# IDENTIFICATION OF HIGHWAYS

# AND MAIN ROADS THAT MAY BE AT RISK

# DUE TO A RISE IN SEA LEVEL

**November 2011**


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# Contents

**IDENTIFICATION OF ROADS THAT MAY BE AT RISK DUE TO A RISE IN SEA LEVEL**

**(including a list of sections warranting early attention)**

## 1. THE PROJECT

This Report **considers two scenarios of sea level rise** and the potential implications that such events may have on our coastal road infrastructure. **A rise of 1 metre** is now generally accepted in various scientific papers as being a possibility by the year 2100. (Note that in September 2010 the WA Planning Commission updated the sea level rise value for use in coastal planning to 0.9m by the Year 2100).

Whilst necessary to understand, research relating to the Year 2100 is too far in the future to base today's decisions upon because so much will change in the meantime, (ie the science itself; new datasets; as well as public and political attitudes). Main Roads has determined that in the interim, the assessment of future road infrastructure solutions will include a site-specific assessment of the implications of a 300mm sea level rise. Current science suggests that this quantum of sea level rise is possible within our current planning and road design horizons – ie within the next 20 to 30 years. (See Main Roads technical website).

Accordingly, discussion in this Report includes a **300mm sea level rise scenario** and, together with the 1 metre scenario, relates to all roads that are managed by Main Roads and which may be affected.

At this stage storm surge has not been taken into account as part of the desktop and subsequent field analyses. Considerable research will be required before there is a useful understanding of the potential effect that climate change will have on the consequential and compounding affect of storm surge along specific coastal areas.

The local aerial photos and associated Maps throughout this Report draw attention to those road segments with the potential to be inundated under the scenarios presented herein.

In order to develop a prioritized list of those road sections warranting early attention, road-related data was downloaded from IRIS. Consideration was given to a range of factors including road usage (traffic volumes), the proportion of heavy vehicles, pavement age, roughness, network importance and whether adverse affects are likely to be felt within the next 20 to 30 years.

A brief discussion on the science of climate change is provided in Section 2 and the methodology is described in detail in Section 3. The considerable input from regional staff is very much appreciated and has served to confirm or clarify the initial desktop indications in relation to specific sites.

Section 4 describes the system of priority ranking used to determine those verified sections that warrant more urgent assessment. Section 5 includes an adjusted list of roads that reflect the results of field verification. The final table lists those road sections with the highest priority.

It is envisaged that other state and local government agencies will be interested to peruse this Report as they consider the risks of future sea level rise in relation to their coastal infrastructure.

The Report reaches the following conclusions.

Based on a scenario of a **300mm rise in sea level** – a possibility by the Year 2031 - the total length of highways and state roads at potential risk is approximately **121 km**.

Based on a scenario of a **1 metre rise in sea level** – a possibility by the Year 2100 - the length of highways and state roads at potential risk is about **166 km**.

Of those road sections that have been identified, 52.75 km have been assessed as warranting early, more detailed, evaluation.  Those sections comprise:

| | **Road Name** | **SLK from** | **To SLK** | **Length** | **Description** |
|---|---|---|---|---|---|
| | | | | | |
| **Kimberley** | Great Northern Highway | 3185.23 | 3195 | 9.77 | Wyndham port area |
| | Broome Highway | 25.44 | 31.7 | 6.24 | Nth Broome |
| | Broome Highway | 37.9 | 40.6 | 2.7 | Port environs |
| | | | | | |
| **Pilbara** | Great Northern Highway | 1600 | 1615 | 15 | Pt Hedland T/O |
| | Dampier Road | 18.89 | 22.79 | 3.9 | Dampier Salt |
| | Pt Samson – Roebourne Road | 16.41 | 17.12 | 0.71 | Harding River |
| | | | | | |
| **South West** | Pinjarra Road | 4.02 | 4.91 | 0.89 | West of Forrest Hwy |
| | Pinjarra Road | 8.73 | 9.59 | 0.86 | West of Forrest Hwy |
| | Lakelands – Lake Clifton Road | 10.51 | 11.29 | 0.78 | Harvey Estuary |
| | | | | | |
| **Perth CBD** | Kwinana Freeway (L) | 0.6 | 4.89 | 4.2 | Perth CBD |
| | Kwinana Freeway (R) | 0.6 | 7.5 | 6.9 | Perth CBD |
| | Mounts Bay Road | 0.06 | 0.56 | 0.5 | Perth CBD |
| | Hay St (Causeway to the west) | 0 | 0.3 | 0.3 | Perth CBD |
| | | | | | |
| | | | | **52.75km** | |

## 2. BACKGROUND

In 2007, the Intergovernmental Panel on Climate Change (IPCC) concluded that:

*"Warming of the climate system is unequivocal, as now evident from observations in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level".*

The international panel examined the rise in $CO_2$ and other Greenhouse Gases (GHG) and developed a range of future climate-related scenarios. The scenarios were based on the belief that some changes are already "in the system" and will run their course regardless of what we decide to do today.

The next few decades are anticipated to reflect high emission scenarios before, hopefully, a number of effective global emission reductions 'kick-in', bringing some form of stabilisation later in the century. Over the first half of this century, the scientific opinion is that the rate of change can be expected to reflect the higher emission scenarios.

Figure 1 shows the IPCC projections of global surface warming for a range of representative scenarios. The A2 scenario is associated with a fragmented and relatively weak international response, whereas B1 represents a highly effective global response aimed at stabilising emissions. Shading denotes the plus/minus one standard deviation. The orange line is for the scenario in which GHG concentrations are held constant at year 2000 values.

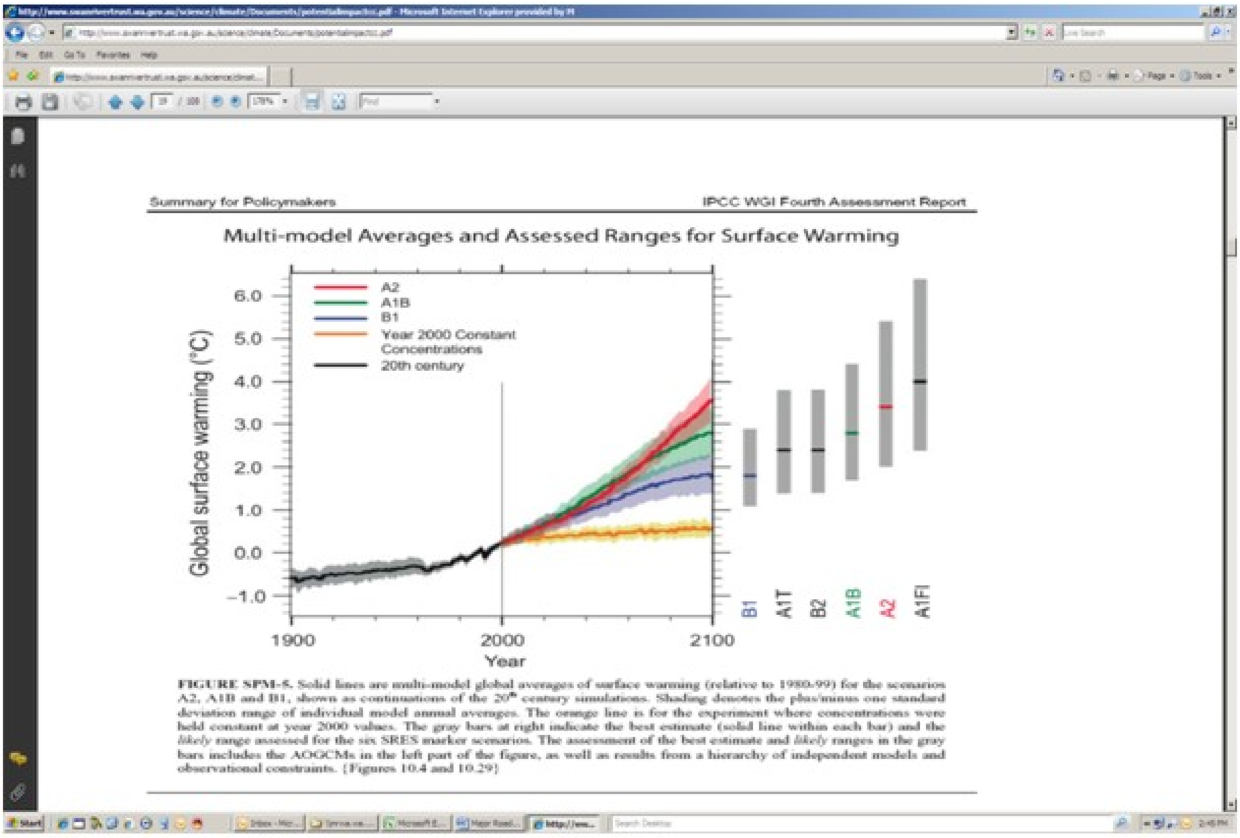



**Figure 1**

It is interesting to note that this graph has been revisited a number of times since it was first published, and the more recent measurements show that the current global trend since 2000 is at, or even worse than, the most pessimistic of these scenarios.

The ocean acts as a sink for captured heat from the atmosphere and water from the melting of glaciers and ice caps. Thermal expansion and physical movement, together with the break-up of glaciers and ice caps, drive sea level rise. The rise in sea level will in turn affect transport and other infrastructure in coastal areas with a consequential increased risk of inundation, wave overtopping and associated flooding. The Report “Climate Change Risks to Australia’s Coast” (2009) suggests that between 18,700 and 28,900 residential buildings in Western Australia will be at risk by the end of the century.

The increasing frequency and severity of extreme climate events impacting on transport infrastructure and systems also has the potential to produce a corresponding increase in the risk of accidents involving property damage, injuries and fatalities. This would in turn increase the potential liability and insurance costs to transport authorities, managers, operators and owners. (Garnaut 2008).

As a starting point it is necessary to complete an inventory of key infrastructure to determine whether and where projected local climate changes might be consequential. Taking measures now to evaluate and protect the most vulnerable transportation infrastructure will pay off by diminishing maintenance expenditure and reducing the risk of catastrophic failure. Measures might include strengthening or elevating some coastal roads, railways and bridges - particularly those that serve as sole access routes for communities. Alternatively, where that infrastructure is nearing the end of its economic life, a local realignment onto higher ground may provide a sufficient safeguard into the future. The interface with ports and associated infrastructure will also require close collaboration with other agencies, with the potential to work jointly towards comprehensive solutions that best meet desired environmental, social and economic outcomes.

This Report lists road sections (for which Main Roads is responsible) that are at risk from either of the two scenarios of sea level rise described above. In addition a number of factors have been assessed in order to prioritise sections and thereby identify which of those warrant early attention in the form of more detailed and site-specific evaluation.

Our network managers, and strategic and project planners, will need to apply more extensive probabilistic investment analyses and design approaches, in order to trade off the costs of making the infrastructure more robust versus the economic costs of disruption or failure.

# 3. METHODOLOGY

## 3.1 Tides

Tidal information has been obtained from the National Tide Centre (Bureau of Meteorology) and is sourced from various tidal stations along the WA coast (**Appendix A**). The generally accepted definition of tidal variations is contained in a US publication by Marnier as follows.

"A period of 19 years is generally considered as constituting a full tidal cycle, for during this time the more important of the tidal variations will have gone through complete cycles. It is therefore customary to regard results derived from 19 years of tide observations as constituting mean values. Hence sea level derived from 19 years of observations may be taken to constitute a primary determination and as giving accurately the datum of mean sea level."

**Marnier, H. A., 1951. Tidal Datum Planes, Special Publication No. 135, Revised (1951) Edition, U.S. Dept of Commerce, Coast and Geodetic Survey, Washington.**

The Highest Astronomical Tide (**Appendix B**) has been adopted as the base, with one metre (or 300mm) added to allow for the future sea level rise scenarios. The published values in the Tide Tables are the HATs (under average meteorological conditions) that occur during a nineteen year epoch. Coastal tides between the tidal stations have been interpolated to enable the most likely areas of inundation to be identified.

## 3.2 Terrain Surface

In the Metropolitan area existing mapping or detailed survey information (e.g. LIDAR) has been used as the base data. This information however does not cover areas outside the Metropolitan area and so Digital Elevation Models (DEMs) were used to create contours based on the projected sea level height. Because the accuracy of these DEMs vary, the results of the projected inundation should only be used as an indication of areas that may be affected.

Where bridges exist within the predicted flooding area the length of the bridge has been included in the SLK limits. It should be noted that bridge structures are normally constructed higher than the approach road and it is therefore less likely that the structure itself would be inundated.

## 3.3 Effect of Cyclone Alby on sea level

Although this Report does not consider possible storm surge effects, it is necessary to place some perspective on the rising sea levels discussed herein.

As a result of Cyclone Alby in April 1978 …. "large waves and a storm surge generated by the northerly winds caused substantial coastal erosion along the Lower West coast particularly in the Geographe Bay area. Low-lying areas at Bunbury and Busselton were flooded, forcing the evacuation of many homes including the Bunbury Nursing Home. An approximate 1.1 m storm surge at Busselton caused the tide to peak at 2.5m, about 1m above the highest astronomical tide. The Busselton Jetty was severely damaged.

At Fremantle the surge was about 0.6m causing a high tide of 1.8 m, about 0.5m above the highest astronomical tide. While this was not sufficient to cause flooding in Perth it did combine with large waves to scour beaches. A large number of small boating craft were damaged."

This record confirms that a sea level rise of the order of that being considered in the two scenarios is not excessive. For further details about this storm event refer to the Bureau of Meteorology website www.bom.gov.au/wa/cyclone/about/perth/alby.shtml

A list of useful reference material can be found in **Appendix C**.

## 3.4 Affected Highways and Main Roads

A subset of the IRIS road centreline was created for roads that are within 4km of the WA coast, and generated contours were then used to identify where inundation might occur. Due to the difficulty in isolating parts of the DEM, some maps may show isolated areas of inundation even though there is no path or channel for the sea to reach the area. (For an example of this refer to Map D.23 – top of page 67). Additional road sections that showed possible flooding but were less than 200m in length have not been included due to the limited accuracy of the DEMs.

Table 1 shows a network summary (by Region) of road sections that may be impacted by either the 300mm or 1m sea level rise scenarios. It is based on the desktop analysis alone.

**Table 1 - Length of Main Roads' road infrastructure at possible risk due to sea level rise**

**Initial desktop assessment**

| | Road length (km) affected by: | | Overall Road Length | | | Proportion of road length affected by: | |
|---|---|---|---|---|---|---|---|
| | 0.3m rise | 1m rise | Auslink | State | Total | 0.3m rise | 1m rise |
| **Kimberley** | 74.97 | 76.98 | 1317 | 792 | 2109 | 3.6% | 3.7% |
| **Pilbara** | 62.29 | 65.95 | 756 | 1431 | 2187 | 2.8% | 3.0% |
| **Gascoyne** | 3.8 | 10.46 | 0 | 1588 | 1588 | 0.2% | 0.7% |
| **Mid West** | 21.18 | 29.35 | 840 | 1377 | 2217 | 1.0% | 1.3% |
| **South West** | 11.96 | 21.34 | 115 | 1469 | 1584 | 0.8% | 1.3% |
| **Gt Southern** | 1 | 1.96 | 0 | 1570 | 1570 | 0.1% | 0.1% |
| **Metro** | 18.09 | 20.99 | 204 | 600 | 804 | 2.2% | 2.6% |
| Goldfields / Esperance | 0 | 0 | 1071 | 1267 | 2338 | | |
| WBS | 0 | 0 | 0 | 1598 | 1598 | | |
| WBN | 0 | 0 | 590 | 1263 | 1853 | | |
| **Totals** | **193.287** | **227.03** | **4893** | **12955** | **17848** | **1.08%** | **1.27%** |

The following locations and lengths were developed from the desktop exercise and were used to provide regional personnel with a guide for their own assessment and site verification. The last column refers to **Appendix D** where comprehensive maps and aerial photos for each site can been found.

### 3.4.1 KIMBERLEY

| ROAD NUMBER | ROAD NAME | SLK FROM | SLK TO | Highest Astronomical Tide | LENGTH OF ROAD IMPACTED BY | | PAGE NUMBER |
|---|---|---|---|---|---|---|---|
| | | | | | 0.3M RISE | 1M RISE | |
| H006 | Great Northern Highway | 1941.06 | 1944.43 | 10.51 | 3 | 3.37 | 61 |
| H006 | Great Northern Highway | 2138 | 2153 | 11.46 | 15 | 15 | 62 |
| H006 | Great Northern Highway | 2258.61 | 2270.98 | 11.79 | 12 | 12.37 | 63 |
| H006 | Great Northern Highway | 3174.17 | 3178.10 | 9.67 | 3.7 | 3.93 | 64 |
| H006 | Great Northern Highway | 3178.81 | 3183.68 | 9.68 | 4.87 | 4.87 | 64 |
| H006 | Great Northern Highway | 3185.23 | 3195 | 9.69 | 9.77 | 9.77 | 64 |
| H042 | Broome Highway | 25.44 | 31.7 | 11.56 | 6 | 6.24 | 47 |
| H042 | Broome Highway | 34.34 | 35.59 | 11.56 | 1.25 | 1.25 | 47 |
| H042 | Broome Highway | 37.9 | 40.6 | 11.56 | 2.2 | 2.7 | 47 |
| H047 | Derby Highway | 27.4 | 31.9 | 11.82 | 4.5 | 4.5 | 57 |
| H047 | Derby Highway | 32.33 | 33.75 | 11.83 | 1.42 | 1.42 | 57 |
| H047 | Derby Highway | 34.0 | 37.1 | 11.83 | 2.9 | 3.1 | 57 |
| H047 | Derby Highway | 41.24 | 42.86 | 11.83 | 1.62 | 1.62 | 58 |
| M012 | Derby Gibb River Road | 0 | 1.38 | 11.83 | 1.28 | 1.38 | 55 |
| M012 | Derby Gibb River Road | 5 | 10 | 11.83 | 5 | 5 | 55 |
| M012 | Derby Gibb River Road | 585.35 | 585.81 | 9.57 | 0.46 | 0.46 | 56 |
| | Total of individual elements: | | | | 74.97 | 76.98 | |

### 3.4.2 PILBARA

| ROAD NUMBER | ROAD NAME | SLK FROM | SLK TO | Highest Astronomical Tide | LENGTH OF ROAD IMPACTED BY | | PAGE NUMBER |
|---|---|---|---|---|---|---|---|
| | | | | | 0.3M RISE | 1M RISE | |
| H006 | Great Northern Highway | 1600 | 1615 | 8.69 | 13.8 | 15 | 59 |
| H006 | Great Northern Highway | 1880.6 | 1896.4 | 10.2 | 15.8 | 15.8 | 60 |
| H046 | Dampier Road | 18.89 | 22.79 | 6.02 | 3.9 | 3.9 | 54 |
| H051 | Port Hedland Road | 0 | 10.38 | 8.49 | 10.38 | 10.38 | 77 |
| M009 | Burrup Peninsula Road | 5.3 | 6.5 | 6.1 | 1.1 | 1.2 | 48 |
| M035 | Point Samson Roebourne Road | 0 | 8.1 | 7.2 | 8.1 | 8.1 | 75 |
| M035 | Point Samson Roebourne Road | 15.48 | 15.86 | 7.2 | 0.27 | 0.38 | 76 |
| M035 | Point Samson Roebourne Road | 16.41 | 17.12 | 7.2 | 0.54 | 0.71 | 76 |
| M049 | Onslow Road | 66.08 | 69.30 | 4.06 | 2.4 | 3.22 | 73 |
| M049 | Onslow Road | 69.85 | 70.04 | 4.06 | 0 | 0.19 | 73 |
| M049 | Onslow Road | 70.75 | 74.21 | 4.06 | 3.1 | 3.46 | 73 |
| M049 | Onslow Road | 75.01 | 76.62 | 4.06 | 1.5 | 1.61 | 73 |
| M049 | Onslow Road | 77.4 | 79.4 | 4.06 | 1.4 | 2 | 73 |
| | Total of individual elements: | | | | 62.29 | 65.95 | |

### 3.4.3 GASCOYNE

| ROAD NUMBER | ROAD NAME | SLK FROM | SLK TO | Highest Astronomical Tide | LENGTH OF ROAD IMPACTED BY | | PAGE NUMBER |
|---|---|---|---|---|---|---|---|
| | | | | | 0.3M RISE | 1M RISE | |
| H044 | Carnarvon Road | 3.49 | 5.09 | 3.00 | 0 | 1.6 | 50 |
| H048 | Minilya Exmouth Road | 181 | 188.5 | 3.89 | 3 | 7.5 | 71 |
| M011 | Shark Bay Road | 91.09 | 92.05 | 2.61 | 0.5 | 0.96 | 79 |
| M047 | Coral Bay Road | 11.8 | 12.2 | 3.46 | 0.3 | 0.4 | 53 |
| | Total of individual elements: | | | | 3.8 | 10.46 | |

### 3.4.4 MID WEST

| ROAD NUMBER | ROAD NAME | SLK FROM | SLK TO | Highest Astronomical Tide | LENGTH OF ROAD IMPACTED BY | | PAGE NUMBER |
|---|---|---|---|---|---|---|---|
| | | | | | 0.3M RISE | 1M RISE | |
| H004 | Brand Highway | 356.9 | 358.1 | 2.21 | 0 | 1.2 | 46 |
| M045 | Indian Ocean Drive | 210 | 212.64 | 2.25 | 0 | 4.96 | 65 |
| M045 | Indian Ocean Drive | 217.29 | 226 | 2.25 | 6.7 | 8.71 | 65 |
| M058 | Northampton – Port Gregory Road | 41.56 | 56.04 | 2.26 | 14.48 | 14.48 | 72 |
| | Total of individual elements: | | | | 21.18 | 29.35 | |

### 3.4.5 SOUTH WEST

| ROAD NUMBER | ROAD NAME | SLK FROM | SLK TO | Highest Astronomical Tide | LENGTH OF ROAD IMPACTED BY | | PAGE NUMBER |
|---|---|---|---|---|---|---|---|
| | | | | | 0.3M RISE | 1M RISE | |
| H015 | Kwinana Freeway | 62.08 | 62.82 | 2.32 | 0 | 0.74 | 67 |
| H015 | Kwinana Freeway | 63.01 | 63.2 | 2.32 | 0 | 0.19 | 67 |
| H015 | Kwinana Freeway | 63.28 | 63.45 | 2.32 | 0 | 0.17 | 67 |
| H059 | Willinge Drive | 0.4 | 2.1 | 2.23 | 1.1 | 1.7 | 81 |
| M023 | Pinjarra Road | 4.02 | 4.91 | 2.32 | 0.3 | 0.89 | 74 |
| M023 | Pinjarra Road | 8.73 | 9.59 | 2.32 | 0.86 | 0.86 | 74 |
| M043 | Caves Road | 10.1 | 10.2 | 2.23 | 0 | 0.1 | 51 |
| M043 | Caves Road | 10.4 | 11 | 2.23 | 0 | 0.6 | 51 |
| M074 | Lakelands – Lake Clifton Road | 10.51 | 11.29 | 2.32 | 0.3 | 0.78 | 68 |
| M074 | Lakelands – Lake Clifton Road | 16.85 | 17.30 | 2.28 | 0 | 0.45 | 69 |
| M074 | Lakelands – Lake Clifton Road | 34.83 | 35.01 | 2.28 | 0.1 | 0.18 | 70 |
| M074 | Lakelands – Lake Clifton Road | 35.31 | 36.51 | 2.28 | 1.2 | 1.2 | 70 |
| M074 | Lakelands – Lake Clifton Road | 36.70 | 37.68 | 2.28 | 0.2 | 0.98 | 70 |
| M074 | Lakelands – Lake Clifton Road | 38.02 | 38.2 | 2.28 | 0 | 0.18 | 70 |
| PR.M043 | Proposed Caves Road | 0.8 | 5.8 | 2.23 | 2.2 | 5 | 52 |
| PR.M043 | Proposed Caves Road | 7.1 | 14.43 | 2.23 | 5.3 | 7.32 | 52 |
| | Total of individual elements: | | | | 11.56 | 21.34 | |

### 3.4.6 GREAT SOUTHERN

| ROAD NUMBER | ROAD NAME | SLK FROM | SLK TO | Highest Astronomical Tide | LENGTH OF ROAD IMPACTED BY | | PAGE NUMBER |
|---|---|---|---|---|---|---|---|
| | | | | | 0.3M RISE | 1M RISE | |
| H009 | South Coast Highway | 475.52 | 476.15 | 2.23 | 0 | 0.63 | 80 |
| H040 | Princess Royal Drive | 3.3 | 4.53 | 2.23 | 1 | 1.23 | 78 |
| H040 | Princess Royal Drive | 5.0 | 5.1 | 2.23 | 0 | 0.1 | 78 |
| | Total of individual elements: | | | | 1 | 1.96 | |

### 3.4.7 PERTH CBD

| ROAD NUMBER | ROAD NAME | SLK FROM | SLK TO | Highest Astronomical Tide | LENGTH OF ROAD IMPACTED BY | | PAGE NUMBER |
|---|---|---|---|---|---|---|---|
| | | | | | 0.15M RISE | 0.5M RISE | |
| H001 | Albany Highway | 0 | 0.18 | 2.33 | 0.18 | 0.18 | 45 |
| H015 | Kwinana Freeway | 0.6 | 4.88 | 2.34 | 4.2 | 4.2 | 66 |
| H015R | Kwinana Freeway | 0.6 | 7.5 | 2.34 | 6.9 | 6.9 | 66 |
| 1240042 | Barrack Street | 0 | 0.1 | 2.33 | 0.09 | 0.1 | 45 |
| 1240103 | Mounts Bay Rd | 0.06 | 0.56 | 2.33 | 0.268 | 0.5 | 45 |
| 1240110R | Adelaide Tce (Near Plain St to Causeway) | 1.2 | 1.35 | 2.33 | 0 | 0.15 | 45 |
| 1240111 | Hay Street (Causeway to Near Plain Street) | 0 | 0.3 | 2.33 | 0.1 | 0.3 | 45 |
| 1240111R | Hay Street (Causeway to Near Plain Street) | 0 | 0.3 | 2.33 | 0.1 | 0.3 | 45 |
| 1240121 | Barrack Sq (Bell Tower) | 0 | 0.4 | 2.33 | 0.4 | 0.4 | 45 |
| 1240122 | Riverside Drive | 0 | 1.89 | 2.33 | 1.89 | 1.89 | 45 |
| 1240122R | Riverside Drive | 0 | 1.89 | 2.33 | 1.89 | 1.89 | 45 |
| 1240123 | Governors Avenue | 0 | 0.15 | 2.33 | 0.15 | 0.15 | 45 |
| 1240124 | Terrace Rd | 0 | 0.12 | 2.33 | 0.12 | 0.12 | 45 |
| 1240125 | Victoria Ave | 0 | 0.2 | 2.33 | 0.2 | 0.2 | 45 |
| 1240132 | Plain Street | 1.21 | 1.48 | 2.33 | 0.24 | 0.27 | 45 |
| 1240134 | Nelson Avenue | 0.1 | 0.8 | 2.33 | 0.18 | 0.7 | 45 |
| 1240204 | Trinity Avenue | 0 | 0.2 | 2.33 | 0.2 | 0.2 | 45 |
| 1240222 | Hay Street Causeway Access | 0 | 0.19 | 2.33 | 0.07 | 0.13 | 45 |
| 1240223 | Riverside Access (Off Causeway | 0 | 0.35 | 2.33 | 0 | 0.35 | 45 |
| 1260008 | South Perth Esplanade | 0 | 1.15 | 2.33 | 0.267 | 1.15 | 45 |
| 1260249 | Esplanade Ramp | 0 | 0.62 | 2.33 | 0.35 | 0.62 | 45 |
| 1290103 | Taylor Street | 0.05 | 0.34 | 2.33 | 0.29 | 0.29 | 45 |
| | Total of individual elements: | | | | 18.085 | 20.99 | |

## 3.5 Onsite verification

Site inspections and discussions with many regional staff have been used in to verify the desktop analysis and the following information summarises those conversations.

### 3.5.1 Kimberley Region

A site inspection of the Great Northern Highway (GNH) with Darren Jackson in August 2011generally confirmed the areas of interest (approaching Wyndham) as per Map D.20, although there was some doubt expressed in relation to SLK 3174 to 3178 where the section is not currently flooded due to tidal influence, but that high tides significantly slow the passage of surface drainage across the floodway. To date there has been no need to close the highway due to water depth. However, it was acknowledged that with a potentially higher sea level this "standing water" effect will worsen and eventually cause traffic disruption.

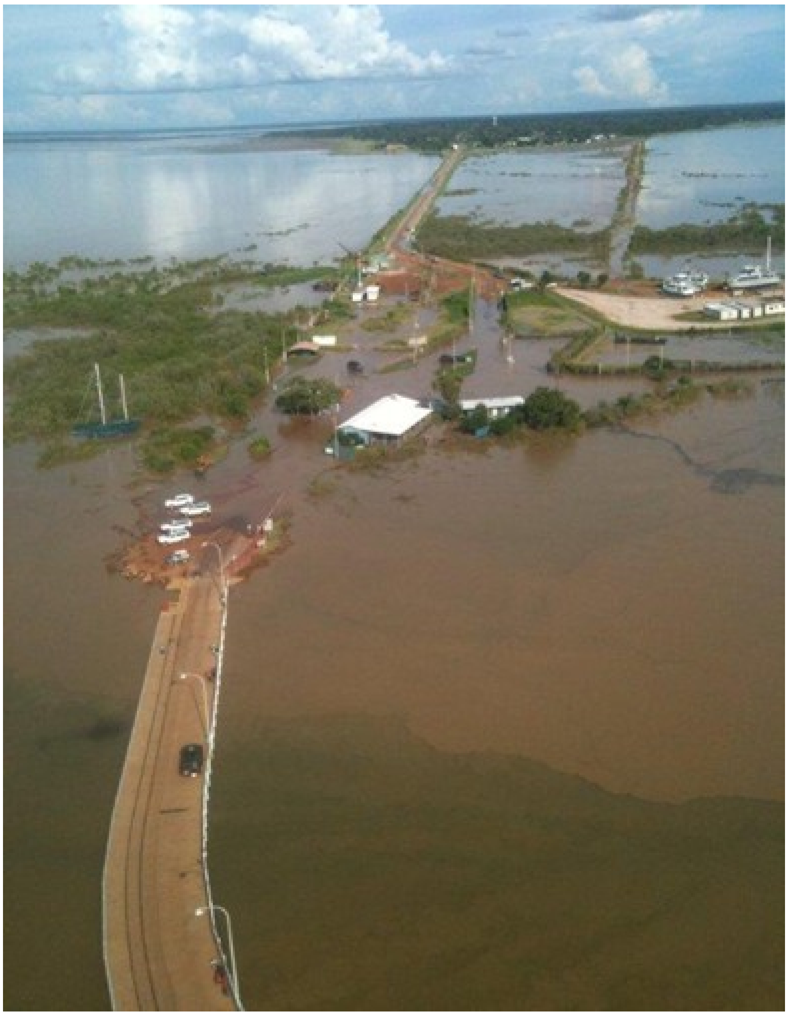
The section that appeared to be at most risk starts at a floodway near the "Wyndham 10km" distance sign. North from here the highway comprises a number of slight profile undulations meaning that future inundation would be periodic rather than continuous along the road length. It was noted that on occasions at high tide, water floods across the road section approaching the port area (at approximate SLK 3194).

**GNH (Wyndham Section) – Looking north from approx 3194 SLK**

The Region has been allocated funding in 2011/12 for design development associated with widening the section 3184 to 3189 and a comprehensive review of drainage requirements is underway taking sea level implications into account. It may be possible to raise the existing road by 300mm (or 1m) as part of that widening project by shifting the alignment closer to the escarpment, to reduce susceptibility to sea level rise and thereby safeguard future road access to the port.

It was noted that the local racetrack currently goes under water in high tides. Salt deposits are very evident – particularly on the western side of the highway. The old 6 Mile Hotel is very low-lying and is therefore also susceptible.

The Kimberley Network Manager, Gary Bradshaw, has provided aerial photos of a particularly high tide at Derby (on the wharf peninsula) that occurred on 22 March 2011. The photos confirm that road access and some existing infrastructure are periodically inundated under current tidal extremes. Gary is not aware of tidal encroachment along the link road between town and port, or to the local government streets along the town extremities even with tides of the magnitude of last March - “but it gets close.” (Map D.14 refers).



**Looking East from the wharf towards Derby townsite**

**High tide (RL 10.5) on 22 March 2011**

The section between Derby and the Gibb River Road junction at 36 SLK does not appear to be particularly susceptible. However, to the south of that junction the existing Derby Highway vertical profile is relatively low and appears to be more vulnerable to sea level rise. The local airstrip and associated access road adjacent to SLK 34 also appear to be at risk as highlighted on Map D.13.

The section of Gibb River Road out to the old leprosarium road (approx SLK 9.2) does not appear to be particularly low or warranting early attention. Map D.11 refers.

Darren Jackson advised that the floodway at Pentecost River on the Gibb River Road (Map D.12) regularly flows 300 to 400mm deep due to tidal fluctuations.

**GNH 2145 SLK - Roebuck Plains – Looking west**

Roebuck Plains (Map D.18 refers) is located on the GNH just south of the GNH/Derby Highway junction between 2138 and 2153 SLK. According to Kimberley Network Manager Gary Bradshaw, the area comprises extensive clayey material known as marl and was once the mouth of the Fitzroy River. This very flat, treeless area is considered to be more flood prone due to slow runoff over flat grades rather than to tidal influences. The ocean is about 20 km to the west.

The section of GNH near Logue River west of Willare Roadhouse (2258 – 2270 SLK) is locally referred to as Tombstone Flats due to the extensive numbers of termite mounds. Map D.19 refers. The Network Manager is of the opinion that the area is less likely to be affected by tidal movements, but is more likely caused by surface drainage which is very slow-moving due to the very flat flood gradient.

**GNH 2265 SLK – Looking north-west (Tombstone Flats)**

Gary Bradshaw expressed concern about Salt Creek Flats (GNH SLK 1941 to 1944.4) even though it is well inland from the sea. Throughout these sections the highway is relatively very low in comparison with the surrounding terrain. Map D.17 refers. Gary advised that the area has periodically been affected by very high tides and so may be a candidate section for further study.

The section of Broome Highway at the eastern end of the international airport runway is relatively very low and grades downwards as it enters the town precinct near Napier Terrace. Although not part of Main Roads responsibility, this section has been subjected to periodic flooding during very high tides. On 22 March 2011 a 10.5m tide resulted in extensive local flooding of town streets, and water came within centimeters of the runway itself. The Australian Hydrographic Office has assessed this event as being the Highest Astronomical Tide for the current epoch. The photos on the following page confirm that current tidal movements around Broome inundate existing roads – a feature that will become more frequent and longer lasting. Disruption to traffic and increasing potential of pavement softening can be expected into the future.

Any increase in sea level will exacerbate the risk and problems caused by tidal inundation.

Map D.3 shows the extent of town roads that are Main Roads responsibility and that warrant closer examination of the potential risk for disruption or damage due to sea level rise.

**Broome Highway / Napier Terrace intersection  - High tide (RL 10.5) 22 March 2011**

**Looking west from Broome Highway towards the international runway**

**High tide (RL 10.5) 22 March 2011**

### 3.5.2 Pilbara Region

A number of site inspections were undertaken in October 2011 by Regional Asset Manager Manish Gupta, Annamarie Mathews and Tom Webb to review the desktop assessment.

A site inspection of the Port Hedland Road (0 – 10.38 SLK) generally confirmed the areas of interest as per Map D.33, although there was some doubt expressed in relation to how quickly the effects may be noticed. Manish thought that there is a proposal to duplicate this road in the relatively near future at which time it would be wise to raise the gradeline to account for possible sea level rise effects. However, Mike Cosson advised that, whilst duplication is "on the radar", there is no commitment for an upgrade within the next 10 years. Map D.15 suggests that the airstrip may be at risk unless the section of GNH between 1600 and 1615 SLK is raised.

On the Point Samson to Roebourne Road (0 to 8.1 SLK) the bridge at Popes Nose (photo below) has been a problem since its original construction. Map D.31 refers. Senior Contract Surveillance Officer Tom Webb – who has lived and worked in this area for more than 11 years - has seen regular damage to protection works (wash-aways) and the development of shifting sand bars in the creek itself.

**Point Samson to Roebourne Road – Bridge at Popes Nose**

Sections of the Point Samson to Roebourne Road adjacent to Harding River (15.48 – 15.86 and 16.41 – 17.12 SLK) may well be at risk as Tom has noticed increasing water levels – even reaching the edge of road shoulder on several occasions. (Map D.32). The shire road to Cossack is also quite low with high tide regularly lapping the edge of shoulder.

Tom Webb is not overly concerned about the low point on the Burrup Peninsula Road. (Map D.4). It doesn't strike him as being at significant risk although it will need to be monitored as this road provides the sole access to the peninsula north.

Current high tides adjacent to the causeway section of the Dampier Highway (Map D.10) regularly reach the shoulder and Tom Webb predicts that, unless the causeway is raised, those tides will be causing real problems within the next 5 - 10 years. Advice from Mike Cosson is that the section is about to be duplicated as part of a staged upgrading project due for completion in 2012. The Project Proposal Report "Dampier

Highway Duplication", March 2009 refers. According to Project Director Brian Norris the causeway is not directly exposed to the ocean and is protected by the Dampier Salt operations and a 3 meter high gas bund along its eastern side. However, sea level rise is still likely to affect the road in places and has the potential to impact on the causeway itself.

**Dampier Road – Looking west**

The section of GNH known as Sandfire Flats (SLK 1880.62 – 1896.5) was identified as an area of interest through the desktop analysis but is located about 20km inland from the coast and Gary Bradshaw advised that it is unlikely to be affected by sea level rise.

The Onslow Road (Map D.29) provides access to the coastal town of Onslow and has a number of low sections warranting attention.

### 3.5.3 Gascoyne Region

A number of site inspections were undertaken by A/Regional Manager Ernie Reynolds in October 2011 to review the desktop assessment.

Further discussions were held with Regional Manager Peter Sewell who confirmed that the system of levees surrounding the township of Carnarvon is expected to generally shield the township from the effects of sea level rise, but the town drainage system would need to be examined in order to prevent backflow into town. Map D.6 was prepared without reference to the levee system and thus suggests that the airport may be a risk of inundation with a sea level rise of 300mm. The RM is confident that this is not the case.

The road to Coral Bay contains a 400m section of concern. Map D.9 refers. The Regional Manager acknowledged that this low section and the local airstrip on the northern side of the road will be at risk with only a small increase in sea level. Local roads leading from the two affected intersections would also need to be raised.

The 7.5km section of the Minilya - Exmouth Road was also considered to be at risk and would need to be raised accordingly. See Map D.27.

The road to Shark Bay is characterized by a narrow isthmus between L'Haridon Bight and Freycinet Reach. Map D.35 suggests that a 1km section would be affected by sea level rise, effectively isolating the community during future Highest Astronomical Tide events.

### 3.5.4 Mid West Region

A number of site inspections were undertaken in September 2011 to verify the desktop assessment.

In September 2011 an inspection was made of the section of Indian Ocean Drive (IOD) north of Green Head. The proximity of the town of Leeman to the ocean and the flat nature of the topography suggest that the town may be at risk. The adjacent section of IOD (210 to 212.64 SLK) is virtually at ground level and would be similarly affected. Whilst part of the 2.64km section is protected by heavily vegetated sand dunes, there are sections (notably near the town jetty) that are exposed and will freely allow seawater to enter the town under the scenarios described in this Report, also placing a significant number of residences at risk. Map D.21 refers. Water ingress could also occur through the "back door", whereby seawater could find its way south into town from the east via a shallow natural valley.

**Indian Ocean Drive – approx 223 SLK – Looking south**

The northern section (217 to 226 SLK), located either side of the Eneabba Road junction, is characterised by substantial and heavily vegetated sand-dunes to the west which isolate the IOD from local inundation. The junction itself is similarly "protected". However, to the north of the junction at approx 220 SLK, the dunes give way to open, low lying country which is regularly inundated by tidal movements. The road formation is relatively close to that natural surface and therefore would be exposed to relatively small increases in sea level.

This exposure may also allow the migration of seawater southwards towards the Eneabba junction and beyond. (This flood-out area is highlighted on the aerial photo as shown on Map D.21).

The section of Brand Highway south of Geraldton passes through an area known as Rudds Gully. (Map D.2). The highway is currently above natural surface such that an increase in sea level of 300mm is unlikely to affect the road or its operation but a one metre increase may. The Geraldton North South Highway Route Definition Planning Study (May 2010) refers to this section as being a wide waterway and that the proposed realignment would be on a very high fill embankment of up to 9m in this area. (Personal discussion with Kim Ingle refers).

**Brand Highway – near Rudds Gully – Looking north**

The current section along the Northampton - Port Gregory Road (adjacent to the Hutt Lagoon) is relatively very low with tidal movements depositing salt very close to the road shoulder. (Map D.28) According to Mark Salt there has been a periodic need (in past years) to lift the road formation via 200mm overlays along those sections that have become badly distorted or have failed. The pavement is holding for now but is likely to be at increasing risk due to sea level rise. Because there is an alternative route to Kalbarri, the urgency to upgrade/raise this road section is not immediate.

### 3.5.5 South West Region

A site inspection (D Clarke / R Grove) was undertaken in November 2010 to review the road sections identified in Section 3.4.5. In summary:

The nominated sections of the new Kwinana / Forrest Highway between 62.08 and 63.45 SLK (Map D.23) are adjacent to the Serpentine River which will be partially influenced by sea level rise due to proximity to the Peel Inlet. The shoulder level of the lowest section of the newly constructed highway alignment is RL 4.2m – suggesting that a sea level rise to RL 2.3m (plus river gradient) will not overtop the formation, although local PSPs and culverts will be affected.

The section of "old" Perth-Bunbury Highway now the Lakelands – Lake Clifton Road immediately to the east of the Mandurah Estuary Bridge (10.51 – 11.29 SLK) has a lowest road surface level of about RL 2.3, suggesting that water may be lapping against the embankment for significant periods in the future. (See Map D.24).

The sections of Old Coast Road now the Lakelands – Lake Clifton Road between 34.8 to 38.2 SLK are located on a very low formation to the west of the Estuary. (Map D.26 refers). Visual inspection (in the absence of accurate level information) confirmed that there are significant lengths of relatively low road formation that are likely to be at risk.

Pinjarra Road is relatively close to the Murray and Serpentine Rivers. (See Map D.30). In the section 4.02 to 4.91 SLK, parts of the existing road are at RL 1.7m suggesting that the road will be substantially affected by the various sea level rise scenarios and should be a priority for further examination of options to understand and mitigate the likely effects.

**Pinjarra Road - Looking west from approx 4.2 SLK**

Along the section 8.73 to 9.59 SLK, the existing road is at approximate RL of 2.3 to 2.5 suggesting that there will be little freeboard during periods of highest astronomical tide under the sea level scenarios being considered. The high water level will also adversely affect local table drains and cross drainage.

The northern end of Caves Road (Map D.7) is characterized by a number of short timber bridges crossing a series of Water Corp drains which apparently operate as part of a gated drainage system. The road is about one hundred meters from the coast and, with the exception of several drains which have sea outfalls that are silted over and contain rotting material, the bridges are currently about 2m to 3m above sea level and will therefore not be affected by the scenarios described in this Report.

**Caves Road at Tobey's Inlet**

However at various locations along Caves Road (notably near Toby Inlet at chainage 10.1 SLK), the road is at RL 1.9m, suggesting that parts could be inundated. Of perhaps greater concern is that sea level rise will affect drainage outfalls in this very flat area, with the potential for even greater flooding of local properties than was experienced in 1999. In 2010 the Department of Water completed a Floodplain Development Strategy which includes detail mapping of the 100 year flood contours surrounding Tobey Inlet. The information will be of great benefit when a more detailed analysis of this area is required.

Flooding along the coastal plain is not new. The photo below shows the flooding impact of heavy rainfall around Busselton in 1999 – an area where drainage outfall to the sea are also limited.

**1999 Busselton floods**

Advice from Manager Project Programming Mike Cosson is that there are plans to realign the section of Caves Road as shown in Map D.8, but construction is very much a long term proposal and unlikely to occur in the next 10 years unless other factors arise. Notwithstanding, it is possible that a short section of the route (at the Busselton Bypass end) could be required in 2014/15 as part of a realignment to accommodate the Vasse-Newtown development.

### 3.5.6 Great Southern Region

The only significant road sections earmarked for review in Albany can be found on the Princess Royal Drive (Map D.34). The very short section adjacent to the Port of Albany is not affected by a 300mm seas kevel rise but may be by a 1m rise. The longer section to the west along the foreshore is slightly lower in elevation warranting a more detailed study.

On the South Coast Highway, at Hay River east of Wilson Inlet (Map D.36), there is a 600m road section which does not appear to be at short-term risk but may be inundated by a 1m sea level rise.

### 3.5.7 Perth CBD

In the lower reaches of the Swan and Canning River system the water level regimes are dominated by ocean water levels, whereas upstream of the Causeway and Canning Bridge catchment runoff currently dominates the extreme water levels. That makes an assessment of the impact associated with the sea level rise scenarios between the coast and Perth CBD more difficult. The extent to which sea level rise will be felt upstream along the Swan and Canning Rivers is not yet clear.

What is clear is that the open areas of Perth and Melville Waters have significant fetches, and waves can be 0.5m to 1m in height, with extreme events causing waves greater than 1m.

The City of South Perth, Main Roads and the Swan River Trust have been collaborating in relation to the susceptibility of the South Perth (western) foreshore to the impacts of climate change. Under the auspices of the SRT, Main Roads Metro staff are participating in the development of a long term strategy for erosion control along the Kwinana Freeway / Swan River foreshore, between the Narrows and Mt Henry bridges. Map D.22 refers.

The following photograph from The West Australian newspaper clearly shows the overtopping experienced during high water level events when accompanied by strong winds and waves. In this case the high river water levels were caused by the combination of storm surge and high winter tides. This occurs to some extent during most winters. Wave conditions depend upon wind speed, direction, duration, and fetch distance (the length of water that the wind is acting over).


**Waves overtopping a seawall along the Kwinana Freeway in 1995**

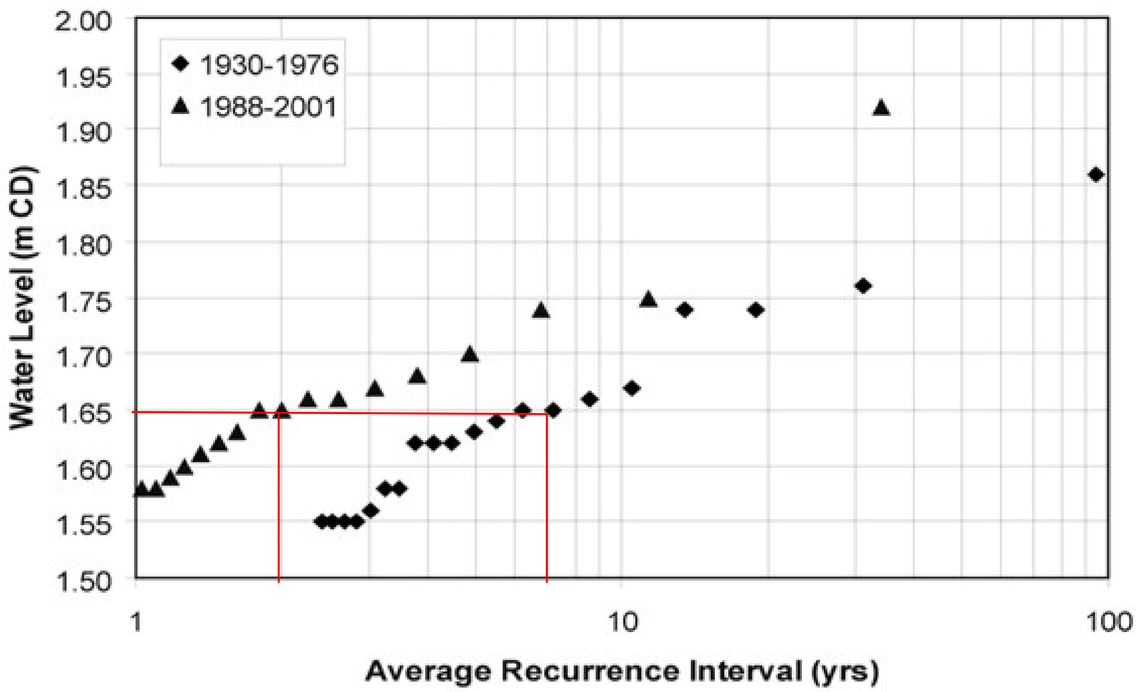
*Source*: The West Australian newspaper (13 July 1995)

Metro staff have determined that parts of the Kwinana Freeway and associated PSPs are at risk from erosion arising as a consequence of a number of factors including

- reclamation works undertaken in the 1950s,
- the lack of maintenance dredging since the Public Works Department was disbanded, and
- storm surge due to the combination of tide, rising sea level, strong winds and storms.

**Erosion behind the sea wall near the Narrows Bridge**

Water level data from the Barrack Street tide gauge illustrates a change in the recurrence interval of extreme water levels between 1930 – 1976 and 1988 – 2001. For example, a water level of 1.65m, with an expected seven year recurrence interval during the period 1930 – 1976, would now be expected to occur every two years.




(Source: Potential Impacts of Climate Change on the Swan and Canning Rivers)

It is anticipated that the effect of sea level rise will not be fully replicated in the Swan River near the CBD. Accordingly, and for the purposes of this Report, a lesser rise of either 500mm or 150mm has been adopted pending more detailed assessment.

Sea level rise is likely to progressively worsen the wave impact on riverside road infrastructure within the tidal reaches of the Swan and Canning River systems, such as the Kwinana Freeway and Mounts Bay Road. Storm surges are already a concern for the Kwinana Freeway at Como and the low lying roads within the Perth foreshore.

Asset Manager (South Metro) Forbes Watson confirmed that the Kwinana Freeway section (Map D.22) should be a priority section for more detailed analysis in the short term.

**Riverside Dr - Localised flooding associated with storm surge - 16 May 2003**

(Source: Lee Evelegh, reproduced by BOM)

Riverside Drive is also periodically affected by strong winds and storm surges and the associated flooding will only be exacerbated in the event of sea level rise.

Map D.1 shows those road sections that could be at risk in the event that a 1meter or 300mm rise in the Indian Ocean partially affected levels in the Swan and Canning Rivers.

## 4 ASSIGNING PRIORITY

As a result of regional reviews and site inspections the list of roads at possible risk was revised as per Table 2.

| Table 2 - Length of Main Roads' road infrastructure at possible risk due to sea level rise (adjusted to reflect regional input) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Road length (km) after site check: | | Overall Road Length | | | As adjusted Proportion of road length affected by: | |
| | 0.3m rise | 1m rise | Auslink | State | Total | 0.3m rise | 1m rise |
| **Kimberley** | 39.27 | 49.61 | 1317 | 792 | 2109 | 1.9% | 2.4% |
| **Pilbara** | 35.01 | 50.15 | 756 | 1431 | 2187 | 1.6% | 2.3% |
| **Gascoyne** | 3.8 | 8.86 | 0 | 1588 | 1588 | 0.2% | 0.6% |
| **Mid West** | 21.18 | 28.15 | 840 | 1377 | 2217 | 1.0% | 1.3% |
| **South West** | 2.96 | 6.22 | 115 | 1469 | 1584 | 0.2% | 0.4% |
| **Gt Southern** | 1 | 1.96 | 0 | 1570 | 1570 | 0.1% | 0.1% |
| **Metro** | 18.087 | 20.99 | 204 | 600 | 804 | 2.2% | 2.6% |
| **Goldfields / Esperance** | 0 | 0 | 1071 | 1267 | 2338 | 0.0% | 0.0% |
| **WBS** | 0 | 0 | 0 | 1598 | 1598 | 0.0% | 0.0% |
| **WBN** | 0 | 0 | 590 | 1263 | 1853 | 0.0% | 0.0% |
| **Totals** | **121.307** | **165.94** | **4893** | **12955** | **17848** | **0.68%** | **0.93%** |

**Table 2**

In order to identify those road sections warranting early attention, road-related data was downloaded from IRIS. Consideration was given to a range of factors including road usage (traffic volumes), the proportion of heavy vehicles, pavement age, roughness, network importance and whether adverse affects are likely to be felt within the next 20 to 30 years, viz our current planning and design horizon. A scoring system was applied to each parameter and different values were used for sensitivity testing.

## 4.1 Traffic Volumes

Information relating to Average Annual Daily Traffic is readily available and provides a good indication of current usage and the relative social and economic importance of the road segment to the local community. Although the datasets vary in terms of the data currency, the IRIS information allows for growth rates to be applied and future changes in usage to be monitored. A loss of serviceability will clearly be more disruptive on the more highly trafficked roads.

| Traffic volume | Score |
|---|---|
| 0 | 0 |
| 150 | 0.5 |
| 500 | 1.0 |
| 3000 | 1.5 |
| 8000 | 2.0 |

**Rural Roads**

| Traffic volume | Score |
|---|---|
| 0 | 0 |
| 500 | 0.25 |
| 3000 | 0.5 |
| 8000 | 1 |
| 40000 | 1.5 |

**Urban Roads**

## 4.2 Commercial Vehicles

A compounding element associated with traffic volumes is the proportion of heavy vehicles in the traffic composition. It is a further measure of the economic importance of the road section under consideration as well as a guide to possible early pavement deterioration as wetting of the existing pavement progresses with exposure to rising sea levels. Local pavement weaknesses will quickly become more apparent on those roads with large numbers of heavy vehicles.

| No. of Heavy vehicles | Score |
|---|---|
| 0 | 0 |
| 15 | 0.5 |
| 50 | 1 |
| 300 | 1.5 |

## 4.3 Pavement Age

The current age of the road pavement gives an indication of when a road section may be approaching the end of its economic life. In Western Australia pavements are designed for a 40 year life before they can be expected to gradually succumb to increasing roughness and rutting.

| Pavement Age | Score |
|---|---|
| 0 | 0 |
| 10 | 0.25 |
| 20 | 0.5 |
| 30 | 1.0 |
| 40 | 1.5 |

**Rural Roads**

| Pavement Age | Score |
|---|---|
| 0 | 0 |
| 20 | 0.25 |
| 40 | 0.5 |
| 60 | 1 |

**Urban Roads**

### 4.4 Roughness

At one time roughness was considered to be a useful measure of remaining (pavement) life but, more recently, surface improvement techniques to reduce pavement imperfections, have affected that apparent correlation. Nonetheless, as ride quality deteriorates, road safety can become compromised and this measure remains an important indicator.

| Roughness | Score |
|---|---|
| 0 | 0 |
| 70 | 0.25 |
| 80 | 0.5 |
| 100 | 1 |
| 120 | 1.5 |

### 4.5 Strategic Importance

Even though a particular road may have relatively low traffic volumes, it may still be a key linkage in the overall state road network. A Strategic Factor has been incorporated in the evaluation to acknowledge National Highways, roads linking major centres and other key tourist/access roads as being of particular importance regardless of their actual AADT. This recognizes the strategic importance of critical links in our state network.

| Strategic Importance | Score |
|---|---|
| National Hwy | 1 |
| State Hwy | 0.5 |
| Main Road | 0.5 |
| Special case | 1 |

## 4.6 Urgency

Greater emphasis has been given to those road sections where the desktop evaluation and subsequent site inspections suggest that the road segment is likely to be susceptible to a relatively small rise in sea level – viz the section is likely to be affected sooner rather than later. A factor of 1 has been added where the road section under consideration is likely to be affected within the relative short-term.

## 4.7 Ranking

By categorizing each of these road segments in terms of road usage, the proportion of heavy vehicles, pavement age, roughness, network importance and whether adverse affects are likely to be felt within the next 20 to 30 years, a simple sieving system has been developed to identify those sections at greatest risk.

| Score | Ranking |
|---|---|
| 5.6 | 1 |
| 4 | 2 |
| 2.6 | 3 |
| 0 | 4 |

A Ranking of 1 suggests that a particular road section warrants early attention via a more detailed assessment of local site and shoreline characteristics (including a bathymetric survey), more precise level information, analysis of current and future drainage implications - leading to the development of options to mitigate or prevent disruption and damage likely to be caused by sea level rise.

| Ranking | No. of Road Sections | Length (km) |
|---|---|---|
| 1 | 13 | 49.14 |
| 2 | 28 | 65.17 |
| 3 | 13 | 27.18 |
| 4 | 10 | 71.96 |

**Tables 3 to 9** on the following pages include a priority listing by Region for each of the identified road sections. Where the field verification has concluded that a suggested road section is unlikely to be at risk, it is shown in ~~**red**~~ and the road section and length have been excluded from the totals.

## Table 3 - Ranking of Kimberley road infrastructure at possible risk due to sea level rise

| | ROAD NUMBER | ROAD NAME | SLK FROM | SLK TO | LENGTH OF ROAD IMPACTED BY 0.3M RISE | LENGTH OF ROAD IMPACTED BY 1M RISE | Site confirmation | pavement age | roughness | AADT | %commercials | strategic priority | Ranking | Description |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kimberley | H006 | Great Northern Highway | 1941.06 | 1944.43 | 3 | 3.37 | Yes | 31 | 45 | 402 | 29.0% | n | 2 | Salt Creek Flats |
| | H006 | Great Northern Highway | 2138 | 2153 | ~~15~~ | ~~15~~ | No | 32 | 39 | 360 | 29.0% | n | | Roebuck Plains |
| | H006 | Great Northern Highway | 2258.61 | 2270.98 | ~~12~~ | ~~12.37~~ | No | 43 | 59.4 | 630 | 20.7% | n | | Logue River |
| | H006 | Great Northern Highway | 3174.17 | 3178.1 | ~~3.7~~ | 3.93 | Yes | 46 | 47 | 250 | 19.1% | n | 2 | Wyndham |
| | H006 | Great Northern Highway | 3178.81 | 3183.68 | 4.87 | 4.87 | Yes | 43 | 58.7 | 300 | 19.1% | n | 2 | Wyndham |
| | H006 | Great Northern Highway | 3185.23 | 3195 | 9.77 | 9.77 | Yes | 46 | 76.2 | 550 | 14.9% | n | 1 | Wyndham |
| | H042 | Broome Highway | 25.44 | 31.7 | 6 | 6.24 | Yes | 46 | 62.6 | 5100 | 9.8% | s | 1 | Nth Broome |
| | H042 | Broome Highway | 34.34 | 35.59 | 1.25 | 1.25 | Yes | 4 | 55 | 2750 | 48.9% | s | 2 | Broome bypass |
| | H042 | Broome Highway | 37.9 | 40.6 | 2.2 | 2.7 | Yes | 46 | 62.3 | 2750 | 48.9% | s | 1 | Broome port area |
| | H047 | Derby Highway | 27.4 | 31.9 | 4.5 | 4.5 | Yes | 8 | 38 | 1640 | 10.8% | s | 3 | Derby South |
| | H047 | Derby Highway | 32.33 | 33.75 | 1.42 | 1.42 | Yes | 39 | 43.3 | 1640 | 10.8% | s | 2 | Derby South |
| | H047 | Derby Highway | 34 | 37.1 | 2.9 | 3.1 | Yes | 44 | 59.5 | 1640 | 10.8% | s | 2 | Derby South |
| | H047 | Derby Highway | 41.24 | 42.86 | 1.62 | 1.62 | Yes | 11 | 64.8 | 2180 | 4.2% | s | 2 | Derby South |
| | M012 | Derby Gibb River Road | 0 | 1.38 | 1.28 | 1.38 | Yes | 42 | 70.6 | 300 | 17.1% | s | 2 | Gibb R junction |
| | M012 | Derby Gibb River Road | 5 | 10 | ~~5~~ | 5 | Yes | 41 | 48.9 | 250 | 17.1% | s | 2 | To Leprosarium T/O |
| | M012 | Derby Gibb River Road | 585.35 | 585.81 | 0.46 | 0.46 | Yes | 50 | 50 | 135 | 28.0% | s | 2 | Pentecost River |
| Total of individual elements: | | | | | 39.27 | 49.61 | | | | | | | | |

## Table 4 - Ranking of Pilbara road infrastructure at possible risk due to sea level rise

| | ROAD NUMBER | ROAD NAME | SLK FROM | SLK TO | LENGTH OF ROAD IMPACTED BY 0.3M RISE | LENGTH OF ROAD IMPACTED BY 1M RISE | Site confirmation | pavement age | roughness | AADT | %commercials | strategic priority | Ranking | Description |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pilbara | H006 | Great Northern Highway | 1600 | 1615 | 13.8 | 15 | Yes | 39 | 54 | 4700 | 28.0% | n | 1 | Pt Hedland T/O |
| | H006 | Great Northern Highway | 1880.6 | 1896.4 | ~~15.8~~ | ~~15.8~~ | No | 32 | 44 | 400 | 29.0% | n | | Sandfire Flats |
| | H046 | Dampier Road | 18.89 | 22.79 | 3.9 | 3.9 | Yes | 41 | 52 | 10150 | 15.1% | s | 1 | Dampier salt |
| | H051 | Port Hedland Road | 0 | 10.38 | ~~10.38~~ | 10.38 | Yes | 28 | 62 | 6200 | 15.5% | s | 2 | leading to town |
| | M009 | Burrup Peninsula Road | 5.3 | 6.5 | ~~1.1~~ | 1.2 | Yes | 29 | 66 | 4025 | 18.0% | s | 2 | Burrup |
| | M035 | Point Samson Roebourne Road | 0 | 8.1 | 8.1 | 8.1 | Yes | 29 | 54 | 2150 | 12.0% | s | 2 | From Popes Nose |
| | M035 | Point Samson Roebourne Road | 15.48 | 15.86 | 0.27 | 0.38 | Yes | 29 | 63 | 2990 | 12.5% | s | 2 | Harding River |
| | M035 | Point Samson Roebourne Road | 16.41 | 17.12 | 0.54 | 0.71 | Yes | 42 | 53 | 2990 | 12.5% | s | 1 | Harding River |
| | M049 | Onslow Road | 66.08 | 69.3 | 2.4 | 3.22 | Yes | 25 | 47 | 172 | 14.7% | s | 3 | Onslow |
| | M049 | Onslow Road | 69.85 | 70.04 | 0 | 0.19 | Yes | 25 | 36 | 172 | 14.7% | s | 4 | Onslow |
| | M049 | Onslow Road | 70.75 | 74.21 | 3.1 | 3.46 | Yes | 25 | 44 | 172 | 14.7% | s | 3 | Onslow |
| | M049 | Onslow Road | 75.01 | 76.62 | 1.5 | 1.61 | Yes | 25 | 36 | 172 | 14.7% | s | 3 | Onslow |
| | M049 | Onslow Road | 77.4 | 79.4 | 1.4 | 2 | Yes | 49 | 65 | 172 | 14.7% | s | 2 | Onslow |
| Total of individual elements: | | | | | 35.01 | 50.15 | | | | | | | | |

## Table 5 - Ranking of Gascoyne road infrastructure at possible risk due to sea level rise

| | ROAD NUMBER | ROAD NAME | SLK FROM | SLK TO | LENGTH OF ROAD IMPACTED BY | | Site confirmation | pavement age | roughness | AADT | %commercials | strategic priority | Ranking | Description |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0.3M RISE | 1M RISE | | | | | | | | |
| Gascoyne | H044 | Carnarvon Road | 3.49 | 5.09 | ~~0~~ | ~~1.6~~ | No | 28 | 55 | 5350 | 5.1% | s | | Carnarvon |
| | H048 | Minilya Exmouth Road | 181 | 188.5 | 3 | 7.5 | Yes | 47 | 51 | 380 | 14.8% | s | 2 | Exmouth |
| | M011 | Shark Bay Road | 91.09 | 92.05 | 0.5 | 0.96 | Yes | 34 | 34 | 330 | 13.4% | s | 2 | Shark Bay |
| | M047 | Coral Bay Road | 11.8 | 12.2 | 0.3 | 0.4 | Yes | 21 | 54 | 300 | 10.5% | s | 3 | Coral Bay |
| Total of individual elements: | | | | | 3.8 | 8.86 | | | | | | | | |

## Table 6 - Ranking of Mid West road infrastructure at possible risk due to sea level rise

| | ROAD NUMBER | ROAD NAME | SLK FROM | SLK TO | LENGTH OF ROAD IMPACTED BY | | Site confirmation | pavement age | roughness | AADT | %commercials | strategic priority | Ranking | Description |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0.3M RISE | 1M RISE | | | | | | | | |
| Mid West | H004 | Brand Highway | 356.9 | 358.1 | ~~0~~ | ~~1.2~~ | No | 8 | 41 | 3550 | 20.1% | s | | Rudds Gully |
| | M045 | Indian Ocean Drive | 210 | 212.64 | 0 | 4.96 | Yes | 23 | 41 | 1000 | 7.9% | s | 3 | Nth of Greenh |
| | M045 | Indian Ocean Drive | 217.29 | 226 | 6.7 | 8.71 | Yes | 23 | 41 | 1000 | 7.9% | s | 2 | Eneabba junct |
| | M058 | Northhampton – Port Gregory Road | 41.56 | 56.04 | 14.48 | 14.48 | Yes | 11 | 30 | 370 | 11.8% | s | 3 | Hutt lagoon |
| Total of individual elements: | | | | | 21.18 | 28.15 | | | | | | | | |

## Table 7 - Ranking of South West road infrastructure at possible risk due to sea level rise

| | ROAD NUMBER | ROAD NAME | SLK FROM | SLK TO | LENGTH OF ROAD IMPACTED BY | | Site confirmation | pavement age | roughness | AADT | %commercials | strategic priority | Ranking | Description |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0.3M RISE | 1M RISE | | | | | | | | |
| South West | H015 | Kwinana Freeway | 62.08 | 62.82 | ~~0~~ | ~~0.74~~ | No | 2 | 32 | 9930 | 13.7% | s | | Serpentine Riv |
| | H015 | Kwinana Freeway | 63.01 | 63.2 | ~~0~~ | ~~0.19~~ | No | 2 | 37 | 9930 | 13.7% | s | | Serpentine Riv |
| | H015 | Kwinana Freeway | 63.28 | 63.45 | ~~0~~ | ~~0.17~~ | No | 2 | 39 | 9930 | 13.7% | s | | Serpentine Riv |
| | H059 | Willinge Drive | 0.4 | 2.1 | ~~1.1~~ | ~~1.7~~ | No | 2 | 30 | 1850 | 17.1% | s | | Bunbury |
| | M023 | Pinjarra Road | 4.02 | 4.91 | 0.3 | 0.89 | Yes | 32 | 67 | 10220 | 4.8% | s | 1 | west of Forres |
| | M023 | Pinjarra Road | 8.73 | 9.59 | 0.86 | 0.86 | Yes | 47 | 52 | 10220 | 4.8% | s | 1 | west of Forres |
| | M043 | Caves Road | 10.1 | 10.2 | ~~0~~ | 0.1 | Yes | 38 | 40 | 5100 | 5.3% | s | 2 | Old Caves Roa |
| | M043 | Caves Road | 10.4 | 11 | ~~0~~ | 0.6 | Yes | 38 | 45 | 5100 | 5.3% | s | 2 | Old Caves Roa |
| | M074 | Lakelands – Lake Clifton Road | 10.51 | 11.29 | 0.3 | 0.78 | Yes | 25 | 45 | 14900 | 5.8% | s | 1 | Harvey estuar |
| | M074 | Lakelands – Lake Clifton Road | 16.85 | 17.3 | 0 | 0.45 | Yes | 18 | 48 | 15900 | 5.2% | s | 2 | Harvey estuar |
| | M074 | Lakelands – Lake Clifton Road | 34.83 | 35.01 | 0.1 | 0.18 | Yes | 30 | 61 | 2210 | 6.8% | s | 2 | Harvey estuar |
| | M074 | Lakelands – Lake Clifton Road | 35.31 | 36.51 | 1.2 | 1.2 | Yes | 30 | 61 | 2210 | 6.8% | s | 2 | Harvey estuar |
| | M074 | Lakelands – Lake Clifton Road | 36.7 | 37.68 | 0.2 | 0.98 | Yes | 25 | 64 | 2210 | 6.8% | s | 2 | Harvey estuar |
| | M074 | Lakelands – Lake Clifton Road | 38.02 | 38.2 | 0 | 0.18 | Yes | 25 | 31 | 2210 | 6.8% | s | 3 | Harvey estuar |
| | PR.M043 | Proposed Caves Road | 0.8 | 5.8 | ~~0.8~~ | ~~5~~ | No | 38 | 59 | 4850 | 5.6% | s | | realignment |
| | PR.M043 | Proposed Caves Road | 7.1 | 14.43 | ~~7.1~~ | ~~7.32~~ | No | 38 | 50 | 5050 | 5.3% | s | | realignment |
| Total of individual elements: | | | | | 2.96 | 6.22 | | | | | | | | |

## Table 8 - Ranking of Great Southern road infrastructure at possible risk due to sea level rise

| | ROAD NUMBER | ROAD NAME | SLK FROM | SLK TO | LENGTH OF ROAD IMPACTED BY | | Site confirmation | pavement age | roughness | AADT | %commercials | strategic priority | Ranking | Description |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0.3M RISE | 1M RISE | | | | | | | | |
| Gt Southern | H009 | South Coast Highway | 475.52 | 476.15 | 0 | 0.63 | Yes | 42 | 44 | 1960 | 9.1% | s | 2 | Hay River |
| | H040 | Princess Royal Drive | 3.3 | 4.53 | 1 | 1.23 | Yes | 39 | 56 | 3515 | 13.4% | s | 2 | Albany foresh |
| | H040 | Princess Royal Drive | 5 | 5.1 | 0 | 0.1 | Yes | 19 | 66 | 1830 | 16.3% | s | 3 | Albany port pr |
| Total of individual elements: | | | | | 1 | 1.96 | | | | | | | | |

## Table 9 - Ranking of Perth CBD road infrastructure at possible risk due to sea level rise

| | ROAD NUMBER | ROAD NAME | SLK FROM | SLK TO | LENGTH OF ROAD IMPACTED BY | | Site confirmation | pavement age | roughness | AADT | %commercials | strategic priority | Ranking | Description |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0.3M RISE | 1M RISE | | | | | | | | |
| Metro | H001 | Albany Highway | 0 | 0.18 | 0.18 | 0.18 | 0 | 11 | 69 | 17032 | 3.9% | s | 2 | Perth CBD |
| | H015 | Kwinana Freeway | 0.6 | 4.88 | 4.2 | 4.2 | 0 | 46 | 40 | 30700 | 1.0% | s | 1 | Perth CBD |
| | H015R | Kwinana Freeway | 0.6 | 7.5 | 6.9 | 6.9 | 0 | 46 | 40 | 30700 | 1.0% | s | 1 | Perth CBD |
| | 1240042 | Barrack Street | 0 | 0.1 | 0.09 | 0.1 | 0 | 91 | 40 | 20430 | 0.0% | sc | 2 | Perth CBD |
| | 1240103 | Mounts Bay Rd | 0.06 | 0.56 | 0.27 | 0.5 | 0 | 67 | 40 | 19800 | 1.0% | sc | 1 | Perth CBD |
| | 1240110R | Adelaide Tce (Near Plain St to Causeway) | 1.2 | 1.35 | 0 | 0.15 | 0 | 46 | 40 | 34600 | 0.0% | sc | 4 | Perth CBD |
| | 1240111 | Hay Street (Causeway to Near Plain Street) | 0 | 0.3 | 0.1 | 0.3 | 0 | 84 | 40 | 17140 | 1.0% | sc | 1 | Perth CBD |
| | 1240111R | Hay Street (Causeway to Near Plain Street) | 0 | 0.3 | 0.1 | 0.3 | 0 | 84 | 40 | 17140 | 0.0% | sc | 2 | Perth CBD |
| | 1240121 | Barrack Sq (Bell Tower) | 0 | 0.4 | 0.4 | 0.4 | 0 | 43 | 40 | 600 | 0.0% | sc | 3 | Perth CBD |
| | 1240122 | Riverside Drive | 0 | 1.89 | 1.89 | 1.89 | 0 | 13 | 40 | 0 | 0.0% | sc | 3 | Perth CBD |
| | 1240122R | Riverside Drive | 0 | 1.89 | 1.89 | 1.89 | 0 | 13 | 40 | 0 | 0.0% | sc | 3 | Perth CBD |
| | 1240123 | Governors Avenue | 0 | 0.15 | 0.15 | 0.15 | 0 | 19 | 40 | 4010 | 0.0% | sc | 3 | Perth CBD |
| | 1240124 | Terrace Rd | 0 | 0.12 | 0.12 | 0.12 | 0 | 39 | 40 | 9130 | 0.0% | sc | 2 | Perth CBD |
| | 1240125 | Victoria Ave | 0 | 0.2 | 0.2 | 0.2 | 0 | 34 | 40 | 16660 | 0.0% | sc | 2 | Perth CBD |
| | 1240132 | Plain Street | 1.21 | 1.48 | 0.24 | 0.27 | 0 | 98 | 40 | 11410 | 0.0% | sc | 2 | Perth CBD |
| | 1240134 | Nelson Avenue | 0.1 | 0.8 | 0.18 | 0.7 | 0 | 58 | 40 | 210 | 0.0% | sc | 3 | Perth CBD |
| | 1240204 | Trinity Avenue | 0 | 0.2 | 0.2 | 0.2 | 0 | 11 | 40 | 0 | 0.0% | sc | 3 | Perth CBD |
| | 1240222 | Hay Street Causeway Access | 0 | 0.19 | 0.07 | 0.13 | 0 | 13 | 40 | 0 | 0.0% | sc | 3 | Perth CBD |
| | 1240223 | Riverside Access (Off Causeway | 0 | 0.35 | 0 | 0.35 | 0 | 13 | 40 | 0 | 0.0% | sc | 4 | Perth CBD |
| | 1260008 | South Perth Esplanade | 0 | 1.15 | 0.267 | 1.15 | 0 | 23 | 40 | 1689 | 0.0% | sc | 3 | Perth CBD |
| | 1260249 | Esplanade Ramp | 0 | 0.62 | 0.35 | 0.62 | 0 | 20 | 40 | 918 | 0.0% | sc | 3 | Perth CBD |
| | 1290103 | Taylor Street | 0.05 | 0.34 | 0.29 | 0.29 | 0 | 87 | 40 | 110 | 0.0% | sc | 2 | Perth CBD |
| Total of individual elements: | | | | | 18.09 | 20.99 | | | | | | | | |

## 5 CONCLUSIONS

Two scenarios of potential sea level rise have been considered in the context of Main Roads infrastructure.

**Tables 3 to 9** indicate the approximate length of existing road that may be at risk from either a 300mm or 1 meter rise in sea level. These sections were initially derived from a desktop analysis and have been corroborated by site visits in company with regional staff. Where the field verification has concluded that a desktop-inspired road section is unlikely to be at risk, it is shown in **red** and the road section and length have been excluded from the totals.

Based on a scenario of a **1 metre rise in sea level** – a possibility by the Year 2100 - the length of highways and state roads at potential risk is about **166 km**.

Based on a scenario of a **300mm rise in sea level** – a possibility by the Year 2031 - the length of highways and state roads at potential risk is approximately **121 km**. Whilst this represents only a very small proportion of our overall network, the roads in question are primary links to ports, significant towns and tourist destinations. To avoid significant disruptions to the travelling public and industry, it is considered important to identify and prioritise those sections warranting closer scrutiny.

In terms of Priority Ranking, a total length of 52.75 km has been identified as warranting early, more detailed, evaluation. **Table 10** lists the 13 road sections that have been identified with the highest ranking.

There are considerable tidal fluctuations in the north of the state and several roads are already and periodically flooded during the Highest Astronomical Tides – particularly near Wyndham, Derby, Broome and Port Hedland. Photos on pages 14, 15 and 18 refer.

A detailed study of a priority site - such as at Wyndham, Derby, Broome or Port Hedland - is likely to cost in the order of $250,000 to $300,000. It would include such elements as confirmation of local site constraints and conditions (possibly including a bathymetric survey), shoreline characteristics, precise level information on landform and key infrastructure, analysis of current and future drainage implications - leading to the development of options to mitigate or prevent disruption and damage attributable to sea level rise.

**Appendix E** contains a compilation of Townsite Maps superimposed with the results of scenario modeling for sea level rise

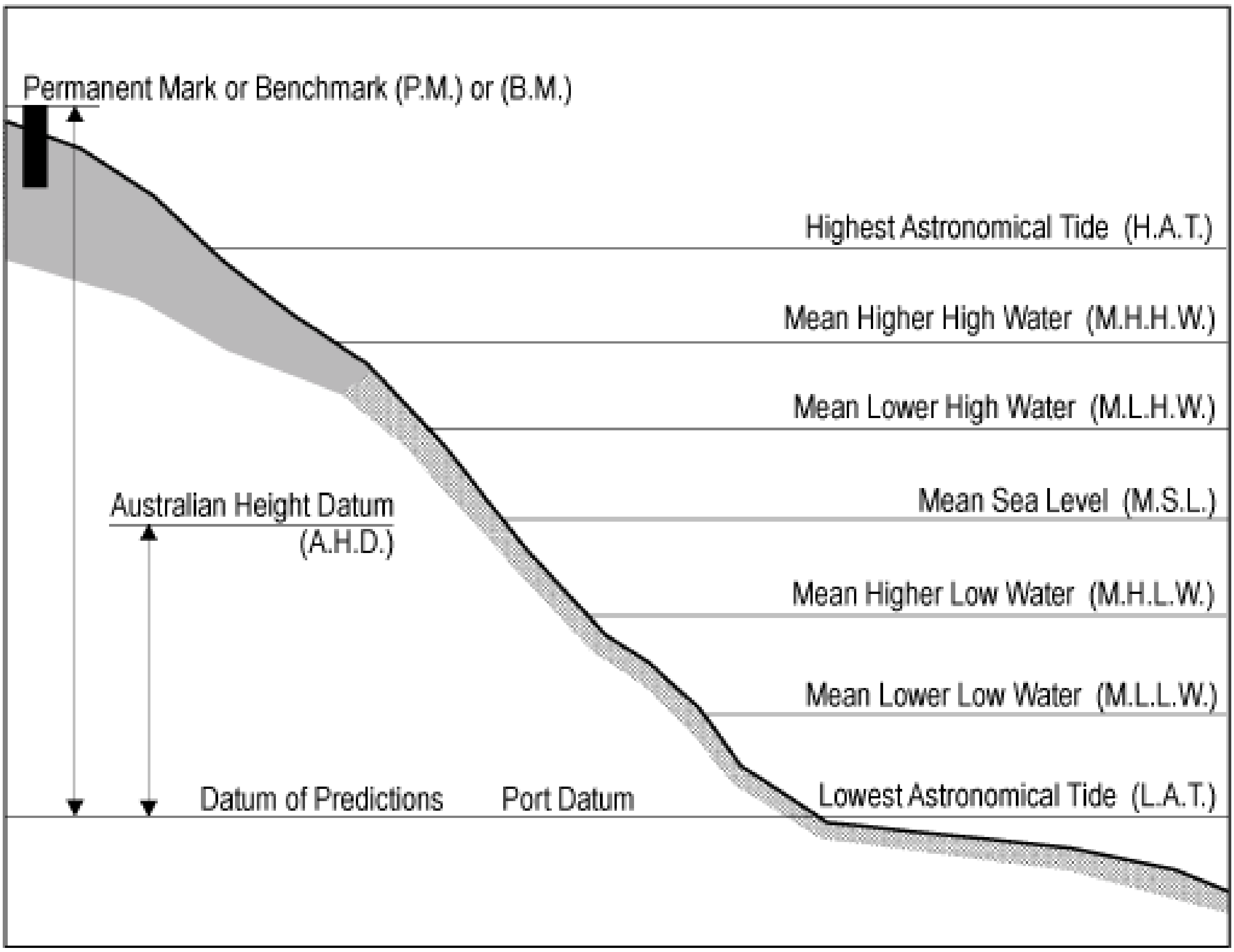
## Table 10 - Summary of Road Sections with a Ranking of 1

| | ROAD NUMBER | ROAD NAME | SLK FROM | SLK TO | LENGTH OF ROAD IMPACTED BY | | Site confirmation | pavement age | roughness | AADT | %commercials | strategic priority | Ranking | Description |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0.3M RISE | 1M RISE | | | | | | | | |
| Kimberley | H006 | Great Northern Highway | 3185.23 | 3195 | 9.77 | 9.77 | Yes | 46 | 76.2 | 550 | 14.9% | n | 1 | Wyndham |
| | H042 | Broome Highway | 25.44 | 31.7 | 6 | 6.24 | Yes | 46 | 62.6 | 5100 | 9.8% | n | 1 | Nth Broome |
| | H042 | Broome Highway | 37.9 | 40.6 | 2.2 | 2.7 | Yes | 46 | 62.3 | 2750 | 48.9% | n | 1 | Broome port a |
| Pilbara | H006 | Great Northern Highway | 1600 | 1615 | 13.8 | 15 | Yes | 39 | 54 | 4700 | 28.0% | n | 1 | Pt Hedland T/C |
| | H046 | Dampier Road | 18.89 | 22.79 | 3.9 | 3.9 | Yes | 41 | 52 | 10150 | 15.1% | s | 1 | Dampier salt |
| | M035 | Point Samson Roebourne Road | 16.41 | 17.12 | 0.54 | 0.71 | Yes | 42 | 53 | 2990 | 12.5% | s | 1 | Harding River |
| Gascoyne | | - - | | | | | | | | | | | | |
| Mid West | | - - | | | | | | | | | | | | |
| South West | M023 | Pinjarra Road | 4.02 | 4.91 | 0.3 | 0.89 | Yes | 32 | 67 | 10220 | 4.8% | s | 1 | west of Forre |
| | M023 | Pinjarra Road | 8.73 | 9.59 | 0.86 | 0.86 | Yes | 47 | 52 | 10220 | 4.8% | s | 1 | west of Forre |
| | M074 | Lakelands – Lake Clifton Road | 10.51 | 11.29 | 0.3 | 0.78 | Yes | 25 | 45 | 14900 | 5.8% | s | 1 | Harvey estuar |
| Gt Southern | | - - | | | | | | | | | | | | |
| Perth CBD | H015 | Kwinana Freeway | 0.6 | 4.88 | 4.2 | 4.2 | | 46 | 40 | 30700 | 1.0% | sc | 1 | Perth CBD |
| | H015R | Kwinana Freeway | 0.6 | 7.5 | 6.9 | 6.9 | | 46 | 40 | 30700 | 1.0% | sc | 1 | Perth CBD |
| | 1240103 | Mounts Bay Rd | 0.06 | 0.56 | 0.27 | 0.5 | | 67 | 40 | 19800 | 1.0% | sc | 1 | Perth CBD |
| | 1240111 | Hay Street (Causeway to Near Plain Street) | 0 | 0.3 | 0.1 | 0.3 | | 84 | 40 | 17140 | 1.0% | sc | 1 | Perth CBD |
| | | | | Totals | 49.14 km | 52.75 km | | | | | | | 13 sections | |

# APPENDIX A – TIDE STATIONS

| Name | Number | Ratio | HAT | MHHW | MLHW | MSL | AHD | MHLW | MLLW | ISLW | TGZ | LAT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Esperance** | 62080 | 1.312 | 1.369 | 1.048 | 0.837 | 0.627 | 0.577 | 0.417 | 0.207 | 0.072 | -0.130 | 0.014 |
| **Albany** | 62120 | 1.850 | 1.394 | 1.093 | 0.940 | 0.680 | 0.661 | 0.420 | 0.267 | 0.161 | | 0.012 |
| **Bunbury** | 62190 | 2.702 | 1.234 | 0.963 | 0.850 | 0.612 | 0.570 | 0.374 | 0.261 | 0.208 | -0.070 | 0.008 |
| **Fremantle** | 62230 | 2.863 | 1.356 | 1.098 | 0.993 | 0.760 | 0.716 | 0.527 | 0.422 | 0.374 | | 0.208 |
| **Geraldton** | 62290 | 2.485 | 1.217 | 0.953 | 0.808 | 0.582 | 0.547 | 0.356 | 0.211 | 0.163 | | 0.011 |
| **Denham** | 62341 | 1.470 | 1.635 | 1.345 | 0.998 | 0.806 | | 0.614 | 0.267 | 0.192 | -0.100 | 0.044 |
| **Carnarvon** | 62370 | 0.800 | 2.008 | 1.719 | 1.085 | 1.037 | 0.954 | 0.989 | 0.355 | 0.215 | 0.140 | 0.013 |
| **Exmouth** | 62435 | 0.394 | 2.876 | 2.342 | 1.730 | 1.457 | 1.400 | 1.184 | 0.572 | 0.223 | | 0.020 |
| **Onslow** | 62470 | 0.370 | 3.067 | 2.483 | 1.837 | 1.565 | | 1.293 | 0.647 | 0.308 | | 0.093 |
| **Thevenard Island** | 62475 | 0.391 | 2.883 | 2.309 | 1.696 | 1.431 | | 1.166 | 0.553 | 0.210 | | 0.018 |
| **Wapet Landing** | 62490 | 0.289 | 3.699 | 2.981 | 2.096 | 1.744 | | 1.392 | 0.507 | 0.149 | | 0.006 |
| **Tanker Mooring** | 62491 | 0.238 | 4.750 | 4.005 | 2.812 | 2.379 | | 1.946 | 0.753 | 0.366 | | 0.019 |
| **King Bay** | 62540 | 0.212 | 5.109 | 4.401 | 3.098 | 2.631 | | 2.164 | 0.861 | 0.487 | -0.120 | 0.064 |
| **Cape Lambert** | 62550 | 0.176 | 6.226 | 5.474 | 3.831 | 3.272 | | 2.713 | 1.070 | 0.683 | | 0.062 |
| **Port Hedland** | 62590 | 0.143 | 7.558 | 6.685 | 4.619 | 3.949 | 3.902 | 3.279 | 1.213 | 0.822 | | 0.015 |
| **Broome** | 62650 | 0.107 | 10.556 | 9.276 | 6.313 | 5.407 | 5.322 | 4.501 | 1.538 | 1.124 | 0.860 | 0.060 |
| **Yampi Sound** | 62860 | 0.107 | 11.020 | 9.839 | 6.555 | 5.456 | | 4.357 | 1.073 | 0.603 | | -0.006 |
| **Cape Voltaire** | 63001 | 0.191 | 7.761 | 6.627 | 4.442 | 3.821 | | 3.200 | 1.015 | 0.479 | | -0.058 |
| **Wyndham** | 63090 | 0.301 | 8.699 | 7.839 | 5.885 | 4.559 | 4.454 | 3.233 | 1.279 | 0.292 | 0.260 | -0.010 |

# APPENDIX B - TIDAL DEFINITIONS




For this report the Highest Astronomical Tide has been adopted as the base, with one metre (or 300mm) added to allow for the future sea level rise scenarios. The published Highest Astronomical Tide (HAT) values given in the Tide Tables are the highest astronomical tides (under average meteorological conditions) that occur during a nineteen year epoch. Coastal tides between the tidal stations have been interpolated to enable the most likely areas of inundation to be identified.

# APPENDIX C - USEFUL REFERENCES

**"Natural Hazard Risk in Perth Western Australia",** Geoscience Australia, 2005

**"Potential Impacts of Climate Change on the Swan and Canning Rivers"**, Swan River Trust, December 2007.

**"The Garnaut Climate Change Review"**, Ross Garnaut, 2008

**"Climate Change risks to Australia's Coast – A First Pass National Assessment",** Australian Government, Department of Climate Change, 2009

**"Cape to Cape – 2100 sea level rise"**, Curtin University, 22 July 2010.

**"The Science of Sea level Rise: Implications for Perth and surroundings"**, Prof Chari Pattiaratchi, UWA, 2010.

**"Engineering a Response to Sea Level Rise: an international perspective"**, Prof Paul Hardisty, Worley Parsons, 2010.

**"Western Foreshore - Beach Movement Analysis",** M P Rogers and Associates for the City of South Perth, March 2010

**"Adapting to Climate Change – An Australian Government Position Paper",** Department of Climate Change, 2010

**"Floodplain Development Strategy – Murray Drainage and Associated Studies",** Department of Water, September 2010.

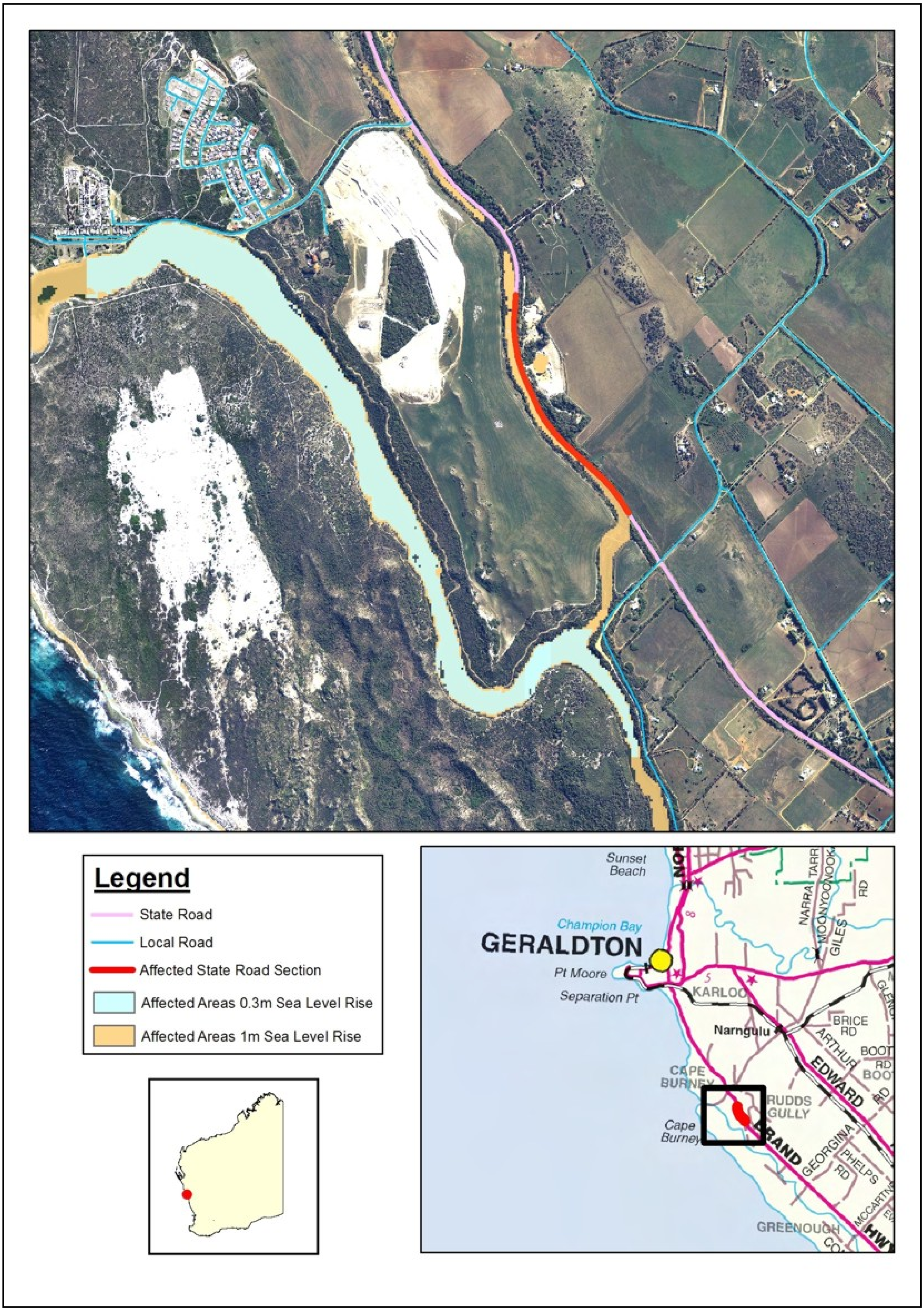
# APPENDIX D – ROAD SECTION MAPS

## D.1 Perth CBD

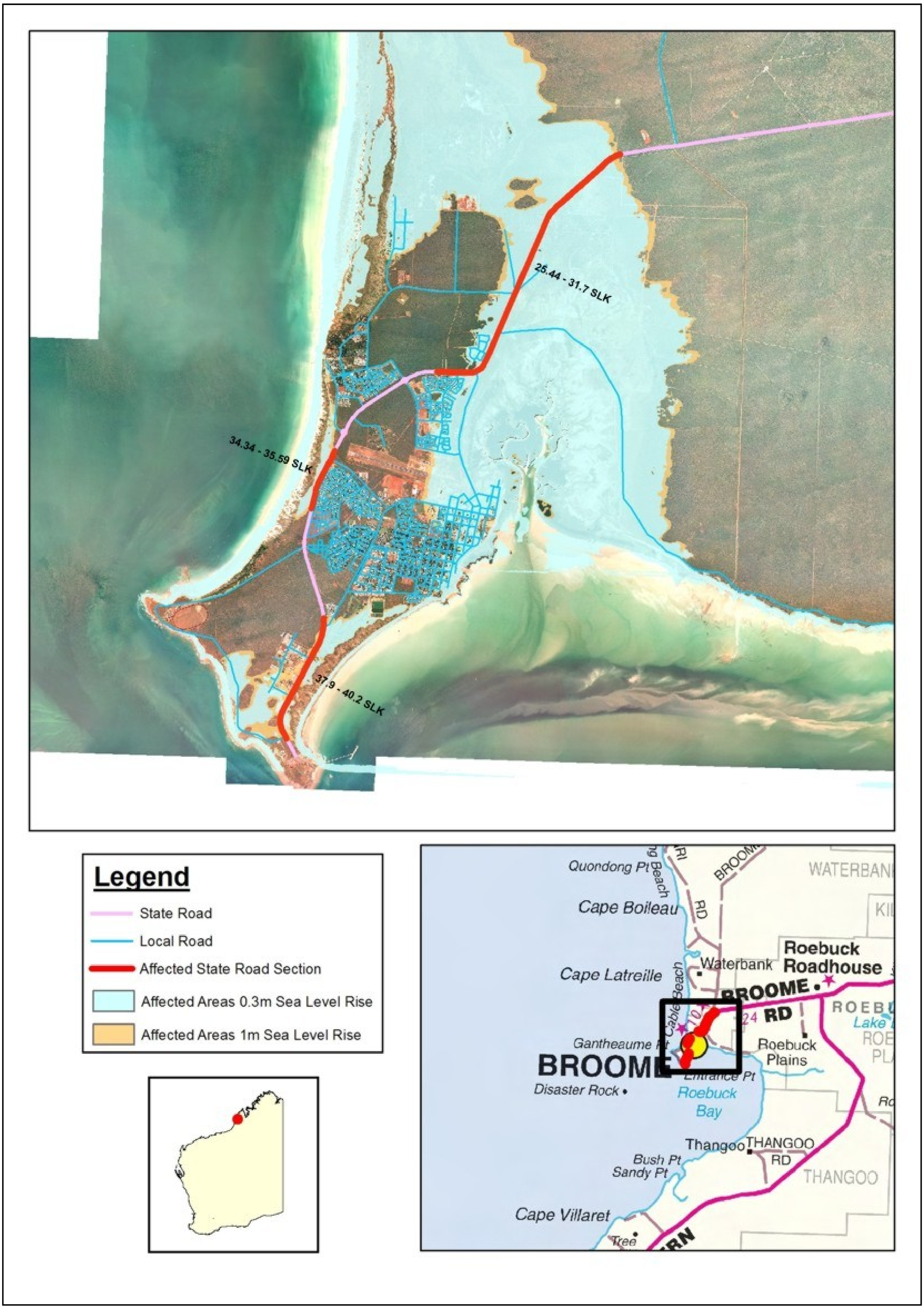
The effect of sea level rise will be progressively less as it moves upstream in both the Swan and Canning Rivers. In the absence of more reliable information, a water level rise of 500mm and 150mm has been modeled for the CBD

### D.2 Brand Highway (356.9 – 358.1 slk)

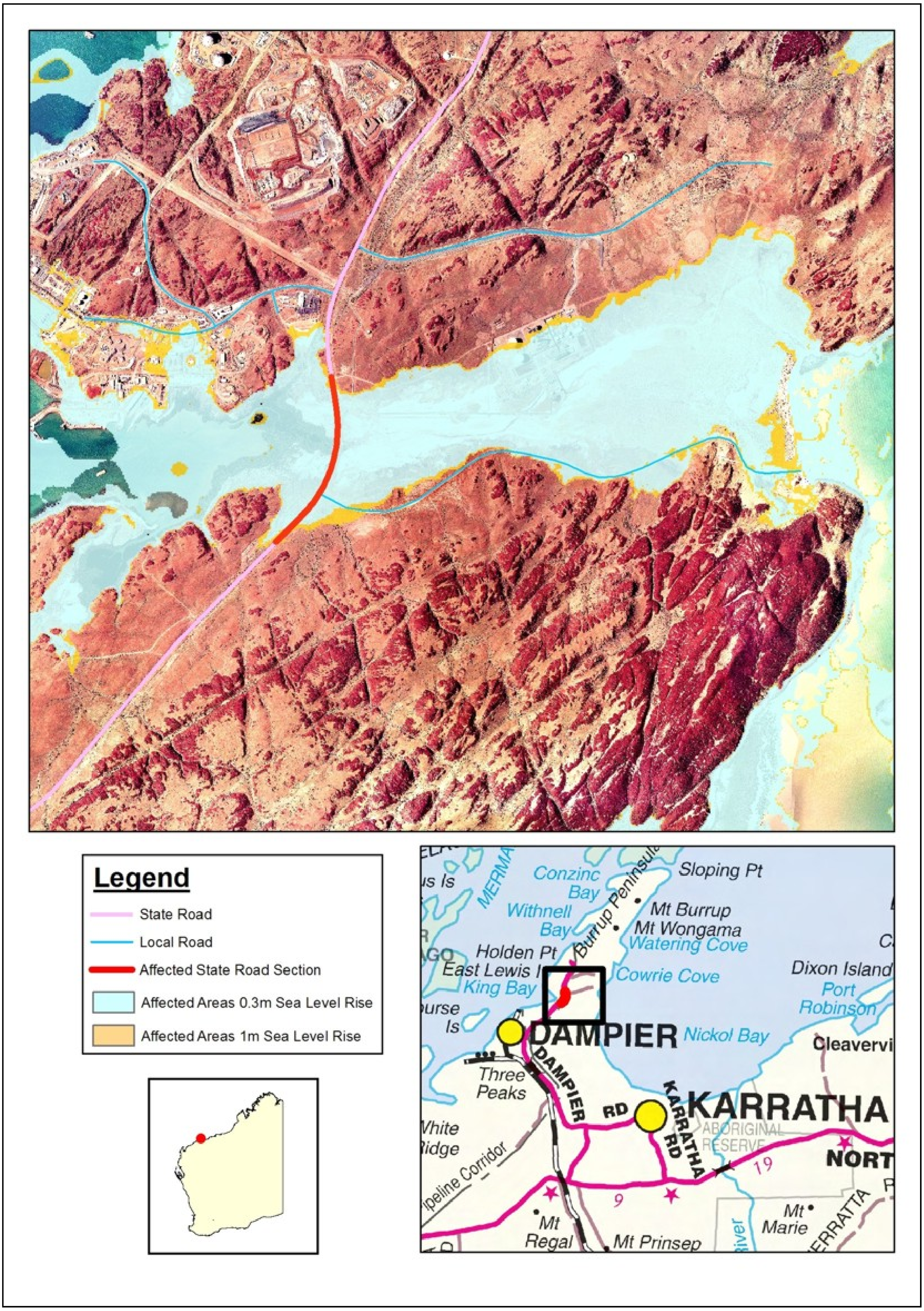
This section is unlikely to be affected by a 0.3m sea level rise.



**D.3 Broome Highway (25.44 – 31.7, 34.34 – 35.59, 37.9 – 40.6 slk)**



**D.4 Burrup Peninsula Road (5.3 - 6.5 slk)**

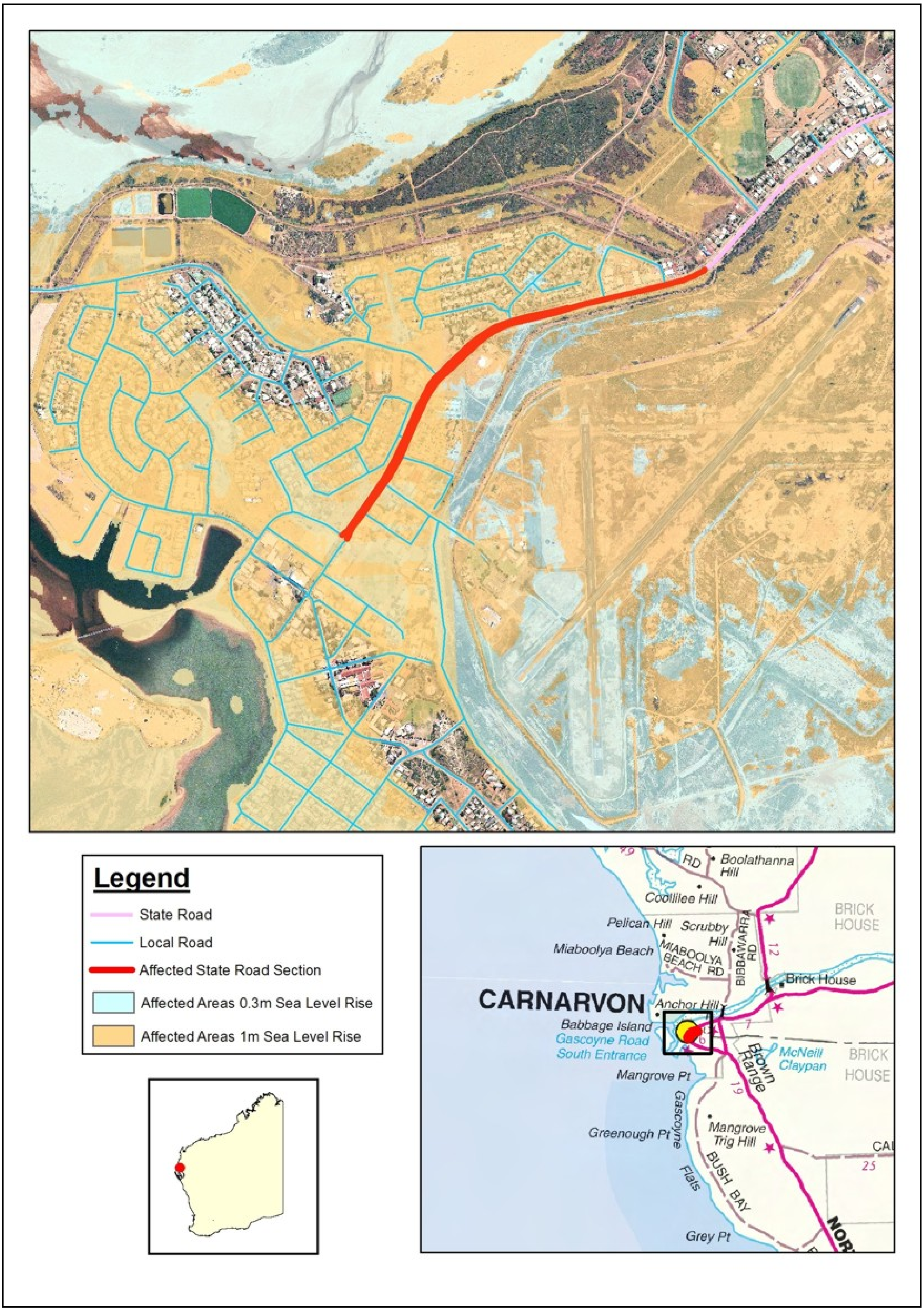


## D.5 Canning Highway (6 - 6.2 slk)

This section has been modeled using a 150mm and 500mm water level rise (Refer Map D.1).

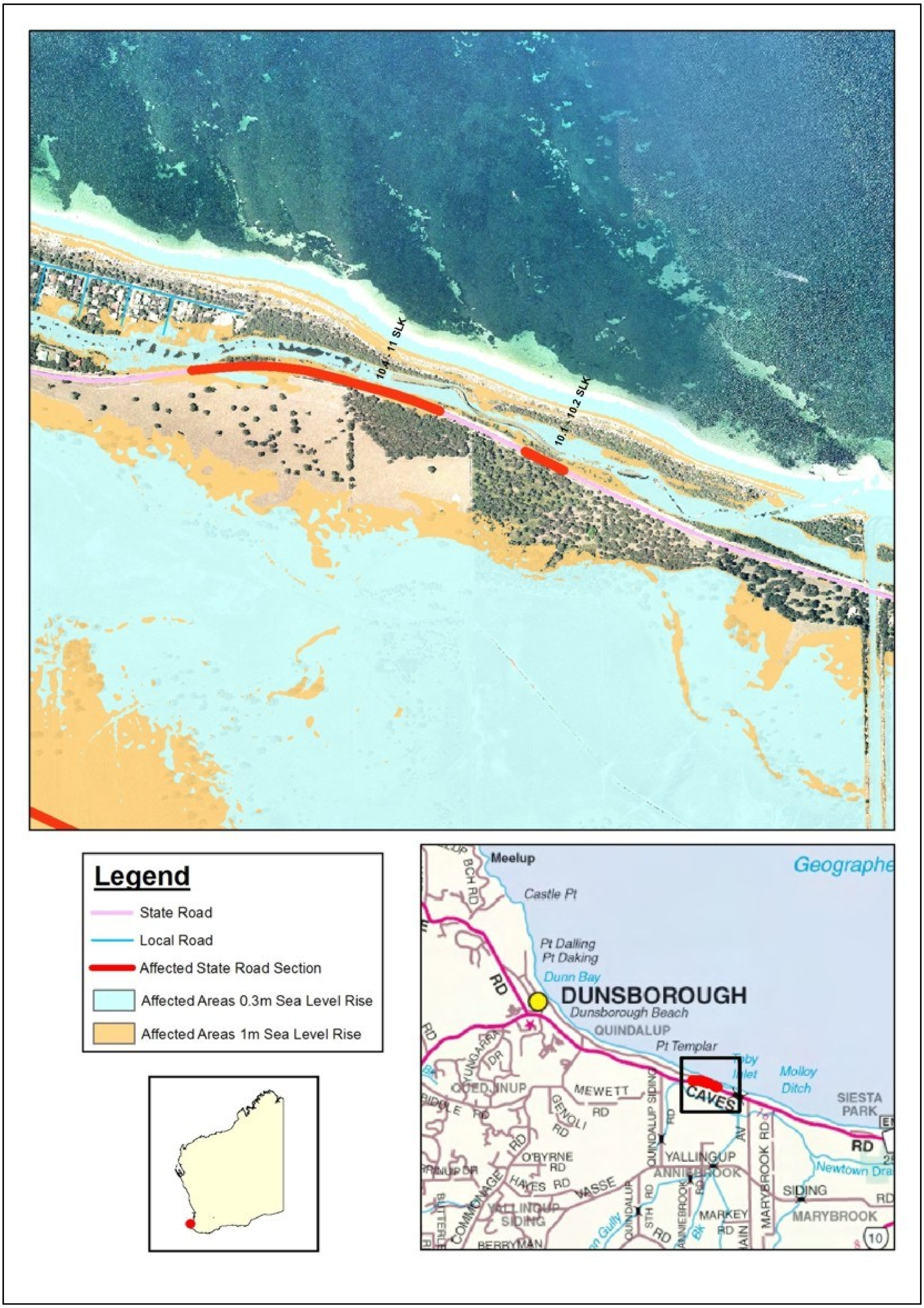
### D.6 Carnarvon Road (3.49 – 5.09 slk)

This section is unlikely to be affected by a 0.3m rise in sea level.



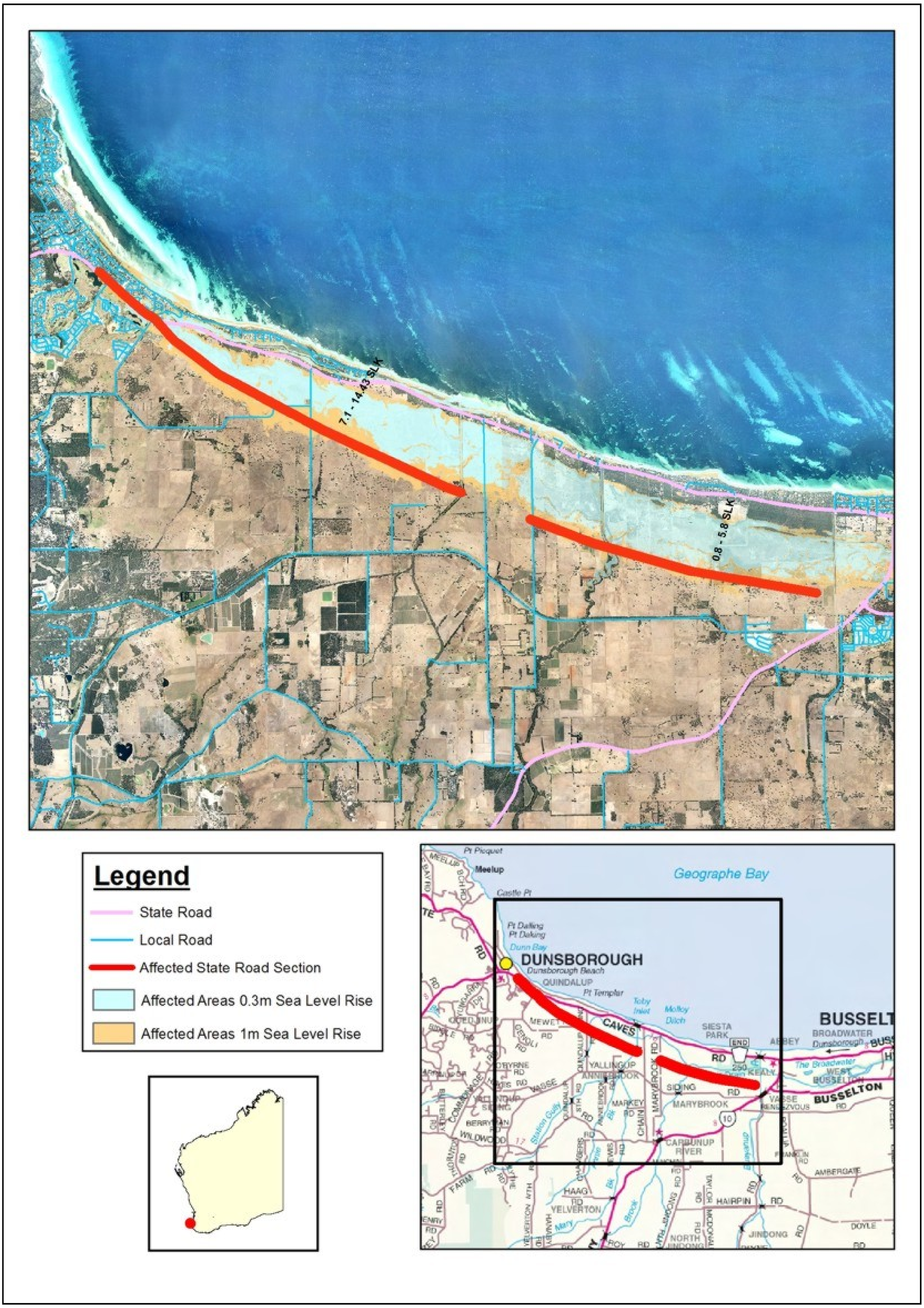
## D.7 Caves Road (10.1 – 10.2, 10.4 – 11 slk)

This section is unlikely to be affected by a 0.3m rise in sea level.



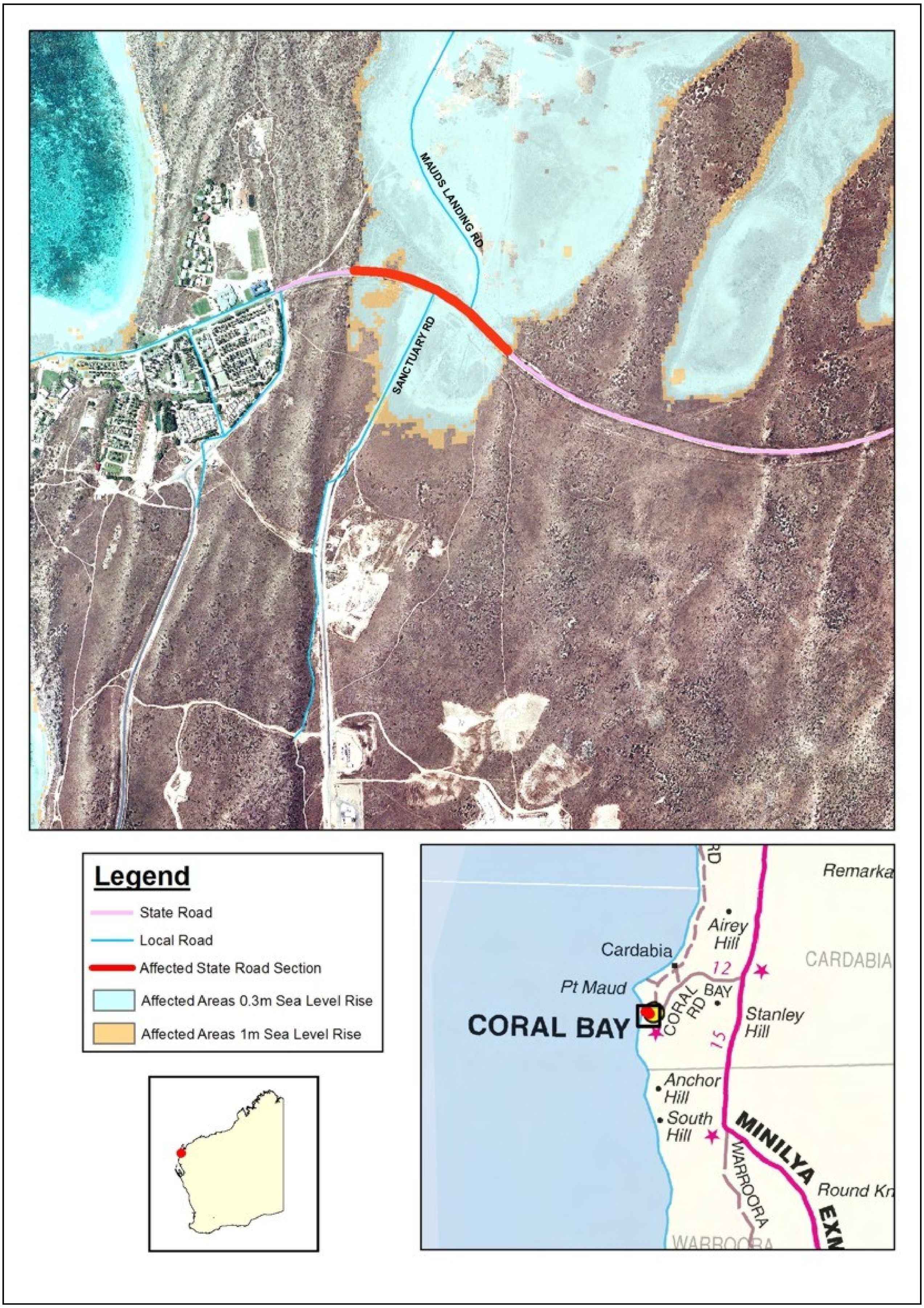
## D.8 Caves Road (Proposed) (0.8 – 5.8, 7.1 – 14.43 slk)

The proposed realignment of Caves Road would need to be built at least 1 metre above ns to not be affected by a 1 metre rise in sea level. The section from 0.8SLK to 3.8 SLK is unlikely to be affected by a 0.3m rise in sea level.

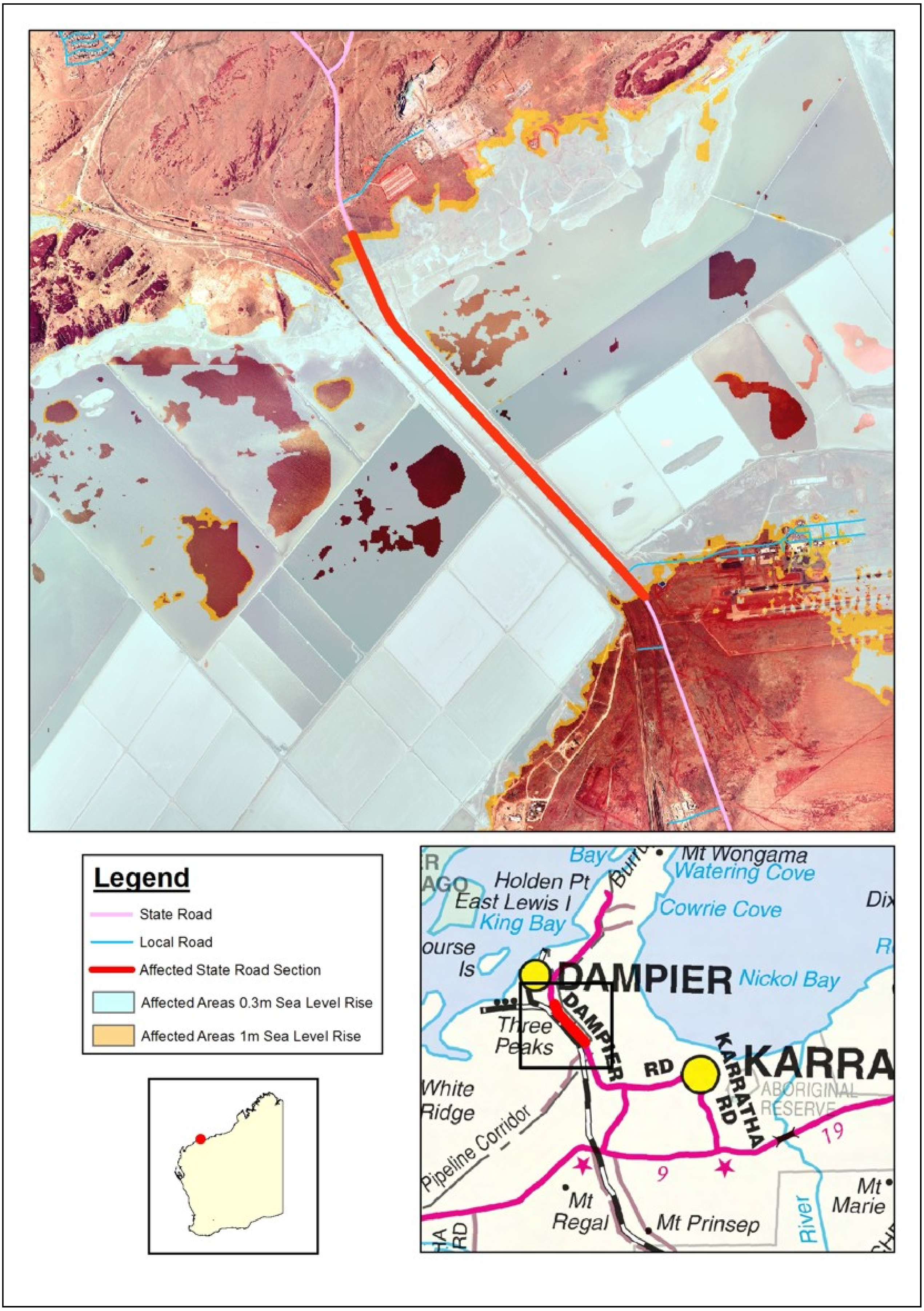


**D.9 Coral Bay Road (11.8 - 12.2 slk)**

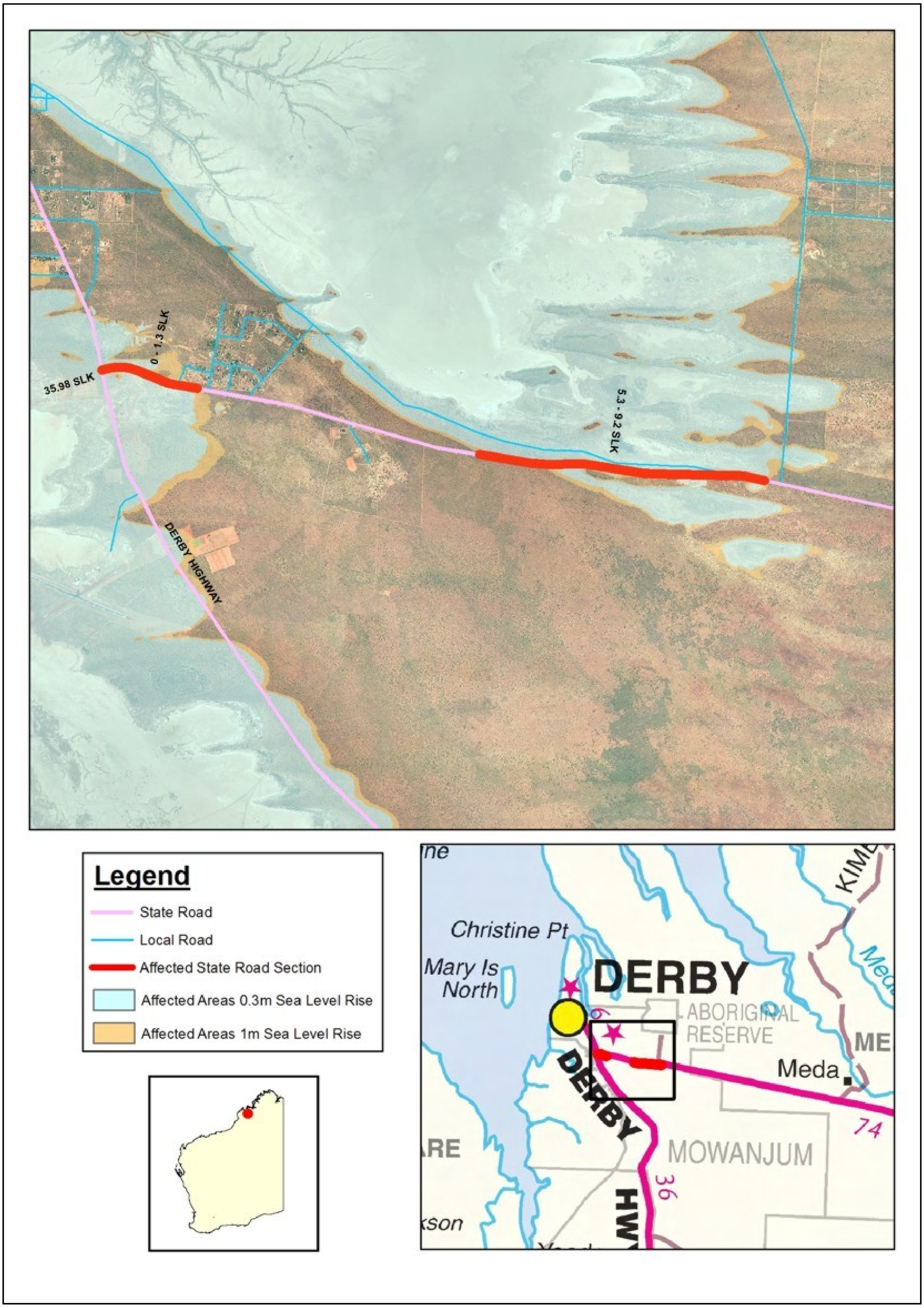
This section is likely to be affected by a 0.3m rise in sea level.



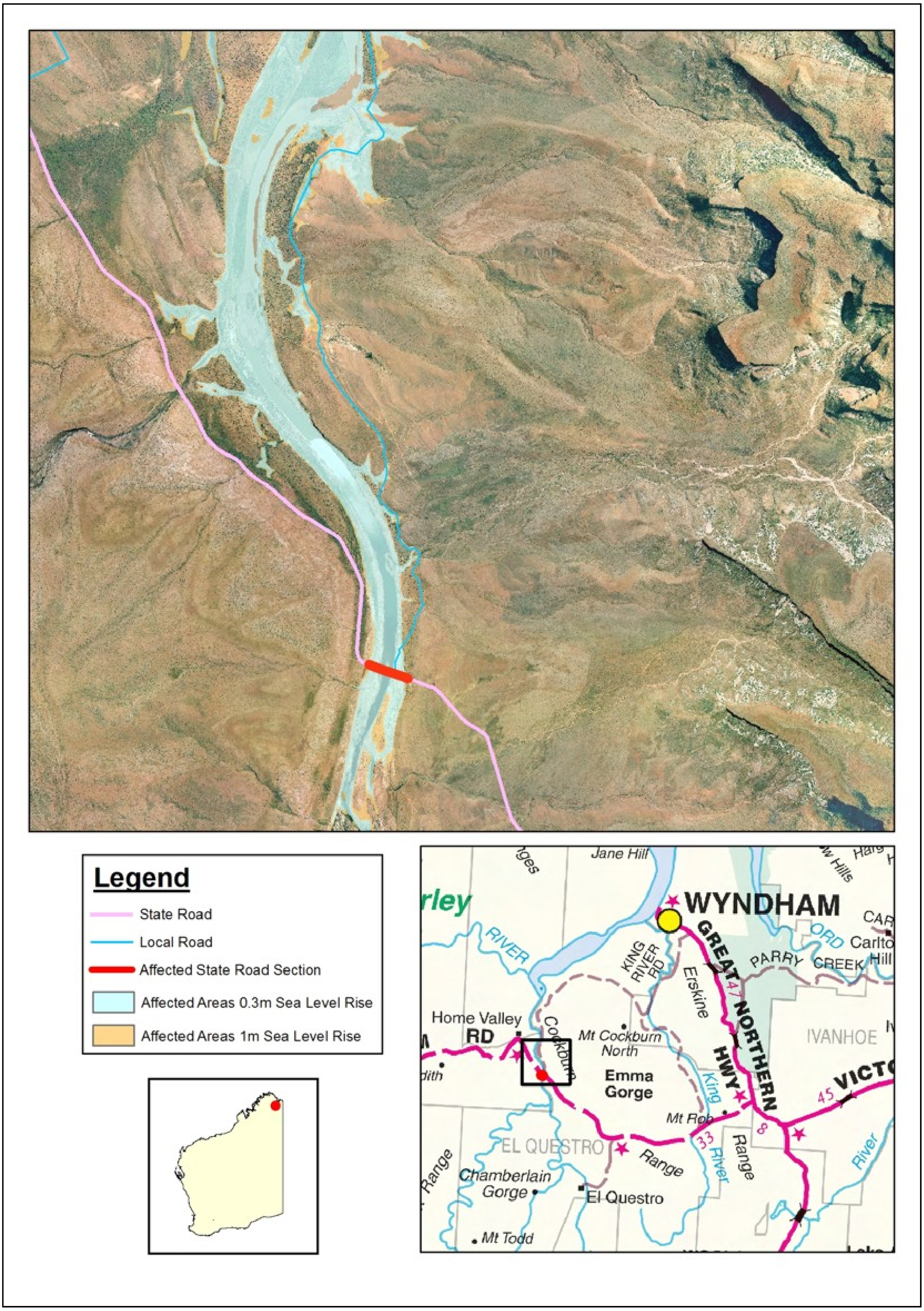
### D.10 Dampier Road (18.89 – 22.79 slk)



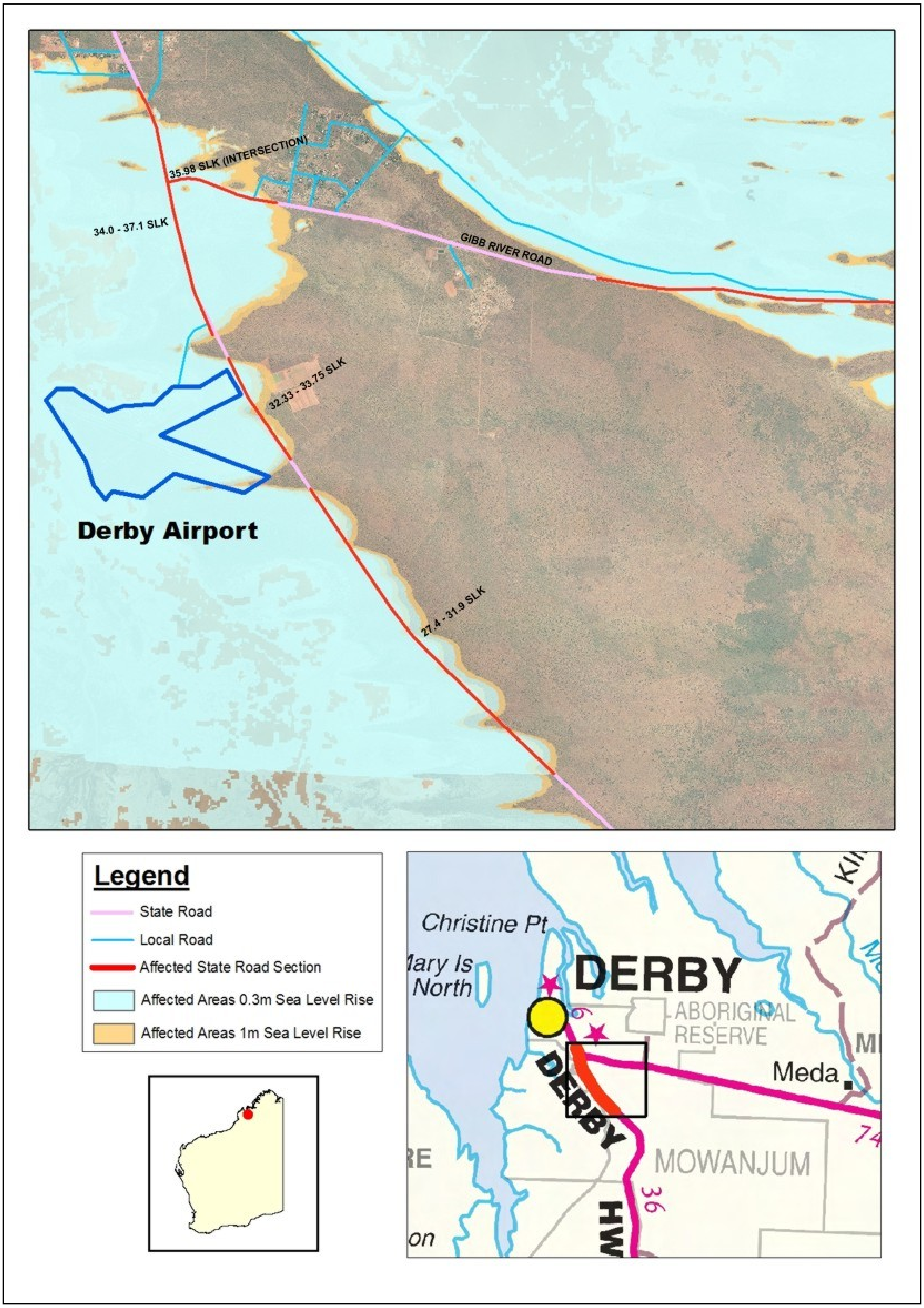
**D.11 Derby Gibb River Road (0 – 1.3, 5.3 – 9.2 slk)**



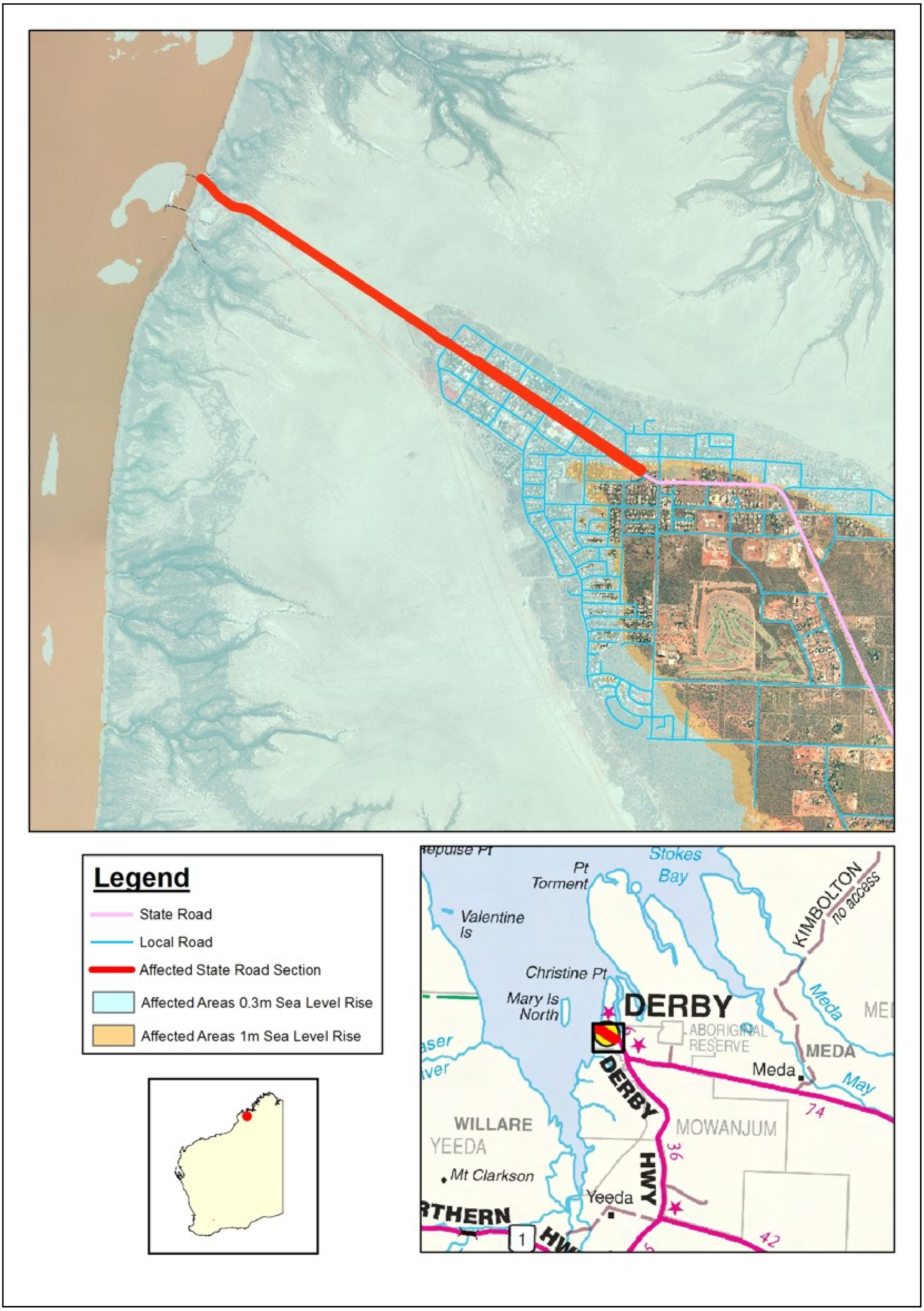
## D.12 Derby Gibb River Road (585.35 – 585.81 slk)



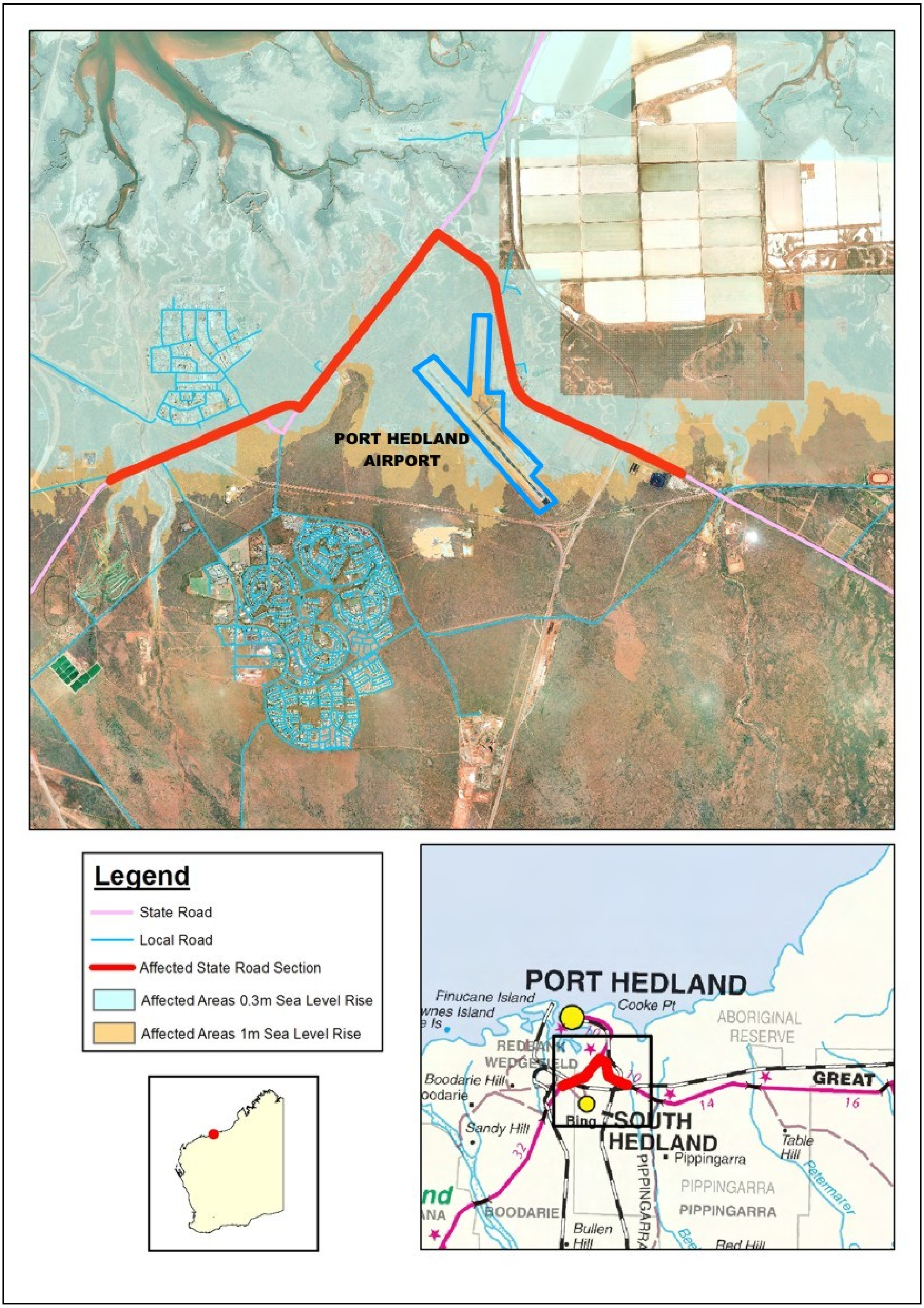
**D.13 Derby Highway (27.4 – 31.9, 32.33 – 33.75, 34.0 – 37.1 slk)**



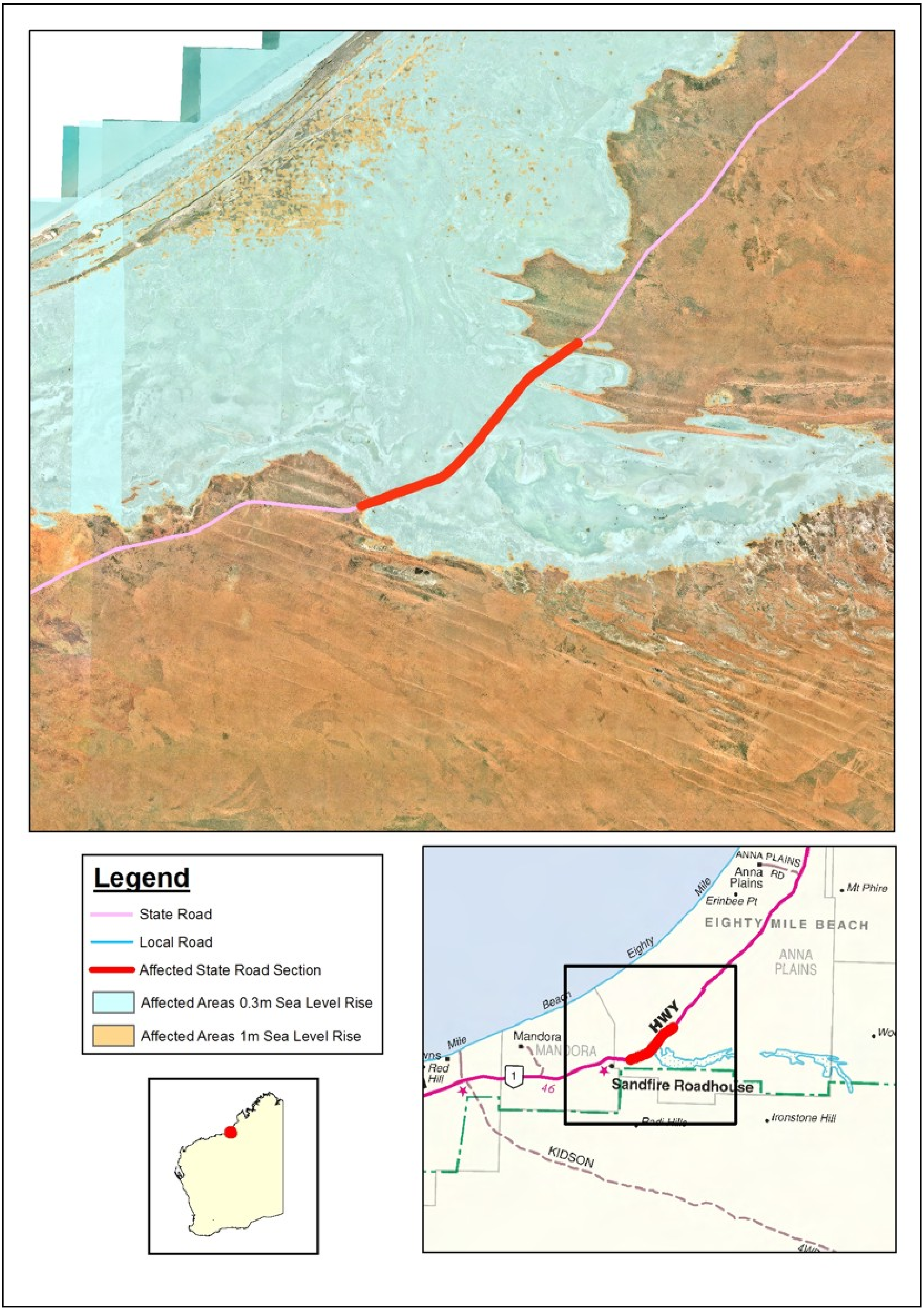
**D.14 Derby Highway (41.24 – 42.86 slk)**



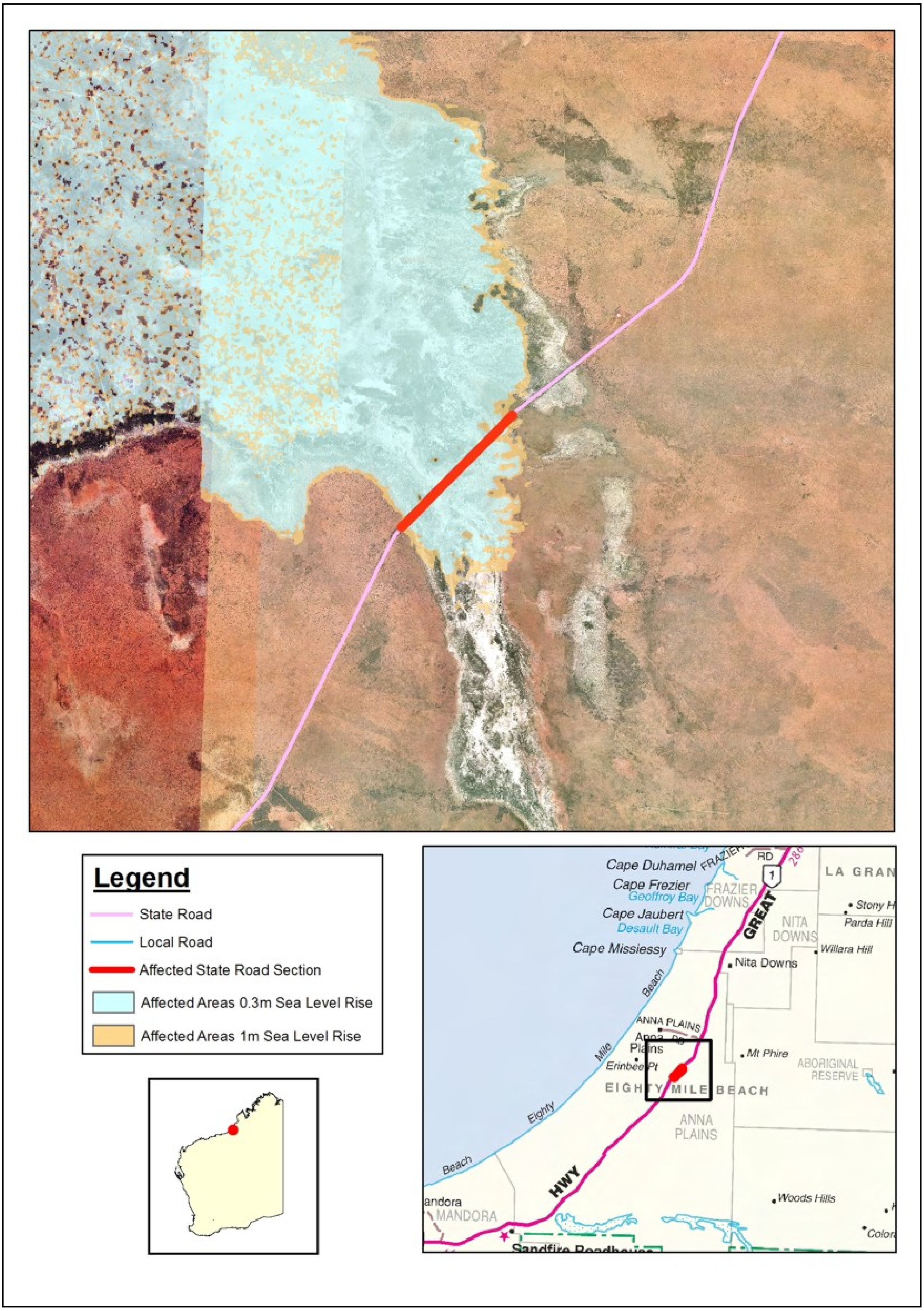
**D.15 Great Northern Highway (1600 – 1615 slk)**



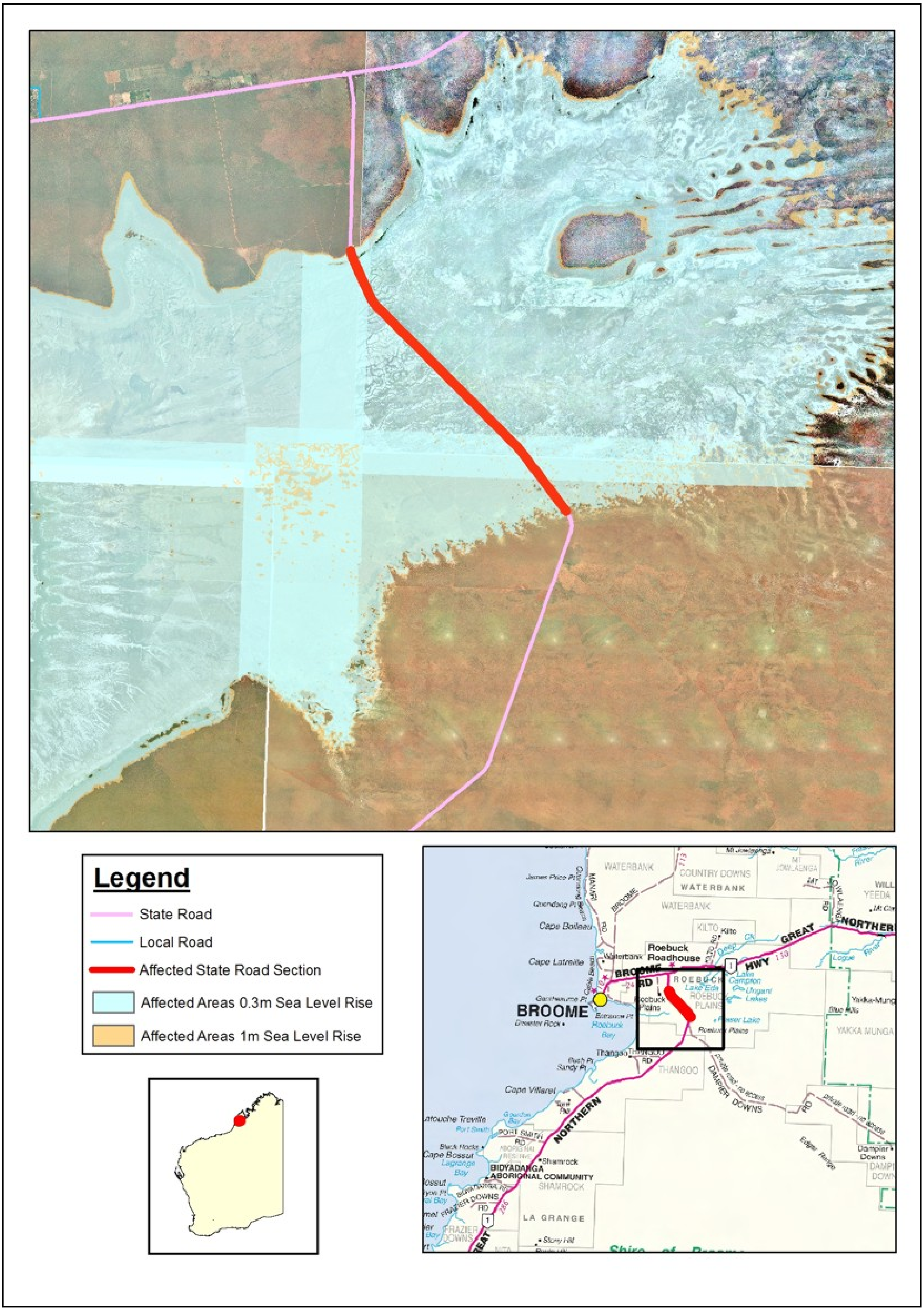
## D.16 Great Northern Highway (1880.62 – 1896.49 slk)



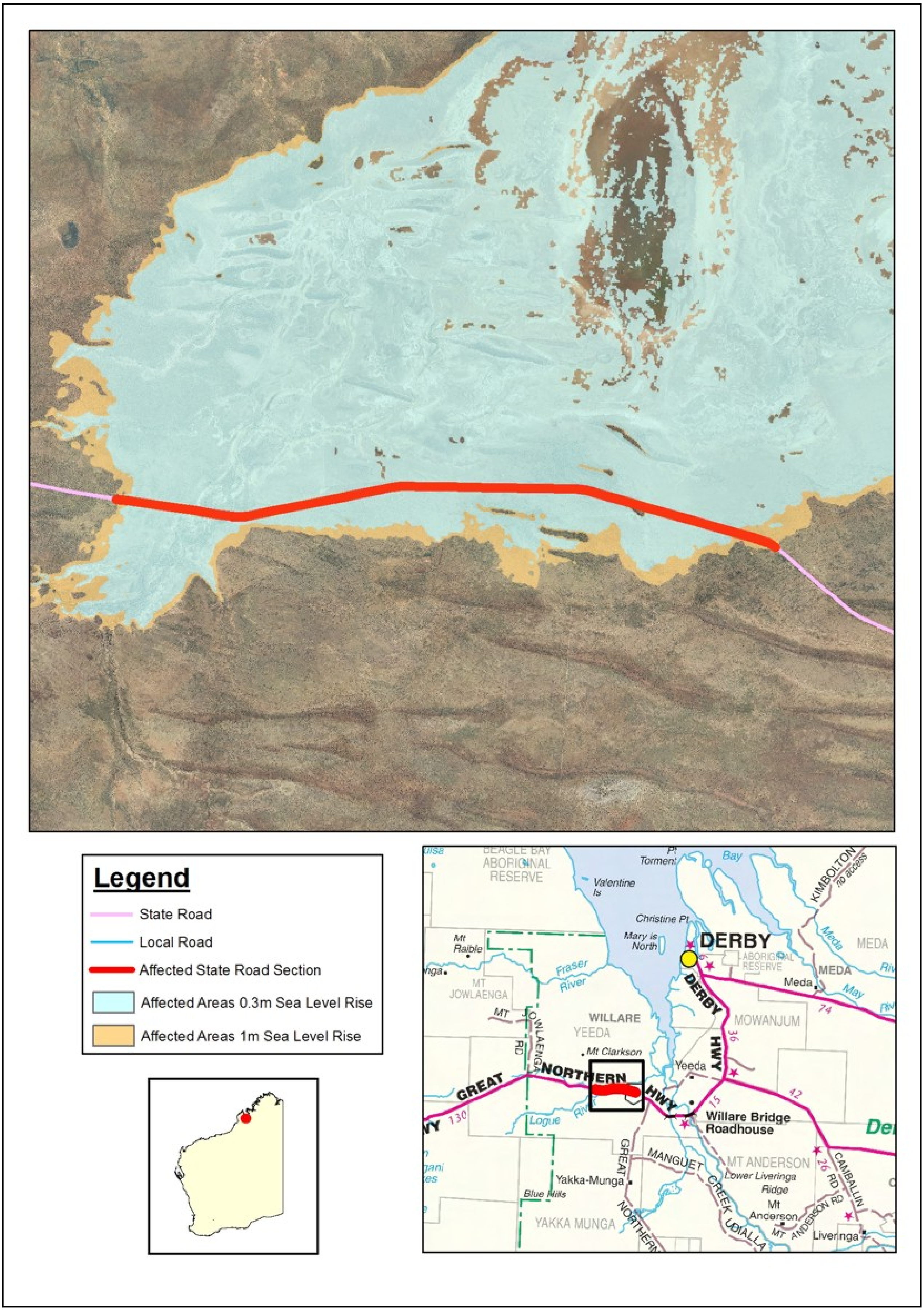
## D.17 Great Northern Highway (1941.06 – 1944.43 slk)



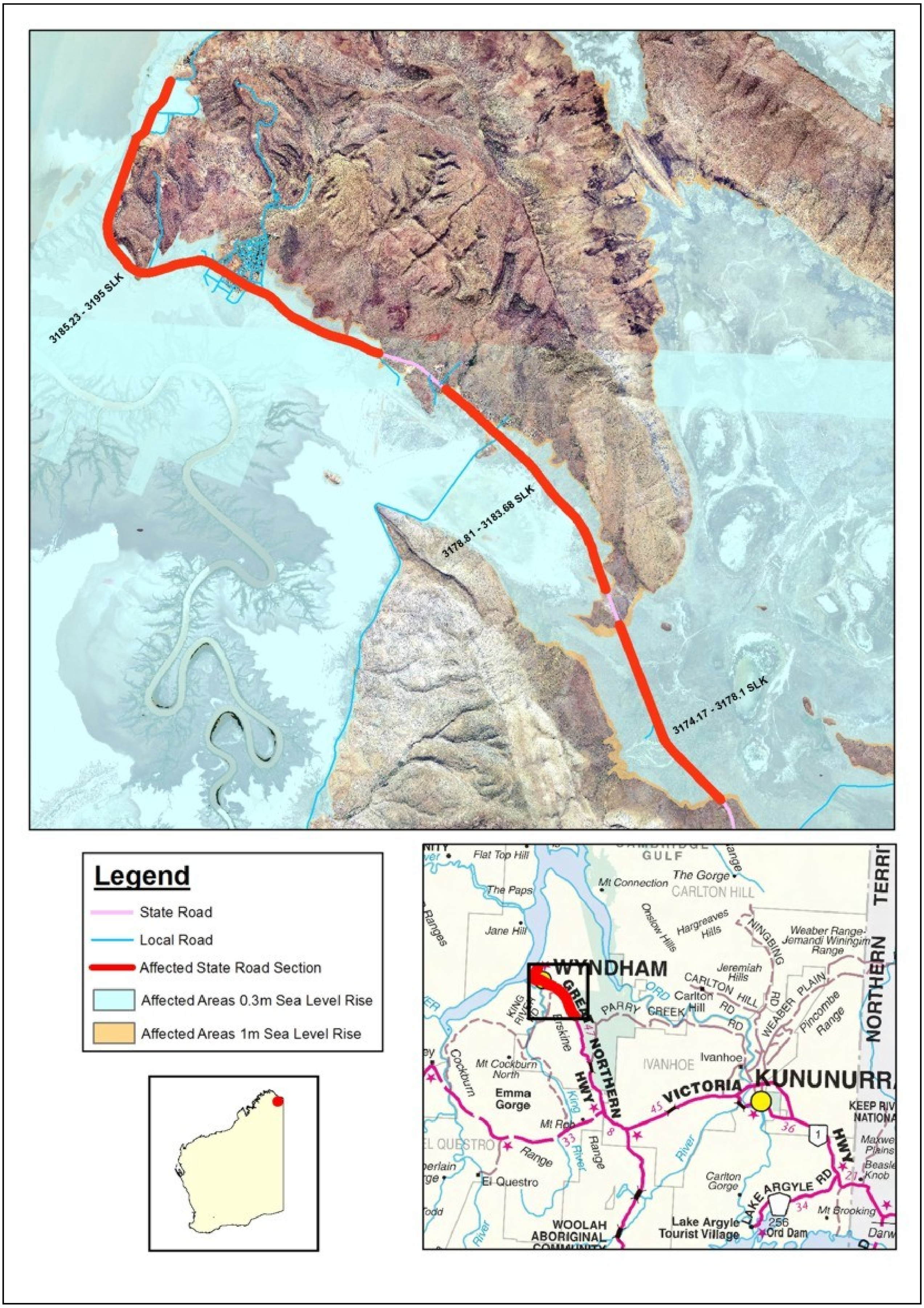
## D.18 Great Northern Highway (2138 – 2153 slk)



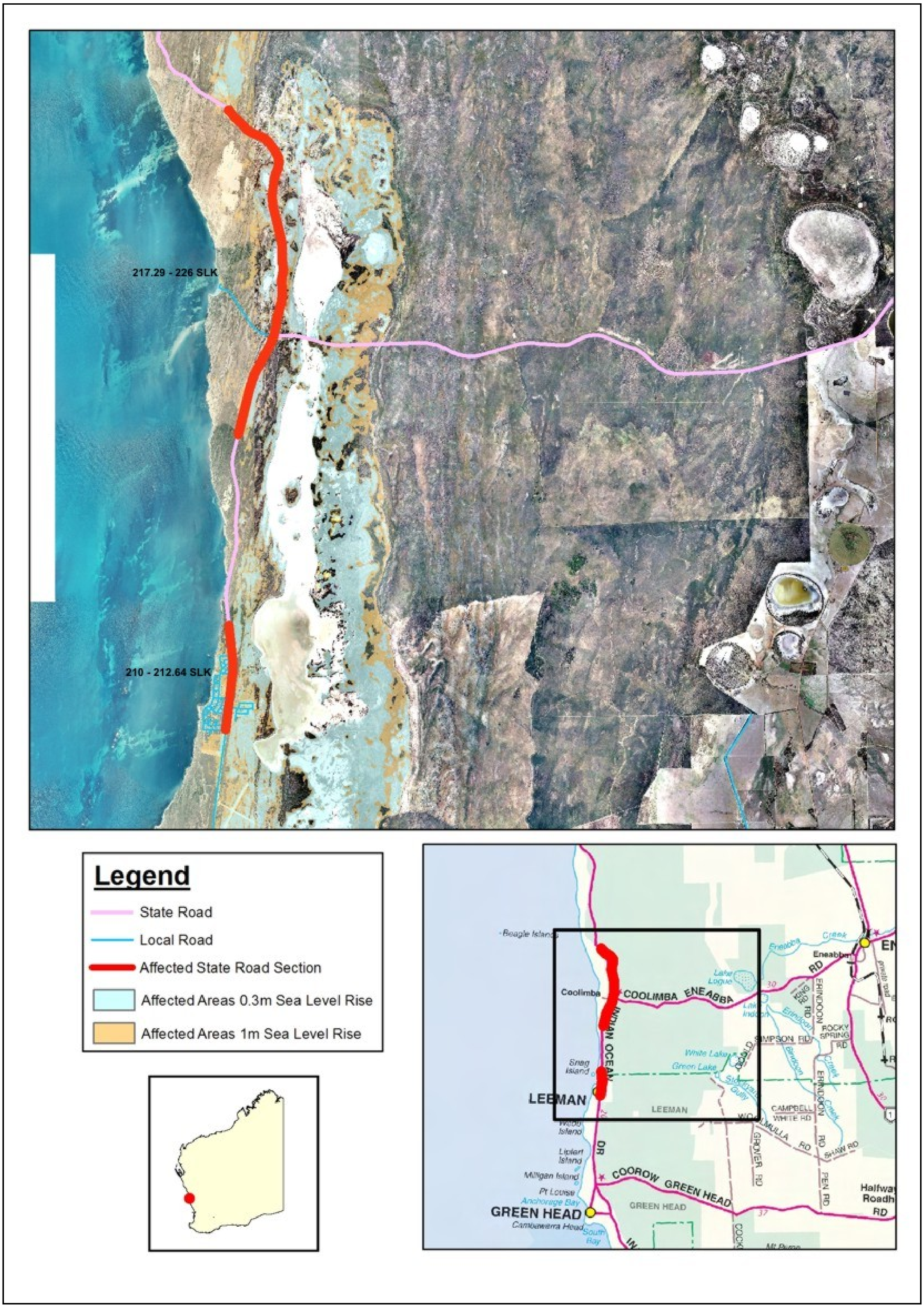
### D.19 Great Northern Highway (2258.61 – 2270.98 slk)



**D.20 Great Northern Highway (3174.17 – 3178.10, 3178.81 – 3183.68, 3185.23 - 3195 slk)**

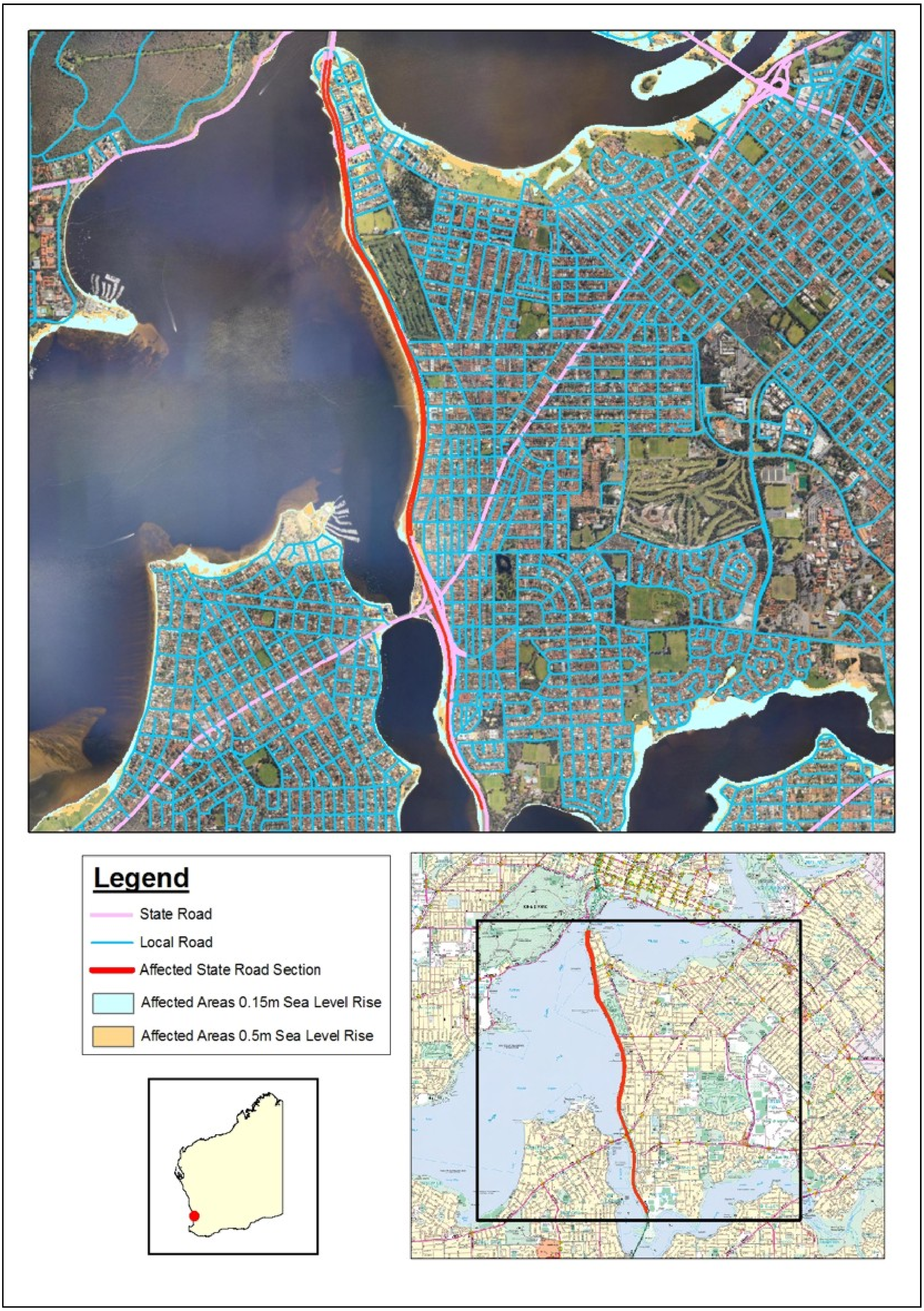


**D.21 Indian Ocean Drive (210 – 212.64, 217.29 – 226 slk)**



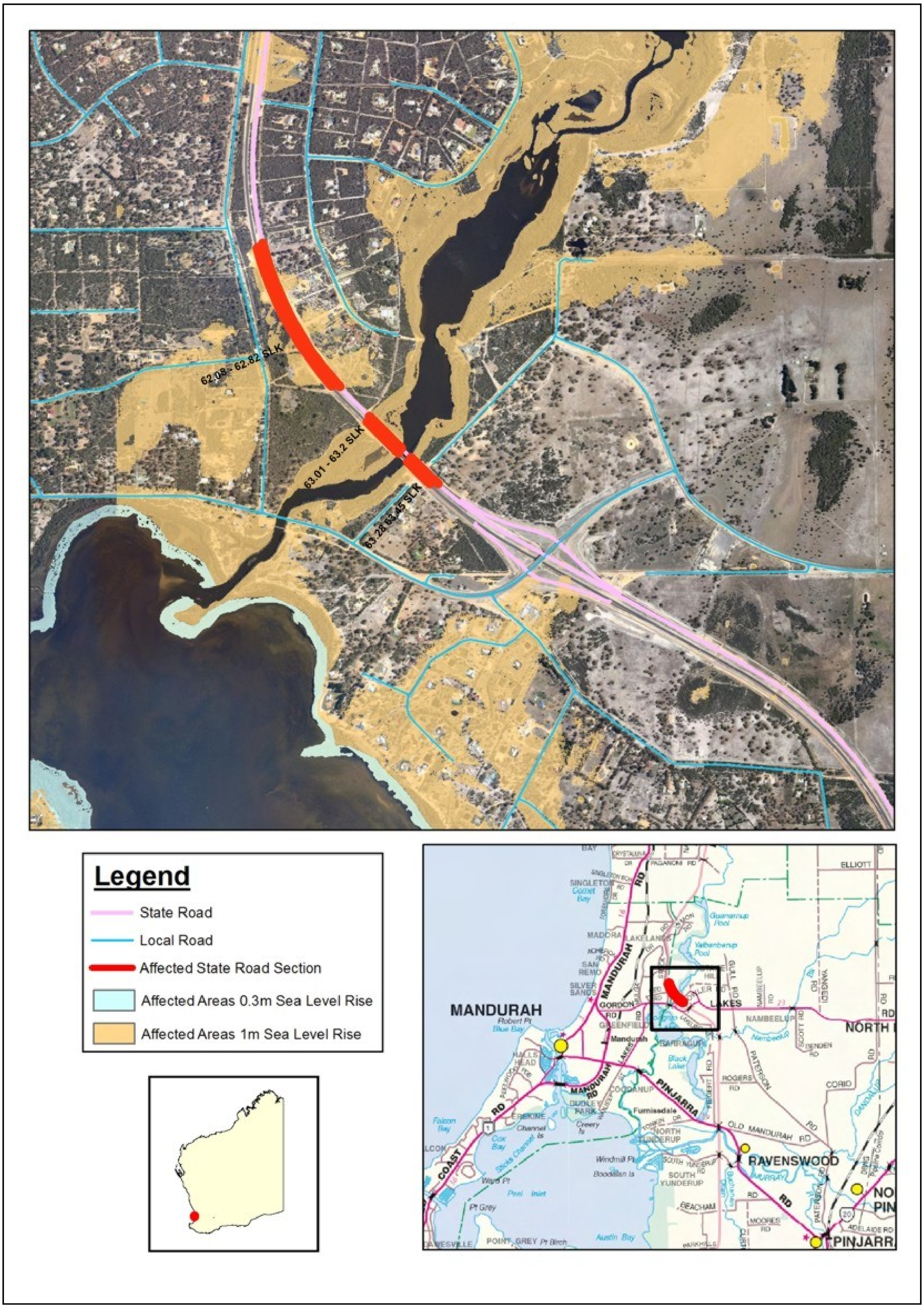
**D.22 Kwinana Freeway (0.6 - 7.5 slk)**

This section has been modeled using a 150mm and 500mm water level rise (Refer Map D.1).



### D.23 Kwinana Freeway (62.08 – 62.82, 63.01 – 63.2, 63.28 – 63.45 slk)

This section is unlikely to be affected by a 0.3m rise in sea level.



### D.24 Lakelands – Lake Clifton Rd (Old Coast Rd) (10.51 – 11.29 slk)

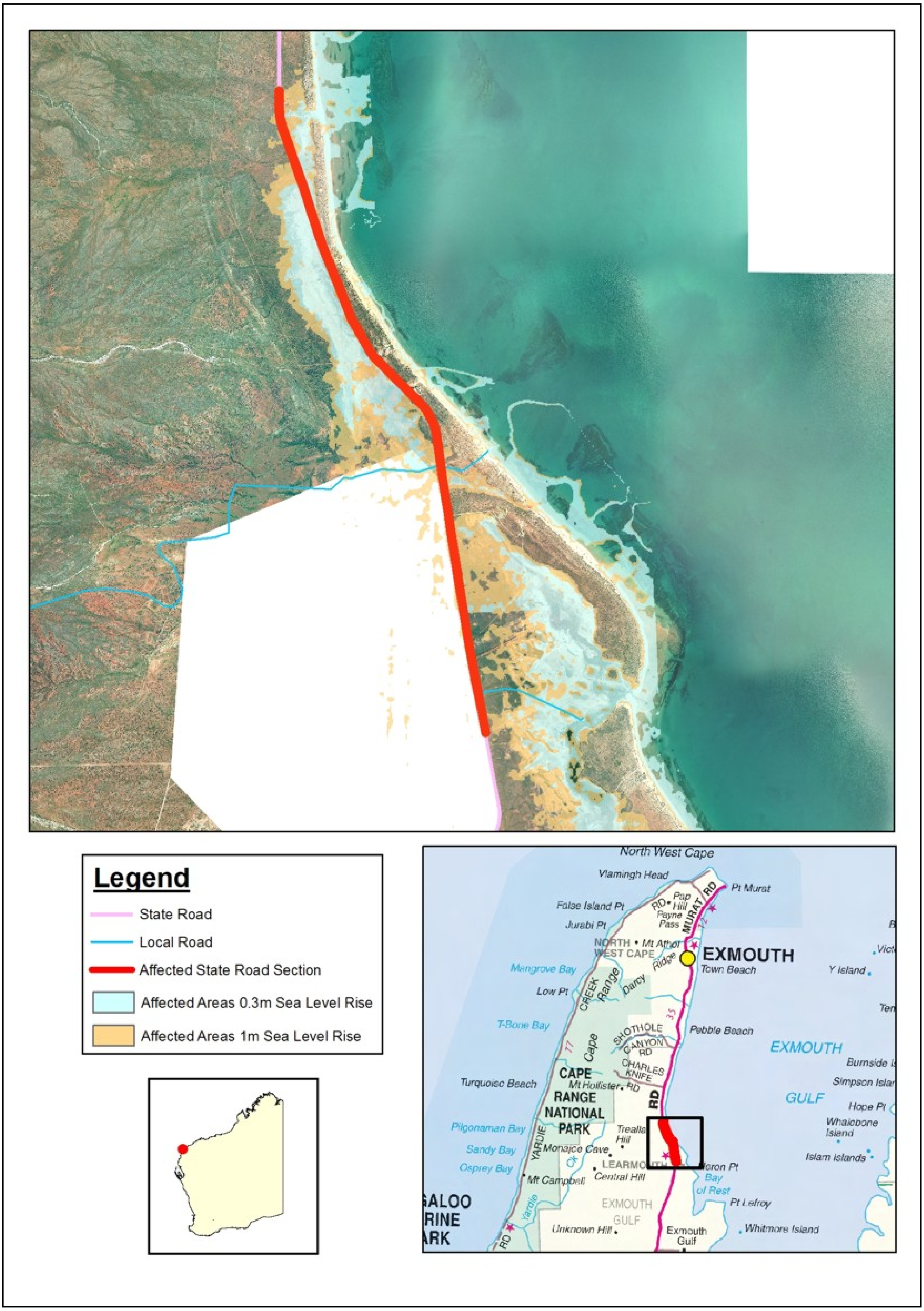
This section is unlikely to be affected by a 0.3m rise in sea level.

### D.25 Lakelands – Lake Clifton Rd (Old Coast Rd) (16.85 – 17.30 slk)

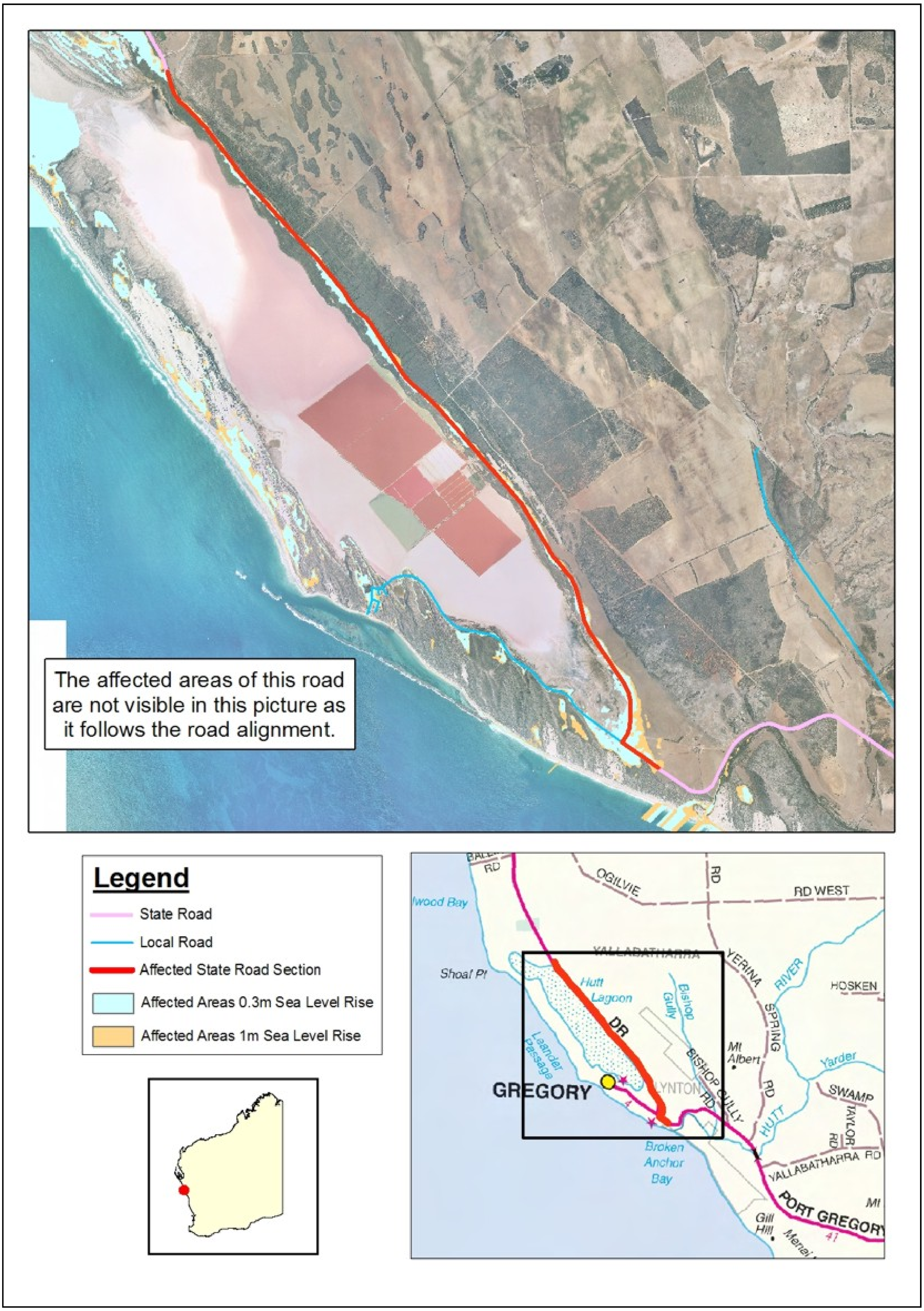
This section is unlikely to be affected by a 0.3m rise in sea level.

**D.26 Lakelands – Lake Clifton Rd (Old Coast Rd) - (34.83 – 35.01, 35.31 – 36.51, 36.7 – 37.68, 38.02 – 38.2 slk)**

## D.27 Minilya Exmouth Road (181 – 188.5 slk)

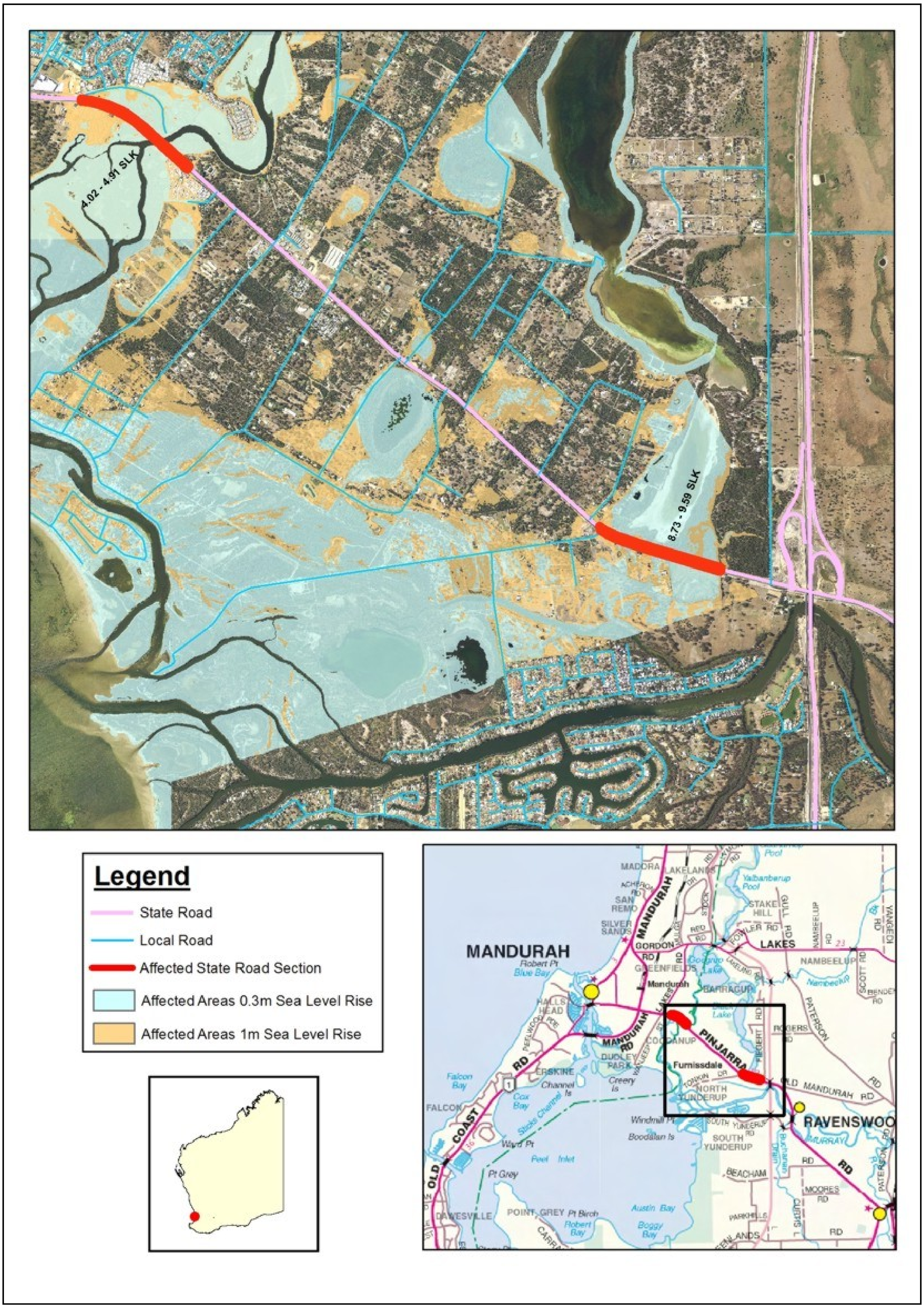


### D.28 Northampton Port Gregory Road (41.56 – 56.04 slk)

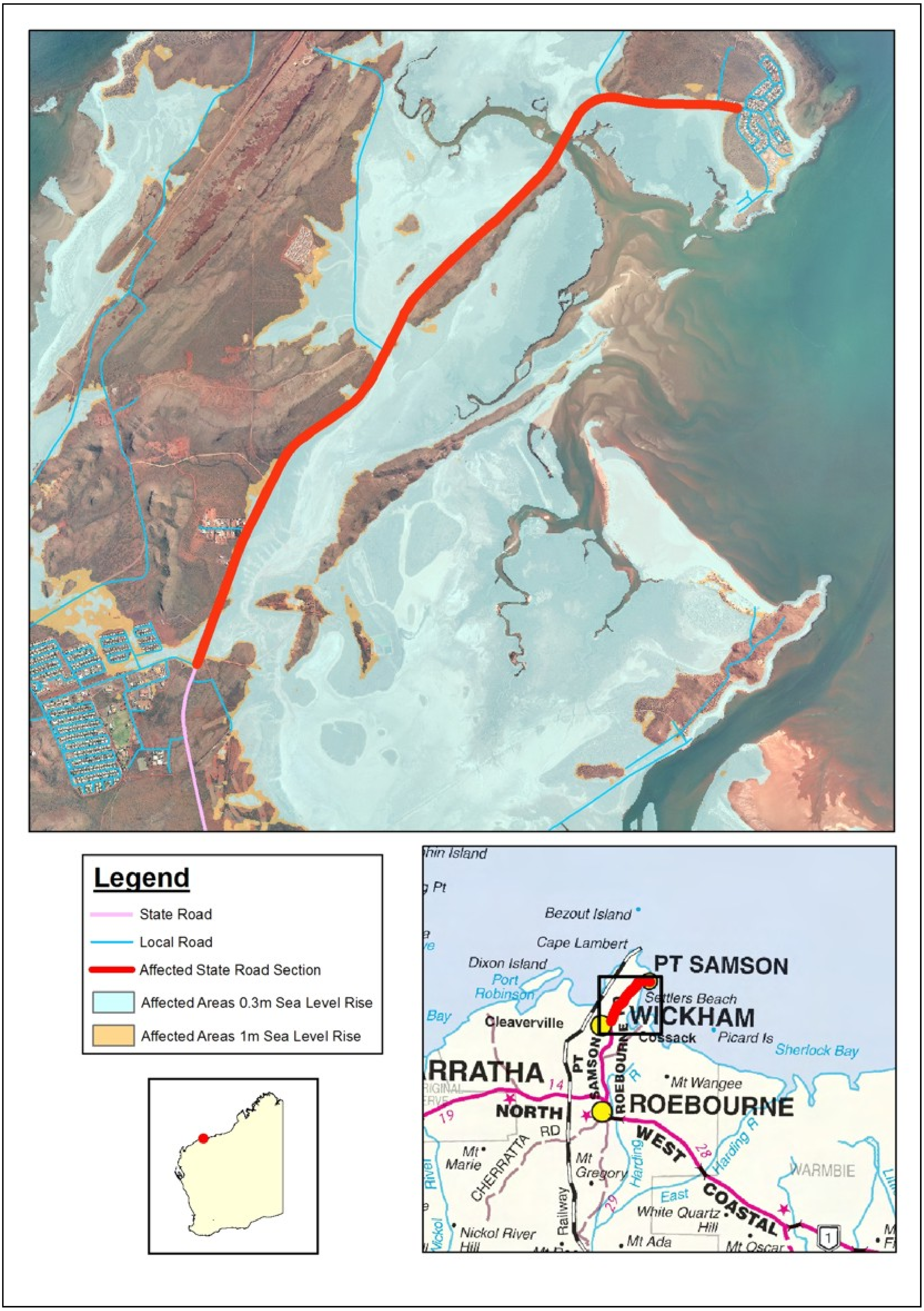


**D.29 Onslow Road (66.08 – 69.36, 69.85 – 70.04, 70.75 – 74.21, 75.01 – 76.62, 77.4 – 79.4 slk)**

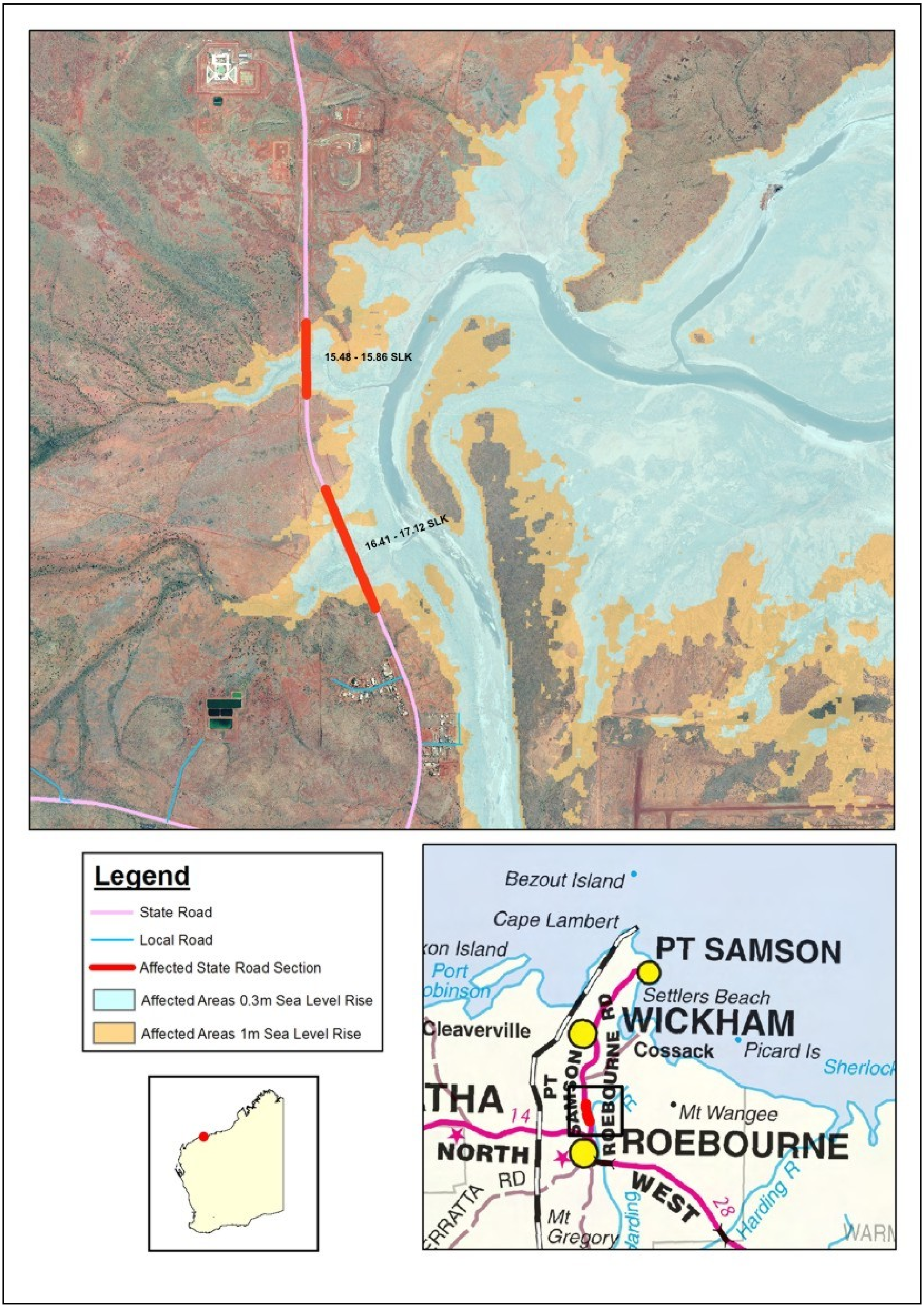
**D.30 Pinjarra Road (4.02 – 4.91, 8.73 – 9.59 slk)**



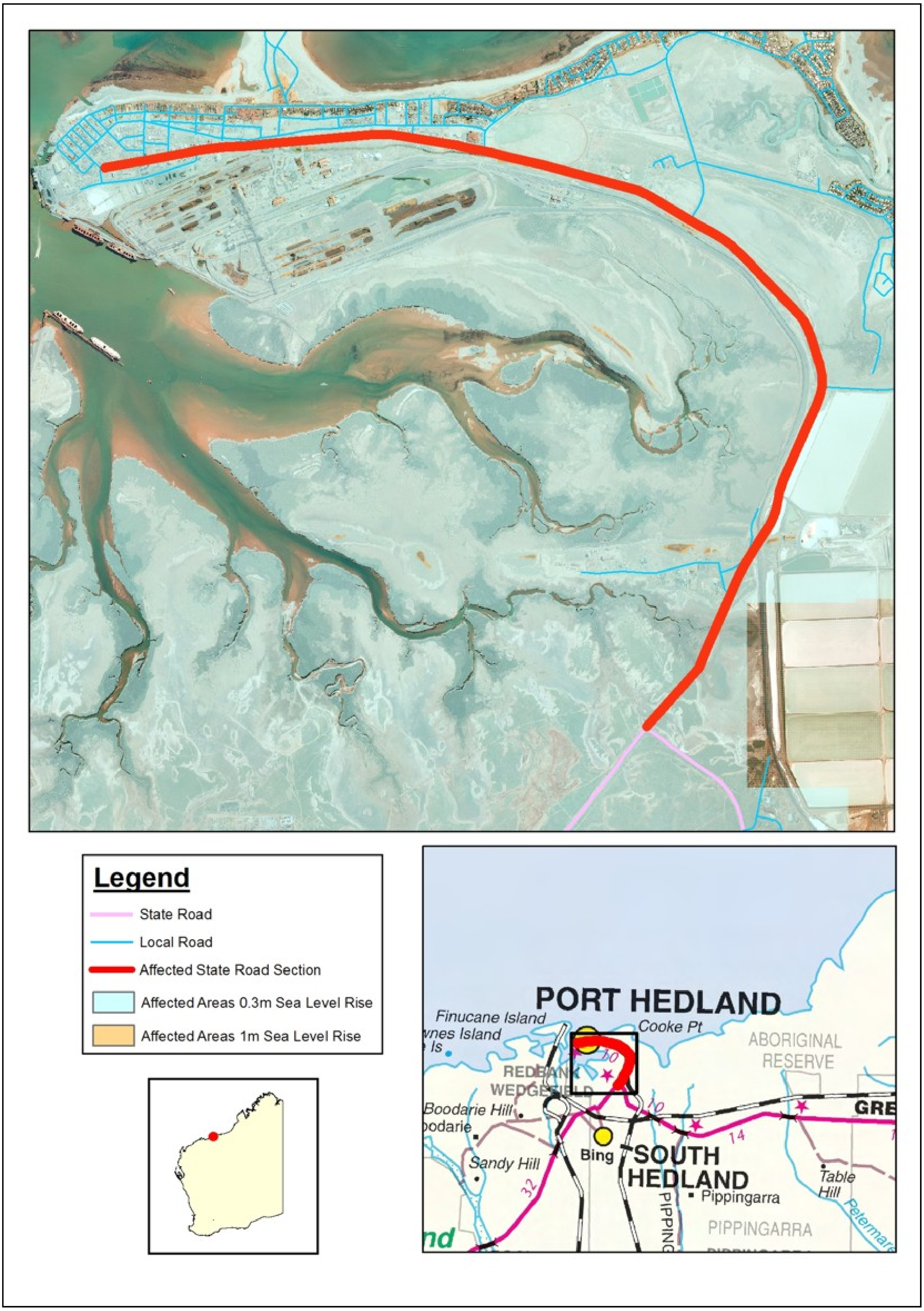
### D.31 Point Samson Roebourne Road (0 – 8.1 slk)



**D.32 Point Samson Roebourne Road (15.48 – 15.86, 16.41 – 17.12 slk)**

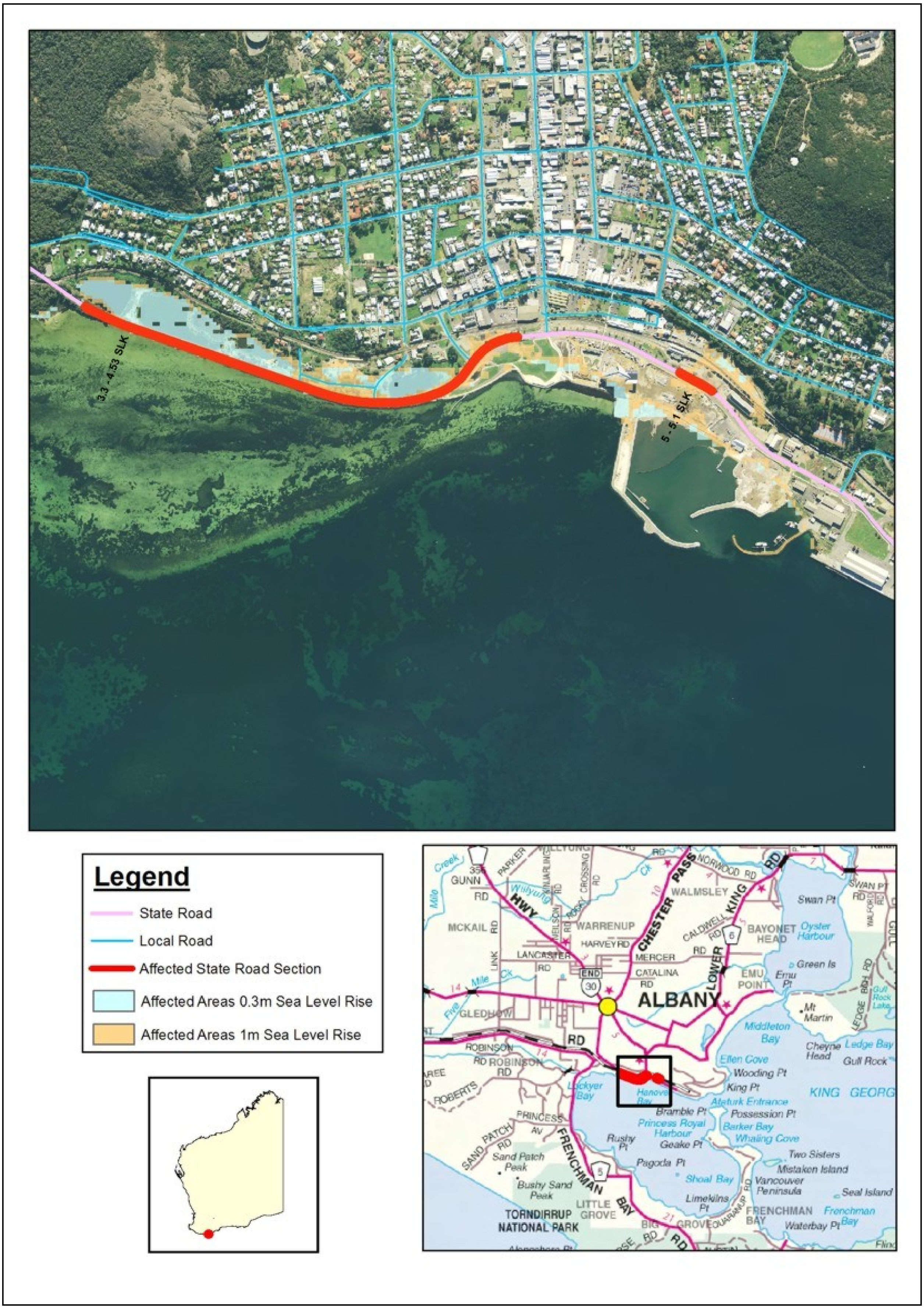


**D.33 Port Hedland Road (0 - 10.38 slk)**

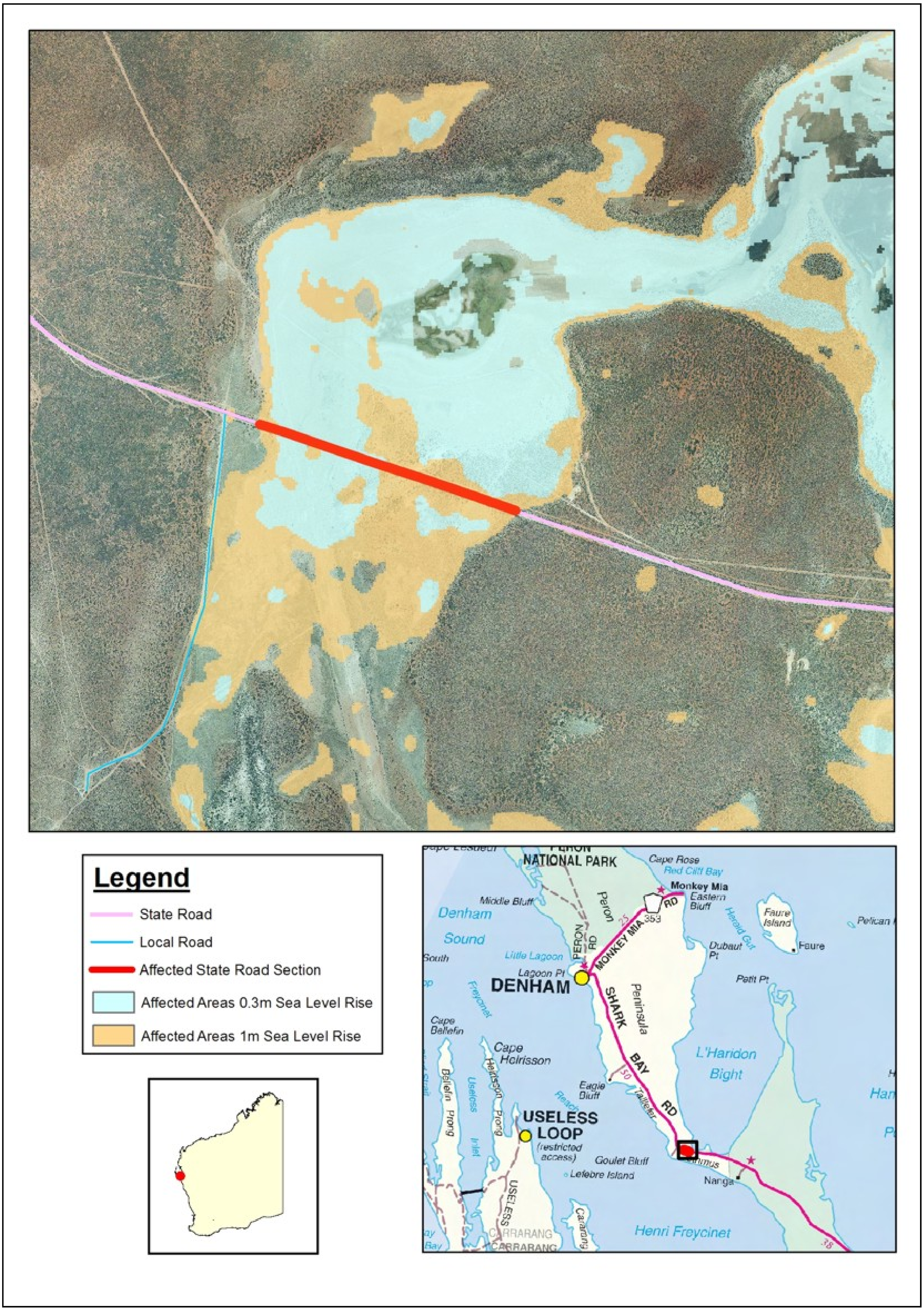


## D.34 Princess Royal Drive (3.3 – 4.53, 5.0 – 5.1 slk)

The 5.0 – 5.1 SLK section is unlikely to be affected by a 0.3m rise in sea level.

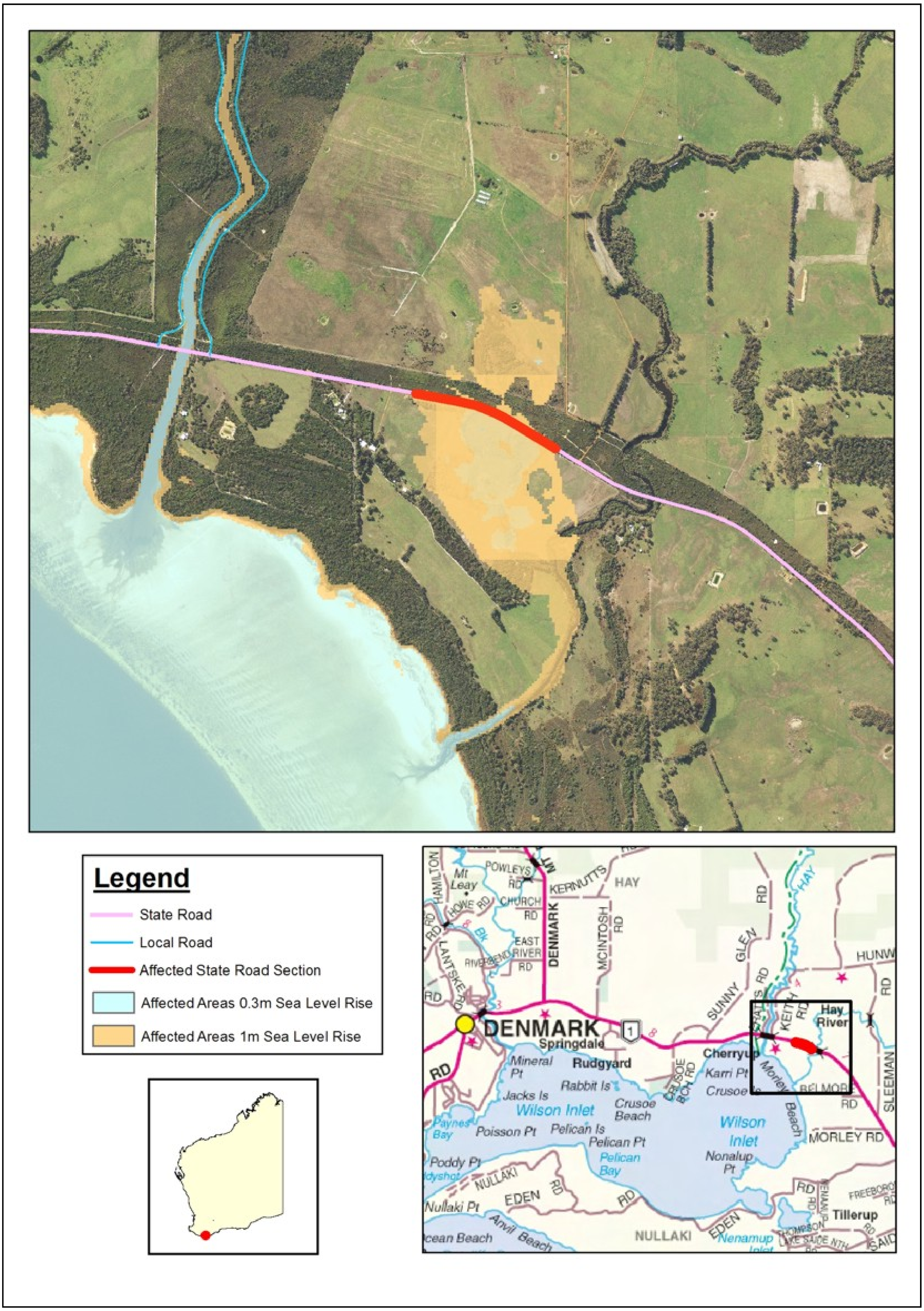


**D.35 Shark Bay Road (91.09 – 92.05 slk)**

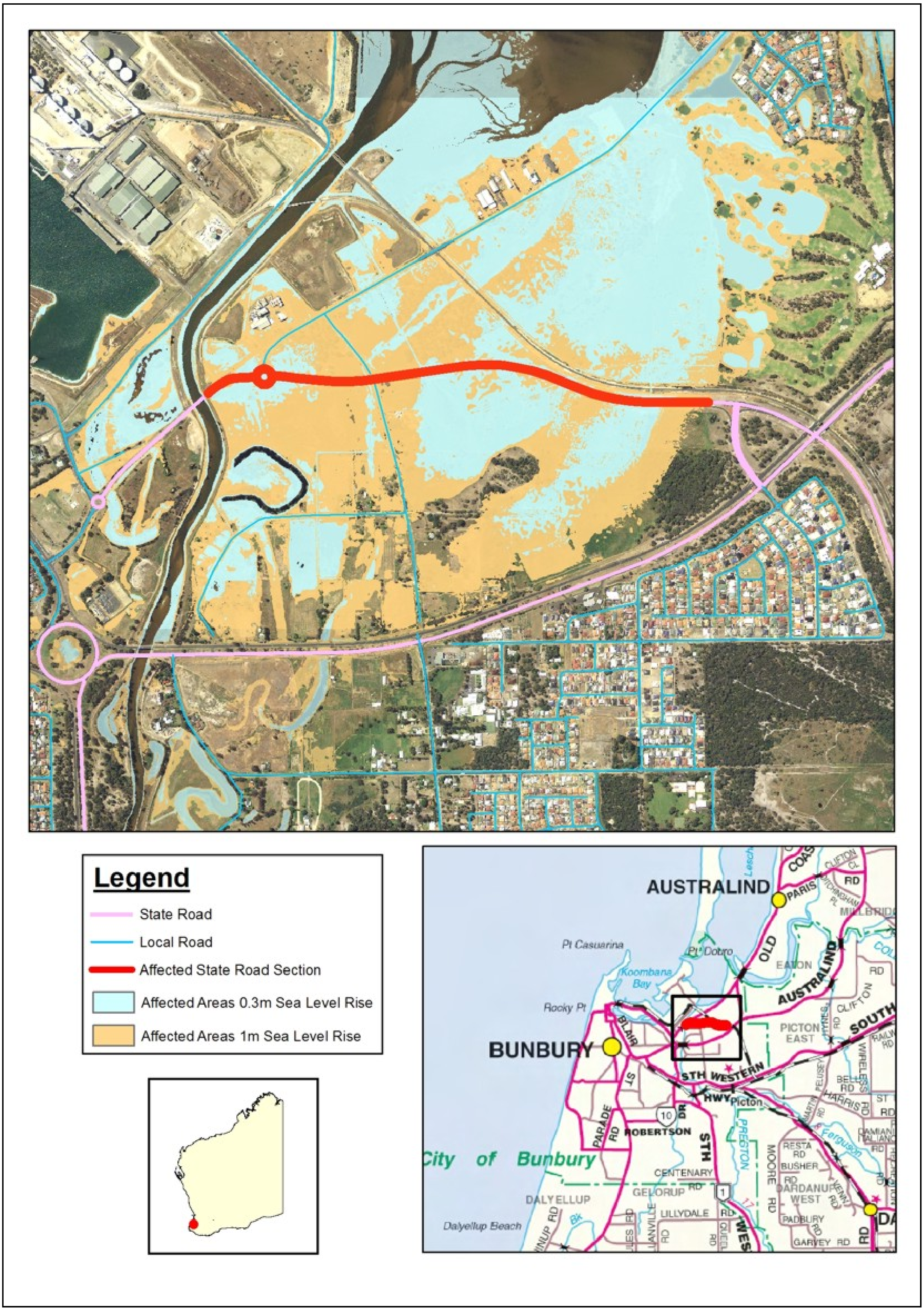


**D.36 South Coast Highway (475.52 – 476.15 slk)**

This section is unlikely to be affected by a 0.3m rise in sea level.



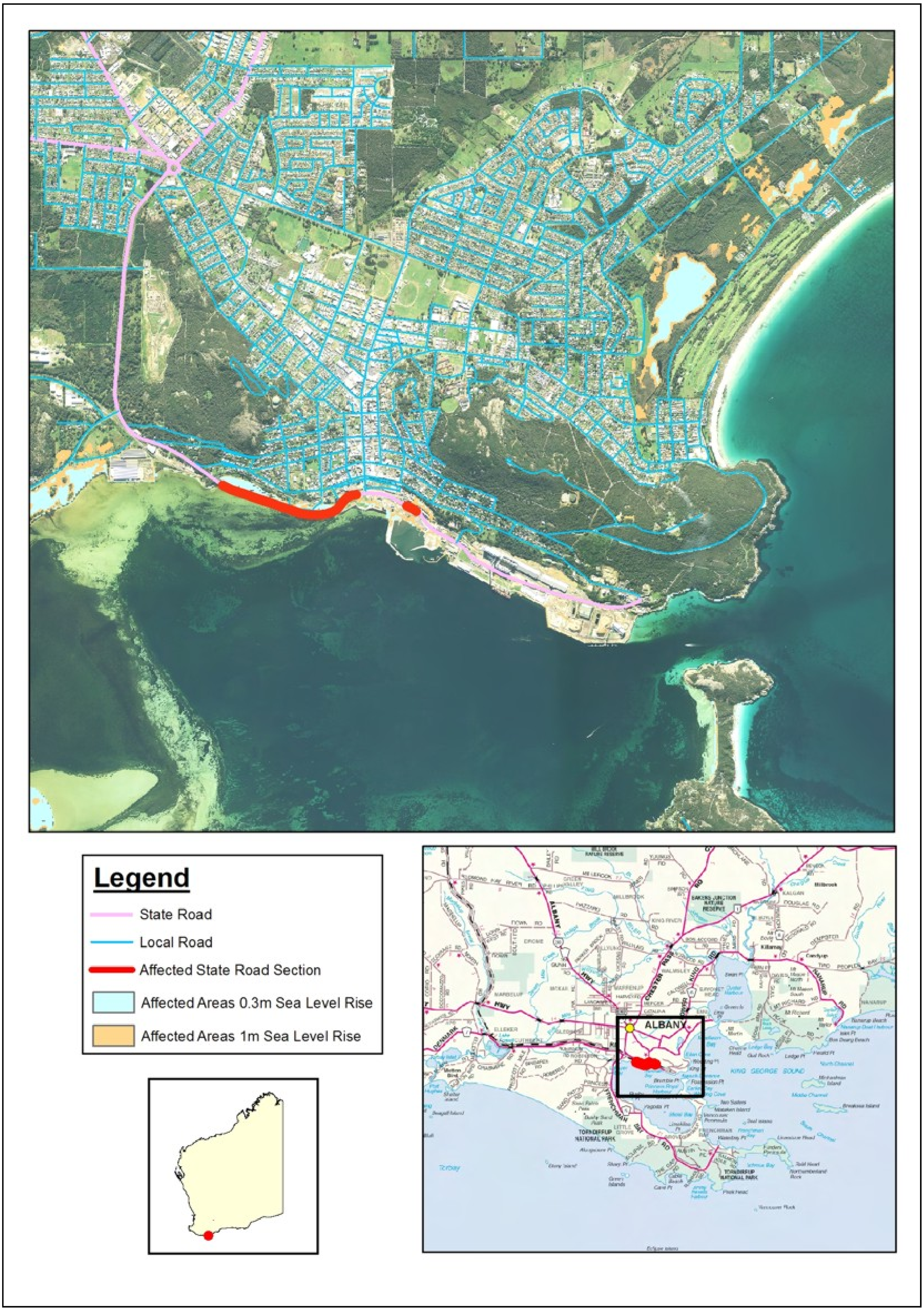
**D.37 Willinge Dr (0.4 – 2.1slk)**



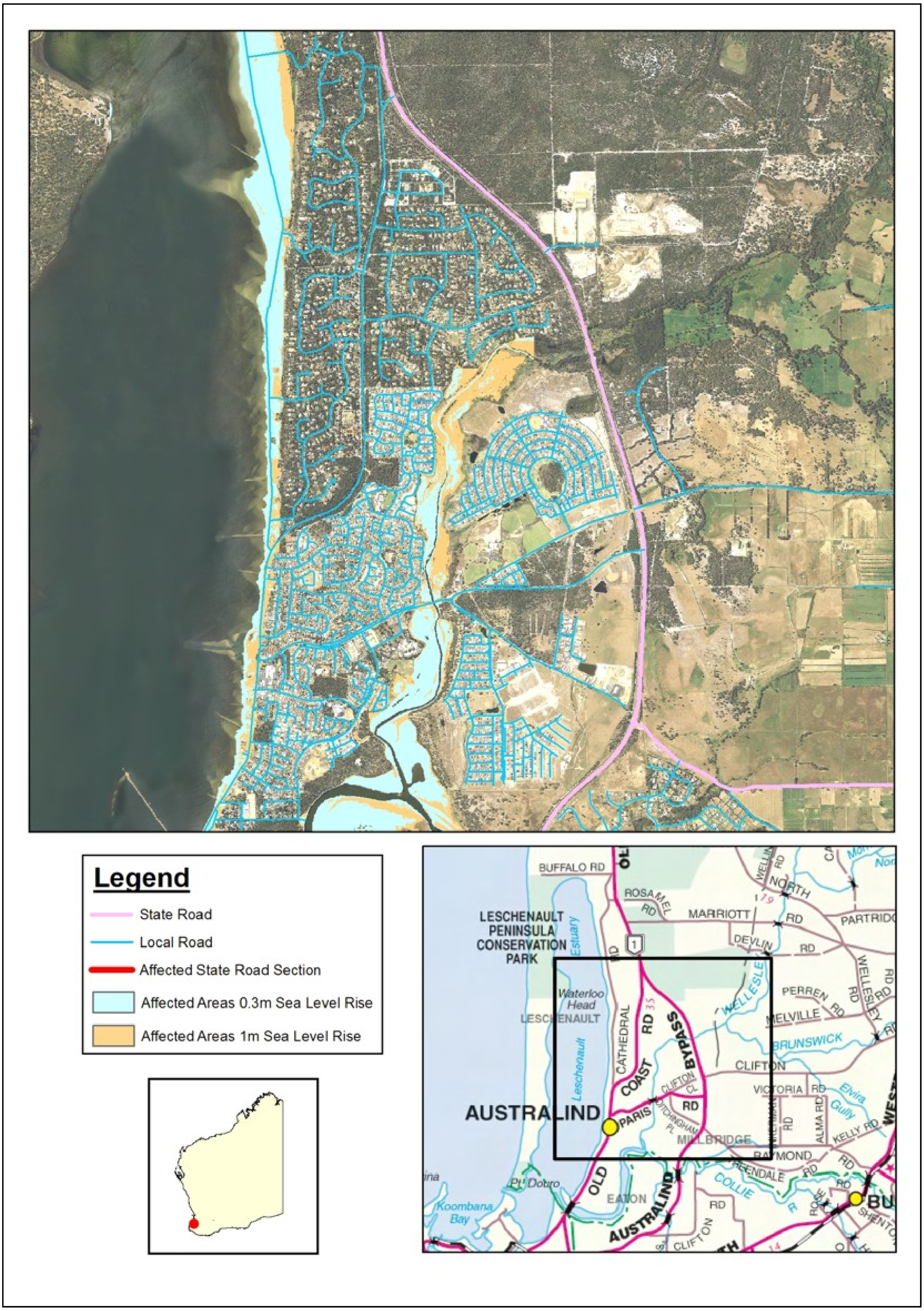
# APPENDIX E - MAPS OF MAJOR COASTAL TOWNS

## SEA LEVEL RISE MODELLING

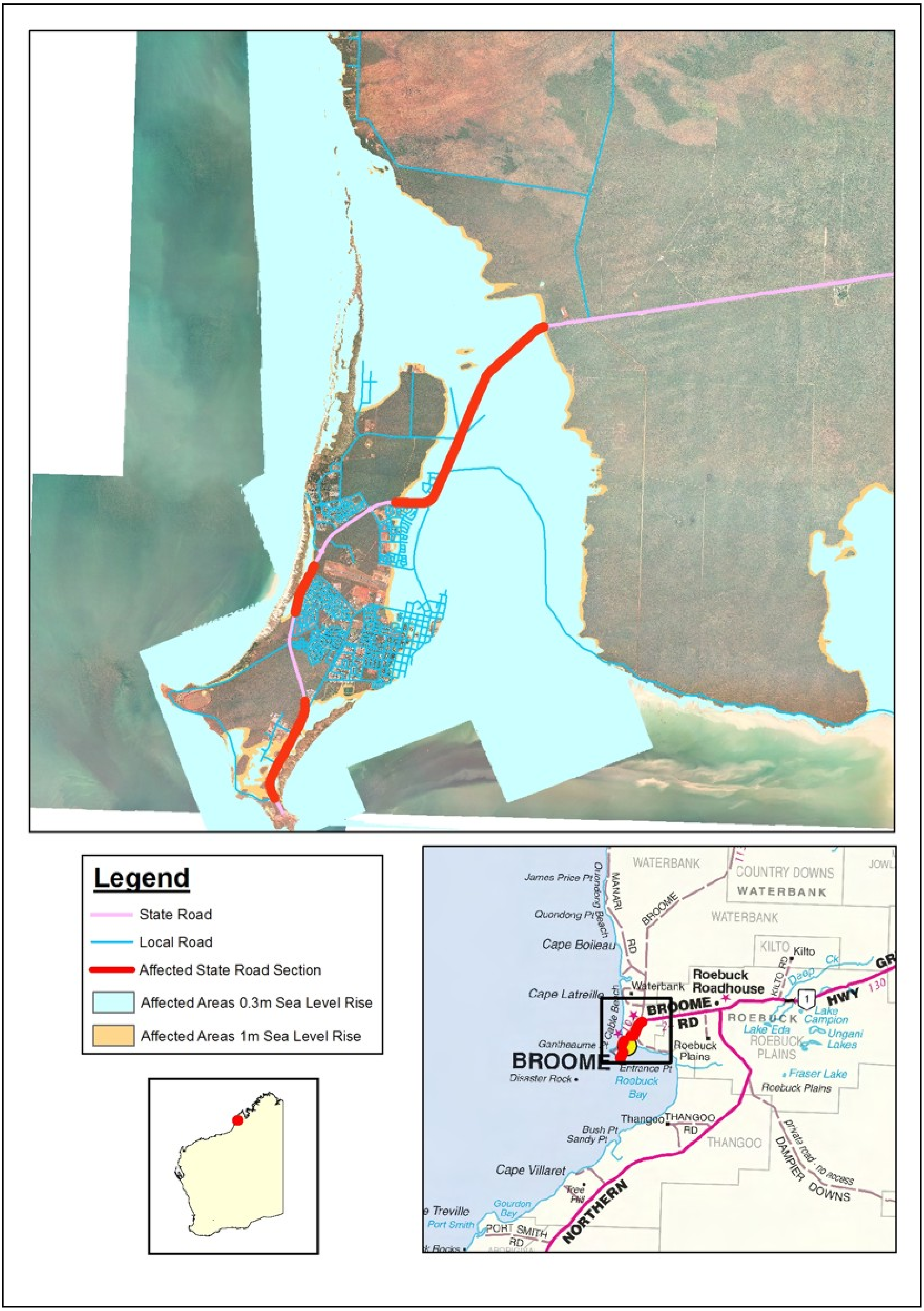
## Townsite Sea Level Rise Modeling – Albany



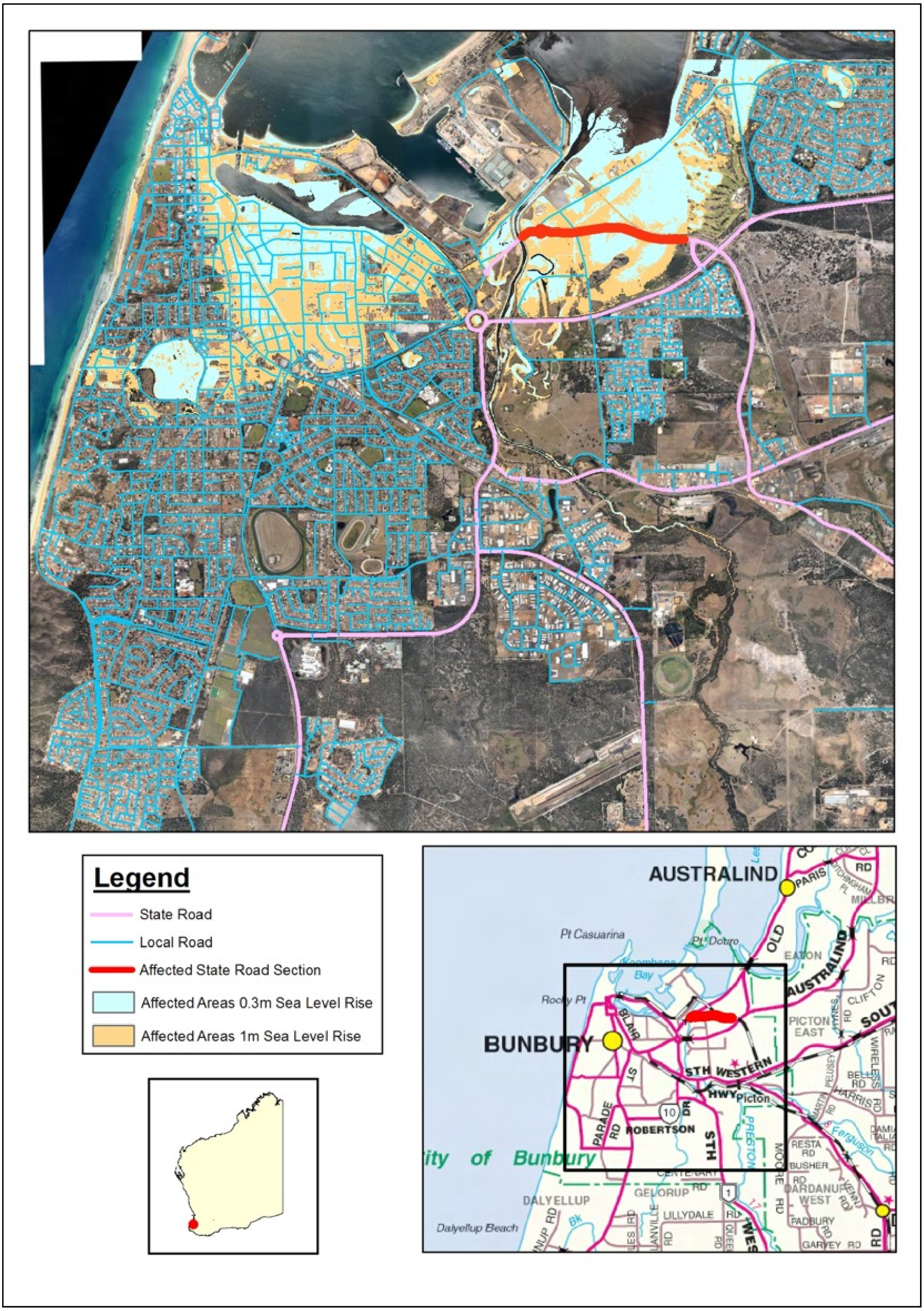
**Townsite Sea Level Rise Modeling – Australind**



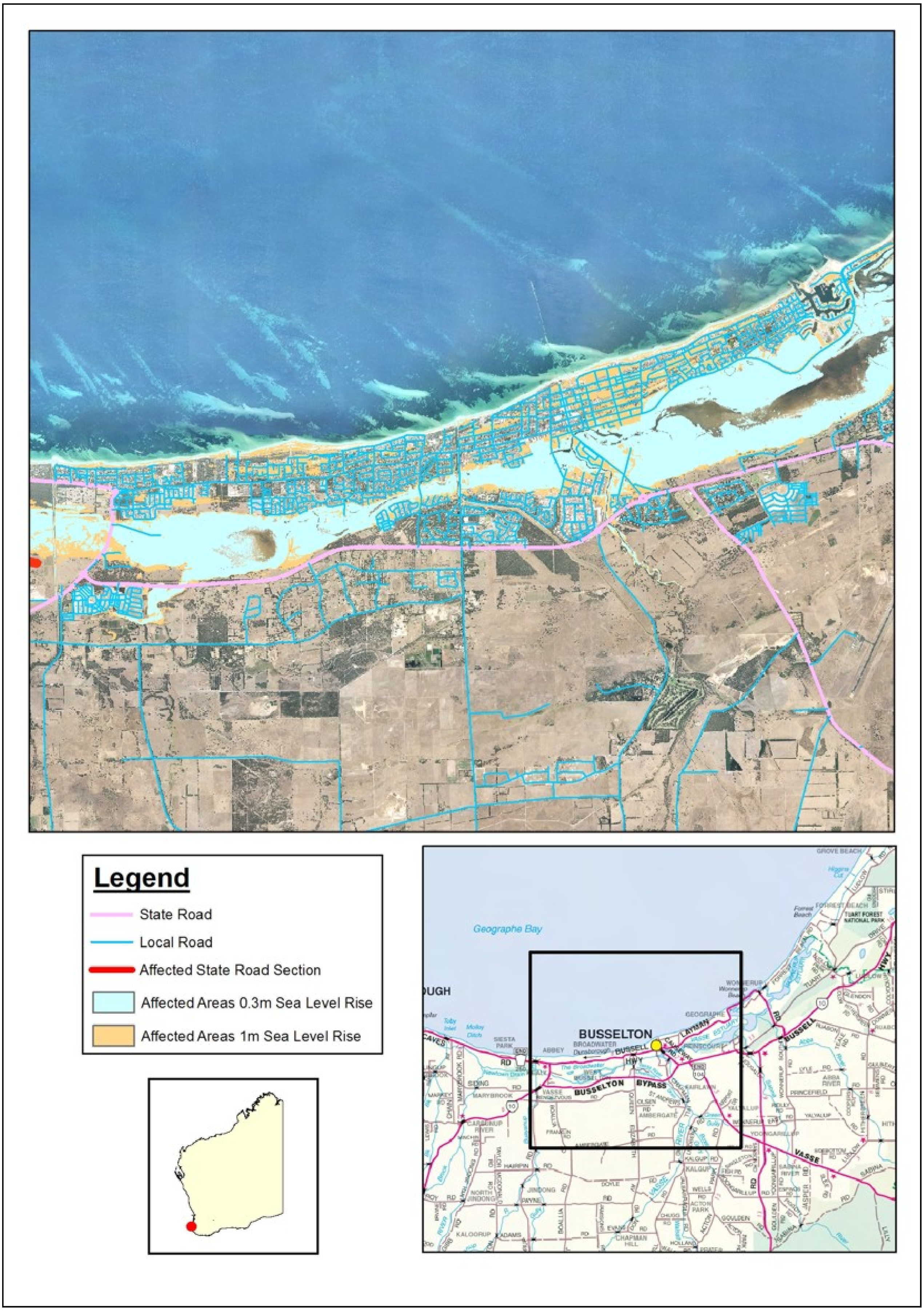
## Townsite Sea Level Rise Modeling – Broome



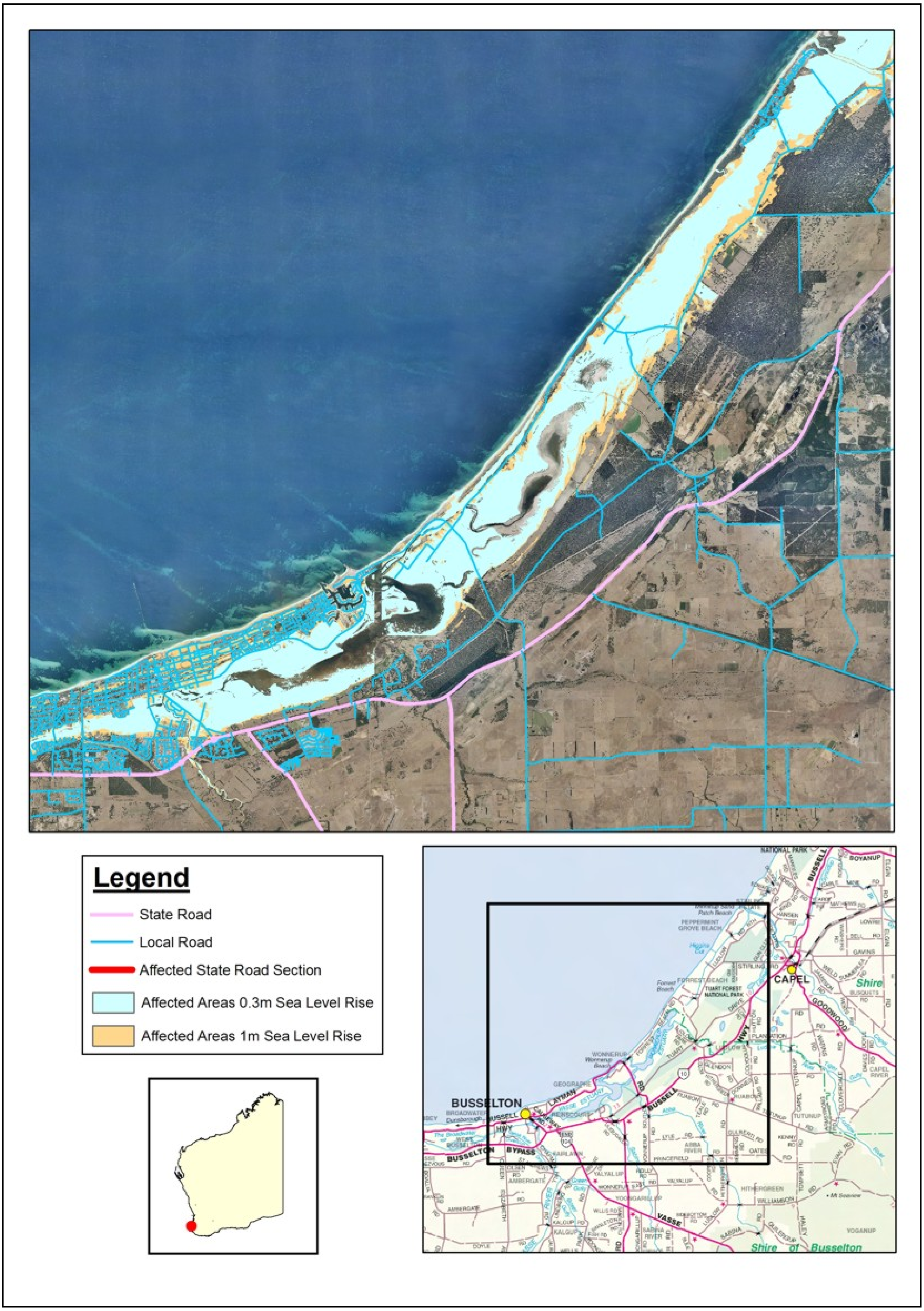
**Townsite Sea Level Rise Modeling – Bunbury**



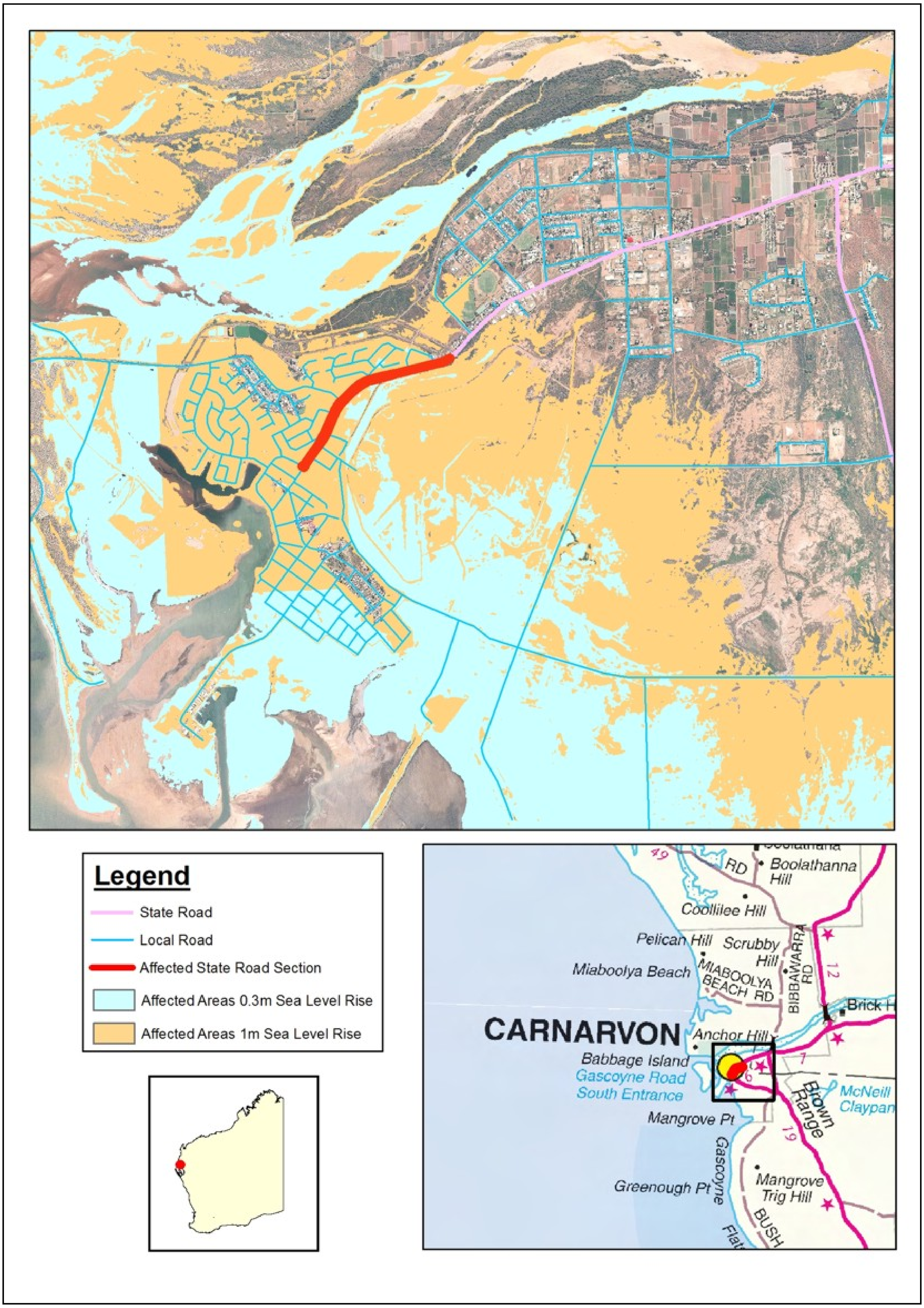
## Townsite Sea Level Rise Modeling – Busselton



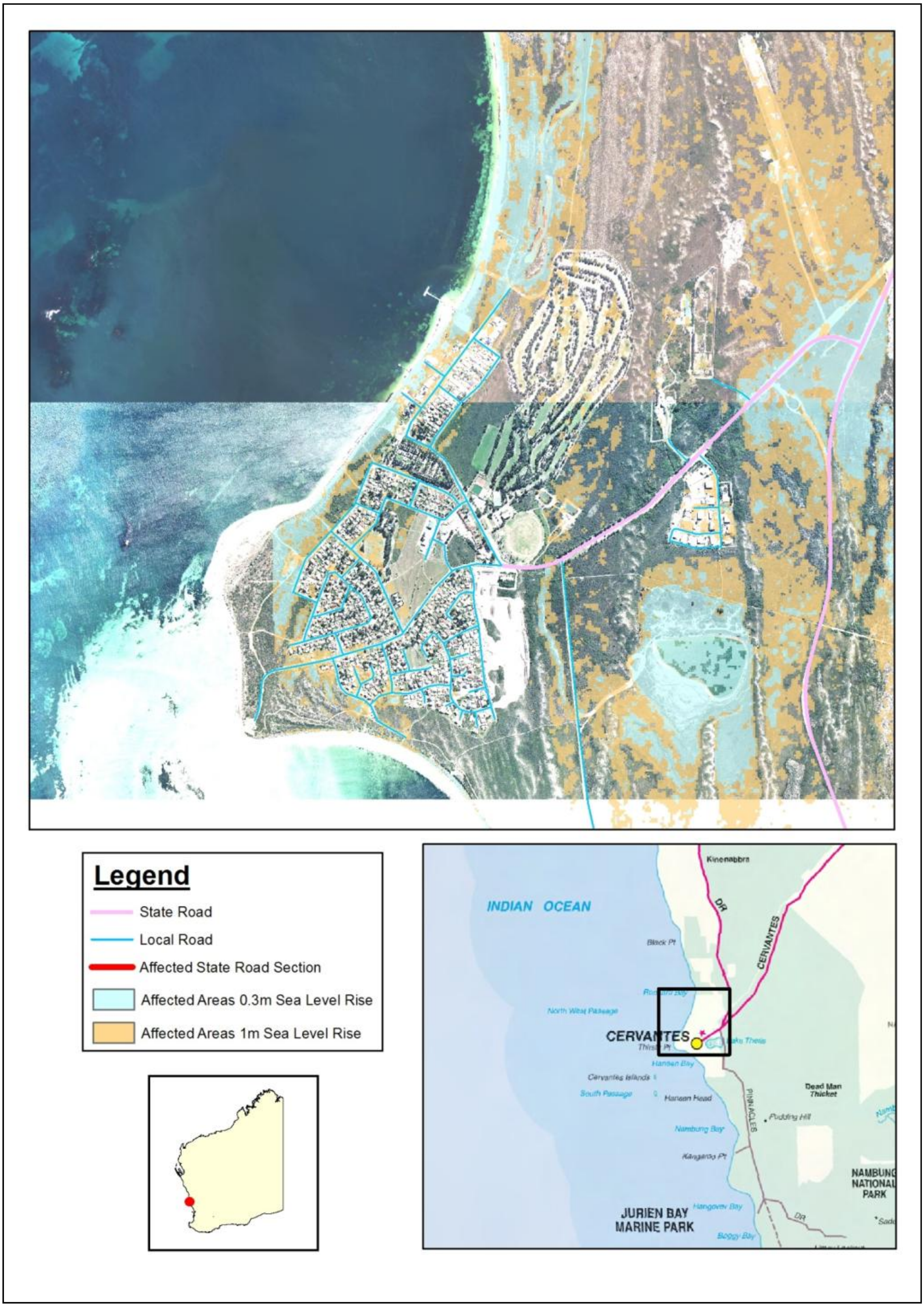
**Townsite Sea Level Rise Modeling – Busselton Surrounds**



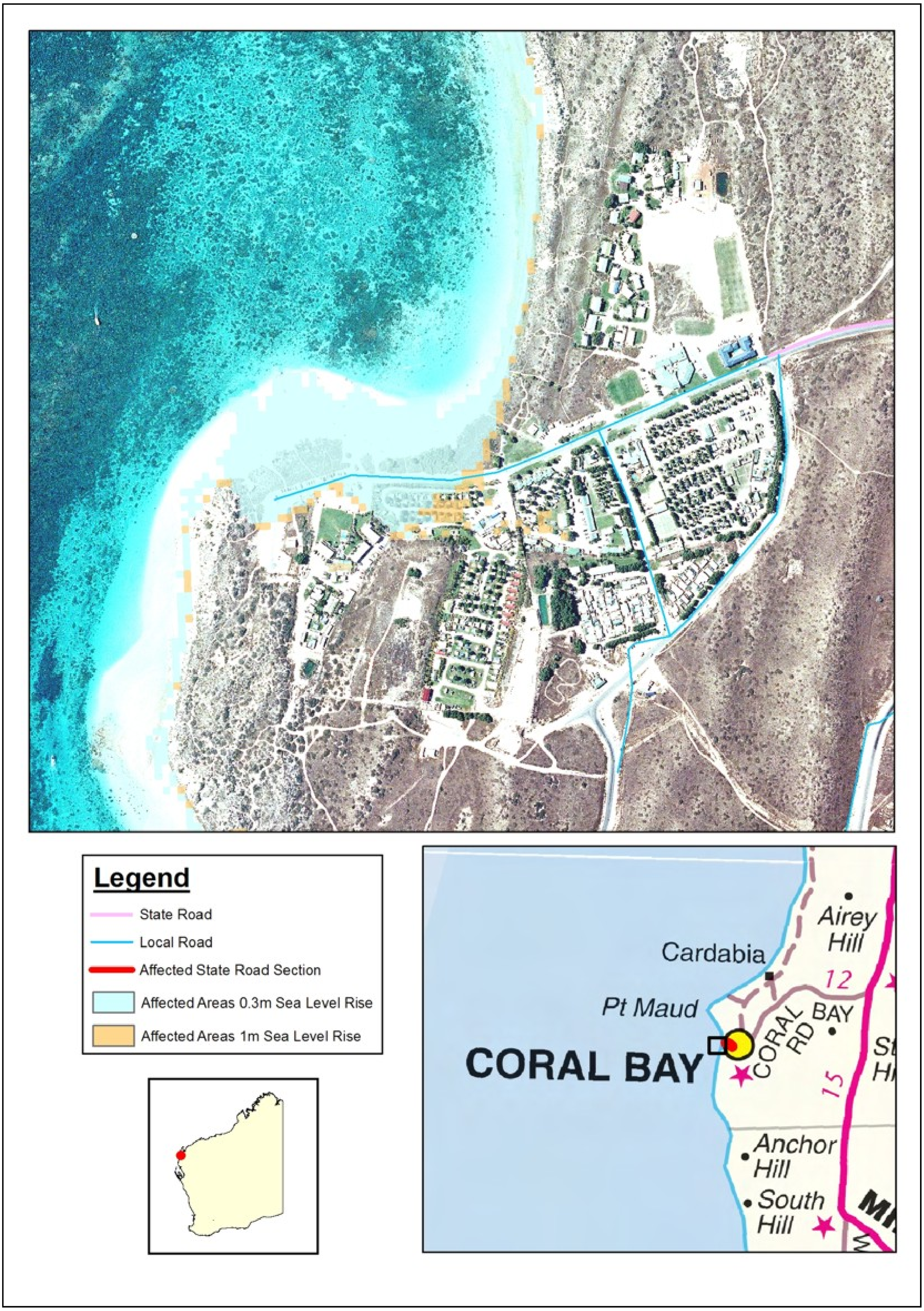
## Townsite Sea Level Rise Modeling – Carnarvon



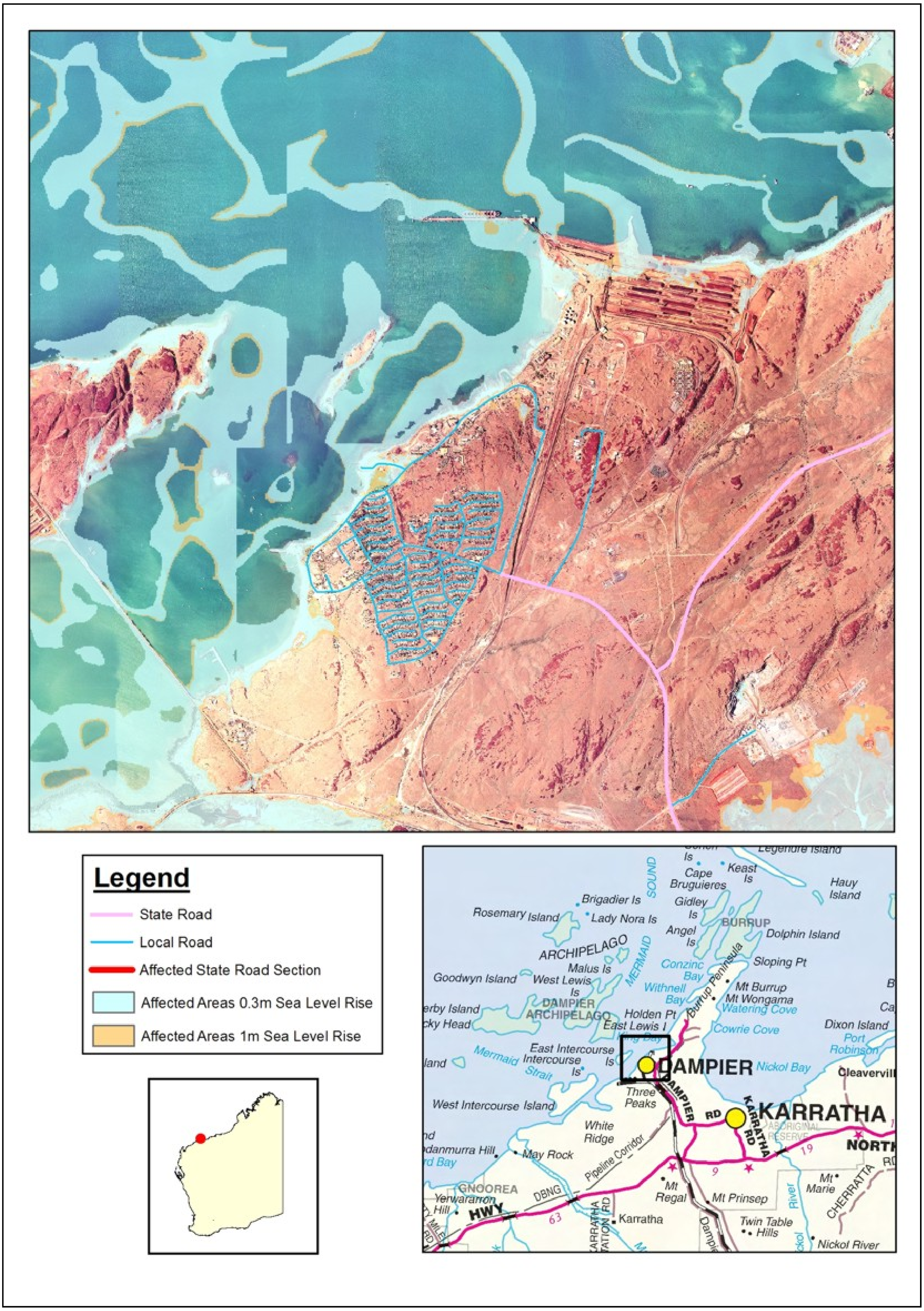
## Townsite Sea Level Rise Modeling – Cervantes



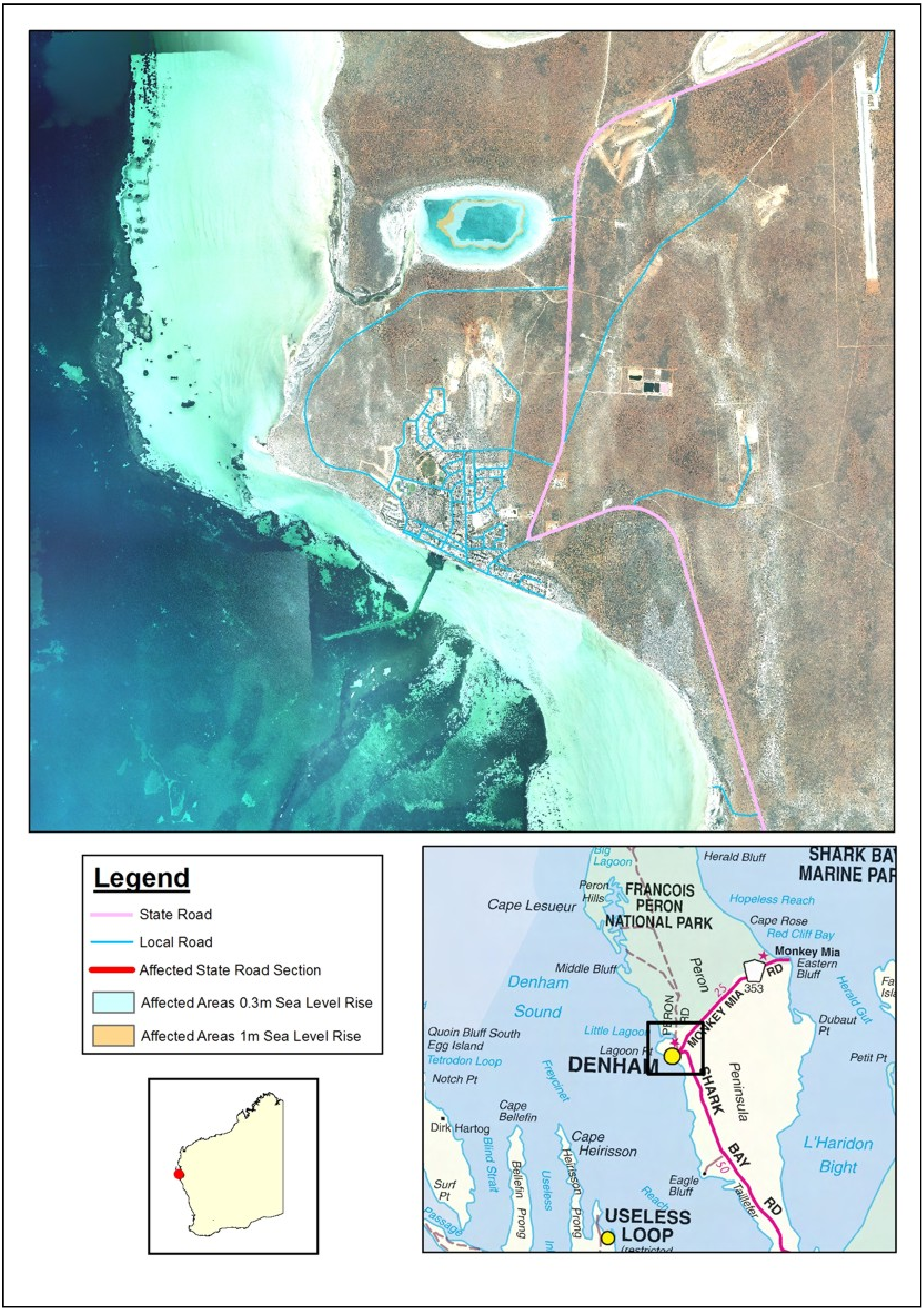
## Townsite Sea Level Rise Modeling – Coral Bay



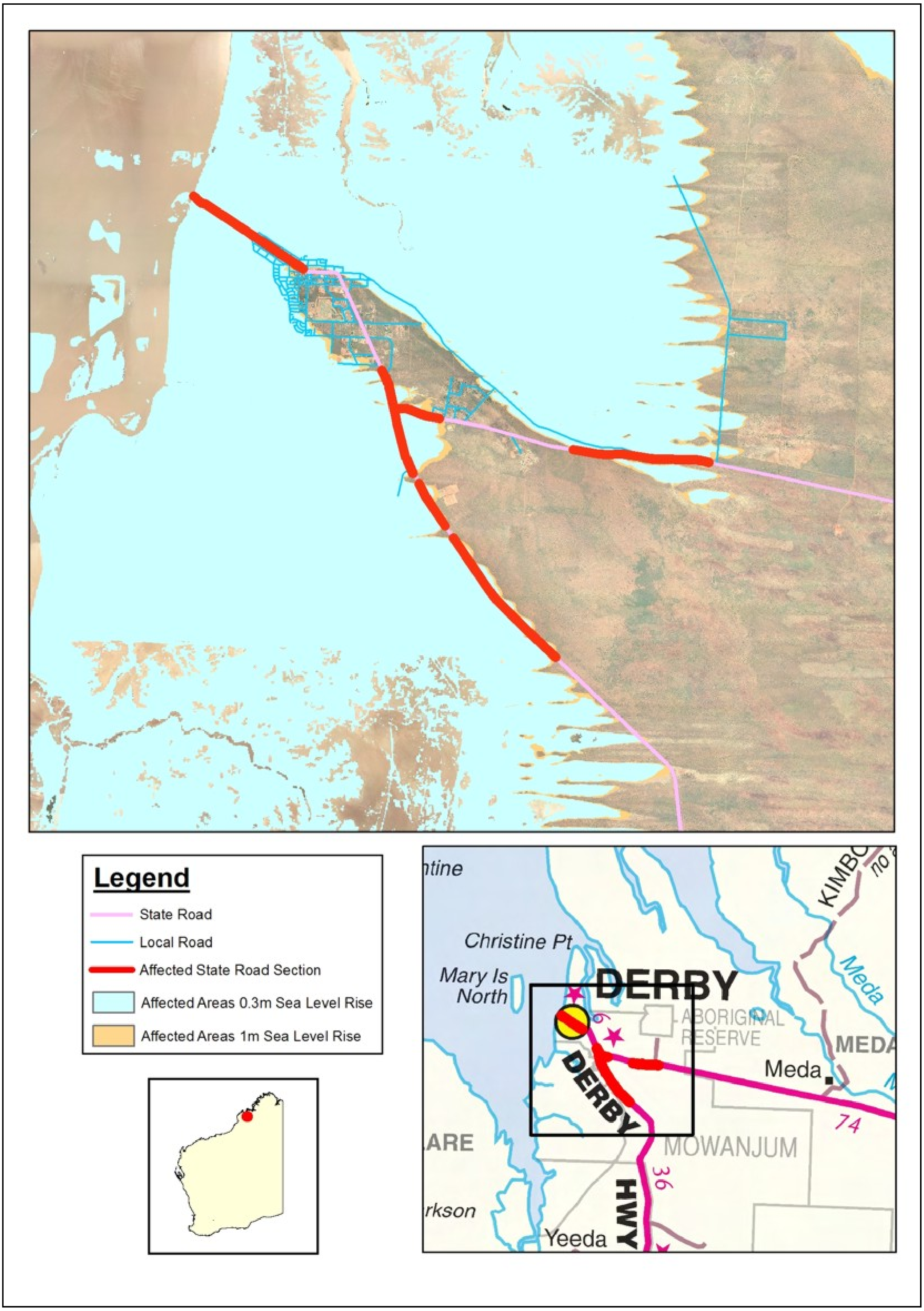
**Townsite Sea Level Rise Modeling – Dampier**



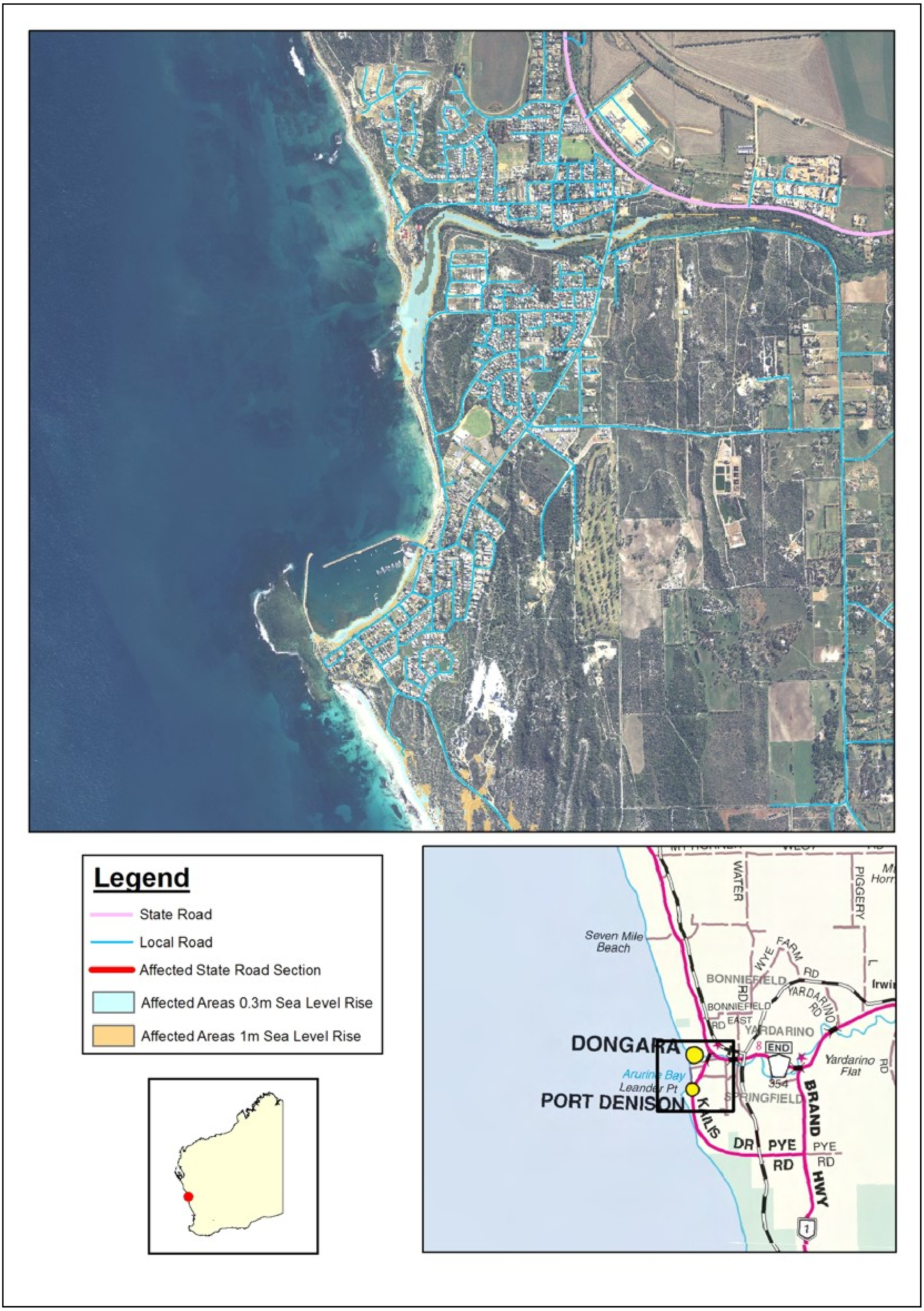
**Townsite Sea Level Rise Modeling – Denham**



**Townsite Sea Level Rise Modeling – Derby**

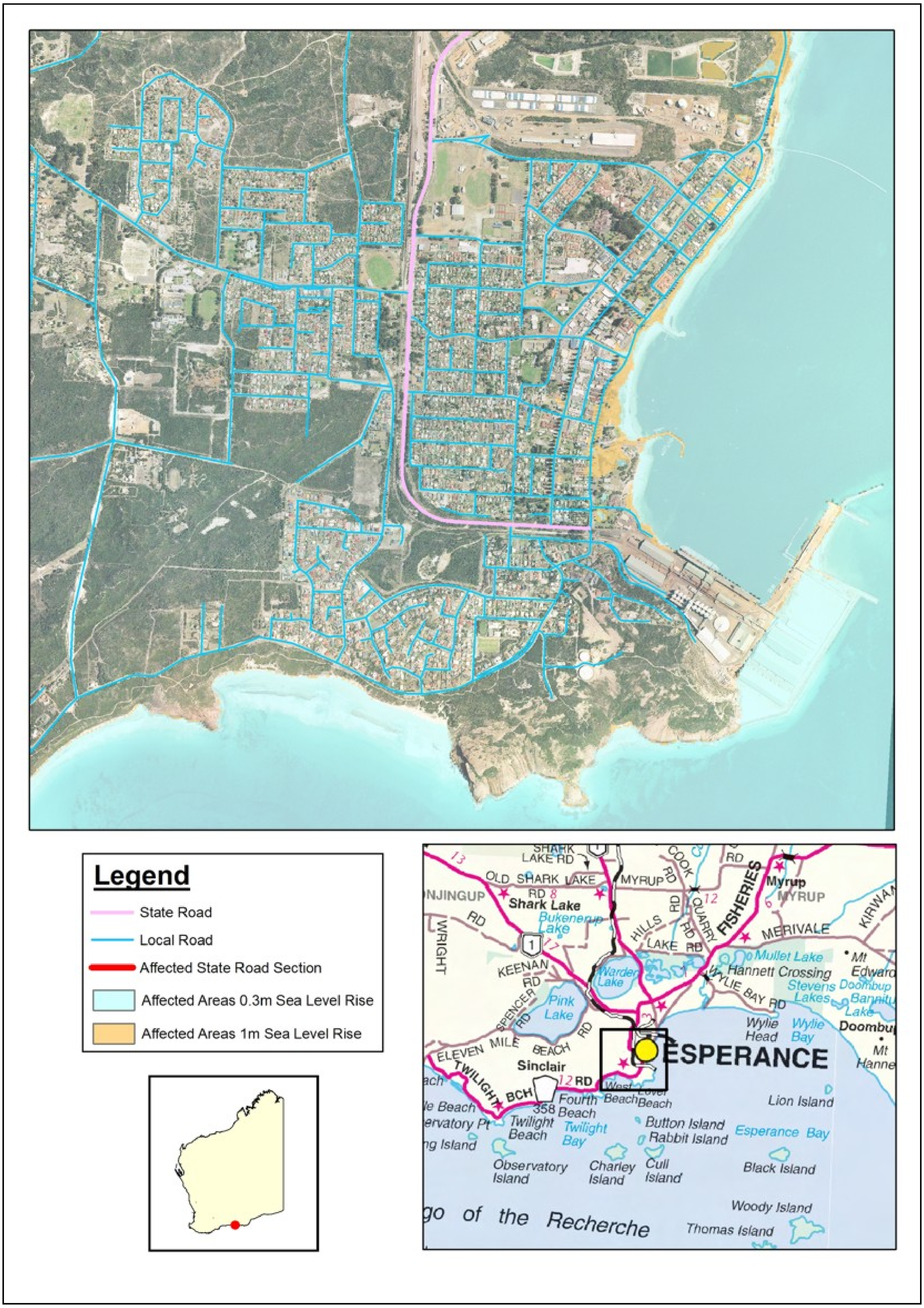


## Townsite Sea Level Rise Modeling –Dongara/Pt Denison

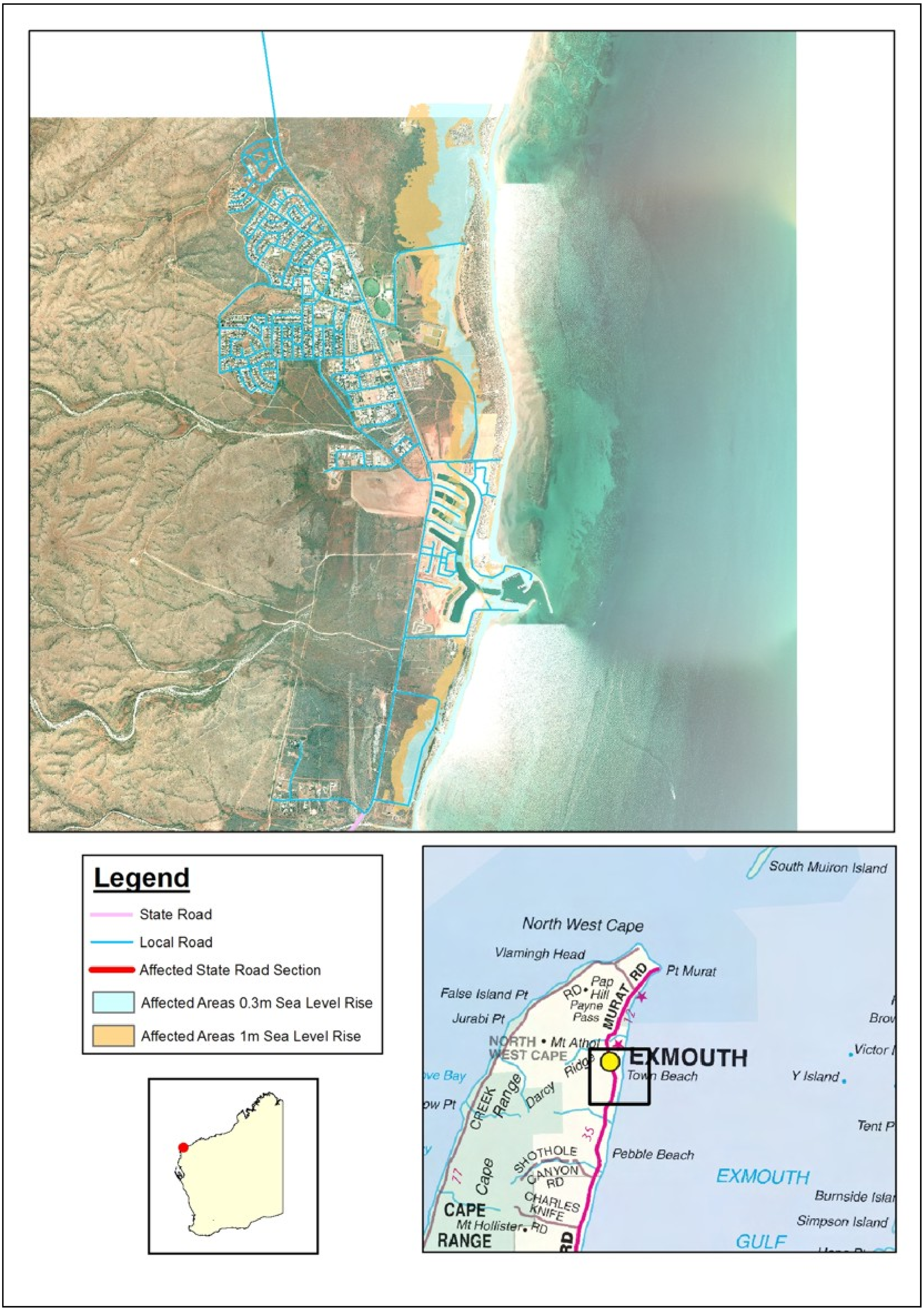


**Townsite Sea Level Rise Modeling – Dunsborough**

**Townsite Sea Level Rise Modeling – Esperance**



## Townsite Sea Level Rise Modeling – Exmouth

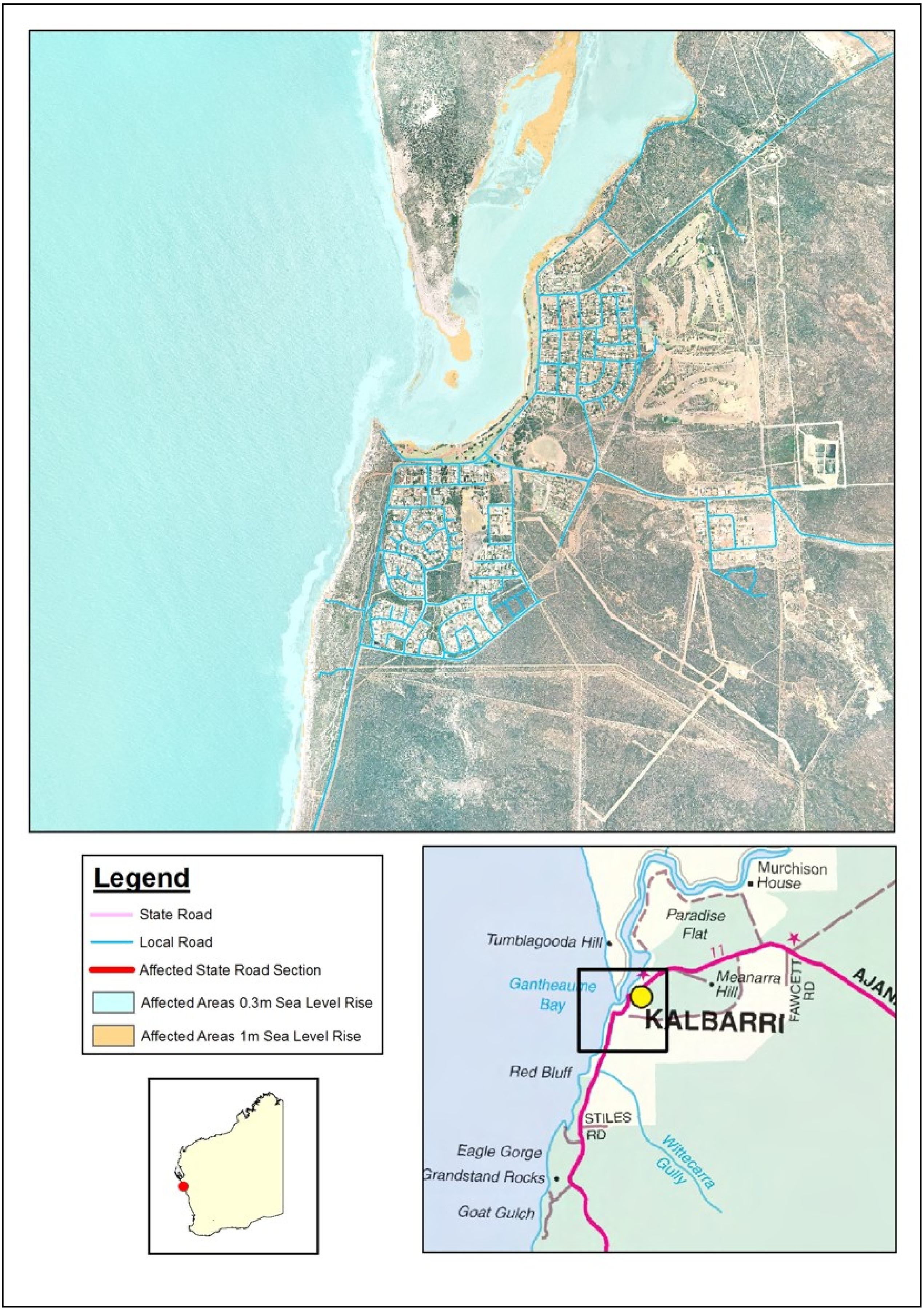


**Townsite Sea Level Rise Modeling – Fremantle**

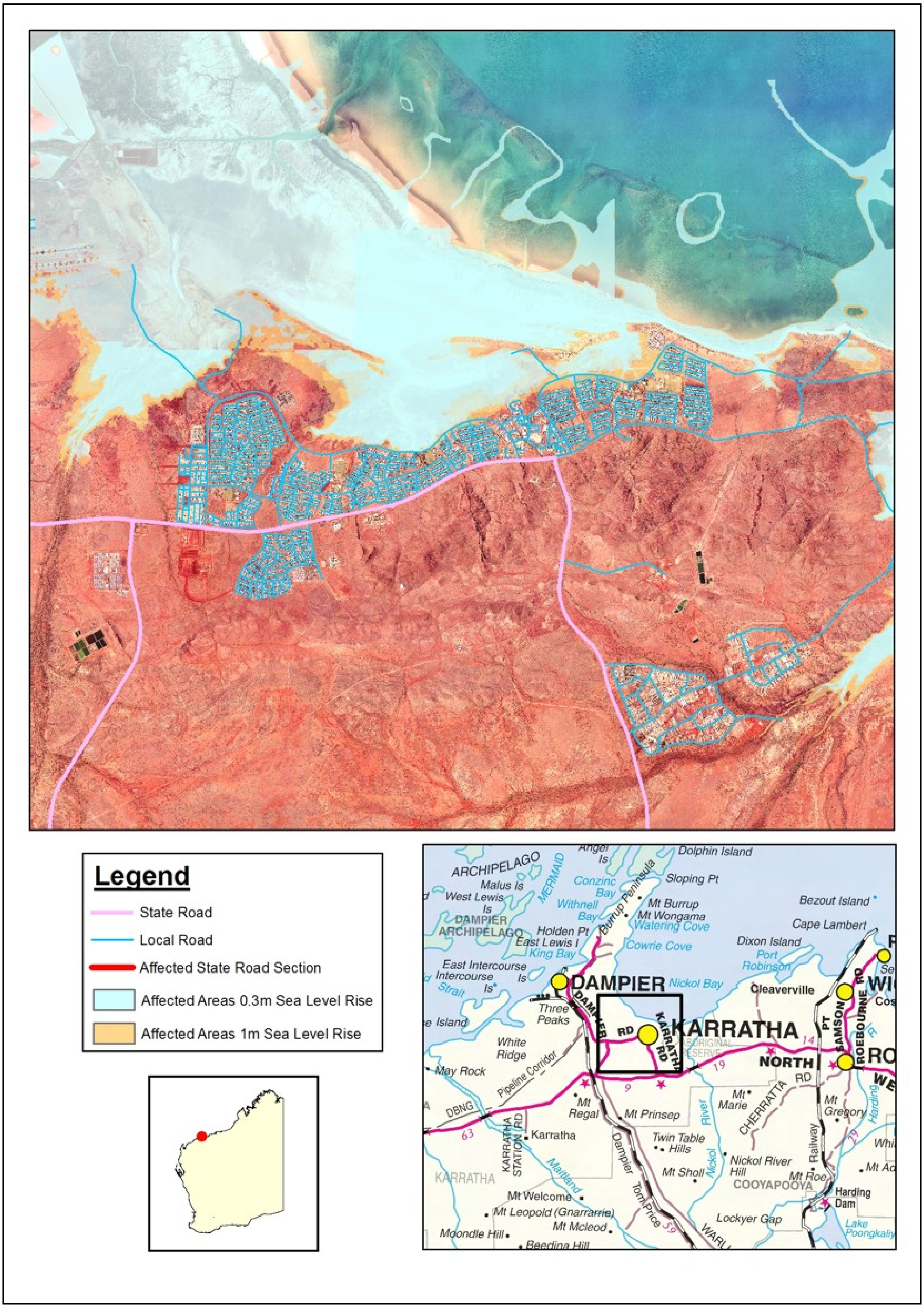
## Townsite Sea Level Rise Modeling – Greenhead

**Townsite Sea Level Rise Modeling – Hillarys Boat Harbour**

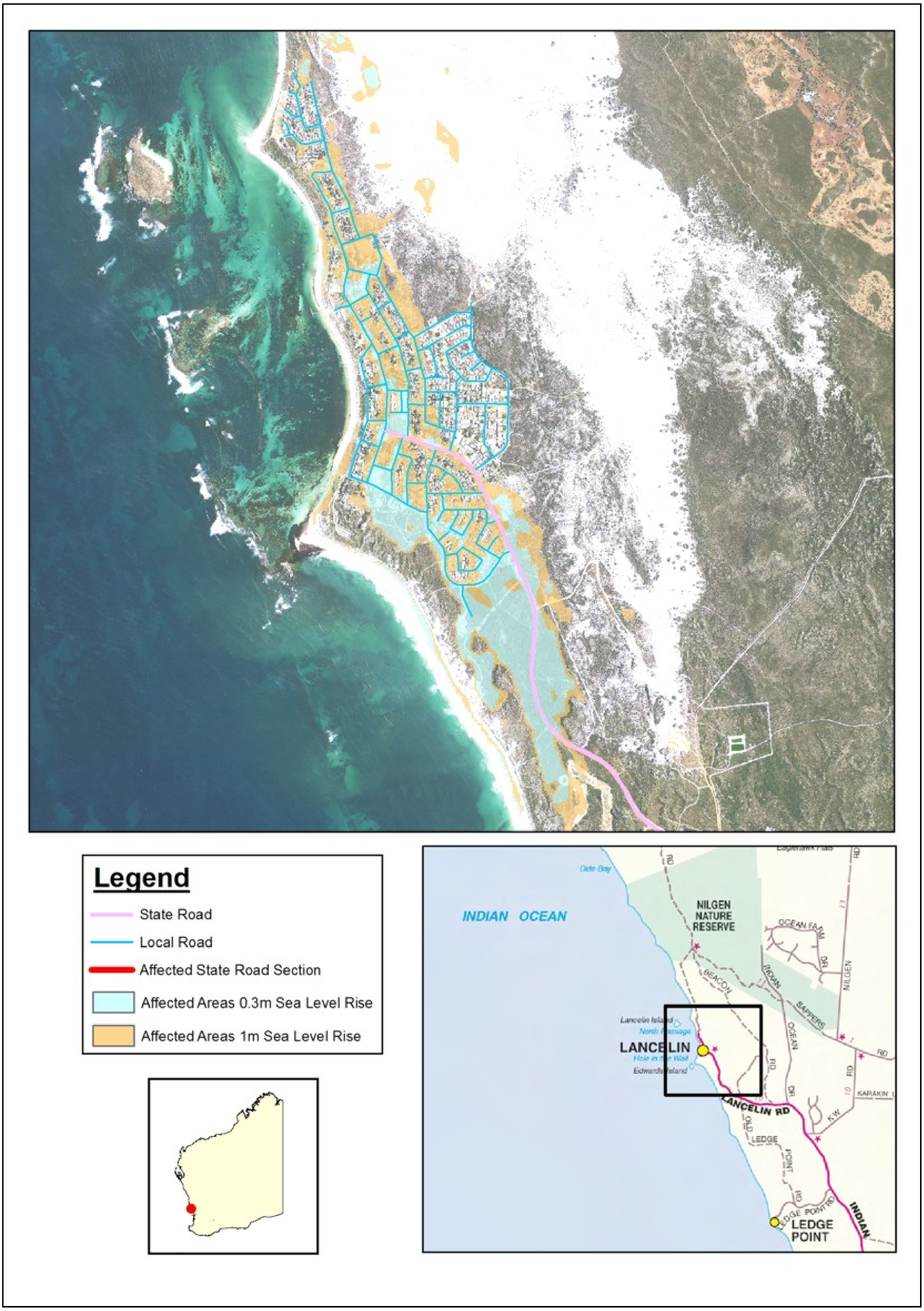
## Townsite Sea Level Rise Modeling – Kalbarri



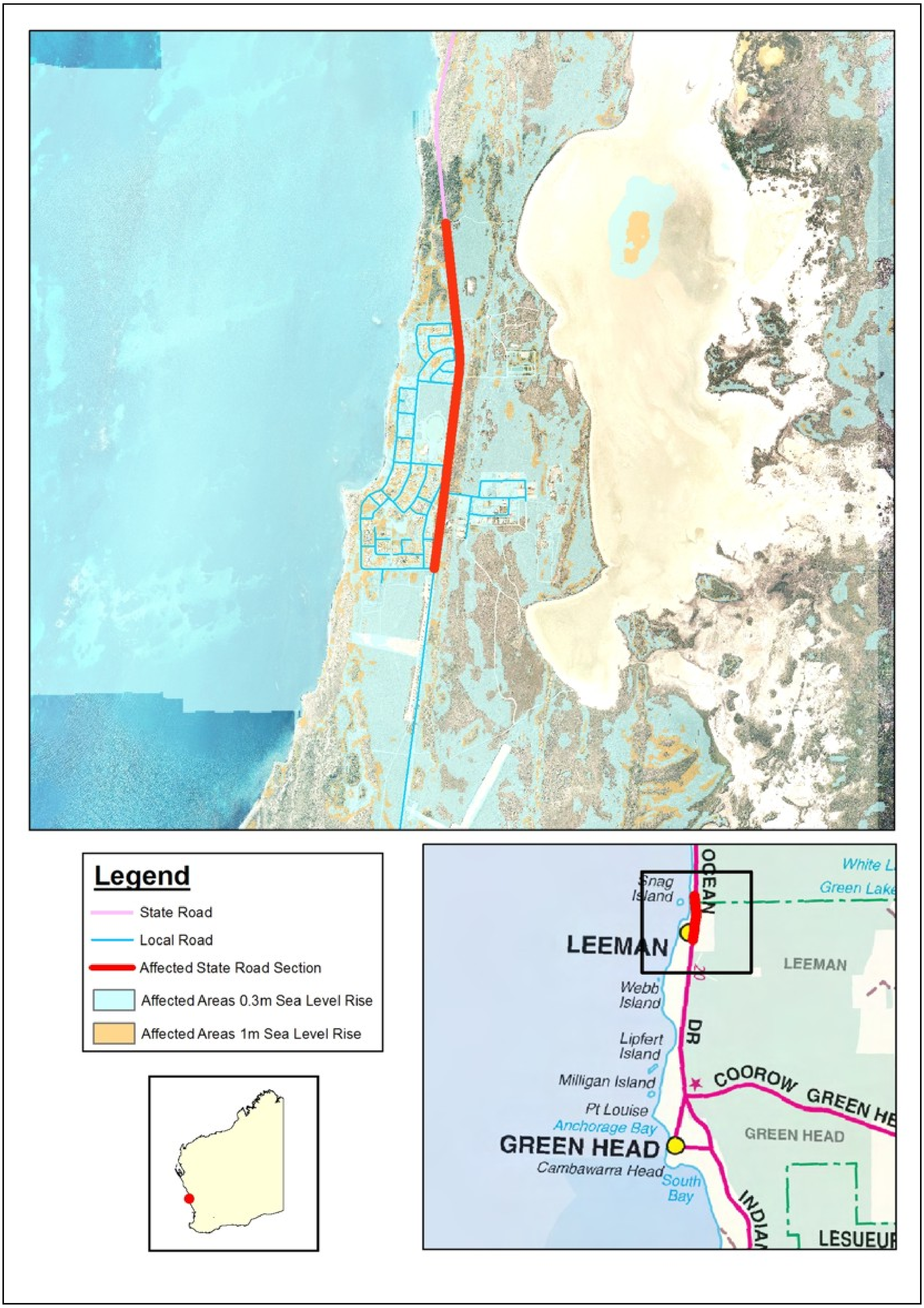
## Townsite Sea Level Rise Modeling – Karratha



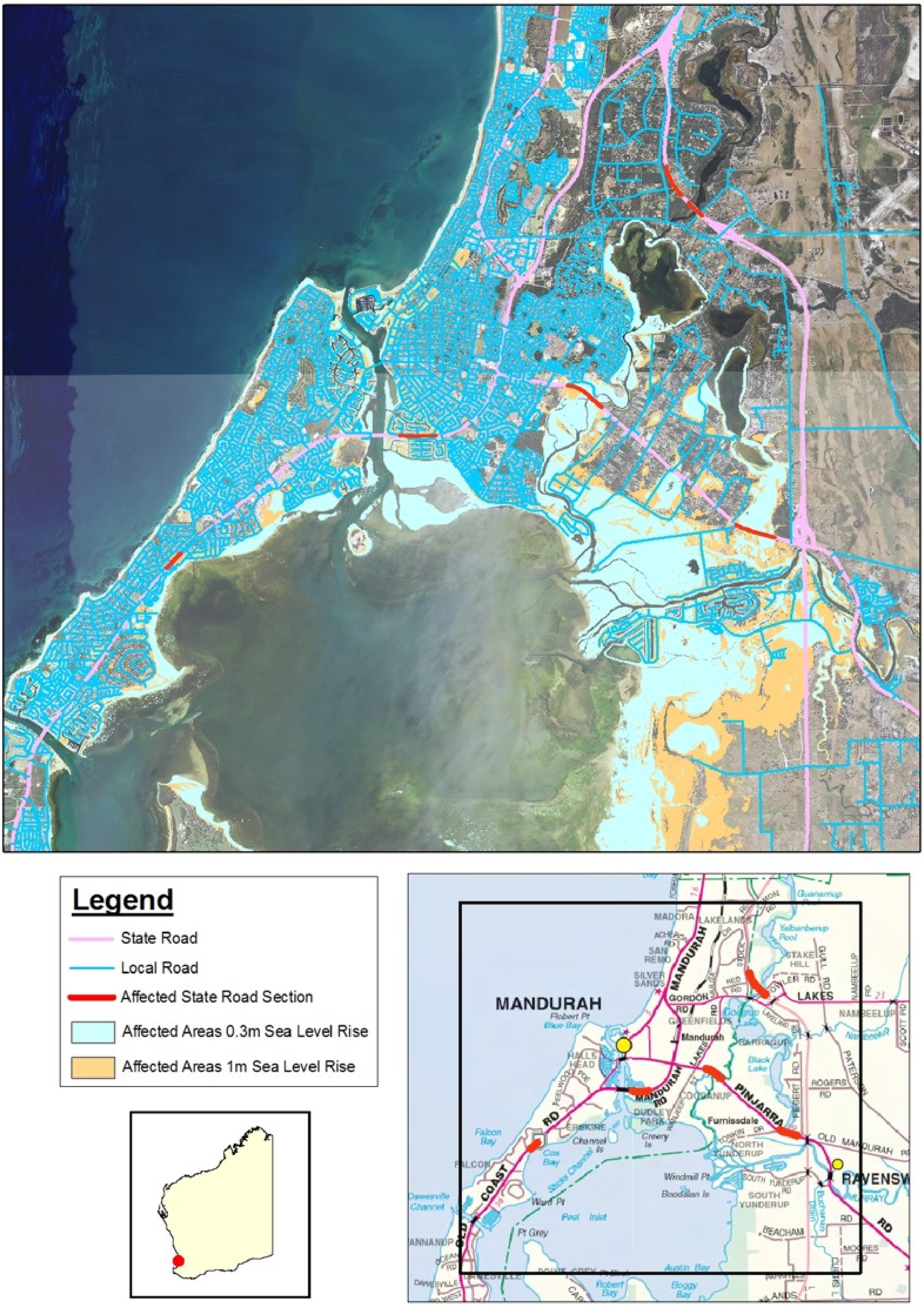
## Townsite Sea Level Rise Modeling – Lancelin



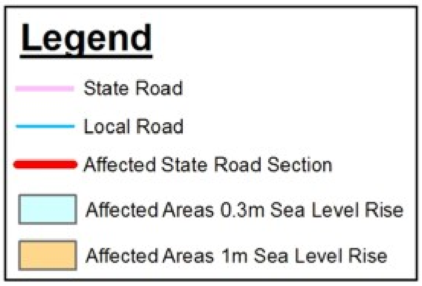
**Townsite Sea Level Rise Modeling – Leeman**

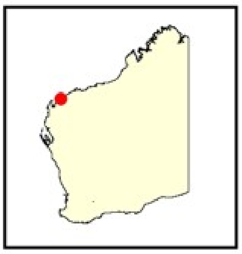


**Townsite Sea Level Rise Modeling – Mandurah**

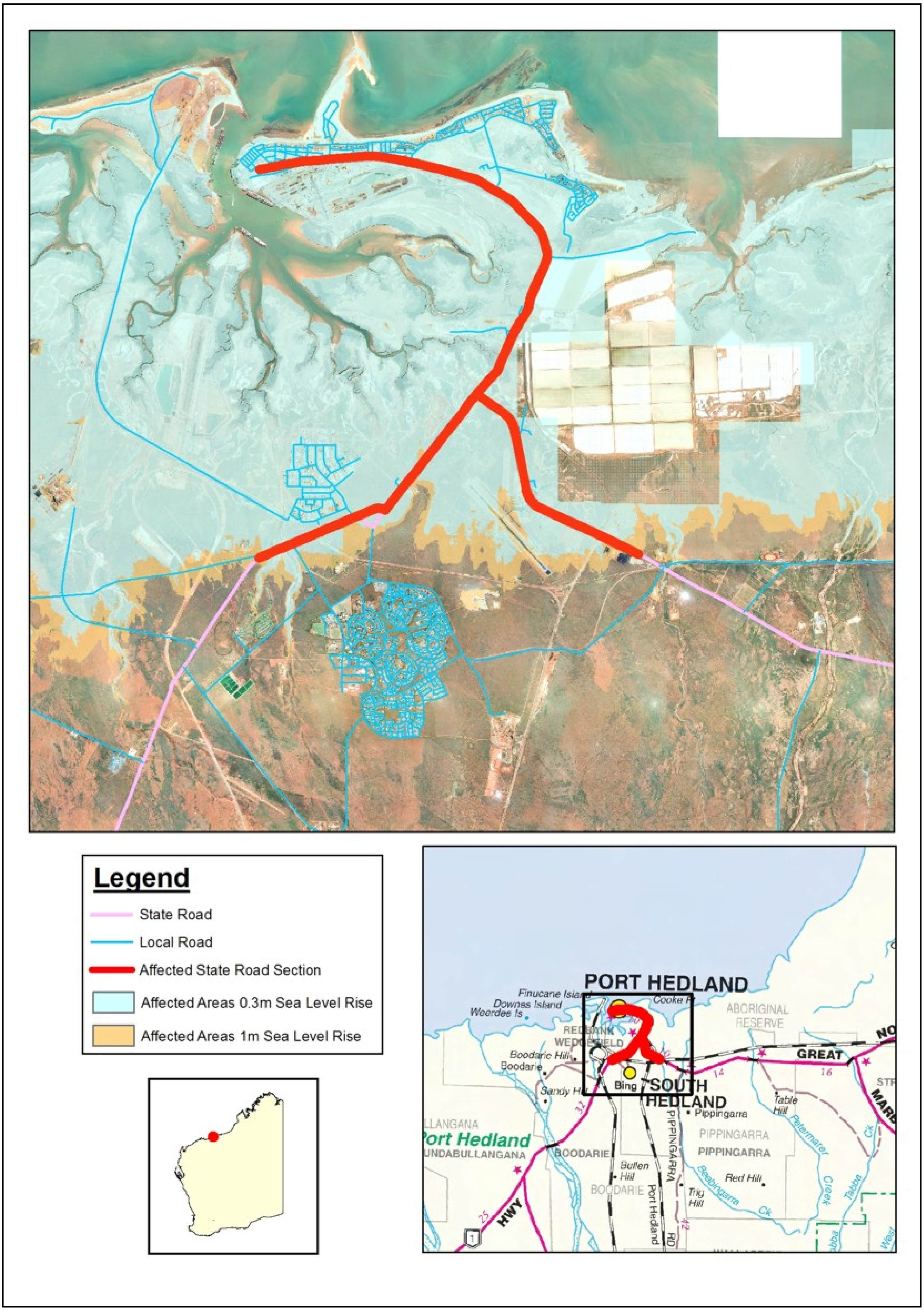


**Townsite Sea Level Rise Modeling – Onslow**

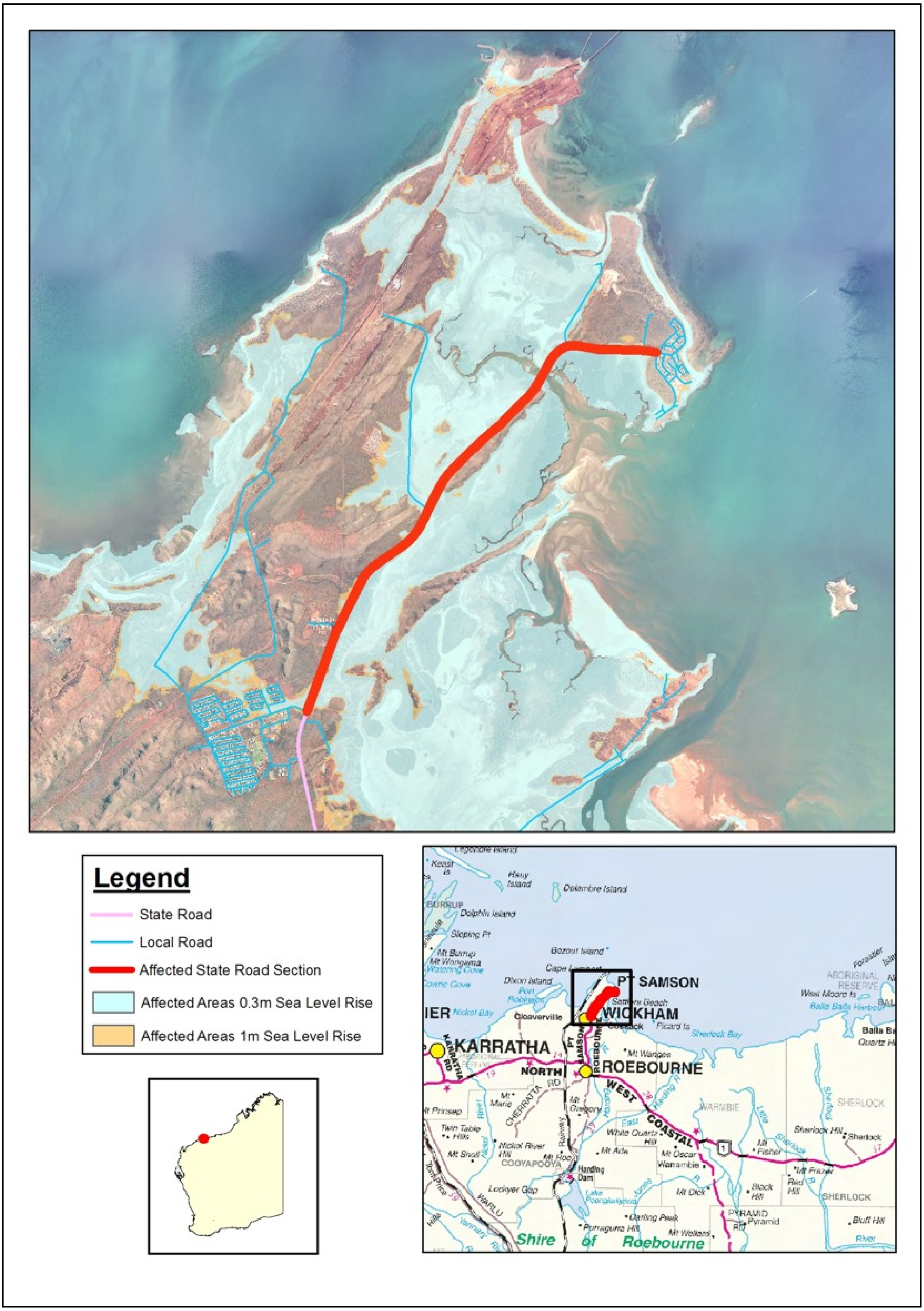


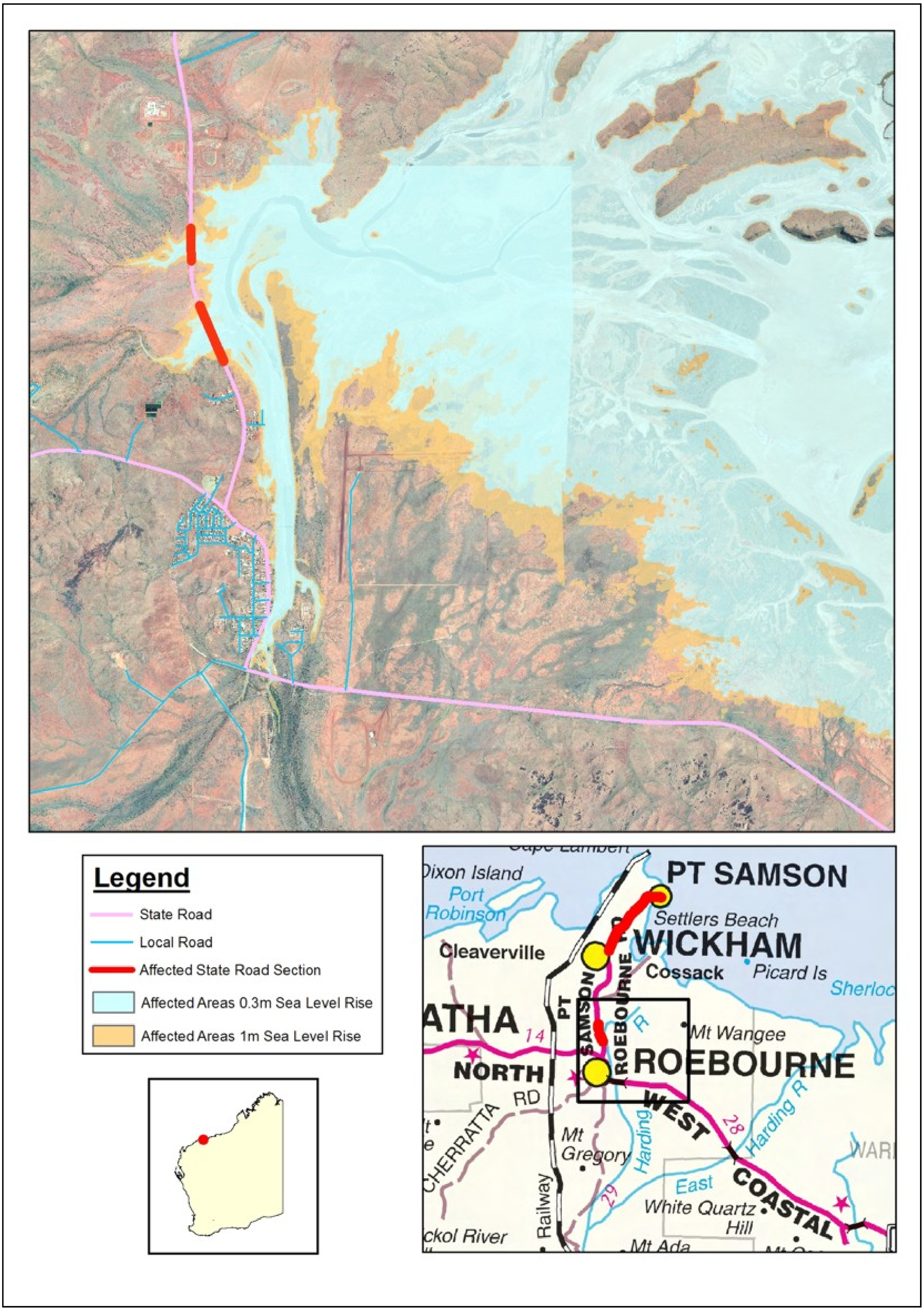
**Townsite Sea Level Rise Modeling – Port Hedland**



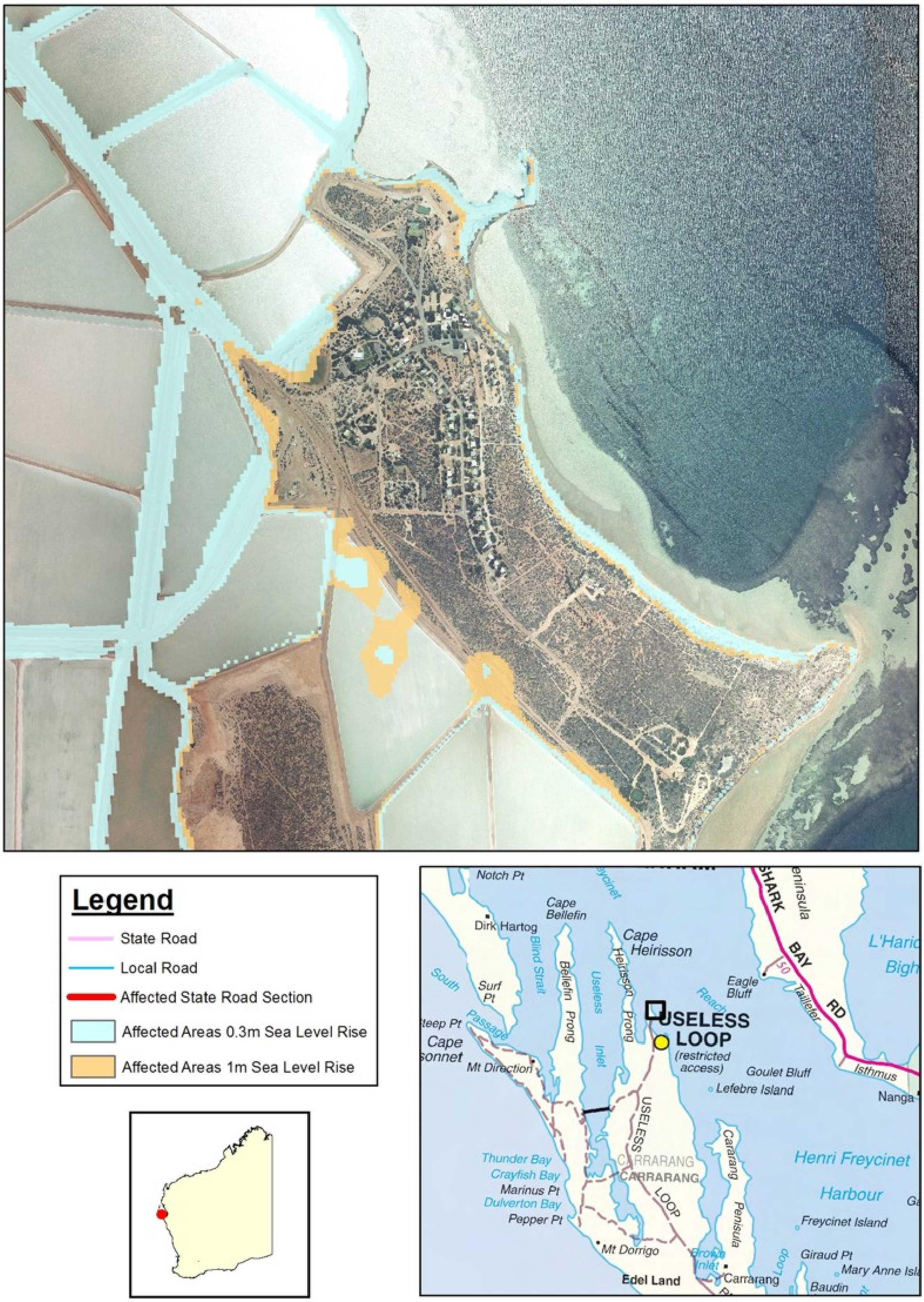
**Townsite Sea Level Rise Modeling – Pt Samson/Wickham**



## Townsite Sea Level Rise Modeling – Roebourne



## Townsite Sea Level Rise Modeling – Useless Loop



## Townsite Sea Level Rise Modeling – Woodman Point

## Townsite Sea Level Rise Modeling – Wyndham