Roebourne Townsite

Stormwater and Flood Management Plan

Prepared for Shire of Roebourne

By Essential Environmental

February 2013

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EXECUTIVE SUMMARY

Objectives for the flood and stormwater management plan relate to; environmental protection, protection of assets, and safety of residents.

Key objectives of this plan are considered to be as follows:

- **Environmental protection.** To maintain the natural flow of stormwater and floodwaters through the landscape and support the social and environmental services provided by local ecosystems. To protect ecosystems from potential adverse impacts caused by human occupation in the landscape.
- **Protect private and public infrastructure.** To provide adequate protection for infrastructure that has potential to be damaged from floods and/or conveyance of stormwater. To allow effective management of infrastructure assets which are impacted by flooding and/or stormwater.
- **Manage public safety.** To limit the risk of injury to residents that can result from flow of water and inundation in stormwater drainage systems and during flood events.
- **Provide social amenity.** To provide an appropriate level of amenity and serviceability for infrastructure within the community. Manage potential nuisances to the community as a result of flooding.

Development of the strategy has drawn upon various principles for flood management that are advocated by the Department of Water and presented in SCARM73 as well as policy measures from the currently gazetted edition of *State planning policy no. 2.6: State coastal planning policy* (WAPC 2006). Overarching principles that have guided selection of management strategies and that should be used to guide future decision making in the area can be summarised as follows.

- property impacts of existing flooding problems are managed to acceptable levels
- proposed development has adequate 100 year ARI flood protection
- proposed development does not detrimentally impact on the existing 100 year ARI flooding regime of the general area
- the form and pattern of proposed development considers the likely impacts of flooding, coastal forces and sea level rise
- the impacts of existing flooding problems on the well-being of individuals are managed to acceptable levels
- the natural function of floodplains to convey flood waters and/or sustain flood dependent ecosystems is preserved, and enhanced where possible
- planning and use of floodplains as a resource for the whole community is encouraged
- likely impacts of coastal forces and sea level rise are understood and managed to acceptable levels

A risk assessment framework was used to examine key risks that affect the objectives described above and to formulate the stormwater and flood management plan with an appropriate response.

A stormwater and flood management strategy is presented which includes strategies for land use planning, development and building controls, structural measures and flood emergency planning. These strategies respond to the unique hydrological and hydraulic circumstances present in Roebourne bringing together Harding River flood risks, storm surge and coastal inundation risks and risks presented by local drainage systems.

In addition to guidance for future development in the townsite, a number of existing flood management issues were identified. The following structural measures aimed at addressing the risks associated with those site specific issues and constraints are recommended:

- Consider drainage infrastructure improvements to provide more efficient conveyance of flood waters away from residential areas to more suitable downstream locations for management. Suggested improvements could include:
  - establishment of new drainage reserves connecting residential streets in the vicinity of Crawford Way and Andover Street to Lockyer Way reserve
  - upgrade of undersized culverts passing Roe Street
  - provision of formalised flow paths at western edge of NASH development
  - upgrades to Cleaverville road drainage system
  - formal recognition and management of informal flow paths
  - provision of new culverts limiting passage of storm flows over roads to major events only
  - provision of improved flood protection for the power substation site
  - upgrades to drainage adjacent to Fraser Street
- Undertake assessment of ecosystems potentially affected by existing drainage and undertake targeted interventions restore environmental flows improve sediment management and manage existing or potential erosion

CONTENTS

Tables

Figures

if not now...

land & water solutions

when?

1 INTRODUCTION

This stormwater and flood management plan has been prepared to inform decisions regarding the future use and management of land in and around the existing Roebourne town site.

1.1 Background

The Shire of Roebourne is preparing a structure plan that will guide future development in and around the Roebourne townsite.

The location of the townsite on the western bank of the Harding River exposes developments in the area to risks associated with riverine flooding as well as possible impacts from coastal processes. In addition to flood risk from external sources, stormwater drainage through the townsite and surrounding land may present additional constraints to development of the area.

The Shire of Roebourne is currently pursuing resolution of planning matters within the structure plan area to provide guidance for the future development of the townsite.

1.2 Purpose

The Shire of Roebourne engaged Essential Environmental to undertake an assessment of surface hydrology and analysis of drainage to inform future development of land in the Roebourne townsite.

The purpose of this *Stormwater and flood management plan* is to identify key constraints and required management actions in regards to flood risk and stormwater management and in doing so inform the structure plan that is being developed by the Shire.

This stormwater and flood management plan will:

- Identify key characteristics of coastal processes, hydrology and local stormwater drainage which are likely to affect the townsite area.
- Provide a risk assessment of potential impacts from flooding and stormwater management on development and of any future development on natural processes.
- Identify stormwater management principles and a flood risk mitigation strategy for current and future development in the townsite.

1.3 Study area

Roebourne is located in the Pilbara region in the north of Western Australia approximately 11 km south west of the coast, 1300 km north of Perth and 30 km east of Karratha (Figure 1). A large portion of the existing townsite is located between the Harding River and “Welcome Mountain” although there is an industrial area further north and residential and tourism land uses on the eastern side of the Harding River. The current structure plan study area includes the existing townsite and currently undeveloped land to the north and west as indicated in Figure 1.

North-east of the study area the Harding River opens up to a wide floodplain and riverine delta discharging to tidal plains and Sherlock Bay. The study area for this management plan is limited to the structure plan area and adjacent Harding River.

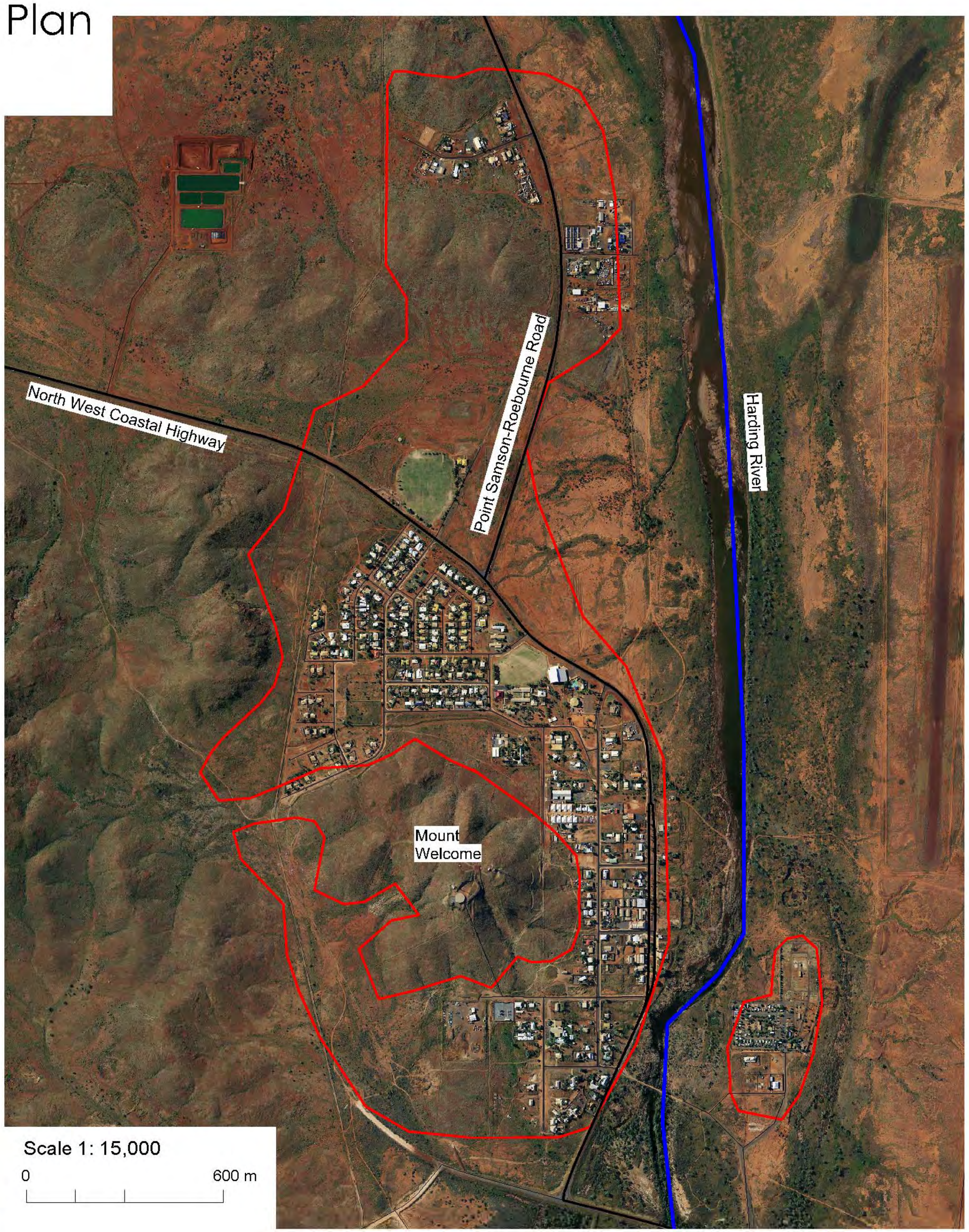
1.4 Management Objectives

The first step in developing the management strategy is to define the objectives of the strategy. By setting objectives, the context and need for specific management actions is established. Objectives for the flood and stormwater management plan relate to; environmental protection, protection of assets, and safety of residents.

It is proposed that key objectives of flood and stormwater management planning in the townsite be considered as follows:

- **Environmental protection.** To maintain the natural flow of stormwater and floodwaters through the landscape and support the social and environmental services provided by local ecosystems. To protect ecosystems from potential adverse impacts caused by human occupation in the landscape.
- **Protect private and public infrastructure.** To provide adequate protection for infrastructure that has potential to be damaged from floods and/or conveyance of stormwater. To allow effective management of infrastructure assets which are impacted by flooding and/or stormwater.
- **Manage public safety.** To limit the risk of injury to residents that results from flow of water and inundation in stormwater drainage systems and during flood events.
- **Provide social amenity.** To provide an appropriate level of amenity and serviceability for infrastructure within the community. Manage potential nuisances to the community as a result of flooding.

Roebourne, Stormwater and Flood Management Plan
Figure 1 - Site Location and Study Area



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Datasource: Landgate, Tourism Western Australia, Created by: H Lamparski. Projection: MGA50: zone 50.

2 RELEVANT POLICY AND GUIDELINES

Various policies and guidelines provided by government and technical institutions are relevant to development of the site and preparation of a stormwater and flood management plan. Key policy statements are described below.

The location of the site, within the north west region of Western Australia and adjacent to coastal and riverine floodplains means that it is necessary to consider vulnerability of the site from coastal forces and possible impacts of tropical cyclones; addressing the intent and key requirements of the Western Australian Planning Commission's (WAPC) *Statement of planning policy 2.6: Coastal planning policy (2006 and 2012)* and *Statement of planning policy No.3.4: Natural hazards and disasters (2006)*. Further guidance on best management practices for flood risk is provided in *Floodplain management in Australia, best practice principles and guidelines* (CSIRO, 2000).

Stormwater management planning needs to consider relevant guidance that is provided by the *Stormwater management manual for Western Australia* (DoW 2004-2009) and relevant statements provided by the Shire of Roebourne. In addition to these, guidance can be sought from Engineers Australia, through *Australian rainfall and runoff* (Pilgram 2001) and the Institute of Public Works Engineering Australia through *Local Government guidelines for subdivisional development* (IPWEA 2009).

A description of the key policy statements and guidelines relating to stormwater and flood management at the site are outlined below.

2.1 Statement of planning policy no. 3.4: Natural hazards and disasters

The state government sets outs its intention to plan for natural hazards in *Statement of planning policy no. 3.4: Natural hazards and disasters* (WAPC 2006) *(SPP 3.4)*. Specific requirements of this policy are to plan for hazards such as:

- Flood
- Severe storms and cyclones
- Storm Surge
- Tsunami
- Coastal Erosion
- Bush fires
- Landslides, and
- Earthquakes.

In regards to flood hazards, the policy provides key statements that may affect development of the site, which can be summarised as follows:

- The 100-year average recurrence interval flood should be used as the defined flood event.
- The floodplain of a defined flood event should be used as the areas over which controls on land use and development need to recognise the impacts of flooding.
- A floodway is generally defined as the part of the floodplain where floodwaters are flowing fast and deep.
- Development on a floodplain is considered acceptable with regard to major flooding as long as it does not produce an adverse impact on surrounding development and has an adequate level of flood protection.

- Development proposed within a floodway that is obstructive to major flooding is not acceptable as upstream flood levels may increase.
- All habitable, commercial and industrial buildings should have their floor levels above the level of the defined flood event.
- The Department of Water is the state government's lead agency in floodplain mapping and floodplain management strategies.

In regards to storm surge, the policy states that "*new permanent buildings should be constructed to take account the effects of storm* surge" and suggests that developments should ensure inundation does not occur.

In regards to coastal erosion, the policy refers to *Statement of planning policy No. 2.6*.

The other hazards outlined in the policy relate to other matters such as building codes, land use planning and other issues not directly related to stormwater and flood management and will not be addressed by this plan.

2.2 Statement of planning policy no. 2.6: State coastal planning policy

The currently gazetted edition of *State planning policy no. 2.6: State coastal planning policy* (WAPC 2006) (current *SPP2.6*) (last amended 19 December 2006) provides guidance on planning and development in coastal areas.

Policy measures include clauses relating to:

- Protection of public interests
- Identification of coastal foreshore reserves
- Preparation of coastal strategies and management plans
- Protection of environmental and cultural features
- The form and pattern of development, and
- Setback to allow for physical processes.

This coastal management plan aims to address key aspects of the policy as they relate to the development site.

In regards to the site and the potential impact of physical processes the relevant clause of the current *SPP 2.6* (5.1(xxii)) requires that planning applications:

> *Ensure new buildings and foreshore infrastructure on the coast are positioned to avoid risk of damage from coastal processes and, where possible, avoid the need for physical structures to protect development from potential damage caused by coastal processes……*

Schedule 1 of the current *SPP 2.6* provides further guidance, suggesting that for 'cyclone prone areas' (north of Latitude 30):

- Setback should be considered on a case-by-case basis including allowance for:
    - S1 (Setback for acute erosion from an extreme storm sequence),
    - S2 (Setback to allow for long term erosion of the shoreline), and
    - S3 (Setback to allow for sea level change)
- Development should be set back from any areas that would potentially be inundated by the ocean during the passage of a Category 5 cyclone tracking to maximise its associated storm surge.

2.3 Draft State planning policy no. 2.6: State coastal planning policy

A draft revision of *Statement of planning policy no. 2.6: State coastal planning policy* (WAPC 2006) (draft *SPP 2.6*) was released for public comment in February 2012.

The revised Schedule 1 provides alternative guidance to calculate the extent of coastal processes to be considered in planning a foreshore reserve. The definitions of coastal processes in the draft *SPP 2.6* are generally consistent with the current *SPP 2.6* except for the following recommendations:

- For erosion and accretion, consideration is given to ocean forces and coastal processes which have a 1 per cent probability of being equalled or exceeded in any given year over the planning timeframe.
- For storm surge inundation, consideration is given to ocean forces and coastal processes that have a 0.2 per cent probability of being equalled or exceeded in any given year over the planning timeframe.
- The allowance for sea level rise should be based on a vertical sea level rise of 0.9 metres over a 100-year planning timeframe to 2110.

In regards to coastal hazards, the new draft policy requires that the development proposals are considered in the context of coastal hazard risk management and adaption planning undertaken by the responsible authority or proponent of the development. The accompanying draft guidelines to draft *SPP 2.6* outline the recommended process for such planning and suggest that the following elements are required:

1. Establishment of the context.
2. Coastal Hazard risk identification.
3. Coastal hazard risk analysis.
4. Coastal hazard risk evaluation.
5. Coastal hazard risk adaption planning.
6. Monitor and review.

It is important to note that while draft *SPP 2.6* maintains Schedule 1 there is no equivalent requirement that development should be set back to avoid inundation from a specific storm (as per the current *SPP 2.6*). Rather this requirement is replaced by the need for a risk assessment as discussed above.

2.4 Shire of Roebourne Town Planning Scheme No.8

Shire of Roebourne Town Planning Scheme No.8 (TPS8) Part 7 and the Scheme maps define special control areas for which additional provisions apply. The scheme defines all the land between the North West Coastal Highway and the coast, including the subject site, as the "Storm Surge Risk Area".

Clause 7.5.1 and 7.5.2 states that in determining planning applications in the Storm Surge Risk Area, Council should have regard to the most up-to-date information about potential storm surge including sea level rise.

Clause 7.5.3 goes on to say that development within the "Residential ……" categories of the zoning table, of which the proposed development lies, is not permitted within an area known to be subject to 1 in 100 year storm surge events.

2.5 Floodplain management in Australia

The Department of Water, in carrying out its role in floodplain management, provides advice and recommends guidelines for development on floodplains with the object of minimising flood risk and damage. The Department of Water uses the following guiding principles to ensure proposed development in flood prone 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 100 year ARI flooding regime of the general area

The Department of Water's recommended floodplain development strategy includes the following provisions and is graphically represented by Figure 2.

1. Proposed 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 0.5 metre above the adjacent 100 year ARI flood level is recommended to ensure adequate flood protection.
2. Proposed development (ie, filling, building, etc) that is located within the floodway and is considered obstructive to major flows is not acceptable as it would increase flood level upstream. No new dwellings are acceptable within the floodway.
3. A failure to properly adhere to these recommendations will result in a greater exposure to risks of flood damage. This advice is related to major flooding only and other planning issues, such as environmental and ecological considerations, may also need to be addressed.

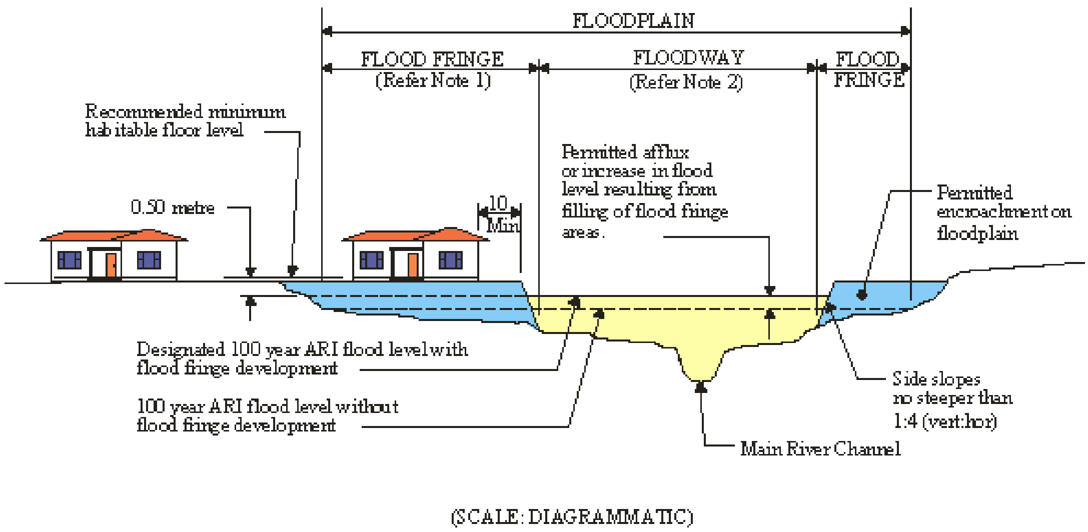


Figure 2: Department of Water floodplain development strategy

The Department of Water assists local governments in the establishment of floodplain management strategies based on these guiding principles and floodplain management principles as set out in documents such as *Standing Committee on Agriculture and Resource Management Report 73 (SCARM73), Floodplain Management in Australia, Best Practice Principles and Guidelines* (CSIRO, 2000). SCARM73 sets out four principal objectives for floodplain management as follows:

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

2.6 Stormwater management

The Government of Western Australia provides guidance for stormwater management through guiding principles and objectives set out in the *Stormwater management manual for Western Australia* (DoW 2004-2009). The *Stormwater management manual* has been developed with various state government departments including the Department of Environment, Department of Water and Swan River Trust between February 2004 and June 2009. Design guidelines for source controls, non-structural and structural techniques for stormwater management are presented throughout the manual.

A key aspect of the guidance provided by the state government is incorporation of water sensitive urban design into developments across the state. Water sensitive urban design can be thought of as a design philosophy whereby the built environment facilitates effective water resource management. The key elements of water resource management in the context of stormwater management include protection from flooding and management of water quantity and quality to achieve ecological objectives and water conservation, efficiency and use.

The *Stormwater management manual* (DoW 2004-2009) lists nine objectives that relate to the management of stormwater. They are:

1. Water Quality - To maintain or improve the surface and groundwater quality within the development areas relative to pre development conditions.
2. Water Quantity - To maintain the total water cycle balance within development areas relative to the predevelopment conditions.
3. Water Conservation - To maximise the reuse of stormwater.
4. Ecosystem Health - To retain natural drainage systems and protect ecosystem health.
5. Economic Viability - To implement stormwater management systems that are economically viable in the long term.
6. Public Health - To minimise the public risk, including risk of injury or loss of life, to the community.
7. Protection of Property - To protect the built environment from flooding and water logging.
8. Social Values - To ensure that social, aesthetic and cultural values are recognised and maintained when managing stormwater.
9. Development - To ensure the delivery of best practice stormwater management through planning and development of high quality developed areas in accordance with sustainability and precautionary principles.

Many of the objectives outlined above are addressed through preparation of this stormwater management plan and the appropriate management of stormwater quantity and quality defined as follows.

- Quantity management – appropriate management of large rainfall events to protect people and prevent damage to property or to the environment, and;

- Quality management – structural and/or non-structural controls to manage the quality of stormwater which leaves the site to protect downstream ecosystems.

Quantity management is typically managed through application of hydraulic design criteria for the design of drainage infrastructure. Hydraulic design criteria are based on the acceptable recurrence of failure for different parts of a drainage system. In this way the hydraulic design can addresses key issues such as the acceptable level of service, safety and the risk of damage to private and/or public infrastructure as a result of flooding.

The Shire of Roebourne provides advice regarding design of drainage infrastructure through their *Stormwater design guidelines for residential development* (SoR 2011) and reference to the advice contained within the *Local Government guidelines for subdivisional development* (IPWEA 2009).

3 PREVIOUS STUDIES

There are a number of previous studies which are relevant to the assessment of flood risk and stormwater management within the study area. A brief description of those studies is as follows:

1. *The Roebourne Townsite Harding River Flood Study* (Water Authority 1987) undertook to estimate the peak flood in the Harding River at Roebourne using available data at the time of the study.
2. Hydraulic analysis and floodplain mapping prepared by the Water Authority in 1987 provides an estimate of the extent of inundation at the Roebourne townsite during a 100-year ARI flood of the Harding River.
3. The *Harding Dam, Extreme flood study* (DoE, 2004) reviewed flood frequency of historical data and estimated peak flows into and out of the Harding Dam.
4. The *Karratha drainage management plan* (GHD 2010) was prepared to examine the condition of drains within the Karratha townsite and to provide guidance for management and future expansion of the drainage network.
5. *The Karratha coastal vulnerability study* (Karratha CVS) (JDA et at. 2011) was recently undertaken to study the impacts of climate change, characterise the hydrology around Karratha, assess shoreline stability in Nickel Bay and model flooding from storm surge and riverine flooding.

The last two of these studies do not apply directly to the site but provide useful information regarding regional characteristics, processes and the current approach to stormwater management.

4 ENVIRONMENTAL FACTORS

A review of relevant documents and available information was undertaken to determine the key environmental factors which influence flood and stormwater management requirements. A description of the existing biophysical environment is presented below under the following categories:

- Climate;
- Topography;
- Geology and Geomorphology; and
- Coastal Forces.

4.1 Climate

The arid and semi-arid climate of Roebourne townsite is typical of the Pilbara region of Western Australia, with hot summers accompanied by irregular rainfall and milder, dry winters. Average annual rainfall since 1887 is 312 mm.

The north coast of the Pilbara region experiences occasional tropical cyclones which results in highly variable rainfall patterns in the region. The Bureau of Meteorology operates a weather station in Roebourne. The station has been operating continuously since 1887.

Both temperature and rainfall reach their maximums in summer, with average maximum temperature peaking in December at 39°C, and rainfall peaking at 67.5 mm in February. During the winter, the situation is reversed with maximum temperatures reaching their lowest point in July (approximately 27°C) whilst rainfall reaches its lowest amount, of approximately 0.7 mm, later in the year, in October (shown in Figure 2 below).

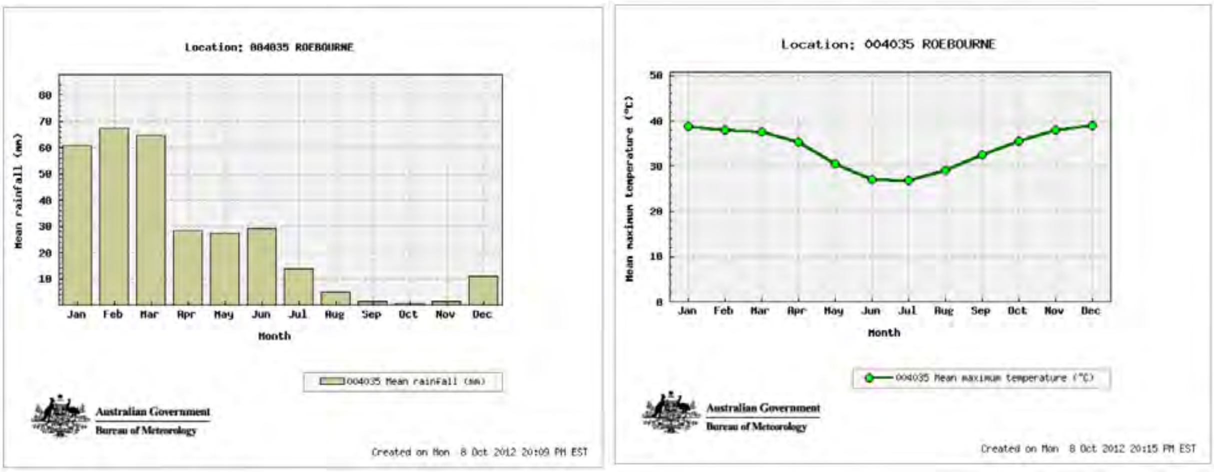


Figure 3: Mean temperature and rainfall at Roebourne

4.2 Topography and landform

The Roebourne townsite local structure plan area extends north-south, situated between a series of hills along the western boundary and the Harding River along its eastern boundary. A smaller area of the Roebourne townsite lies separate from the main site, disconnected by the Harding River to the southeast.

Large parts of the townsite and local structure plan area are relatively flat, with most of the current and future development areas lying at an elevation between 10 – 20 m AHD. Major hills surrounding the development areas rise steeply from low lying areas. By example, Mount Welcome which divides the existing townsite, peaks at approximately 70 m AHD and has natural rocky slopes as steep as 1m vertical to 4m horizontal.

Ridge lines west of the Roebourne townsite, including the highest point at Mount Welcome, are the defining landform of the townsite local structure plan area (Figure 4).

The steep gradients in surrounding hills and within the local drainage catchments reduces the water holding capacity of the landscape and results in significantly higher peak flow rates than would be generated by similar sized drainage catchments on flatter gradients.

The catchment of the Harding River extends approximately 63 km south from Roebourne to the Chichester Range. The highest points within the catchment are near the southern extent (within the Millstream Chichester National Park) and include Barowanna Hill (356 m AHD) and Mt Herbert (362 m AHD) as well as other higher peaks up to 381 m AHD. The southern two thirds of the Harding River catchment (1068 km^2) flows into Lake Poongkaliyarra, the result of the Harding River Dam which is designed to commence overflow at approximately 60 m AHD.

The slope of the river upstream of the dam is naturally steeper than that downstream. The Harding River falls approximately 230 m over 41 km to the lake (5.6 m/km) and then approximately 50 m over 28 km between the dam and Roebourne (1.7 m/km). The long sections of relatively low gradient in the lower (northern) portion of the Harding River provide significant volumes of storage for flood waters and act to detain riverine floods and reduce peak flow rates. Further discussion on hydrology of the Harding River is provided in section 6.1.

4.3 Soils and geology

Soils in Roebourne are generally a combination of floodplain alluvial sediments (Qa) consisting of sands and clay (GHD, 2012 and Stewart *et al.*, 2008) and igneous rock (Adav) (Figure 5).

Alluvial sediments present in large parts of the study area are highly weathered fine silts and clays which have low infiltration capacity and can be hydrophobic (non-wetting) in response to long periods of drought.

The clay soils and rock that are present with the drainage catchments increases the stormwater runoff potential and contributes to significantly higher storm flows than would be observed in sandy catchments.

Also of interest are the Gilgai soils that have been observed in similar environments found around Karratha (Coffey Geotechnics Pty Ltd, 2008) and between Karratha and Tom Price (Main Roads, 2006). These are soils consisting of clay that rapidly expand as they absorb moisture and then contract as they dry. These soils create instable surfaces which can result in cracking of any infrastructure built over them. Given the presence of alluvial sediment of similar origin in Roebourne, there is also potential for Gilgai soils to be present in the structure plan area.

The geology of the Roebourne townsite local structure plan area may be broadly described as granite and greenstone (Van Vreeswyk *et al.*, 2004). The Hydrogeological Atlas of WA describes the geology of Roebourne as: Volcanic and sedimentary rocks in greenstone belts, undifferentiated (DoW, 2012). The geology of Roebourne has been similarly mapped by the Department of Mines and Petroleum as part of the Ruth Well Formation which is composed of Metamorphosed basic and ultrabasic volcanic and intrusive rocks (DMP, 2012).

Geological mapping of the broader area indicates the Harding River catchment includes similar soil types as well as large areas characterised by metamorphic rock and colluvium. As a consequence, runoff generation within the catchment is expected to be relatively high with catchment losses resulting largely from localised retention in local ponds rather than steady infiltration into soils throughout the catchment.

4.4 Tides

Coastal areas north of Roebourne are subjected to semi-diurnal tides with a tidal range of approximately 6 m. Tide predictions are prepared by the National Tide Centre for Cape Lambert (approx. 18 km north of Roebourne). The highest tide predicted for 2012 is 6.01 m CD (approx. 2.8 m AHD) for Saturday 30th March.

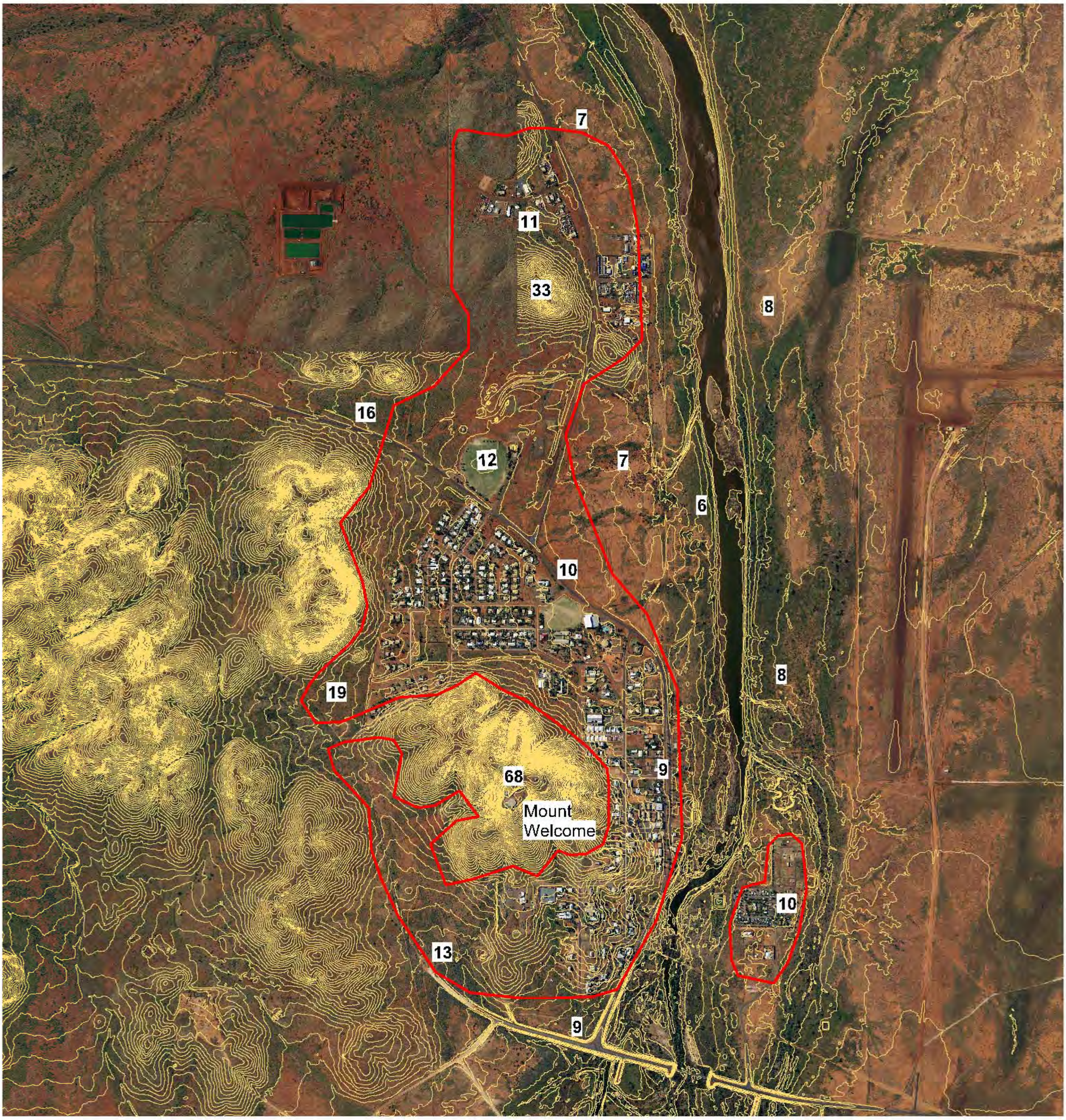
Table 1 reproduces the tidal planes for Cape Lambert (Department of Defence 2010) and an approximate conversion to AHD, assuming that mean sea level observed at Cape Lambert is approximately 0.0 m AHD.

Table 1: Tidal planes

Tidal Plane		Water Level	
		(m CD)	(m AHD)
Highest Astronomical Tide	HAT	6.2	3.0
Mean Higher High Water	MHHW	5.5	2.3
Mean Lower High Water	MLHW	3.8	0.6
Mean Sea Level	MSL	3.2	0.0
Mean Higher Low Water	MHLW	2.7	-0.5
Mean Lower Low Water	MLLW	0.8	-2.4
Lowest Astronomical Tide	LAT	0.0	-3.2

It is noted that the highest astronomical tides are higher than observed ponded water levels in the base of the Harding River adjacent to the study area (around 2.0 m AHD). Notwithstanding, downstream hydraulic controls in the river delta will affect the extent to which diurnal tides can affect the river and no local observations were available at the time of this study to consider if high tides currently influence water levels in the river.

Roebourne, Stormwater and Flood Management Plan
Figure 4 - Topography



LEGEND

Study Area

Contours (1 m)

Scale 1: 20000

0 400m

Data source: Shire of Roebourne, Landgate.

Created by: N Ludkins. Projection: MGA: zone 50.

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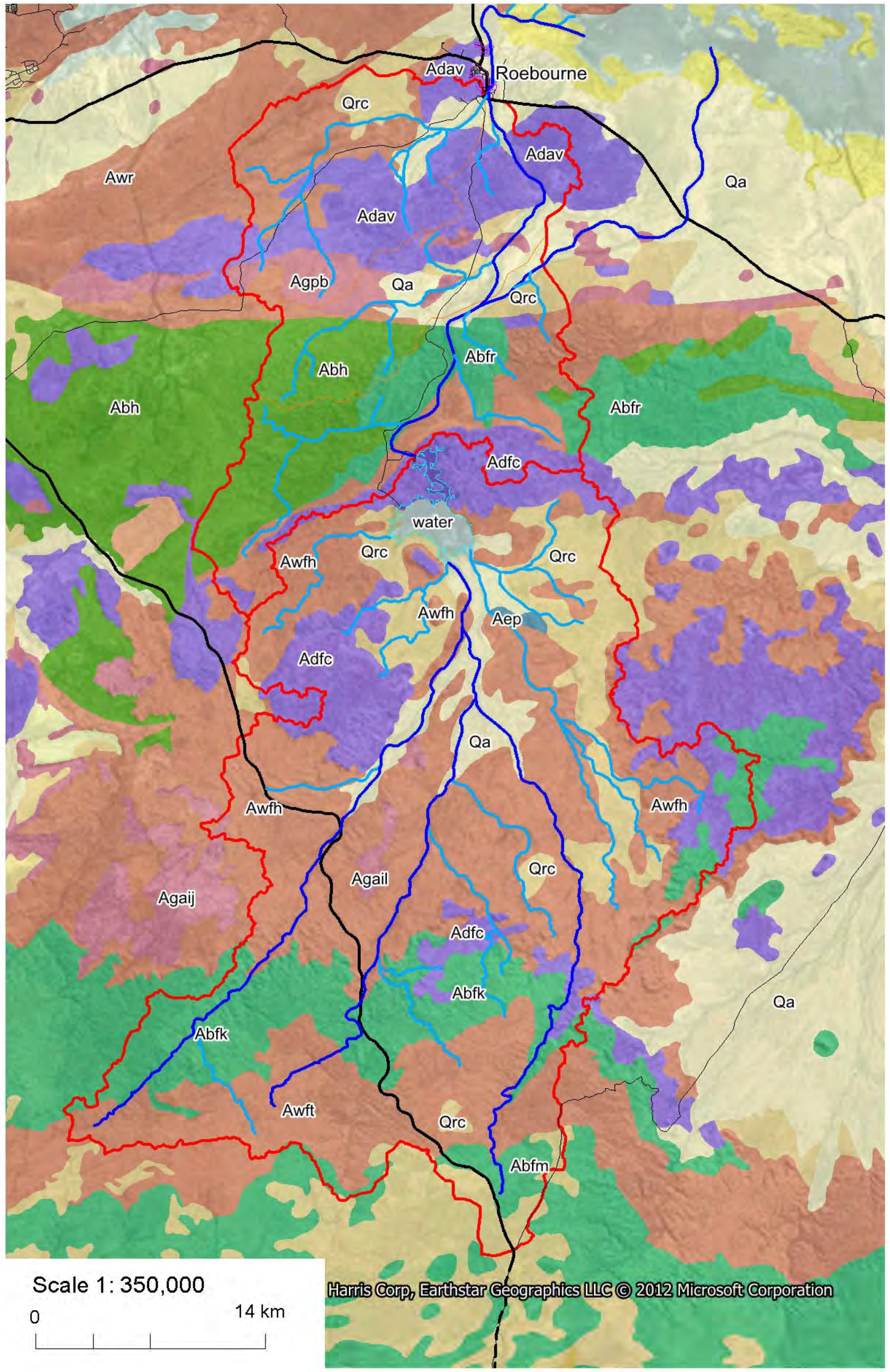
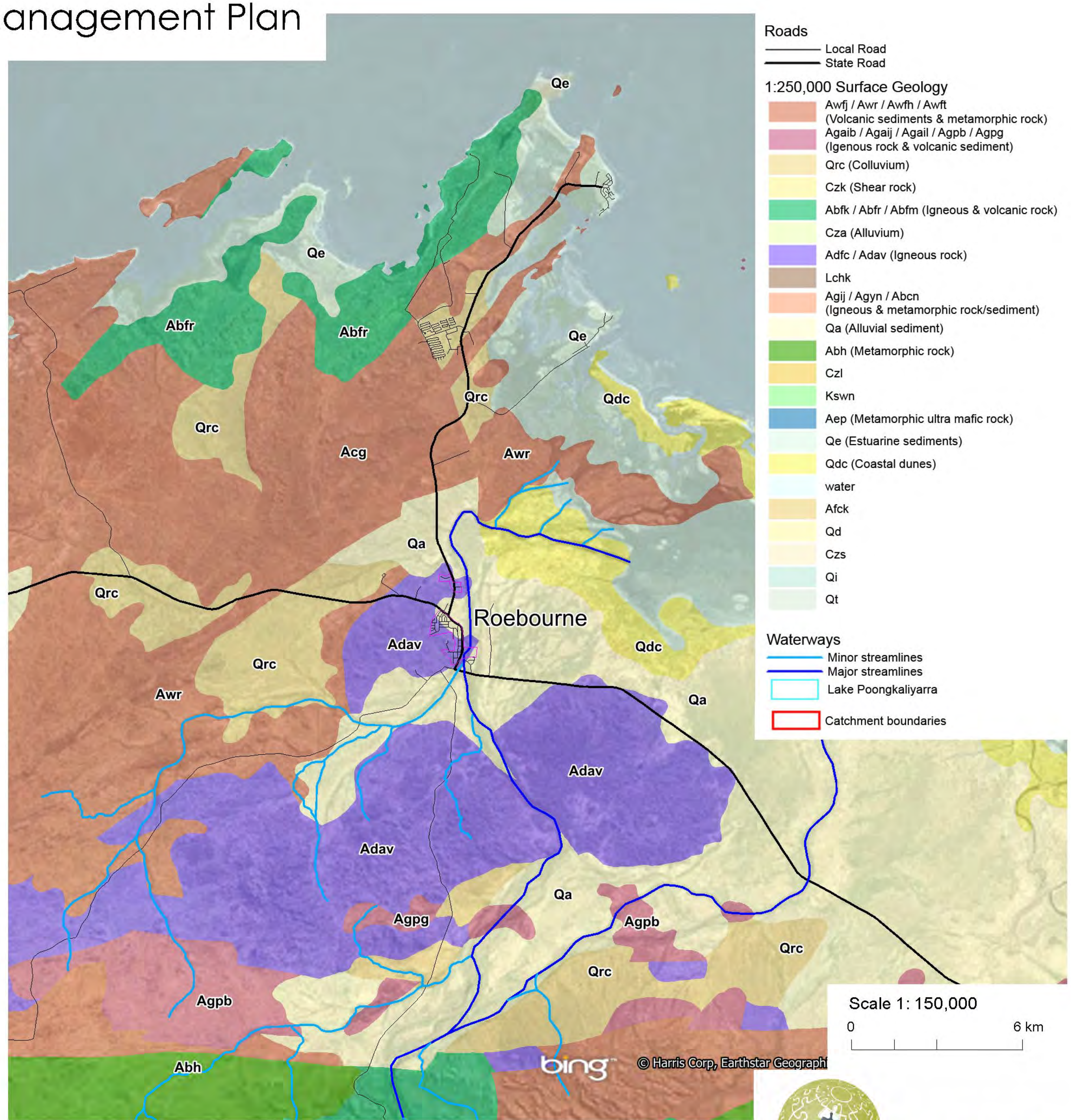
Roebourne, Stormwater and Flood Management Plan
Figure 5 - Surface Geology





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Datasource: Landgate, DoW, Main Roads WA. Created by: K Norris. Projection: MGA50: zone 50.

5 COASTAL VULNERABILITY

The Roebourne townsite is located a sufficient distance from the coast such that it is unlikely to be affected by erosion as a result of coastal processes. Notwithstanding, the low relief of the coastal plain and intensity of storm activity in the region suggests that parts of the study area may be influenced by extreme tides and could be at risk of inundation during storm surge events.

The *Karratha coastal vulnerability study* (Karratha CVS) provides the most recent study of coastal processes in the region and an assessment of likely impacts of climate change. While the site specific analysis undertaken as part of that study is not relevant to the Roebourne townsite, the broad discussion of regional processes provides the context for climatic influences and regional characteristics.

Draft *SPP 2.6* recommends consideration of coastal forces and sea level rise as part of future planning and development in coastal areas. A discussion of coastal processes which are relevant to the site, consistent with the policy is presented below.

5.1 Risk of impact from coastal erosion

The currently gazetted and draft SPP 2.6 require that development setbacks and/or coastal foreshore reserves are provided to respond to site specific issues and to accommodate physical processes. Schedule 1 of SPP 2.6 provides guidance on the classification of coastal types and calculation of appropriate setbacks for coastal erosion.

The coastline immediately north of Roebourne is characterised by extensive tidal mudflats created by a build-up of fine sediments through tidal forces and alluvial processes in the Harding and East Harding Rivers (Figure 6). This environment is characterised as a “Coastal Lowland” in SPP 2.6. The movement of water across the coastal lowlands will provide significant dissipation of the energy and limits the potential for coastal erosion at the high tide shoreline.

The closest distance of the shoreline on the tidal mud flats is approximately 5.4 km from the study area as indicated in Figure 6. On this basis it is considered that coastal erosive forces (storm generated wave action and long term movement of coastal sediment) should not directly affect the study area.

The key impact of sediment movements at the coast is the possible influence on riverine flooding in the Harding River. If the predicted sea level rise results in a corresponding accumulation of sediment within the tidal delta or results in formation of coastal sediment barriers then a future flood of the Harding River could be restricted. To account for this possibility the flood modelling in 6.1 has considered the impact of increased water levels in downstream reaches of the river.

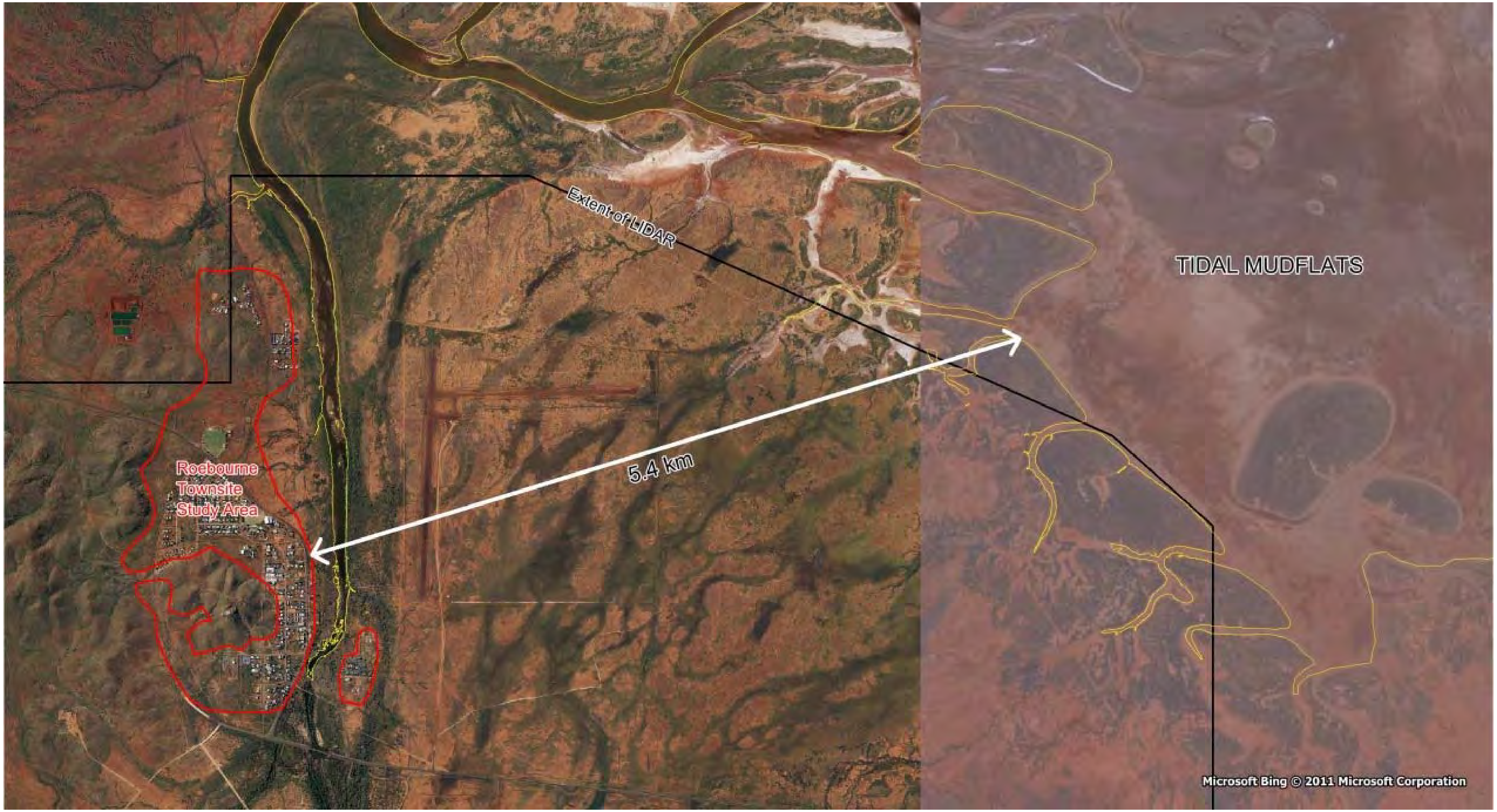


Figure 6: Roebourne coastline

5.2 Risk of inundation

Worst case potential for inundation from coastal forces comes from the phenomenon known as storm surge. Storm surge is a short term increase in sea level which results from the atmospheric conditions that establish as storms cross the coast. Low air pressure, and high winds result in mounding of sea water against the coast and raise the still water level. The predicted rise in sea level will increase the height to which storm surges will reach because they will be starting from an already elevated sea level.

As described in section 2 above, the provisions of draft SPP 2.6 require consideration of events which have a 1% (for erosion) and 0.2% (for inundation) probability of being exceeded in any given year over the planning timeframe (100 years).

A previous study by GEMS (1998) provides a relevant assessment of the current probability of inundation as a result of storm surge events. That assessment estimated that the 1% AEP and 0.1% AEP storm surge inundation at Roebourne Aerodome is 7.2 m AHD and 8.9 m AHD respectively.

Previous practice for coastal inundation management, considered the flood encroachment impacts of the 1% and 0.2% AEP probability events. That is; the events that have 1% and 0.2% likelihood of occurring within any single year. These events have the same probability of occurring each year regardless of how long it is since they last occurred.

In considering the impacts of these events over a fixed planning timeframe we should consider the probability of these events occurring during the whole planning timeframe rather than in any one specified year. This discussed further in section 7.5 and Table 8 where it can be seen that the 1% AEP event has a 63% chance of occurring within the 100 year planning timeframe and the 0.2% AEP event has an 18% chance of occurring within the 100 year planning timeframe.

When considering sea level rise, applying the 1% and 0.2% AEP events to the sea level at the end of the planning timeframe will result in events that have less than 10% chance of occurring during the planning timeframe, because it is only in those later years when there is any significant chance of an exceedance being observed. Therefore, management of these events would be a considerably more conservative approach than has been previously applied.

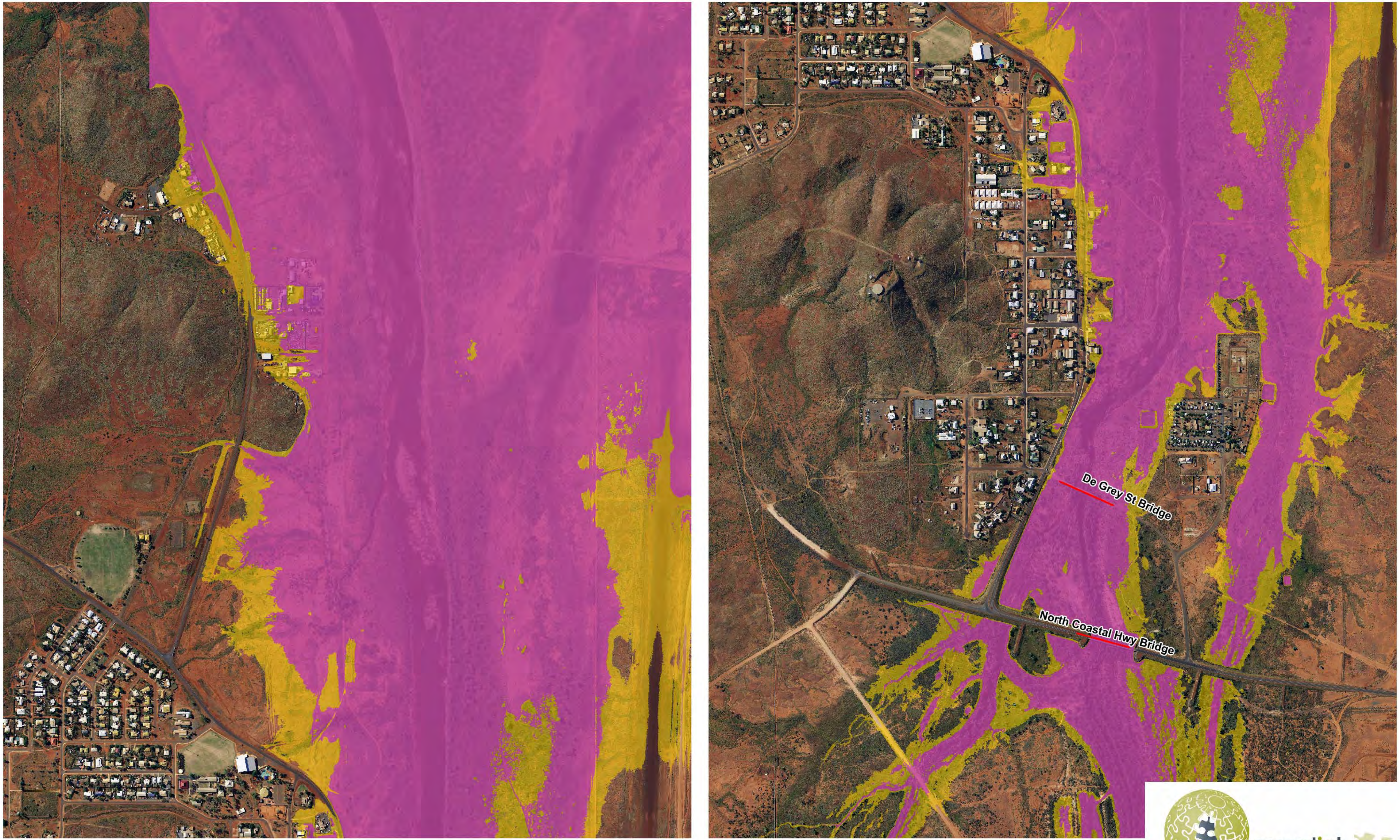
In the Roebourne townsite, the impact of using the more conservative approach is insignificant because the risk of impacts from Harding River flooding are far greater and development controls for riverine flooding are likely to override those for coastal inundation and sea level rise. For other locations, where coastal inundation and sea level rise are more critical planning constraints, it is recommended that a more detailed examination of the cumulative probability of events occurring during the whole planning timeframe is undertaken.

To consider the worst case inundation event described by SPP 2.6 (as above) flood levels for the year 2110 can be calculated by adding 0.9 m sea level rise to the estimates of current storm surge inundation. Inundation mapping for these events is presented in Figure 7.

Further discussion on predicted storm surge and sea level rise is provided below.

Roebourne, Stormwater and Flood Management Plan
Figure 7 - Estimated storm surge inundation in 2110

LEGEND
- Storm Surge Flood 100 yr ARI (2110); 8.1m AHD
- Storm Surge Flood 500 yr ARI (2110); 9.0m AHD



Data source: Shire of Roebourne, Created by: K Norris. Projection: MGA50: zone 50.

Scale 1: 10,000
0 400 m

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5.2.1 Storm surge

Storm surge is a short term increase in sea level which results from the atmospheric conditions that establish as storms cross the coast. Low air pressure, and high winds result in mounding of sea water against the coast and raise the still water level.

Extreme tides caused by storm surge or other natural forces can result in increased erosion of sandy shores and inundation of low lying areas. The effects of storm surge are amplified if storms occur at times of naturally high tide. The combined effect of any mean sea level anomaly, celestial tides and storm surge produces the still water level of the ocean at any time and the combined result of these factors can be observed through long term tidal records. Notwithstanding, coastal landforms, bathymetry and near shore processes affect the level of inundation which could result from the same storm surge event at different parts of the coast.

A number of technical studies have been undertaken for sites along the north-west coast which can provide an indication of the magnitude of storm surge and probabilities for still water level which may affect the coast at Roebourne. These include:

- Most recently, the storm surge and coastal inundation study (GEMS 2011) undertaken as part of the *Karratha coastal vulnerability study* examined the probability of inundation in Nickel Bay and surrounding areas. The estimated current (2010) 100 year ARI (500yr ARI) storm event surge level along the coast varied between 6.6 m AHD (6.9 m AHD) and 7.3 m AHD (8.6 m AHD).
- An earlier study; the *Cape Lambert storm surge study* undertaken by the Bureau of Meteorology and GEMS in 1998 estimated 100-year ARI (1000-year ARI) storm surge levels between 5.3 m AHD (6.6 m AHD) at Point Samson and 7.2 m AHD (8.9 m AHD) for Roebourne Airport

These studies are consistent in their assessment of storm surge risk; adopting an estimate based on local bathymetry and coastal landforms to derive a 100-year ARI storm still water levels for inundation at different parts of the coast. The estimates derived in the GEMS 1998 study are of similar magnitude to those estimated in the more recent study in Nickel Bay.

The provisions of the draft SPP 2.6 require consideration of events (for inundation) which has 0.2% probability of being exceeded. The GEMS study provides an assessment of the probability of storm surge inundation for the Roebourne Aerodome suggesting that the 1% annual exceedance probability (AEP) event (equivalent to 100-year ARI) is 7.2 m AHD and the 0.1% AEP event (1 in 1000yr ARI) is 8.9 m AHD. Interpolating these predictions, the corresponding storm surge level with 0.2% annual exceedance probability (500 year ARI) is likely to be around 8.0 m AHD.

5.2.2 Sea level rise

The draft SPP 2.6 and current WAPC position statement requires that setback for development and/or foreshore reserves that are established to allow for physical processes should consider a sea level rise of 0.9 m by 2110; reflecting the IPCC A1FI scenario in accordance with recommendations from CSIRO. It is noted that the approximation of 0.9 m sea level rise is conservative when compared to the most recent IPCC prediction of sea level rise for 2100. It is understood that the A1F1 scenario (thought to represent the 1% probability of sea level rise) predicts mean sea level rise of approximately 0.7 m from 2000 through to 2100 and increase of this number to 0.9 m reflects the CSIRO extrapolation of the IPCC scenario from 2100 to 2110.

Sea level rise is not expected to occur as a step change in a single year. So in considering sea level rise over a fixed planning timeframe, we should consider its gradual increases during the planning timeframe rather than in any one specified year and the cumulative impact that this will have on coastal inundation events.

To illustrate this important consideration, it is useful to examine Figure 8 which considers the probability of storm surge at Fremantle which have been prepared using the CANUTE *"sea level calculator"* which was developed by the Antarctic Climate and Ecosystems CRC:

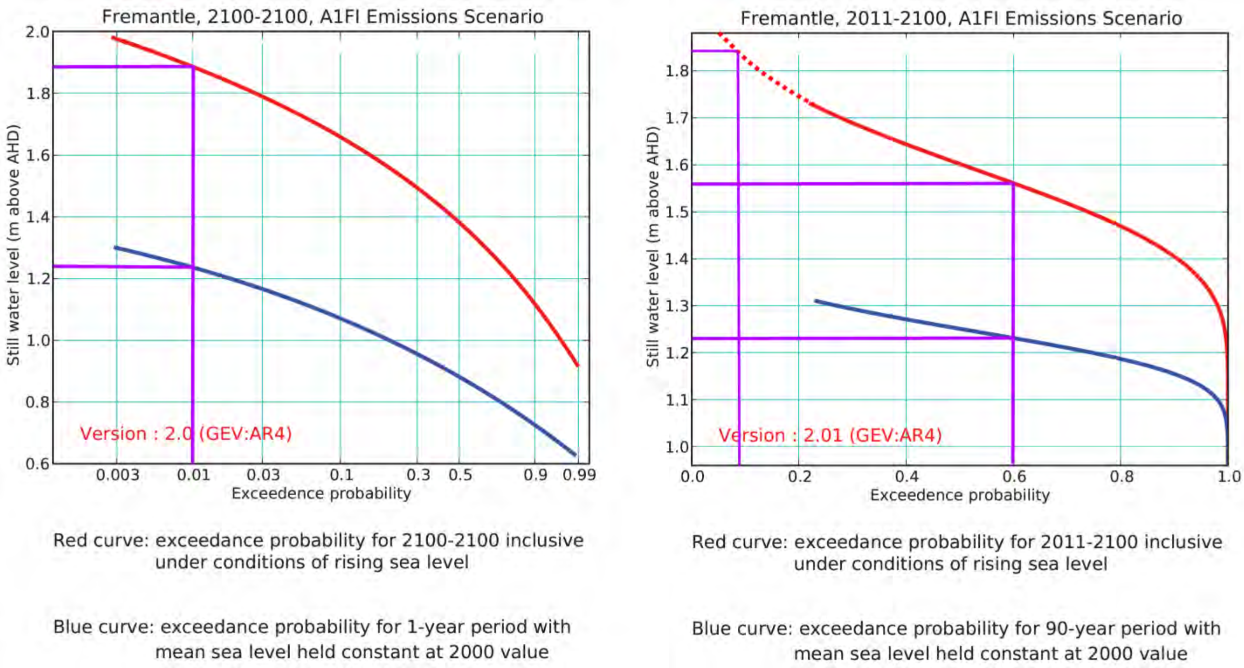


Figure 8: Annual Exceedance Probability vs. Cumulative Exceedance Probability

The chart on the left illustrates the predicted increase in sea level and the effect on the AEP in the year 2100; on this chart it is noted that the 1% AEP event in the year 2000 corresponds to an inundation level of 1.23 m AHD which rises to 1.9m AHD in the year 2100, an increase of 0.67 m over 90 years.

The chart on the right illustrates the cumulative probability of exceedance over the same 90 year period; here it is observed that if there was no sea level rise, then the 1% AEP event (inundation at 1.23 m AHD) has a 60% chance of occurring over the 90 year timeframe and that if we incorporate sea level rise then the water level with the same 60% chance of occurring over the 90 year timeframe is approximately 1.57 m AHD, an increase of 0.34 m representing the same probability event over the 90 year timeframe.

Further, through a conservative extrapolation of the probability curve it is noted that the water level corresponding to the 1% AEP in the year 2100 (1.9 m AHD) has a cumulative probability of less than 10% over the planning timeframe.

For the Roebourne townsite, the desire to limit development below the 1% AEP storm surge level calculated for 2110 (7.2 mAHD + 0.9m) does not pose significant constraint on development that would warrant further detailed analysis because riverine flooding provides a more onerous control on development levels as discussed in section 6.1. Notwithstanding, the effect of time cumulative probability on appropriate management actions is important to consider in assessing inundation risk other sites along the coastline, where storm surge will present the greatest risk to flooding.

6 SURFACE WATER

The north west of Western Australia experiences unreliable and highly variable rainfall. Rainfall occurs predominantly in summer as a result of the Northern Australian wet season and often as a result of tropical cyclones. Consequently, much of the north west region is subject to major flooding during cyclonic events due to riverine flooding and local runoff from smaller catchments.

The location of the townsite on the western bank of the Harding River exposes developments in the area to risks associated with riverine flooding as well as possible impacts from coastal processes. In addition to flood risk from external sources, stormwater drainage through the townsite and surrounding present additional risk associated with inundation or damage from passage of stormwater generated locally and within the surrounding hills.

Key issues to consider for the Roebourne townsite in regards to surface water hydrology are therefore (1) flood hydrology of the Harding River, and (2) management of local stormwater generated on the site or in adjacent areas.

6.1 Harding River

The Harding River originates in the Chichester Ranges and flows across the region in a northerly direction, discharging to the coast approximately 5 km north east of Roebourne.

Figure 9 illustrates the catchment which contributes to stream flow in the Harding River adjacent to the Roebourne townsite. The total catchment area is approximately 1,560 km^2 of which approximately 68% (1070 km^2) is upstream of the Harding Dam. Floods generated in the upper catchment will be controlled by the presence of the dam and Lake Poongkaliyarra, such that flooding experienced at the Roebourne townsite is predominately influenced by the hydrology of the lower (downstream) catchment and overflow of the dam.

Approximately 13 km downstream of the Harding Dam, there is a bifurcation of the Harding River where there is potential for some flood water to flow into the East Harding River which crosses North Coastal Highway approximately 15 km south east of Roebourne.

Another notable feature of the downstream catchment is the contribution of significant tributaries: namely Murray Camp Creek, which joins the Harding River approximately 3 km downstream of the bifurcation, and the lower subcatchment which comes from the west (as per Cherratta road) and joins the Harding River immediately upstream of North Coastal Highway.

6.1.1 Previous Studies

A previous hydrological study undertaken by the Water Authority in 1987 provided an estimate of peak flow rates at the Roebourne townsite for various exceedance probabilities. The peak flow estimates were derived through analysis of rainfall excess and non-linear flood routing (RORB modelling) using parameters developed for ungauged catchments and considering a previous calibration of stream flow records from the upper catchment. The peak flow estimates for the Roebourne town site were calibrated to a single observed flood event (after Cyclone Chloe in March 1984).

A subsequent review of flood frequency undertaken by the DoE in 2004 (The Harding Dam, Extreme Flood Study) combined previous stream flow records with estimates of peak flow derived from continuous dam water level readings. The review considered that the previous rating curve significantly underestimated flows for large events and therefore adjusted previous record to a new rating curve. In doing so, the estimated peak flow from the 1984 event (observed at the approximate location of the Harding Dam) increased from 2490 m^3/s to 4425 m^3/s. As a result of the revised peak flow observations, the revised RORB model developed for the Harding Dam Catchment had significantly different parameters than those adopted in the previous study.

Given the revised flow estimate at the location of the Harding Dam, it is likely that the previous calibration was only able to be achieved due to a corresponding underestimate of the peak flow at Roebourne and/or underestimate of the flow diverted into the East Harding River at the bifurcation.

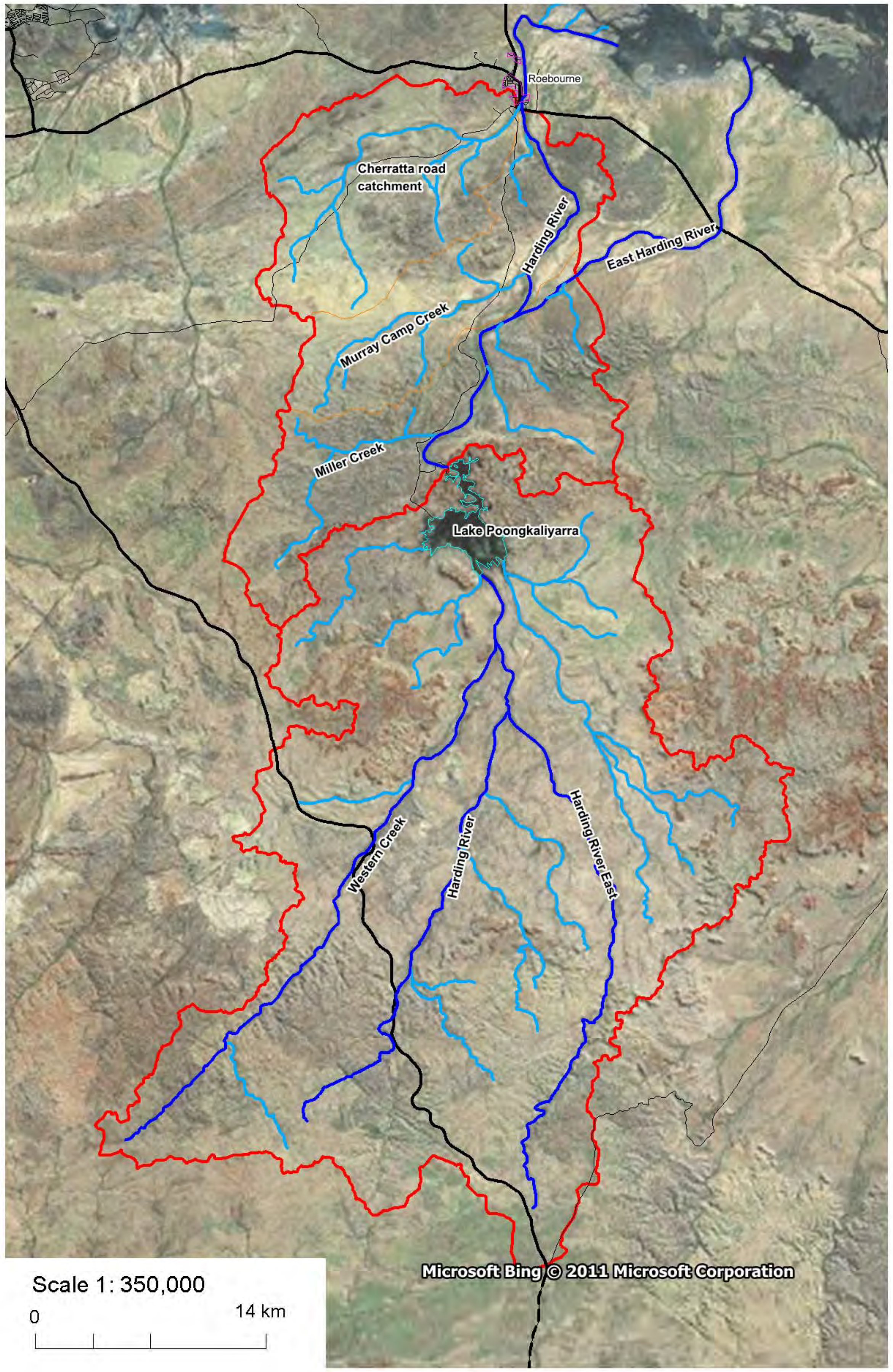
A comparison of the revised runoff routing and flood frequency analysis undertaken by DoE, against the previous predictions for Roebourne in Table 2 indicates that the peak flow predictions by SMEC and the Water Authority were calibrated against unreliable data.

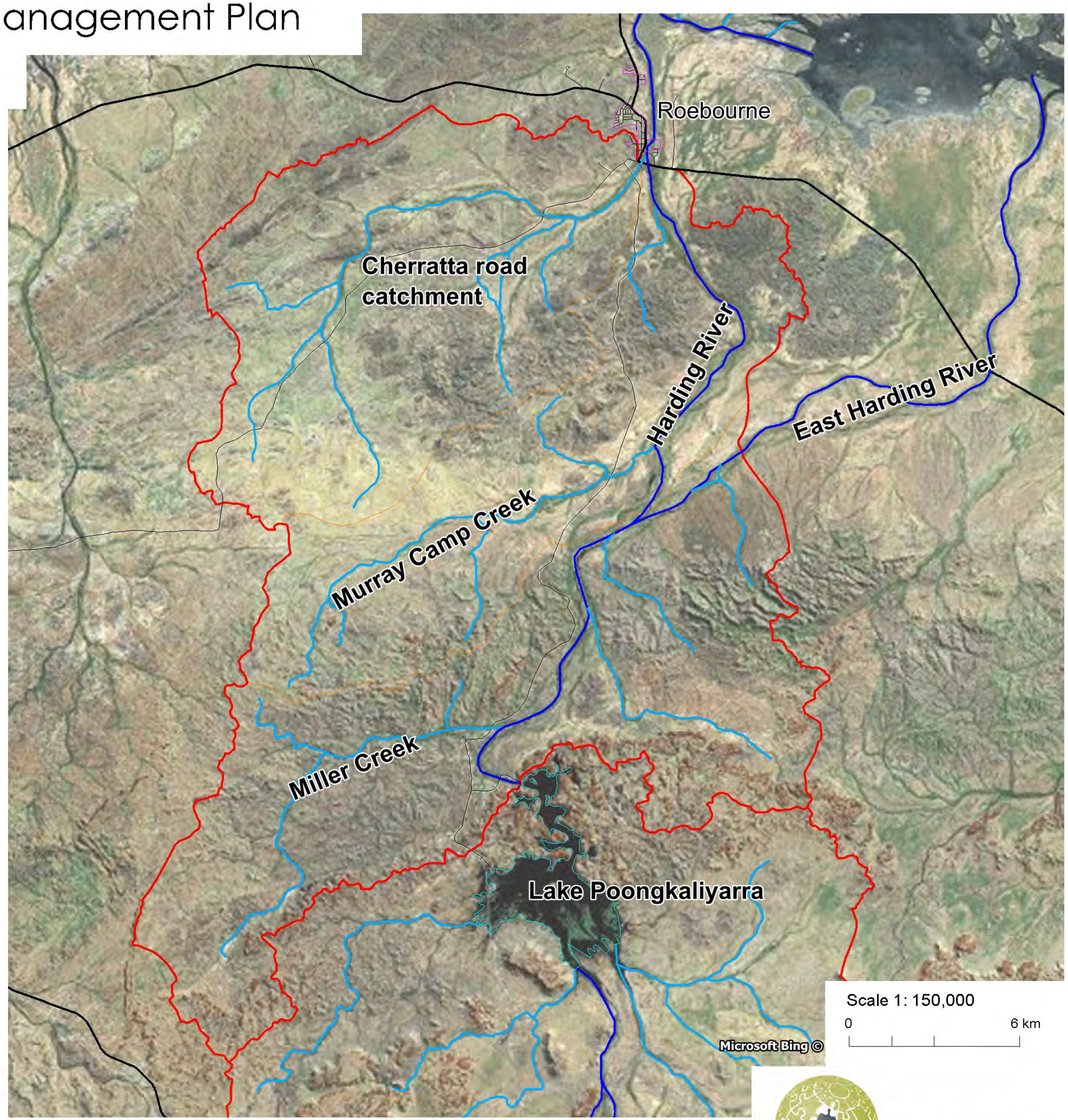
Table 2: Previous peak flow predictions

Study	Roebourne	Harding Dam Catchment	
	WA (1987)	SMEC (1983)	DoE (2004)
Observed 1983 event (m^3/s)	2200	2490	4425(1)
Adopted Kc	28	17.5	10
1 in 100yr AEP (m3/s)	2700	3840	5730
1 in 50yr AEP (m3/s)	1850	3100	1240

(1) As per revised rating curve calculated by DoW in 2003.

Roebourne, Stormwater and Flood Management Plan
Figure 9 - Harding River catchment





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Datasource: Landgate, DoW, Main Roads WA. Created by: K Norris. Projection: MGA50: zone 50.

6.1.2 Revised hydraulic modelling

A hydraulic model of the Harding River through the study area was developed by Essential Environmental in HECRAS v4.1.0 using LiDAR survey data flown in April 2012 and data collected during a site inspection in October 2012. The hydraulic model was calibrated against the flood levels which were observed during Cyclone Chloe at the locations as indicated in previous flood modelling undertaken by the Water Authority in 1987. Assumed friction losses were adjusted to arrive at a steady state hydraulic profile similar to that which was observed.

A reasonable calibration to the observed flood profile was achieved by adjusting effective friction losses (Mannings 'n') along the river reach to 0.04 (overbank) and with increasing friction loss in the main channel between open areas of the main channel (adopting 0.035) and densely vegetated areas (adopting 0.080). This outcome is consistent with available literature on friction losses including Pilgram 1998 (Book VII Table 1.1) and observations that the river channel is densely vegetated with established trees. Plate 1 illustrates the variety of vegetation observed in the Harding River channel and floodplain areas.

Plate 1: Observed vegetation in main channel and floodplain of Harding River

Adopting these friction losses, it is estimated that the peak flow of between 2200 m^3/s and 3000 m^3/s would have been required to generate the observed flood levels after Cyclone Chloe. It is considered that this assessment is consistent with the previous estimate of peak flow (2050 m^3/s) estimated by Main Roads in 1984. The revised calibration is considered more accurate due to more accurate survey data being available to improve representation of the hydraulic performance of the river reach. The model layout and assumed locations of observations during the Cyclone Chloe are illustrated in Figure 10. The calibration of the observed flood against various flow rates is presented in the flood profiles in Figure 11.

The hydraulic model used for the calibration was modified to include the North West Coastal Highway Bridge and used to generate flood profiles for the design flow rates predicted in section 6.1.3. The predicted flood profiles and flooding extent are illustrated in Figure 12 and Figure 13.

6.1.3 Revised hydrologic modelling

A revised assessment of flood hydrology was prepared using the revised flow data and predictions for the Harding Dam.

Australian Rainfall and Runoff (Pilgram 1998) recommends initial and continuing loss rates for the Pilbara loam soils and methods for estimating runoff and flood routing (RORB) parameters for ungauged catchments. For the northwest region Pilgram 1998 recommends adopting **m = 0.8** and estimating parameter $\mathbf{k_c}$ using the regional relationship given by Flavell et al. (1983) as follows:

$$k_c = 1.06\,L^{0.87}\,S^{-0.46}$$

where: L = mainstream length (in km)
S = equal area slope (m/km)

The downstream portion of the Harding catchment was divided into nine sub-areas for calculation of rainfall excess and flood routing as illustrated in Figure 14. Rainfall data and flood hydrographs outlined in the DoE (2004) study were used in RORBWin v6.15 to reproduce a flood hydrograph for the Cyclone Chloe (March 1984) rainfall event. Hydrological parameters for the catchment were taken from the values and regional relationships recommended by Pilgram 1998 as follows:

L = 44.2 km
S = 1.57 m/km
Kc = 23.2
m = 0.8
IL = 40 mm
CL = 5 mm/hr

As expected, initial model runs predicted a significantly higher peak flow at Roebourne than was previously estimated. The estimated peak flow if assuming that 20% is diverted into the East Harding River is 4027 m^3/s. This outcome is inconsistent with observed water levels during this event (derived above) and is approximately double that than was previously estimated.

Given the hydraulic profile calibration fits well to observed data, it is most likely that the previous estimate of flow spilt at the bifurcation was incorrect and that more water is diverted into the East Harding River. As such, the hydrological model was adjusted to change the amount of water diverted into the East Harding River in order to calibrate predicted flow rates against observed flood levels at Roebourne. By this method, and assuming that 45% of upstream flow is diverted into the East Harding River, the estimated peak flow at Roebourne is 3050 m^3/s, which is consistent with revised hydraulic analysis discussed further above (Figure 14).

The parameters outlined above were used with design rainfall scenarios and estimated peak overflow rates from the dam (DoW 2004) to derive revised peak flow hydrographs at Roebourne as illustrated in Figure 15.

The initial loss for the 500 year ARI design scenario was reduced (to 10mm) to be consistent with assumptions of reduced losses for larger events as suggested by DoW (2004).

6.1.4 Further refinement of flood model

The assessment presented above has used available data to estimate the severity and extent of riverine flooding in the Harding River. As with all assessments of this nature, the accuracy of the estimate is limited by the availability of observations and data concerning historical floods and the response of the catchment and local hydraulic influences.

It is noted that hydraulics at the bifurcation of the Harding and East Harding Rivers has a significant influence estimate of peak flow for the Roebourne town site. Notwithstanding, it is considered that detailed modelling of this bifurcation is of little value because interpretation could lead to misleading results. Specifically, it is possible that following construction of the dam in 1987, the altered flow regime has affected local sediment morphology at this location and that an observation of current conditions would not adequately represent conditions at the time of the calibration event.

The hydraulic model that has been used to calibrate flows and estimate flood extent has been developed using LiDAR survey. Key uncertainty in the latest modelling come from assumptions of downstream hydraulic performance, and the accuracy of calibration flow estimates and observed water levels. Further survey of the downstream river reach to the river mouth, additional streamflow monitoring and water profile observations would be required to improve the accuracy of the hydraulic model.

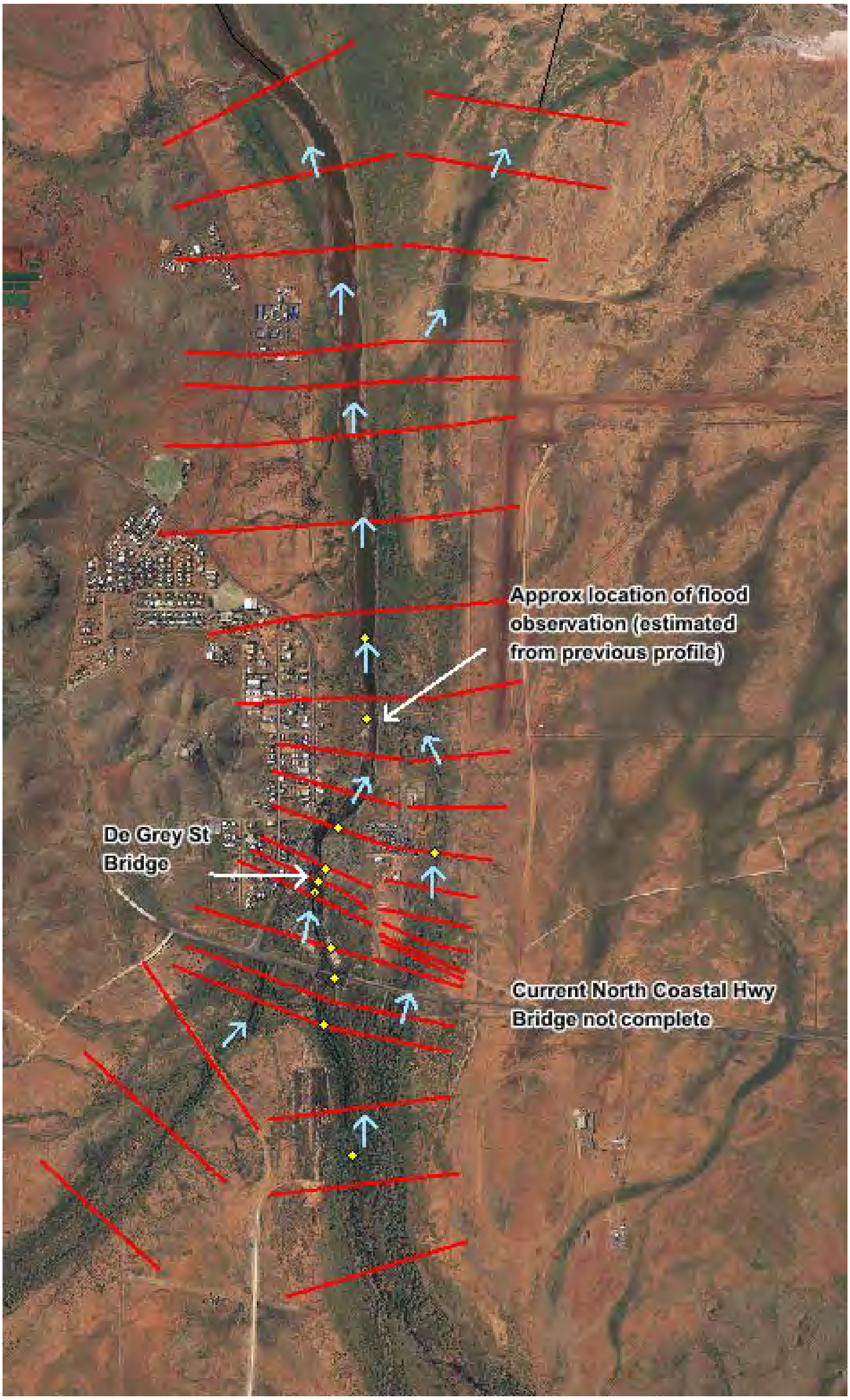

Figure 10: Harding River hydraulic calibration model layout

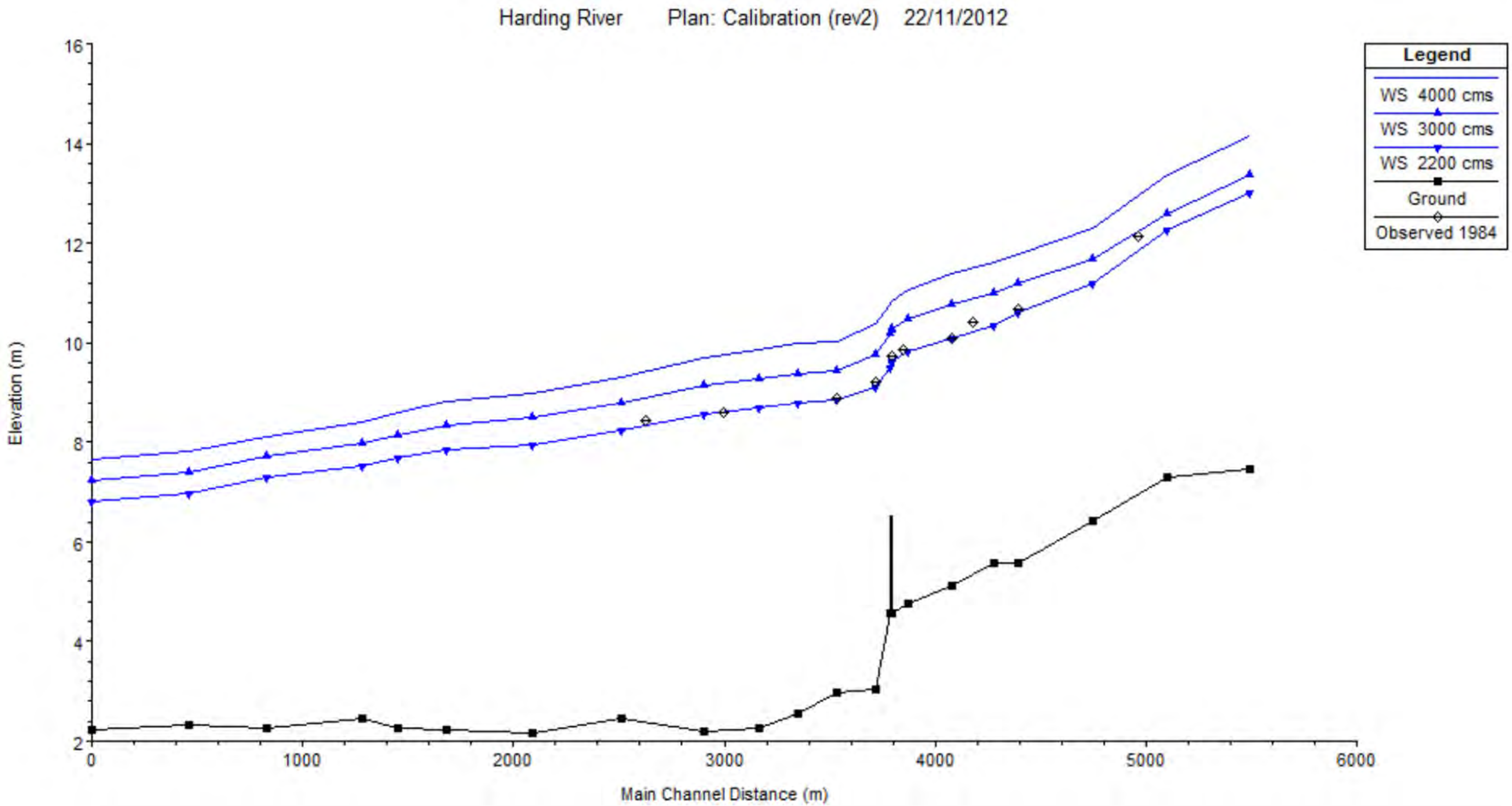

Figure 11: Harding River hydraulic calibration profiles

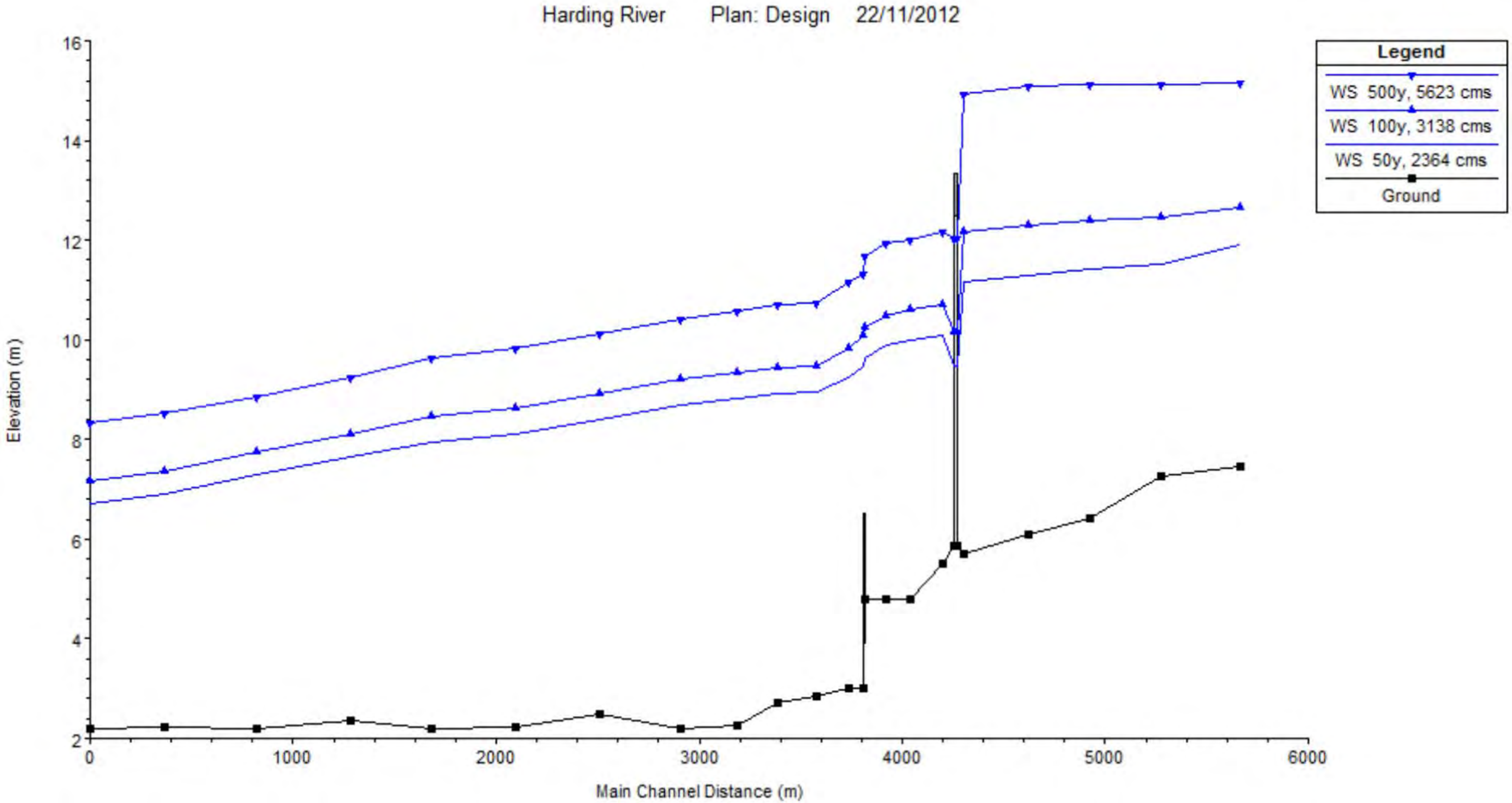

Figure 12: Harding River design flood profiles

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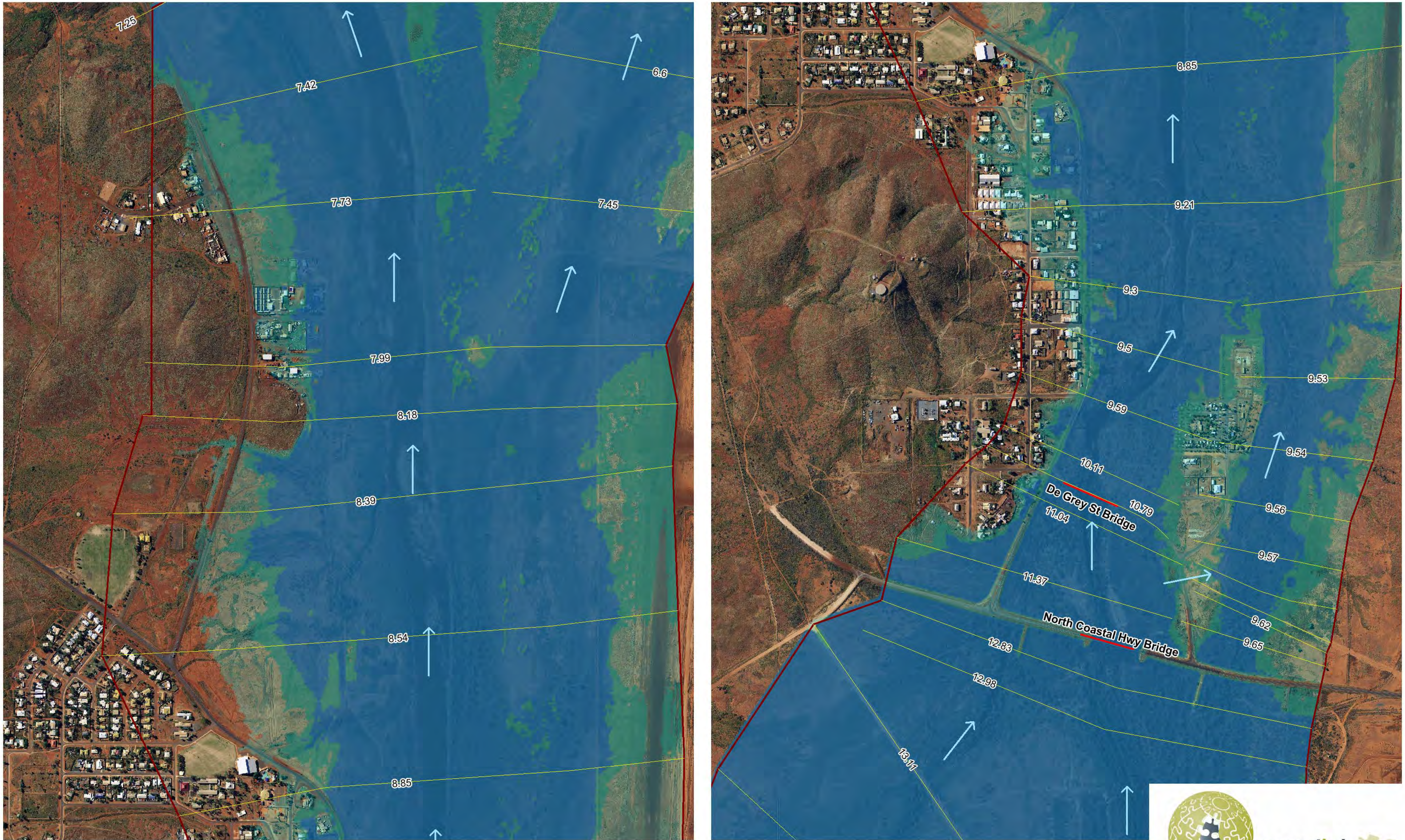
Figure 13 - Harding River design flood extent of inundation

LEGEND

- Mapping extent
- Hydraulic model section (100yr level)
- 50yr ARI River Flood
- 100yr ARI River Flood
- 500yr ARI River Flood



Datasource: MRWA, Microsoft Corporation, RORBWin v6.15, Created by: K Norris. Projection: MGA50: zone 50.

Scale 1: 150,000

0 3 km

N

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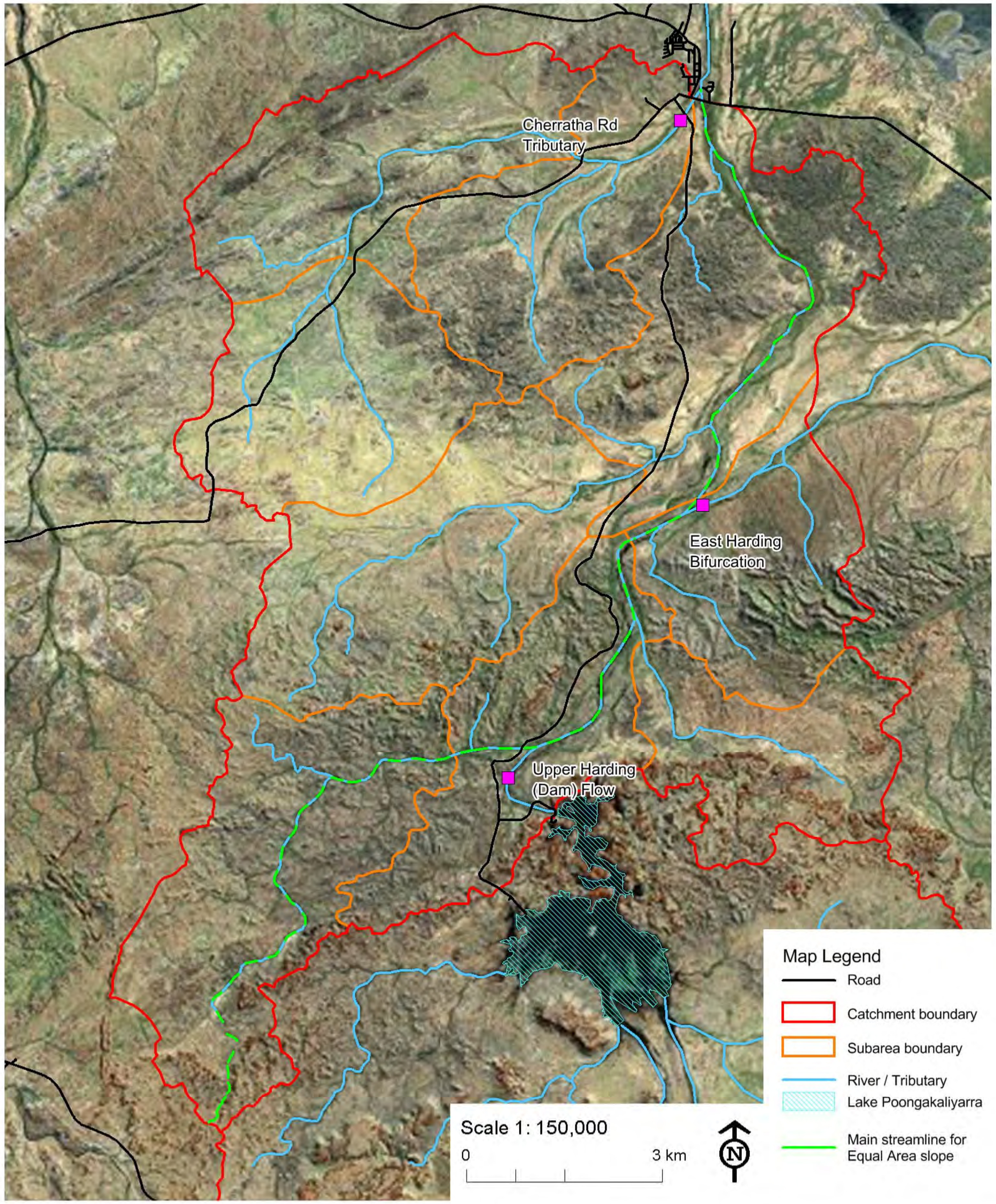
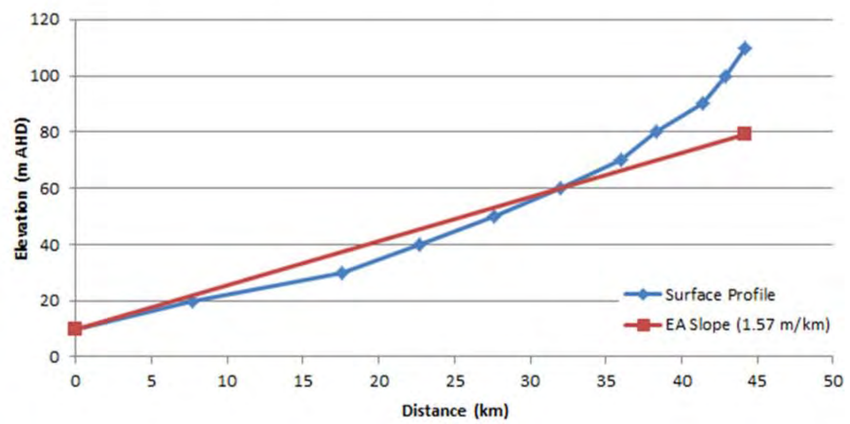
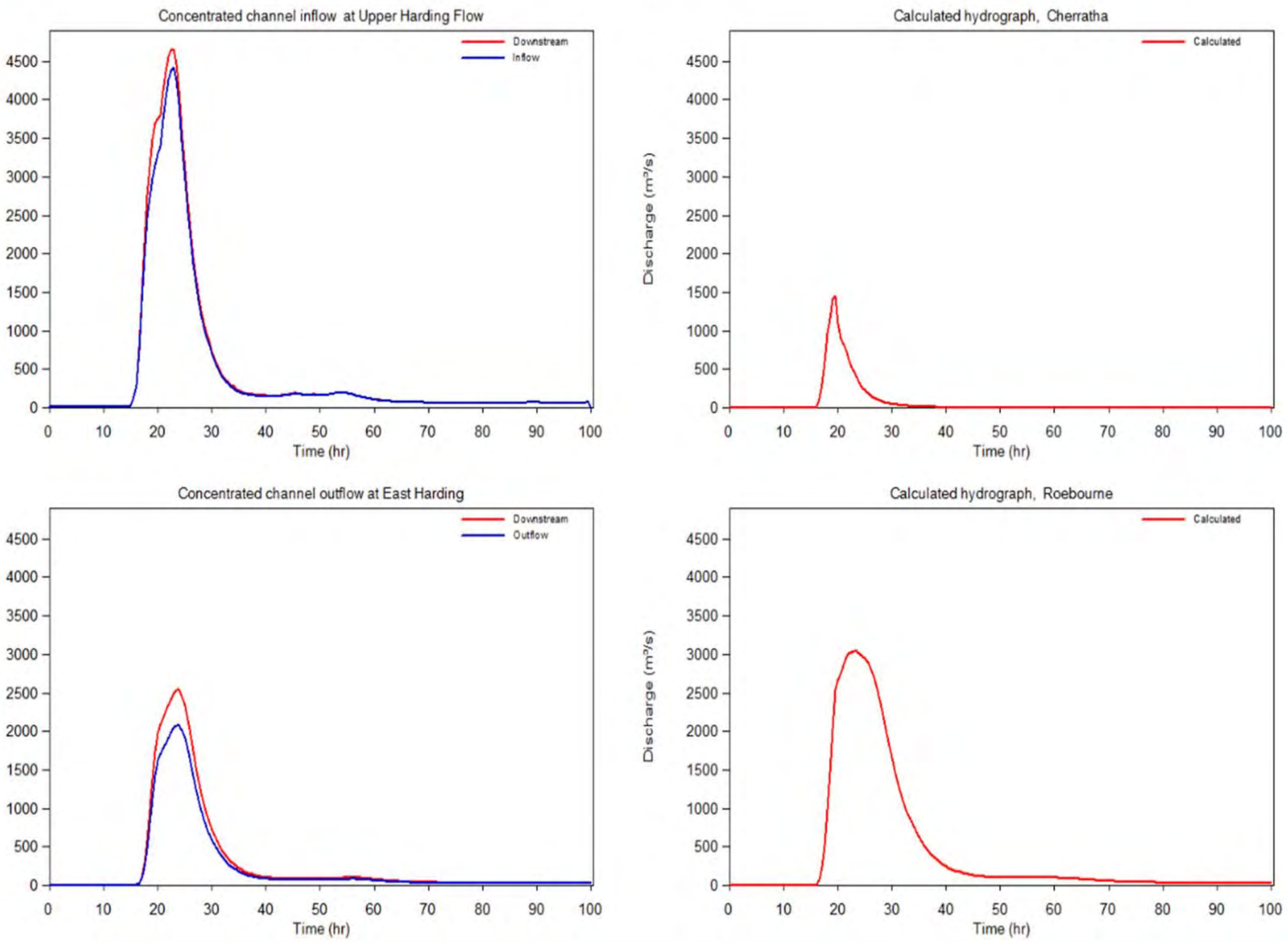
Roebourne, Stormwater and Flood Management Plan
Figure 14 - Harding River RORB model



Lower Harding Catchment Equal Area Slope



Estimated Hydrographs for Cyclone Chloe (March 1984)



Datasource: MRWA, Microsoft Corporation, RORBWin v6.15, Created by: K Norris. Projection: MGA50: zone 50.

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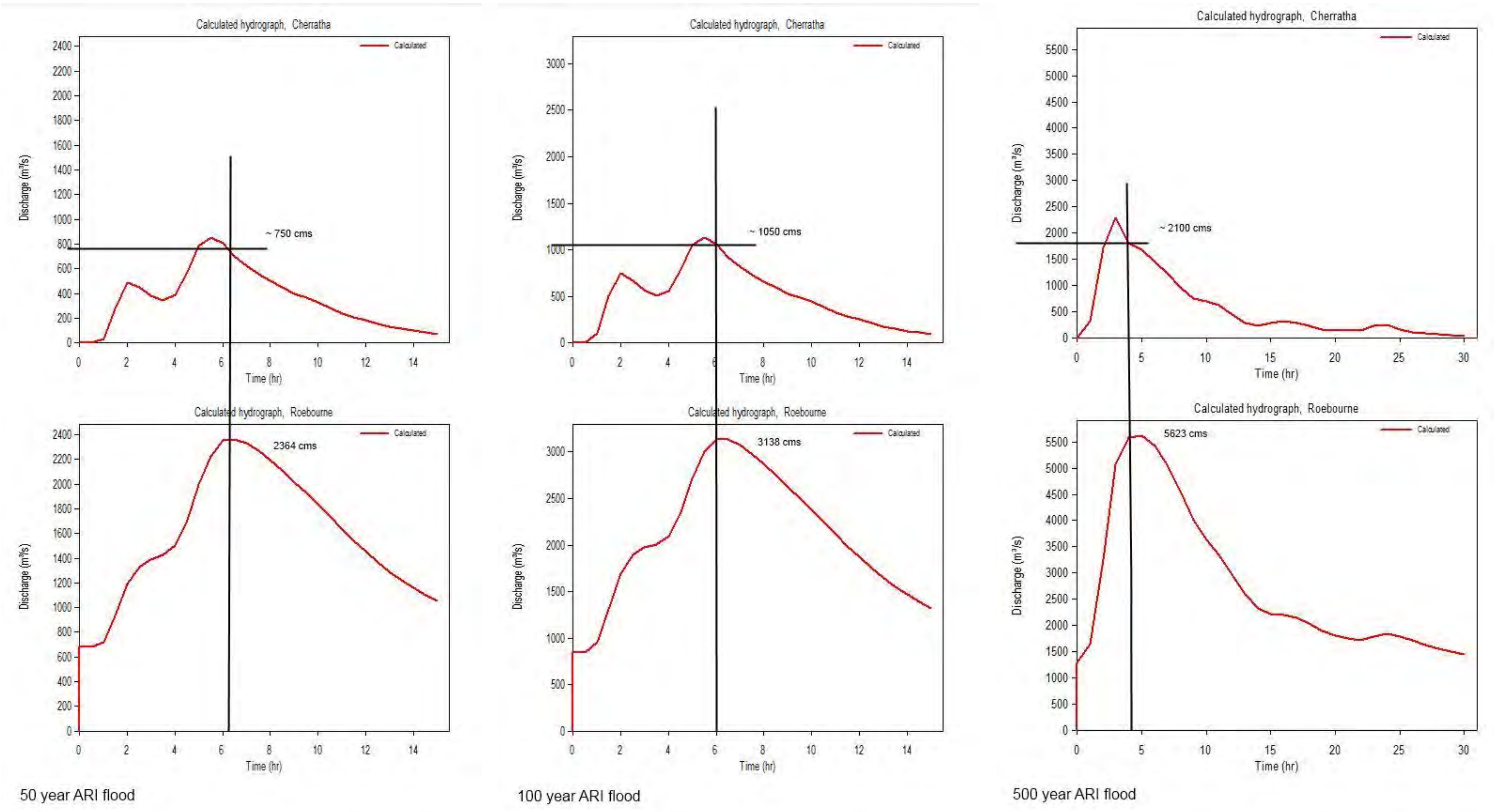


Figure 15: Design Flood Hydrographs

6.2 Stormwater Drainage

Due to the large volumes of water generated in cyclonic events, the priority for stormwater management in the north west region of WA has been the rapid removal of stormwater away from infrastructure to avoid flood related damages. The existing drainage network within the Roebourne townsite has been designed around a series of open drains which are the most efficient way to safely remove stormwater from the area.

Essential Environmental prepared hydrologic and hydraulic model[1] of the stormwater drainage in the townsite to assess the current potential for flooding and potential constraints on future development and redevelopment opportunities.

6.2.1 Existing drainage system

A detailed inspection of the site was performed to document the nature of open drains and details of culverts and other structures that impact on the hydraulic performance of the drainage network. The majority of observed structures are culverts at road crossings or crossovers.

Drainage is predominantly achieved via overland flow along the roads. Where open drains do exist they are generally trapezoidal in shape and have varying capacity.

Site observations revealed that while most drainage structures are in good condition, some culverts are obstructed by sediment and debris. Plate 2 illustrates the various degrees of obstruction which was observed during the site inspection. Obstructions have potential to limit the capacity of the drainage system and can result in additional flooding of the upstream drainage and road reserves, adjacent properties and flooding or overtopping of the road.

Obstruction by debris will occur more severely where culverts are small and prevent the passage of smaller items. Notwithstanding, a build-up of debris can also occur at other culverts where larger objects such as tree branches, shopping trolleys and other items obstruct flow and result in a build-up of smaller pieces of debris.

Plate 2: Typical obstructions observed at some culverts

[1] Hydrologic and hydraulic models were developed in Infoworks CS

6.2.2 Catchment delineation and runoff estimation

A digital terrain model was developed using LiDAR survey information and used to along with contours and site observations to define the extent of the catchments and delineate drainage subcatchments as illustrated in Figure 16.

Within the study area it is appropriate to consider the different rainfall responses that will occur on impervious surfaces, pervious urban surfaces, and pervious rural surfaces.

Impervious surfaces include things such as roads, paved areas and roofs where runoff flows directly into the drainage system. For these surfaces it is assumed that an initial 1 mm depth of rainfall is required to "wet" the impervious surface after which all rainfall will contribute to storm flow.

Pervious surfaces include bare soil, gardens, road verges or undeveloped rural land. The hydrologic model selected for this study considers an initial retention of rainfall before applying the Horton infiltration loss equation to estimate runoff from pervious areas. No infiltration testing or flow monitoring has been undertaken to inform selection of runoff parameters in the study area. In the absence of site specific data, parameters were selected to reflect the dominant soil types in the study area consisting of fine sands and clay which have moderate infiltration capacity. Lower infiltration capacity is applied to the pervious surfaces in urban areas to account for the compaction that will have occurred through human activities on the land. The assumed parameters for different pervious surfaces are presented in Table 2. The selected parameters are consistent with the US SCS Soil Groups "C" and "D", representing soils with low to very low infiltration capacity. The initial loss reflects localised ponding of water and storage within the catchment.

Table 3: Pervious area runoff parameters

	Urban	Rural
Initial Loss (mm)	0.003	0.005
Initial Infiltration, f0 (mm/hr)	76	125
Limiting infiltration rate, fc (mm/hr)	2.5	6.3
Decay factor (k)	2	2
Reference	SCS "D"	SCS "C"

A large portion of roof runoff in residential areas flows into gardens and other pervious areas and could be considered "disconnected" impervious areas. Notwithstanding, there will be significant runoff from residential land uses during the large rainfall events when onsite storage and infiltration capacities are exceeded. For this study a relatively high % impervious has been assumed for all landuses, to ensure flood risk assessment remains conservative. The assumed breakdown of runoff surfaces for different landuses is outlined in Table 4.

It is noted that current theories regarding water sensitive urban design and protection of environmental assets consider that interception of stormwater on-site provides significant benefits for water quality and maintenance of natural water cycles. Therefore, while the selected parameters are considered appropriate to ensure a conservative assessment of flood risk, this should not be interpreted as a recommendation in regards to the need for on-site retention and infiltration of minor storm events.

Aerial photography and site observations were used to identify existing land uses across the study area. The landuse distribution was then used to estimate a breakdown (percentage) of each runoff surface type for each subcatchment and applied to the runoff model. The observed landuses and resulting breakdown of runoff surfaces, summarised for each catchment, is presented in Figure 17 and Table 5.

Design rainfall series for the 5-year ARI and 100-year ARI was applied to the runoff model for each of the sub-catchments illustrated in Figure 16 and used to simulate the flood response in the hydraulic model described below.

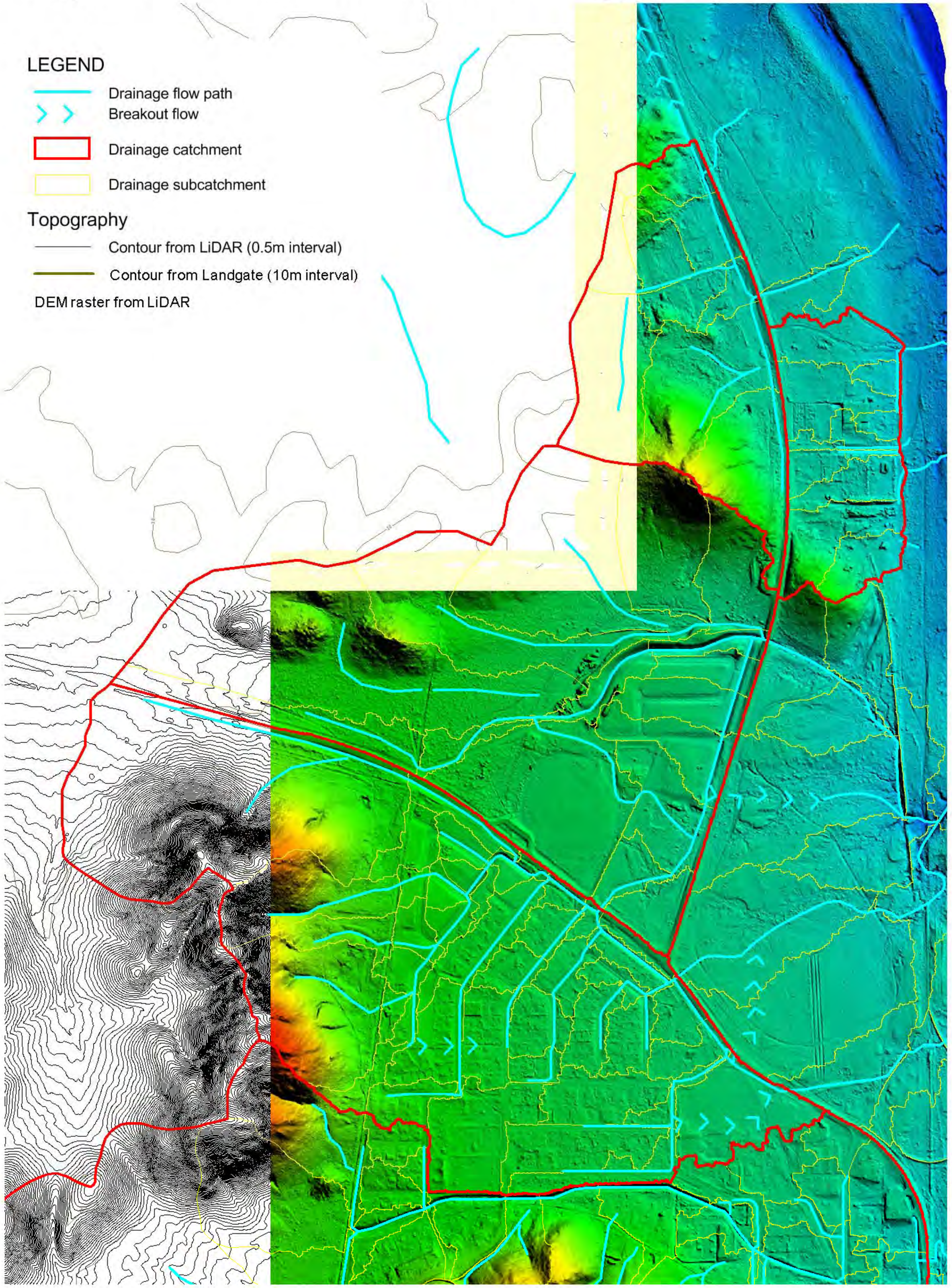
Table 4: Assumed runoff surface breakdown for different landuses

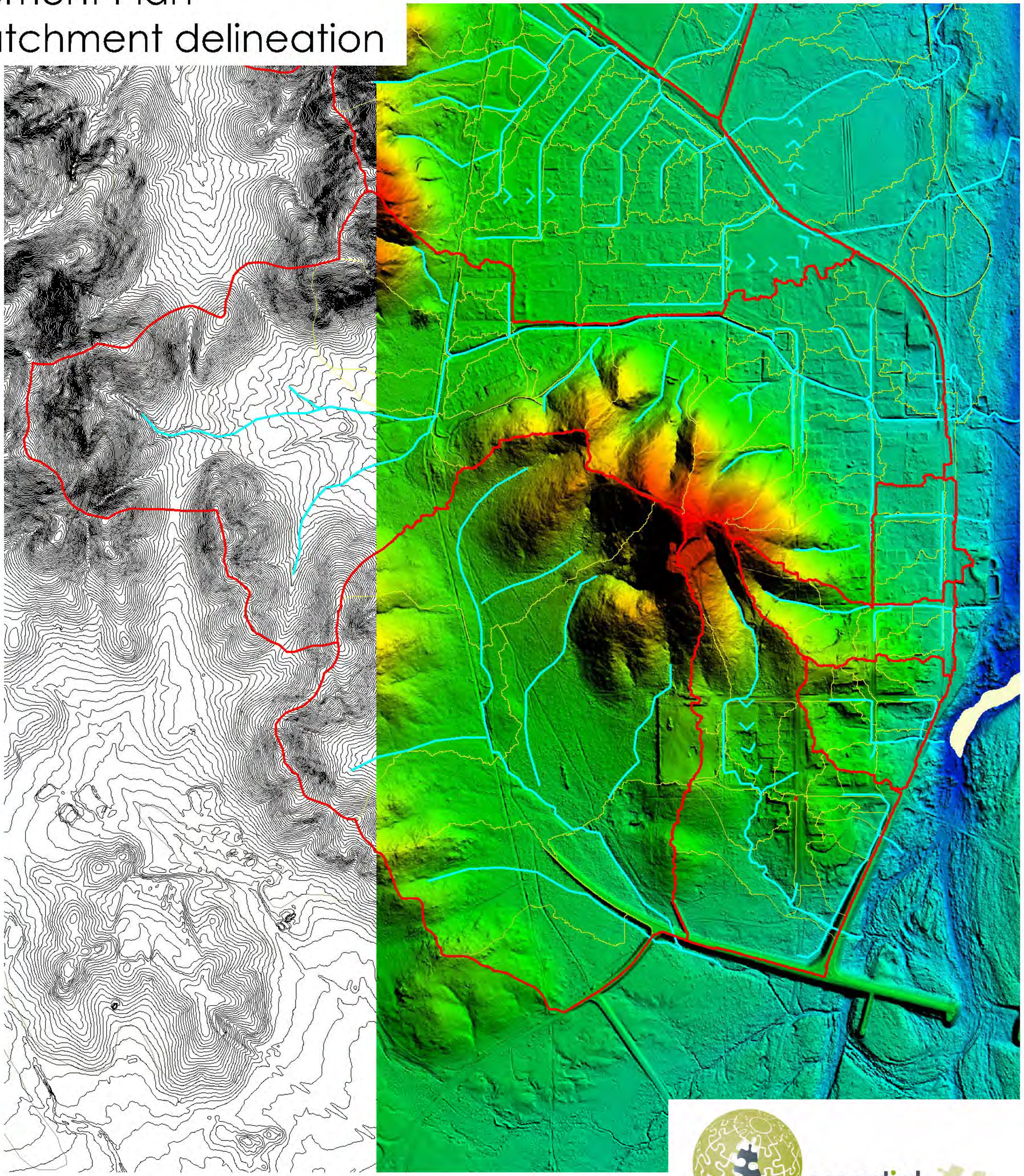
Landuse	Impervious	Pervious Urban	Pervious Rural
Impervious	90	10	0
Industrial	80	20	0
Open Space / Drainage	5	80	15
Community / Education	40	60	0
Road Reserve	70	30	0
Rural	5	0	95
Undeveloped Urban	5	10	85
Urban	60	40	0

Table 5: Catchment landuse breakdown

Catchment	Area (ha)	Landuse (%)		
		Impervious	Pervious Urban	Pervious Rural
1	21.3	24	11	65
2	11.7	49	14	37
3	62.9	13	13	74
4	69.7	32	25	43
5	105.6	18	12	70
6	4.9	60	39	1
7	6.8	33	20	47
8	7.0	40	27	33
9	28.1	30	14	56
10	81.4	7	1	92

Roebourne, Stormwater and Flood Management Plan
Figure 16 - Townsite drainage layout and catchment delineation



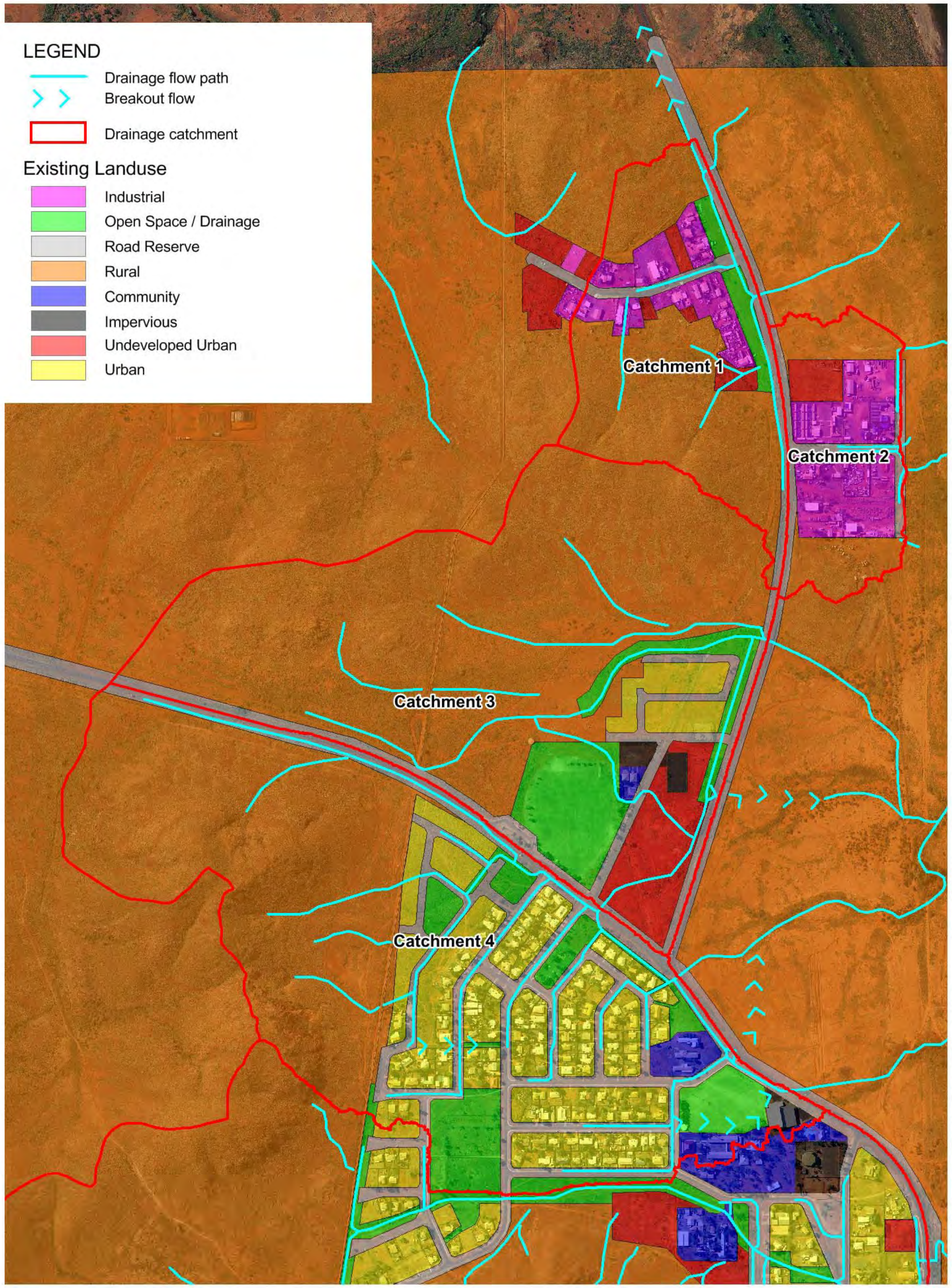


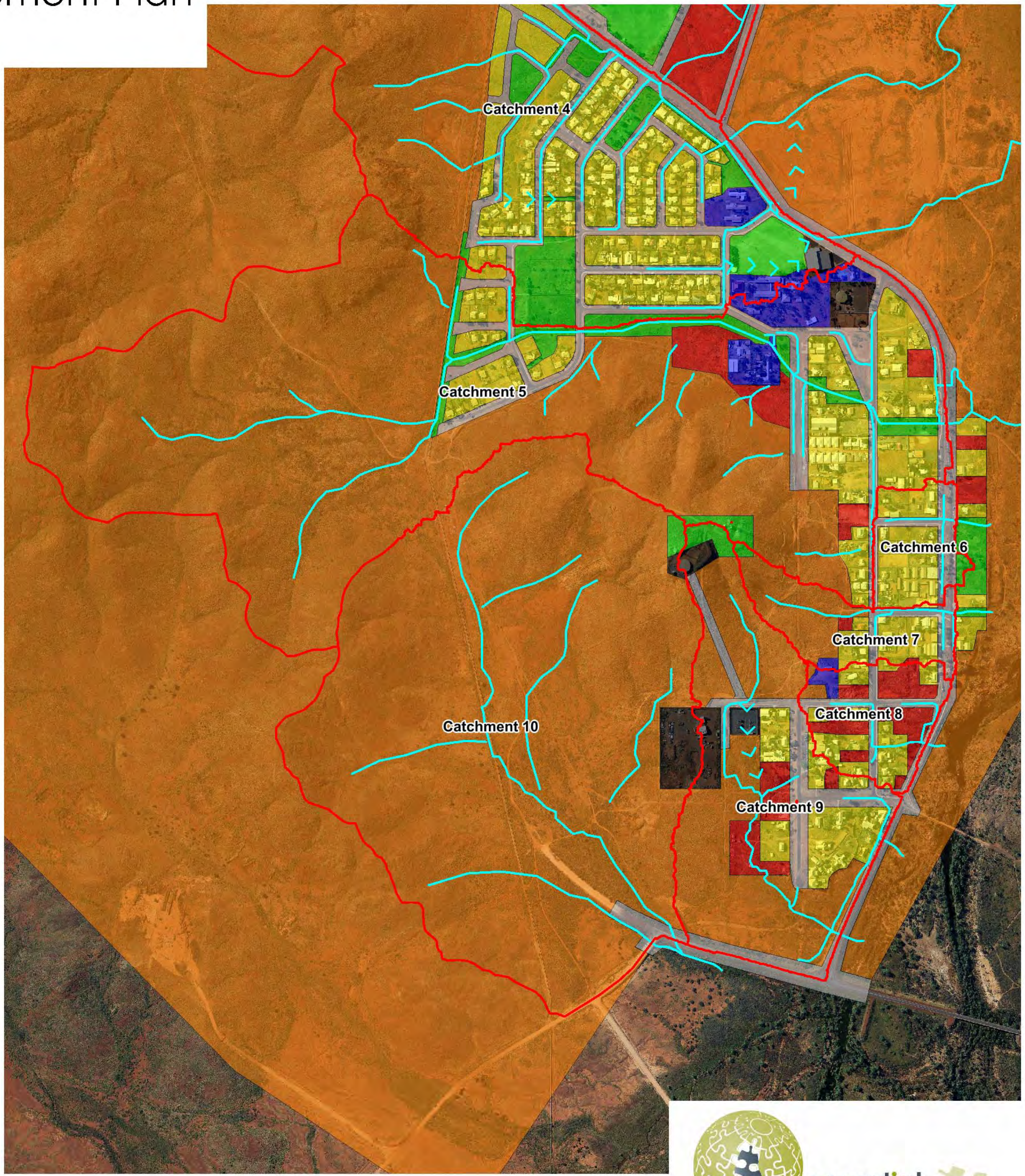
Datasource: Shire of Roebourne, Landgate. Created by: K Norris. Projection: MGA50: zone 50.

Scale 1: 10,000
0 400m

essential environmental

Roebourne, Stormwater and Flood Management Plan
Figure 17 - Townsite landuse breakdown





Datasource: Shire of Roebourne, Landgate. Created by: K Norris. Projection: MGA50: zone 50.

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6.2.3 Hydraulic capacity and flood mapping

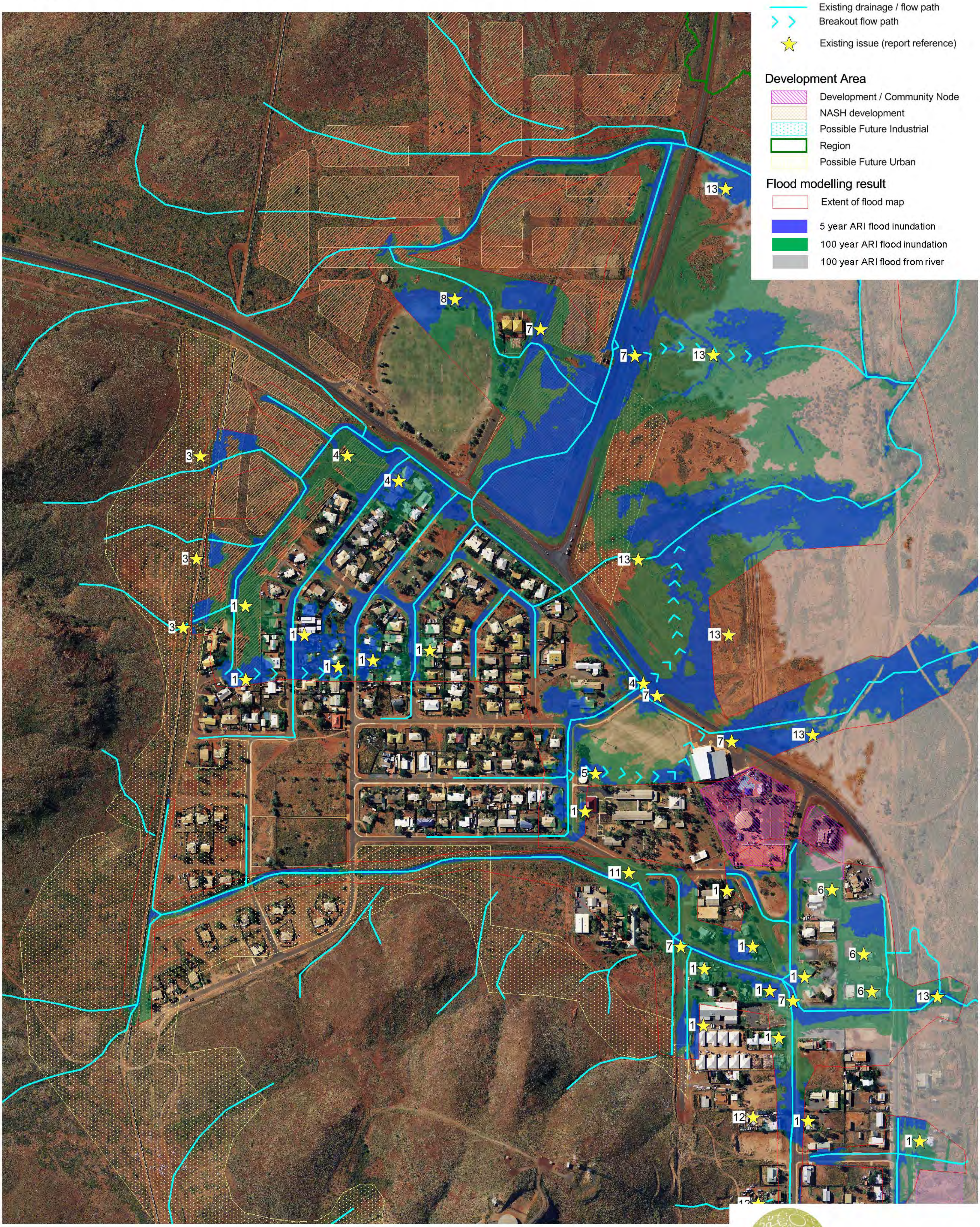
LiDAR survey was used to identify inverts and cross sections of open drains and road levels. This information along with measurements and observations recorded during the site inspection was used to develop a detailed hydraulic model of the existing drainage system. The general layout of the drainage system is illustrated in Figure 16.

The runoff model described above and the hydraulic model of the drainage system was used to develop estimates of flood extend for the 5-year ARI and 100-year ARI design rainfall events as illustrated in Figure 18 and Figure 19.

The mapping of predicted flooding allows identification of key capacity constraints and existing flood management issues. The key issues described below and nominally identified in Figure 18 and Figure 19 by corresponding numbers.

1. Existing developed properties set lower than (or with insufficient clearance to) adjacent drainage flow paths are at risk of flooding when flow rates exceed the hydraulic capacity of the drain (road surface or formal drainage).
2. The estimated depth and velocity of flow in local streets presents a hazard to the community.
3. Lack of formalised flow paths at western edge of NASH development presents a risk to properties within the overland flow path.
4. The capacity of the drainage system along the south side of Cleaverville Road (North West Coastal Highway) is limited, resulting in flood risk to adjacent properties and potential overtopping of the highway at the intersection of Harding Street.
5. Flood risk on Welcome Street is currently mitigated by an informal flow path created by overflow of the kerb into the school oval. In the absence of formal recognition, there is a risk that this flow path is compromised in the future.
6. The limited capacity of the culvert under the Roe Street results in flooding of the arterial drain and potential inundation of the adjacent properties during the 100-year ARI event.
7. Passage of stormwater over of roads presents a risk to community safety and potential for damage to infrastructure.
8. Unmanaged overland flow across the northern boundary of the town playing field could result in damage to public infrastructure.
9. Unmanaged overland flow through the power substation site has potential to impact on the town power supply.
10. Unmanaged overland flow through the police station has potential to impact the ability of authorities to respond in the case of an emergency.
11. Breakout of flow from the main drainage into Fraser Street will increase the hazards associated with flow depth and velocity on downstream parts of Frazer Street and Hampton Street North.
12. Overland flow from Welcome Mountain through existing properties on the west side of Sholl Street presents a risk to properties within the overland flow path.
13. Concentration of stormwater through culverts and artificial channels has altered the distribution of environmental flows, potentially reducing the availability of water to some water dependant ecosystems and increasing the potential for erosion in the environment downstream of the culverts.

Roebourne, Stormwater and Flood Management Plan
Figure 18 - Stormwater Inundation, Map 1



Datasource: Shire of Roebourne,
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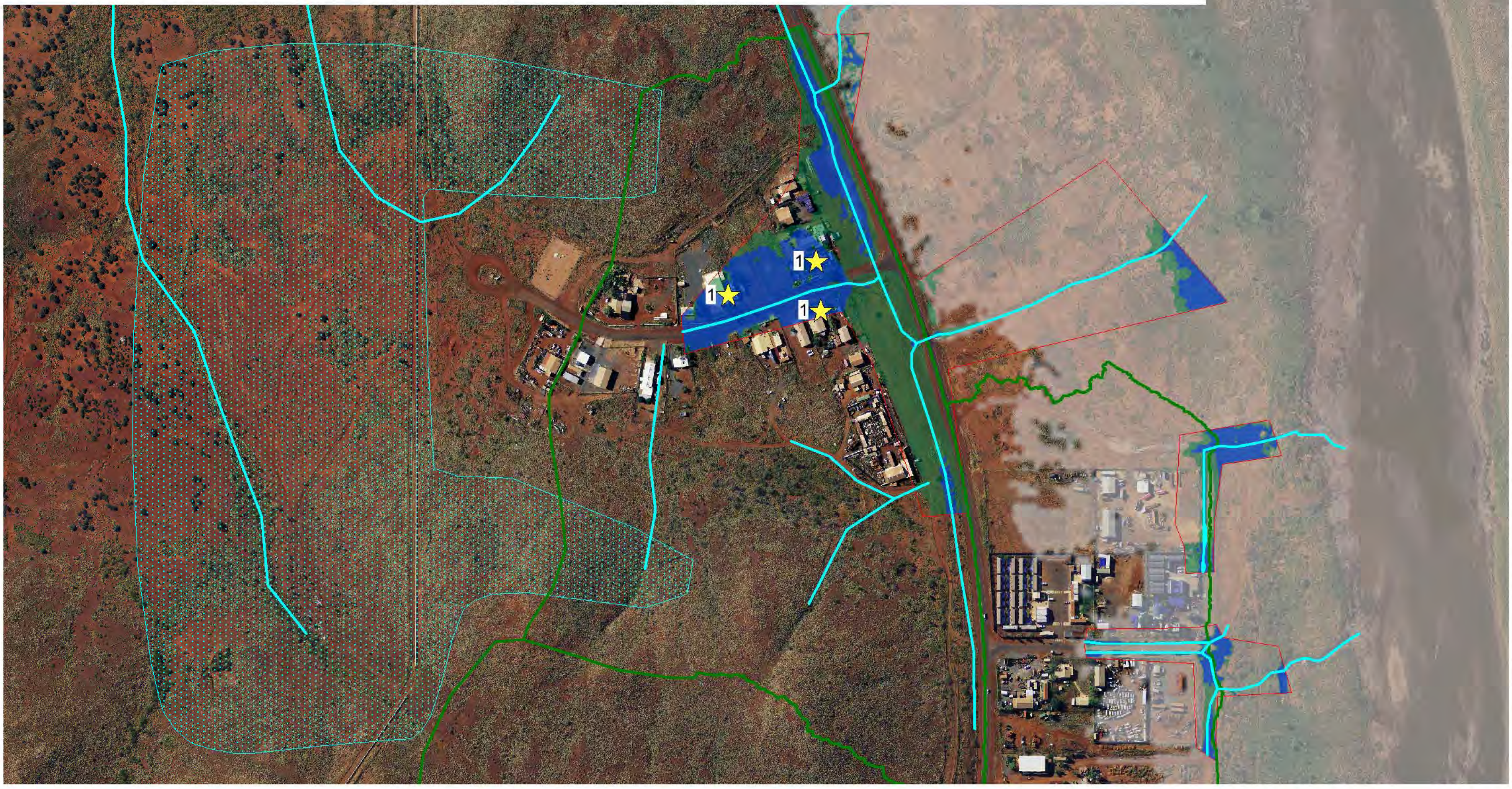
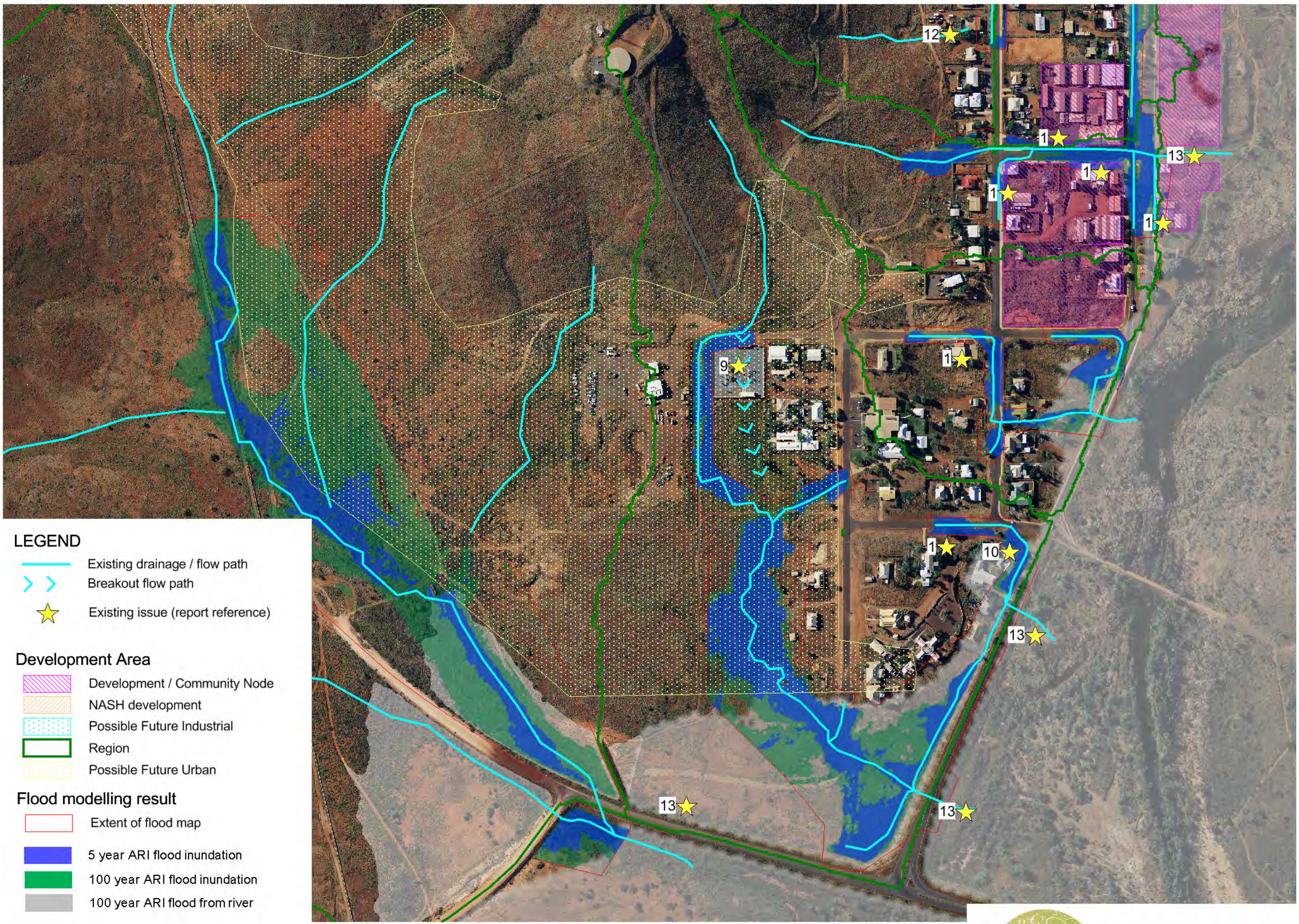
Roebourne, Stormwater and Flood Management Plan
Figure 19 - Stormwater Inundation, Map 2





Datasource: Shire of Roebourne,
Created by: K Norris. Projection: MGA50:zone 50.

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Scale 1: 5000 at A3

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7 RISK ASSESSMENT

Various policy and guideline documents described in Section 2 support the use of a risk framework to identify policy and controls for management of hazards associated with flooding and coastal vulnerability. It is also possible to consider stormwater design criteria within this framework in order to provide a consistent approach to development of the stormwater and flood management plan.

Using a risk assessment framework to inform the stormwater and flood management plan provides a flexible approach to consideration of hazards and other risks to existing and future development, recreational uses, and ecological and other values to be protected.

A risk assessment for the study area has been undertaken using the framework established within AS/NZS ISO 31000 (Standards Australia, 2009).

7.1 Flood hazard

Broadly accepted management standards to address flood hazard have been adopted by government agencies and documented in engineering standards. The following notes provide an overview of some relevant design criteria and standards adopted by industry:

1. Austroads (2008) and Alderson (2006) draw upon the recommendations of ARRB Special Report 34, suggesting that appropriate design of flood immunity for finished floor levels should vary between 50-year and 500-year ARI depending on land use. Table 4.2 from Austroads (2008) is reproduced as Table 6 for convenience.
2. To maintain the safety of pedestrians during flood events, *Australian rainfall and runoff* (Pilgram 2001) suggests that “the product of velocities and depths in streets and major flow paths should not exceed 0.4 m2/s”.
3. Engineers Australia (2011) provides a review of safety criteria for vehicles and suggests “Draft, interim” criteria for stationary vehicle stability; adopting floating limits of between 0.3m and 0.5m and depth x velocity limits between 0.3 and 0.6 m^2/s depending on the type of vehicle.

Standing Committee on Agriculture and Resource Management Report 73 (SCARM73), Floodplain Management in Australia, Best Practice Principles and Guidelines (CSIRO, 2000) describes a risk based approach to floodplain management that considers a function of flood depth and velocity as well as considering the ability to evacuate populated areas. Figure 20 presents the SCARM73 flood hazard categories which are defined in Table 7.

The assessment of flood hazard by this method requires an assessment of the flood depth and velocity throughout the study area to enable assessment against the graph to give the relevant hazard category. The SCARM73 approach allows a robust assessment of flood hazards throughout the study area and has therefore been used in this assessment.

A flood hazard assessment of the site was undertaken using hydraulic modelling information and Figure 21 Figure 22 presents the resultant flood hazard mapping based on the peak 100 year ARI flood depth and velocity. This is a conservative approach because it assumes that peak flood depth occurs simultaneously with peak velocity however it provides a reasonable assessment to aid development of flood management strategies.

Table 6: Minimum recurrence interval for flood immunity recommended by AUSTROADS

Priority	Situation	ARI (years)
A	Floor levels of hospitals and civil defence headquarters.	500
	Floor levels of police, ambulance, fire stations, water and waste centres, electric and gas supply stations, convalescent homes and buildings designated as emergency housing used during extreme flooding events.	200
B	Floor levels of residences, essential food, pharmaceutical, retail stores, department stores, centres employing a large labour force, community administration and education centre, centres of rare artefacts, venues for entertainment, dining, popular indoor sport.	100
	Floor levels of factories and outlets supplying non-essential items, premises of businesses and institutions employing a small labour force, premises of sport or community activities infrequently used. Town centres and intense industrial areas including central business district.	50
C	Grounds of all units belonging to priority 'A' outdoor areas where rare artefacts are displayed or stored.	5 to 10
	Grounds of all units belonging to priority 'B'.	3 to 5
	Other open space areas including general parks and outdoor sport and recreation areas.	1 to 3

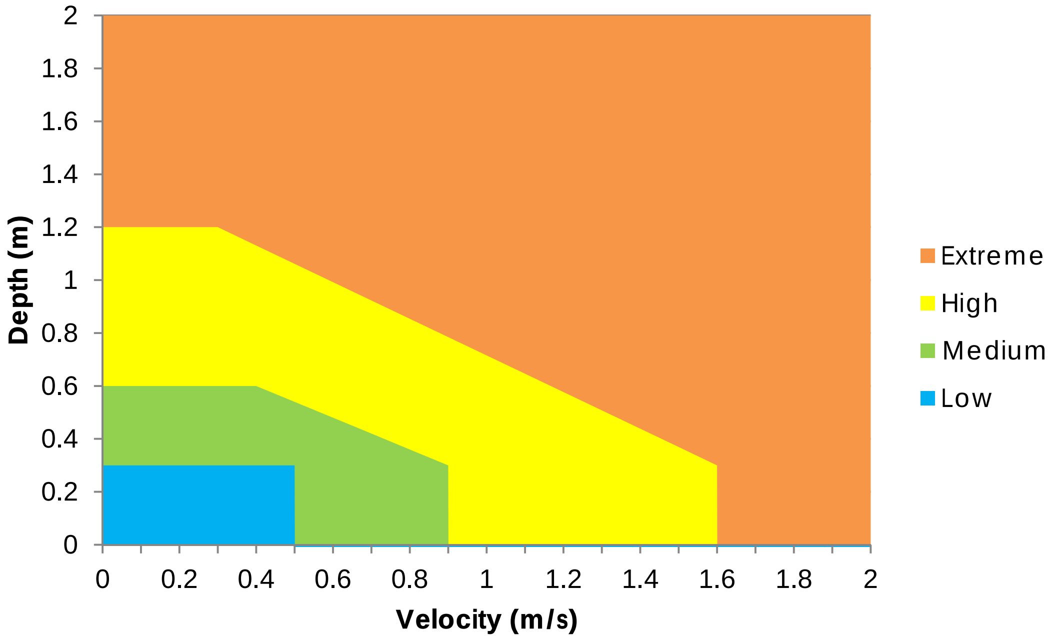
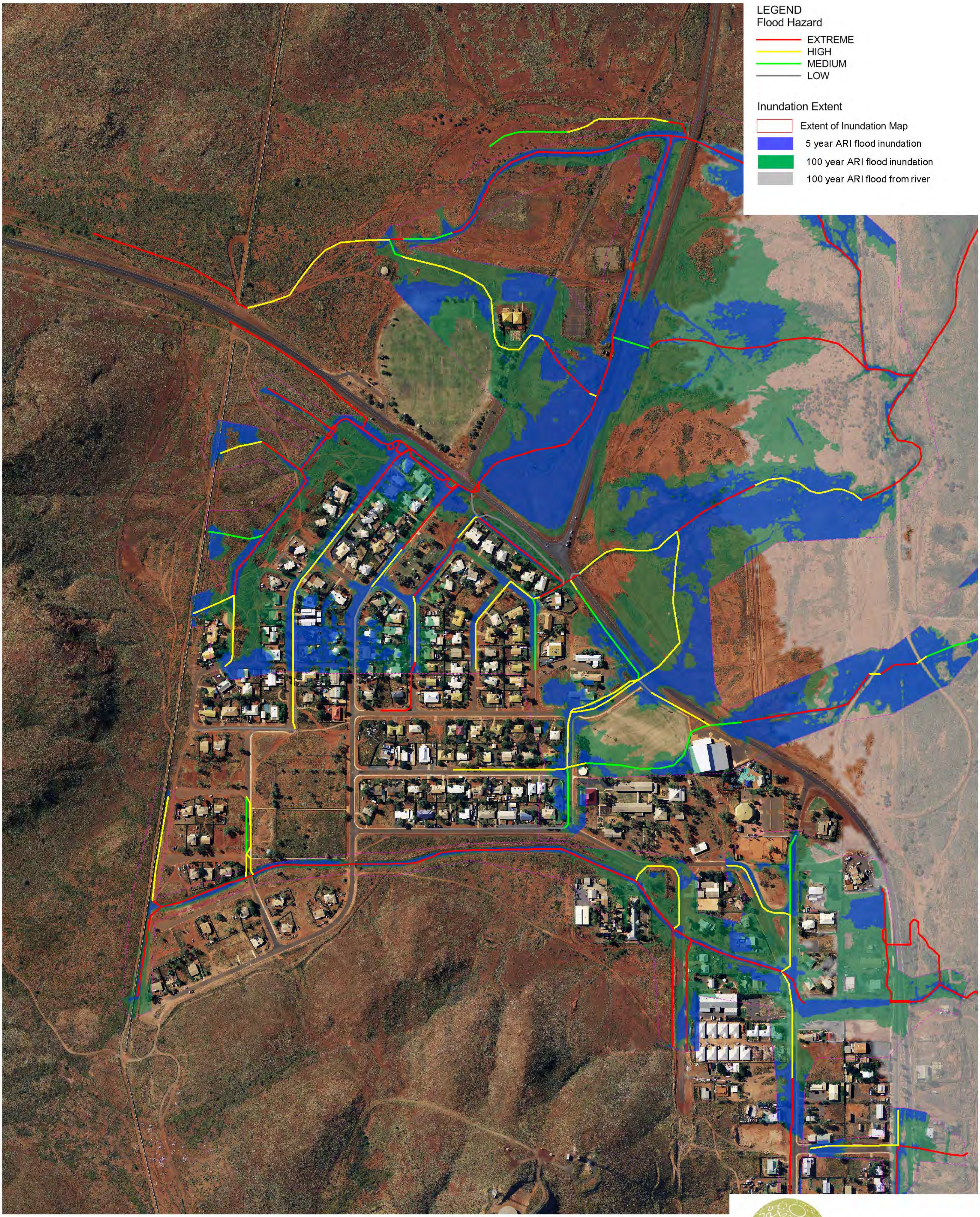


Figure 20: Flood hazard estimation (SCARM73)

Table 7: Flood hazard category definitions (SCARM73)

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 1.0 m and velocities up to 1.5 m/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 1.0 m and velocity exceeds 1.5 m/s	• Open space • Club houses with appropriate protection

Roebourne, Stormwater and Flood Management Plan
Figure 21 - Flood Hazard, Map 1



Datasource: Shire of Roebourne,
Created by: K Norris. Projection: MGA50:zone 50.

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Scale 1: 5000 at A3
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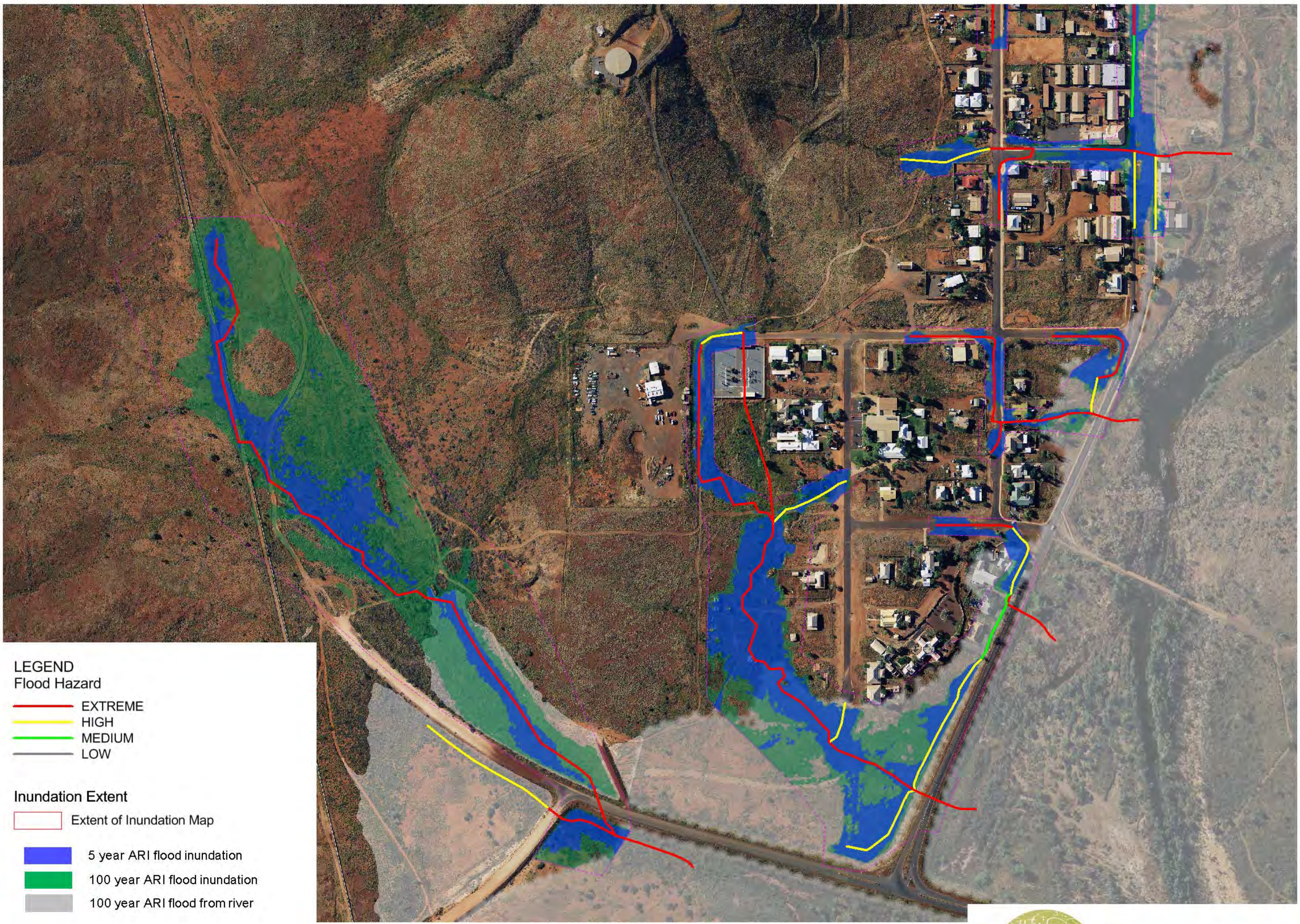
Roebourne, Stormwater and Flood Management Plan
Figure 22 - Flood Hazard, Map 2



LEGEND
Flood Hazard
- EXTREME
- HIGH
- MEDIUM
- LOW

Inundation Extent
- Extent of Inundation Map
- 5 year ARI flood inundation
- 100 year ARI flood inundation
- 100 year ARI flood from river

Datasource: Shire of Roebourne,
Created by: K Norris. Projection: MGA50:zone 50.

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Scale 1: 5000 at A3
0 200m

essential environmental

7.2 Coastal hazards

In regards to coastal hazards, draft SPP2.6 requires that planning in coastal areas is considered in the context of coastal hazard risk management and adaption planning undertaken by the responsible authority or proponent of the development. The accompanying draft guidelines to draft *SPP 2.6* outline the recommended process for such planning and suggest that the following elements are required:

1. Establishment of the context.
2. Coastal Hazard risk identification.
3. Coastal hazard risk analysis.
4. Coastal hazard risk evaluation.
5. Coastal hazard risk adaption planning.
6. Monitor and review.

It is important to note that while draft *SPP 2.6* maintains Schedule 1 there is no equivalent requirement that development should be set back to avoid inundation from a specific storm (as per the current *SPP 2.6*), rather this requirement is replaced by the need for a risk assessment as discussed above and the need for a coastal foreshore reserve to manage risks.

Given that the town site lies a significant distance from the coast it is reasonable to assess the hazard risk generated by storm surge inundation consistent with the recommendations described in Section 7.1; assuming that water is static.

7.3 Context and Objectives

The first step in understanding risks to be managed is to establish the context for by defining the objectives of the assessment. Objectives for this risk assessment relate to environmental protection, protection of assets and facilitating social outcomes for the Roebourne community. Section 1.4 outlined the objectives for the management plan which can be summarised as follows:

- Environmental protection.
- Protect private and public infrastructure.
- Manage public safety.
- Provide social amenity.

Each of these objectives is affected by risks which may require planning controls and/or active management actions.

7.4 Risk Identification

The coastal vulnerability and surface water assessments outlined in section 5 and 6 and changes to land uses in the study area present risks to the achieving the objectives identified above. Specific risks associated with each of the objectives have been identified as follows.

Environmental protection

1. <u>Damage to downstream environments caused by sediment transport.</u> Transport of sediment into receiving environments could cause damage to ecosystem processes affecting the viability of natural systems. Further, long term accumulation of sediment in the lower reaches of the Harding River could increase flood risk to the townsite.

2. Modification of environmental flows to water dependant ecosystems. Maintaining natural surface water flow paths is important to ensure health of dependant ecosystems. This is particularly relevant in the north west region where rainfall is infrequent and water received via surface water contributes a significant portion of total water use by some ecosystems.

   The nature of topography and soils in the region means that natural flow paths are often present as braided channels and sheet flow across broad floodplains. Installation of infrastructure within the catchment can results in concentration of storm flows to a smaller number of channels with subsequent effects on downstream environmental flows.

   An example of where this has occurred is in the area immediately west of Point Samson Roebourne Road and north of Cleaverland Road, where drainage of minor events from the upstream catchment has been concentrated into one of three discharge points. This change has affected the distribution of ecosystems in the area.

3. Erosion in natural systems. Increased flow velocities caused by concentration of storm flow can result in unnaturally erosive velocities which can cause acute erosion of in-line environmental areas and/or downstream environments.

   Erosive velocities are associated with water entering and exiting culverts, overtopping of roads or levees and concentrated flow in natural channels which would naturally be exposed to lower flow rates.

Protect private and public infrastructure

4. Acute damage from storm events. Movement of water through drainage systems and across the built environment can result in forces which cause an acute damage or complete failure of property and infrastructure.

   Design of infrastructure based on insufficient information and lack of maintenance are common causes of infrastructure failure. Drainage systems, waterways and adjacent infrastructure need to be designed to address the risk of acute damage and facilitate ease of maintenance. In the absence of an effective maintenance program, blockage of drainage systems can result in undesirable performance of drainage infrastructure resulting in potential acute damage when alternative flood paths are not established or properly managed.

5. Incremental damage from storm events. Ongoing exposure to erosive forces can impact on property and infrastructure through incremental damage, potentially undermining the structural integrity of infrastructure or otherwise affecting the build environment.

6. Damage from inundation. Infrastructure and property can be damaged or made temporarily unserviceable through inundation.

   The consequence of temporary or permanent damage can vary significantly; by example, temporary closure of a minor road may be of little consequence, while failure of essential service infrastructure or impacts on emergency services may have significant impacts.

Manage public safety

7. <u>Injury from interaction with drainage infrastructure and floodways.</u> Exposure of people to high velocities and/or deep water associated with waterways, floodways and drainage infrastructure can result in injury or fatality from impact or drowning.

   The common management response to this risk is to exclude public access to drainage and waterways during frequent events (via underground drainage infrastructure) and manage flow depth and velocity for lower probability events.

8. <u>Injury in overland flow path.</u> In the north west region, high runoff potential combined with high intensity of rainfall during significant storm events can result in high velocities in informal drainage systems and overland flow paths.

   In such an environment, flow along local roads or overland through private or public property presents risk of injury.

9. <u>Health and safety impact from inundation.</u> Inundation of private property can have significant effect on the health and wellbeing of occupants through damage to personal belongings or perishables and creating environments that can encourage infection or disease.

   Additional risks are generated where service infrastructure is affected. By example, failure of sewerage networks as a result of storm infiltration or pump station failure presents additional risk to public health.

Provide social amenity

10. <u>Nuisance from overland flow.</u> Poorly defined or under capacity overland flow paths can result in nuisance flooding, minor erosion and maintenance issues which affect the amenity of public spaces and/or private land.

11. <u>Poor social outcomes from design of drainage and waterways.</u> Natural and artificial waterways can provide aesthetic value to the community and can be designed to support multiple uses. Conversely, poorly designed spaces and infrastructure can detract from overall amenity and in some cases facilitate poor social outcomes.

12. <u>Compromised serviceability of roads and public space.</u> The condition of roads, parks and other public infrastructure can be affected by damage, the need for maintenance or other short term constraints after a storm event. The level of serviceability that is provided will be a compromise between community expectations and resource constraints.

    By example, roads may require maintenance to remove foreign material and/or parks may be saturated for an extended period of time following a rainfall event.

7.5 Risk Analysis

Qualitative assessments of the likelihood and consequences for each of the identified risks needs to be undertaken in order to consider the need for management actions. In order to undertake this assessment it is necessary to describe the uncertainty in risk through definitions of likelihood and consequence of occurrence for the defined risk event.

Management of surface water is commonly established through definition of an acceptable recurrence of failure or exceedance for different infrastructure or events. In this way design of future infrastructure or management interventions can addresses key issues such as the acceptable level of service, safety and the risk of damage to private and/or public infrastructure as a result of flooding.

To align the concept of flood recurrence (annual exceedance probability) to measures of likelihood which are relevant to the planning context it is necessary to consider the cumulative exceedance probability that an event will occur within the planning timeframe as outlined in Table 8.

Table 8: Likelihood of exceedance

Average Recurrence Interval (ARI)	Annual Exceedance Probability (AEP)	Design Life (100 year) exceedance probability
1 year	63.2 %	100 %
5 years	18.1 %	100 %
20 years	4.9 %	99 %
50 years	1.98 %	86 %
100 years	1 %	63 %
500 years	0.2 %	18 %
1000 years	0.1 %	10 %

Local drainage systems are designed to manage community expectations surrounding serviceability of roads and ponding of rainfall during small events. Due to the variable nature of climate and intensity in rainfall it is not practical to manage large storm events in the same way.

To address the competing objectives of amenity, cost and function, various guiding documents[2] advocate consideration of a major and a minor event in hydraulic design of stormwater systems.

Such analysis considers two types of design rainfall events:

(1) A “minor event” (commonly between 1 in 1-year and 1 in 20-year ARI) in which nuisance flooding concerns are addressed.

(2) The “major event” (usually 1 in 100-year ARI) for which failure of the system, damage to private property, and safety is considered.

[2] Including; Pilgram 2001, DEC 2004, Austroads 2008, and IPWEA 2009.

The annual and design life exceedance probabilities outlined in Table 8 illustrate the relative frequency of occurrence and the role of "minor" event management as nuisance flooding and "major" events for flood hazard management.

The Table 9 and Table 10 outline the definitions of risk likelihood and consequence in the context of flood recurrence which can be used to characterise flood hazards and performance in a risk assessment framework.

Table 9: Qualitative measures of Likelihood

Level	Descriptor	Example description
A	Rare	Highly unlikely that the event will occur. Not recorded historically and not expected to occur. 0 – 20% probability of occurring over the timeframe. (inc 0.1% AEP)
B	Unlikely	Low possibility that the event will occur. Infrequent and isolated occurrence. 20 – 40% probability of occurring over the timeframe. (inc 0.2% AEP)
C	Possible	Might occur or should be expected to occur. 40 – 60% probability of occurring over the timeframe.
D	Likely	Likely the event will occur. History or probability of casual occurrence. 60 – 80% probability of occurring over the timeframe. (inc 1% AEP)
E	Almost certain	High possibility the event will occur. History or probability of periodic occurrence. 80 – 100% probability of occurring over the timeframe. (inc >2% AEP)

Table 10: Qualitative Measures of Consequence

Level	Descriptor	Community / Infrastructure	Health / Environment
1	Insignificant	Little or no impact on communities and services. Minor temporary impact to private property or infrastructure. Temporary treatments required to maintain amenity.	No health impacts. Minor naturally assimilated environmental damage. No treatments / interventions required.
2	Minor	Minor or temporary impact on services for small population. Minor impact to private properties or infrastructure. Temporary, isolated treatments are required to maintain services or protect property and infrastructure. Permanent treatments required to maintain amenity.	Minor injury to individual. Potential harmful impact to local ecosystem with impacts contained to a specific site. First aid or medical treatment. Site specific intervention to assist in ecosystem recovery.
3	Moderate	Minor impact on services large population. Moderate impact to private properties or infrastructure. Temporary treatments are required to maintain services or protect property and infrastructure. Relocation of temporary infrastructure.	Minor injury to more than one person. Potential harmful impact to local ecosystem with impacts contained but occurring at multiple sites. First aid or medical treatment. Site specific interventions and monitoring to assist in ecosystem recovery.
4	Major	Major impact on services for small population. Major impact to private properties or infrastructure. Permanent treatments are required to maintain services or protect property and infrastructure. Relocation of permanent infrastructure.	Significant injury to small number of people causing lost time or restricted capacity. Long term, potentially irreversible damage to local ecosystem with impacts primarily contained, but potential for regional impacts. Medical treatment or hospitalisation required with expected full recovery. Widespread interventions and monitoring to assist in ecosystem recovery.
5	Catastrophic	Major impact on services for large population. Irreversible impact to large number of private properties or infrastructure. Permanent treatments are required to maintain services or protect property and infrastructure. Viability of land uses compromised, relocation of permanent infrastructure.	Fatality or permanent injury to an individual. Temporary injury to large number of people causing lost time or restricted capacity. Long term damage to regional ecosystem or loss of threatened species. Ongoing medical treatment for permanent injury. Isolated medical treatment or hospitalisation required for large number of people. Widespread interventions and monitoring to assist in ecosystem recovery.

7.6 Risk Evaluation and Controls

The purpose of the risk assessment is to inform the management plan by considering what actions are required to reduce risk to a tolerable / acceptable level.

In order to evaluate risks and consider the need for risk management actions or controls it is necessary to define the level of acceptable risk. In order to do this the following definitions are considered.

- **Low risk** is tolerable and no further action is required.
- **Moderate risk** is tolerable but should be further reduced where possible and requires ongoing monitoring and communication to affected people.
- **High risk** is unacceptable and further action is required to reduce risk where possible.
- **Very high risk** is unacceptable and further actions are required before activities should be allowed to continue.

The definitions of risk, likelihood and consequence are considered to derive the qualitative assessment of risk presented in Table 11.

Table 11: Qualitative risk evaluation table

Likelihood	Consequence 1 Insignificant	 2 Minor	 3 Moderate	 4 Major	 5 Catastrophic
A Rare	Low	Low	Moderate	Moderate	Moderate
B Unlikely	Low	Moderate	Moderate	High	High
C Possible	Low	Moderate	Moderate	High	Very High
D Likely	Moderate	Moderate	High	Very High	Very High
E Almost Certain	Moderate	High	Very High	Very High	Very High

It is noted under Table 11 the proposed assessment of a risk evaluated as "Rare" but "Catastrophic" is "Moderate" and therefore a tolerable outcome. This is important to reflect the fact that in some cases it is not possible to eliminate risk of a catastrophic event. By example, there are hazards which with current resources and social constraints cannot be eliminated and which could generate a fatality. It is important that in assessment of hazards that fall within this evaluation category there is a formal recognition that there are limits on the resources of the responsible authority and that there must be some acceptance of the principle and the community that not all hazards can be eliminated.

SCARM Report 73 describes best practice management measures that can be used to reduce the likelihood or consequence of flood hazards. Management measures are broadly grouped into four categories as follows:

- **Land use planning (removing people from the flood).** The least resource intensive control is to remove uses which are sensitive to flood hazards such that they occur outside of flood prone land. There is a limit to which this approach can be implemented due to community desire to use of flood prone land for economic or social outcomes.

- **Structural measures (removing the flood from people).** Structures such as stormwater drainage infrastructure, or levees and bridges in major waterways can effectively control flood water and reduce flood risk. Careful design and adequate maintenance is required to ensure that structures are able to perform their intended function. Here it is important to note that poor design and/or failure of structural measures can result in higher risks than that which exists in natural conditions.

- **Development and building controls (managing consequences).** Design of developments can provide effective flood risk management by reducing the damage to property and infrastructure. Controls may include selection of building design and materials, setting minimum floor levels and provision of evacuation routes from flood prone areas.

- **Flood emergency plans (major flood response).** Emergency management planning is required to address the risk posed by floods that will eventually occur in excess of that addressed by other measures.

The assessment presented in Table 12 provides an assessment of inherent risk in the absence of management planning or other controls and the residual risk after proposed controls are implemented. Table 13 presents more detailed assessment of the likelihood and consequence of each of the identified risks.

Many of the management actions identified in Table 12 are mutually exclusive or overlap. Actions for each of the specific risks have been further developed into the management strategies outlined in Section 8.

7.7 Risk adaption planning, monitoring and review

The definitions of likelihood and consequence and the proposed evaluation of risk described above provide a subjective assessment of the level of risk which might be considered tolerable in the current social and administrative context.

Further, the identification of key risks (section 7.4), assessment of likelihood and consequence (Table 13) and evaluation of risks presented (Table 12) considers the current understanding and information about local hydrological and coastal processes and likely impacts. This is particularly relevant given the rate at which new knowledge regarding climate change and potential impacts on rainfall patterns and coastal forces has been developed over the past few years, and the potential impacts that this will have on community expectations.

These observations highlight the need for ongoing monitoring and review to continuously refine the assessment of risks, consider new information and observations, and to reflect changing needs and aspirations of society. It is therefore necessary that the risk assessment and outcomes reflected in this stormwater and flood management plan are reviewed every 5 to 10 years.

Table 12: Risk assessment for Roebourne stormwater and flood management

Objective	Risk ID		Likelihood	Consequence	Risk	Proposed Action / Control	Likelihood	Consequence	Risk
Environmental Protection	1	Damage to downstream environments caused by sediment transport	D	3	HIGH	Design future drainage systems to manage sediment transport and address existing issues through review and targeted intervention.	D	2	MODERATE
	2	Modification of environmental flows to water dependant ecosystems	E	4	VERY HIGH	Design future drainage systems to manage environmental flows and protect water dependant ecosystems. Targeted intervention to restore environmental flows or manage transition of ecosystems currently under stress from existing drainage.	D	2	MODERATE
	3	Erosion in natural systems.	E	3	VERY HIGH	Design drainage systems to protect downstream ecosystems by dissipating energy prior to discharge.	D	2	MODERATE
Protect private and public infrastructure	4	Acute damage from storm events	E	4	VERY HIGH	Isolation of stormwater and/or structural controls to be implemented to protect infrastructure and property from acute damage from events up to 1% AEP (100-year ARI). Emergency planning to address possibility of failure in larger events.	C	3	MODERATE
	5	Incremental damage from storm events.	D	3	HIGH	Design of infrastructure to limit incremental damage and maintenance programs established to maintain drainage functions for potentially affected infrastructure.	C	1	LOW
	6	Damage from inundation.	E	4	VERY HIGH	Set development controls to limit the potential for flooding in accordance with the recommendations of Austroads. Local Emergency Management plans should address flood risk for existing developments.	C	2	MODERATE
Manage public safety	7	Injury from interaction with drainage infrastructure and floodway's	C	5	VERY HIGH	Where possible provide structural controls to contain frequent events and reduce interaction between the public and drainage infrastructure. Manage flow velocities to limit risk of injury. Incorporate community education into Emergency Management Plans to further reduce likelihood.	A	5	MODERATE
	8	Public safety in overland flow paths	C	4	HIGH	Where possible limit flow velocities in overland flow paths to limit risk of injury. Local Emergency management plans to educate community regarding risks of overland flow.	B	3	MODERATE
	9	Health and safety impact from inundation	E	3	VERY HIGH	Set development controls to limit the potential for flooding in accordance with the recommendations of Austroads. Local Emergency Management plans should address flood risk for existing developments.	C	2	MODERATE
Provide social amenity	10	Nuisance from overland flow	D	1	MODERATE	Identify the alignment and capacity of overland flow paths and look for opportunities to reduce impacts. Education of community regarding residual risk to facilitate acceptance of consequences.	C	1	LOW
	11	Poor social outcomes from design of drainage and waterways	D	3	HIGH	Where possible incorporate drainage infrastructure as part of complimentary landuses (POS or Road Reserves).	B	1	LOW
	12	Compromised serviceability of roads and public space	E	2	HIGH	Design of drainage in public spaces should maintain the level of serviceability which is expected by the community. Local Emergency Management plans should identify contingency actions and educate the community to minimise consequences.	C	1	LOW

Table 13: Assessments of Likelihood and Consequence

Risk ID	Prior to implementation of control / action		After implementation of control / action	
	Initial Likelihood	Initial Consequence	Final Likelihood	Final Consequence
1	Likely (D) - In the absence of sediment control, the urban area will generate sediment discharge in all rainfall events environmental damage is only expected from repeat occurrences.	Moderate (3) - Likely to cause harmful impacts to local ecosystems at multiple sites, potential minor increase in flood risk causing a minor impact to private properties.	Likely (D) - With sediment controls and monitoring in place sediment transport is likely to occur only in less frequent rainfall events. Notwithstanding, large events that periodically occur will still mobilise sediment.	Minor (2) - with lower frequency of occurrence and ongoing maintenance, sediment transport can be naturally assimilated but may require site specific interventions.
2	Almost Certain (E) - In the absence of consideration in design and intervention for existing issues, development will alter environmental flows to downstream ecosystems.	Major (4) - Long term, irreversible damage to local ecosystems.	Likely (D) - Drainage systems designed to maintain environmental flows will significantly reduce the likelihood of damage to local ecosystems.	Minor (2) - when damage does occur it is likely to be as a result of infrastructure failure and affecting a specific site, requiring minor intervention.
3	Almost Certain (E) - In the absence of consideration in design and intervention for existing issues, erosive velocities will occur frequently during most rainfall events.	Moderate (3) - Likely to cause harmful impacts to local ecosystems at multiple sites, site specific interventions required.	Likely (D) - Following consideration in design and intervention for existing issues, erosive velocities will occur periodically during rainfall events which exceed the probabilities considered in design.	Minor (2) - when damage does occur it is likely to be at a specific site, requiring minor intervention.
4	Almost Certain (E) - Without adequate protection or controls for development and intervention for existing issues, acute damage to infrastructure should be expected to occur periodically during large rainfall events.	Major (4) - Major impact to private properties or infrastructure. Permanent treatments required to protect infrastructure.	Possible (C) - The likelihood of acute damage is reduced significantly with events larger than the 1% AEP still presenting the risk of acute damage.	Moderate (3) - Reduced impact to private properties or infrastructure because flood is managed and implications of exceedance are understood. Permanent treatments required to protect infrastructure.
5	Likely (D) - Likely that incremental damage will occur without consideration in design and maintenance. History of casual occurrence at some sites.	Moderate (3) - in the event that incremental damage causes low performance or failure of drainage infrastructure is likely to be moderate impacts that require temporary treatments.	Possible (C) - The likelihood of incremental damage is reduced through design of infrastructure and maintenance programs.	Insignificant (1) - incremental damage is addressed through minor treatments to infrastructure before more significant impacts are realised.
6	Almost Certain (E) - In the absence of development control, inundation of infrastructure allowed to be constructed in low lying areas will occur periodically as a result of large rainfall events. Damage is likely to occur unless infrastructure is designed to withstand this inundation.	Major (4) - failure of essential services and/or emergency services as a result of inundation would have major impact on services for a small population. Moderate impacts also exist from damage caused by inundation of individual properties.	Possible (C) - The probability of inundation is understood and likelihood of inundation is reduced to those events which exceed the design flood immunity (eg: 1% AEP for residential). Likelihood of damage is reduced to an appropriate level through design of infrastructure to withstand inundation.	Minor (2) - Consequence of damage from inundation is likely to be temporary and isolated in nature; reduced through design and contingency actions identified in the Local Emergency Management Plan.
7	Unlikely (B) - Without appropriate controls it is possible although unlikely that a member of the public could be injured through trying to cross a floodway or otherwise interact with drainage infrastructure within the townsite.	Catastrophic (5) - Possible permanent injury or fatality.	Rare (A) - Likelihood of the event is significantly reduced through management of frequent events, identification of specific risks and education of community.	Catastrophic (5) - Consequence remains the same: possible permanent injury or fatality.
8	Possible (C) - The perceived risk of injury in overland flow paths will be less than for major drainage infrastructure, which increases the probability that an injury will occur.	Major (4) - significant injury to an individual with first aid treatment or possible hospitalisation.	Unlikely (B) - Reduced likelihood of dangerous overland flow and increased community awareness will reduce likelihood.	Moderate (3) - minor injury to an individual with first aid treatment or possible hospitalisation.
9	Almost Certain (E) - In the absence of development control, inundation of property and infrastructure allowed to be constructed in low lying areas will occur periodically as a result of large rainfall events. Health and safety of the community is likely to be impacted unless infrastructure is designed to withstand this inundation.	Moderate (3) - Failure of essential services and damage to personal belongings as a result of inundation would have moderate impact on the health and safety for a small population that could require medical treatment.	Possible (C) - The probability of inundation is understood and likelihood of inundation is reduced to those events which exceed the design flood immunity (eg: 1% AEP for residential). Likelihood of failure of infrastructure is reduced to an appropriate level through design of infrastructure and/or management actions to withstand inundation.	Minor (2) - Consequences are reduced because the impact is reduced to specific individuals rather than a small population. Possible health impacts to individuals could require medical treatment.

Risk ID	Prior to implementation of control / action		After implementation of control / action	
	Initial Likelihood	Initial Consequence	Final Likelihood	Final Consequence
10	Likely (D) - Poorly managed overland flow paths are likely to be considered a nuisance by the community. nuisance will be most obvious during significant rainfall events.	Insignificant (1) - Temporary treatments are required to maintain / restore amenity.	Possible (C) - increased serviceability and understanding from community will reduce the likelihood of impacts and manage expectations.	Insignificant (1) - Temporary treatments are required to maintain / restore amenity.
11	Likely (D) - Historically drainage corridors have been excluded from public access presenting opportunities for poor social outcomes and missed opportunities for urban amenity.	Moderate (3) - moderate, ongoing impact to properties adjacent to traditional drainage reserves. Possible permanent treatments required to improve amenity and protect property.	Unlikely (B) - Reduced likelihood of poor outcomes through improved urban design.	Insignificant (1) - Temporary treatments may be required to maintain / restore amenity.
12	Almost Certain (E) - In the absence of appropriate structural controls and contingency planning impacts of stormwater on the serviceability of public infrastructure will occur periodically as a result of all rainfall events.	Minor (2) - minor, temporary impact on services for small population, isolated treatments required to maintain services.	Possible (C) - Drainage systems designed to provide the expected level of serviceability are likely to be exceeded in infrequent events, which may or may not compromise serviceability.	Insignificant (1) - Contingency planning will reduce the consequence of temporary impacts.

8 STORMWATER & FLOOD MANAGEMENT STRATEGY

The discussion of environmental factors, surface water modelling and qualitative risk assessment presented in this Plan provide a basis for developing management strategies for the study area.

The following section outlines key recommendations which together form the proposed strategy for surface water management in the study area. Key components of the strategy are illustrated in Figure 23.

The analysis contained in this report provides a site specific risk assessment in regards to coastal hazards and other flood risks in the Local Structure Plan area. It is considered that this assessment provides a coastal hazard risk assessment as intended by the draft SPP2.6 and that the outcomes are not inconsistent with the provisions under section 7.5 of TPS 8.

8.1 Principles

The following principles have been adapted from the general floodplain management principles advocated by the Department of Water and presented in SCARM73 as well as policy measures from the currently gazetted edition of *State planning policy no. 2.6: State coastal planning policy* (WAPC 2006).

- property impacts of existing flooding problems are managed to acceptable levels
- proposed development has adequate 100 year ARI flood protection
- proposed development does not detrimentally impact on the existing 100 year ARI flooding regime of the general area
- the form and pattern of proposed development considers the likely impacts of flooding, coastal forces and sea level rise
- the impacts of existing flooding problems on the well-being of individuals are managed to acceptable levels
- the natural function of floodplains to convey flood waters and/or sustain flood dependent ecosystems is preserved, and enhanced where possible
- planning and use of floodplains as a resource for the whole community is encouraged
- likely impacts of coastal forces and sea level rise are understood and managed to acceptable levels

These principles have guided selection of management strategies and should be used to guide future decision making in the area.

8.2 Land use planning

Land use planning and development controls are the primary mechanism for flood and stormwater management. Appropriate planning controls, consistent with the land use planning strategies listed below, should be reflected in structure planning outcomes and included future amendments to the town planning scheme.

Harding River floodway and flood fringe and storm surge inundation mapping is provided in Figure 23 based on modelling undertaken in this study and with consideration of the risk assessment presented in in section 7 of this report. The following land use planning strategies apply in respect of flooding from the Harding River and storm surge:

- No new development is to occur within defined floodways.
- No expansion of the footprint of existing development within defined floodways is to occur.
- Redevelopment of existing buildings within the floodway may be acceptable provided there is no increase to the level of obstruction and the proposed building is given adequate protection from the 100 year ARI event flood (inundation and erosive forces)
- Existing undeveloped lots which are currently zoned to allow development but are located within floodways should be rezoned and/or otherwise addressed through planning controls.
- Development outside floodways in areas identified as being at risk of inundation from the 100 year ARI flood event and/or storm surge event are to comply with relevant building and development controls presented in section 9.3.
- The Shire of Roebourne can consider alternative development requirements for non-habitable commercial or industrial developments located in floodplains on a case by case basis where the risk of flooding is an acceptable business risk to the proponent and future occupants.

Hydraulic stormwater modelling of the Roebourne townsite has identified overland drainage flow paths which should be similarly protected through land use planning and development controls. The following strategies apply in respect of defined overland flow paths:

- No development is to occur within defined overland flow paths
- Existing buildings within or adjacent to defined overland flow paths should be relocated or provided with suitable structural protection from inundation
- Existing undeveloped land which is zoned to allow development and located within defined overland flow paths should be reserved for drainage
- Development in areas adjacent to defined overland flow paths are to comply with relevant building and development controls presented in section 9.3

8.3 Development and building controls

New developments will be required to consider the implications of flooding from the Harding River, stormwater inundation and storm surge incorporating an allowance of sea level rise.

It is the proponent's responsibility to undertake the necessary reviews, assessments and modelling to demonstrate, to the satisfaction of the Shire of Roebourne and Department of Water, that the proposed development is consistent with the following floodplain management strategies:

- Development in areas identified as being at risk of inundation from the 100 year ARI flood event that are outside the floodway are to be provided with a minimum 0.5 m clearance between finished floor levels of habitable rooms and the modelled 100 year ARI event flood level
- Development in areas identified as being at risk of inundation from the 100 ARI year storm surge event, including allowance for sea level rise (currently 8.1m AHD) are to be provided with a minimum 0.5 m clearance between finished floor levels of habitable rooms to this storm surge level
- Development in areas adjacent to and/or potentially affected by flooding in defined overland flow paths or stormwater drainage infrastructure are to be provided with a minimum 300 mm clearance from the 100 year ARI flood level in the adjacent overland flow paths or infrastructure.

- Suitable emergency access and evacuation routes that are trafficable in the 100 year ARI flood and/or storm surge event are to be defined by the proponent.
- Design of future drainage systems will be such that:
  - the quantity and distribution of environmental flows are maintained
  - sediment transport and potential erosion during major storm events is managed
  - downstream peak-flow rates and levels for the critical 100 year ARI events are not increased
  - maximum flow velocities in open channels do not exceed 2 m/s
- Design of developments will ensure:
  - the 5 year ARI flood is contained below kerb height
  - the habitable floor level of residential dwellings have a minimum of 300 mm clearance above the kerb height

8.4 Structural measures

Key capacity constraints and existing flood management issues have been identified in section 6.2.3 and Figure 18 and Figure 19. Capital works are to reduce the frequency of inundation and severity of flood hazard to those areas. The following structural measures are recommended to manage the risks associated with these site specific issues and constraints:

- Consider drainage infrastructure improvements to provide more efficient conveyance of flood waters away from residential areas to more suitable downstream locations for management. Improvements may include:
  - establishment of new drainage reserves connecting residential streets in the vicinity of Crawford Way and Andover Street to Lockyer Way reserve
  - upgrade of undersized culverts passing Roe Street
  - provision of formalised flow paths from the western edge of NASH development
  - upgrades to Cleaverville road drainage system
  - formal recognition and management of informal flow paths
  - provision of new culverts limiting passage of storm flows over roads to major events only
  - provision of improved flood protection for the power substation site
  - upgrades to drainage adjacent to Fraser Street
- Undertake assessment of ecosystems potentially affected by existing drainage and undertake targeted interventions restore environmental flows improve sediment management and manage existing or potential erosion

In addition, the Shire of Roebourne in undertaking its role in management and maintenance of drainage infrastructure should:

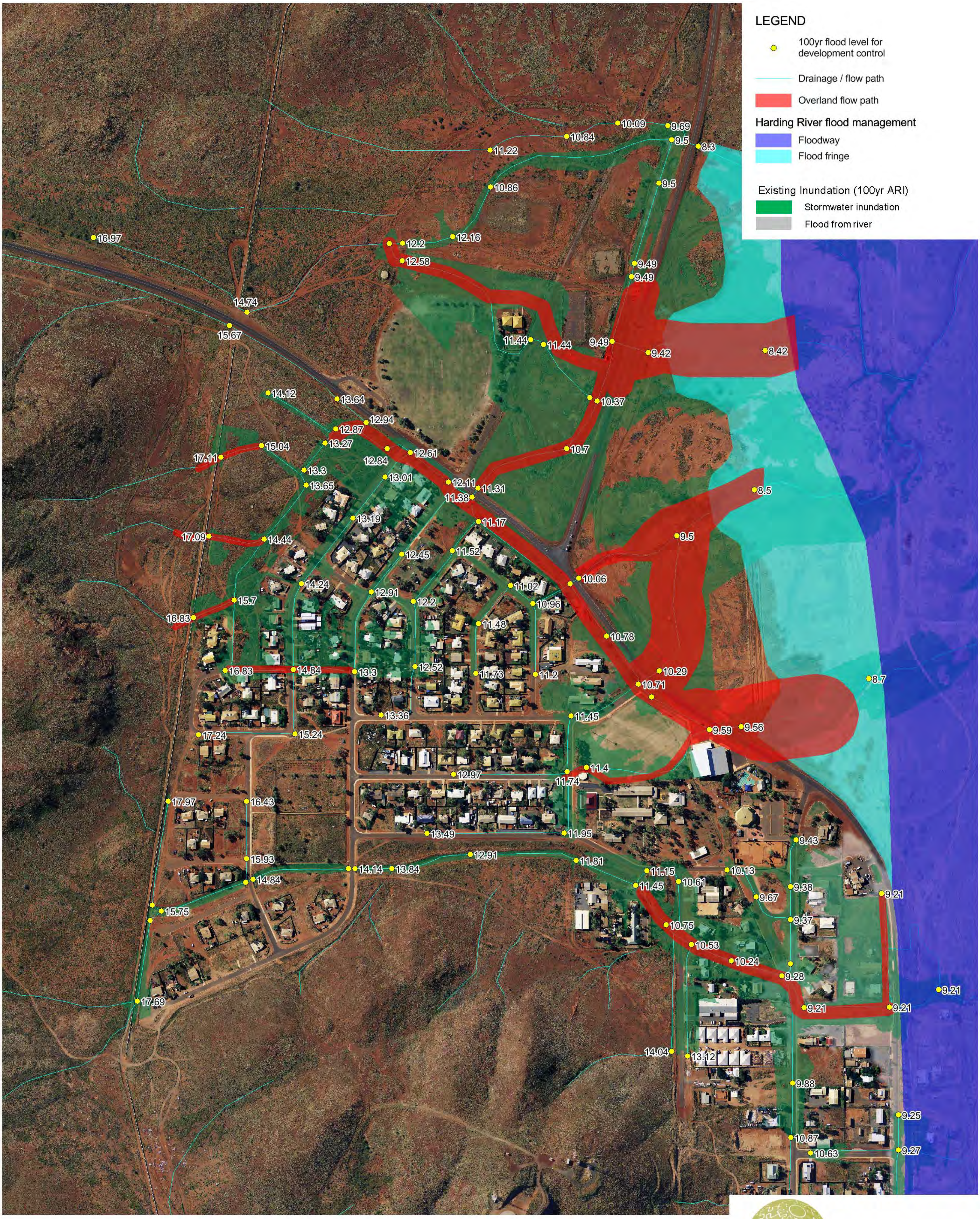
- Undertake annual inspections of drainage systems prior to the cyclone system and following significant storm events and will:
  - remove weeds and sediment build up from culverts and other hydraulic control points
  - remove major obstructions from drains and overland flow paths
  - reinforce floodways and other drainage infrastructure as necessary to manage incremental wear and tear and prevent major failure.

8.5 Flood emergency plan

Emergency planning for the Roebourne townsite is required to adequately manage the risks that are presented by flooding and stormwater drainage. Emergency Management Plans should be developed and/or refined in collaboration with state emergency services to address risks identified in this study. As a minimum it is recommended that emergency planning includes:

- definition of emergency evacuation assembly points and safe zones with 2 m clearance above the 100 year ARI flood and estimated storm surge level, incorporating sea-level rise.
- identification of roads that remain trafficable in the 100 year ARI flood and/or storm surge event, incorporating sea-level rise, that can function as emergency access and/or evacuation routes
- provision of community education programs and signage that identify suitable emergency procedures and safe access/evacuation routes as well as clearly identifying key risks and 'no go areas'

Roebourne, Stormwater and Flood Management Plan
Figure 23 - Surface Water Management Strategy, Map 1



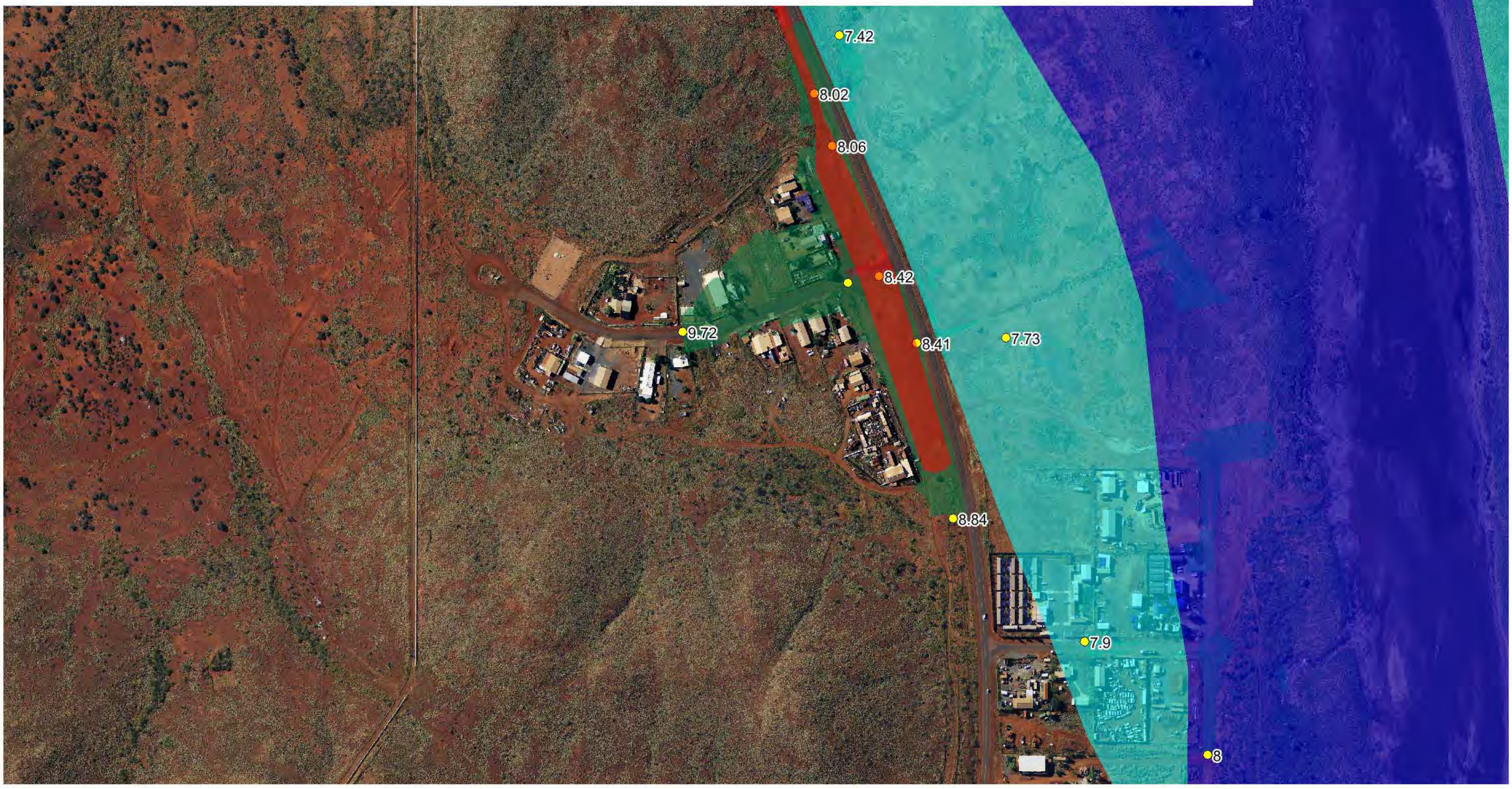
Datasource: Shire of Roebourne,
Created by: K Norris. Projection: MGA50: zone 50.

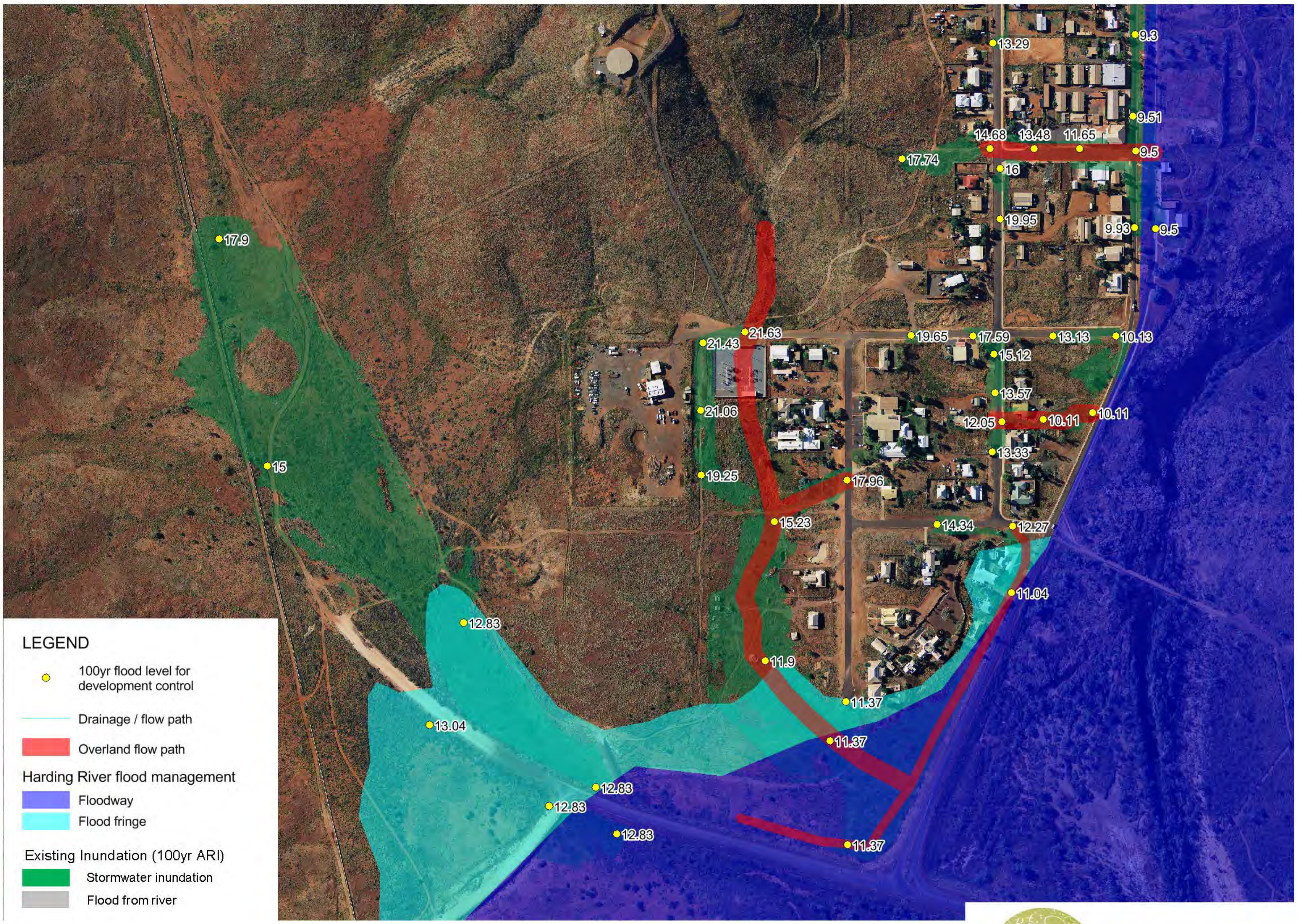
N

Scale 1: 5000 at A3
0 200m

essential environmental

Roebourne, Stormwater and Flood Management Plan
Figure 24 - Surface Water Management Strategy, Map 2





Datasource: Shire of Roebourne,
Created by: K Norris. Projection: MGA50:zone 50.

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Scale 1: 5000 at A3

0 200m

essential environmental

9 FUTURE DEVELOPMENT

The draft structure plan concept for the Roebourne town site identifies development and redevelopment of key areas to improve the sustainability of the town. From the hydraulic modelling of adjacent drainage, key constraints to development of these areas can be identified as follows.

NASH development

Proposed commercial development Cleaverland Road and Point Samson Roebourne Road will need to be designed to consider management of existing drainage through the site and inundation resulting from capacity of the adjacent floodway.

The peak water 100-year ARI water level at this location (10.7 m AHD) should be considered in the context of impacts to future users at the site and used to inform building design and development controls. Development proposals for this site will need to demonstrate how existing overland flow paths from the south and from the existing oval site are to be managed.

The undeveloped portion of the NASH development receives overland flow from the north and west, which will need to be carefully managed in design of the subdivision and development.

Northern community hub

Access to the community hub during a large storm event may be limited by the passage of flood water over Sholl Street and Roe Street (to the south) and Cleaverland Road to the north.

Assessment of inundation risk and design of infrastructure in this area will need to consider flooding from riverine flooding, arterial drainage and local drainage capacity.

The peak water 100-year ARI water level in the stormwater flow path immediately north is estimated to be 9.6 m AHD.

Business hub redevelopment

Water from the upstream slope of Mount Welcome currently flows overland along Padbury Street and across Roe Street before discharging to the Harding River. Existing and future development on adjacent properties will need to consider management of inundation and safety risk associated with this flow path. The estimated peak stormwater flow rate on Padbury Street, at 2.8 m^3/s, is unlikely to be contained within the kerbs of the road, flowing at an estimated depth of 0.25 m and velocity of 1.7 m/s. The hazard at this location should be considered “extreme” in accordance with SCARM73 and must be managed accordingly.

Existing and future development on the eastern side of Roe Street should be considered in the context of predicted riverine flooding, the hazard assessment and risk tolerance outlined in section 7. On this basis it is recommended that development or redevelopment of private infrastructure in this area is not permitted.

Southern development zone

The future urban expansion on the south side of Mount Welcome will need to be designed in such a way as to manage drainage from local catchment runoff and the arterial drainage route from this area through to the Harding River.

Existing flood levels should inform the conceptual design of future subdivision and development layout. The proponent of the development will need to demonstrate an understanding of future flood levels throughout the development.

It is considered that establishing a link road around the southern and western side of the mountain will provide an important access that can be used in the case of an emergency movement of residents. Consideration should be given to establishing the alignment for this road along the higher edge of the development and providing a connection to North Coastal Highway.

<u>Industrial expansion</u>

The future industrial expansion west of the current industrial area will need to be designed in such a way as to manage drainage from local catchment runoff.

Drainage capacity and flood risk in this area is potentially affected by the passage of floodwater from the river tributary located immediately north of the development area and the hydraulic capacity of the flood crossing of this tributary over Point Samson Roebourne Road. Flood and stormwater management for development in this area will need to be considered in the context of the additional surface water analysis and relevant strategies outlined in section 8.

<u>Eastern development precinct</u>

The existing caravan park and any future development of adjacent land is at significant risk of inundation and damage as a result of riverine flooding. Aside from the inherent risk to safety and of damage to property, potential consequences from flooding of the Harding River are further increased by the separation of this land on all sides and possible total isolation during overtopping or failure of the North West Coastal Highway bridge.

It is recommended that landuse planning controls are implemented to ensure that no further development of this land is permitted.

Further, opportunities to relocate existing landuses in this area should be explored.

Emergency Management Planning should identify specific actions to facilitate safe evacuation for occupants of the existing development in this area.

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Client: Shire of Roebourne

Report	Version	Prepared by	Reviewed by	Submitted to Client	
				Copies	Date
Draft report	V1	KN	SSh	Electronic	11 December 2012
Final report	V2	KN	SSh	Electronic	18 February 2013

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