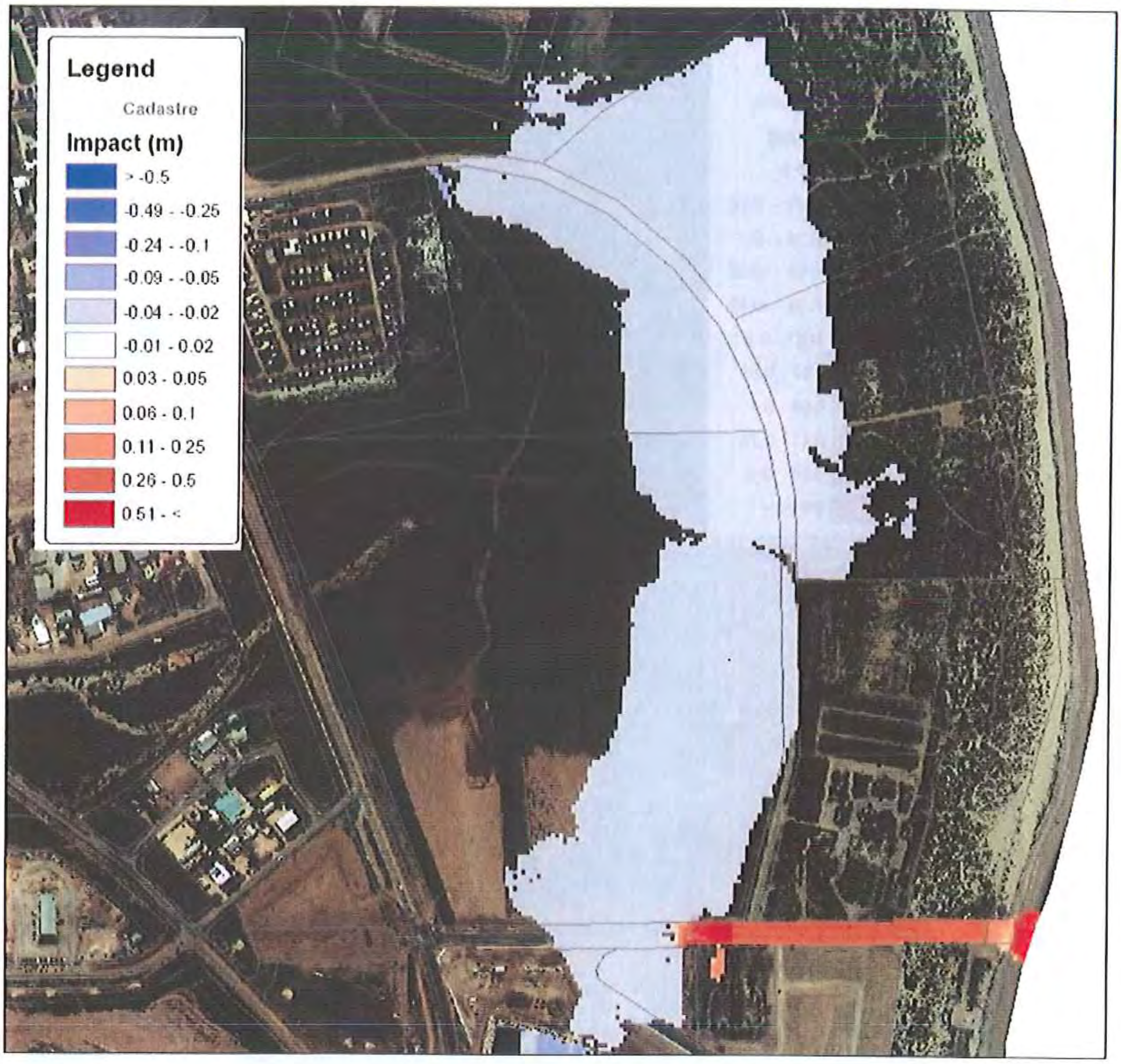
Through negotiation with DoW and Council, it was agreed that a levee on Market Street Creek was a suitable flood mitigation measure to test as it would reduce the amount of fill required to develop the EMV. At the time of this study, the construction of the EMV was nearing completion and the Council was required to provide development clearances. Further filling of the development would result in delays and cost to the developer.

The current impact of the bund is discussed in Section 4.2.2. Through discussion with Council and DoW, it was concluded that the bund could be reconstructed to a suitable standard and height and that this could be deemed an appropriate flood mitigation option for the EMV and the land directly north of the structure. It is noted that levees are not considered current best practice in floodplain management however, in this situation, it was considered the only viable flood management option.

- Figure 5-7 Impact of Closing the Northern Breakout on 100 year ARI Flooding



▪ Figure 5-8 Impact of Developing a Breakout at Warne Street on 100 year ARI Flooding



5.5 Non-structural Mitigation Options

5.5.1 Land Use Planning

The raw flood hazard maps discussed in Section 5.3 were interpreted in accordance with the guidance from the Department of Water contained in Figure 5-2.

"Low" and "Medium" SCARM73 hazard categories generally represented areas of shallow floodplain and the fringe of ponded areas and thus, these were used to define "Flood Fringe". It was considered likely that these areas could be filled in a way that it did not impact greatly on regional flood levels however each development application in this zone would require hydraulic assessment.

"High" and "Extreme" SCARM73 hazard categories generally correlated with areas of high conveyance or deep ponded water and these were used to define "Floodway". It was assumed that development in these areas would cause afflux in the surrounding floodplain and therefore development should favour less flood prone areas.

Further assessment of the hazard mapping was required to identify areas isolated by flooding. The raw flood hazard maps for the investigation area are attached in Appendix B.

It is proposed that the flood zones are adopted by Council for future floodplain development planning to provide guidance for land-use suitability. This is discussed further in Section 6.

5.5.2 Building Development Controls

Shallow flooding of the LIA and Preston Street areas was known to have occurred in recent rainfall events. The area of Preston Street is rural residential and the LIA is a mix of commercial, industrial with some residential areas. These areas should be subject to building development controls. All future development in these flood prone areas should be set at 0.5 m above the 100 year ARI flood levels described in this document. Opportunities should be sought for the voluntary raising of the affected residences to be above the 100 year ARI flood level.

5.6 Assessment of Flood Management Options

5.6.1 LIA Creek Improvements

Of all of the options, the greatest benefit comes from providing improvements to the drainage and existing protection measures in the LIA Creek catchment. If the bunding along LIA Creek is improved along with the drainage and drainage structures under Reid Street, it would remove the majority of the flooding problems through the LIA and mitigate the impacts of the EMV on Murat Road.

Further, if the flow is contained in the channel, the water would be delivered to the ponded area behind the coastal dunes and not down Reid Street to the EMV. By doing this, the mitigation measure uses the natural storage behind the dunes to offset regional flooding impacts.

5.6.2 Murat Road Drainage

This option provided limited benefit and if the improvements were made to LIA Creek as discussed above (Section 5.6.1), this option would not be necessary. The construction of drainage under Murat Road would be expensive and costly to maintain.

5.6.3 Construction or Altering of Breakouts

Two options were tested for the altering of existing breakouts; closing the Northern Breakout and widening McLeod Street Breakout. One option was tested for the construction of a new breakout at Warne Street.

The action of the breakouts is a natural process and they will open and close through climatic and coastal cycles. The maintenance of a breakout will be expensive and an ongoing cost for Council as the natural coastal wind and tide action deposit new material onto the coast. The maintenance of breakouts is a common flood mitigation measure for coastal communities however it should be avoided if possible as it is direct interference with a natural process.

The hydraulic modelling found that the volume of the floodplain in the storage area behind the coastal dunes was very large when compared to the volume of 100 year ARI flooding. Further, the flow capacity of the existing breakouts, based on bed invert and channel width, was much less than the inflow rates coming off the catchments. In all, this balanced out and the modelling found that increasing the breakouts' conveyance capacities did little to alter the flood risk to the existing populated areas of Exmouth. The flood effects on the storage area behind the coastal dunes had a clear separation from the effects on flowing floodwaters in the LIA and through the town catchment.

Based on the hydraulic modelling, it is recommended that the natural coastal processes be left in place along the coastal dunes and that the available storage area behind the coastal dunes be left undeveloped to serve that purpose. More suitable land for development is available to the east of Murat Road along the length of the investigation area.

Breakouts could be opened up as a measure to drain water that may become trapped after a flood if breakouts do not reopen. This would reduce the risk of mosquito borne disease after a flood and reinstate the flood storage for subsequent rainfall events. However, ongoing widening and maintenance would be costly for Council unless there was a market that could be established for the sand products and if the appropriate environmental approvals could be gained.

The storage area behind the coastal dunes is a vital element to the management of flood waters in Exmouth and currently provides storage that prevents flooding in the town. The area behind the dunes is a "high" hazard based on the SCARM guidelines and therefore, the area should be set aside for the floodplain and only appropriate land uses should be developed such as passive recreation. No further filling of this floodplain should be allowed to occur as it will reduce the quantity of flood storage and has the potential to impact on the area's habitat values.

5.6.4 Market Street Bund

Through discussion with Council and DoW, it was deemed that the Market Street bund could deliver flood mitigation results that would reduce the development costs of the EMV and allow it to be an approved development. At the time of this investigation, the EMV construction was nearing completion and seeking final development clearances from the Council.

However, it was agreed that a levee would require redesign and reconstruction unless suitable documentation could be produced to evidence that it was of a suitable standard. It was also agreed that the levee would alter the flow regime and would require that Murat Road be armoured so as to pass floods without damage.

It was agreed that the levee would increase flood levels to the south of the EMV however the land was not developed and Council considered that there were no direct property impacts. It was also agreed that the flow regime of the area would alter greatly and more flow would exit from the McLeod Street Breakout than would have previously and naturally passed through the mouth of the Boat harbour. This is likely to result in the McLeod Street Breakout increasing in size to find a new equilibrium during future flood events.

It was agreed that the primary beneficiary of the bund was the EMV with some secondary benefit in reducing the length of flooding across Murat Road.

5.7 Flood Damages Assessment

A flood damages assessment was undertaken to understand the benefits of the various flood mitigation options. A detailed flood damages assessment was not required as part of this project and that was mainly due to the being limited information on flood damage. Fortunately, the town has avoided major damages to date.

The hydraulic modelling has found that flood damages in the LIA and the adjacent roads can be reduced or removed through the construction of the improvements to LIA Creek as discussed previously. This option would also mitigate damages due to the filling of the floodplain for the EMV because it will send floodwaters to the storage area behind the coastal dunes.

However, the construction of the Market Street bund counteracts some of this benefit by increasing flood levels south of the EMV without providing benefit to existing dwellings. It does reduce the length of Murat Road flooded however it will require for the length of Murat Road affected to be structurally formalised into a floodway.

The impact of existing and developed conditions flooding on residential and commercial properties was assessed for the 100 year ARI event. The modelled flood extent and aerial photography were used to manually identify the location of 117 buildings potentially affected by flooding.

Based on the site investigations, it was considered that most of the flood prone properties had a floor level at least 200mm higher than the surrounding terrain and, based on this assumption, approximately 32 properties were deemed to be affected by the 100 year ARI event for the Existing Case.

With the flood mitigation strategies in place, this was reduced to 27 properties however this does not account for the number of properties that would be benefited in the EMV by the reduced flood levels from the market Street bund.

Of the affected properties, a series of commercial buildings to the west of Murat Road near Maidstone Street are inundated with approximately 300mm of water in both the Existing and Developed Cases. Similarly, four residential buildings off Learmonth Rd experience inundation levels of approximately 200mm in both the Existing and Developed Cases.

Five buildings within the LIA area inundated in the Existing Case 100 year ARI event are no longer inundated in the Developed Case due to the protection provided by flood mitigation works at Reid Street. These works also reduce flows along Reid Street to Murat Road. Under existing conditions water breaks out of LIA Creek and flows approximately 1km down Reid Street. In the Developed Case, only 220m of Reid Street is inundated and water flows over the floodway rather than down the road. Flooding along Murat Road is confined to approximately 220m in comparison with 2 km under the Existing Case.

The upgrade and extension of the Market Street bund increases ponding of water to the south of the EMV where there are several rural properties, currently used as stables.

Further discussion and mapping on the flood damages assessment is contained in the *Flood Modelling Report (SKM, 2007).*

In conclusion, the flood damages assessment found that the mitigation works will provide a reduction in flood damages. The damages reduction will assist to mitigate the impacts of the EMV on Murat Road and will provide flood protection to approximately five industrial properties.

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6. Floodplain Management Strategy

Based on the investigations, a Floodplain Management Strategy is proposed for the Shire of Exmouth. The strategy incorporates both structural and non-structural measures to manage the flooding risks associated with the floodplains of the area.

6.1 Structural Measures

A number of structural flood mitigation measures were adopted. These were combined in a single hydraulic model referred to as a "Developed Case" scenario. The inundation mapping of the Developed Case is included in the appendices.

6.1.1 LIA Creek Improvements

It is proposed that the existing flood mitigation measures on LIA Creek are enhanced. The existing bund system should be raised and extended to control the flooding through LIA Creek and prevent it from flowing down Reid Street to the EMV.

This measure is proposed to avoid the existing minor flooding experienced through the LIA but, more importantly, it is proposed to offset the impact that will occur due to the development of the EMV in the floodplain. The option will prevent large volumes of flow passing at a high velocity along Murat Road that would likely cause significant damage to roads and create a hazard to the community.

6.1.2 Replacement / Upgrading of Market Street Bund

Through discussion with Council and DoW, it was deemed that the Market Street bund could deliver flood mitigation results to reduce the construction and maintenance costs of the EMV. It was agreed that it would increase the flood levels south of the EMV and alter the geomorphology of the McLeod Street Breakout. However, the Market Street bund was deemed necessary by Council to ensure the development clearances for the EMV. Therefore, the Market Street bund was adopted as part of the Strategy.

It is proposed that the Market Street bund be assessed for adequacy. If a review of its design and construction finds that it is inadequate then it should be removed and replaced with a properly engineered structure. It is known that the structure is susceptible to overtopping in the 100 year ARI flood and should be raised to beyond this level as a minimum to avoid failure of the levee and damaging downstream impacts.

The proposed properly engineered bund should convey flood waters across Murat Road and extend east to also protect new development south of the EMV that has been under formal consideration by the Shire and other statutory authorities since 2003.

6.1.3 Murat Road Causeways

Murat Road is the main access to the amenity and emergency services of Exmouth. The road is currently cut by flooding due to a series of low floodways into town. As development extends away from Exmouth, Council must consider the serviceability of these structures in the event of a flood and the population at risk of being isolated from emergency services. Council should plan to replace the causeways with bridges or culverts over time or provide alternative access through higher roads up into the catchments.

Immediate attention will be required for the crossing of Market Street Creek as this area will experience increased flooding with the Market Street bund in place. It is understood that this currently not a designed floodway structure.

6.2 Non-Structural Measures

6.2.1 Land Use Planning

It is proposed that Council adopt the findings of this report and utilise its mapping outputs in future floodplain development planning. Land should be set aside and designated as "floodways" and "flood fringe" in accordance with the mapping provided in Appendix B. This should be done to avoid impacts on existing floodplain residents and to maintain the existing function of the floodplain through the investigation area.

The "Existing Case" mapping should be used as a default for determining flood levels and development controls until such time as the Market Street Bund measures are completed. After that time, the "Developed Case" mapping should be used. In any areas where the "Developed Case" flood levels are greater than the "Existing Case", the Developed Case levels must be adopted as a precautionary measure.

Careful consideration prior to any future development of flood prone land is recommended and the Department of Water should be consulted for the most appropriate controls and land uses for the land. Section 5.3 outlines where there is current conflict between Council's strategic plan and modelled flood hazard and specific guidance is given in the treatment of these areas.

Land designated "floodway" should not be interfered with and should be left to perform its drainage function.

Land designated "flood fringe" should only be developed after assessing regional flood effects. Such an assessment cannot be undertaken ad-hoc. If an area is being considered for future development and it lies in the flood fringe, the entire region should be assessed to see how much of the land can be developed without impacts rather than doing the assessment on a lot-by-lot or development-by-development basis.

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An "area of special consideration" classification should be given to land that would be affected by flooding if the Market Street Bund were to fail. Although it is recommended that the levee be constructed to a sound, engineered quality and an appropriate elevation, there is always the chance that the levee will be overwhelmed by floods greater than its design capacity. In such an event, levees are prone to failure and, as a minimum, flooding will be experienced on properties that may be otherwise considered to be flood immune.

The nature of this development condition is consistent with floodplain planning throughout WA and the requirements of DoW.

No development should occur within the zone shown on the land use zoning maps without consideration of the impacts of a levee failure. No residential, industrial or commercial development should occur at all within 100m of the levee. Minimum floor levels in the area should be developed at least 500mm above natural surface.

Council should ultimately undertake land use planning over the entire investigation area to identify where future residential development may occur in the floodplains. This should be assessed to establish the maximum developable land and maximum possible encroachment that can occur on the floodplains without flooding impacts. Once this is done, it will give Council surety in its planning and development assessment process.

6.2.2 Building Development Controls

The flood levels reported from this investigation should be used to adopt standards for minimum floor levels for new developments. New residential properties should be constructed with a floor level at least 500mm above the relevant 100 year ARI flood level defined in this investigation. These levels will be subject to change as the investigation goes through ongoing review over time.

The floor levels in the rural residential areas to the south of the investigation area should be investigated to ensure that they are above the 100 year ARI flood level. If not, further investigation should be undertaken into the cost for voluntary house raising or other flood protection measures.

6.2.3 Flood Emergency Response Planning

The EMV, elements of key Council infrastructure and emergency services are currently at risk of isolation from flooding. It is recommended that Council review the flood risk across the investigation area and that this is reviewed regularly, particularly if development continues to extend away from the townsite.

Flood emergency response planning should look at large flood events, greater than the 100 year ARI flood and up to the Probable Maximum Design Flood.

6.2.4 Streamflow and Rainfall Gauging, Data Collection and Ongoing Review

The hydrologic and hydraulic modelling tools used to develop this Strategy could not be calibrated. This is due to a lack of flood level and flood flow data available at the time of the study and the ongoing change occurring to the terrain of the study area.

It is recommended that at least one streamflow gauging station be installed in the investigation area coupled with a pluviograph to measure rainfall. It is also recommended that Council collects flood debris marks after every significant flow event in the catchments of the investigation area. This data should be used to calibrate hydrologic and hydraulic modelling as it becomes available.

This Strategy should be reviewed regularly in light of the findings of revised hydrologic and hydraulic models.

7. Potential Water Harvesting

As part of the investigation, Council requested that an investigation be carried out to understand the ability to harvest surface water to supplement the Shire's existing water supply. This section outlines that investigation.

Drinking water supplies for the Shire of Exmouth are currently supplied from a limestone groundwater aquifer within the Cape Range. The aquifer is a lens of fresh water greater than 150m in thickness (Coleman, 1994) and, according to JDA (1999) this suggests that the beds of the creeks and gullies of the upper catchments are highly permeable.

Council was consulted at the commencement of the project. It was requested that SKM investigate the potential to develop storages in the channels or the valleys of the drainage lines to store surface waters.

7.1 Water Balance Methodology

After a preliminary assessment of the terrain of the site and the climatic patters of the region, it was apparent that it would be difficult to find a surface water storage able to meet the demands of the town. To determine this, a water balance was developed based on the regional climatic patterns.

A water balance was created using the recorded daily rainfall and evaporation data from the Learmonth gauges (005051 and 005007 respectively). The daily water balance sought to find a storage that could reliably supply water to the town. The basis of the water balance assumptions are described in Table 7-1.

■ Table 7-1 Water Balance Base Assumptions

Input	Value	Assumption
Storage surface area	1ha	Assumes a large storage area can be found to accommodate
Average depth	3m	Assumes that a deep storage area will be achieved given the steep upper catchment terrain
Storage catchment area	100ha	Assumes that a large catchment area is available to supply the storage.
Water Demand	250kL/day	Assumes that the storage will supply 1000 equivalent people with 300L/d/EP
Upper soil store	50mm	Assumes that the upper soil layer will store 50mm of rainfall prior to running off. It is assumed that all of the excess above 50mm will run off and not seep to groundwater. These assumptions are expected to give a conservatively high estimation of the amount or runoff from the catchments

7.2 Water Balance Results

The water balance with the base assumptions showed that a large storage described above would be unreliable. The daily reliability was less than 25%. That is, the storage could only meet the demand less than 25 % of the days of the record. The cause of this was twofold.

Firstly, when rainfall did occur, the rainfall was highly infrequent and the resulting runoff was very sharp and short lasting. The runoff could fill the storage quite easily given the intensity that it would fall however, the demand and the evaporation was quick to remove it from the storage.

Manipulation of the water balance found that the storage would be 90% reliable for a demand of just 37kL/d which would meet the demand of approximately 120EP. Given the cost of construction of such a large storage, it was considered that a surface water storage was not cost effective. It is known that the geology of the area is highly permeable and the engineering feasibility of constructing a storage in such geology would need thorough investigation.

7.3 Discussion and Conclusions

Previous reports identified that the geology of the area is highly permeable and caused significant rainfall losses in the upper catchment. This has resulted in a deep aquifer that supplies water for the town.

Given the infrequent nature of rainfall in the area and the high evaporation experienced, it was concluded that surface water diversion or storage schemes near Exmouth should be ruled out as an option for harvesting water.

However, based on the findings, the pervious nature of the upper catchments could allow for the exploiting of surface water resources through increasing groundwater interception in the upper catchments. A series of small storages could be developed in areas where the aquifer is exposed or where it has been specifically exposed for the purpose of harvesting. This could maximise infiltration to the aquifer and, given that the aquifer would not evaporate, could improve aquifer yields. Such a plan would require detailed geological and hydrogeological investigations. Given that the works would be best done in the upper catchments, they would be constructed in a National Park and thus need detailed environmental impact assessments and approvals.

In conclusion, no feasible water harvesting options were identified through the process.

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8. References

ARMCANZ (2000), *Flood Plain Management in Australia Best Practice Principles and Guidelines*, (SCARM report 73), CSRIO Publishing Collingwood VIC 3066

Bureau of Meteorology (2000); *Severe Tropical Cyclone Vance 16 March 1999–23 March 1999;* Department of Environment and Heritage

Engineers Australia (1987); *Australian Rainfall and Runoff*; EA Press

JDA Consultant Hydrologists (1999); *Exmouth Flood Management Study*; Technical report for the Shire of Exmouth

JDA Consultant Hydrologists (2002); *Review of the Exmouth Flood Management Study Assessment of the June 2002 Flood Event*; Technical report for the Shire of Exmouth

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Appendix A Design Floods Mapping

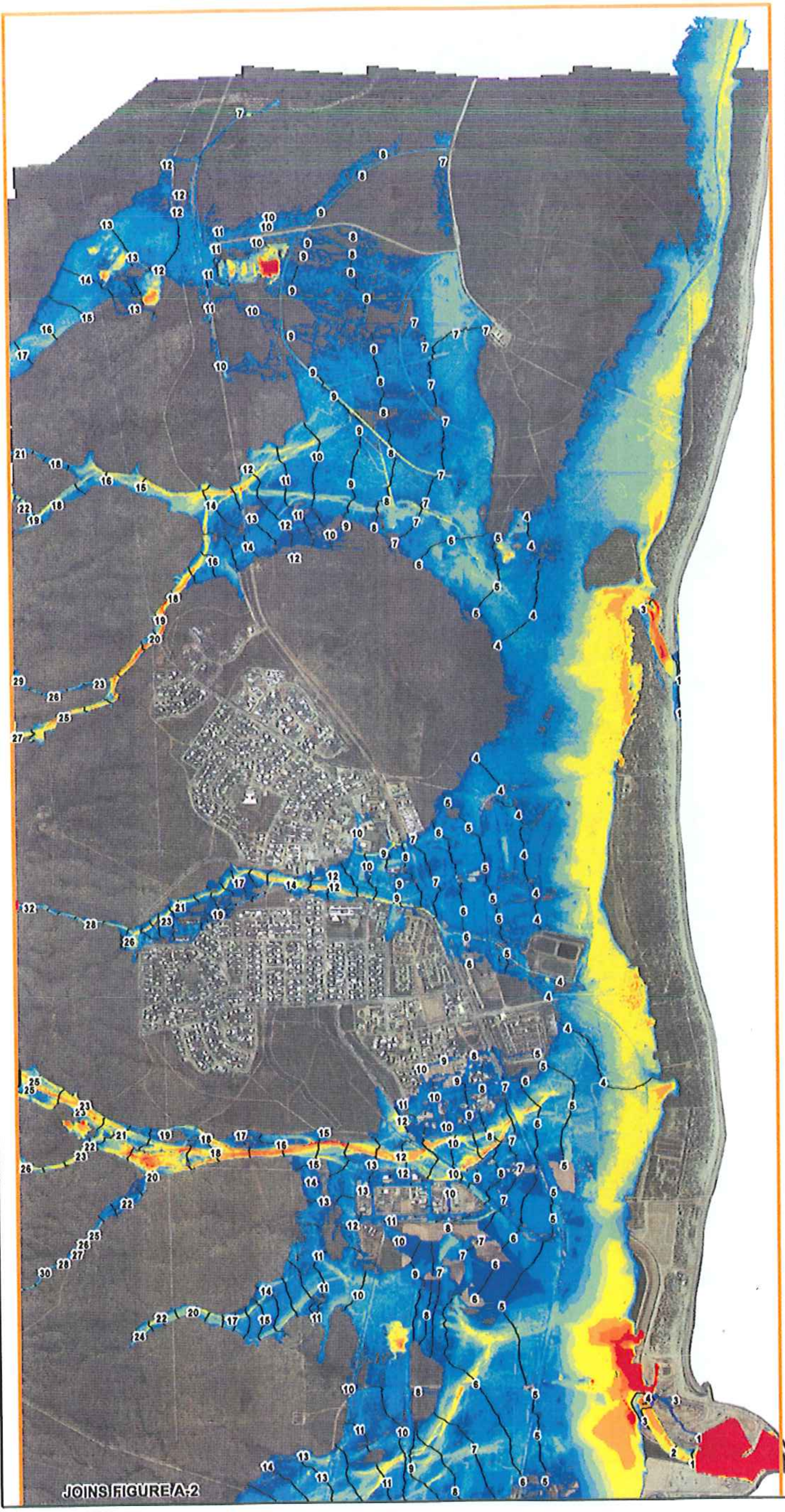


Figure A-1

Exmouth Floodplain Management Study

Q100 Pre-Canals Case Inundation Mapping

Part 1

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

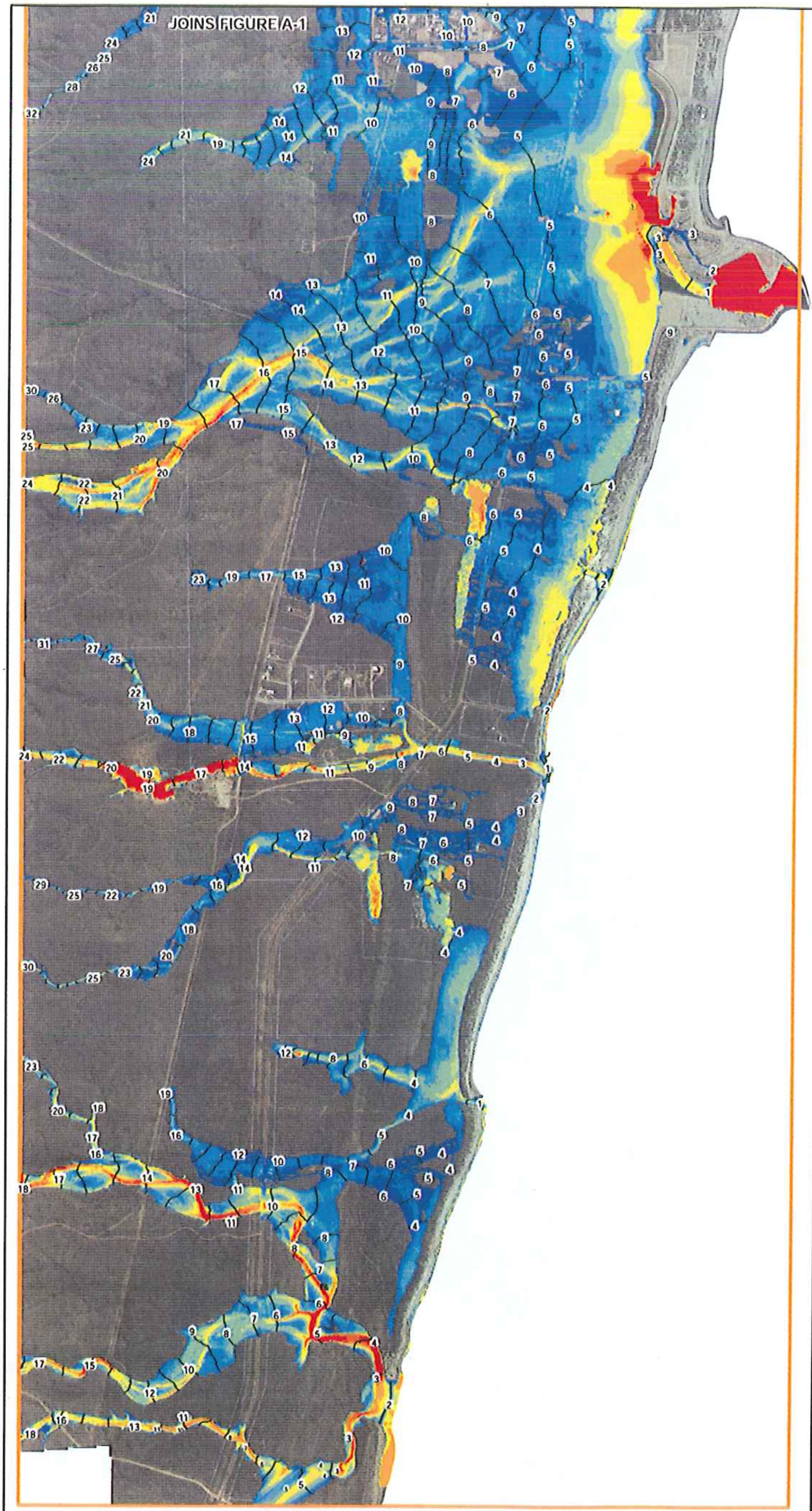


Figure A-2

Exmouth Floodplain Management Study

Q100 Pre-Canals Case Inundation Mapping

Part 2

Legend

- Peak Flood Level Contour (1m interval)
- 12 Flood Level (m, AHD)
- Hydraulic Model Extent
- Cadastre

Compiled Peak Flood Depth (m)

100 year ARI

- 0.0 - 0.01
- 0.01 - 0.1
- 0.2 - 0.3
- 0.4 - 0.5
- 0.6 - 0.8
- 0.9 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- 2.6 - 5.0

N

0 100 200 400 600 800

Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

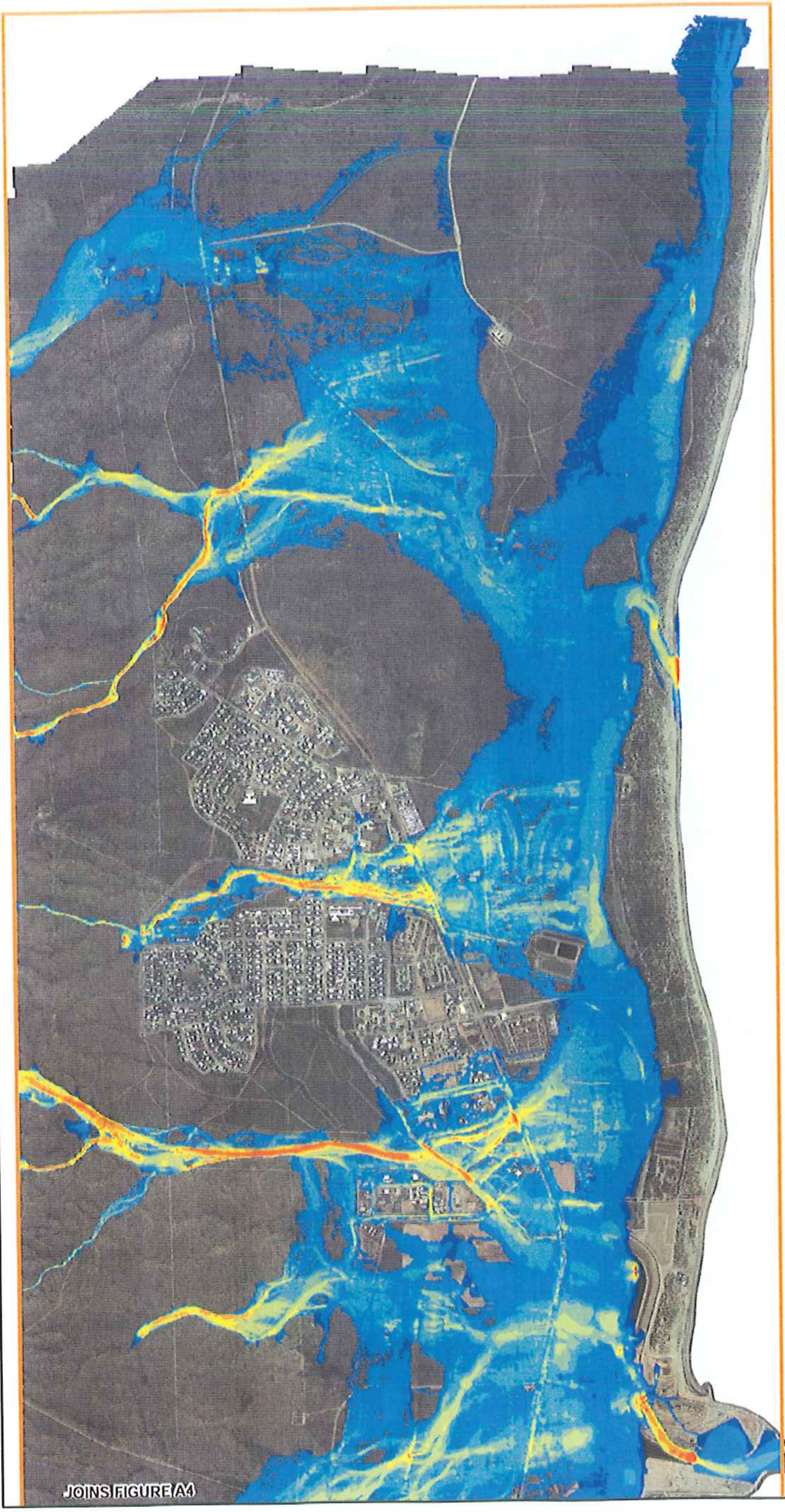


Figure A-3

Exmouth Floodplain Management Study

Q100 Pre-Canals Case
Velocity Mapping

Part 1

Legend

Hydraulic Model Extent

Cadastre

Compiled Peak Velocity (m/s)

100 year ARI

- 0.0 - 0.01
- 0.01 - 0.1
- 0.2 - 0.5
- 0.6 - 0.8
- 0.9 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- 2.6 - 5.0
- 5.1 - 8.0

N

0 100 200 400 600 800
Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

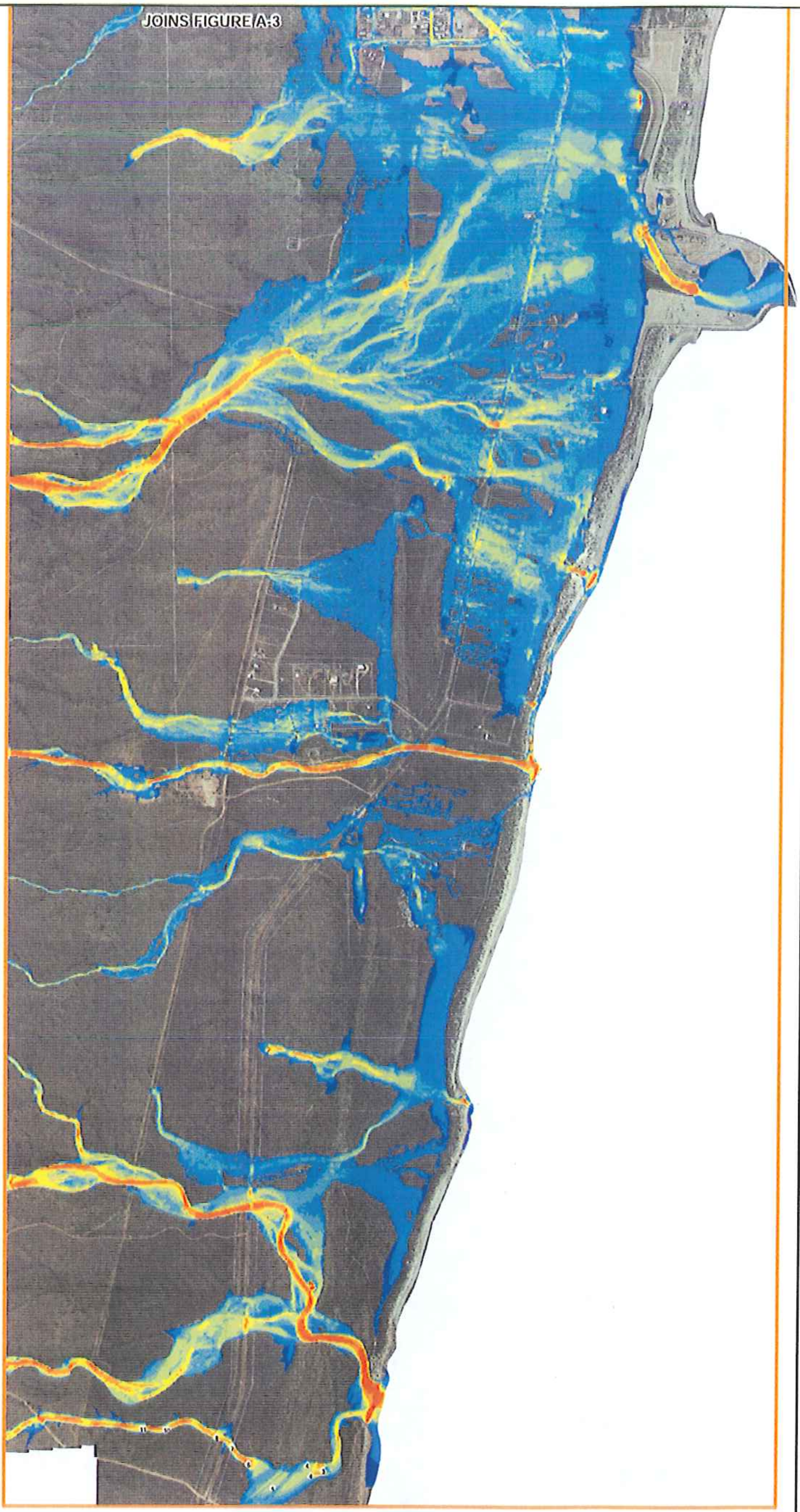


Figure A-4

Exmouth Floodplain Management Study

Q100 Pre-Canals Case Velocity Mapping

Part 2

Legend

- Hydraulic Model Extent
- Cadastre

Compiled Peak Velocity (m/s)

100 year ARI

- 0.0 - 0.01
- 0.01 - 0.1
- 0.2 - 0.5
- 0.6 - 0.8
- 0.9 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- 2.6 - 5.0
- 5.1 - 8.0

N

0 100 200 400 600 800

Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

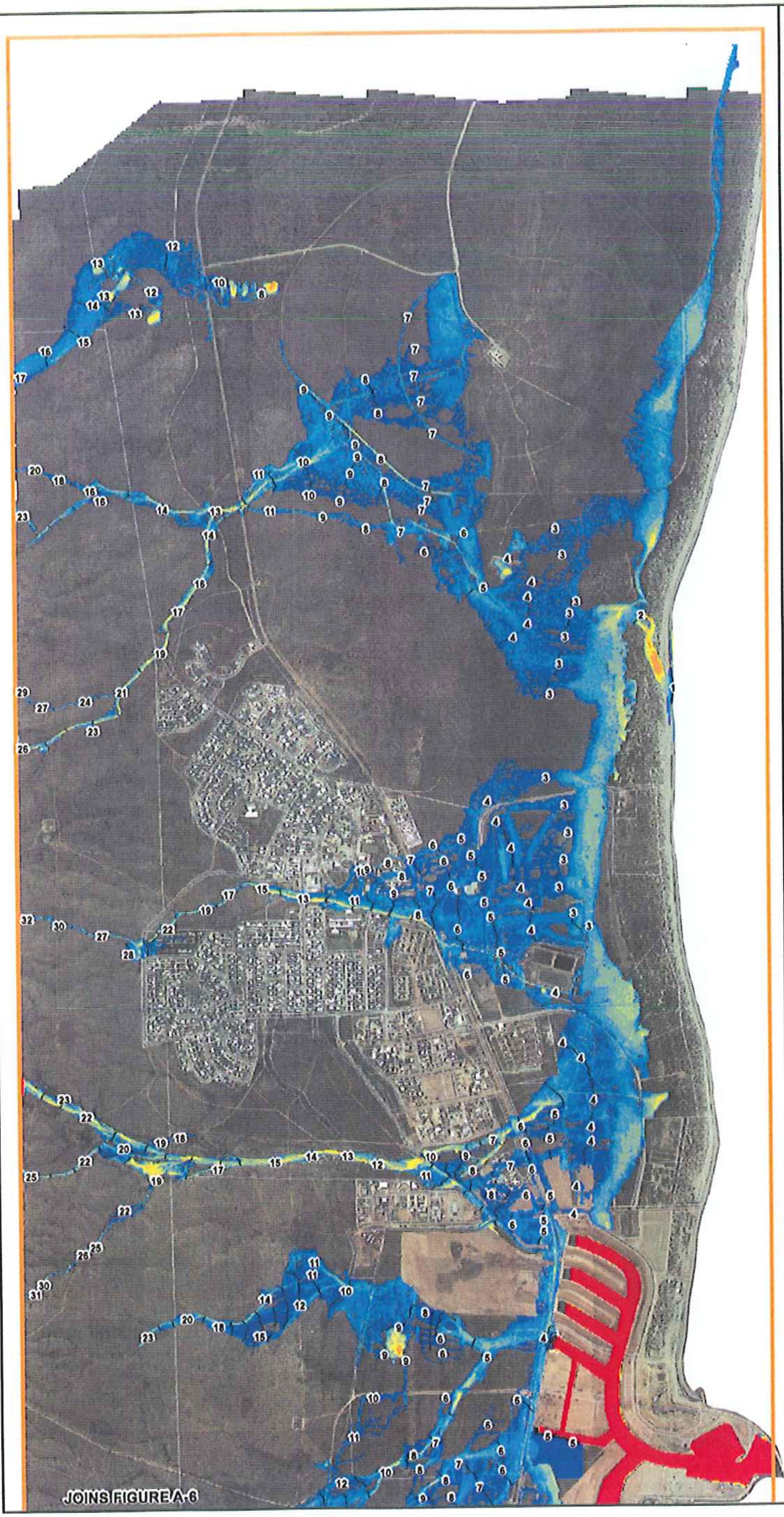


Figure A-5

Exmouth Floodplain Management Study

Q10 Existing Case Inundation Mapping

Part 1

Legend

- Peak Flood Level Contour (1m interval)
- 12 Flood Level (m, AHD)
- Hydraulic Model Extent
- Cadastre

Compiled Peak Flood Depth (m)

10 year ARI

- 0.0 - 0.01
- 0.01 - 0.1
- 0.2 - 0.3
- 0.4 - 0.5
- 0.6 - 0.8
- 0.9 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- 2.6 - 5.0

N

0 100 200 400 600 800

Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

Figure A-6

Exmouth Floodplain Management Study

Q10 Existing Case Inundation Mapping

Part 2

Legend

——	Peak Flood Level Contour (1m interval)
12	Flood Level (m, AHD)
▭	Hydraulic Model Extent
	Cadastre

Compiled Peak Flood Depth (m)

10 year ARI

- 0.0 - 0.01
- 0.01 - 0.1
- 0.2 - 0.3
- 0.4 - 0.5
- 0.6 - 0.8
- 0.9 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- 2.6 - 5.0

N

0 100 200 400 600 800
Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

Figure A-7

Exmouth Floodplain Management Study

Q10 Existing Case Velocity Mapping

Part 1

Legend

Hydraulic Model Extent

Cadastre

Compiled Peak Velocity (m/s)

10 year ARI

- 0.0 - 0.01
- 0.01 - 0.1
- 0.2 - 0.5
- 0.6 - 0.8
- 0.9 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- 2.6 - 5.0
- 5.1 - 8.0

N

0 105 210 420 630 840

Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

Figure A-8

Exmouth Floodplain Management Study

Q10 Existing Case Velocity Mapping

Part 2

Legend

Hydraulic Model Extent

Cadastre

Compiled Peak Velocity (m/s)

10 year ARI

0.0 - 0.01

0.01 - 0.1

0.2 - 0.5

0.6 - 0.8

0.9 - 1.0

1.1 - 1.5

1.6 - 2.0

2.1 - 2.5

2.6 - 5.0

5.1 - 8.0

N

0 105 210 420 630 840

Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

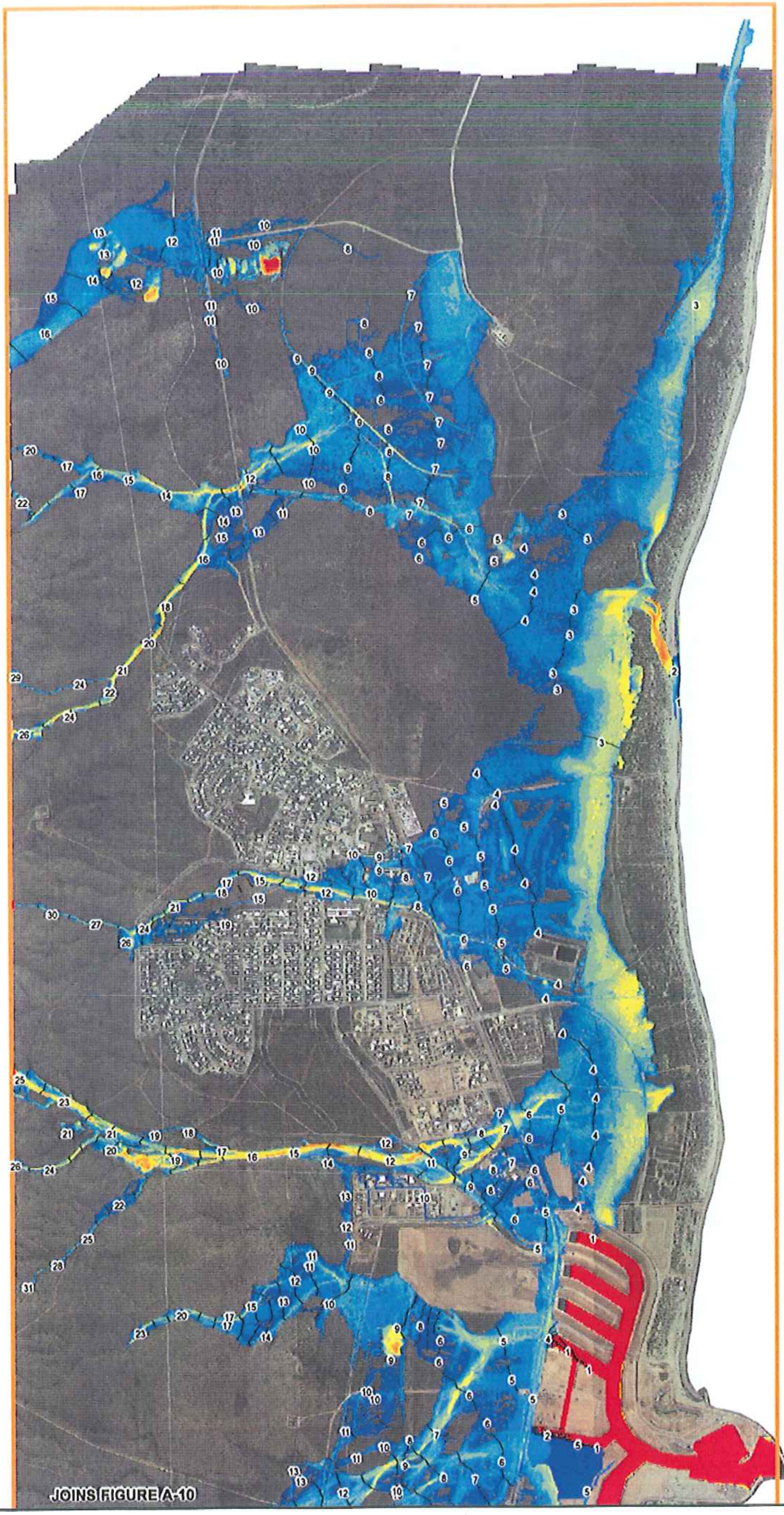


Figure A-9

Exmouth Floodplain Management Study

Q25 Existing Case Inundation Mapping

Part 1

Legend

- Peak Flood Level Contour (1m interval)
- 12 Flood Level (m, AHD)
- Hydraulic Model Extent
- Cadastre

Compiled Peak Flood Depth (m)

25 year ARI

- 0.0 - 0.01
- 0.01 - 0.1
- 0.2 - 0.3
- 0.4 - 0.5
- 0.6 - 0.8
- 0.9 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- 2.6 - 5.0

N

0 100 200 400 600 800
Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

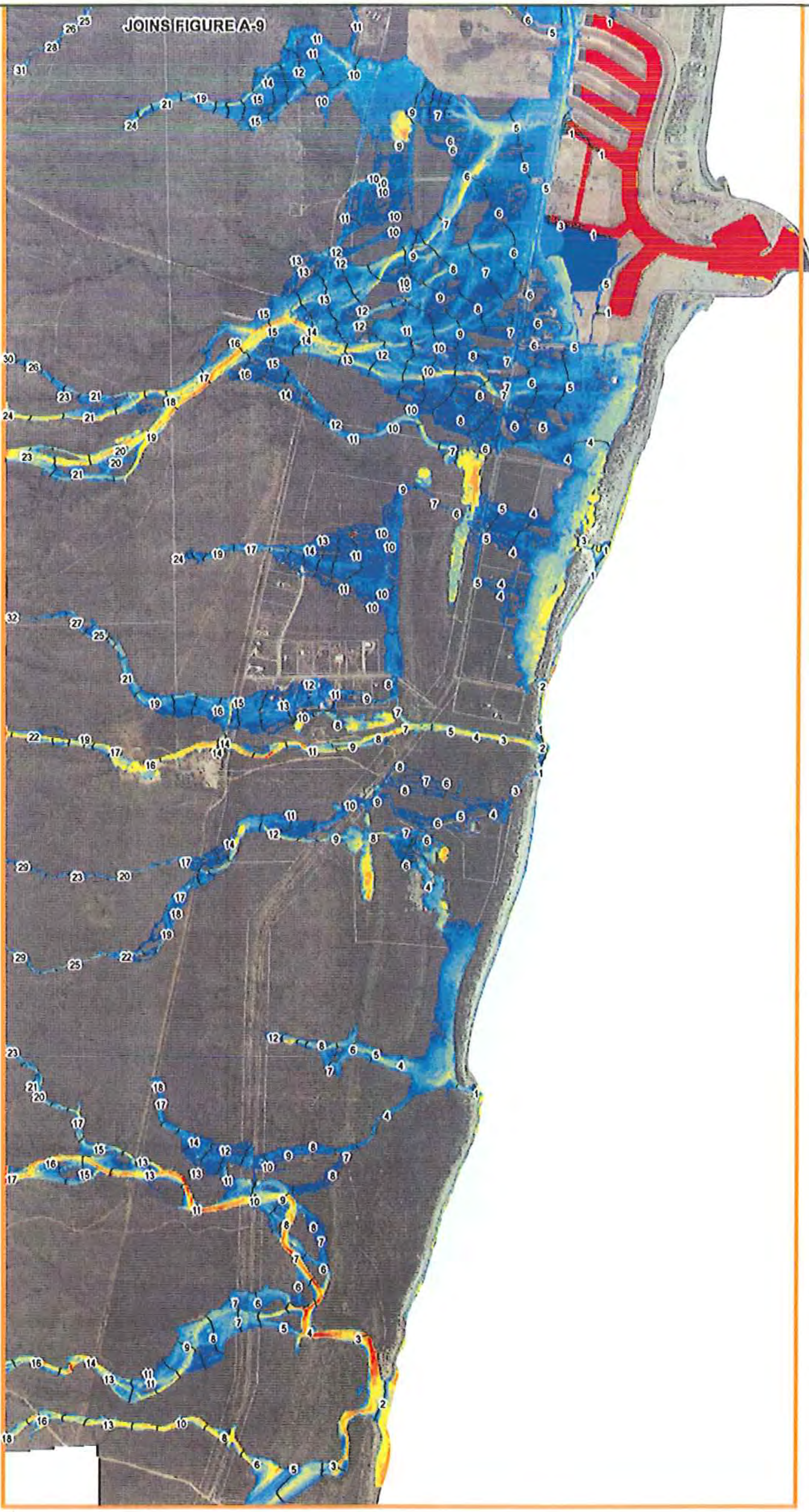


Figure A-10

Exmouth Floodplain Management Study

Q25 Existing Case Inundation Mapping

Part 2

Legend

- Peak Flood Level Contour (1m interval)
- 12 Flood Level (m, AHD)
- Hydraulic Model Extent
- Cadastre

Compiled Peak Flood Depth (m)

10 year ARI

- 0.0 - 0.01
- 0.01 - 0.1
- 0.2 - 0.3
- 0.4 - 0.5
- 0.6 - 0.8
- 0.9 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- 2.6 - 5.0

N

0 100 200 400 600 800

Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

Figure A-11

Exmouth Floodplain Management Study

Q25 Existing Case Velocity Mapping

Part 1

Legend

Hydraulic Model Extent

Cadastre

Compiled Peak Velocity (m/s)

25 year ARI

0.0 - 0.01
0.01 - 0.1
0.2 - 0.5
0.6 - 0.8
0.9 - 1.0
1.1 - 1.5
1.6 - 2.0
2.1 - 2.5
2.6 - 5.0
5.1 - 8.0

N

0 100 200 400 600 800
Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

Figure A-12

Exmouth Floodplain Management Study

Q25 Existing Case Velocity Mapping

Part 2

Legend

Hydraulic Model Extent

Cadastre

Compiled Peak Velocity (m/s)

25 year ARI

0.0 - 0.01

0.01 - 0.1

0.2 - 0.5

0.6 - 0.8

0.9 - 1.0

1.1 - 1.5

1.6 - 2.0

2.1 - 2.5

2.6 - 5.0

5.1 - 8.0

N

0 100 200 400 600 800

Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

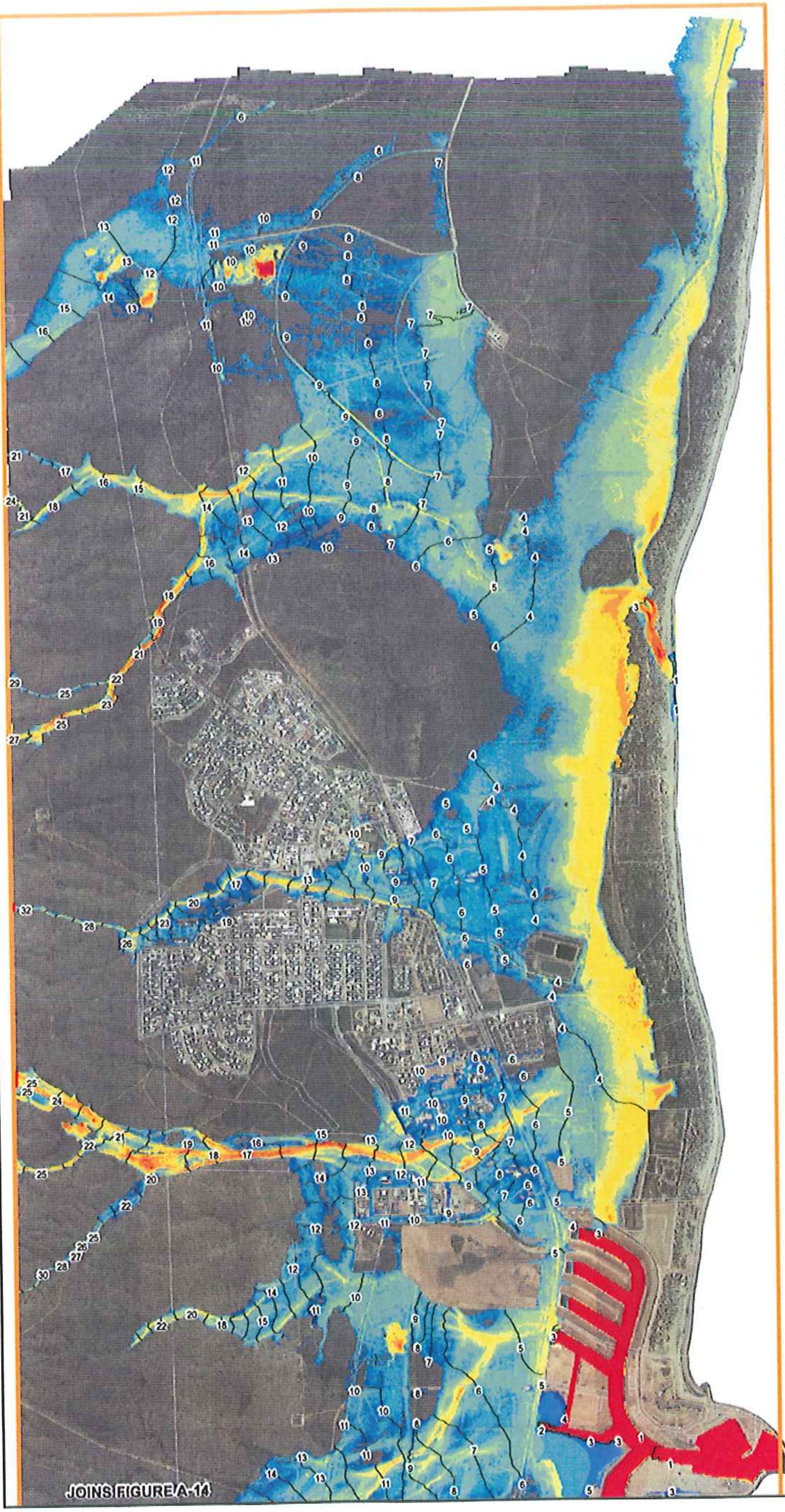


Figure A-13

Exmouth Floodplain Management Study

Q100 Existing Case Inundation Mapping

Part 1

Legend

- Peak Flood Level Contour (1m interval)
- 12 Flood Level (m, AHD)
- Hydraulic Model Extent
- Cadastre

Compiled Peak Flood Depth (m)

100 year ARI

- 0.0 - 0.01
- 0.01 - 0.04
- 0.05 - 0.1
- 0.11 - 0.25
- 0.26 - 0.5
- 0.51 - 0.75
- 0.76 - 1
- 1.01 - 1.5
- 1.51 - 2.0
- 2.01 - 2.5
- 2.51 - 5.0

N

0 100 200 400 600 800
Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

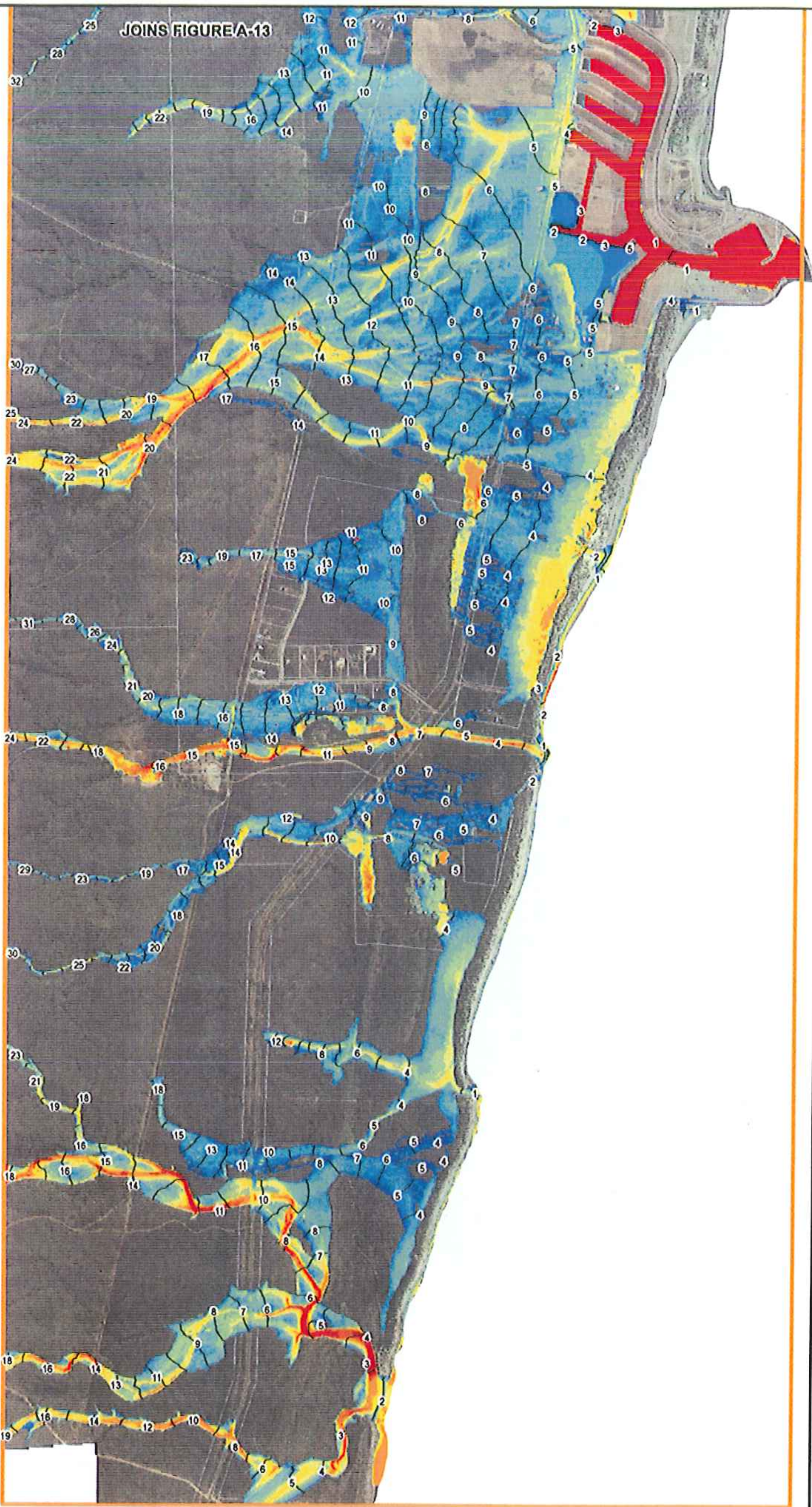


Figure A-14

Exmouth Floodplain Management Study

Q100 Existing Case Inundation Mapping

Part 2

Legend

- Peak Flood Level Contour (1m interval)
- 12 — Flood Level (m, AHD)
- Hydraulic Model Extent
- Cadastre

Compiled Peak Flood Depth (m)

100 year ARI

- 0.0 - 0.01
- 0.01 - 0.04
- 0.05 - 0.1
- 0.11 - 0.25
- 0.26 - 0.5
- 0.51 - 0.75
- 0.76 - 1
- 1.01 - 1.5
- 1.51 - 2.0
- 2.01 - 2.5
- 2.51 - 5.0

N

0 100 200 400 600 800
Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

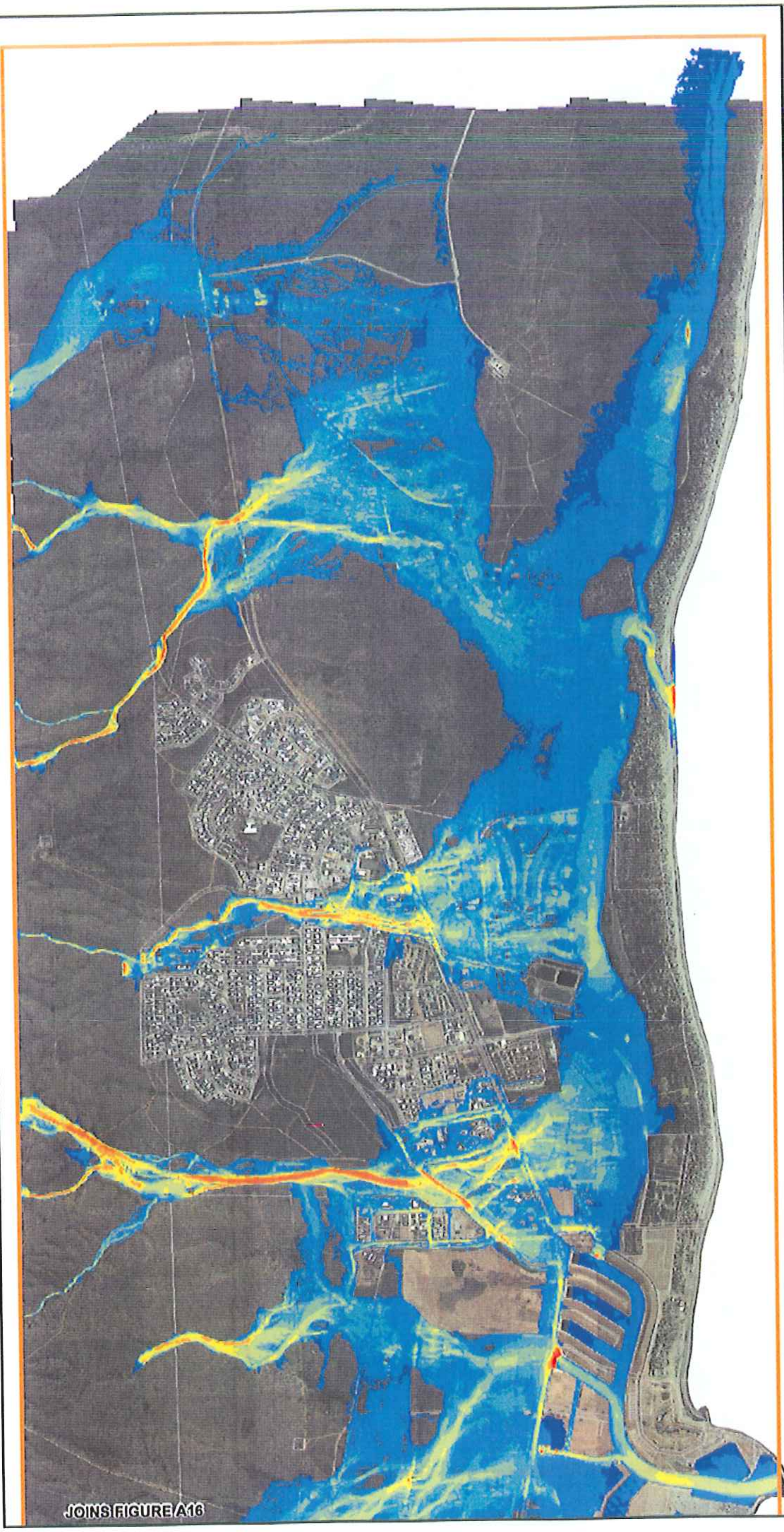


Figure A-15

Exmouth Floodplain Management Study

Q100 Existing Case Velocity Mapping

Part 1

Legend

Hydraulic Model Extent

Cadastre

Compiled Peak Velocity (m/s)

100 year ARI

- 0.0 - 0.01
- 0.01 - 0.1
- 0.2 - 0.5
- 0.6 - 0.8
- 0.9 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- 2.6 - 5.0
- 5.1 - 8.0

N

0 100 200 400 600 800
Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

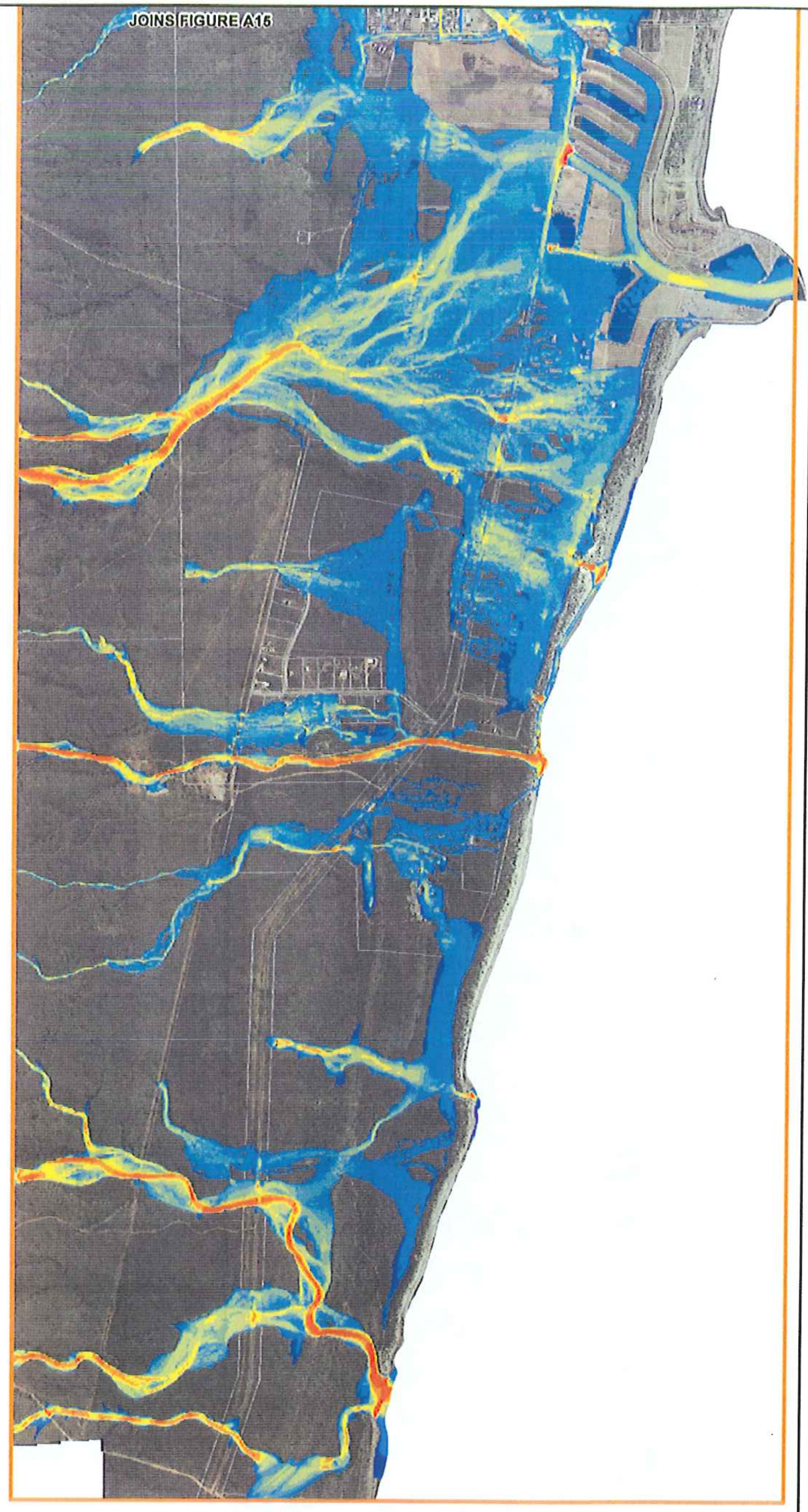


Figure A-16

Exmouth Floodplain Management Study

Q100 Existing Case Velocity Mapping

Part 2

Legend

Hydraulic Model Extent

Cadastre

Compiled Peak Velocity (m/s)

100 year ARI

- 0.0 - 0.01
- 0.01 - 0.1
- 0.2 - 0.5
- 0.6 - 0.8
- 0.9 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- 2.6 - 5.0
- 5.1 - 8.0

N

0 100 200 400 600 800

Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

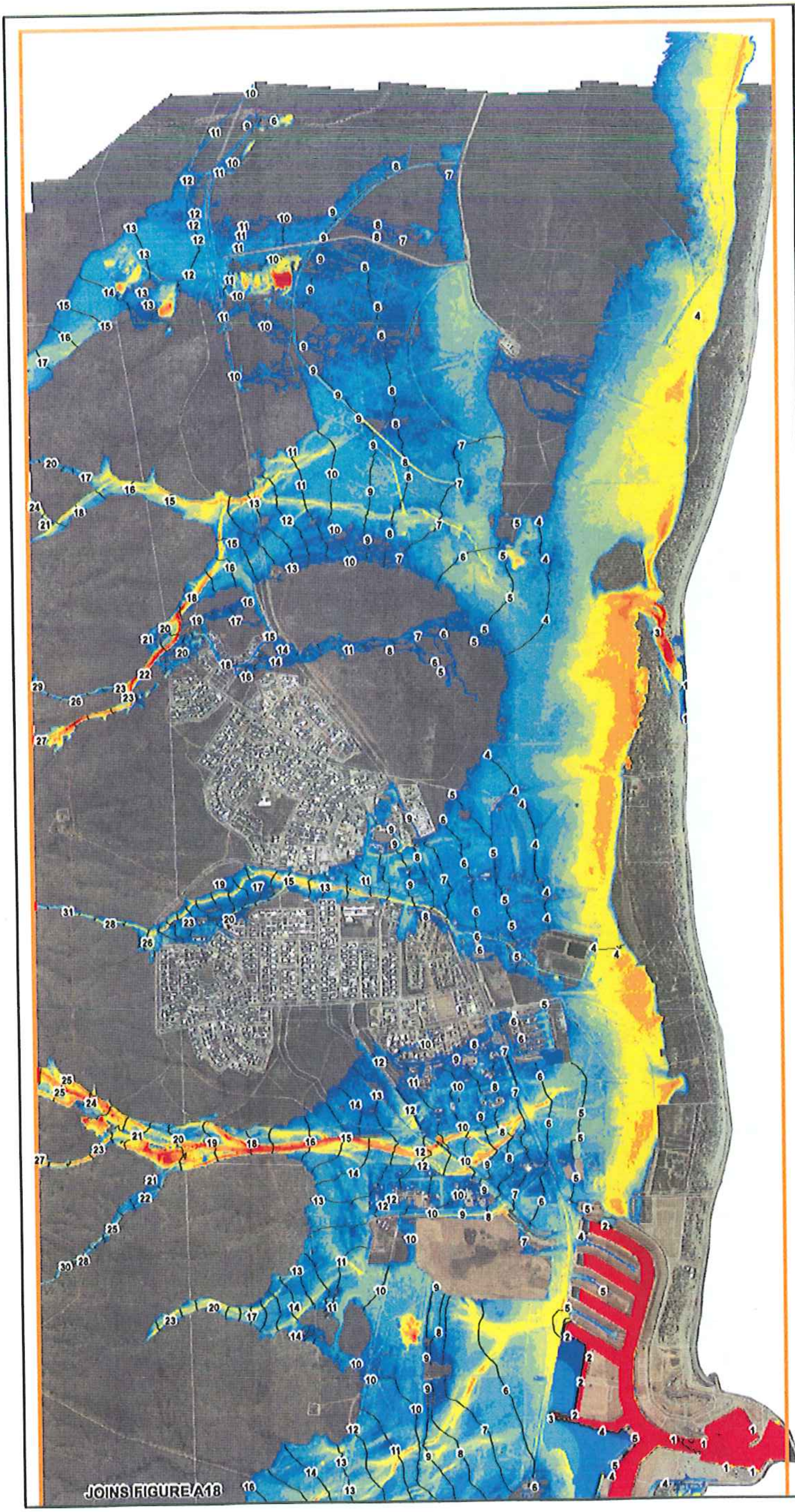


Figure A-17

Exmouth Floodplain Management Study

Q500 Existing Case Inundation Mapping

Part 1

Legend

Peak Flood Level Contour (1m interval)

12 Flood Level (m, AHD)

Hydraulic Model Extent

Cadastre

Compiled Peak Flood Depth (m)

10 year ARI

- 0.0 - 0.01
- 0.01 - 0.1
- 0.2 - 0.3
- 0.4 - 0.5
- 0.6 - 0.8
- 0.9 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- 2.6 - 5.0

N

0 100 200 400 600 800

Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

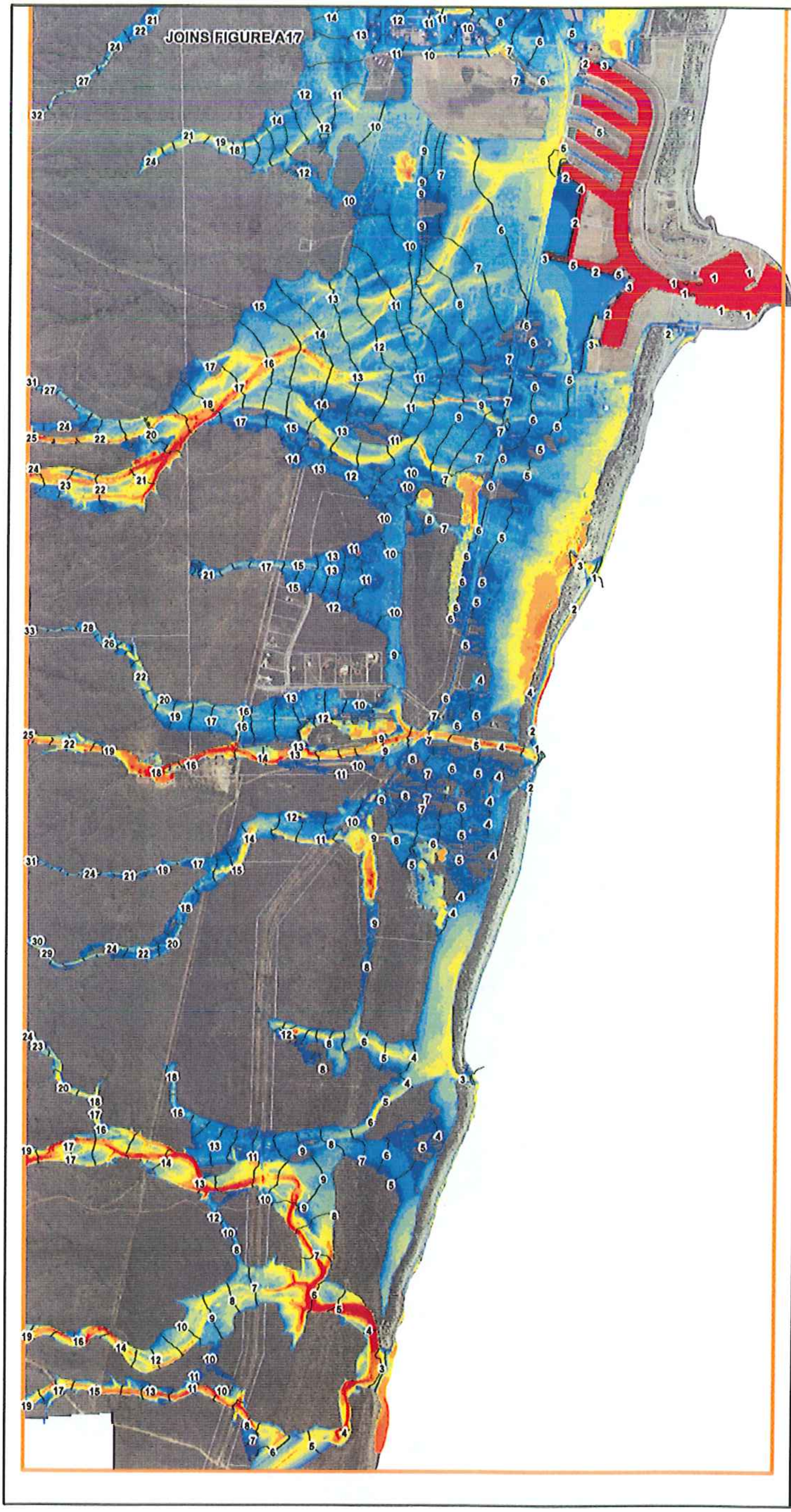


Figure A-18

Exmouth Floodplain Management Study

Q500 Existing Case Inundation Mapping

Part 2

Legend

——	Peak Flood Level Contour (1m interval)
12	Flood Level (m, AHD)
(orange box)	Hydraulic Model Extent
(box)	Cadastre

Compiled Peak Flood Depth (m)

10 year ARI

- 0.0 - 0.01
- 0.01 - 0.1
- 0.2 - 0.3
- 0.4 - 0.5
- 0.6 - 0.8
- 0.9 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- 2.6 - 5.0

N

0 100 200 400 600 800

Metres

Scale 1:25,000 (at A4)

SKM

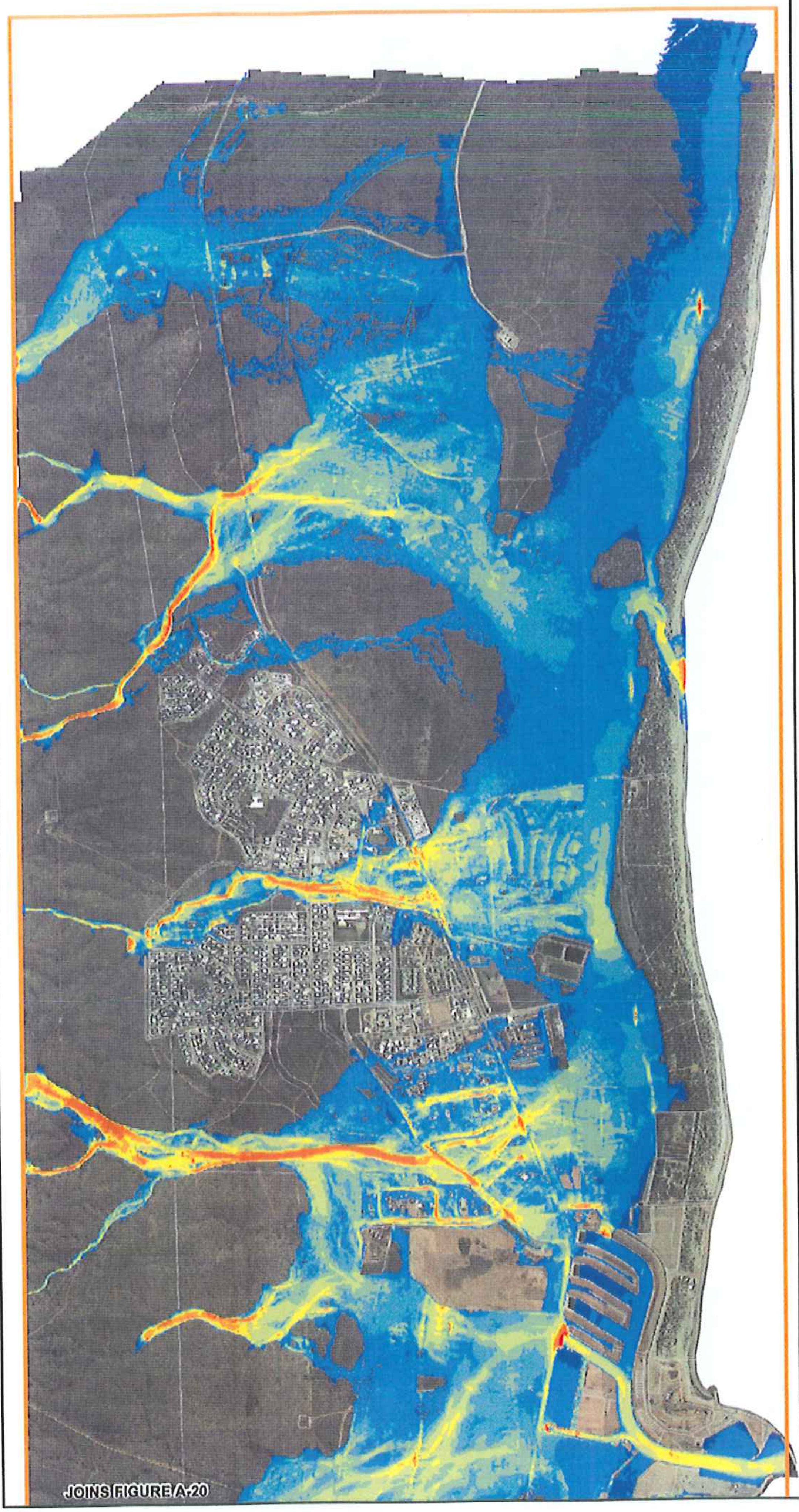
Project Number - QE09355

Figure A-19

Exmouth Floodplain Management Study

Q500 Existing Case Velocity Mapping

Part 1



Legend

Hydraulic Model Extent

Cadastre

Compiled Peak Velocity (m/s)

500 year ARI

0.0 - 0.01

0.01 - 0.1

0.2 - 0.5

0.6 - 0.8

0.9 - 1.0

1.1 - 1.5

1.6 - 2.0

2.1 - 2.5

2.6 - 5.0

5.1 - 8.0

N

0 100 200 400 600 800

Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

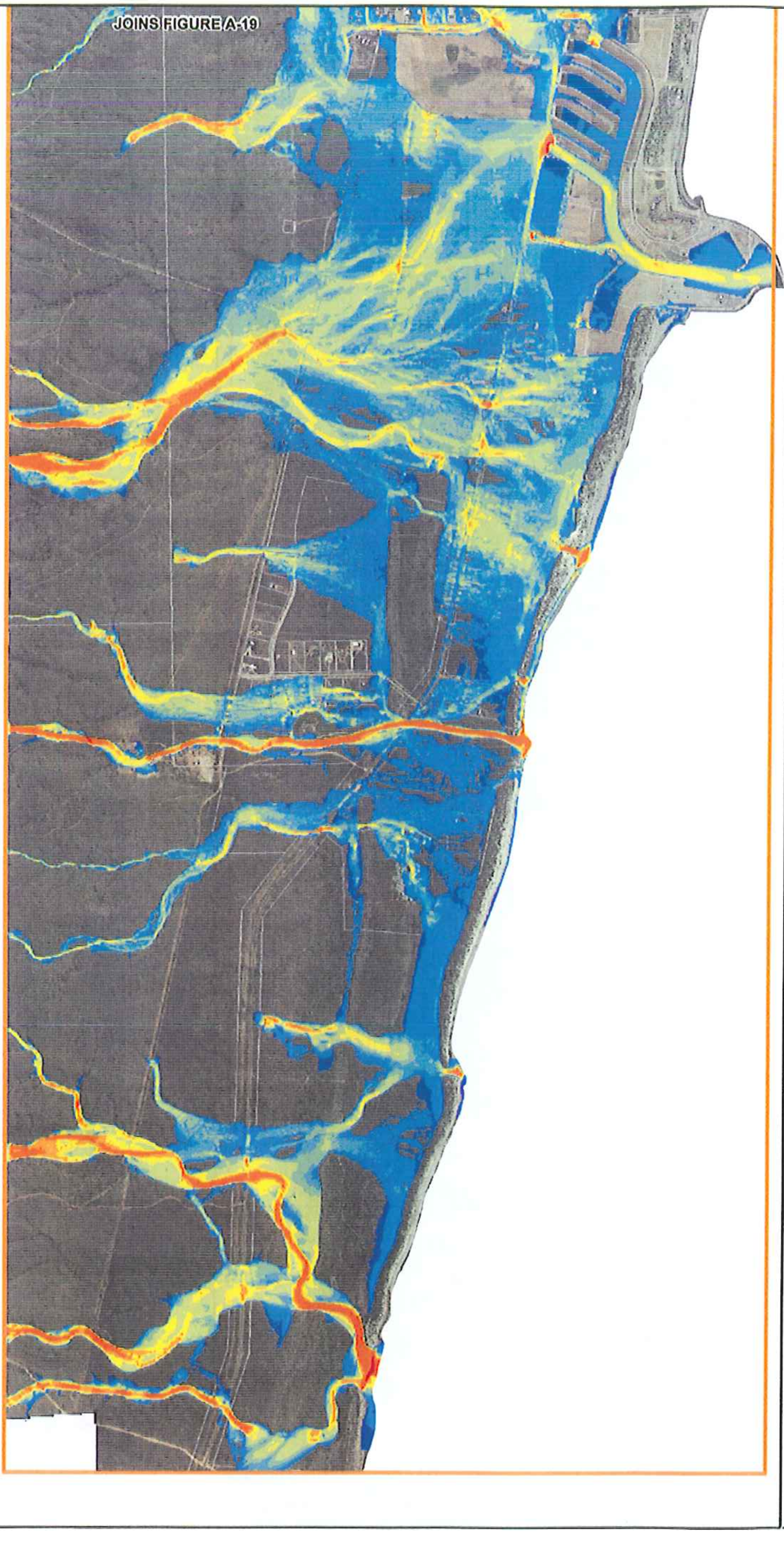


Figure A-20

Exmouth Floodplain Management Study

Q500 Existing Case Velocity Mapping

Part 2

Legend

Hydraulic Model Extent

Cadastre

Compiled Peak Velocity (m/s)

500 year ARI

0.0 - 0.01

0.01 - 0.1

0.2 - 0.5

0.6 - 0.8

0.9 - 1.0

1.1 - 1.5

1.6 - 2.0

2.1 - 2.5

2.6 - 5.0

5.1 - 8.0

N

0 100 200 400 600 800

Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

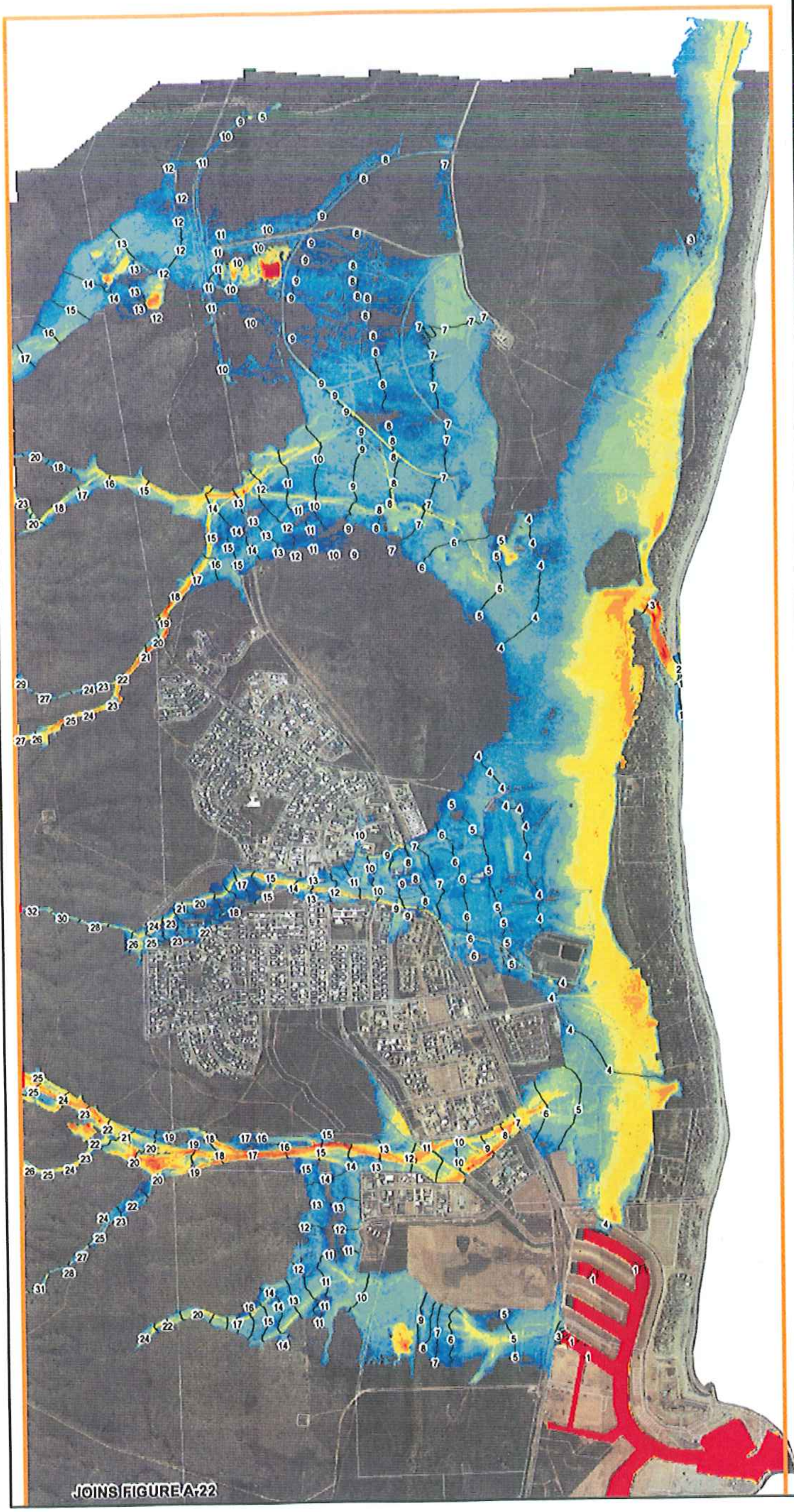


Figure A-21

Exmouth Floodplain Management Study

Q100 Developed Case Inundation Mapping

Part 1

Legend

- Peak Flood Level Contour (1m interval)
- 12 Flood Level (m, AHD)
- Hydraulic Model Extent
- Cadastre

Compiled Peak Flood Depth (m)

100 year ARI

- 0.0 - 0.01
- 0.01 - 0.04
- 0.05 - 0.1
- 0.11 - 0.25
- 0.26 - 0.5
- 0.51 - 0.75
- 0.76 - 1
- 1.01 - 1.5
- 1.51 - 2.0
- 2.01 - 2.5
- 2.51 - 5.0

N

0 110 220 440 660 880

Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

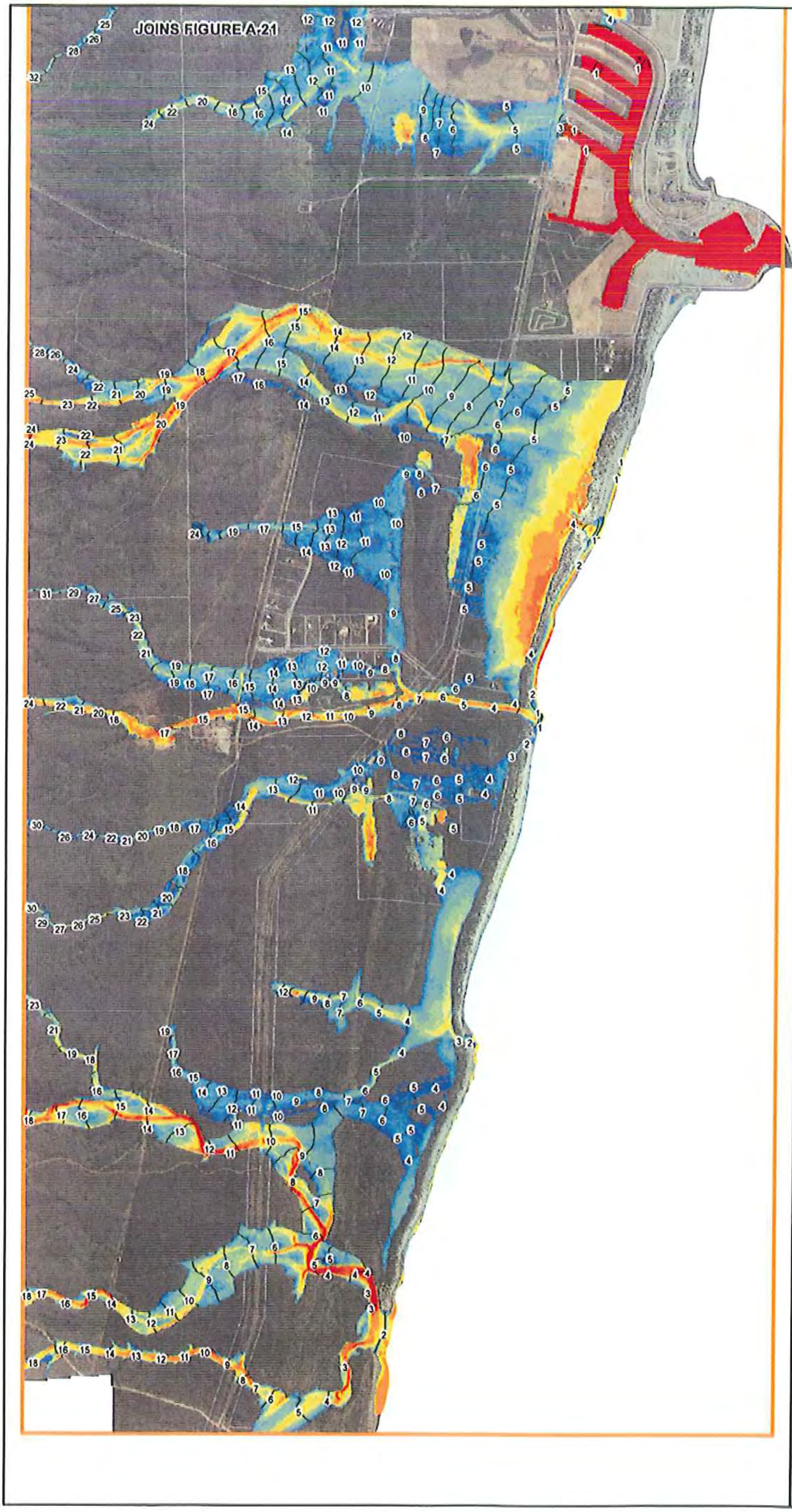


Figure A-22

Exmouth Floodplain Management Study

Q100 Developed Case Inundation Mapping

Part 2

Legend

——	Peak Flood Level Contour (1m interval)
12	Flood Level (m, AHD)
(orange outline)	Hydraulic Model Extent
	Cadastre

Compiled Peak Flood Depth (m)

100 year ARI

- 0.0 - 0.01
- 0.01 - 0.04
- 0.05 - 0.1
- 0.11 - 0.25
- 0.26 - 0.5
- 0.51 - 0.75
- 0.76 - 1
- 1.01 - 1.5
- 1.51 - 2.0
- 2.01 - 2.5
- 2.51 - 5.0

N

0 100 200 400 600 800

Metres

Scale 1:25,000 (at A4)

SKM

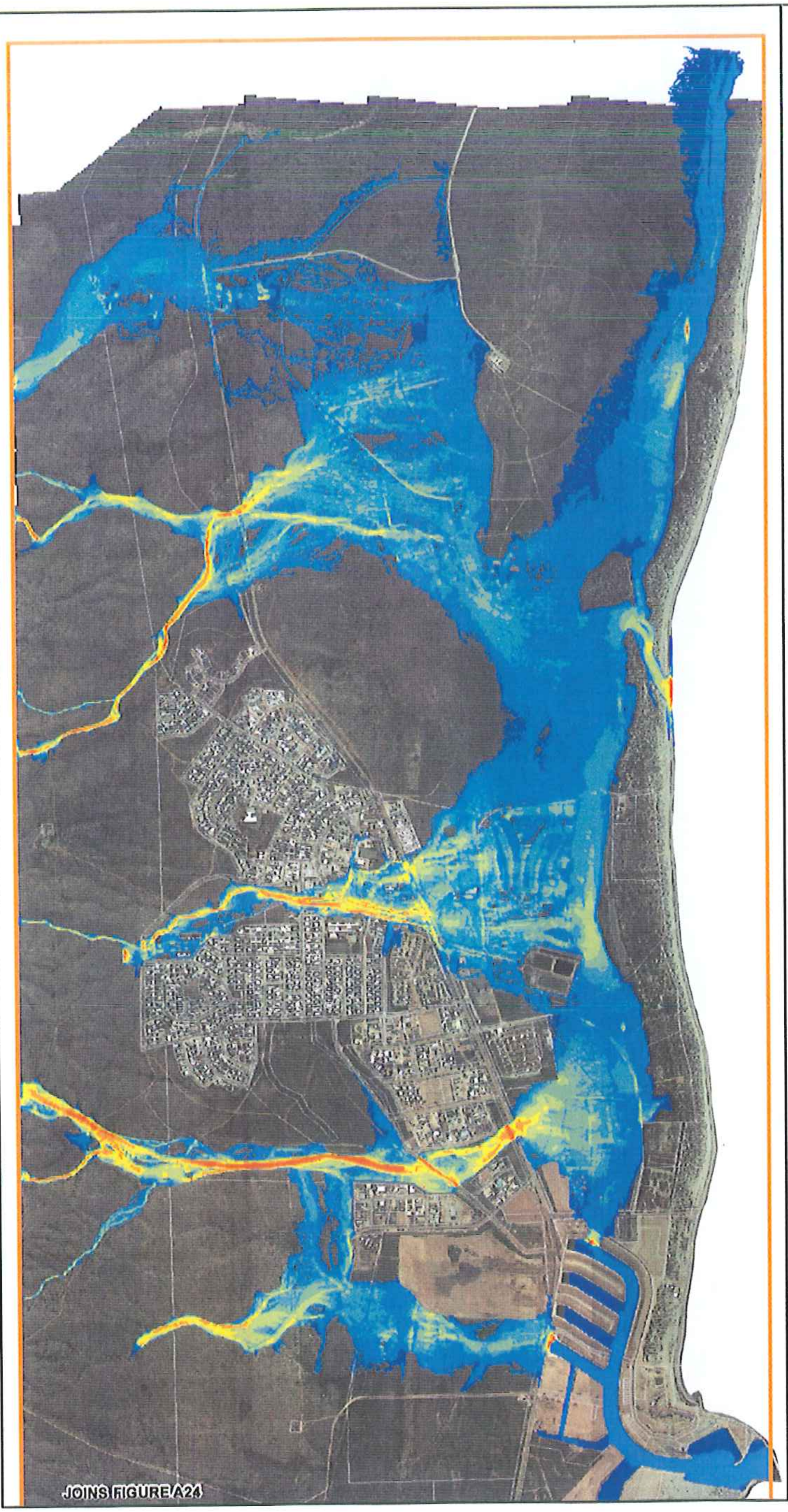
Project Number - QE09355

Figure A-23

Exmouth Floodplain Management Study

Q100 Developed Case Velocity Mapping

Part 1



Legend

Hydraulic Model Extent

Cadastre

Compiled Peak Velocity (m/s)

100 year ARI

0.0 - 0.01

0.01 - 0.1

0.2 - 0.5

0.6 - 0.8

0.9 - 1.0

1.1 - 1.5

1.6 - 2.0

2.1 - 2.5

2.6 - 5.0

5.1 - 8.0

N

0 100 200 400 600 800

Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

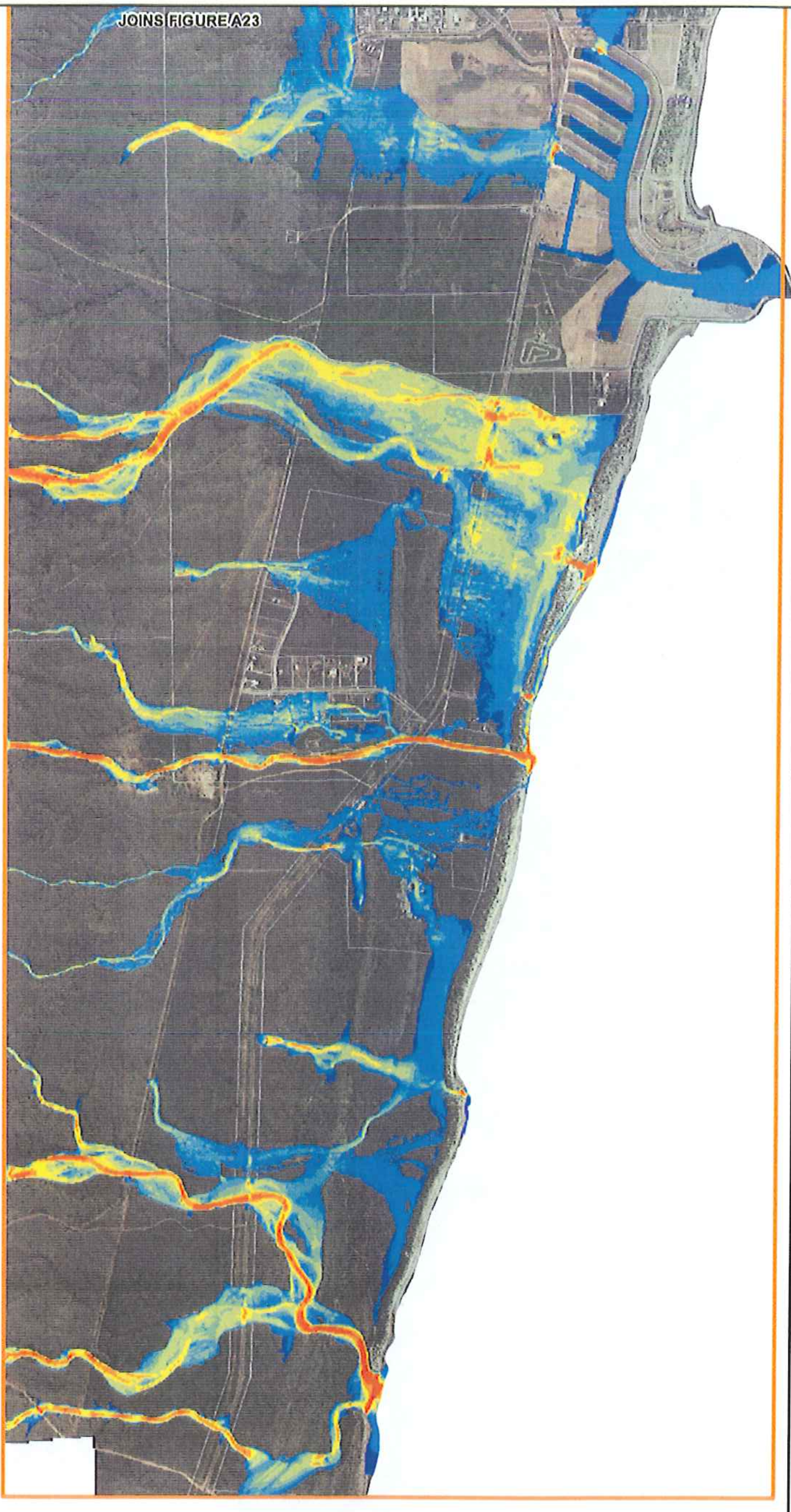


Figure A-24

Exmouth Floodplain Management Study

Q100 Developed Case Velocity Mapping

Part 2

Legend

- Hydraulic Model Extent
- Cadastre

Compiled Peak Velocity (m/s)

100 year ARI

- 0.0 - 0.01
- 0.01 - 0.1
- 0.2 - 0.5
- 0.6 - 0.8
- 0.9 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- 2.6 - 5.0
- 5.1 - 8.0

N

0 100 200 400 600 800

Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

Appendix B Flood Hazard Mapping and Flood Zones

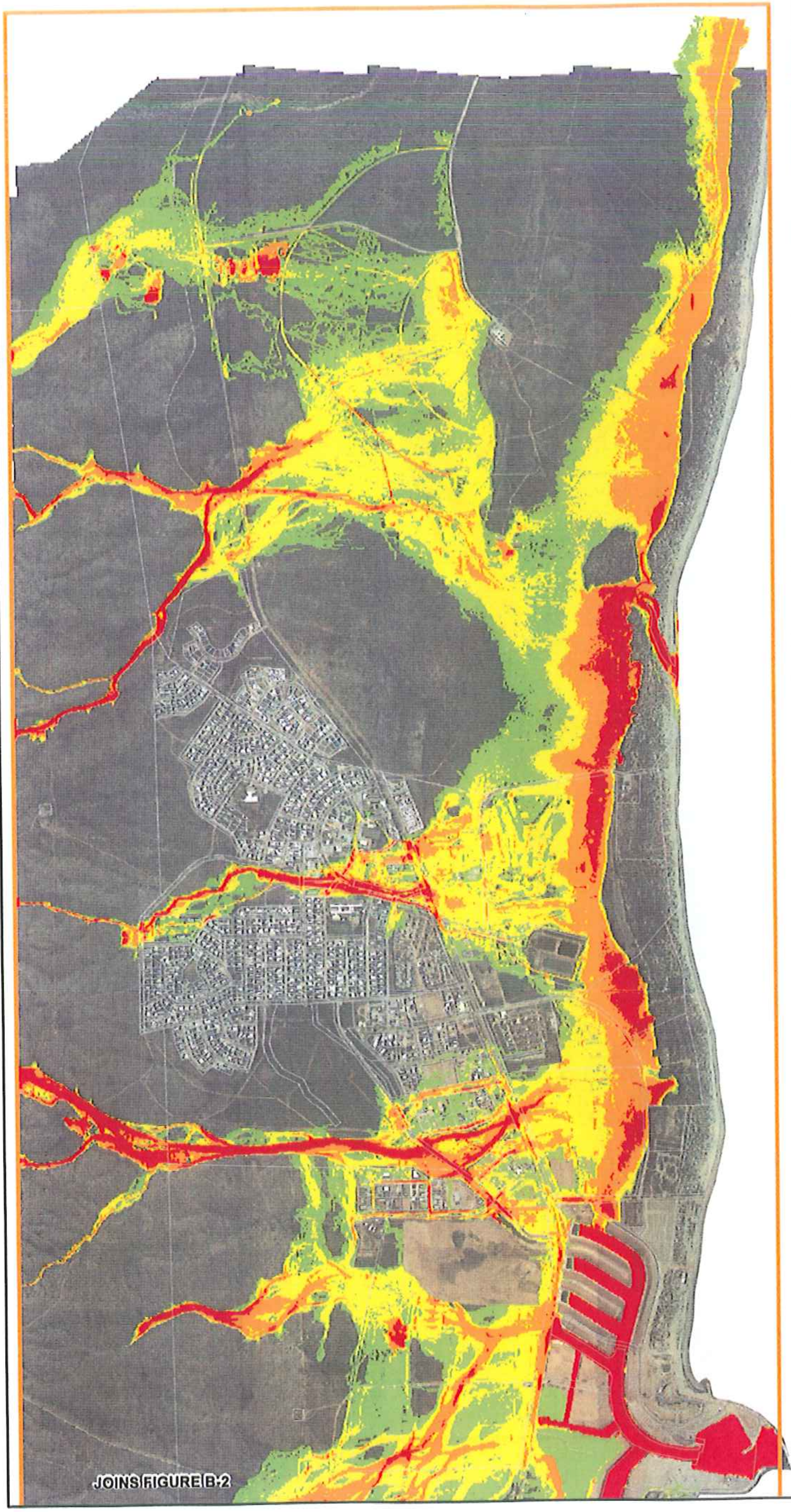
- Figure B-1 Q100 "Existing Case" Hazard Mapping Part 1
- Figure B-2 Q100 "Existing Case" Hazard Mapping Part 2
- Figure B-3 Floodplain Management "Existing Case" Land Use Zoning Part 1
- Figure B-4 Floodplain Management "Existing Case" Land Use Zoning Part 2
- Figure B-5 Q100 "Developed Case" Hazard Mapping Part 1
- Figure B-6 Q100 "Developed Case" Hazard Mapping Part 2
- Figure B-7 Floodplain Management "Developed Case" Flood Zoning Part 1
- Figure B-8 Floodplain Management "Developed Case" Flood Zoning Part 2

Figure B-1

Exmouth Floodplain Management Study

Q100 Existing Case
Hazard Mapping

Part 1



Legend

- Hydraulic Model Extent
- Cadastre

Flood Hazard Classification

- Low
- Moderate
- High
- Extreme

N

0 100 200 400 600 800
Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

Projection: MGA94 Zone 50, GDA94

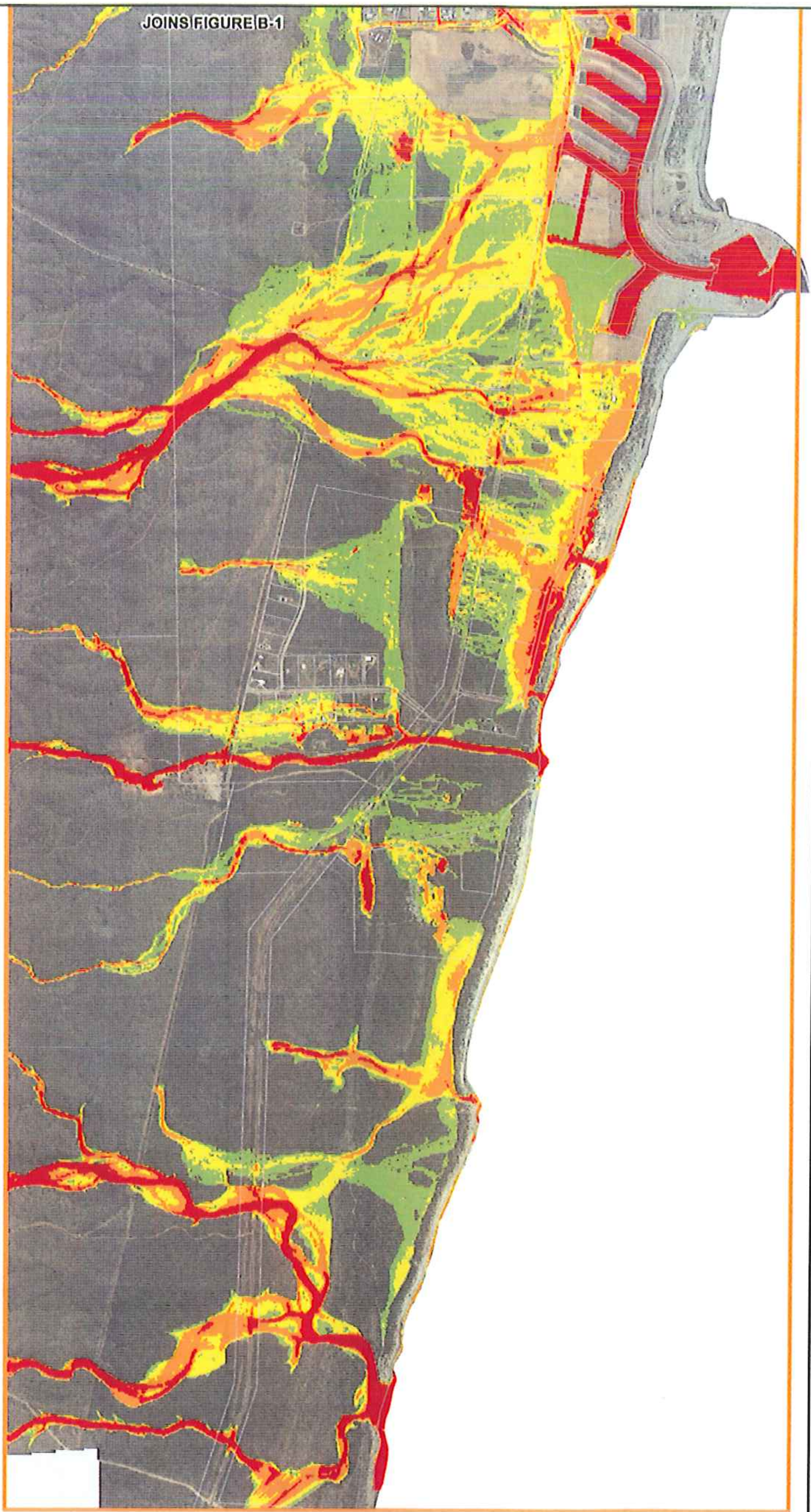


Figure B-2

Exmouth Floodplain Management Study

Q100 Existing Case Hazard Mapping

Part 2

Legend

Hydraulic Model Extent

Cadastre

Flood Hazard Classification

- Low
- Moderate
- High
- Extreme

Scale 1:25,000 (at A4)

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Project Number - QE09355

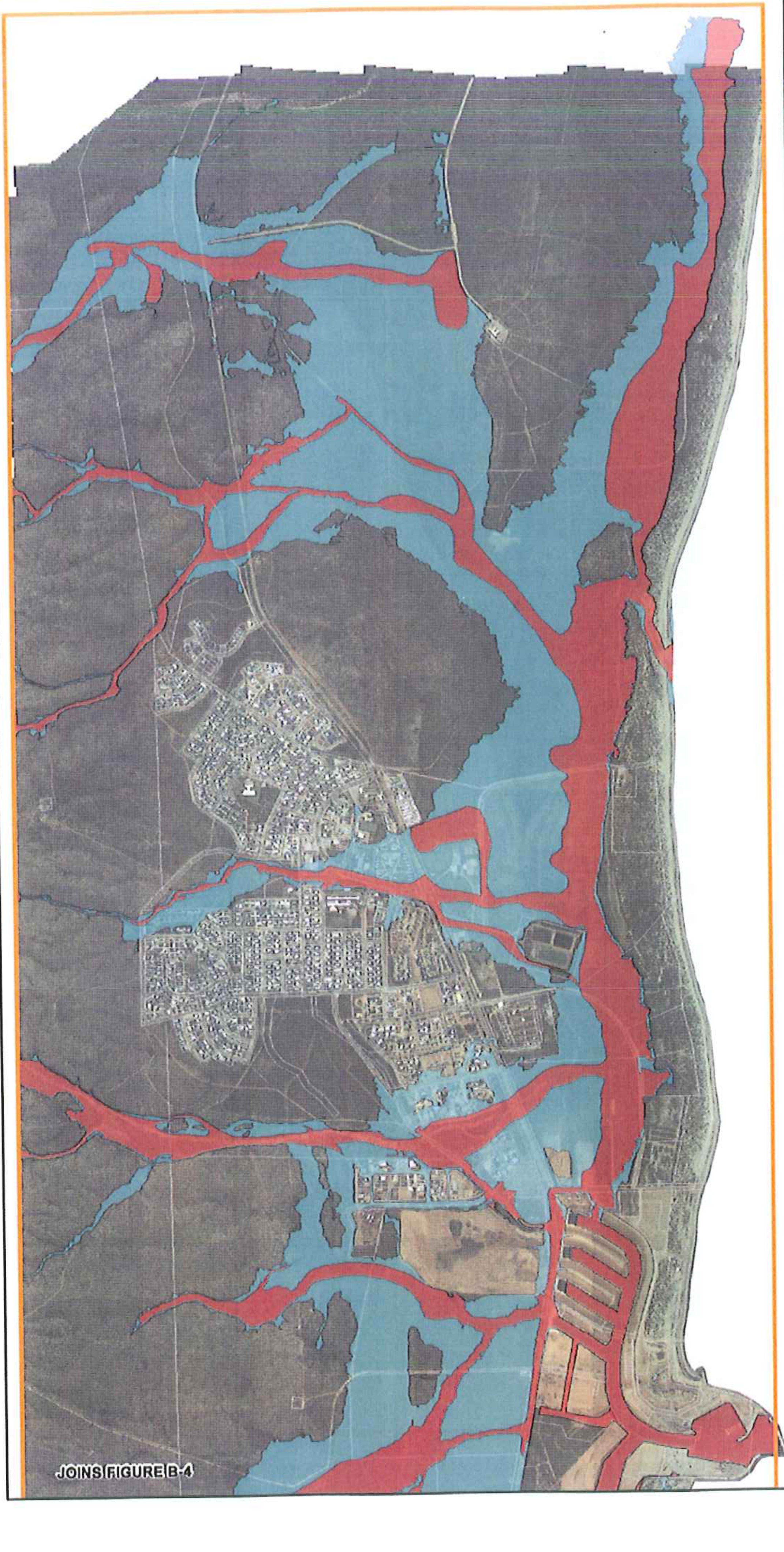

Figure B-3

Exmouth Floodplain Management Study

Floodplain Management Strategy
Flood Zoning
Existing Case
Part 1

Legend

- Flood Way
- Flood Zone
- Area Under Further Consideration
- Hydraulic Model Extent
- Cadastre

N

0 100 200 400 600 800
Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

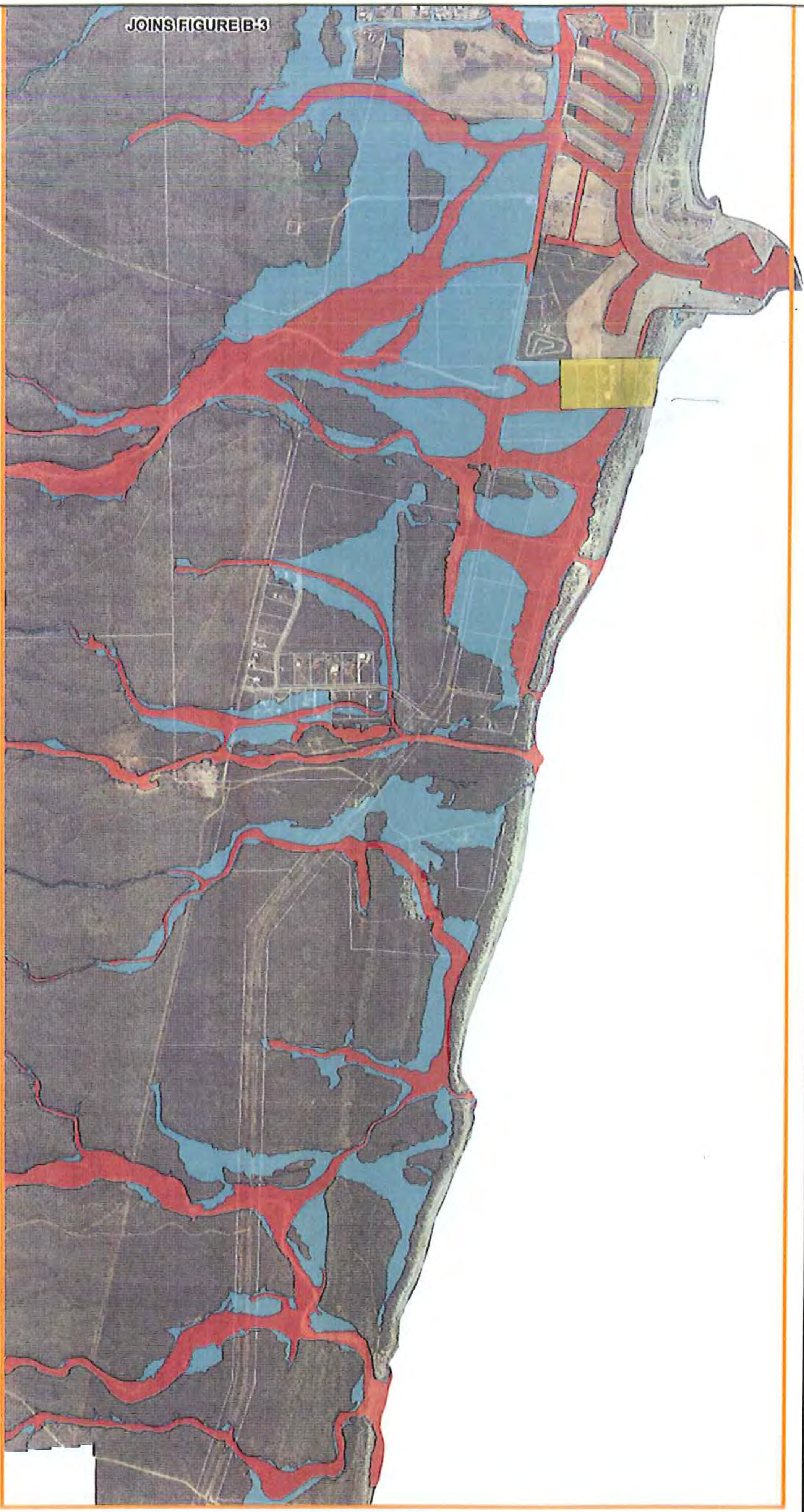

Figure B-4

Exmouth Floodplain Management Study

Floodplain Management Strategy

Flood Zoning Existing Case

Part 2

Legend

- Flood Way
- Flood Zone
- Area Under Further Consideration
- Hydraulic Model Extent
- Cadastre

N

0 95 190 380 570 760
Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

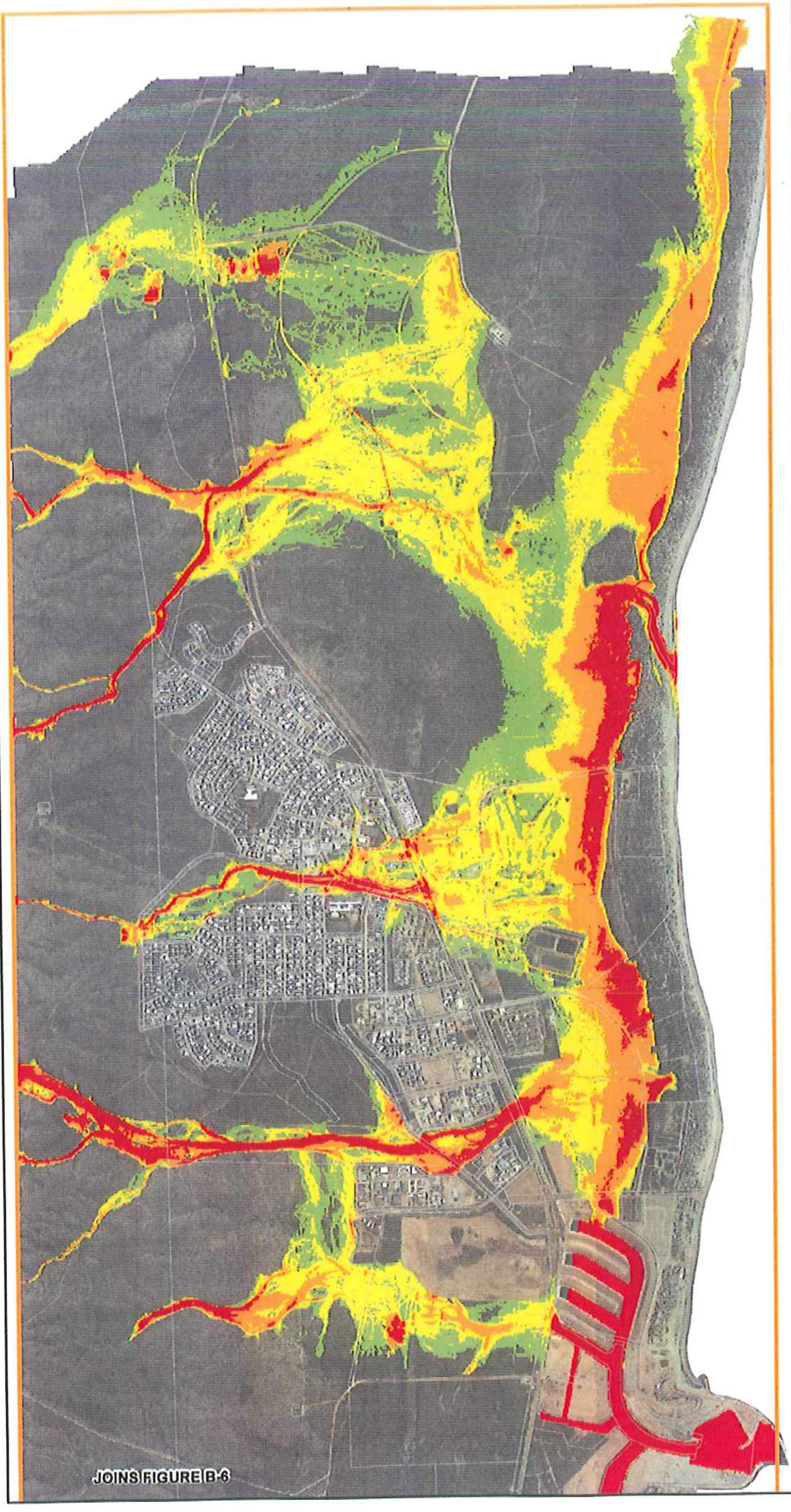

Figure B-5

Exmouth Floodplain Management Study

Q100 Developed Case Hazard Mapping

Part 1

Legend

- Hydraulic Model Extent
- Cadastre

Flood Hazard Classification

- Low
- Moderate
- High
- Extreme

N

0 105 210 420 630 840

Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

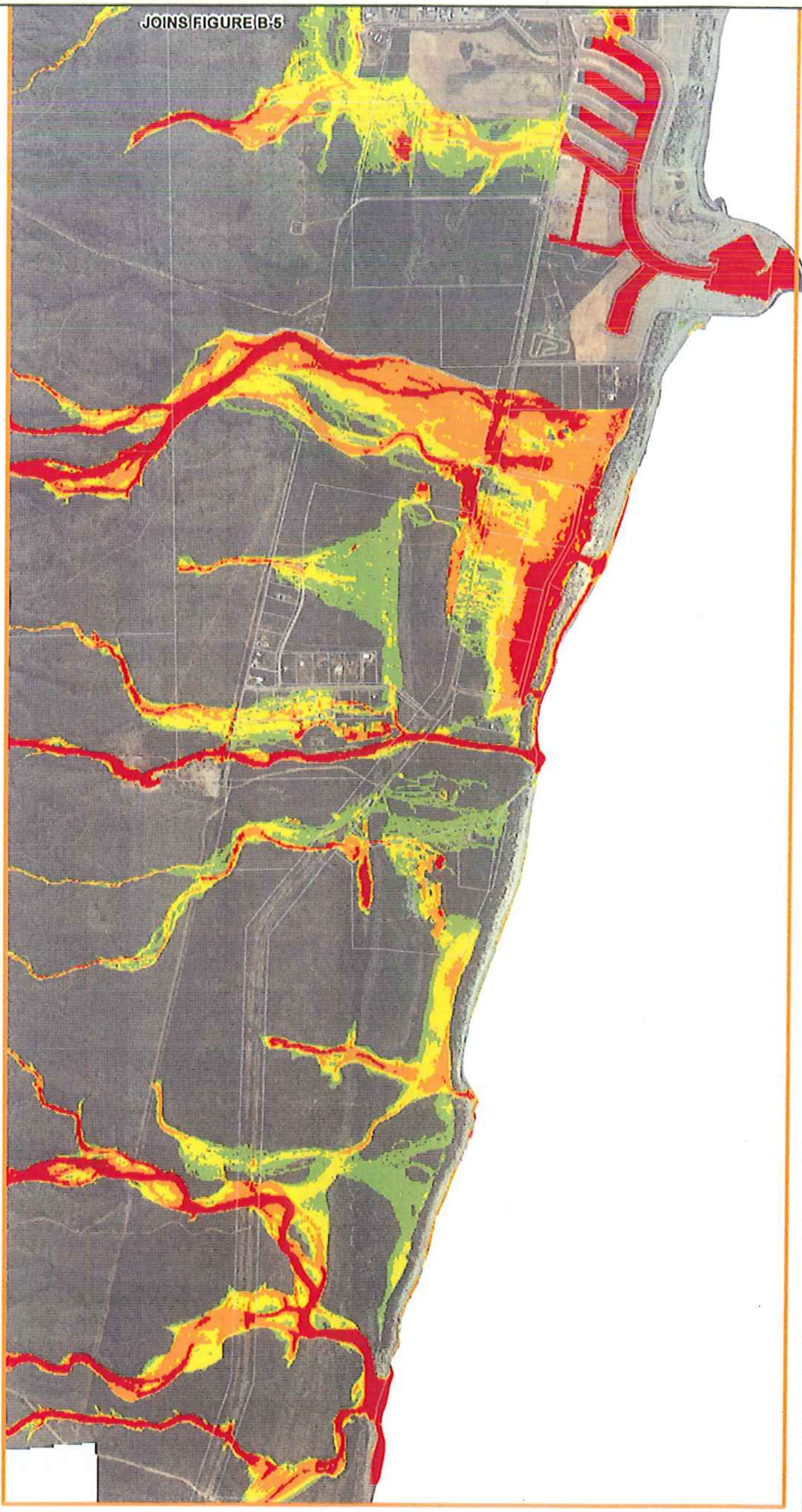

Figure B-6

Exmouth Floodplain Management Study

Q100 Developed Case Hazard Mapping

Part 2

Legend

Hydraulic Model Extent

Cadastre

Flood Hazard Classification

- Low
- Moderate
- High
- Extreme

N

0 100 200 400 600 800

Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

Figure B-7

Exmouth Floodplain Management Study

Floodplain Management Strategy
Flood Zoning
Developed Case
Part 1

Legend

- Flood Way
- Flood Zone
- Area of Special Consideration
- Hydraulic Model Extent
- Cadastre

N

0 100 200 400 600 800

Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355

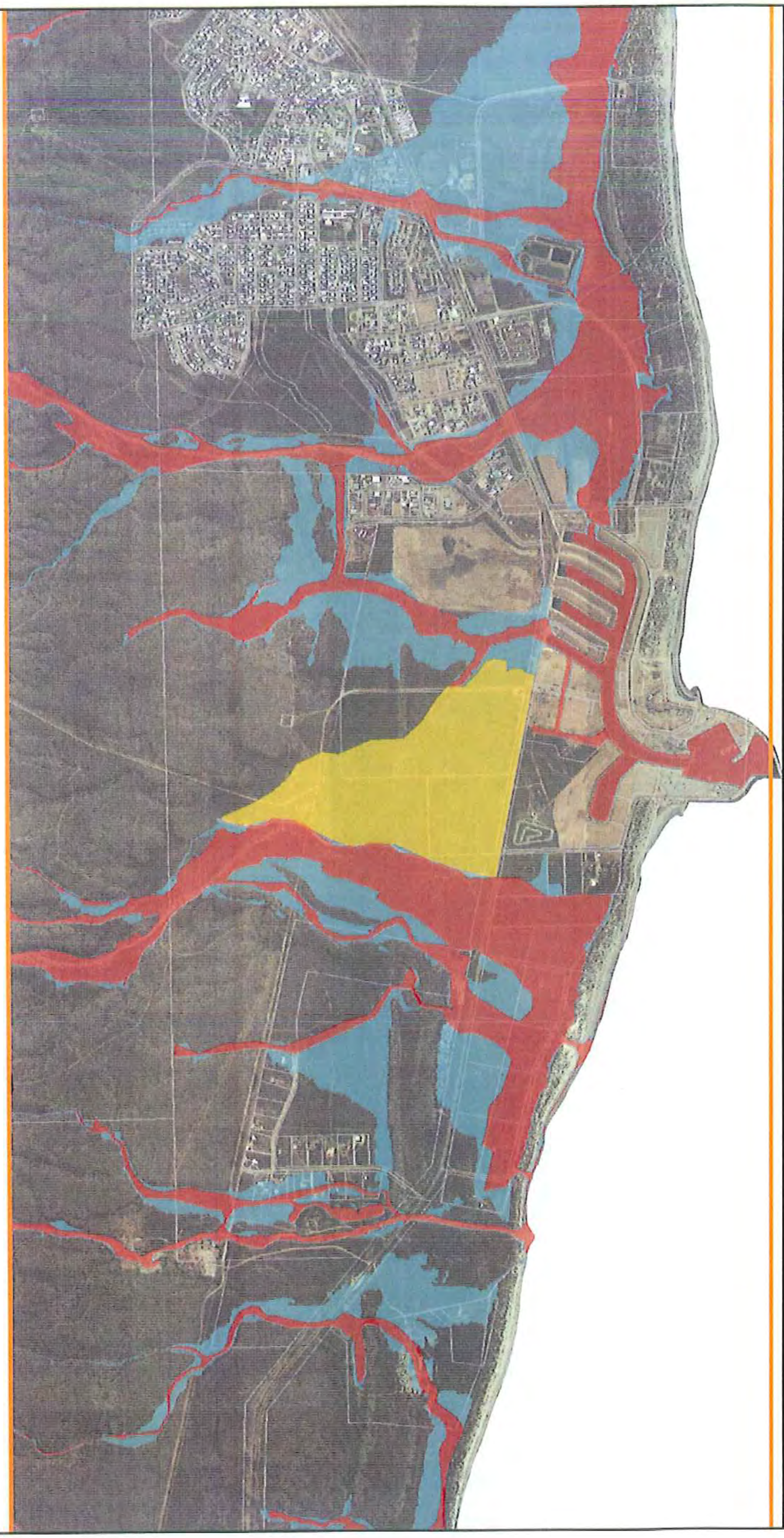

Figure B-8

Exmouth Floodplain Management Study

Floodplain Management Strategy

Flood Zoning Developed Case

Part 2

Legend

- Flood Way
- Flood Zone
- Area of Special Consideration
- Hydraulic Model Extent
- Cadastre

N

0 90 180 360 540 720

Metres

Scale 1:25,000 (at A4)

SKM

Project Number - QE09355