“Where will our knowledge take you?”

# Whitsunday Regional Council
# Town of Whitsunday Drainage Study

**December 2017**

Whitsunday Regional Council

# Document Control Sheet

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**Synopsis:** **This report presents the data, methodology and results for the Town of Whitsunday Drainage Study**

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# Executive Summary

## Background

BMT WBM was commissioned by Whitsunday Regional Council (Council) to undertake a Drainage Study in the Whitsunday Regional Council Local Government Area (LGA) in QLD. The study area is shown in Figure 1-1 and includes the following five sub catchments:

- Crofton Creek;
- Galbraith and Waite Creeks;
- Cannonvale;
- Arlie Creek; and
- Campbell Creek.

## Objective

The objective of the study is to determine the existing flood behaviour and to assess the effects of climate change to inform potential future development as part of Councils Planning Scheme.

## Study Tasks and Deliverables

The study included the following study tasks:

- Develop design rainfall events using the latest industry guidelines; i.e. the 2016 revision of Australian Rainfall and Runoff (ARR 2016).
- The development of URBS hydrologic models to estimate runoff flows based on the design rainfall events.
- The development of TUFLOW hydraulic models to estimate flood levels, velocities and hazards based on the runoff flows computed by the hydrologic models. The downstream boundaries were selected with consideration of BMT WBM's Bowen Water Hazards Assessment Storm Tide Modelling Basis Report (see Section 4.4.1.2). The hydraulic models have a model grid resolution of 5m, which resulted in practical model run times (less than 2 hours).
- Design flood behaviour was simulated for events from the 50% Annual Exceedance Probability (AEP) through to the 1% AEP and for the 'Probable Maximum Flood' (PMF), which provides an upper limit of the potential magnitude of flooding.
- Flood maps of peak flood level, depth, velocities, velocity-depth product and hazard for the 1% AEP design event for each catchment are provided in Appendix C to Appendix G.
- The 2050 and 2100 climate change scenarios were modelled using the 1% AEP design event.
- Model sensitivity analyses were undertaken for the hydraulic roughness parameters and blockage of the structures along Shute Harbour Road and Main street in Airlie Beach.
- All model input and results files were provided to Council for inclusion in Council's GIS database.

The study provides information on the existing flood risk and to guide future development.

### How does this study inform future planning?

Flooding is one of the most serious natural hazards in Australia, incurring the highest economic cost to the community and resulting in a small number of deaths most years. However, flooding is also a highly manageable hazard. An understanding of flood risk, derived from flood models, as developed as part of this study, land use and community characteristics, can be used to develop a plan to manage future floods.

This Town of Whitsunday Drainage Study is the first step to inform future planning. The model results provide the flood characteristics, such as flood levels, depth, velocities and flood hazard. The flood levels together with a consideration of freeboard can be used to inform flood planning levels of future developments. Whitsunday Regional Council has adopted a freeboard of 300mm. Other flood characteristics, such as the flood hazard which is defined as the product of flood depth and flood velocity, together with land use and community characteristics is used to inform flood risk. Flood risk then informs future development and planning and should be communicated to the community to raise flood awareness and flood resilience.

The next step is to undertake a floodplain risk management study which considers isolated communities, evacuation, defining risk using flood hazard (from this study), flood likelihoods and the individual consequences.

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# Definitions

| Term | Definition |
|---|---|
| 1% AEP Event | A **flood** that occurs on average once every 100 years. Also known as a 1% flood. See **annual exceedance probability (AEP)** and **average recurrence interval (ARI).** |
| 2% AEP Event | A **flood** that occurs on average once every 50 years. Also known as a 2% flood. See **annual exceedance probability (AEP)** and **average recurrence interval (ARI).** |
| 10% AEP Event | A **flood** that occurs on average once every 10 years. Also known as a 10% flood. See **annual exceedance probability (AEP)** and **average recurrence interval (ARI).** |
| 20% AEP Event | A **flood** that occurs on average once every 5 years. Also known as a 20% flood. See **annual exceedance probability (AEP)** and **average recurrence interval (ARI).** |
| Annual exceedance probability (AEP) | AEP (measured as a percentage) is a term used to describe **flood** size. It is a means of describing how likely a flood is to occur in a given year. For example, a 1% AEP flood is a **flood** that has a 1% chance of occurring, or being exceeded, in any one year. It is also referred to as the '100 year flood' or '1 in 100 year flood'. The term **1% AEP event**, **2% AEP event, 10% AEP event, 20% AEP event** etc, have been used in this study. See also **average recurrence interval (ARI)**. |
| Australian height datum (AHD)` | A common national plane of level approximately equivalent to the height above sea level. All **flood levels**, floor levels and ground levels in this study have been provided in metres AHD. |
| Average recurrence interval (ARI) | ARI (measured in years) is a term used to describe **flood** size. It is the long term average number of years between floods of a certain magnitude. For example, a 100 year ARI flood is a flood that occurs or is exceeded on average once every 100 years. Since the publication of ARR 2016, the **annual exceedance probability (AEP)** terminology is preferred compared to the ARI terminology**.** |
| Catchment | The land draining through main stream, as well as tributary streams. |
| Discharge | The rate of flow of water measured in terms of volume per unit time, for example**, cubic metres per second ($m^3/s$).** Discharge is different from the speed of **velocity** of flow, which is a measure of how fast the water is moving. |
| Drainage Study | A study that investigates flood behaviour, including identification of flood extents, **flood levels** and flood velocities for a range of flood sizes. |
| Extreme flood | An estimate of the **probable maximum flood (PMF),** which is the largest flood likely to occur. |
| Flood | A relatively high stream flow that overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami. |
| Flood awareness | An appreciation of the likely effects of flooding and knowledge of the relevant flood warning, response and evacuation procedures. |
| Flood hazard | The potential for damage to property or risk to persons during a **flood**. Flood hazard is a key tool used to determine flood severity and is used for assessing the suitability of future types of land use. |

| Term | Definition |
|---|---|
| Flood level | The height of the **flood** described either as a depth of water above a particular location (e.g. 1m above a floor, yard or road) or as a depth of water related to a standard level such as **Australian Height Datum** (e.g. the flood level was 7.8m AHD). Terms also used include **flood stage** and **water level**. |
| Floodplain risk management study | Studies that assess options for minimising the danger to life and property during floods. These measures, referred to as 'floodplain management measured/options' aim to achieve an equitable balance between environmental, social, economic, financial and engineering considerations. |
| Flood planning levels (FPLs) | The combination of flood level and **freeboards** selected for planning purposes, as determined in floodplain management studies and incorporated in **floodplain management plans**. The concept of flood planning levels supersedes the designated flood or the flood standard used in earlier studies. |
| Flood study | A study that investigates flood behaviour, including identification of flood extents, **flood levels** and flood velocities for a range of flood sizes. |
| Floodplain | The area of land that is subject to inundation by floods up to and including the probable maximum flood event, that is, **flood prone land or flood liable land**. |
| Flow | See **discharge**. |
| Freeboard | A factor of safety expressed as the height above the **design flood level**. Freeboard provides a factor of safety to compensate for uncertainties in the estimation of flood levels across the **floodplain**, such and wave action, localised **hydraulic** behaviour and impacts that are specific event related such as levee and embankment settlement, and other effects such as "greenhouse" and climate change. |
| Hydraulics | Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and **velocity**. |
| Hydrology | Term given to the study of the rainfall and runoff process; in particular, the evaluation of **peak discharges**, flow volumes and the derivation of hydrographs (graphs that show how the discharge or stage/flood level at any particular location varies with time during a flood. |
| m AHD | Meters **Australian Height Datum (AHD).** |
| m/s | Meters per second. Unit used to describe the velocity of floodwaters. |
| $m^3/s$ | Cubic meters per second or 'cumecs'. A unit of measurement for creek or river flows or **discharges.** It's the rate of flow of water measured in terms of volume per unit time. |

# 1 Introduction

## 1.1 Background

BMT WBM was commissioned by Whitsunday Regional Council (Council) to undertake the Town of Whitsunday Drainage Study (TOWDS). The TOWDS includes five sub-catchments in the Whitsunday Regional Council Local Government Area (LGA) in QLD. The study area comprises the most populated area in the Whitsunday region, and Council recognises the need for flood resilience in these populated areas. The Whitsunday region is one of the most popular tourist destination in Australia, and welcomes large numbers of visitors every year.

In addition, Council is expecting a significant future growth of population and significant increase in proposed development in the study area. This Town of Whitsunday Drainage Study will be used to inform flooding concerns for future development.

## 1.2 Objectives

The objective of the study is to determine the existing flood behaviour and to assess the effects of climate change. The outcomes will inform potential future development flooding constraints as part of Council's Planning Scheme. The study is also a solid basis for a flood risk management study that would assess the flood problem and present potential flood management solutions; e.g. identify high flood hazard zones which then, in combination with likelihoods and consequences, inform flood risk zones.

## 1.3 Study Area Description

The study area comprises the following 5 catchments in the Whitsunday Regional Council LGA:

- Arlie Creek;
- Cannonvale;
- Campbell Creek;
- Crofton Creek; and
- Galbraith and Waite Creeks.

The Crofton Creek catchment drains in a south west direction (away from the ocean) into Proserpine Creek, which then discharges into the ocean near Conway Beach. The remaining four catchments listed above drain towards the coast. The study area is located along Proserpine – Shute Harbour Road and covers the suburbs of Sugar Loaf, Riodanvale, Cannon Valle, Cannonvale, Airlie Beach and Jubilee Pocket.

The Study Area is shown in Figure 1-1.

## 1.4 Scope

The TOWDS included the following key tasks:

(1) Compilation and review of available data;

(2) Application of Australian Rainfall and Runoff (ARR 2016) to establish design flood events;

(3) Development and use of hydrologic models, using the software URBS, to estimate runoff through the catchments for the design flood events;

(4) Development and use of hydraulic models, using the software TUFLOW Classic, to simulate the flood behaviour for the design flood events (using the hydrologic model results);

(5) Documentation of the modelling details and methodology;

(6) Documentation of model verification;

(7) Mapping of hydraulic model results for the 1% Annual Exceedance Probability (AEP) event and digital compilation of results for all other events;

(8) Climate change and preliminary flood risk assessments; and

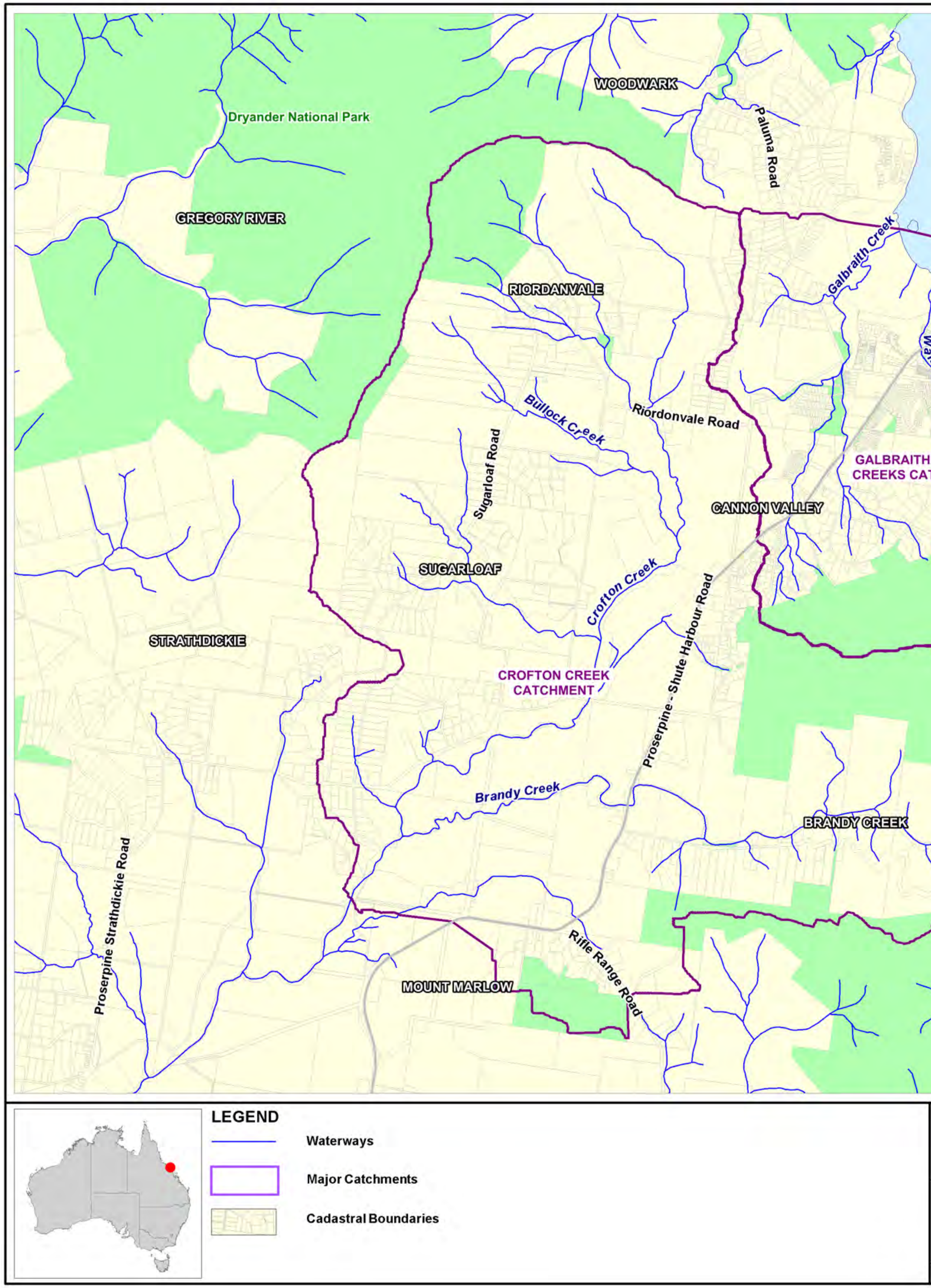
(9) Documentation of the conclusions of the study.

## 1.5 Australian Rainfall and Runoff (ARR) Probability Terminology

A change in the flood probability terminology has been adopted in the recently released version of ARR (2016). Design flood event magnitudes are now referred to using Annual Exceedance Probability (AEP) intervals. The AEP intervals used in this study are listed in Table 1-1 together with the corresponding older ARR terminology, which used Average Recurrence Interval (ARI).

**Table 1-1 AEP - ARI conversions**

| AEP | ARI (years) |
|---|---|
| 50% | 1.44 |
| 20% | 4.48 |
| 10% | 10 |
| 5% | 20 |
| 2% | 50 |
| 1% | 100 |
| 0.2% | 500 |
| 0.05% | 2000 |
| $AEP = 1 - \exp\left(\frac{-1}{ARI}\right)$ | |




Title:
**Study Area**

Figure: 1-1

Rev: A

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# 2 Data Collation

## 2.1 Overview

The development of the TUFLOW flood model required the use of various types of data, including topographical data, aerial photography, cadastral information, surveys of the stormwater drainage networks and statistical rainfall information.

Extensive data collection was undertaken by Council. Site inspections were undertaken by both BMT WBM and Council staff to obtain a good appreciation of the study area.

Datasets received for use in this study are summarised in the following sections. The sections are grouped into categories relevant to the hydraulic modelling.

## 2.2 Topographic Data

The underlying topography of the flood model was derived from Light Detection and Ranging (LiDAR) data captured in October and November 2016 by RPS. The LiDAR data was provided by Council as a processed raster grid with 5m resolution. The LiDAR survey was reported to have a spatial accuracy of ± 0.5m root mean square error (RMSE) relative in the horizontal and of ± 0.1m RMSE relative in the vertical. The average point spacing of the LiDAR point cloud was 4.14 points per square metre. No thinning was applied. The spatial data were geo-referenced in GDA 94, Zone 55 and the elevation data were referenced to Australia Height Datum (AHD).

While the LiDAR data covered the vast majority of the catchments within the study area, it did not cover the catchments in their entirety. Hence, Shuttle Radar Topography Mission (SRTM) data, with a 30m spatial resolution, was utilised where no LiDAR data was available. The LiDAR data covered the entire floodplain within the extents of the hydraulic models.

## 2.3 Bathymetry data

Bathymetry data was not available in the study area. As such, creek bed levels are based on the LiDAR data. It is noted that LiDAR does not penetrate water. Therefore, the LiDAR data will represent the water level rather than the real bed level where there was significant depth of flow in the creeks at the time of survey.

Given that the study focus is on large floods, with the day to day flow volume being a small fraction of the flood flow volume, the approach is considered acceptable.

## 2.4 Aerial Photography

The aerial images were captured by RPS in October and November 2016 and provided by Council geo-referenced to GDA 94-MGA Zone 55.

## 2.5 Gauge Data

There are no river gauges available in the study area. Council has recently commissioned the installation of rainfall and river gauges in the LGA. However, flood data was not available from these new gauges for this study.

## 2.6 Debris Marks

After the Tropical Cyclone Debbie event in March 2017, Council collected debris marks. Selected debris mark photos are provided in Appendix A.

## 2.7 Ocean Levels

Tide records and tide predictions were available from Marine Safety Queensland (MSQ) at Bowen and Shute Harbour.

## 2.8 Stormwater Infrastructure Data

Council provided the Town of Whitsundays urban stormwater network for the purposes of this study. This data was delivered in a geographic information system (GIS) format. Stormwater infrastructure details used in this study are summarised below. Where culvert data was missing, Council undertook an additional site visit to provide culverts dimensions. If data was unavailable, assumptions were made using aerial photography and LiDAR data.

### 2.8.1 Culverts

The culvert information included the following attributes;

- Asset ID
- Zone (broader location of the culvert)
- Culvert dimension (height, width and length)
- Culvert inverts
- Number of culverts (if applicable).

### 2.8.2 Pits and Pipes

The pit information included the following attributes;

- Asset ID
- Zone (broader location of the pit)
- Location of the pit (Easting and Northing)
- Depth of the pit (not given in some instances)
- Pit Type (grated etc.).

## 2.9 Land Use

Council provided the c classification as per Council’s Draft Planning Scheme which describes the expected land use up to the year 2036. This data was georeferenced to GDA 94-MGA Zone 55. This data was used for the hydrologic and hydraulic modelling.

# 3 URBS Hydrologic Modelling

## 3.1 Overview

The software URBS was utilised. A major advantage of this software is that the latest release has been revised to facilitate the implementation of ARR 2016 guidance; some alternatives have not yet been revised to do this. URBS is used by the Bureau of Meteorology for operational flood forecasting throughout Australia. Therefore, the URBS model may provide flood forecasting uses for Council in future.

## 3.2 URBS Software

URBS is a rainfall runoff routing model. Three runoff routing options are available in URBS to describe channel and catchment storage routing, of which two options are recommended: 'Basic Model' and 'Split Model'. The 'Split Model' has been adopted for the TOWDS. For this modelling approach, the channel and catchment routing are separated and represented by a non-linear reservoir. Catchment area and channel length are used to describe the runoff routing through each sub-catchment and from one sub-catchment to the next.

## 3.3 Sub-catchment Delineation

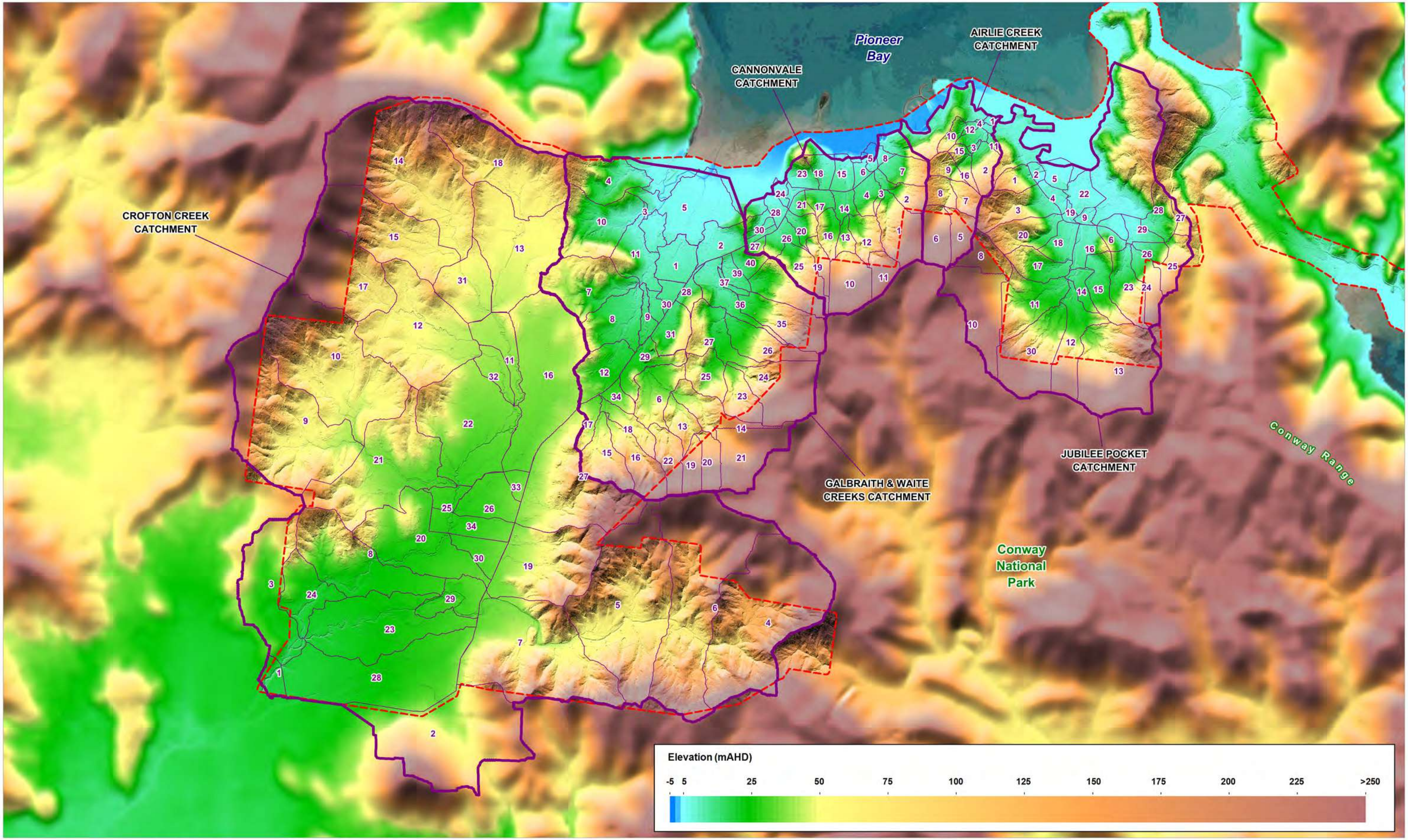
CatchmentSIM software was utilised to delineate creek catchments into smaller sub-catchments using the supplied topographic data. The delineated sub-catchments were then manually checked and altered (if necessary) to better reflect drainage through the study area.

The sub-catchment delineation was based on a 5m Digital Elevation Model (DEM). The DEM was established using Council's 2016 LiDAR data as the primary source and supplemented with SRTM data where LiDAR was missing. The 5m DEM was manipulated to ensure that:

- Flow paths were defined and recognised in CatchmentSIM;
- Major watercourse cross-drainage structures that influence the sub-catchment delineation were identifiable by CatchmentSIM; and
- Main floodplain features, such as highway and road embankments, were identifiable as hydrological boundaries in CatchmentSIM.

The flow paths were reviewed and edited, where necessary, to ensure they were contiguous across cross-drainage structures and that the resulting sub-catchment delineation (and model routing) was appropriate.

The adopted URBS hydrologic model layout and sub-catchments are shown in Figure 3-1. The sub-catchment parameters are documented in Appendix B.




**LEGEND**

Catchment

Subcatchment

LiDAR Coverage

Title:

**Subcatchment Delineation**

Figure: 3-1

Rev: A



N

0 1 2km

Approx. Scale

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## 3.4 Land Use

Land use types across the five catchments have been defined using Council's draft planning scheme zone categorisation for 2036 and aerial photography. These zones were used to define land use within the hydrologic models. A summary of the adopted land use types and the respective percentage impervious is presented in Table 3-1.

**Table 3-1 Land Use Categories**

| Type | Percentage Impervious |
|---|---|
| Emerging Community | 20% |
| Environmental Management and conservation | 0% |
| Future Industry Area | 90% |
| Future Urban Area | 75% |
| Industry Area | 90% |
| Industry Investigation | 90% |
| Low-medium density residential | 30% |
| Nature conservation and open space | 0% |
| Rural | 10% |
| Rural residential | 20% |
| Urban area | 75% |

## 3.5 URBS Parameters

The storage lag parameter (α) and catchment lag parameter (β) used for each catchment is shown Table 3-2:

**Table 3-2 Catchment and Storage Lag Parameter Values**

| Catchment | α Value | β Value |
|---|---|---|
| Airlie Creek | 0.07 | 1.5 |
| Campbell Creek | 0.10 | 1.2 |
| Cannonvale | 0.10 | 1.2 |
| Crofton Creek | 0.27 | 1.1 |
| Galbraith and Waite Creeks | 0.10 | 1.5 |

These values have been selected based on a review of the hydrographs derived from URBS and TUFLOW with the focus of timing and peak discharge. These values are considered appropriate for this study.

## 3.6 Design Rainfall Events

### 3.6.1 Overview

The design flood events were developed using the latest industry guidance, ARR 2016 (made available in November 2016), which prescribed the design storm temporal patterns and intensity-frequency-duration (IFD) data.

ARR 2016 specifies an ensemble of ten point rainfall temporal patterns for each storm duration for bands of event magnitudes (AEP). The point rainfall temporal patterns were used as the catchment sizes were too small to use aerial rainfall temporal patterns. The peak flows derived from the rainfall temporal pattern ensembles were ranked from the smallest peak flow (Rank 1) to the highest peak flow (Rank 10). The temporal patterns are referred to in this report by their ranking from Rank 1 to Rank 10.

The TOWDS includes the following design events: 50%, 20%, 10% and 1% AEP design event. The PMF event was also investigated using estimates of the Probable Maximum Precipitation (PMP). PMP estimates were derived using methods that are separate to ARR 2016 – using guidelines published by the Bureau of Meteorology.

The design rainfall intensities for the design events up to the 1% AEP event, and the climate change scenarios are shown in Sections 3.6.2 and 3.6.3. The temporal pattern of the 'wet tropic' zone was applied.

The 2016 IFD data replace both the ARR87 IFD data and the interim 2013 IFD data. The ARR 2016 IFD data are an improvement on the previous ARR revision due to:

- A more extensive rainfall record length, with more than 30 years of additional records since the previous ARR revision;
- An enhanced spatial resolution of rainfall records due to the wider network of rainfall stations; and
- A more contemporary and robust regional rainfall frequency analysis that is more resistant to the existence of outliers.

Therefore, the ARR 2016 IFD data are expected to provide an improved estimate of the design rainfall depths.

### 3.6.2 Design Event Rainfall Depths

Presented in Table 3-3 are the design event rainfall depth estimates for each catchment for a 60 minute storm duration.

Probable Maximum Precipitation (PMP) estimates for each catchment were calculated using the Generalised Short Duration Method (GSDM). Listed in Table 3-3 are the rainfall estimates for the PMP for each catchment.

**Table 3-3 Design Event Rainfall Estimates (mm) for a 60 minute Storm Duration**

| Catchment | 50% AEP | 20% AEP | 10% AEP | 1% AEP | PMP |
|---|---|---|---|---|---|
| Airlie Creek | 50.9 | 63.6 | 71.9 | 102 | 500 |
| Campbell Creek | 50.7 | 63.0 | 71.4 | 101 | 460 |
| Cannonvale | 50.9 | 63.6 | 71.9 | 102 | 490 |
| Crofton Creek* | 49.5 | 61.5 | 69.6 | 97.9 | 720 |
| Galbraith and Waite Creeks | 50.9 | 63.6 | 71.9 | 102 | 550 |

**After application of the Aerial Reduction Factor*

### 3.6.3 Climate Change Scenario

ARR 2016 provides guidance on rainfall intensity increases due to climate change up to the year 2090. Since the 2100 climate horizon was required for the TOWDS, the 2080 and 2090 rainfall depths were extrapolated to determine the rainfall depths for the 2100 climate horizon. The following climate change scenarios were simulated in the hydrologic models for the 1% AEP event and for the critical duration for each catchment. The critical duration for all catchment except for the Airlie Creek catchment, is different to the 60-minute duration, hence Table 3-4 also provides the climate change rainfall depth for the 60-minute duration, for comparison with Table 3-3.

**Table 3-4 Climate Change Rainfall Estimates**

| Catchment | Rainfall Depth (mm) for 60 min duration | | Rainfall Increase % | |
|---|---|---|---|---|
| | 1% AEP 2050 Scenario | 1% AEP 2100 Scenario | 1% AEP 2050 Scenario | 1% AEP 2100 Scenario |
| Airlie Creek | 107.3 | 113.2 | 5.2 | 11 |
| Campbell Creek | 106.3 | 112.1 | 5.2 | 11 |
| Cannonvale | 107.3 | 113.2 | 5.2 | 11 |
| Crofton Creek | 103.0 | 108.7 | 5.2 | 11 |
| Galbraith and Waite Creeks | 107.3 | 113.2 | 5.2 | 11 |

## 3.7 Losses

ARR 2016 also provided guidance for initial and continuous rainfall losses. However, ARR 2016 notes that these losses are only for rural use and are not for use in urban areas[1].

Hence, the initial and continuous losses presented in Table 3-5, were adopted for all catchments. These losses are considered appropriate for this study.

**Table 3-5 Losses**

| Loss Type | Loss Value |
|---|---|
| Initial Loss | 0 mm |

[1] http://data.arr-software.org/

| Loss Type | Loss Value |
|---|---|
| Continuous Loss | 2.5 mm/hr |

## 3.8 Model Verification

Flow records were not available in the study area. Hence, hydrologic model calibration could not be undertaken. The hydrologic models were verified against the Regional Flood Frequency Estimation Model (RFFE), available from ARR 2016. All results and comparisons in this section are based the 1% AEP event.

The comparison between URBS and RFFE were undertaken for the five catchments. Table 3-6 presents the average discharge, percent difference in discharge, lower and upper confidence limits for the area of interest using RFFE. The discharge derived from URBS is well within the RFFE confidence limits for all catchments. Apart from Crofton Creek, the percent difference between URBS and the average RFFE discharge was 12% at most. The Crofton Creek catchment indicates a difference of up to 37%, however, this difference in discharge is within the confidence limits of RFFE. Hence, there is an acceptable level of confidence in the URBS model, considering the available data. The confidence of the discharge derived from the hydrologic models could be improved through model calibration, if gauge data would be available, in particular for the Crofton Creek catchment.

**Table 3-6 Discharge Comparison between URBS and RFFE**

| Catchment | Sub catchment ID | URBS ($m^3/s$) | RFFE Average ($m^3/s$) | % Difference | 5% Confidence Limits ($m^3/s$) | 95% Confidence Limits ($m^3/s$) |
|---|---|---|---|---|---|---|
| Airlie Creek | air001 | 54.2 | 51.1 | 6.1 | 23.5 | 113 |
| Campbell Creek | S 9 | 116.1 | 131.0 | -11.4 | 60.1 | 289 |
| | S 29 | 40.6 | 39.7 | 2.3 | 18.2 | 87.9 |
| Cannonvale | S 15 | 34.1 | 32.2 | 5.9 | 15.1 | 69.8 |
| | S 5 | 20.1 | 21.6 | -6.8 | 10.1 | 46.7 |
| Crofton Creek | cro013+cro031 | 180.3 | 286 | -37.0 | 139 | 590 |
| | cro012 | 53.4 | 75.8 | -29.6 | 39.3 | 168 |
| Galbraith and Waite Creeks | gal041 | 25.2 | 28.6 | -11.9 | 13.3 | 62.4 |
| | gal036 | 16.2 | 15.9 | 1.9 | 7.5 | 34.3 |

Airlie Creek has one major outlet (at sub-catchment 'air001') at Lions Park located at Airlie Beach with a total discharge of 54.2$m^3/s$ calculated form the URBS model. The result compared well with the RFFE average discharge of 51.1$m^3/s$.

The Campbell Creek catchment outlet is located at sub-catchment '9', as displayed in Figure 3-1. A total discharge of 116$m^3/s$ was calculated at this location from the URBS model, which is well within the RFFE confidence limits. Similarly, a total discharge of 40.6$m^3/s$ was calculated at the discharge outlet for sub-catchment '29'.

The Cannonvale model consists of two minor streams; one stream runs adjacent to Bicentennial Park, while the other stream (Turtle Creek) discharge along the intersection of Proserpine Shute Harbour Road and Coral Esplanade Road. The outlet of the first stream is located in sub-catchment '15'. A total discharge of 34.1m³/s was calculated at this location from the URBS model. Similarly, a total discharge of 20.14m³/s was calculated at the discharge outlet for sub-catchment '5'.

Crofton Creek is a unique catchment in TOWDS. It is the only one that discharges inland and significantly exceeds the other catchments in size. The terrain changes from high slope in upstream areas to extremely flat surface along the main channel. Model results from two focal locations on Brandy Creek (sub-catchment 'cro005') with discharge of 128.5m³/s and Crofton Creek (sub-catchment 'cro012') with 53.4m³/s.

Galbraith and Waite Creek catchment consist of two main creeks. Discharge at sub-catchment 'gal041' on Waite Creek was 25.2m³/s and discharge at sub-catchment 'gal036' on Galbraith Creek was 16.2 m³/s. Both these results are well within the RFFE confidence limits.

## 3.9 Results

The box plots shown in Figure 3-3 to Figure 3-6 illustrate the discharge variability for a given sub-catchment over different storm durations and rainfall temporal patterns for the 1% AEP design event. The blue box indicates the discharge range, the red line the median and the red dot displays the mean discharge.

### 3.9.1 Airlie Creek Box Plots

The largest median peak discharge at the Airlie Creek outlet is produced by a 45-minute storm duration as shown Figure 3-2. According to the critical duration analysis using the hydraulic model, refer to Section 4.5, a 60 minute storm duration event generated the largest peak flood level across the majority of the catchment.

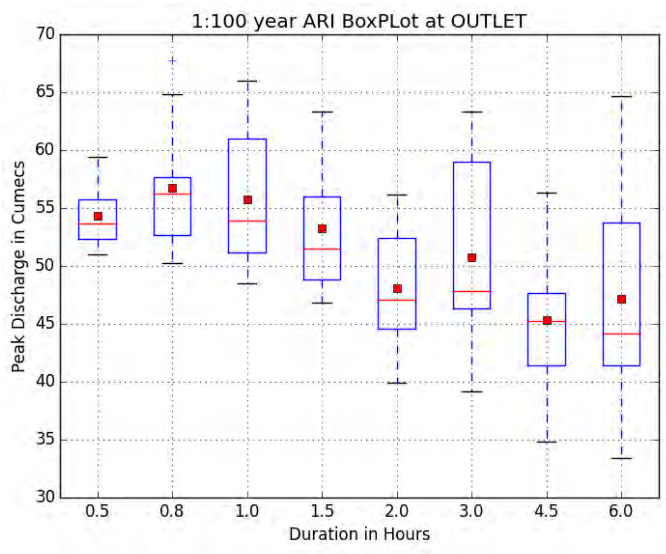



**Figure 3-2 Discharge Variability for Sub-catchment 'air001' in Airlie Creek Catchment**

### 3.9.2 Campbell Creek Box Plots

Figure 3-3shows that the largest median peak discharge at the Campbell Creek outlet is produced by a 60 minute storm duration. The 45 minute storm duration event generated the largest peak flood level using the hydraulic model, refer to Section 4.5.

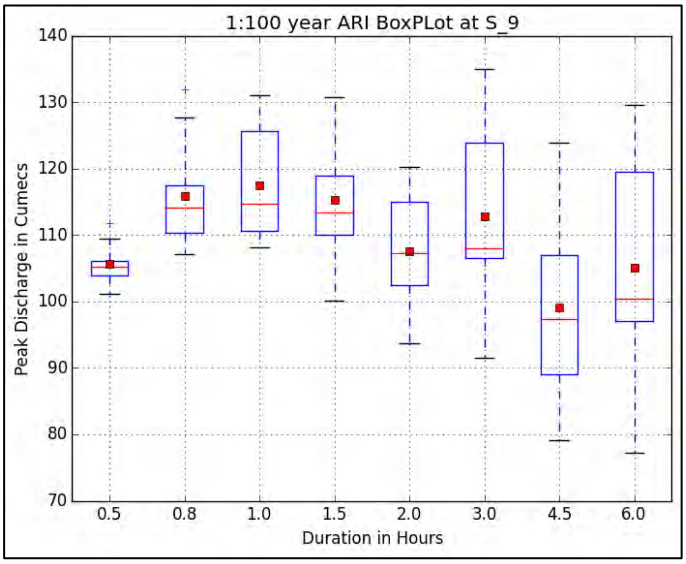



**Figure 3-3 Discharge Variability for Sub-catchment '9' in Campbell Creek Catchment**

### 3.9.3 Cannonvale Box Plots

Figure 3-4 suggests that the largest median peak discharge occurs at the Turtle Creek is caused by a 45 minute storm duration, which is consistent with the critical duration analysis discussed in Section 4.5.

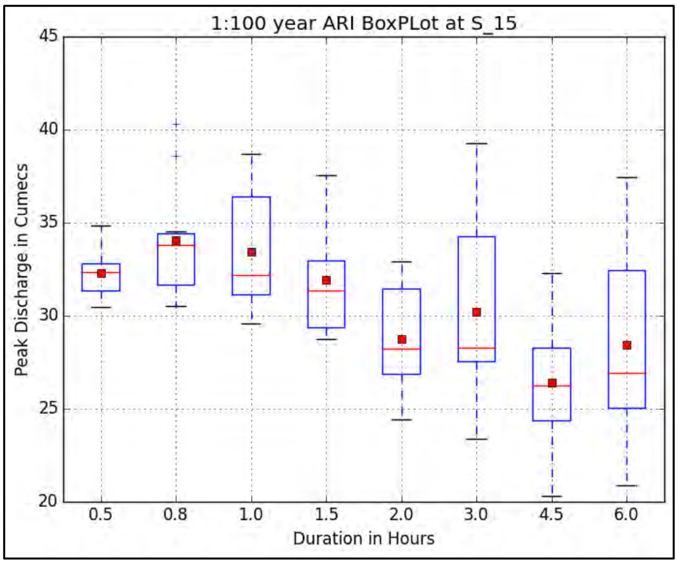



**Figure 3-4 Discharge variability for Sub-catchment '15' in Cannonvale Catchment**

### 3.9.4 Crofton Creek Box Plots

Figure 3-5 presents the hydrologic modelling results for the 1% AEP event. The 18-hour storm duration produces the largest median peak discharge at the Crofton Creek outlet, but in comparison with the other durations it seems to be an outlier. However, the 3 hour storm duration event generates the largest median peak discharge in areas along the main creek where there is potential future development. The critical duration analysis is discussed in Section 4.5, which adopted the 3 hour storm to provide the highest peak flood levels for the majority of the catchment.

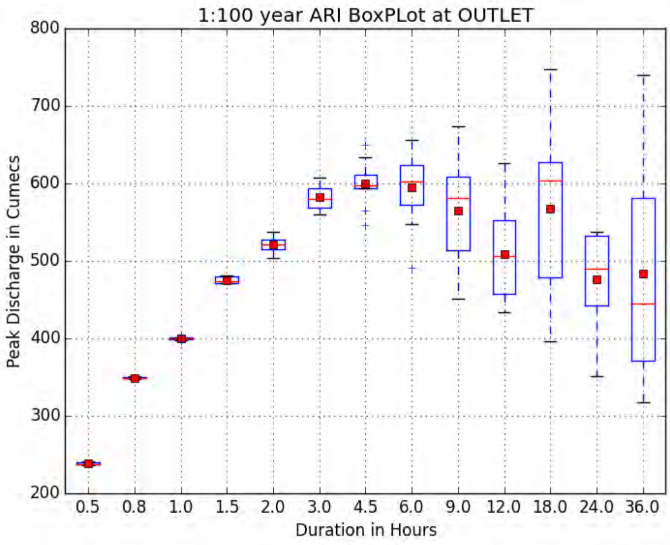



**Figure 3-5 Discharge Variability for Sub-catchment 'cro001' in Crofton Creek Catchment**

### 3.9.5 Galbraith and Waite Creeks Box Plots

The median peak discharge for the Galbraith and Waite Creeks outlet occurs for a 90-minute storm duration, as is shown on Figure 3-6. This is consistent with the critical duration analysis (section 4.5.)

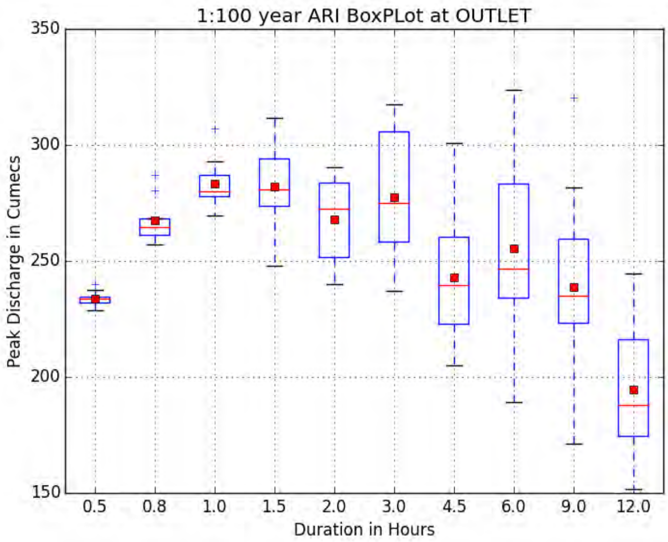



**Figure 3-6 Discharge Variability for Sub-catchment 'gal005' in Galbraith and Waite Creeks Catchment**

# 4 TUFLOW Hydraulic Modelling and Methodology

## 4.1 TUFLOW Modelling Technique

Due to the complex nature of floodplain flow patterns in urban catchments, Council has adopted a computerised modelling approach for the prediction of flood levels in its catchments. These computer models are two-dimensional (2D), which means that water can flow in any direction across a horizontal plane. One-dimensional elements, in which water can only flow in one dimension, forwards or backwards, have been used to model structures such as the sub-surface pipe network and culverts. The 1D and 2D components are dynamically linked so that water can flow between the two components in real time during a simulation. These models are currently the most accurate, cost-effective and efficient tools to predict the flood behaviour of a catchment.

Our approach was to develop a catchment flood model that consists of a high resolution 2D domain that is dynamically linked to a series of 1D domains that simulate the drainage characteristics of the stormwater network (i.e. kerb inlet pits and stormwater pipes and cross drainage structures).

TUFLOW was chosen as the hydraulic modelling software due to its ability to:

- Accurately represent overland flow paths, including flow diversion and breakouts (2D modelling);
- Model the stormwater drainage components of the entire catchment with a relatively high level of accuracy (1D modelling);
- Dynamically link components of the 1D models (i.e. drainage pits) to any point in the 2D model area; and
- Produce high quality flood map output, which is fully Geographical Information System (GIS) compatible.

This study utilised the latest TUFLOW Classic 2016 release at the time the work was undertaken.

## 4.2 Model Layout

### 4.2.1 Overview

The model extents and the TUFLOW model layout of the five TUFLOW models is presented individually for each catchment in the Appendix (Figure C-2, Figure D-2, Figure E-2, Figure F-2 and Figure G-2). The model grid resolution for all five TUFLOW models is 5m, which resulted in practical model run times (less than 3 hours for all catchments). The grid cell size of 5m is considered to be sufficiently fine to represent the variations in floodplain topography and land use.

### 4.2.2 2D Model Domain

The extent of the 2D hydraulic model domains cover most the catchment areas, but excludes the upper reaches. The 2D model domains were entirely covered by the LiDAR data. The full 2D domain is shown in Figure 3-1. Each square grid element (5m x 5m) contains information on ground topography (sampled from the DEM), surface resistance to flow (Manning's 'n' value) and initial water level.

### 4.2.3 Representation of Stormwater Drainage Network

While the floodplain is aptly represented using the 5 metre grid resolution 2D domain, the underground stormwater drainage system and hydraulic structures (such as pipes and culverts) are better modelled in a 1D domain. TUFLOW can represent a pipe network of underground drainage systems that can be linked to either a 1D open channel network and or 2D overland flowpaths. The 1D and 2D components of the hydraulic model are dynamically linked, allowing water to flow from the 2D floodplain into the underground pipe network (1D model), and vice versa (surcharging).

The underground pipe network is linked to the 2D model via a pit inlet, allowing flow in both directions. A schematic diagram of this linkage is presented in Figure 4-1.

Known stormwater pits and pipes larger than 600mm within the study area are included in the flood model. It should be noted that the TUFLOW model incorporates Council’s stormwater network only; no private drainage systems or detention basins on private properties are included.

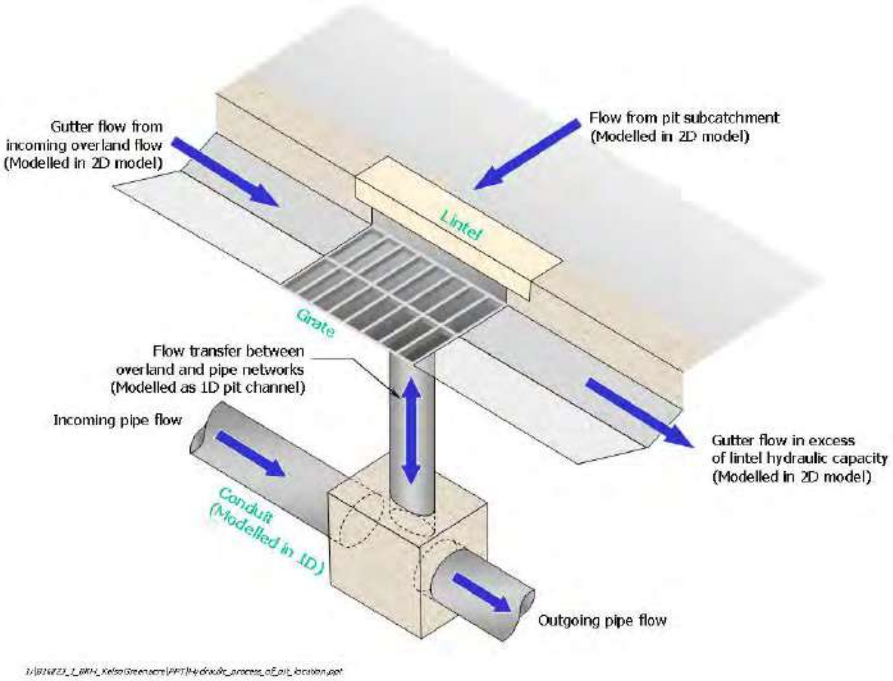



**Figure 4-1 Linking Underground 1D Stormwater Drainage Network to the Overland 2D Domain**

### 4.2.4 Hydraulic Structures

The many hydraulic structures throughout the catchment play a major role in determining flood behaviour in the study area. As such, it is considered important to accurately represent these structures. Table 4-1 lists the largest five structures in each catchment.

**Table 4-1 Hydraulic Structures Summary**

| Catchment | Selected Structure | Type | Width / Diameter (m) | Height (m) | Number of Barrels |
|---|---|---|---|---|---|
| Airlie Creek | 1 | rectangular | 2.13 | 2.13 | 3 |
| | 2 | circular | 1.5 | | 1 |
| | 3 | circular | 1.35 | | 1 |
| | 4 | circular | 0.9 | | 1 |
| | 5 | circular | 0.6 | | 1 |
| Cannonvale | 1 | circular | 1.8 | | 5 |
| | 2 | circular | 1.8 | | 4 |
| | 3 | circular | 1.5 | | 5 |
| | 4 | rectangular | 2.1 | 1.5 | 2 |
| | 5 | rectangular | 1.5 | 0.9 | 2 |
| Campbell Creek | 1 | rectangular | 2.14 | 2.12 | 5 |
| | 2 | rectangular | 2 | 1.53 | 6 |
| | 3 | rectangular | 2.1 | 1.1 | 3 |
| | 4 | rectangular | 1.2 | 0.6 | 5 |
| | 5 | circular | 1.5 | | 4 |
| Crofton Creek | 1 | rectangular | 1.5 | 0.9 | 6 |
| | 2 | rectangular | 1.5 | 0.75 | 4 |
| | 3 | rectangular | 1.5 | 1.2 | 3 |
| | 4 | rectangular | 1.5 | 0.9 | 3 |
| | 5 | circular | 1.5 | | 3 |
| Galbraith and Waite Creeks | 1 | rectangular | 2.6 | 1.8 | 6 |
| | 2 | rectangular | 2.4 | 2.4 | 6 |
| | 3 | rectangular | 2.4 | 1.5 | 6 |
| | 4 | rectangular | 3.0 | 1.55 | 5 |
| | 5 | rectangular | 2.1 | 1.8 | 5 |

## 4.3 Hydraulic Roughness

Roughness coefficients represent the resistance to flood flows in channels and floodplains. The land use delineation of the baseline model is based on aerial photography, observations during site walk-overs and on-site photographs.

The land use delineation applied in the TUFLOW model is presented individually for each catchment in the Appendix (Figure C-2, Figure D-2, Figure E-2, Figure F-2 and Figure G-2).

The hydraulic roughness of the ground surface is represented in the flood model using the Manning's 'n' roughness coefficients. Values of the roughness coefficients have been based on industry standards (e.g. Chow, 1959 and Arcement and Schneider, 1989). The adopted Manning's 'n' roughness coefficients for the land uses within the study area are listed in Table 4-2.

**Table 4-2 Land Use Hydraulic Roughness**

| Land Use Type | Manning's 'n' Coefficient |
|---|---|
| Concrete | 0.03 |
| Dense vegetation | 0.08 |
| Grass (maintained) | 0.04 |
| Grass (unmaintained) | 0.06 |
| Medium density urban | 0.08 |
| High density urban | 0.10 |
| Marshland | 0.03 |
| Ocean | 0.02 |
| Roads | 0.03 |
| Rural Residential | 0.05 |
| Vegetated Channel | 0.06 |

## 4.4 Boundary Conditions

### *4.4.1.1 Model Inflows*

The flows estimated using the URBS models were applied to the hydraulic models as Source-Area (SA) boundaries in the 2D domain either as 'total' or 'local' inflows to the model (depending on the location of the inflow within the model).

- Local inflows represent the runoff draining from a single sub-catchment only.
- Total inflows represent the accumulated runoff draining from the entire portion of the catchment upstream of the selected sub-catchment. This is usually applied as the upstream boundary of the hydraulic model.

The inflow locations for each model are shown in the model layout figures for each catchment in the Appendices (Figure C-1, Figure D-1, Figure E-1, Figure F-1 and Figure G-1).

#### 4.4.1.2 Downstream Boundary Condition - SEAsim and Residual Tide Analysis

Four of the models drain into the ocean. Thus, the downstream boundary conditions will be defined by ocean levels. Appropriate ocean boundary conditions were informed by statistical analyses undertaken by SEAsim (Dr Bruce Harper). The approach is described in BMT WBM's Bowen Water Hazards Assessment Storm Tide Modelling Basis Report (BMT WBM, 2017) undertaken for Council. Please refer to that report for further information.

This SEAsim model was used to estimate tropical cyclone (TC) driven water levels. Figure 4-2 shows the results from the analysis, presenting the extreme water level analysis curves that have been derived using SEAsim (TC component) and tidal residual data resampling (non-TC component).

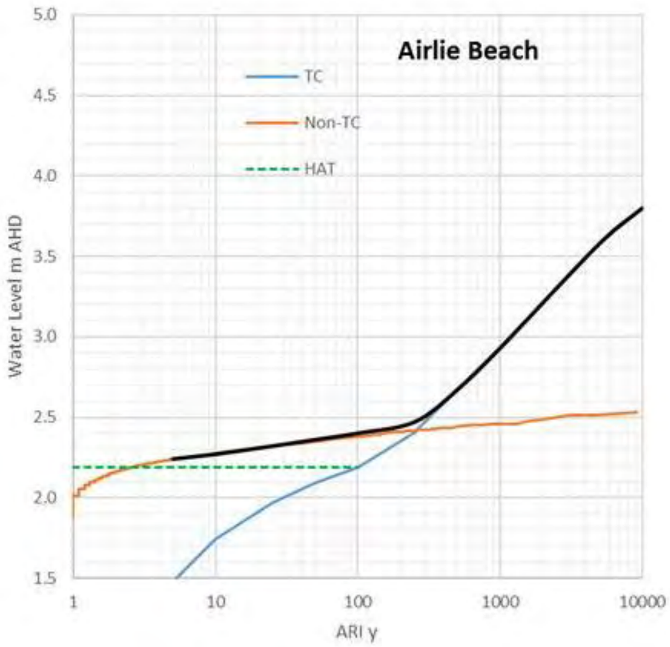



**Figure 4-2 Water Level Analysis Curves at Airlie Beach**

*(provided by SEAsim – Dr Bruce Harper)*

Figure 4-2 presents a combined level of 2.4m AHD for the combined TC and non TC component for the 1% AEP event. Hence a constant water level of 2.4mAHD was applied for all design events at the downstream boundary for all catchments draining into the ocean. It is noted that this is a conservative approach, as it is unlikely that a 1% AEP rainfall event will peak at precisely the same time as the peak of a 1% AEP ocean event. The conservative results will apply to low lying areas near the coast. See the climate change sensitivity analysis in Section 5.3 for an indication of the sensitivity of flood levels to the adopted ocean levels.

The Crofton Creek discharges into Proserpine River. For this catchment, a water level versus flow curve (identified as a HQ boundary in TUFLOW) was applied as the downstream boundary condition. The HQ curve was automatically generated by TUFLOW based on a user defined slope and Manning's equation.

The downstream boundary locations of the five catchments are shown in the Appendices (Figure C-1, Figure D-1, Figure E-1, Figure F-1 and Figure G-1).

## 4.5 Critical Duration Analysis

An assessment of critical storm durations (storm durations that results in the highest peak flood level) was undertaken. The critical durations were initially assessed based on the hydrologic model results (peak flows). However, the final critical durations were selected based on the hydraulic model results (peak water levels). This means that the adopted critical durations were selected based upon the maximum flood levels rather than flows. The critical duration analysis was undertaken for the 1% AEP event and was then applied for all design events expect the PMF.

Since the PMF event is derived from a completely different method with different rainfall temporal patterns, a separate critical duration assessment was done for the PMF using the same approach as described above and below.

To determine the critical storm durations, the following methodology was adopted:

(1) The hydrologic models were simulated for a range of storm durations for the 1% AEP event. The peak flows were extracted from the results and ranked to determine the median peak flows.

(2) The rainfall temporal patterns relating to the median peak flows were adopted as the representative temporal patterns for each critical duration.

(3) The hydraulic models were simulated for a range of storm durations using only the representative rainfall temporal pattern for the 1% AEP event.

(4) The peak flood level results were mapped for the 'maximum envelope' of all the storm durations, noting which storm durations produced the highest water levels in different parts of the catchment. This mapping was used to select a set of critical storm durations (one critical duration for each of the five catchments).

(5) The difference between the peak flood levels from only the selected critical durations and the peak flood levels for the full envelope of storm durations was computed. This was done to assess the sensitivity of the results to adoption of a single critical storm duration.

(6) Selection of the critical durations was confirmed after the comparison in the step above. The adopted critical storm durations is based on the temporal patterns that generated the median peak flows and the storm durations that resulted in the highest flood levels across the most widespread and developed areas.

A summary of the selected critical storm duration for each catchment is outlined in Table 4-3.

Table 4-3 Critical Storm Duration Selection

| Catchment | Assessed Durations | Selected Critical Storm Duration |
|---|---|---|
| Airlie Creek | 0.5, 0.75, 1, 1.5, 3, 4.5, and 6 hours | 1 hour storm |
| Campbell Creek | 0.5, 0.75, 1, 1.5, 3, 4.5, and 6, hours | 45 minute storm |
| Cannonvale | 0.5, 0.75, 1, 1.5, 3, 4.5, and 6, hours | 45 minute storm |
| Crofton Creek | 0.5, 0.75, 1, 1.5, 3, 4.5, 6, 9, 12,18, 24 and 36 hours | 3 hour storm |
| Galbraith and Waite Creeks | 0.5, 0.75, 1, 1.5, 3, 4.5, 6, 9 and 12 hours | 1.5 hour storm |

For each catchment, there is a map that presents the results from the critical duration analysis. Figure C-3, Figure D-3, Figure E-3, Figure F-3 and Figure G-3 shows which events generated the highest peak flood levels in different areas throughout the catchment for the 1% AEP.

The difference comparison for the 1% AEP peak flood levels (as described in step 5 above) are shown in Figure C-4, Figure D-4, Figure E-4, Figure F-4 and Figure G-4. The difference in peak flood levels for the adopted critical durations and for all the storm durations is within 0.01m through the majority of the study area. The key differences are:

- Airlie Creek catchment: Difference in peak flood levels in the small carpark area between Airlie Beach and Coconut Grove and in the narrow channel south of Waterson Way.
- Campbell Creek: Figure D-4 shows that there are small areas with difference of about 0.1m near Timberland Road and near the sharp bend along Proserpine – Shute Harbour Road.
- Cannonvale: Figure E-4 shows a small area of difference within a narrow channel south of Coyne Road.
- Crofton Creek: Figure F-4 demonstrates that only the most upstream areas and an area near the downstream boundary show differences of up to approximately 0.1m.
- Galbraith Creek: Differences of approximately 0.1m occur in the most upstream areas and a larger difference of up to 0.2m occurs upstream of the crossing of Paluma Road and Galbraith Creek.

## 4.6 Climate Change Scenario

The climate change scenario adopted the inflows from URBS with an increase in rainfall intensities and the sea level rise increases shown in Table 4-4. The sea level rise is based on State Planning Policies in Queensland.

Table 4-4 Climate Change Parameters

| CC Event | Increase in Rainfall | Increase in Sea Levels |
|---|---|---|
| CC2050 | 5.2% | 0.4m |
| CC2100 | 11.0% | 0.8m |

## 4.7 Sensitivity Analysis

### 4.7.1 Overview

The following three sensitivity analysis were undertaken using the 1% AEP event and the selected critical duration to gain and understanding of the models sensitivities to hydraulic roughness parameters and blockage of culverts.

- Increase of Manning's 'n' roughness values by 20%;
- Decrease of Manning's 'n' roughness values by 20%; and
- Blockage of structures along Shute Harbour Road, Main Street in Airlie Creek and bridge on Gregory Cannon Valley Road in Crofton Creek catchment by 50%.

The climate change scenarios described in Section 4.6 also describes the model sensitivity to increases in rainfall intensities and sea levels rise applied at the downstream boundary.

## 4.8 Flood Hazard Definitions

Flood hazard categories as outlined by Australian Emergency Management Institute in 2014 was an output of the TUFLOW models and provided to Council (referred to as a ZAEMI result file in TUFLOW). The ZAEMI output values are zero for no hazard and 1 to 6 for H1 to H6 hazard categories respectively. The flood hazard categories are show in Figure 4-3, described in Table 4-5 and the hydraulic limits are listed in Table 4-6 (limiting flood depth, velocity and depth x velocity).

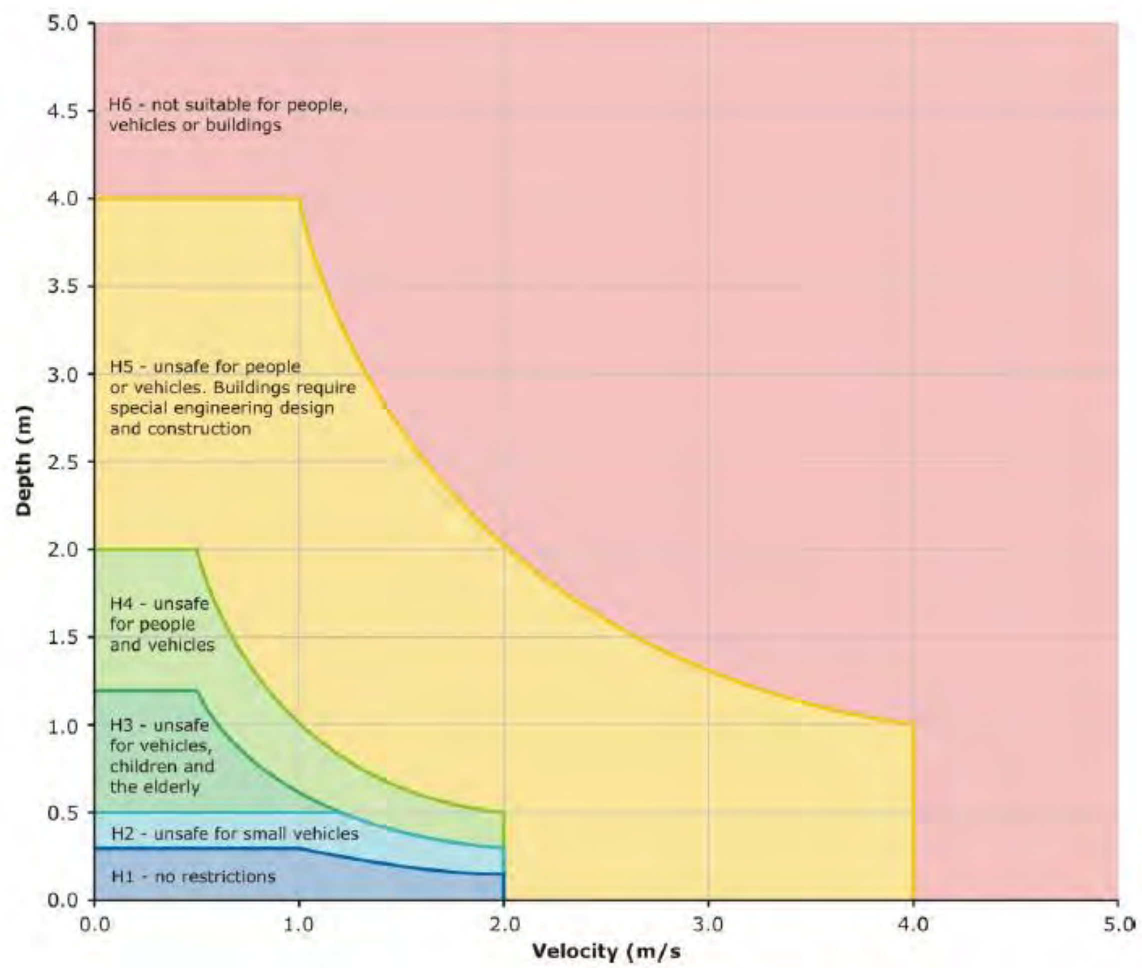



**Figure 4-3 Flood Hazard Chart**

**Table 4-5 Hazard Classification Description**

| Hazard Classification | Description |
|---|---|
| H1 | Relatively benign flow conditions. No vulnerability constraints. |
| H2 | Unsafe for small vehicles. |
| H3 | Unsafe for all vehicles, children and the elderly. |
| H4 | Unsafe for all people and all vehicles. |
| H5 | Buildings require special engineering design and construction. |
| H6 | Unconditionally dangerous. Not suitable for any type of development or evacuation access. All building types considered vulnerable to failure. |

Table 4-6 Flood Hazard Hydraulic Limits

| Flood Hazard Category | Description | Depth-Velocity Limit | Depth Limit | Velocity Limit |
|---|---|---|---|---|
| H1 | Generally safe for vehicles, people and buildings | ≤ 0.3 $m^2/s$ | ≤ 0.3 m | ≤ 2.0 m/s |
| H2 | Unsafe for small vehicles | ≤ 0.6 $m^2/s$ | ≤ 0.5 m | ≤ 2.0 m/s |
| H3 | Unsafe for vehicles, children and the elderly | ≤ 0.6 $m^2/s$ | ≤ 1.2 m | ≤ 2.0 m/s |
| H4 | Unsafe for vehicles and people | ≤ 1.0 $m^2/s$ | ≤ 2.0 m | ≤ 2.0 m/s |
| H5 | Unsafe for vehicles and people<br>All building types vulnerable to structural damage | ≤ 4.0 $m^2/s$ | ≤ 4.0 m | ≤ 4.0 m/s |
| H6 | Unsafe for vehicles and people<br>All building types considered vulnerable to failure | > 4.0 $m^2/s$ | > 4.0 m | > 4.0 m/s |

# 5 Results for Flood Behaviour, Climate Change and Flood Risk

## 5.1 Flood Model Results and Mapping

The model produces a grid of flood behaviour results at 5m intervals over the study area. These results include flood extents, flood levels, flood depths, and flood velocities at regular time intervals throughout the flood simulation. The peak values are also recorded by TUFLOW and output as separate grids. These grids can be interrogated at any location within the study area using a GIS database.

All flood model results have been provided to Council for incorporation into their GIS systems. In addition, the 1% AEP event has been mapped and is presented in Appendix C to Appendix G. The maps provided include:

- Peak flood levels;
- Peak flood depths;
- Peak flow velocities;
- Peak velocity-depth product; and
- Peak flood hazard (ZAEMI).

These flood criteria across the study area and for a range of design events are essential for flood risk assessments and future planning.

## 5.2 Preliminary Flood Risk Assessment

### 5.2.1 Overview

A high-level risk assessment has been undertaken based on the hydraulic model results. However, it is crucial to understand that this assessment is preliminary and very limited, and does not include additional information, such as critical infrastructure and locations of vulnerability, evacuation routes and isolation (e.g. schools, nursing homes, child care facilities, etc.).

The flood extent for the PMF defines the estimated maximum extent of the floodplain in the catchments.

### 5.2.2 Arlie Creek

In the Airlie Creek catchment flooding occurs along Airlie Creek channel and the unnamed tributary that joins Airlie Creek near Marin Street in Airlie Beach. The shops along Main Street and Airlie Creek are inundated in a 1% AEP event. Interestingly, there is a breakout of Airlie Creek at the Waterson Way crossing on undeveloped land. Flood waters then flow parallel to and east of Airlie Creek. Flooding also occurs on the car park west of Shingley Drive near the marina.

Peak flood depths within the Airlie Creek breakout range from 0.1m to 1m near the roundabout off Waterson Way.

Model results indicate that the Airlie Creek Channel has high velocities of more than 2m/s, and high flood depth (larger than 1m) resulting in the highest flood hazard within the catchment. The flood hazard within the Marina car park is a category 2 to 3, mainly due to the flood depth. The shops along Airlie Creek and near Main Street appear to be in a category 1 to 2 in the 1% AEP event, but are at higher risk for larger events. Some key flood locations for further consideration are:

- Marina car park west of Shingley Drive;
- The breakout of Airlie Creek at the Waterson Way crossing (although currently undeveloped land); and
- The shops along Airlie Creek and near Main Street.

### 5.2.3 Campbell Creek

Campbell Creek runs in southerly direction through the catchment through the swampy and low-lying areas near the ocean, along Boatyard Road. Campbell Creek has two main tributaries and a few breakouts; the main outbreak along Jubilee Pocket Road. The hazard is high (category 4 to 5) within the Campbell Creek channel and the two most upstream tributaries. Some key flood locations for further consideration are:

- Some cross flow between the tributaries near Timberland Road;
- Residential area east of Jubilee Pocket Road and west of Sentry Court;
- Residential area near Maeva Street; and
- Residential area along Erromango Drive.

### 5.2.4 Cannonvale

There are five main flow paths through the Cannonvale catchment; each of them crossing Proserpine – Shute Harbour Road. Peak flood velocities and depths are high within most flow paths, resulting in high flood hazard (category 5 to 6) in the 1% AEP event. Some key flood locations for further consideration are:

- Between Coyne Road and Proserpine – Shute Harbour Road;
- To the east of Macarthur Drive;
- On the grounds of the Cannonvale Tafe;
- Near the Airlie Beach Bunnings (north of Proserpine – Shute Harbour Road);
- Within Bicentennial Park; and
- Along the most easterly flow path within the catchment, along Jones Road.

### 5.2.5 Crofton Creek

Crofton Creek has a much larger catchment size, but much sparser development compared to the other catchments. Brandy Creek is a large tributary to Crofton Creek that flows into Crofton Creek towards the downstream part of the study area. Crofton Creek crosses Riordanvale Road within the northern part of the model and Richardson Road at the middle part of the model. There are two main channels between Riordanvale Road and Richardson Road and west of Proserpine – Shute Harbour Road. Most of the high hazard category 4 to 5 is along the main creeks, but current rural land is also covered by high hazard.

Key flood locations include:

- The area between the two main channels between Riordanvale Road and Richardson Road;
- Riordanvale Road crossing; and
- Proserpine – Shute Harbour Road crossing.

### 5.2.6 Galbraith and Waite Creek

The Galbraith Creek is the most westerly channel within the Galbraith and Waite Creek catchment. Galbraith Creek has a large tributary that joins Galbraith Creek near Cutuli Road. Waite Creek runs to the east of Galbraith Creek. Both Creeks discharge into a low-lying and swampy area near the ocean.

Key locations include:

- The area between Valley Drive and Abell Road affected by the Proserpine - Shute Harbour Road crossing of Waite Creek (near the RSL club);
- The tributary to Waite Creek that crosses Valley Drive then flows through the Whitsunday Golf Course;
- The car park of the Whitsunday Plaza and along Myer Lasky Drive (between Cutuli Road and Proserpine – Shute Harbour Road); and
- The area to the east of Parker Road (continuing south from Abell Road) a tributary to the east of Waite Creek. Although it should be noted, that the new development may not have been included in the LiDAR 2016 data that was used for the modelling.

## 5.3 Climate Change Assessment

### 5.3.1 Arlie Creek

Sea level rise increases the inundation area around Coconut Grove, the nearby parking area and Airlie Beach. The 2050 climate change scenario causes only 0.05m increase in flood levels across the Main Street and surrounded areas to the outlet (Figure C-10). The 2100 climate change scenario reaches 0.1m difference (Figure C-11).

### 5.3.2 Campbell Creek

The climate change scenarios have increased the water levels across the Campbell Creek catchment by 0.01m to 0.2m upstream of Proserpine – Shute Harbour Road. The swampy and low lying area downstream of the Mandalay Road has been affected by sea level rise. Here, the difference in water levels between 2100 future climate scenario and current climate scenario is approximately 0.8m (refer to Figure D-11). Similarly, at this location, the difference in water levels for the 2050 future climate scenario compared to the current climate scenario is approximately 0.4m (refer to Figure

D-10). The flood extents have increased slightly along the Campbell Creek floodplain in response to the increase in flood levels.

### 5.3.3 Cannonvale

As expected, the climate change scenarios have increased the water levels across the Cannonvale catchment by around 0.1m to 0.2m. The difference in water levels between the 2100 climate change scenario and current climate scenario at the Coral Esplanade road is approximately 0.4m, whilst the difference in water levels for the 2050 climate change scenario at the same location is 0.1m with a slight increase in flood extent (refer Figure E-10 and Figure E-11).

### 5.3.4 Crofton Creek

As Crofton Creek is discharging inland, only higher rainfalls were applied for simulating both climate change scenarios (i.e. no sea level rise). There is a consistent increase in flood levels throughout the main channel by up to 0.05m for the 2050 climate change scenario (Figure F-10) and up to 0.2m for the 2100 climate change scenario (Figure F-11). The upstream part of Brandy Creek, where the channel is confined, shows higher increases in peak flood levels; for instance, reaching a 0.5m increase for the 2100 climate change scenario.

### 5.3.5 Galbraith and Waite Creek

Galbraith and Waite Creeks are discharging to the ocean and the coastal areas are heavily affected by the increase in sea level. Two locations of interest are at the two Shute Harbor Road main creek crossings. In the 2050 climate change scenario, there is a 0.2m water level increase upstream of Shute Harbour Road (Figure G-10) and 0.5m for the 2100 climate change event (Figure G-11).

## 5.4 Sensitivity Assessment

### 5.4.1 Arlie Creek

Decreasing Manning’s ‘n’ roughness by 20% slightly lowered peak water levels in Airlie Creek catchment. The only exception is at the upstream part of Airlie Creek, upstream of Waterson Way. Conversely, increasing Manning’s ‘n’ values caused lower water levels upstream of Waterson Way and higher peak flood levels for the rest of the catchment. Peak flood levels are within 0.1m difference between the two roughness scenarios (increase and decrease of Manning’s ‘n’). Hence, there is limited sensitivity to the adopted hydraulic roughness parameters in the Arlie Creek catchment.

The application of 50% blockage of structures on Main Street caused an increase in flood levels up to 0.2m upstream of the structures (and south of Main Street).

### 5.4.2 Campbell Creek

As expected, an increase in Manning’s ‘n’ roughness values resulted in higher flood levels across the catchment, while a decrease in Manning’s ‘n’ roughness values resulted in lower flood levels across the catchment. Most of the catchment shows a difference of less than 0.1m. However, there is a more significant difference of up to 0.4m in the mid region of the Campbell Creek catchment within the Campbell Creek channel east of Jubilee Pocket Road.

The 50% blockage on the structures along the Shute Harbour Road increased water levels upstream of Shute Harbour Road by up to 0.1m, and reduced water levels downstream of the Shute Harbour Road (less than 0.1m).

### 5.4.3 Cannonvale

As with the previous two catchments, the Cannonvale catchment recorded higher flood levels across the catchment with an increase in Manning's 'n' roughness, and lower flood levels with a decrease in Manning's 'n' roughness. Most of the catchment shows a difference of less than 0.1m. However, there are small areas within the channel where the difference in peak flood levels is up to 0.4m.

The flood level for the blockage scenario was approximately 0.2m higher upstream of Shute Harbour Road. This effect has also reduced water levels downstream of the Shute Harbour Road.

### 5.4.4 Crofton Creek

Increased Manning's 'n' roughness values resulted in higher flood levels in Crofton Creek catchment and lower levels with decreased Manning's 'n'. The differences varied across the channel between 0.10m to 0.40m.

A significant increase in water level was caused by blockage of the bridge across Brandy Creek on Shute Harbor Road. Upstream of the bridge water levels rose by up to 0.50m. Other structures on Shute Harbor Road cause lower impact of up to 0.20m increase in water level. The 50% blockage on the bridge across the Crofton Creek on Gregory Cannon Valley Road didn't result in a significant changes in flood levels (less than 0.05m change in flood level).

### 5.4.5 Galbraith and Waite Creek

A notable flood level increase of up to 0.2m was produced by the higher Manning's 'n' values in Galbraith and Waite Creeks. On the contrary, decreasing roughness by 20% was less significant with a water level difference reaching only 0.05m in most areas.

Blockage of structures on Shute Harbor Road increased the peak flood levels by up to 0.5m directly upstream of the structures, causing higher water levels throughout the catchment.

# 6 Qualifications

This assessment has relied upon datasets provided by Council, such as LiDAR 2016 data and stormwater network information. The accuracy of this report is therefore limited to the accuracy and completeness of this data and information.

The flood models are catchment scale models suitable for a flood / drainage study. However, the TUFLOW model is limited in its ability to represent fine scale features smaller than the resolution of the model grid (5m) which in turn limits the resolution of the results.

# 7 Conclusion

The following conclusions can be drawn from the study:

- Hydrologic and hydraulic modelling was undertaken to assess the existing flood behaviour in the following 5 catchments:
  - Crofton Creek;
  - Galbraith and Waite Creeks;
  - Cannonvale;
  - Arlie Creek; and
  - Campbell Creek.
- URBS hydrologic models were developed using the latest industry standards and rainfall intensities derived from ARR 2016. Design flood behaviour was simulated using the flood model for events from the 50% AEP through to the 1% AEP and the PMF (which provides an upper limit of the potential magnitude of flooding). Design storms that were input to the model were derived from ARR 2016. Rainfall losses were subtracted to allow for infiltration and other losses.
- TUFLOW Classic models were developed using the coupled 1D/2D approach. The hydraulic models have a model grid resolution of 5m, which resulted in practical model run times (typically less than 2 hours). These run times are also beneficial for potential future uses, for instance flood impact assessments or flood risk mitigation modelling.
- A range of storm durations were tested to determine which produced the highest flood levels. These tests were undertaken on the 1% AEP flood, for storm durations from 30 minutes to 36 hours using the temporal pattern that produced the median peak flow. Results for the 45 minute storm provided the highest flood levels across Cannonvale and Campbell Creek catchments. A 1 hour storm generated the highest flood level at Airlie Creek catchment. Galbraith and Waite Creek catchment reached the highest flood levels with a 90 minute storm and Crofton Creak, due to its size, had a longer critical duration of 3 hours for the majority of the catchment.
- The model results for each catchment provides information on the existing flood risk within the catchment, the effect of climate change and model sensitivities to blockage of selected structures and changes to the land use roughness value (Manning's 'n'). The flood maps are provided in Appendix C to Appendix G.

# 8 Recommendation

It is recommended that:

- Rain and river gauges are to be installed in the study area to enable model calibration;
- The model results (flood inundation extent, level, depth, velocity, hazard) be incorporated into Council's GIS database for use within Council's departments;
- The study outcomes will be used for a flood risk management study considering isolated communities, evacuation, defining risk using flood hazard, flood likelihoods and the individual consequences. A future flood risk management study will benefit from modelling of additional design events, such as the 5%, 2% and 0.1% AEP events;
- The developed models are to be used for additional modelling of future development layouts; and
- The study outcomes are to be used to inform Council's Planning Scheme.

# Appendix A Debris Mark Photos

# Appendix B URBS Sub-catchment Parameters

Table B-1 Airlie Beach Sub-catchment Parameters

| Sub-catchment ID | Area (ha) | Impervious Fraction |
|---|---|---|
| 1 | 2.36 | 0.060 |
| 2 | 13.69 | 0.340 |
| 3 | 1.73 | 0.593 |
| 4 | 0.72 | 0.750 |
| 5 | 21.60 | 0.029 |
| 6 | 33.51 | 0.010 |
| 7 | 14.93 | 0.536 |
| 8 | 16.85 | 0.355 |
| 9 | 14.24 | 0.703 |
| 10 | 9.71 | 0.734 |
| 11 | 2.96 | 0.750 |
| 12 | 2.81 | 0.750 |
| 13 | 1.93 | 0.688 |
| 14 | 7.36 | 0.733 |
| 15 | 3.45 | 0.750 |
| 16 | 9.32 | 0.664 |
| 17 | 7.44 | 0.640 |
| 18 | 15.76 | 0.627 |
| 19 | 18.26 | 0.845 |
| 20 | 13.24 | 0.593 |

Table B-2 Crofton Sub-catchment Parameters

| Sub-catchment ID | Area (ha) | Impervious Fraction |
|---|---|---|
| 1 | 15.24 | 0.120 |
| 2 | 234.03 | 0.085 |
| 3 | 46.51 | 0.180 |
| 4 | 273.05 | 0.035 |
| 5 | 263.02 | 0.091 |
| 6 | 281.24 | 0.047 |
| 7 | 242.43 | 0.116 |
| 8 | 65.58 | 0.122 |
| 9 | 237.48 | 0.142 |
| 10 | 252.37 | 0.141 |
| 11 | 4.035 | 0.750 |
| 12 | 179.06 | 0.206 |
| 13 | 152.20 | 0.118 |
| 14 | 276.9 | 0.069 |
| 15 | 138.05 | 0.159 |
| 16 | 152.4 | 0.674 |
| 17 | 132.5 | 0.138 |
| 18 | 161.05 | 0.115 |
| 19 | 141.64 | 0.073 |
| 20 | 56.66 | 0.423 |
| 21 | 175.53 | 0.482 |
| 22 | 173.59 | 0.705 |
| 23 | 150.22 | 0.100 |
| 24 | 23.08 | 0.106 |
| 25 | 14.83 | 0.750 |

| Sub-catchment ID | Area (ha) | Impervious Fraction |
|---|---|---|
| 26 | 43.67 | 0.743 |
| 27 | 126.0 | 0.109 |
| 28 | 111.1 | 0.101 |
| 29 | 37.88 | 0.100 |
| 30 | 25.59 | 0.100 |
| 31 | 61.06 | 0.218 |
| 32 | 23.16 | 0.750 |
| 33 | 9.95 | 0.712 |
| 34 | 35.65 | 0.728 |
| 35 | 34.75 | 0.110 |
| 36 | 13.29 | 0.105 |
| 37 | 23.53 | 0.110 |
| 38 | 58.52 | 0.223 |
| 39 | 5.37 | 0.110 |
| 40 | 95.26 | 0.230 |
| 41 | 82.21 | 0.150 |
| 42 | 7.19 | 0.100 |
| 43 | 87.19 | 0.110 |

**Table B-3 Cannonvale Sub-catchment Parameters**

| Sub-catchment ID | Area (ha) | Impervious Fraction |
|---|---|---|
| 1 | 49.60 | 0.166 |
| 2 | 16.10 | 0.464 |
| 3 | 7.111 | 0.669 |
| 4 | 15.98 | 0.737 |
| 5 | 2.703 | 0.017 |
| 6 | 7.449 | 0.084 |
| 7 | 27.48 | 0.750 |
| 8 | 13.72 | 0.532 |
| 9 | 12.49 | 0.745 |
| 10 | 46.47 | 0.007 |
| 11 | 19.62 | 0.135 |
| 12 | 23.86 | 0.691 |
| 13 | 9.562 | 0.434 |
| 14 | 11.53 | 0.595 |
| 15 | 13.49 | 0.358 |
| 16 | 17.42 | 0.495 |
| 17 | 11.75 | 0.600 |
| 18 | 18.41 | 0.690 |
| 19 | 13.48 | 0.149 |
| 20 | 13.19 | 0.730 |
| 21 | 7.983 | 0.750 |
| 22 | 3.711 | 0.689 |
| 23 | 15 | 0.716 |
| 24 | 5.672 | 0.591 |
| 25 | 30.85 | 0.303 |
| 26 | 16.25 | 0.705 |
| 27 | 4.88 | 0.750 |
| 28 | 8.93 | 0.728 |
| 29 | 4.086 | 0.624 |
| 30 | 4.26 | 0.756 |

**Table B-4 Galbraith and Waite Creek Sub-catchment Parameters**

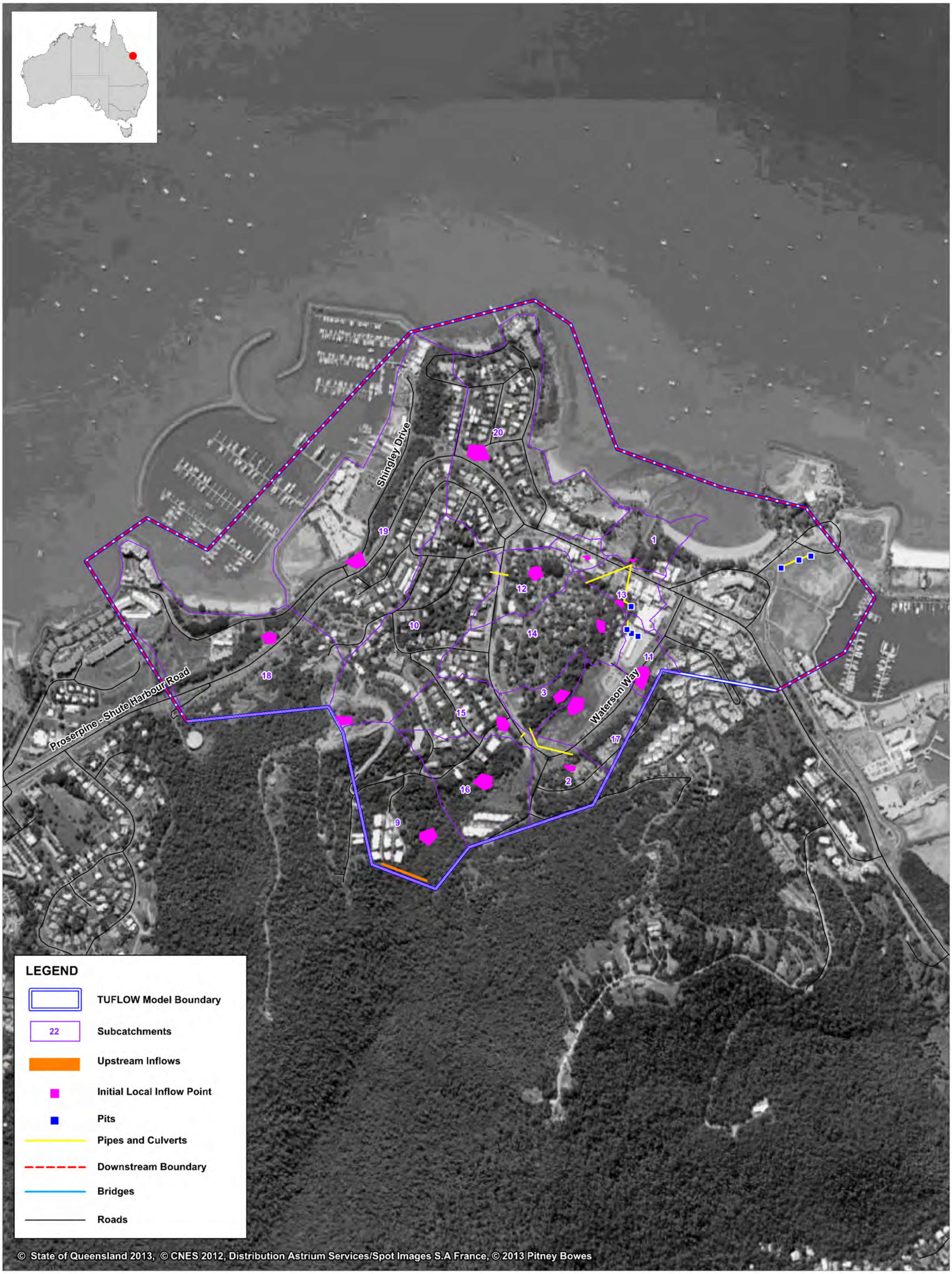
| Sub-catchment ID | Area (ha) | Impervious Fraction |
|---|---|---|
| 1 | 30.89 | 0.687 |
| 2 | 29.40 | 0.659 |
| 3 | 1.19 | 0.300 |
| 4 | 66.09 | 0.200 |
| 5 | 107.9 | 0.232 |
| 6 | 43.74 | 0.196 |
| 7 | 76.44 | 0.185 |
| 8 | 53.91 | 0.659 |
| 9 | 11.30 | 0.607 |
| 10 | 79.75 | 0.196 |
| 11 | 55.32 | 0.518 |
| 12 | 43.54 | 0.750 |
| 13 | 22.67 | 0.096 |
| 14 | 37.89 | 0.119 |
| 15 | 44.06 | 0.151 |
| 16 | 44.61 | 0.089 |
| 17 | 15.55 | 0.556 |
| 18 | 21.53 | 0.351 |
| 19 | 19.56 | 0.000 |
| 20 | 22.37 | 0.000 |
| 21 | 66.57 | 0.000 |
| 22 | 30.14 | 0.031 |
| 23 | 30.84 | 0.237 |
| 24 | 77.09 | 0.042 |
| 25 | 31.57 | 0.401 |
| 26 | 43.79 | 0.417 |
| 27 | 38.01 | 0.750 |
| 28 | 11.16 | 0.713 |
| 29 | 29.38 | 0.578 |
| 30 | 10.31 | 0.750 |
| 31 | 30.45 | 0.750 |
| 32 | 7.80 | 0.798 |
| 33 | 42.80 | 0.392 |
| 34 | 11.94 | 0.374 |
| 35 | 56.71 | 0.247 |
| 36 | 31.84 | 0.606 |
| 37 | 4.207 | 0.750 |
| 39 | 8.411 | 0.750 |
| 40 | 16.82 | 0.748 |
| 41 | 9.165 | 0.050 |

**Table B-5 Campbell Creek Sub-catchment Parameters**

| Sub-catchment ID | Area (ha) | Impervious Fraction |
|---|---|---|
| 1 | 0.1645 | 0.593 |
| 2 | 0.05046 | 0.75 |
| 3 | 0.4754 | 0.48 |
| 4 | 0.09009 | 0.137 |
| 5 | 0.1494 | 0.124 |
| 6 | 0.08682 | 0.75 |
| 7 | 0.08224 | 0.896 |

| Sub-catchment ID | Area (ha) | Impervious Fraction |
|---|---|---|
| 8 | 0.2861 | 0.0514 |
| 9 | 0.09882 | 0.645 |
| 10 | 0.7845 | 0 |
| 11 | 0.58 | 0.5046 |
| 12 | 0.5342 | 0.2283 |
| 13 | 1.307 | 0.0442 |
| 14 | 0.1331 | 0.6863 |
| 15 | 0.3233 | 0.7003 |
| 16 | 0.2028 | 0.6364 |
| 17 | 0.2974 | 0.6912 |
| 18 | 0.2049 | 0.6736 |
| 19 | 0.04118 | 0.9 |
| 20 | 0.3808 | 0.6667 |
| 21 | 0.1546 | 0.5 |
| 22 | 0.2048 | 0.3451 |
| 23 | 0.4012 | 0.4098 |
| 24 | 0.2772 | 0.0185 |
| 25 | 0.2453 | 0.0427 |
| 26 | 0.1027 | 0.2266 |
| 27 | 0.07051 | 0.0829 |
| 28 | 0.2477 | 0.4157 |
| 29 | 0.1217 | 0.4318 |
| 30 | 0.8407 | 0.114 |
| 31 | 0.122 | 0.5 |
| 32 | 0.05592 | 0.5 |
| 33 | 0.1047 | 0.5 |
| 34 | 0.03133 | 0.5 |
| 35 | 0.02892 | 0.5 |
| 36 | 0.02706 | 0.5 |
| 37 | 0.03136 | 0.5 |
| 38 | 0.1171 | 0.5 |
| 39 | 0.07831 | 0.5 |
| 40 | 0.1456 | 0 |
| 41 | 0.1343 | 0 |
| 42 | 0.1001 | 0.5 |
| 43 | 0.03785 | 0.5 |
| 44 | 0.06772 | 0.5 |
| 45 | 0.2043 | 0.5 |
| 46 | 0.1203 | 0.5 |
| 47 | 0.09325 | 0.5 |
| 48 | 0.1288 | 0.5 |
| 49 | 0.1299 | 0.5 |
| 50 | 0.01714 | 0.5 |
| 51 | 0.01421 | 0.5 |
| 52 | 0.01747 | 0.5 |
| 53 | 0.01926 | 0.5 |
| 54 | 0.01943 | 0.5 |
| 55 | 0.01394 | 0.5 |
| 56 | 0.01039 | 0.5 |
| 57 | 0.00818 | 0.5 |
| 58 | 0.02488 | 0.5 |

# Appendix C Arlie Creek Maps






Title:
**Arlie Creek Model Layout**

Figure: **C-1**

Rev: **A**



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Approx. Scale

BMT WBM

www.bmtwbm.com.au

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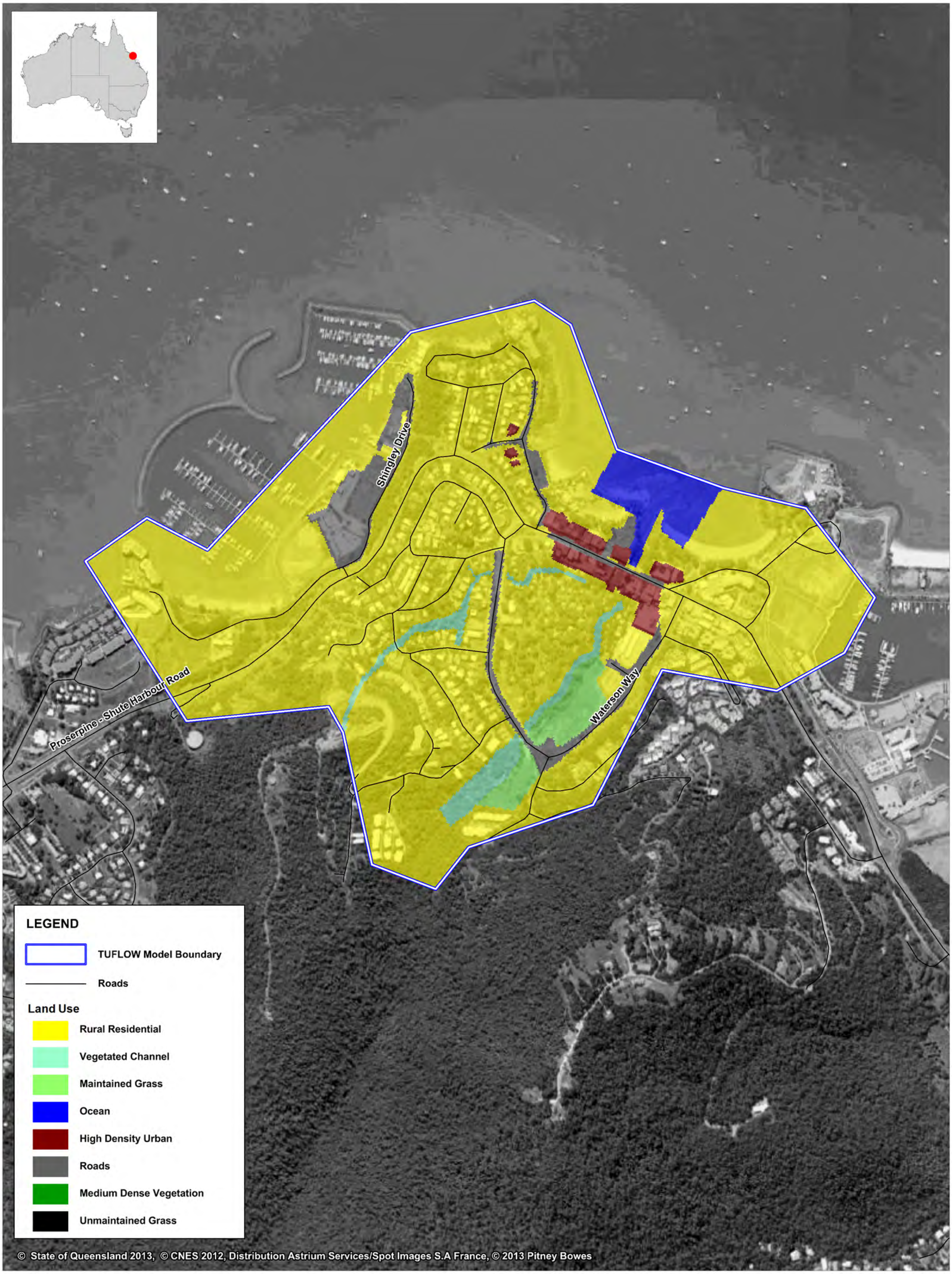


Title:

**Airlie Creek Land Use**

Figure: **C-2**

Rev: **A**



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www.bmtwbm.com.au

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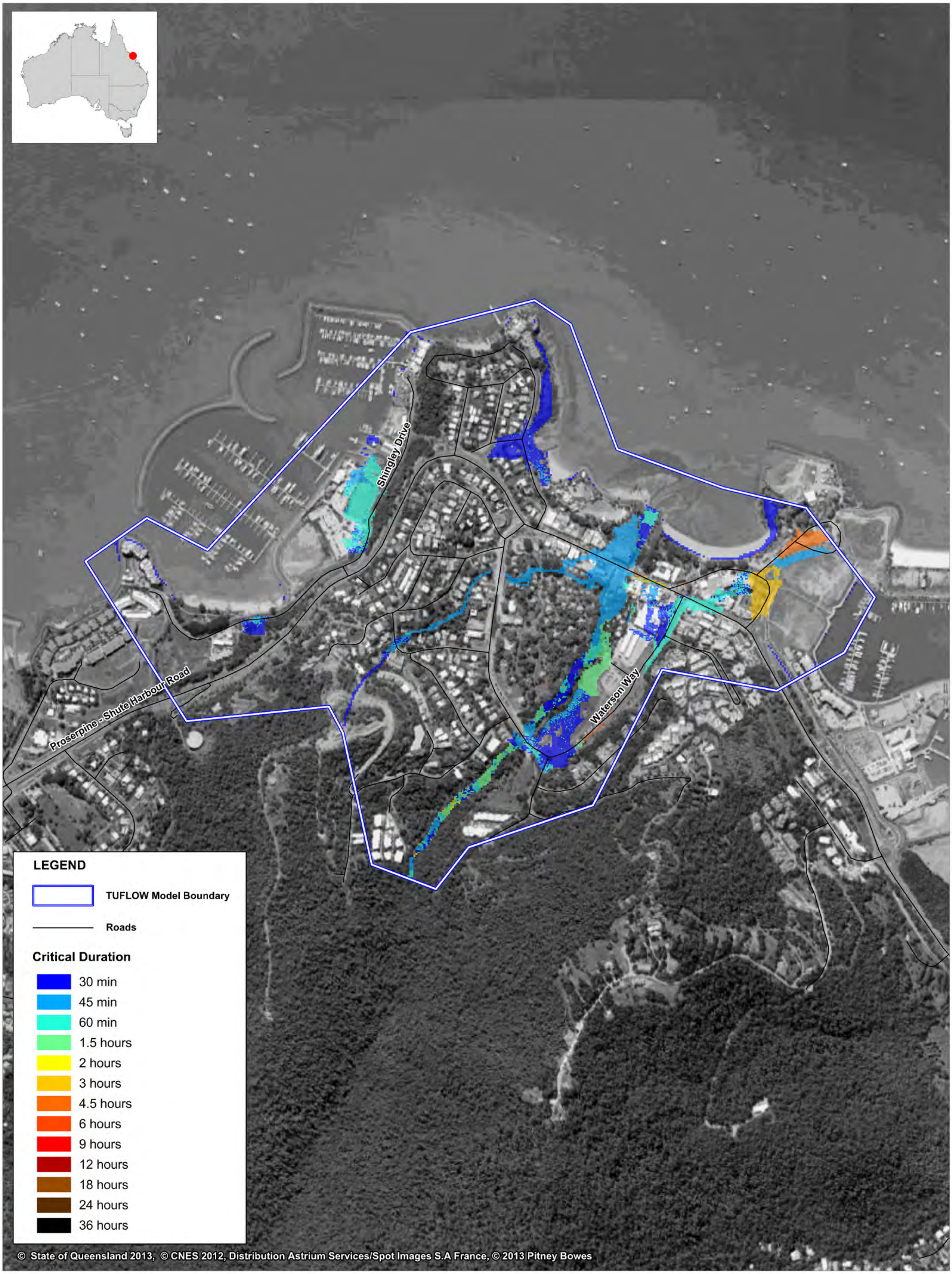




Title:
**Arlie Creek Critical Duration Assessment**

Figure: **C-3**

Rev: **A**



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Approx. Scale

BMT WBM
www.bmtwbm.com.au

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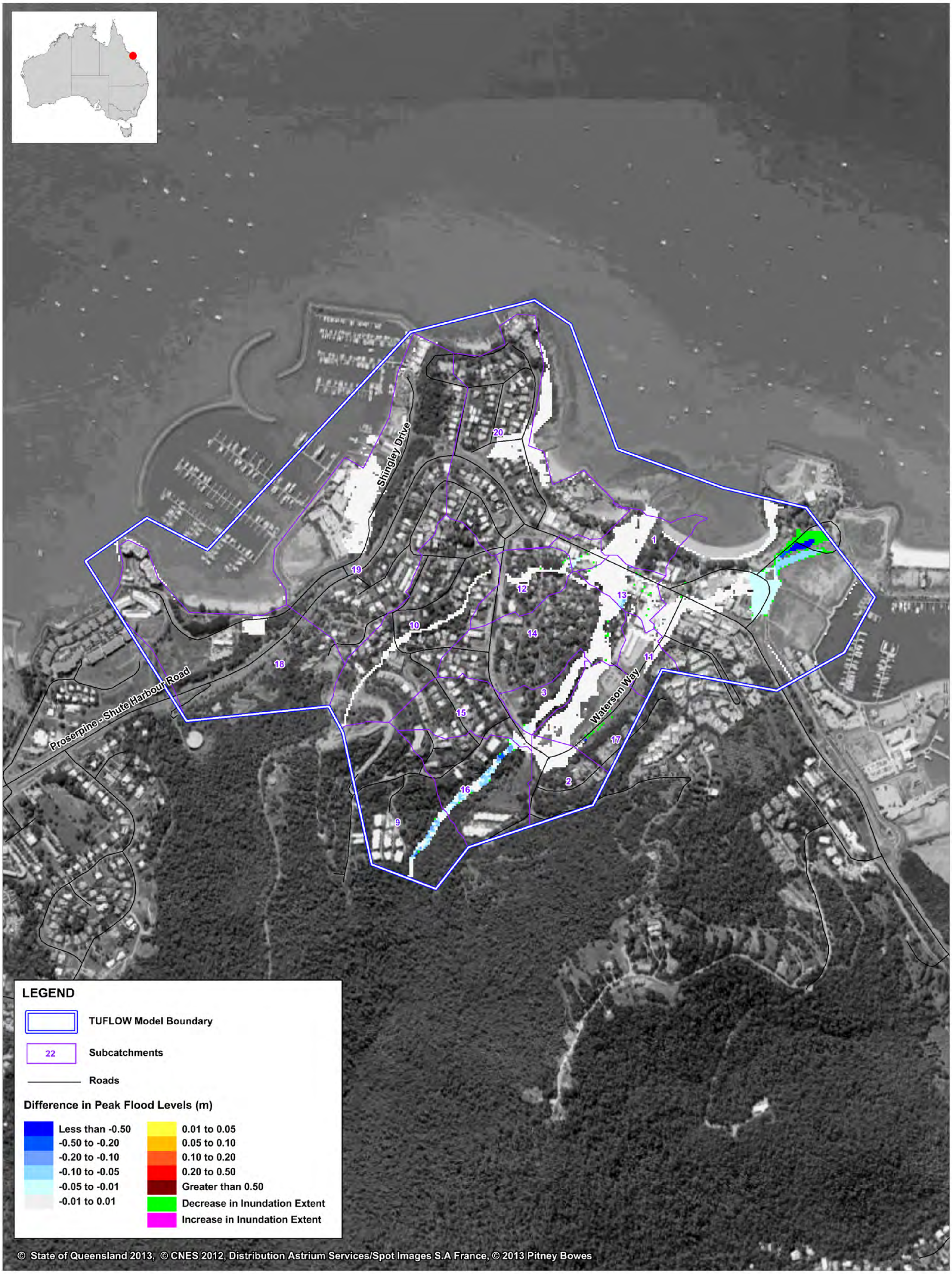




Title:
**Arlie Creek Difference in Peak Flood Levels**

Figure: **C-4**

Rev: **A**



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Approx. Scale

BMT WBM
www.bmtwbm.com.au

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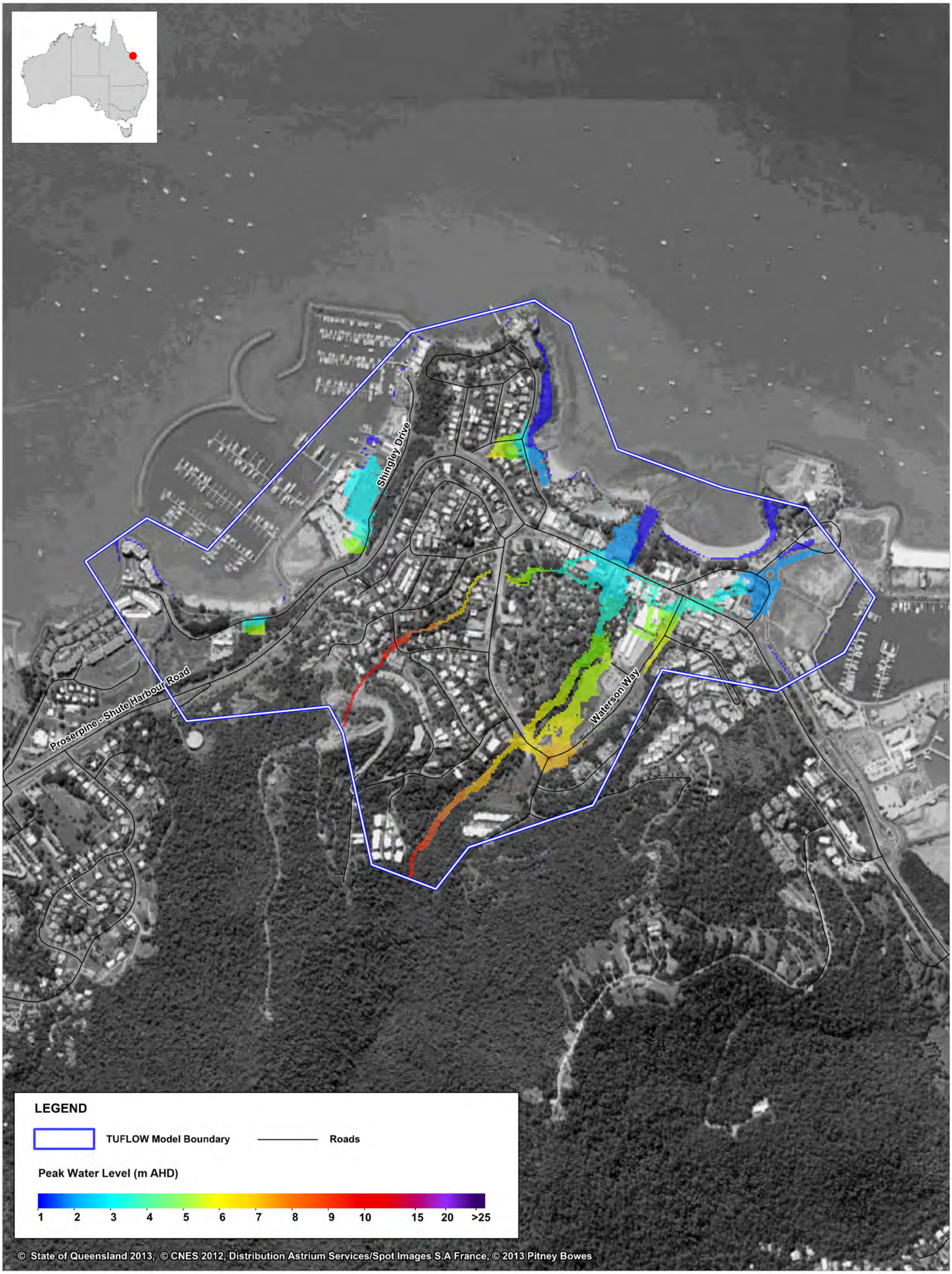


Title: **Airlie Creek Peak Flood Levels**

Figure: **C-5**

Rev: **A**



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Approx. Scale

BMT WBM

www.bmtwbm.com.au

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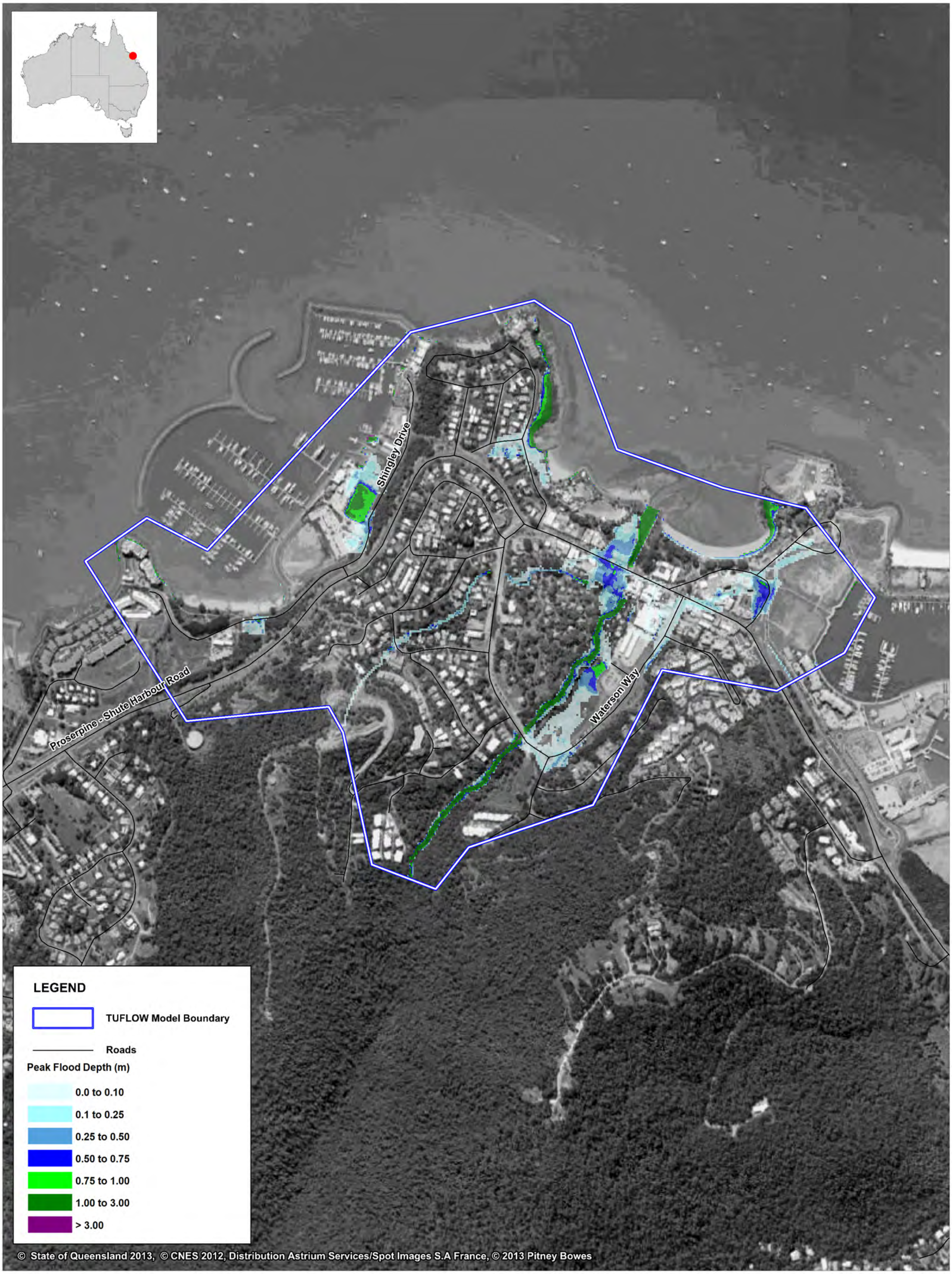




Title:
**Airlie Creek Peak Flood Depths**

Figure: **C-6**

Rev: **A**



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www.bmtwbm.com.au

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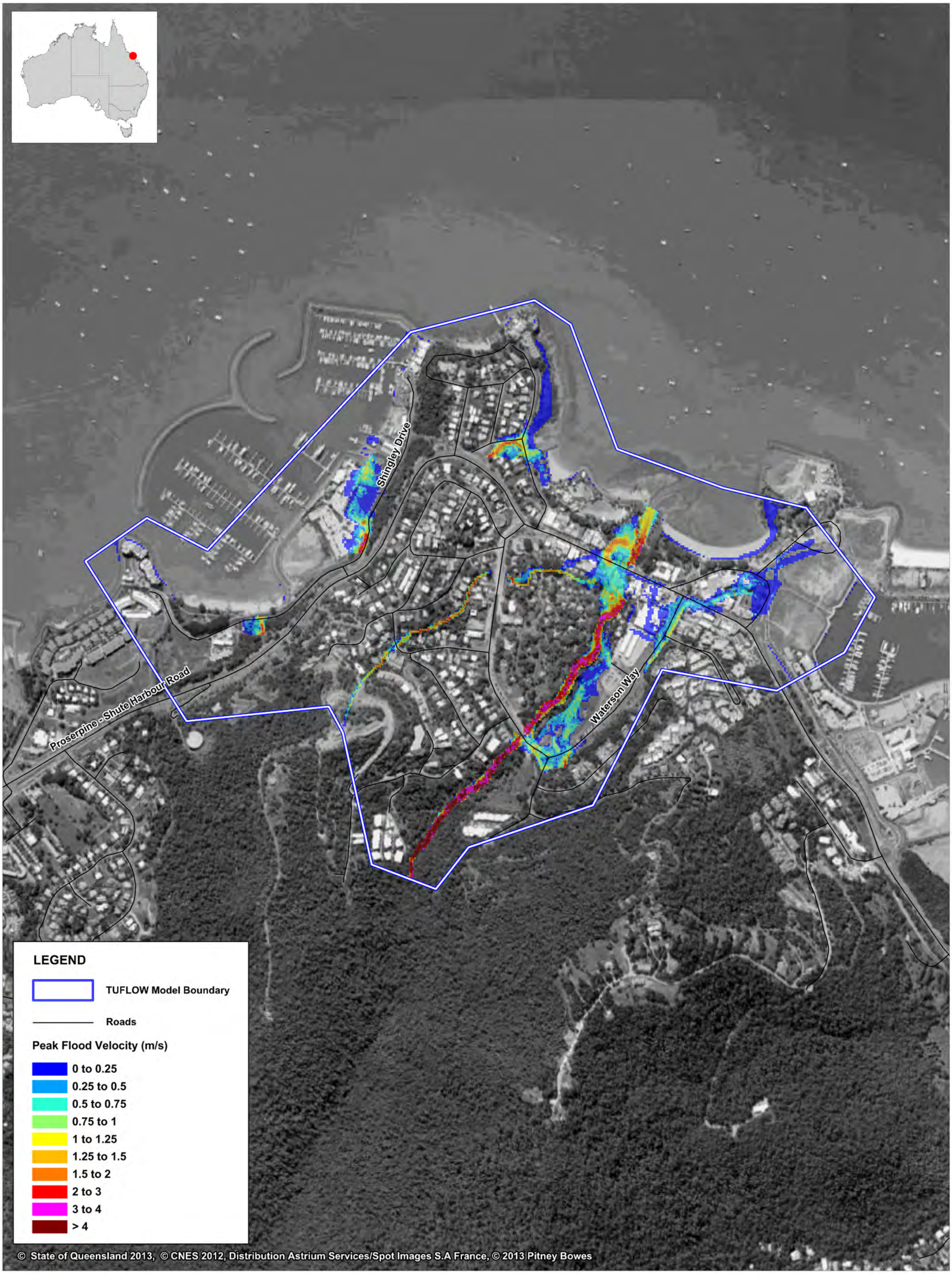




Title:

**Airlie Creek Peak Flood Velocities**

Figure: C-7

Rev: A



BMT WBM
www.bmtwbm.com.au

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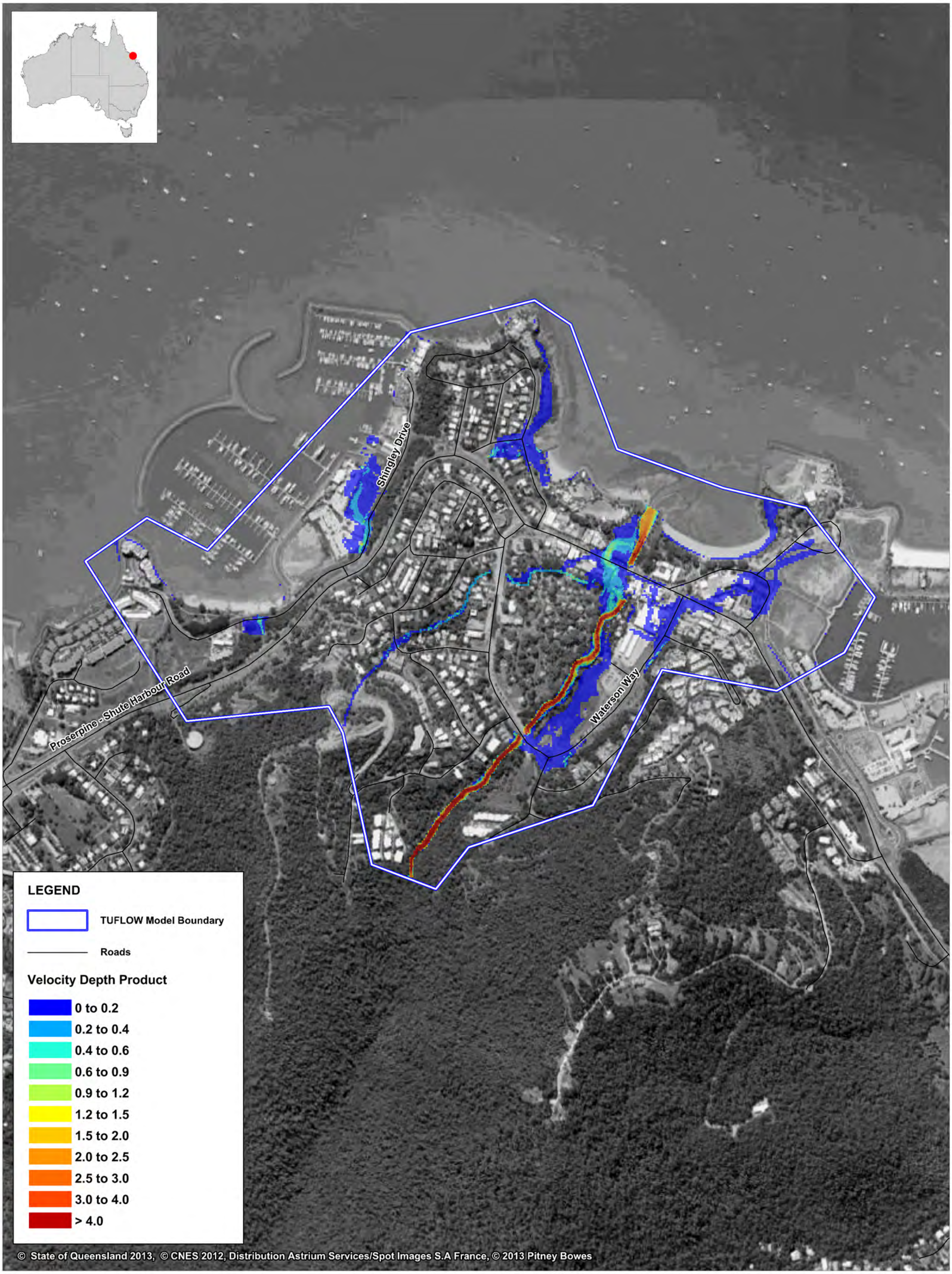


Title:

**Arlie Creek Depth Velocity Product**

Figure: **C-8**

Rev: **A**



BMT WBM
www.bmtwbm.com.au

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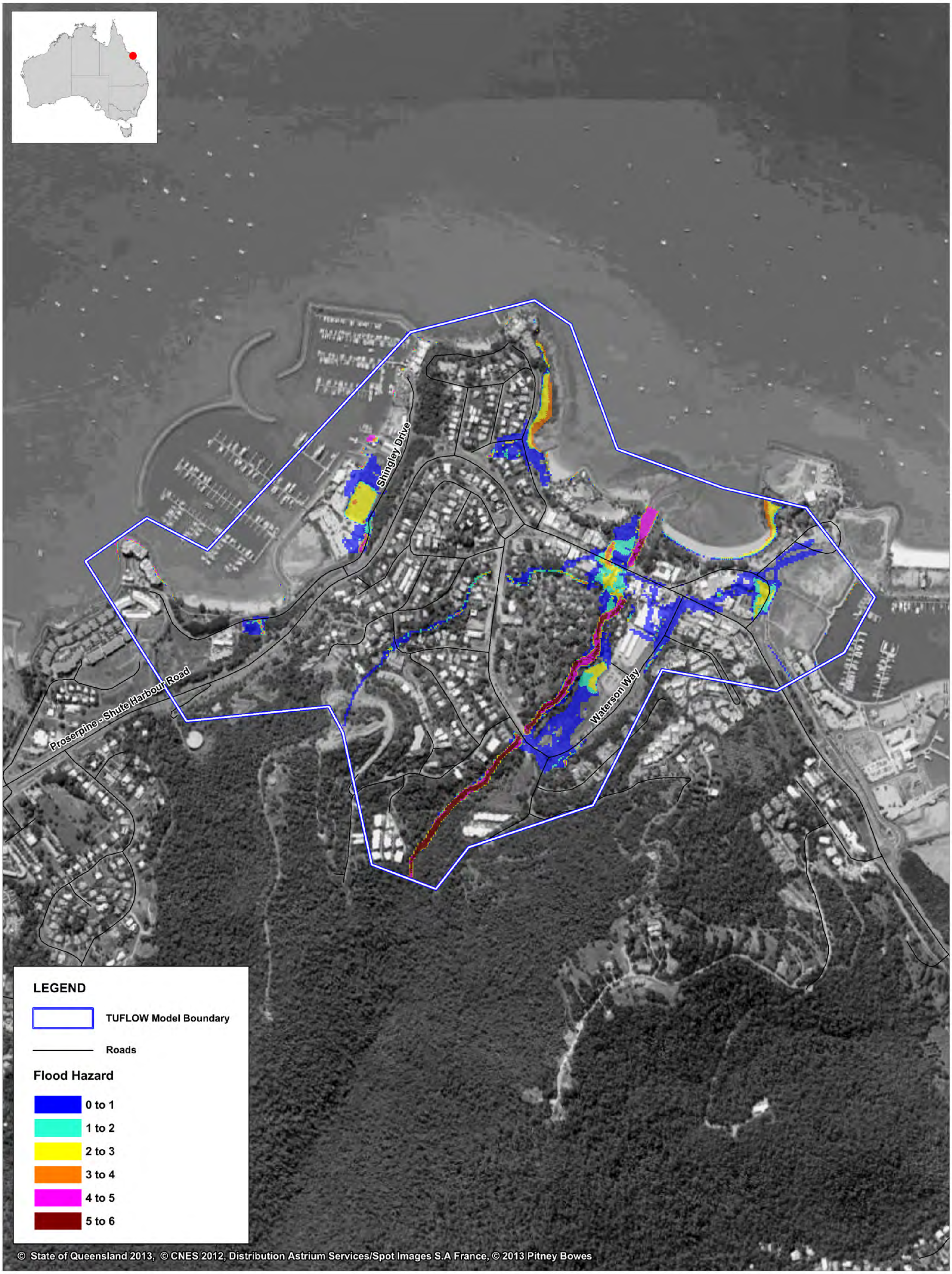




Title:
**Arlie Creek Flood Hazard**

Figure: **C-9**

Rev: **A**



BMT WBM
www.bmtwbm.com.au

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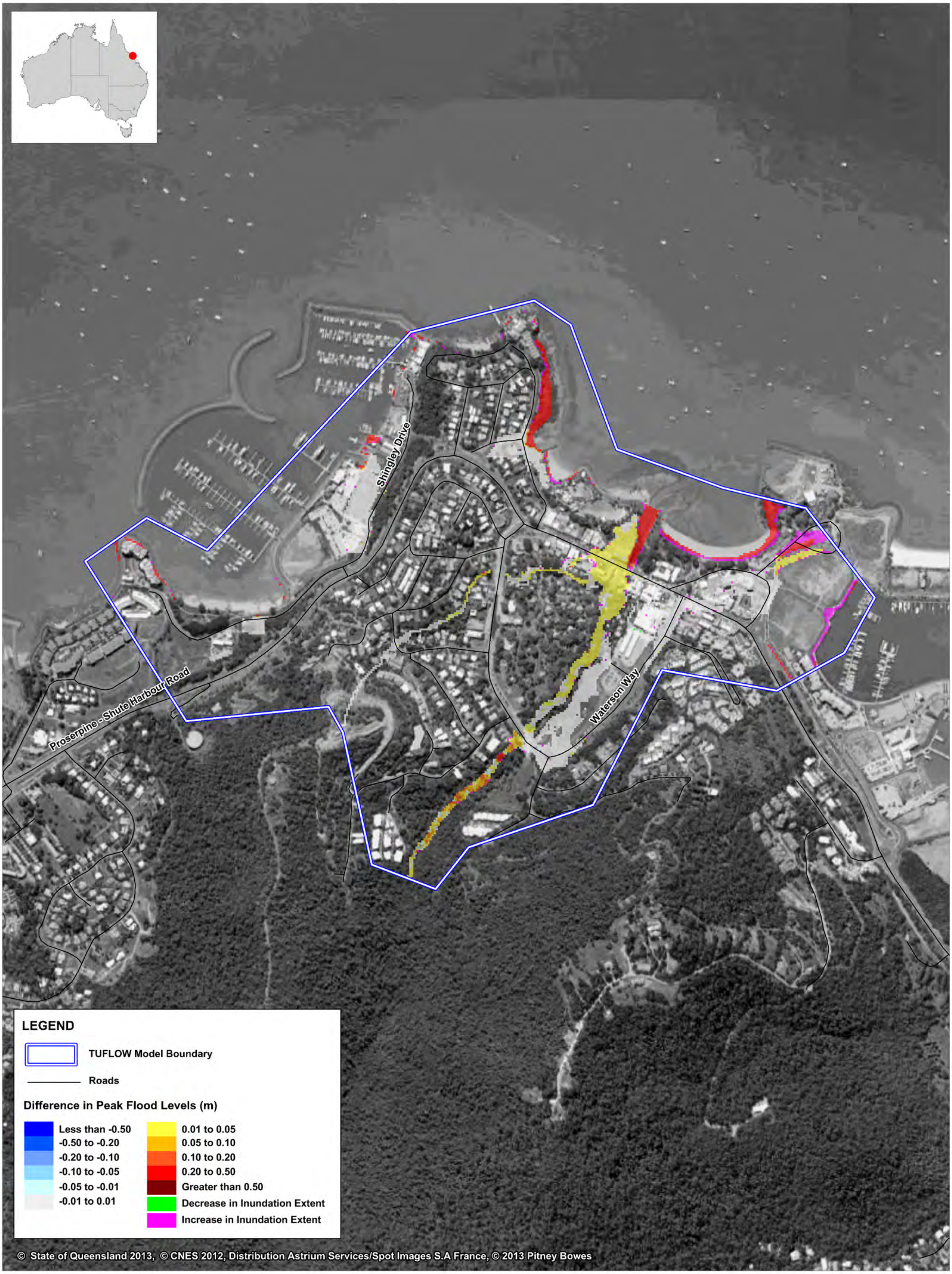




Title:
**Arlie Creek Climate Change 2050 - Peak Flood Level Impact**

Figure: **C-10**

Rev: **A**



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Approx. Scale

BMT WBM
www.bmtwbm.com.au

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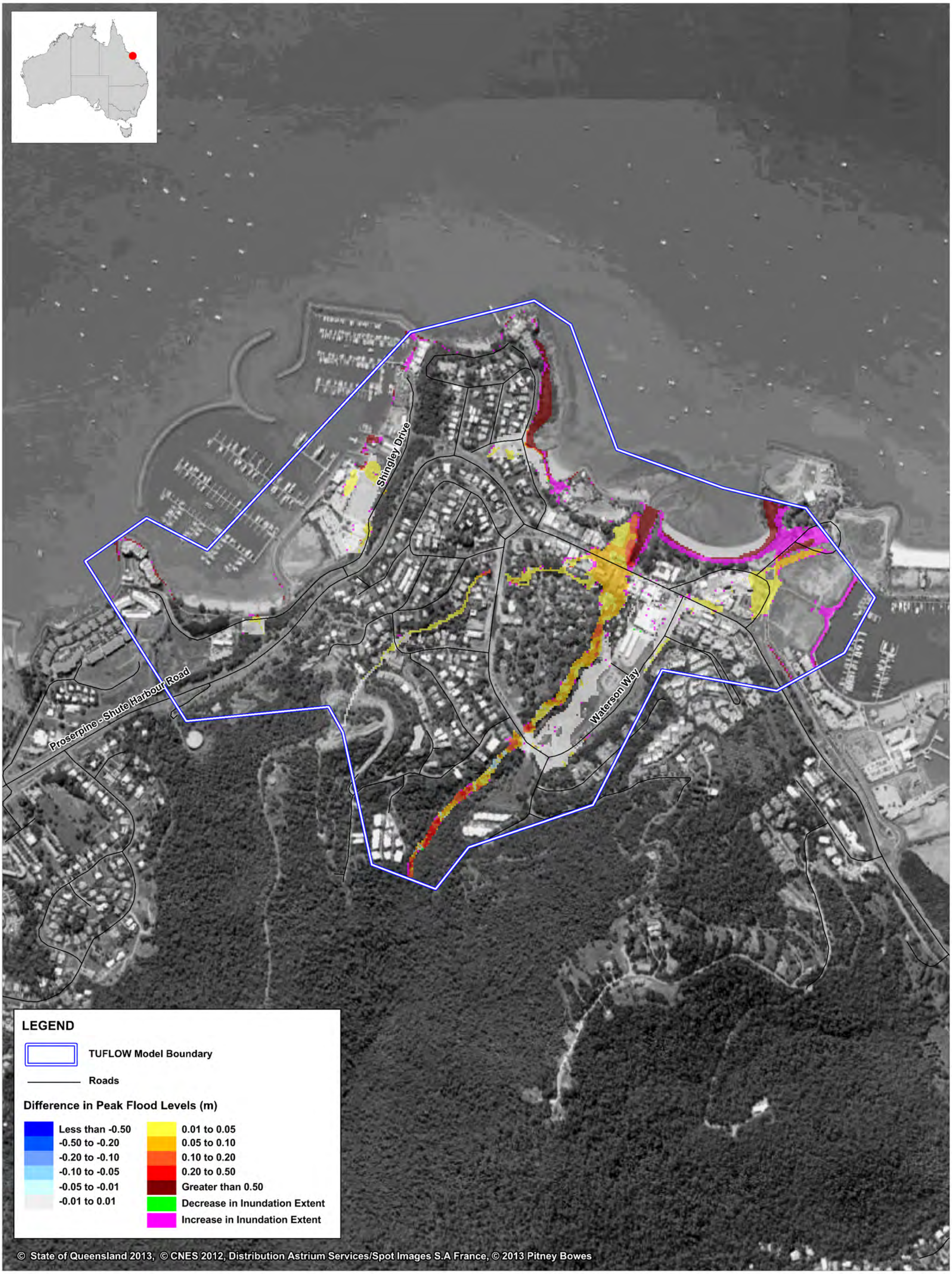


Title:
## Arlie Creek Climate Change 2100 - Peak Flood Level Impact

Figure: C-11

Rev: A



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Approx. Scale

BMT WBM

www.bmtwbm.com.au

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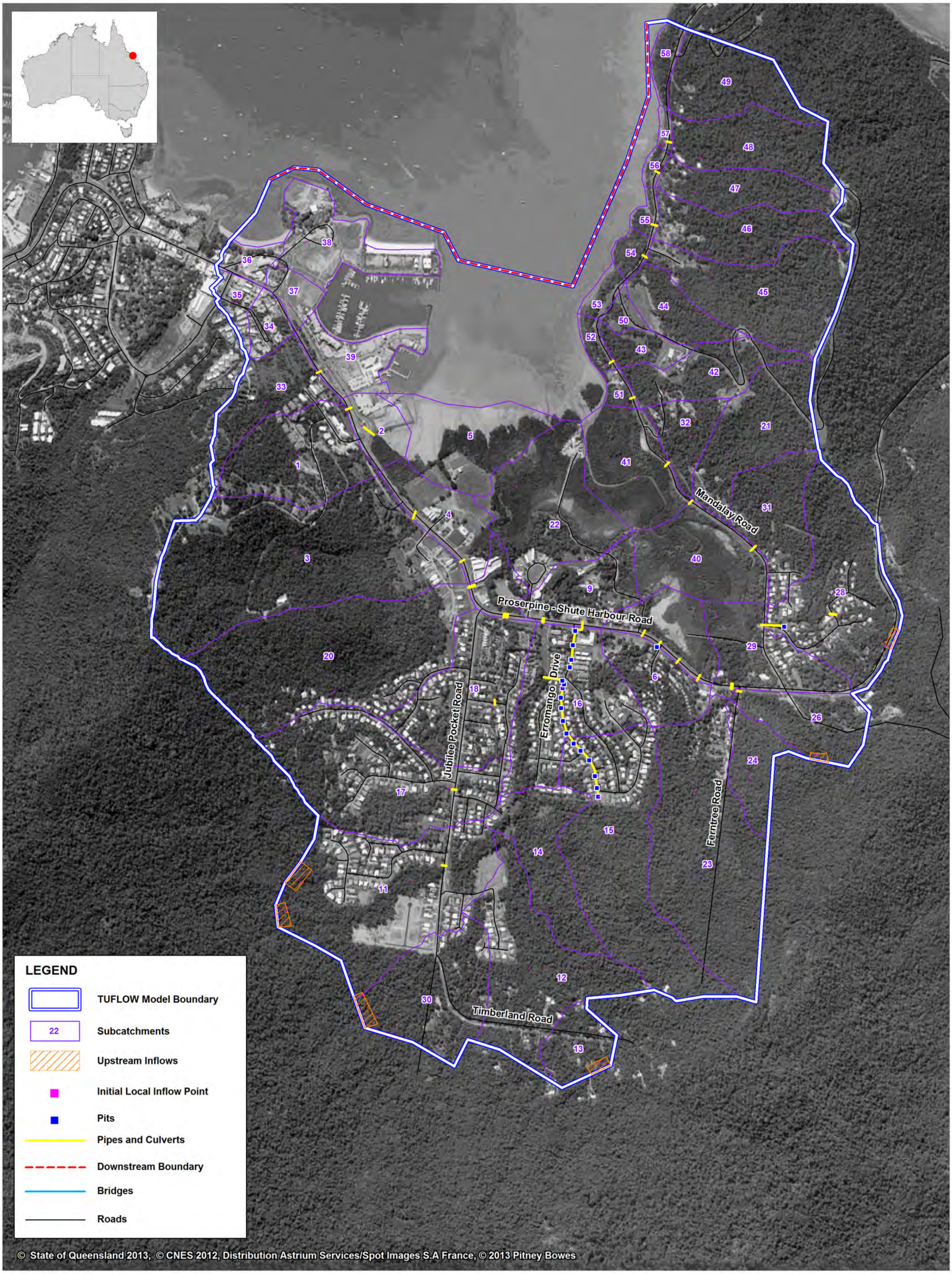
# Appendix D Campbell Creek Maps




Title:
**Campbell Creek Model Layout**

Figure: **D-1**

Rev: **A**



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Approx.Scale

BMT WBM
www.bmtwbm.com.au

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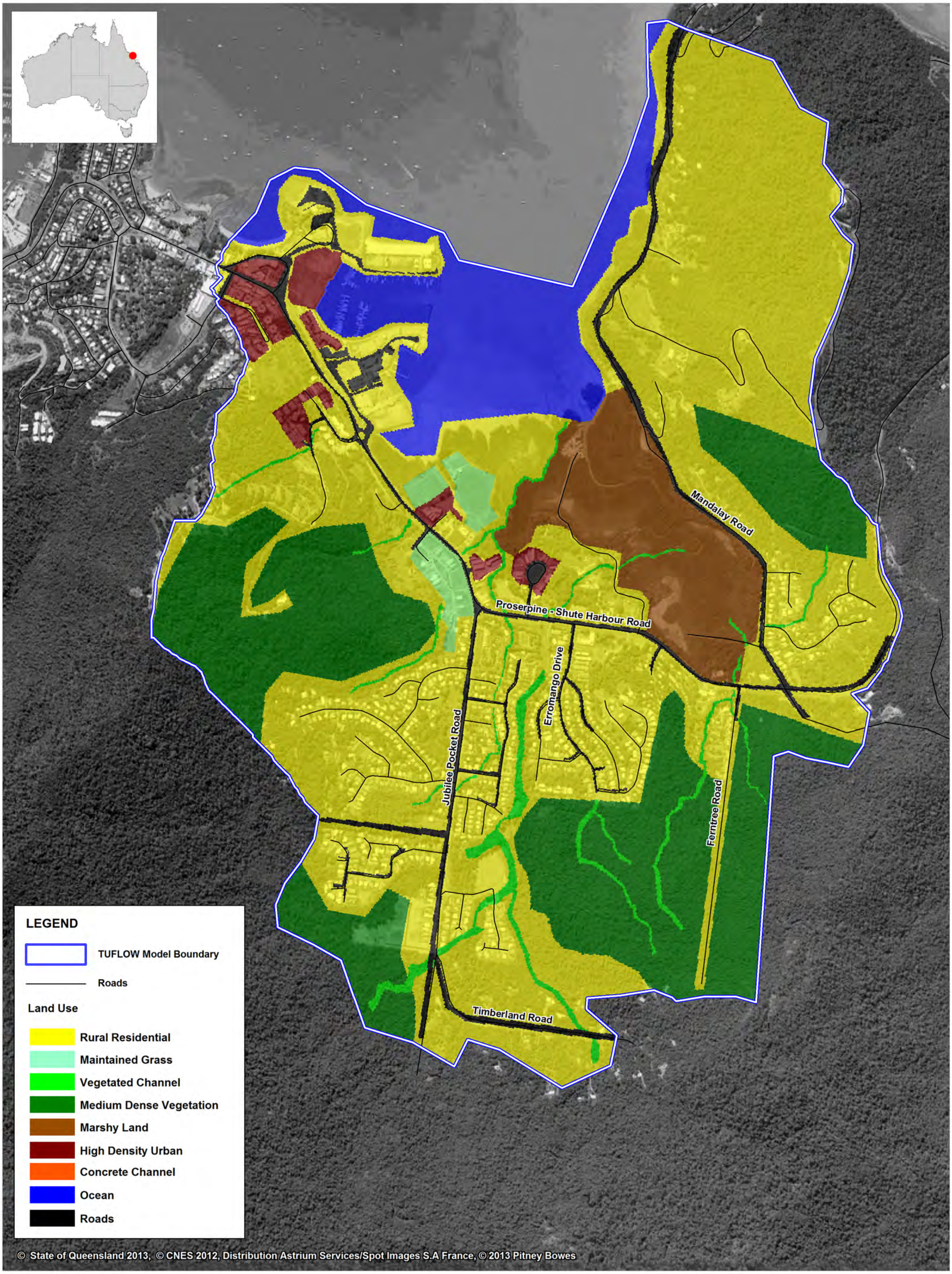


Title:

**Campbell Creek Land Use Map**

Figure: **D-2**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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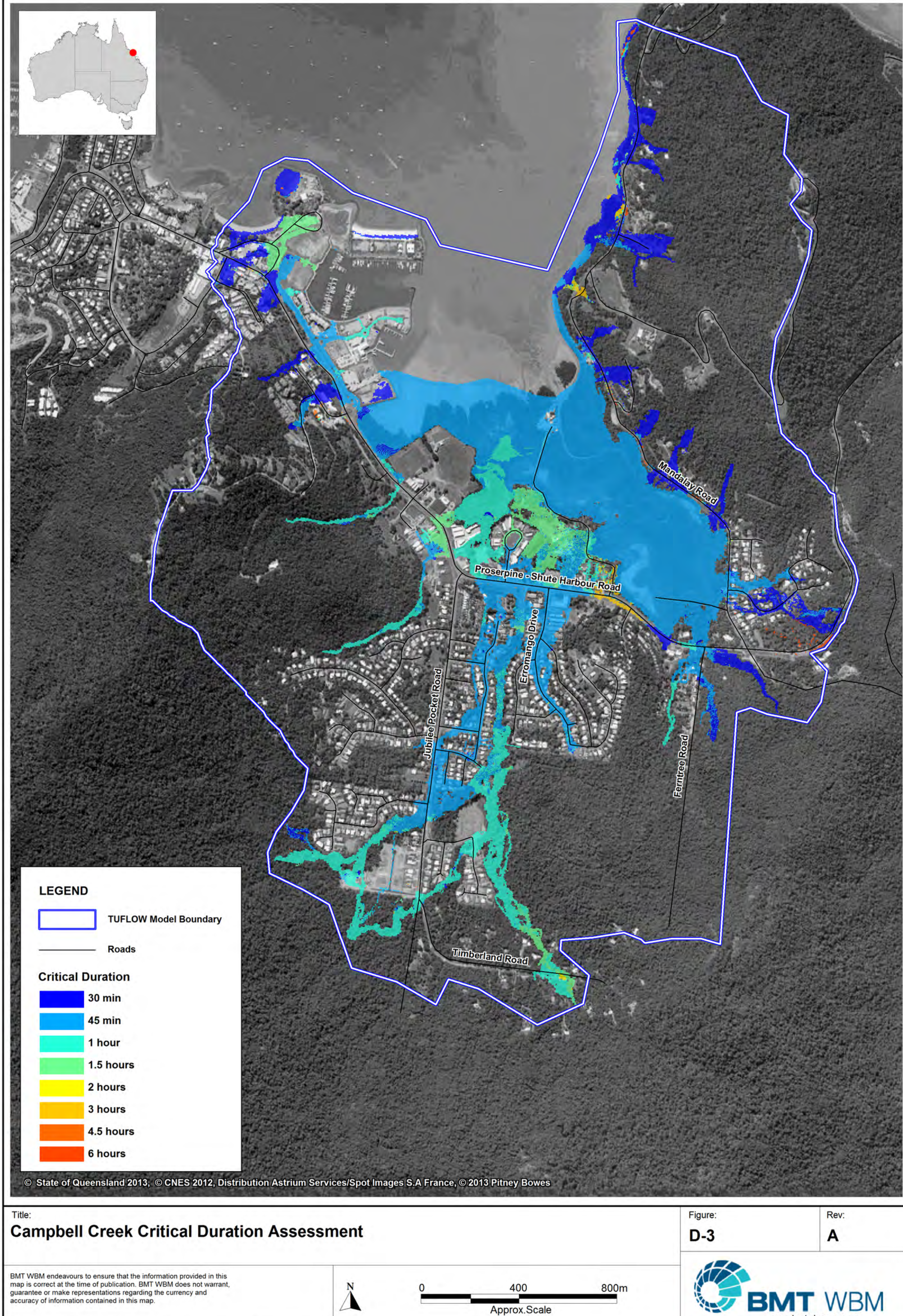




Title:
**Campbell Creek Critical Duration Assessment**

Figure: **D-3**

Rev: **A**



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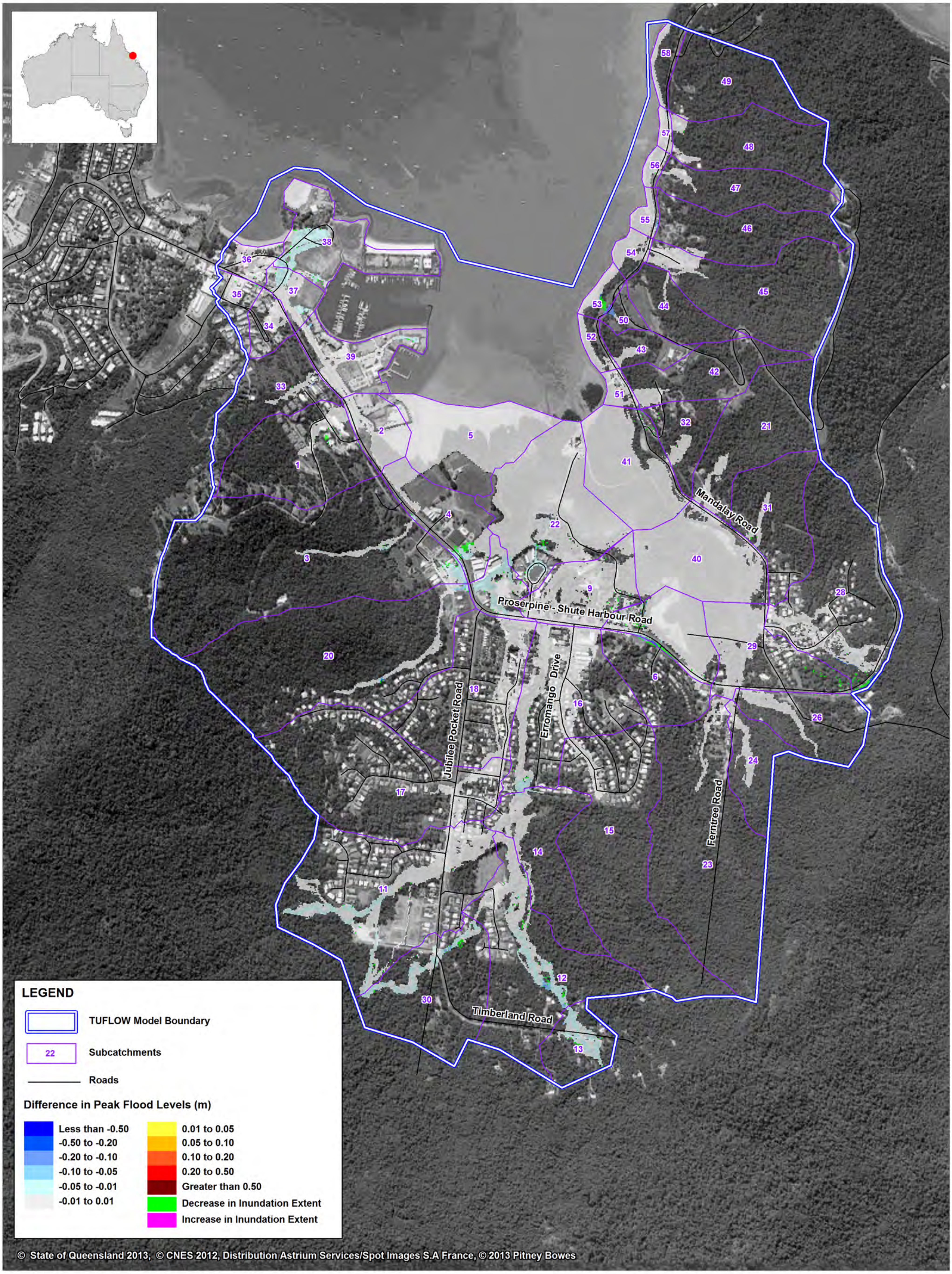




Title:
## Campbell Creek - Difference in Peak Flood Levels

Figure: **D-4**

Rev: **A**



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Approx.Scale

BMT WBM
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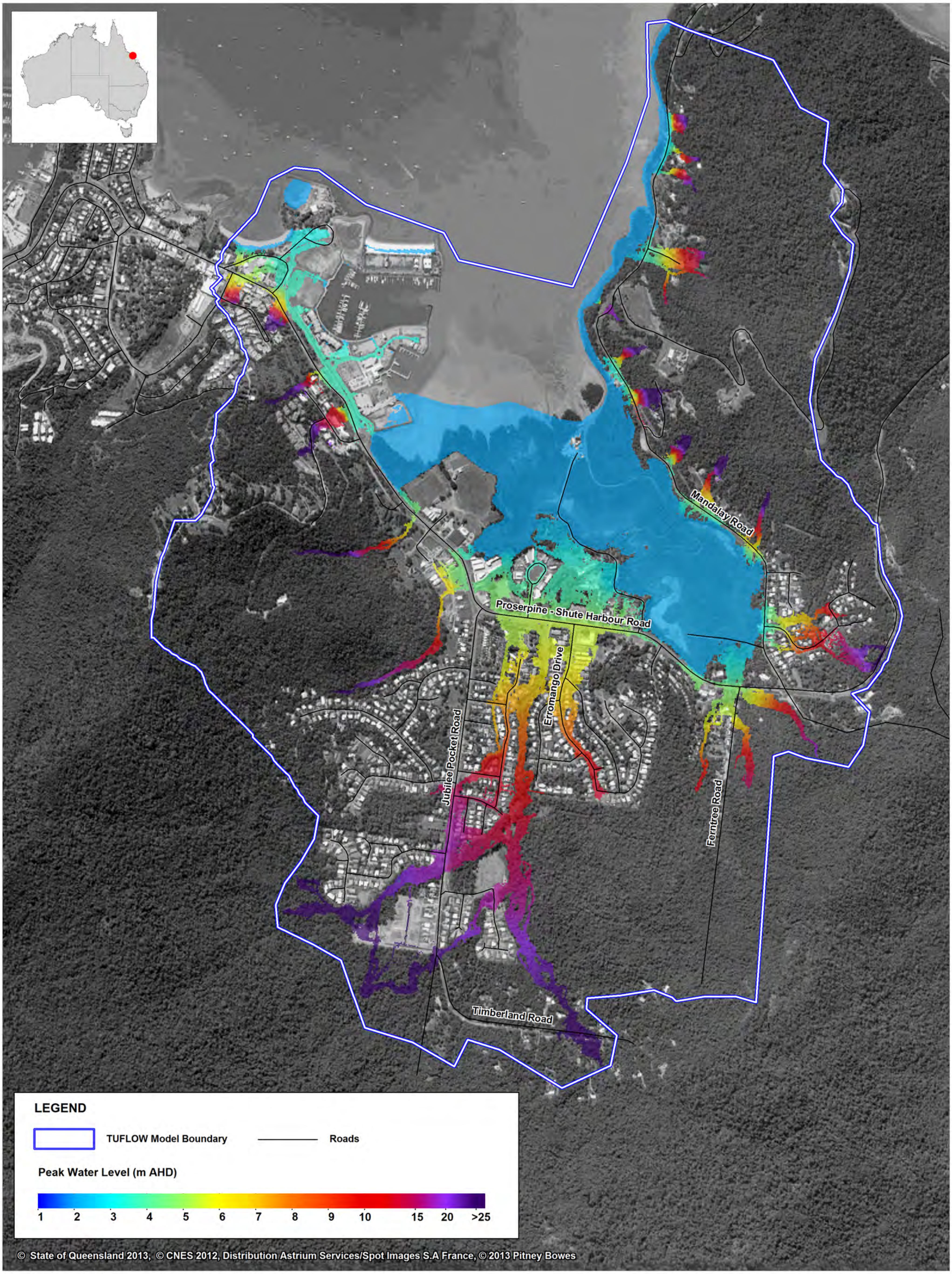




Title:
**Campbell Creek Peak Flood Levels**

Figure: **D-5**

Rev: **A**

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N

0 400 800m
Approx.Scale

BMT WBM
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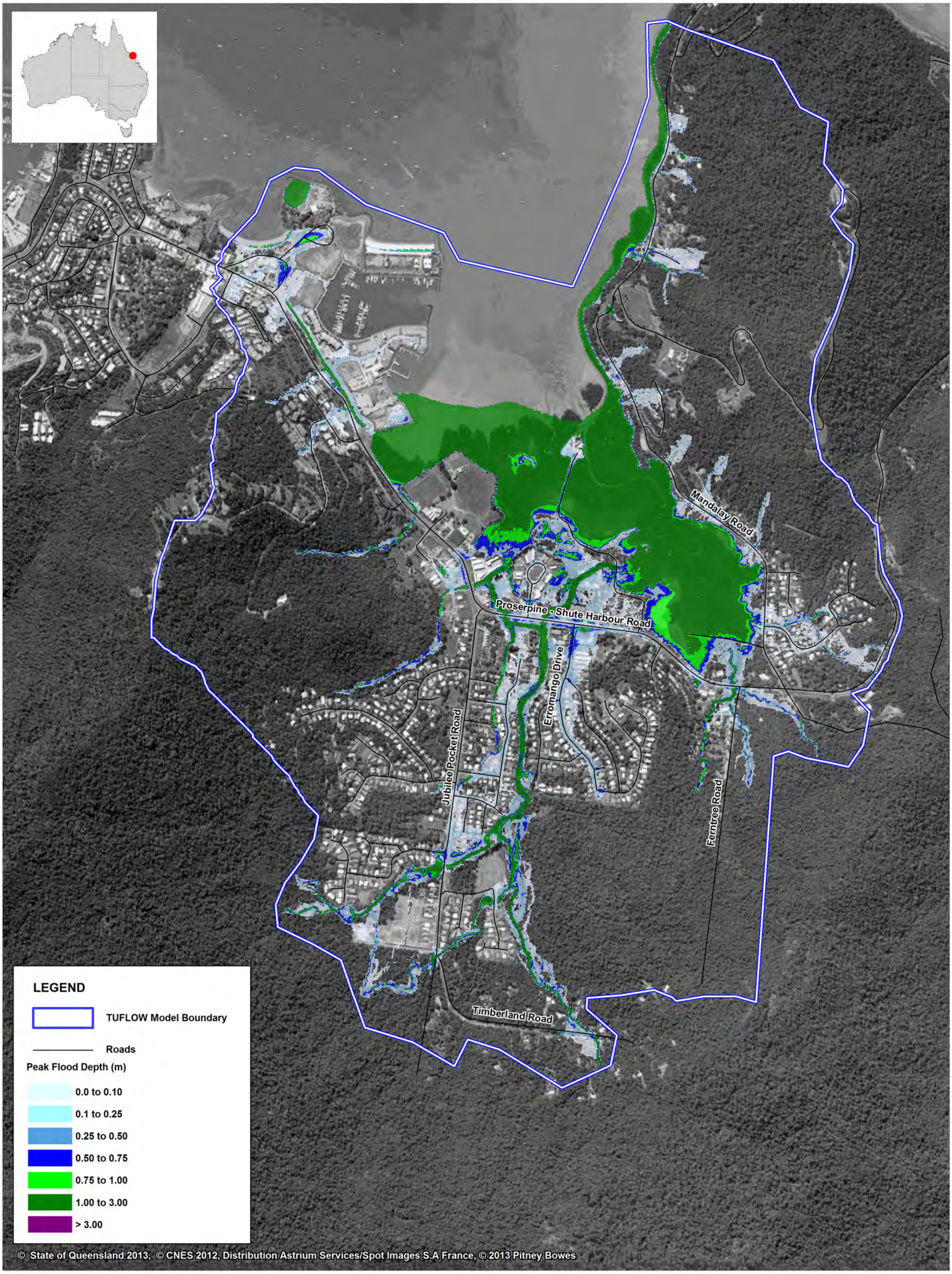





Title:

**Campbell Creek Peak Flood Depths**

Figure: **D-6**

Rev: **A**



N

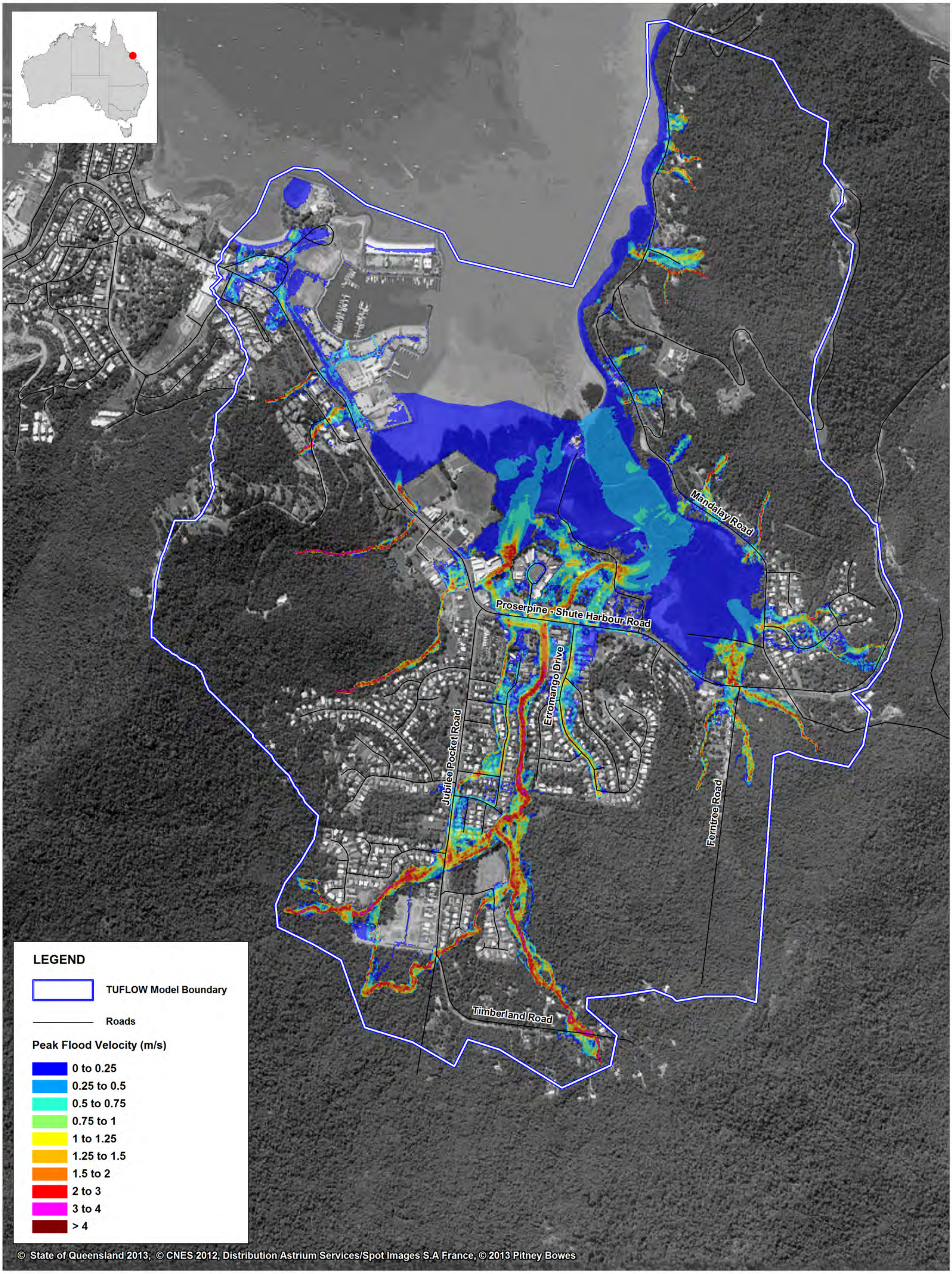
0 400 800m

Approx.Scale

BMT WBM

www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\FLD_010_170831_Peak Flood Depth_Campbell Creek.wor




Title:
**Campbell Creek Peak Flood Velocities**

Figure: **D-7**

Rev: **A**

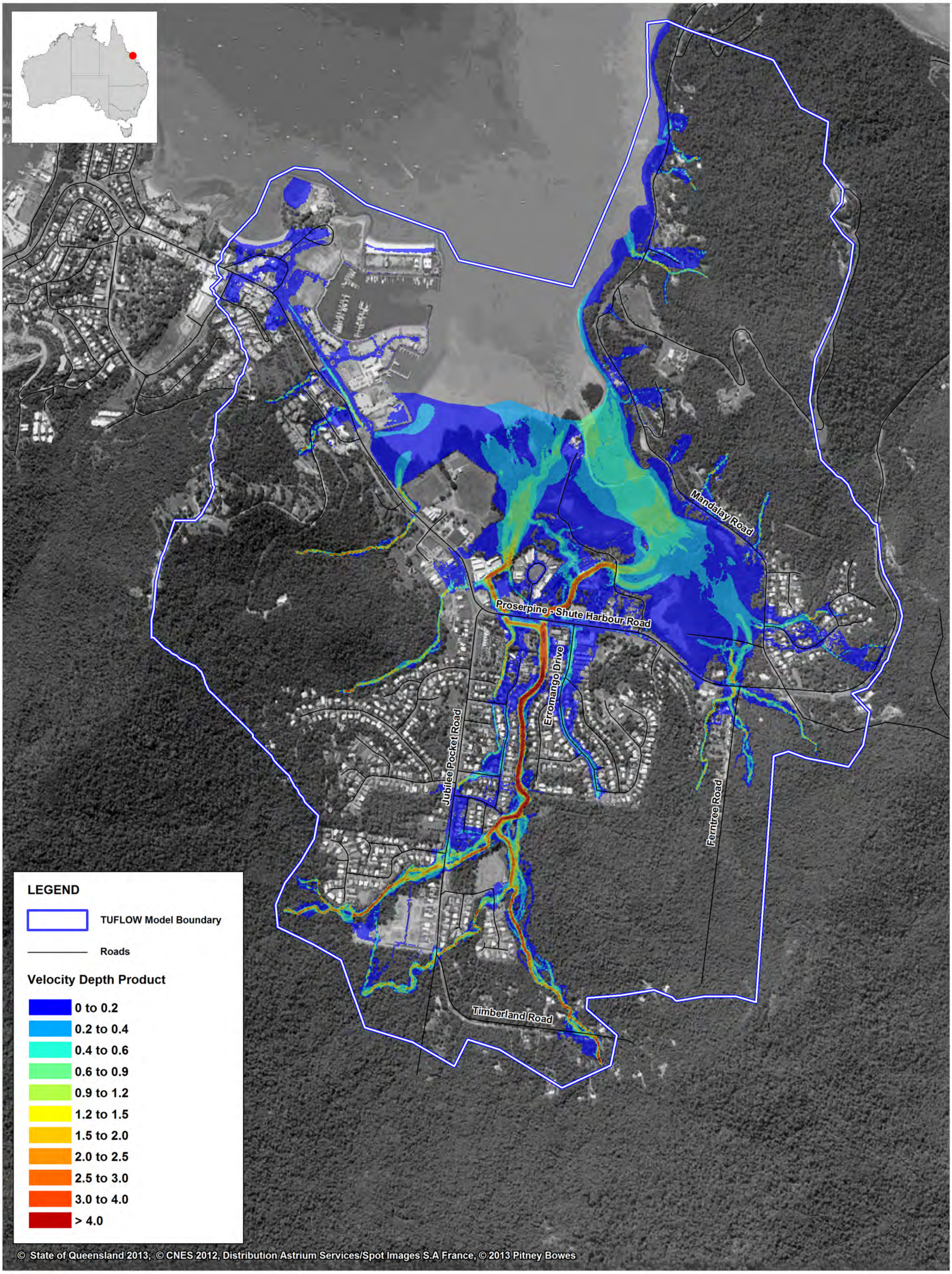
BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 400 800m
Approx.Scale

BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\FLD_011_170831_Peak Flood Velocity_Campbell Creek.wor




Title:
**Campbell Creek Depth Velocity Product**

Figure: **D-8**

Rev: **A**

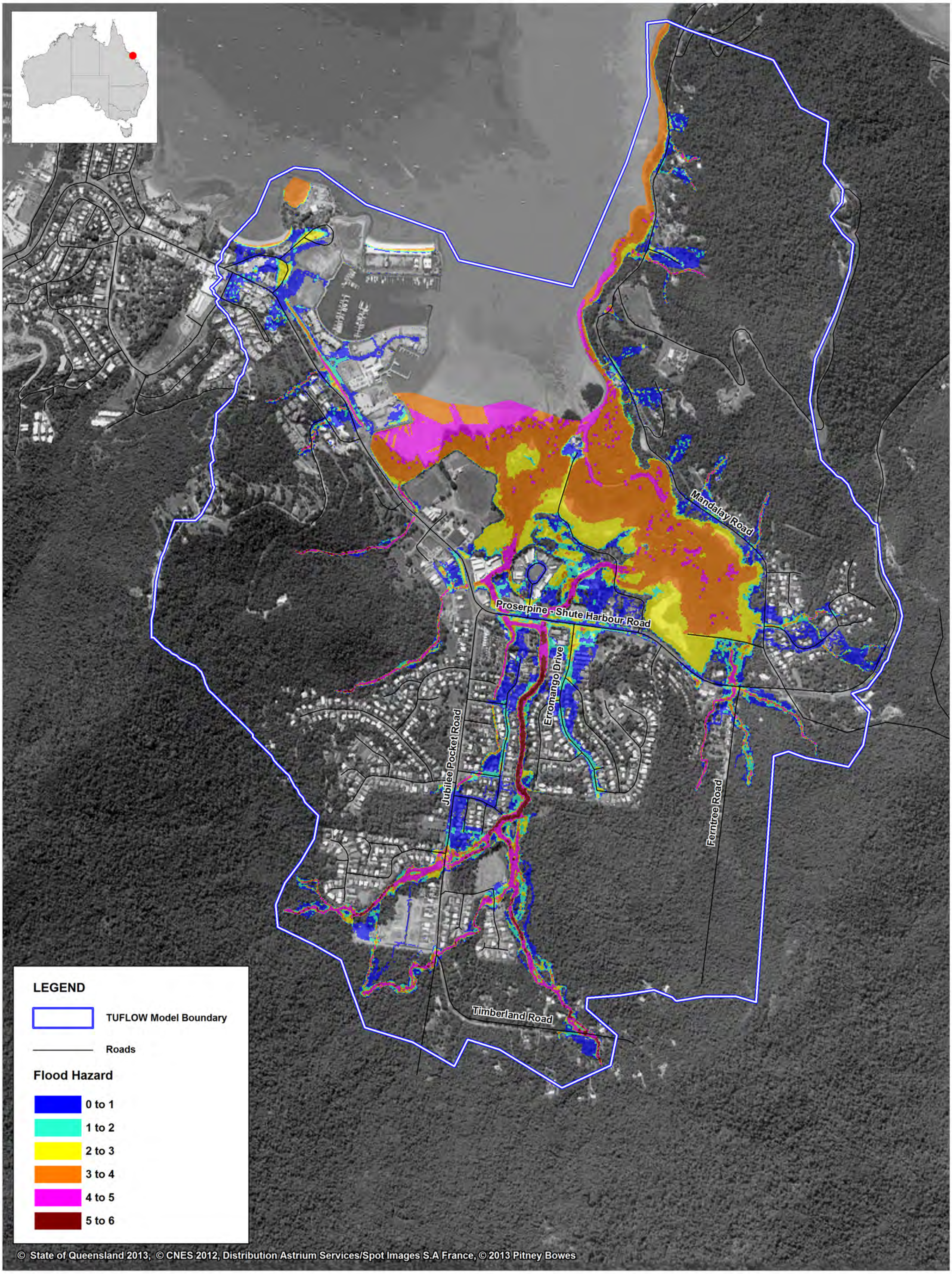
BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 400 800m
Approx.Scale

BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\FLD_013_170831_Depth Velocity Product _Campbell Creek.wor




Title:
**Campbell Creek Flood Hazard**

Figure: **D-9**

Rev: **A**

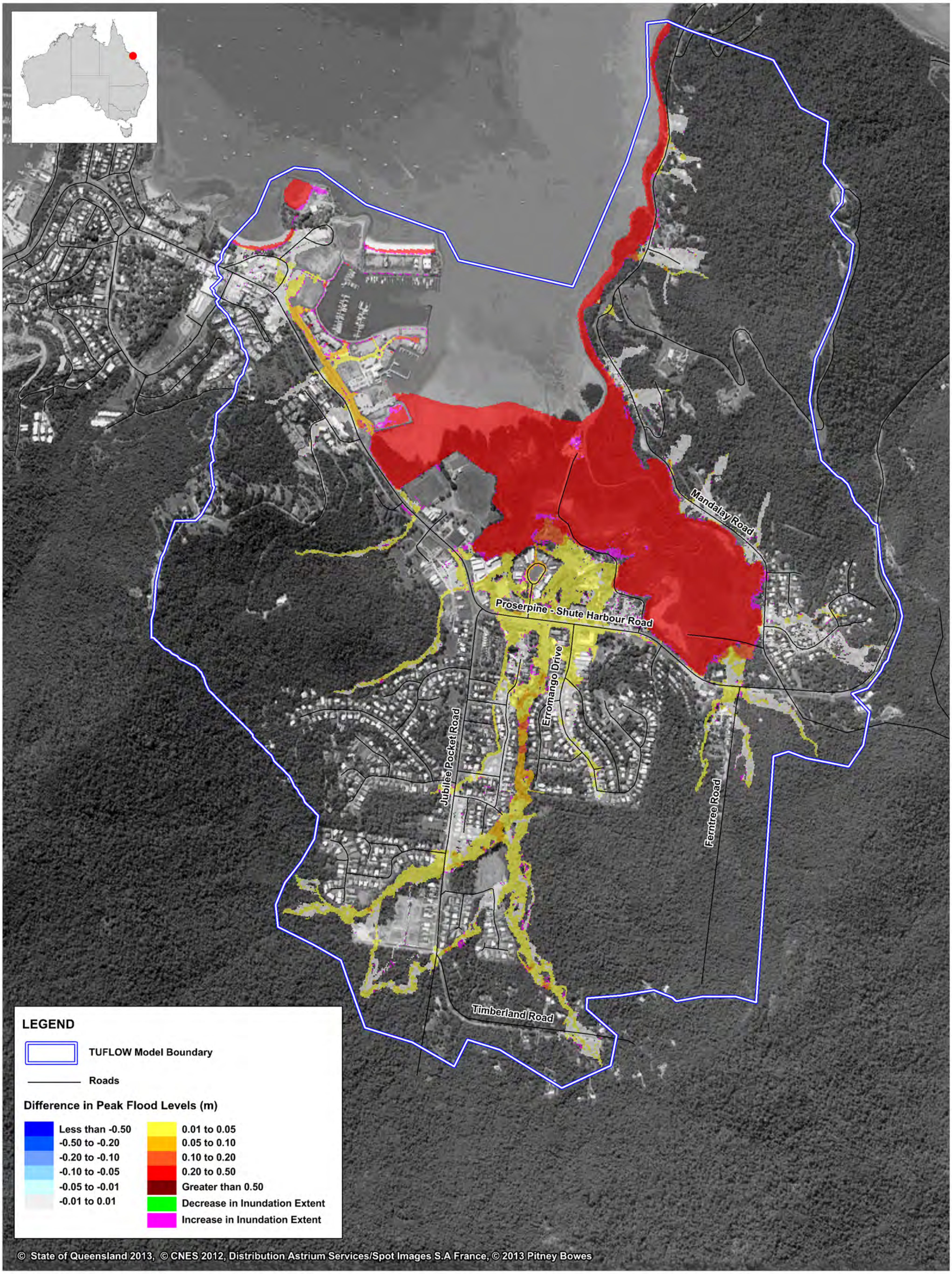


N

0 400 800m
Approx.Scale

BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\FLD_012_170831_Flood Hazard_Campbell Creek.wor






Title:

**Campbell Creek Climate Change 2050 - Peak Flood Level Impact**

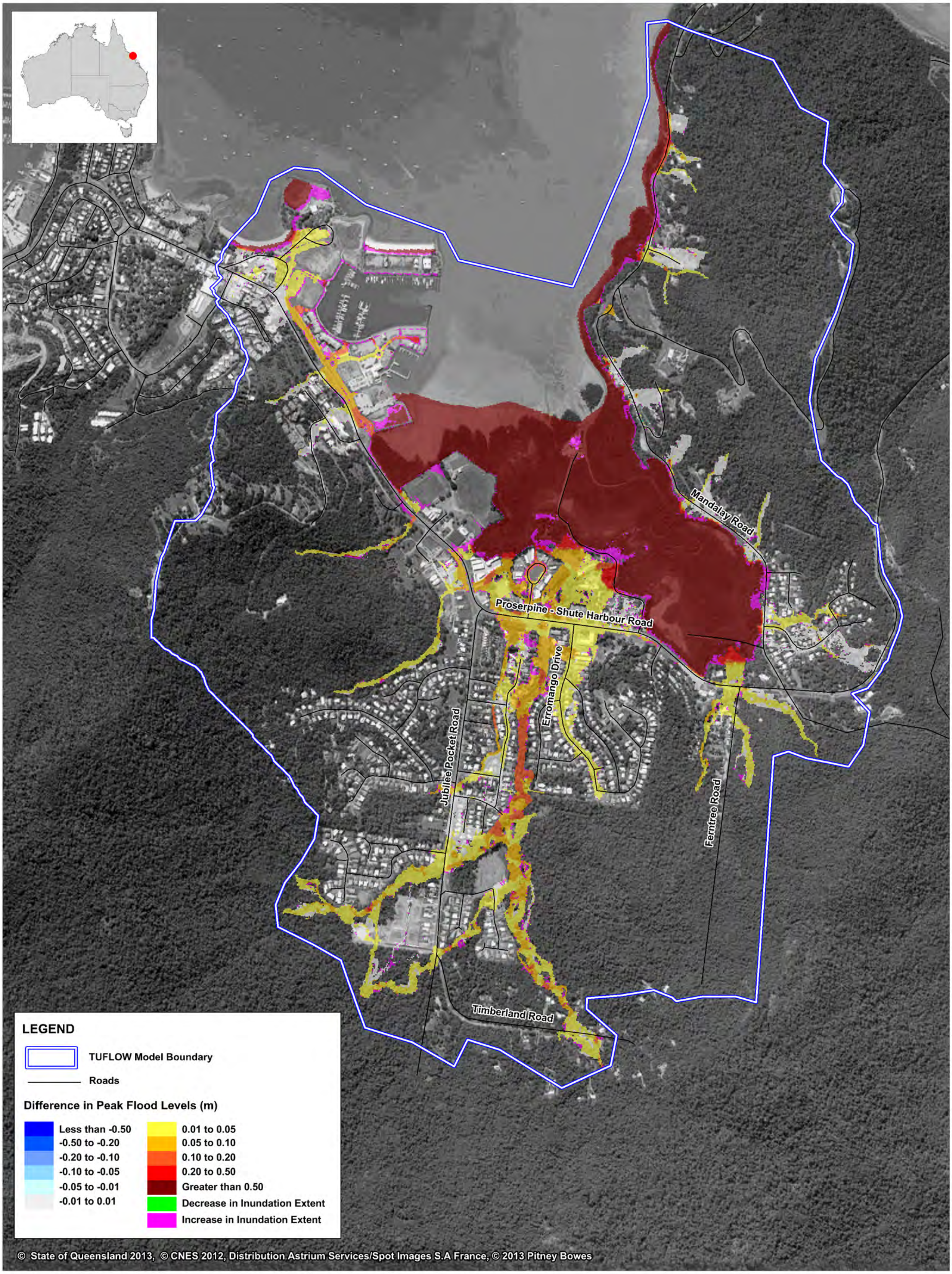
Figure: **D-10**

Rev: **A**



BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\FLD_022_170908_2050_CC_Level_Impact_CampbellCreek.wor




Title:

**Campbell Creek Climate Change 2100 - Peak Flood Level Impact**

Figure: **D-11**

Rev: **A**

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N

0 400 800m

Approx.Scale

BMT WBM

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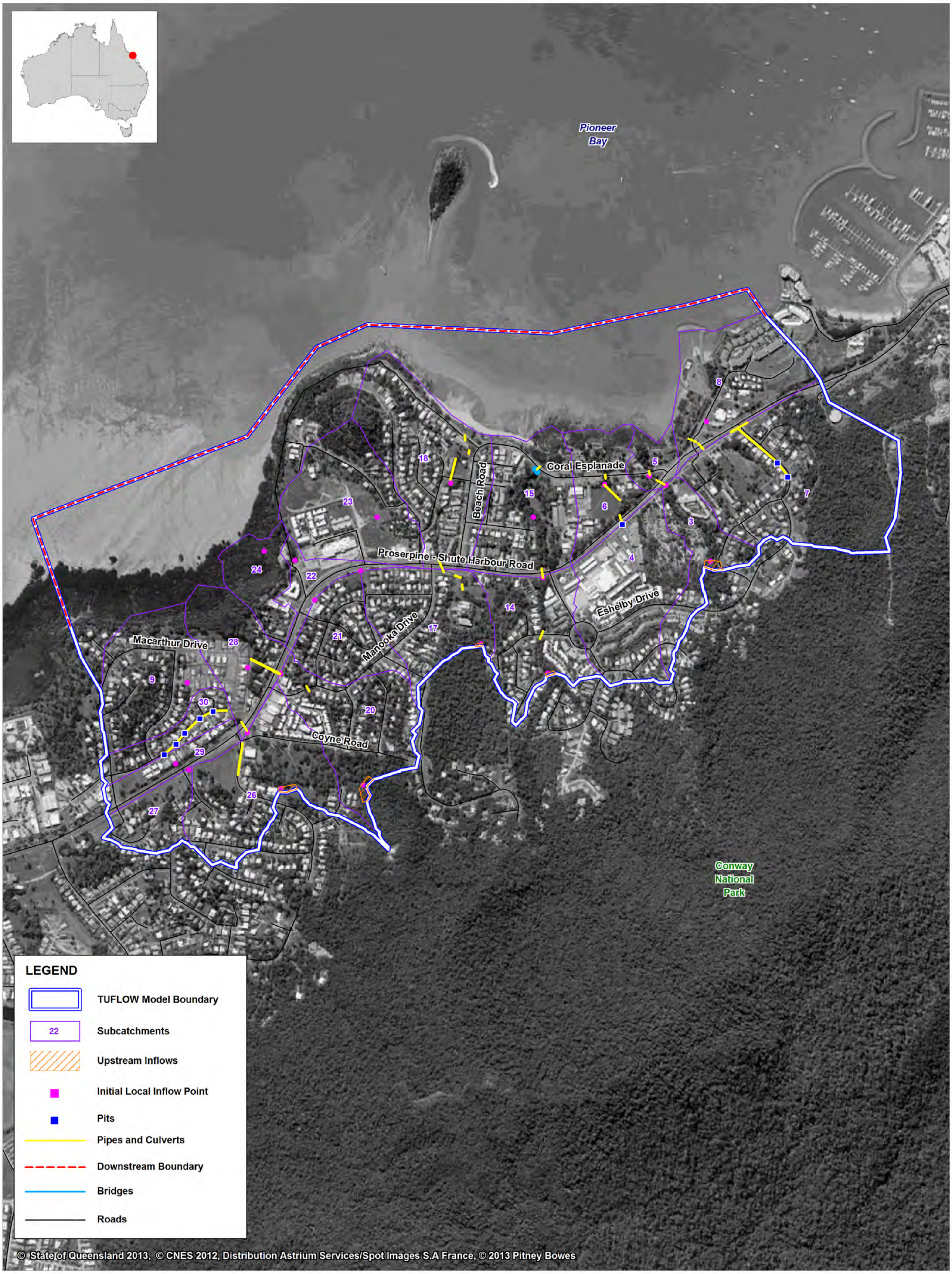
Filepath: I:\B22591_I_ak_TOWDS\DRG\FLD_023_170908_2100_CC_Level_Impact_CampbellCreek.wor

# Appendix E Cannonvale Maps




Title:

**Cannonvale Model Layout**

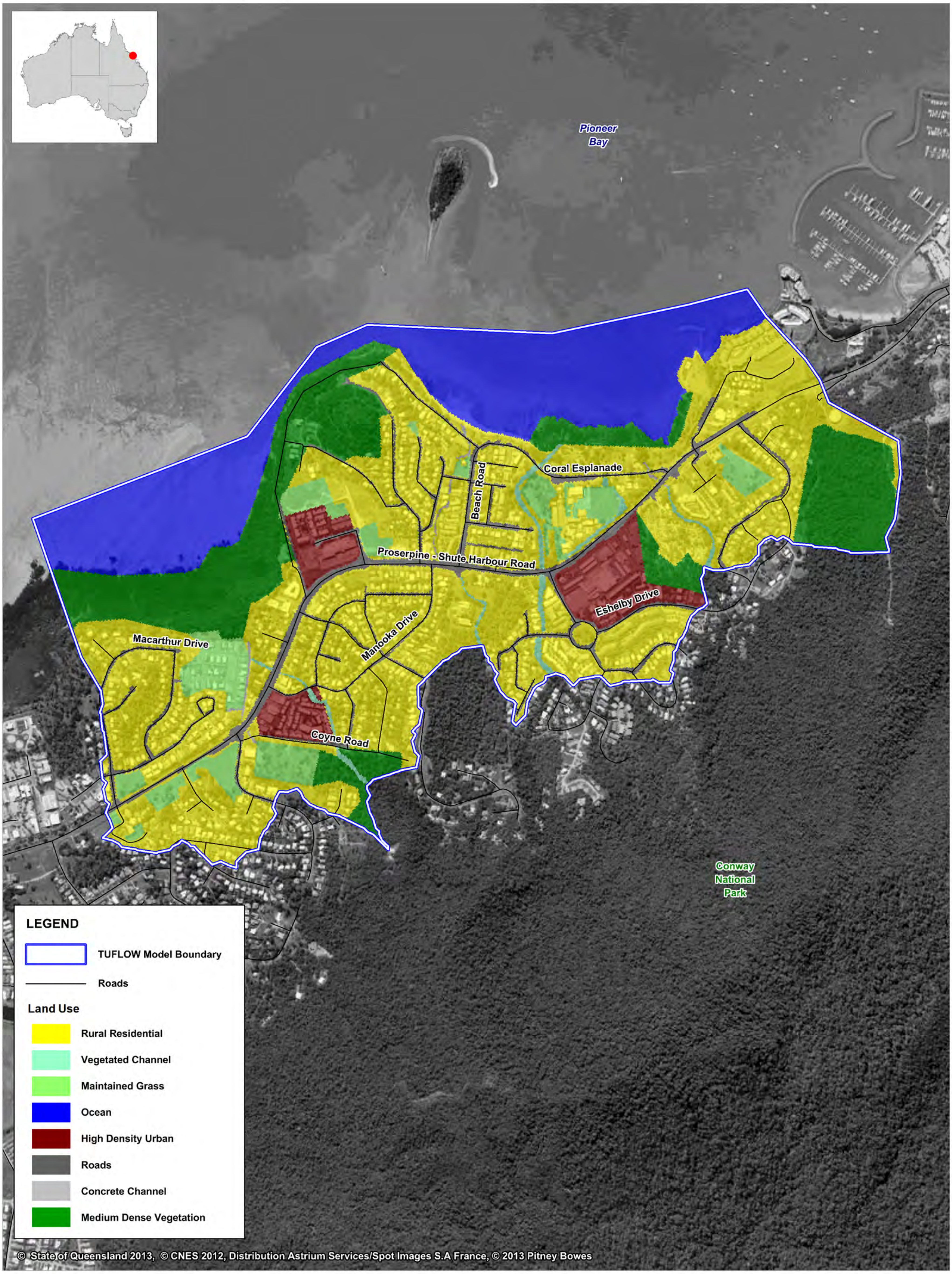
Figure: **E-1**

Rev: **A**



BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\FLD_017_170831_Difference in Peak Flood Levels_Cannonvale.wor




Title:
**Cannonvale Land Use Map**

Figure: **E-2**

Rev: **A**



BMT WBM
www.bmtwbm.com.au

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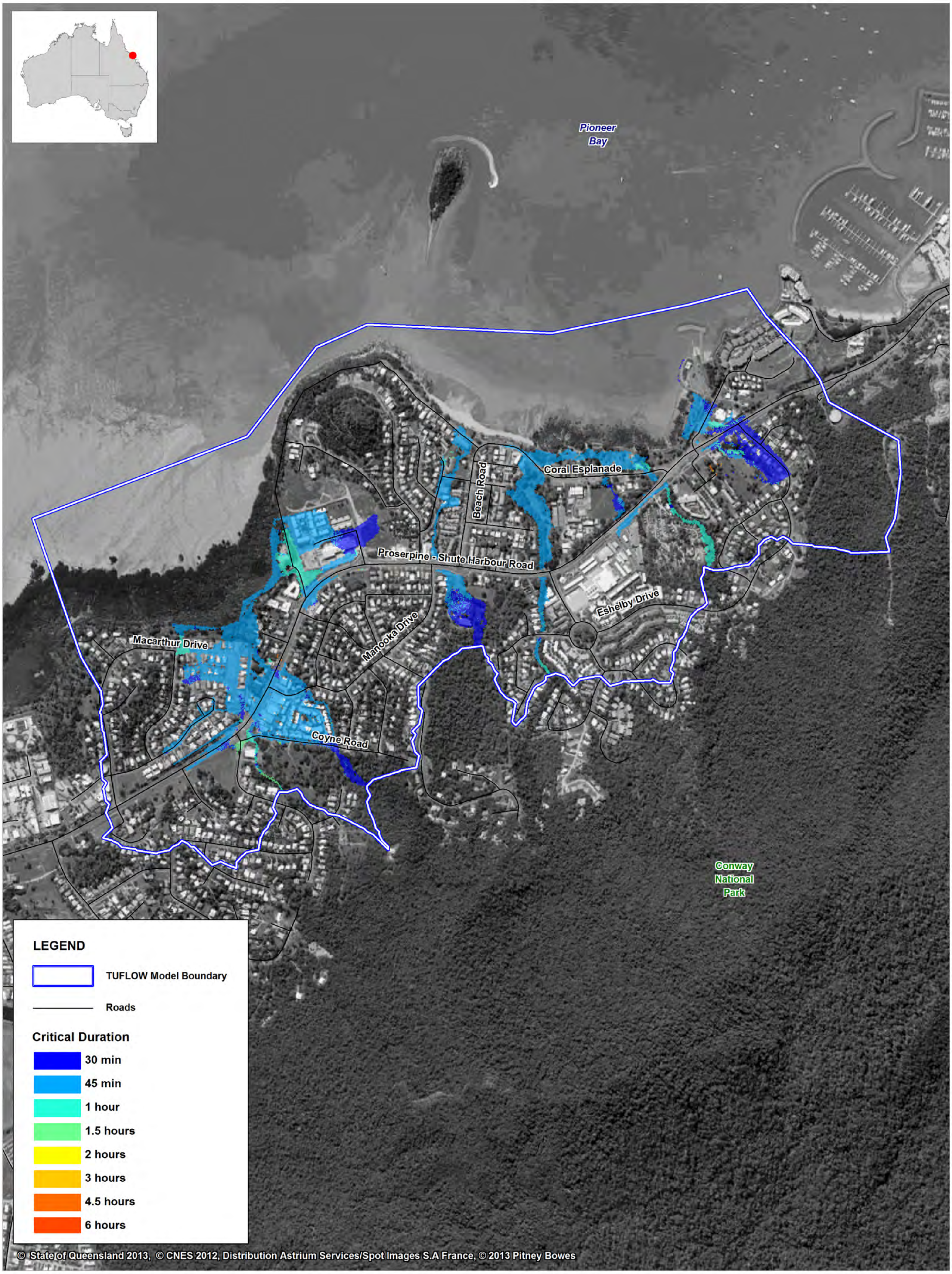





Title:
**Cannonvale Critical Duration Assessment**

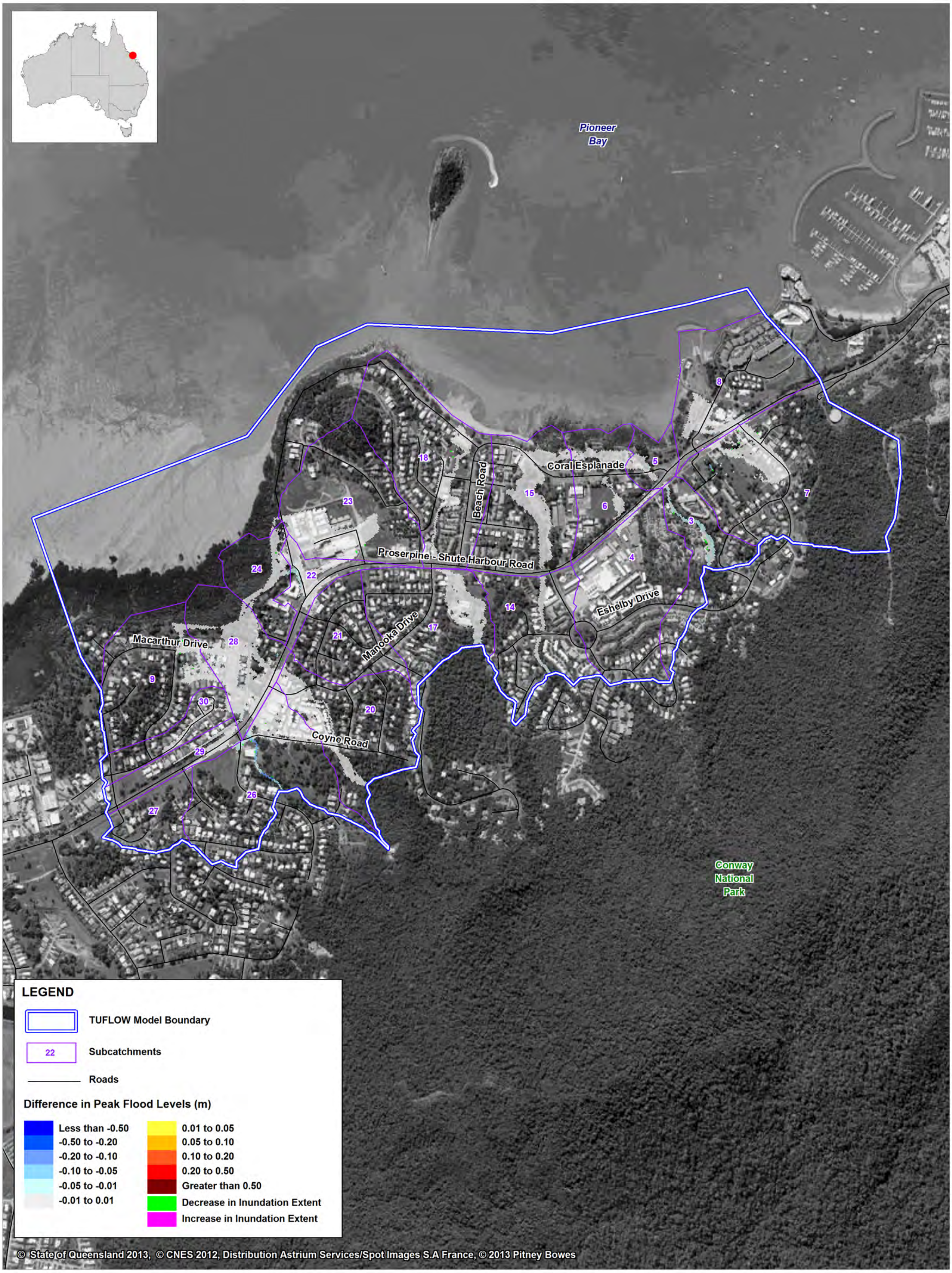
Figure: **E-3**

Rev: **A**



BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\FLD_019_170831_Critical Duration_Cannonvale.wor




Title:

**Cannonvale - Difference in Peak Flood Levels**

Figure: **E-4**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

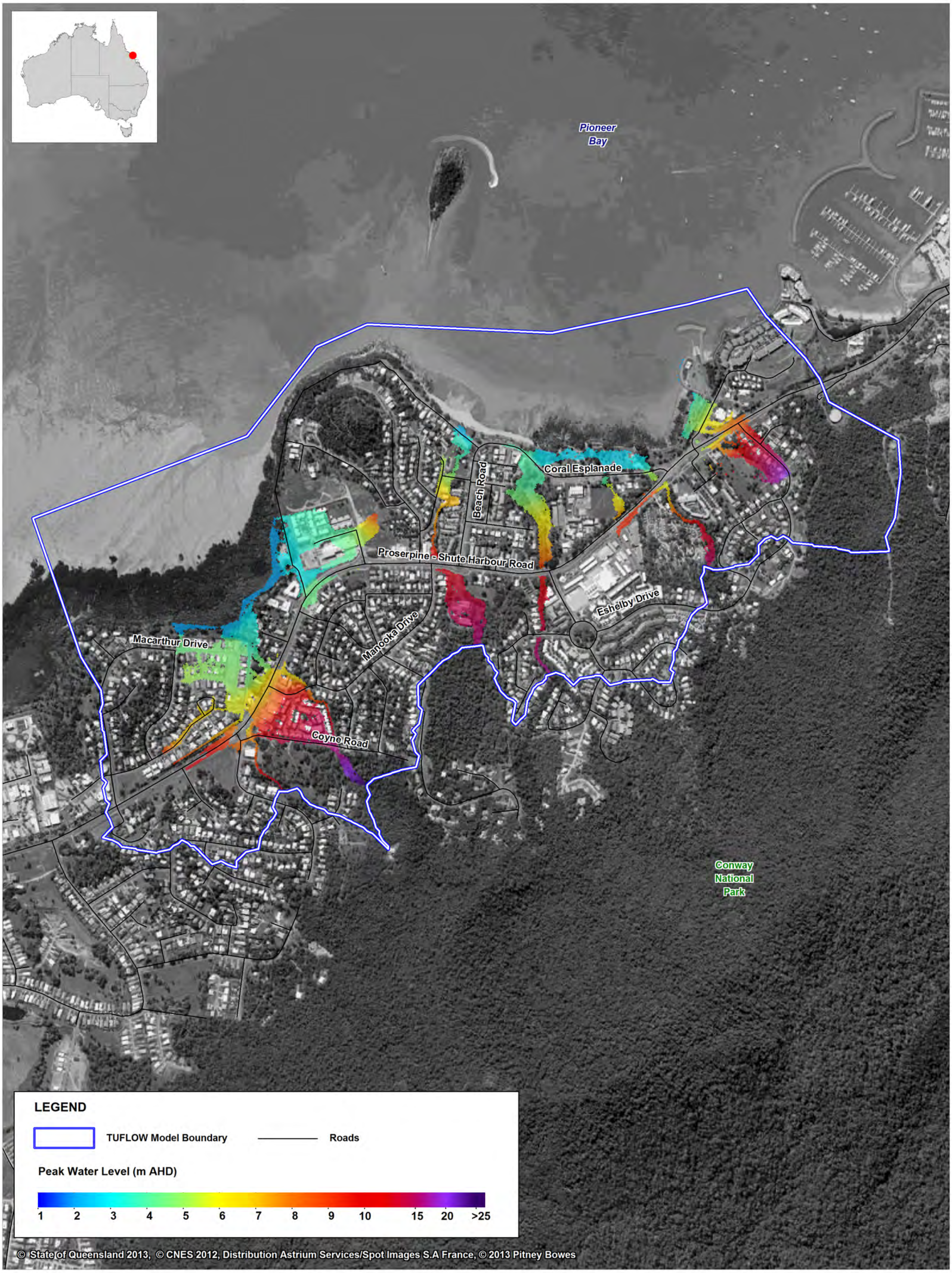
N

0 350 700m

Approx.Scale

BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\FLD_017_170831_Difference in Peak Flood Levels_Cannonvale.wor




Title:

**Cannonvale Peak Flood Levels**

Figure: **E-5**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

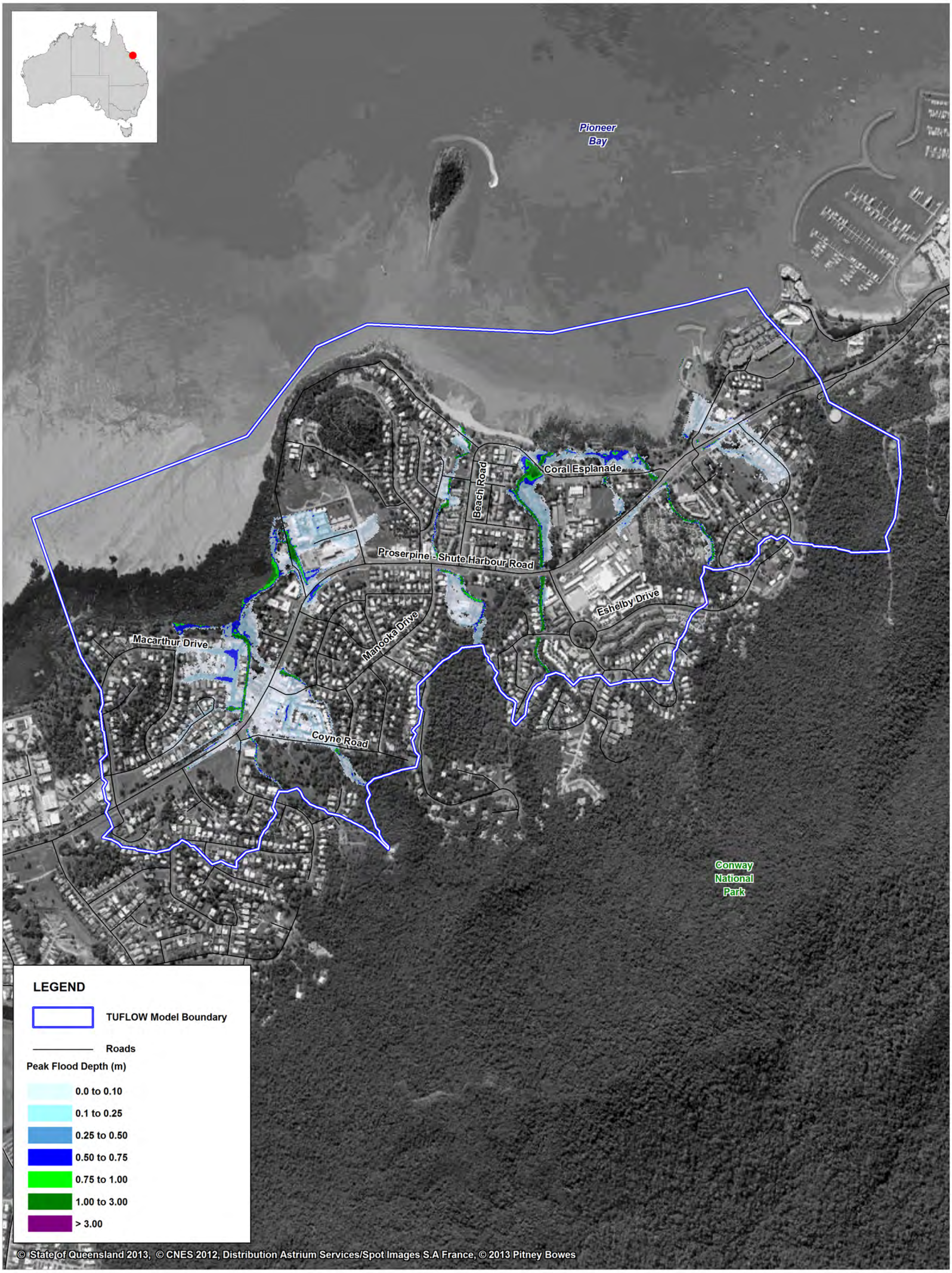
N

0 350 700m

Approx.Scale

BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\FLD_003_170831_Peak Water Level_Cannonvale.wor




Title:
## Cannonvale Peak Flood Depths

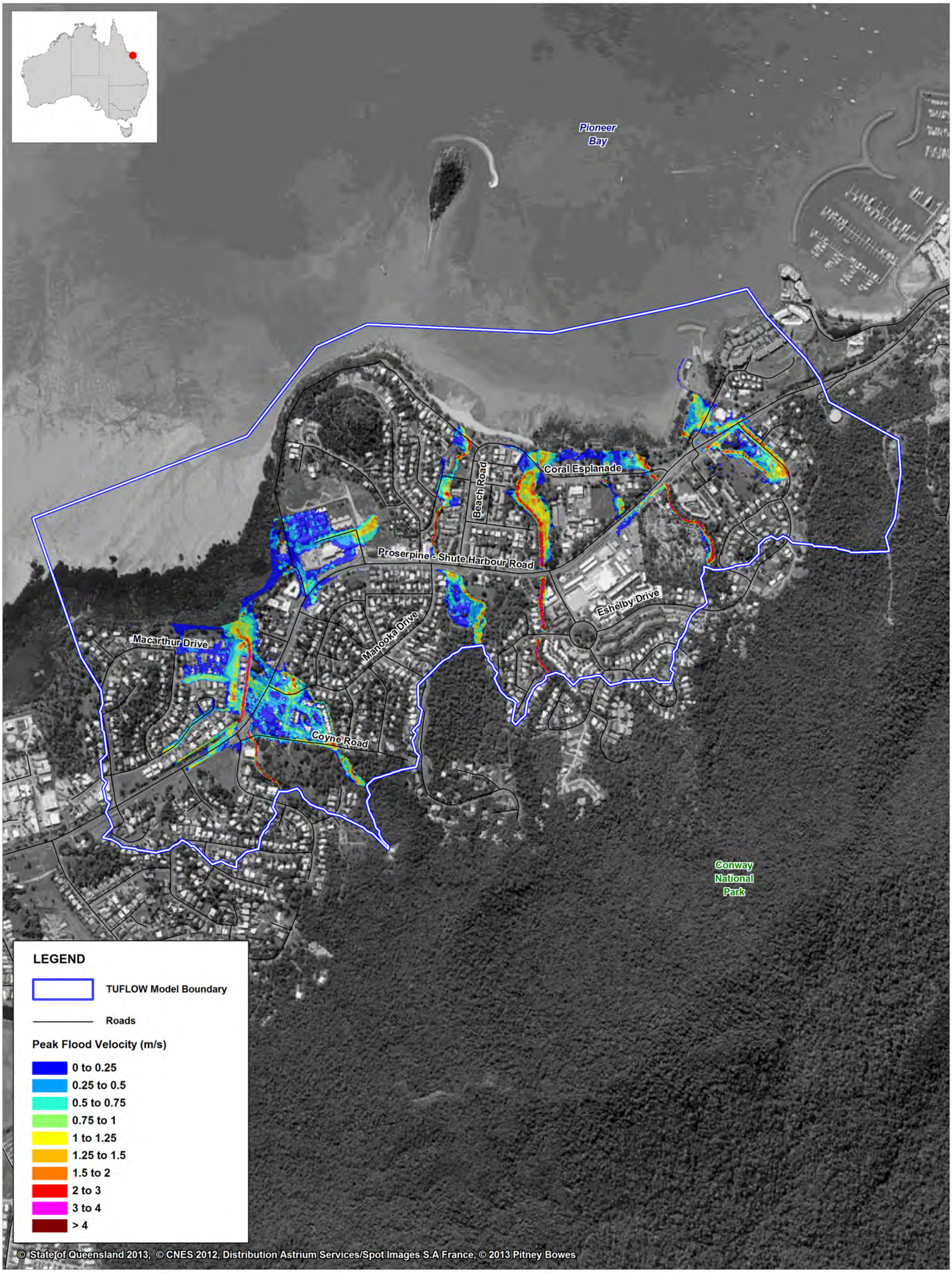
Figure: E-6

Rev: A



BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\FLD_004_170831_Peak Flood Depth_Cannonvale.wor




Title:

**Cannonvale Peak Flood Velocities**

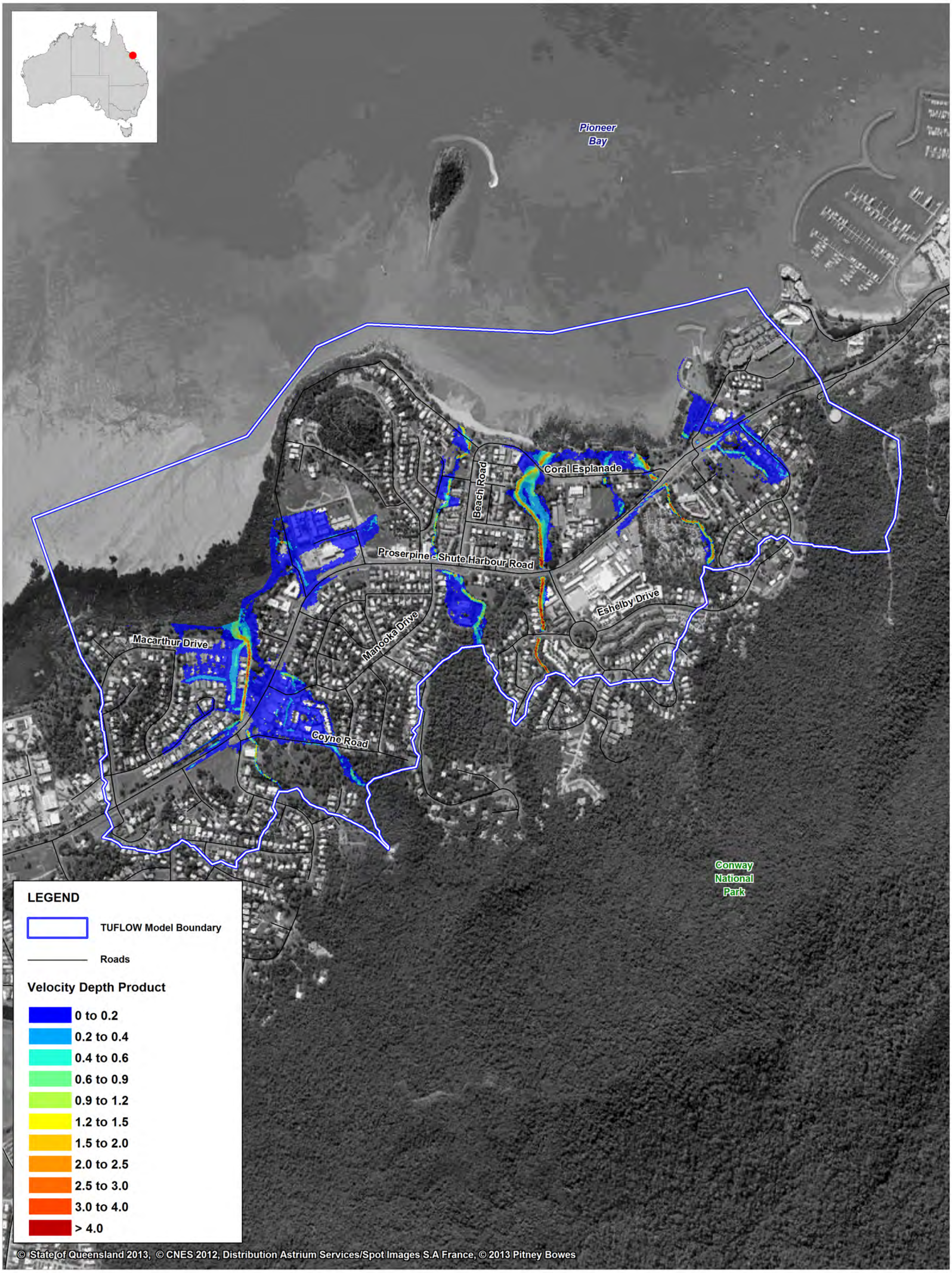
Figure: **E-7**

Rev: **A**



BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\FLD_006_170831_Peak Flood Velocity_Cannonvale.wor




Title:
**Cannonvale Depth Velocity Product**

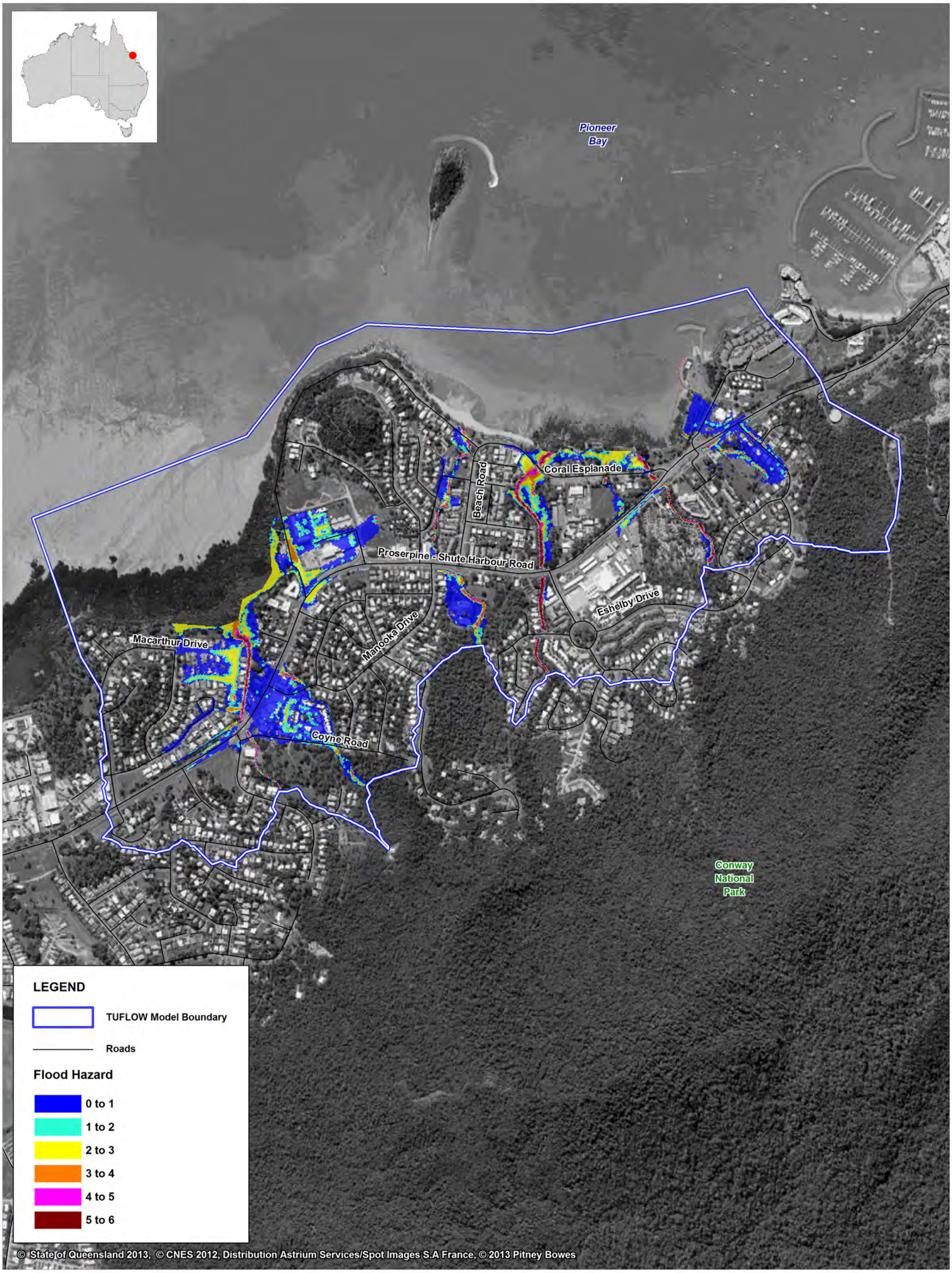
Figure: **E-8**

Rev: **A**



BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\FLD_008_170831_Depth Velocity Product_Cannonvale.wor






Title:
**Cannonvale Flood Hazard**

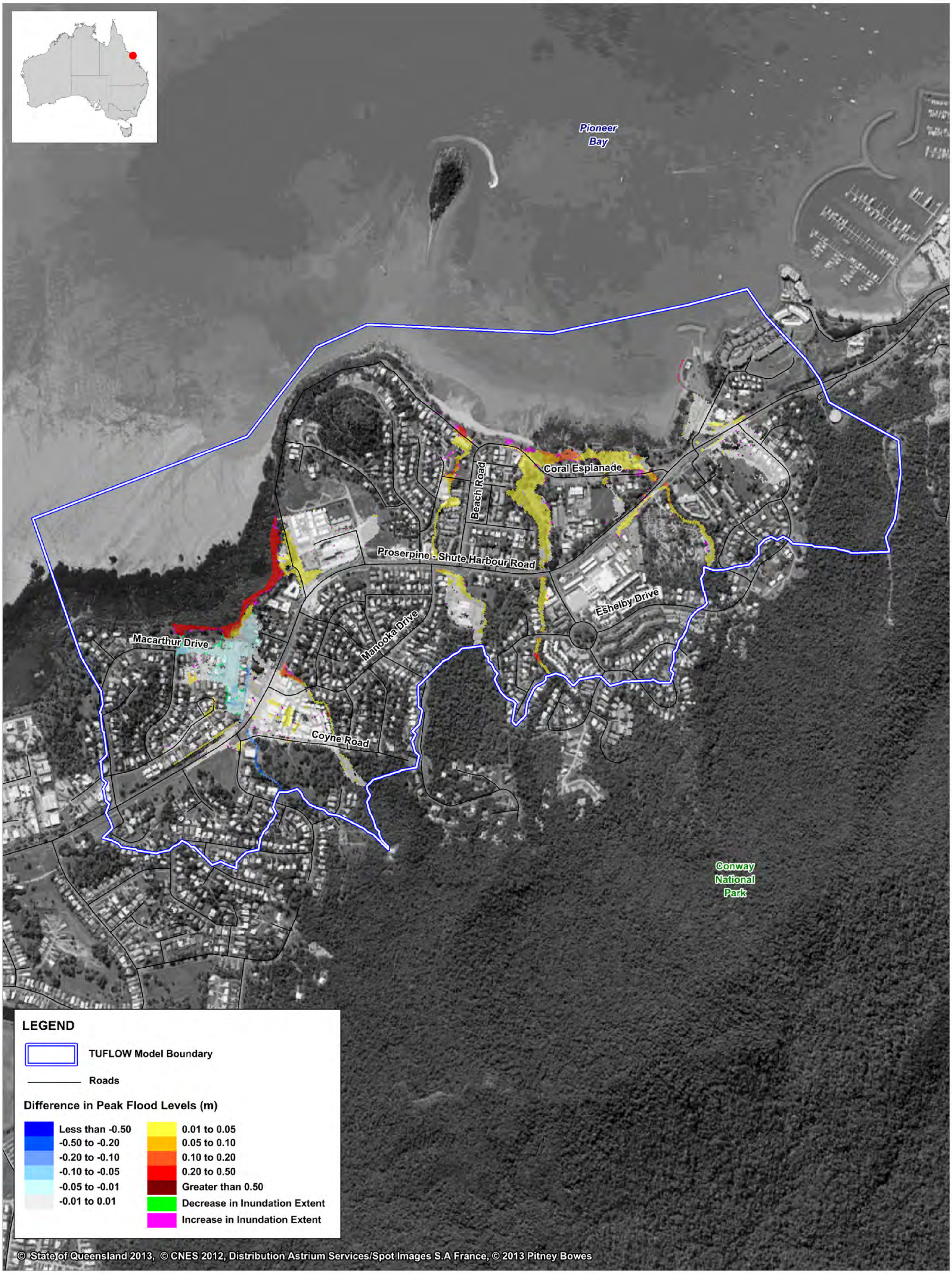
Figure: **E-9**

Rev: **A**



BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\FLD_007_170831_Flood Hazard_Cannonvale.wor




Title:
**Cannonvale Climate Change 2050 - Peak Flood Level Impact**

Figure: **E-10**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

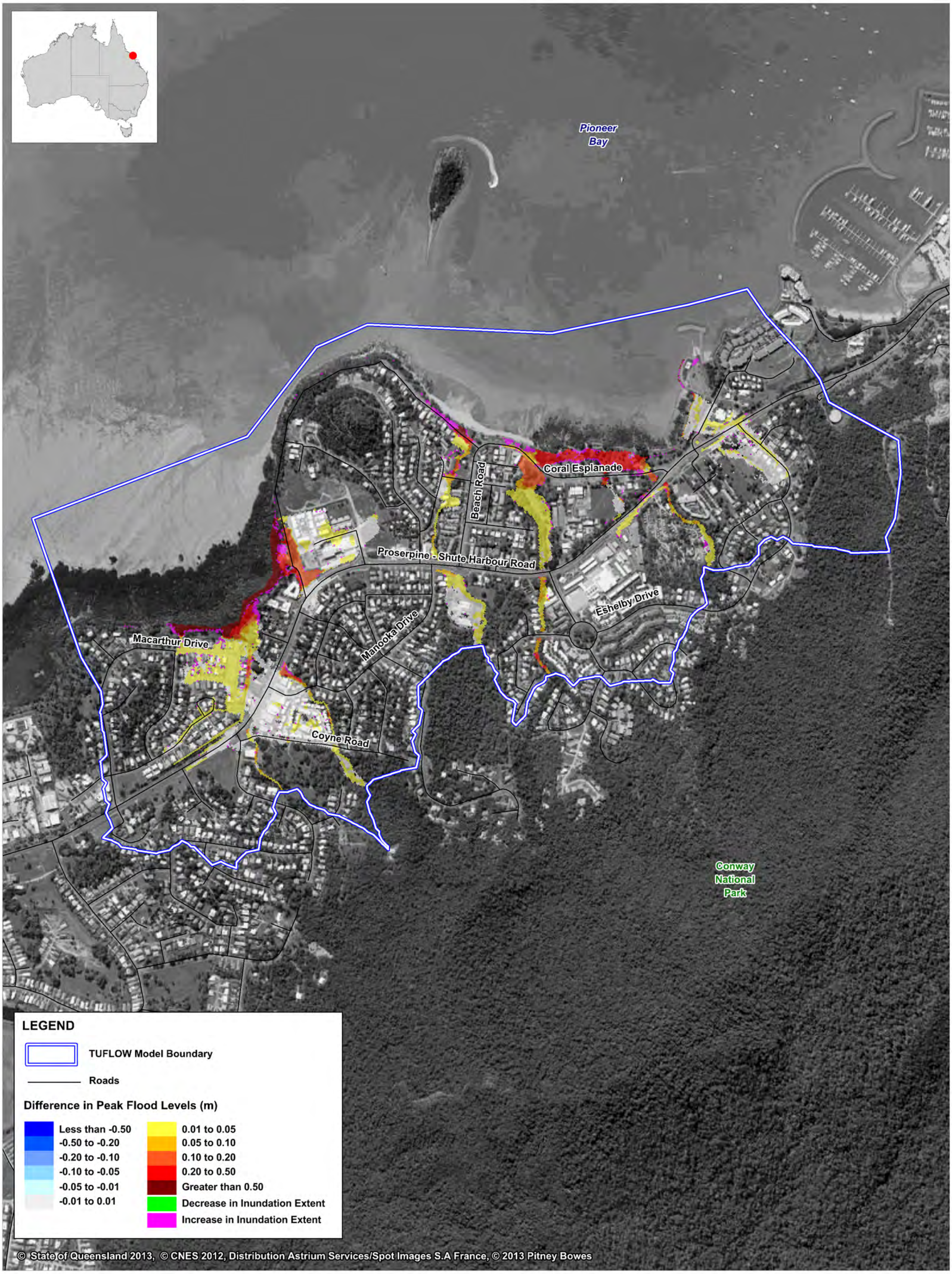
N

0 350 700m

Approx.Scale

BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\FLD_020_170908_2050_CC_Level_Impact_Cannonvale.wor




Title:

**Cannonvale Climate Change 2100 - Peak Flood Level Impact**

Figure: **E-11**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 350 700m

Approx.Scale

BMT WBM

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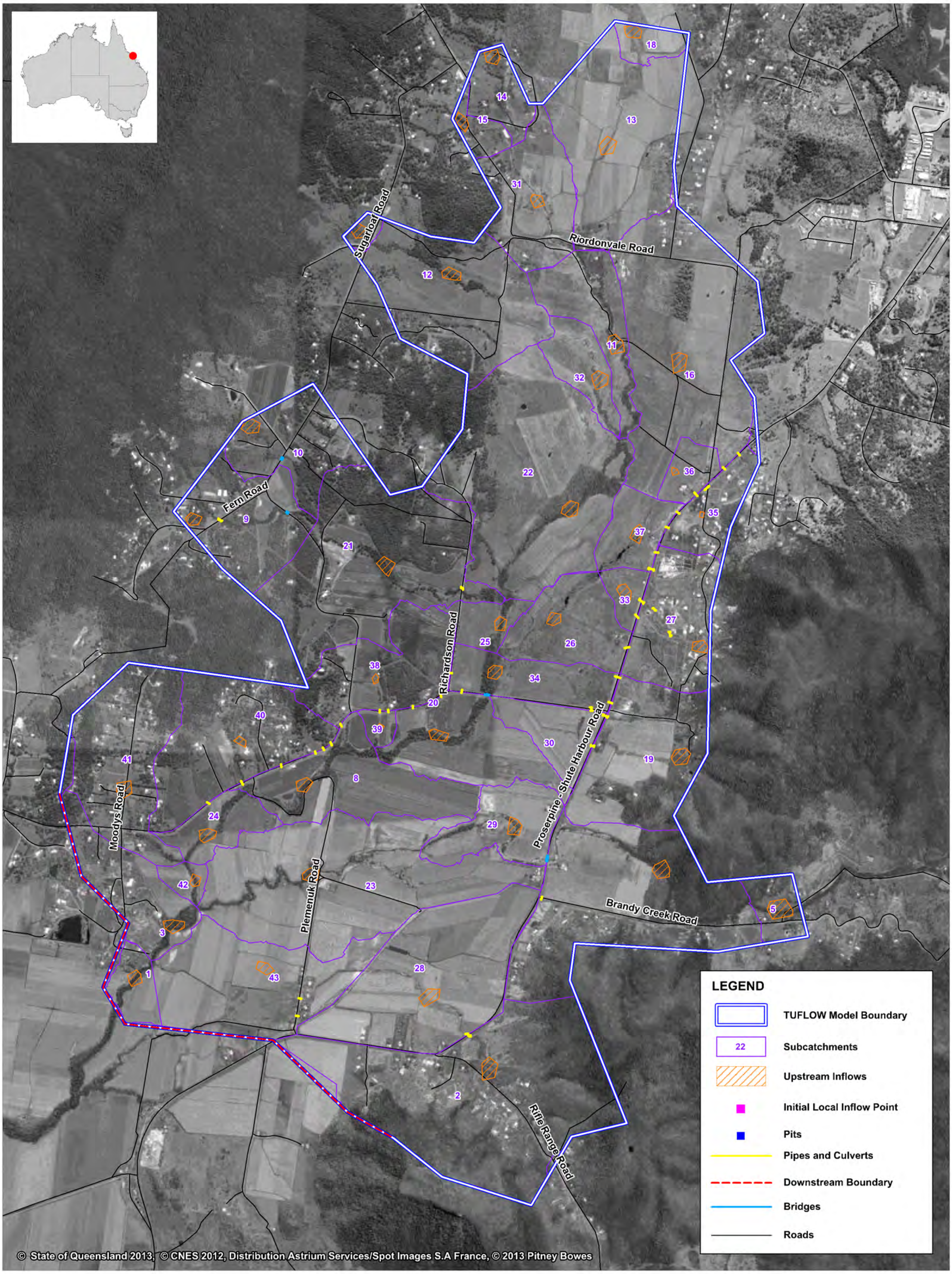
Filepath: I:\B22591_I_ak_TOWDS\DRG\FLD_021_170908_2100_CC_Level_Impact_Cannonvale.wor

# Appendix F Crofton Creek Maps




Title:
**Crofton Creek Model Layout**

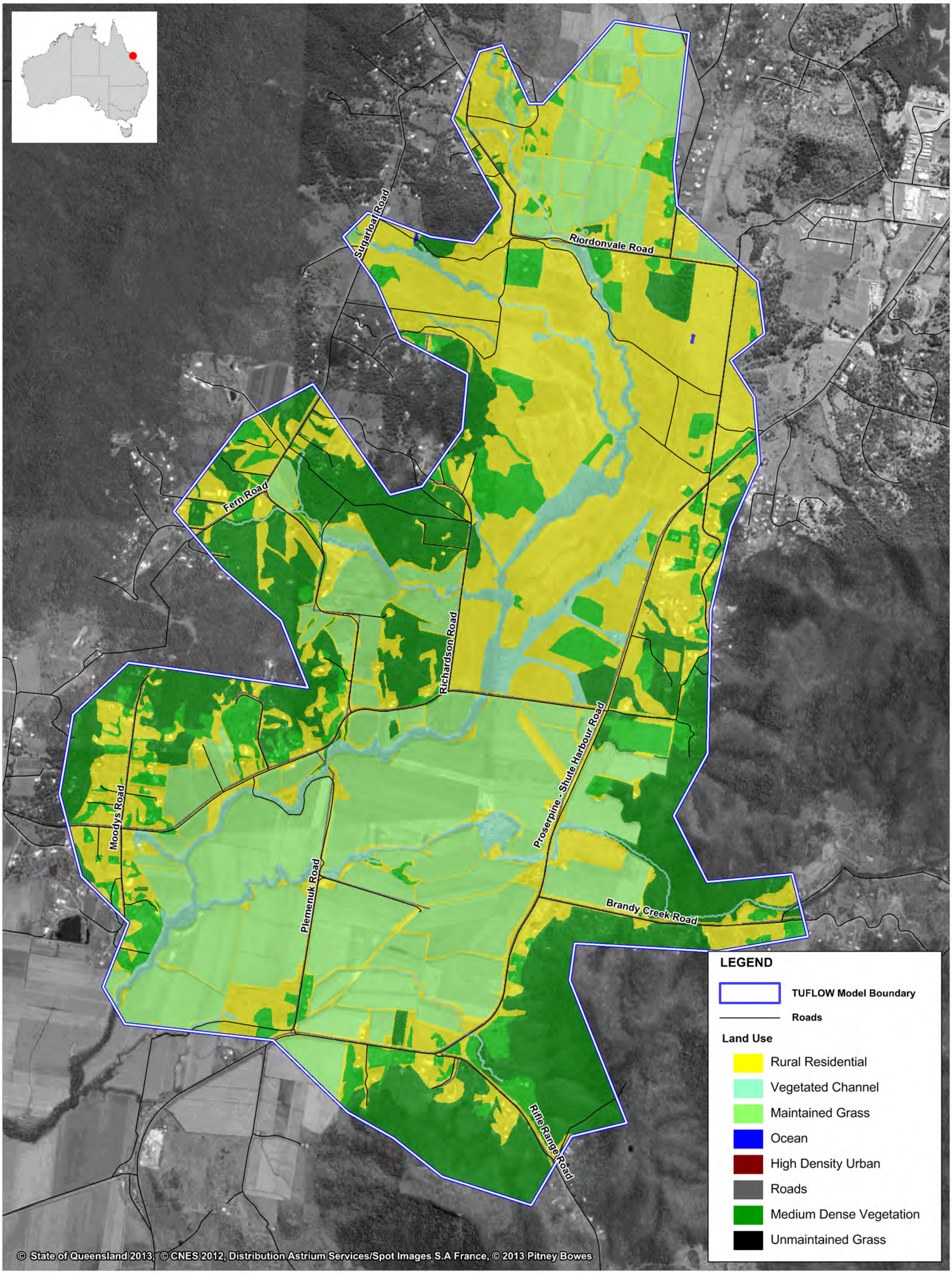
Figure: **F-1**

Rev: **A**



BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\Crofton\FLD_001_170911_Model Inputs_Crofton.wor




Title:
**Crofton Creek Model Landuse**

Figure: **F-2**

Rev: **A**

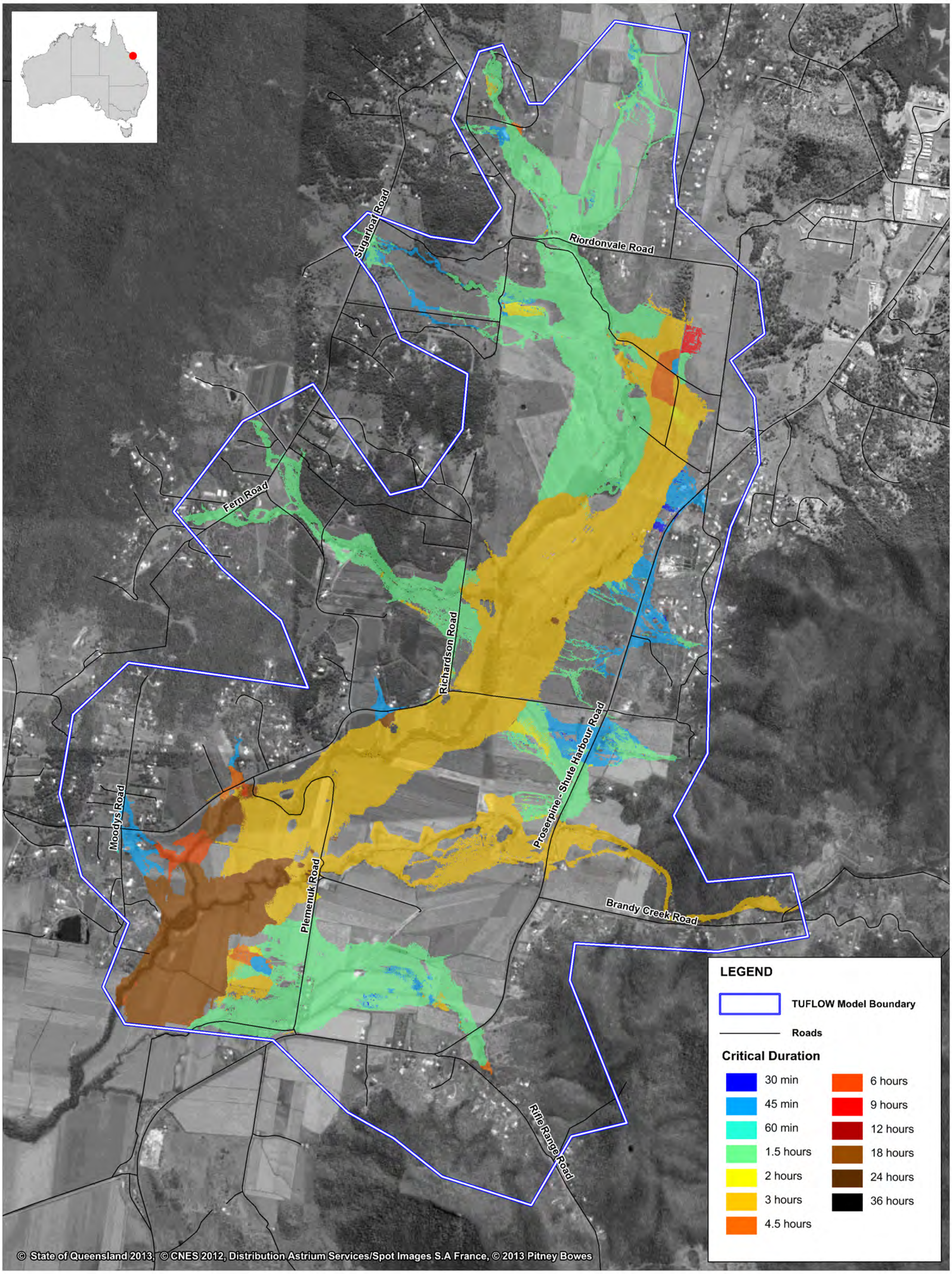
BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 0.5 1km
Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\Crofton\FLD_002_170912_LandUse_Crofton.wor




Title:
**Crofton Creek Critical Duration Assessment**

Figure: **F-3**

Rev: **A**



BMT WBM
www.bmtwbm.com.au

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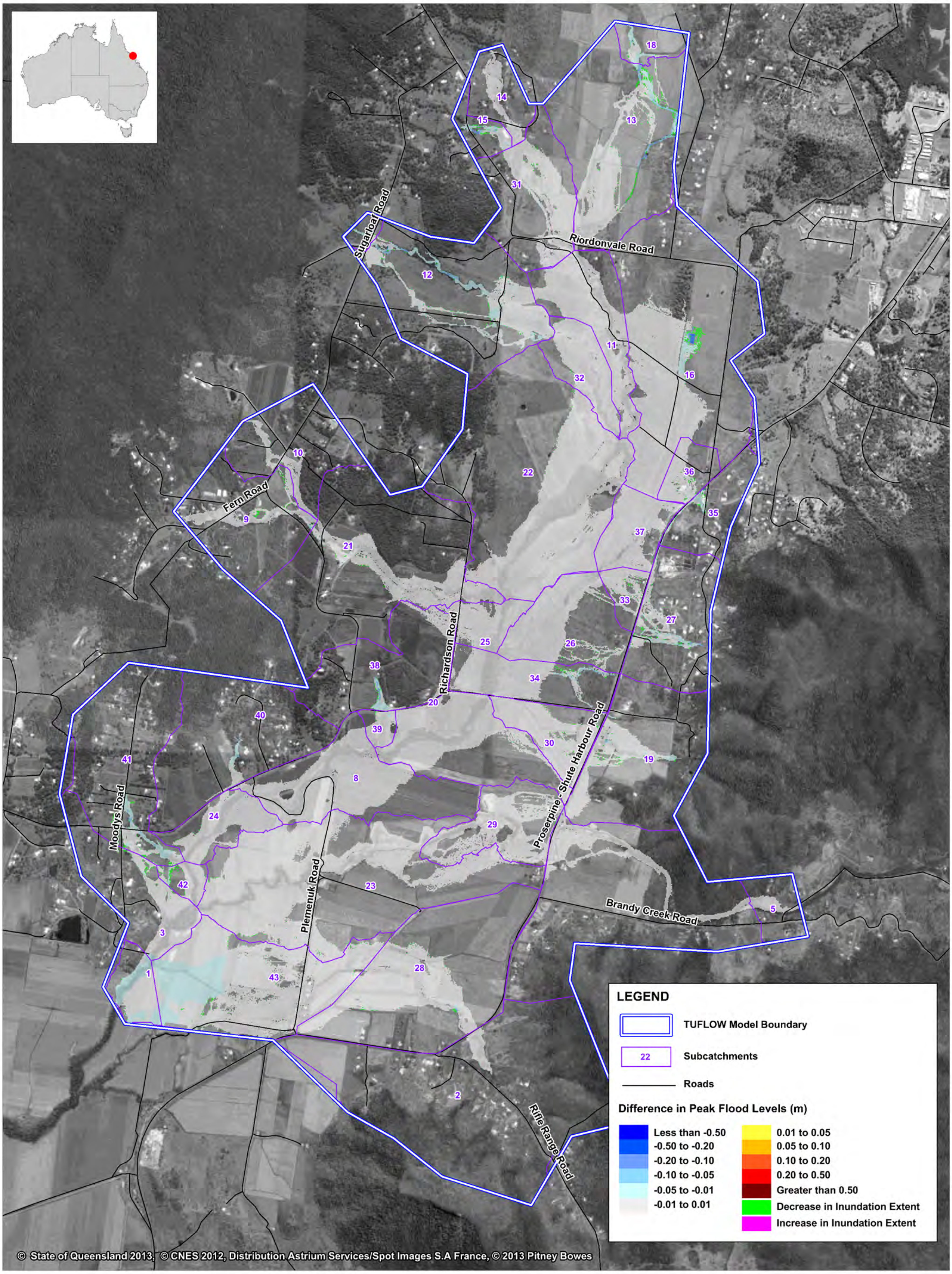



Title:

**Crofton Creek Difference in Peak Flood Levels**

Figure: **F-4**

Rev: **A**



N

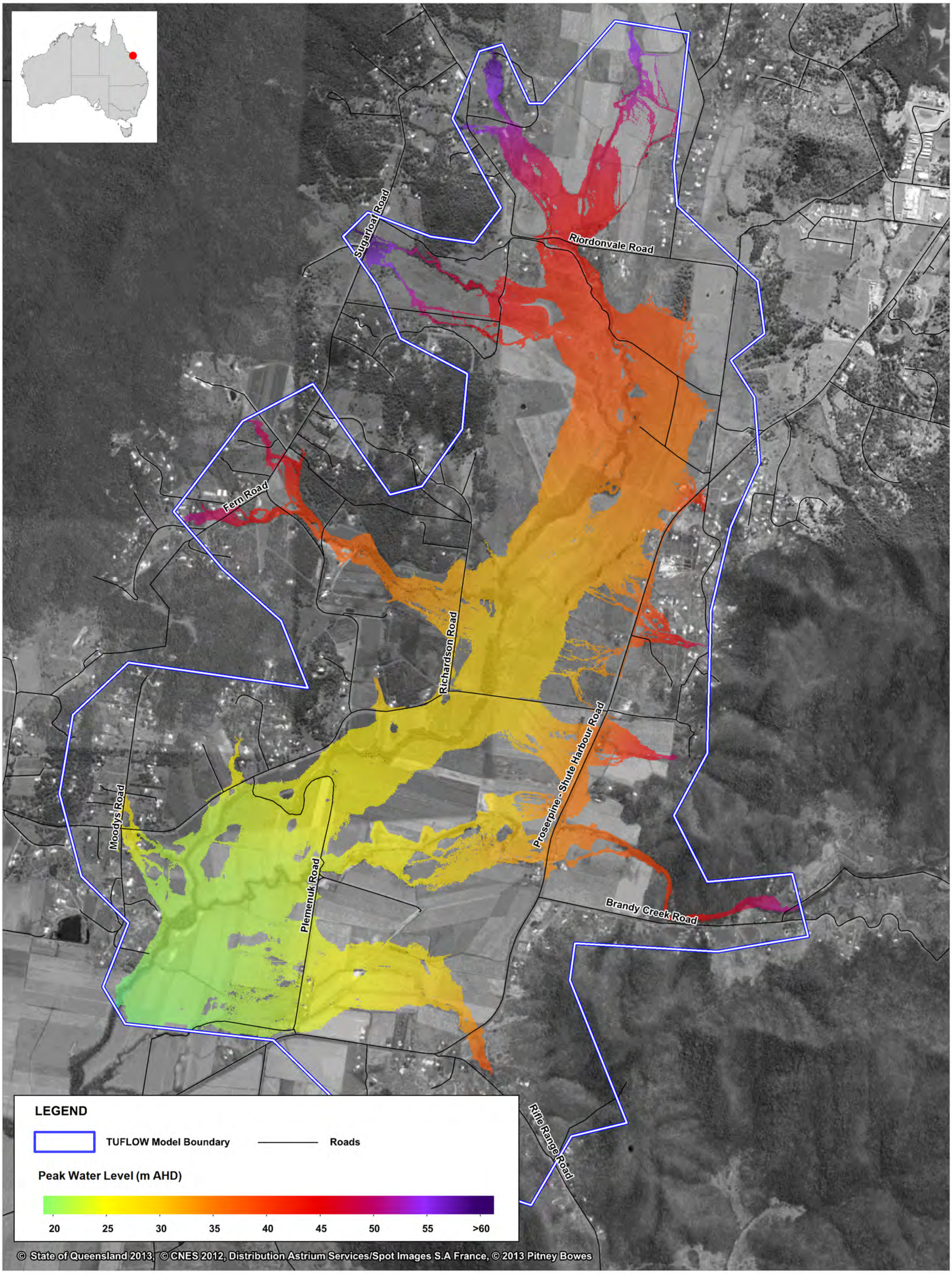
0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\Crofton\FLD_004_170912_FloodLevels_Diff_Crofton.wor






| Title: | Figure: | Rev: |
|---|---|---|
| **Crofton Creek Peak Flood Levels** | **F-5** | **A** |

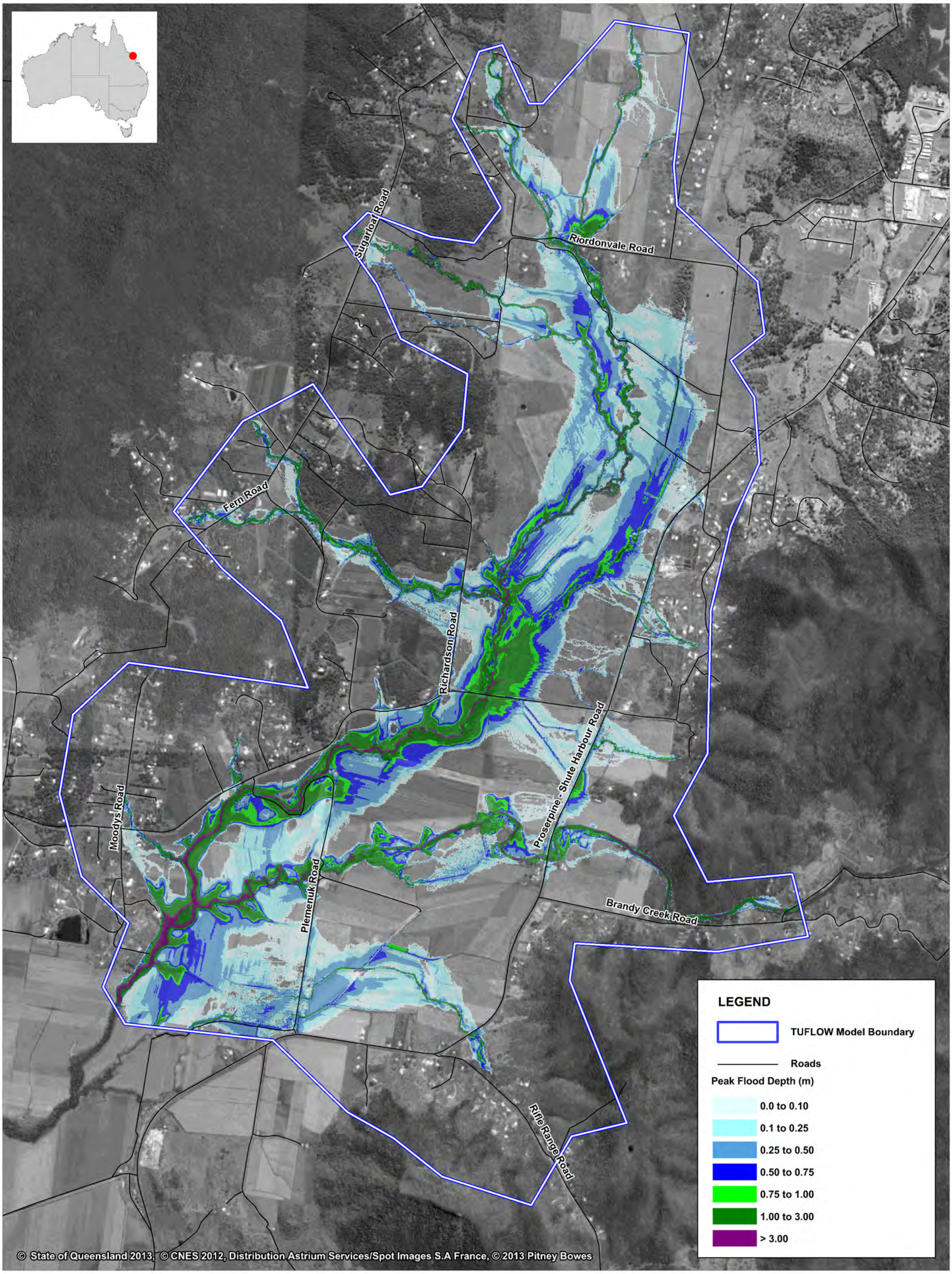


N

0 0.5 1km
Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\Crofton\FLD_005_170912_PeakFloodLevels_Crofton.wor




Title:
**Crofton Creek Model Peak Flood Depths**

Figure: **F-6**

Rev: **A**



N

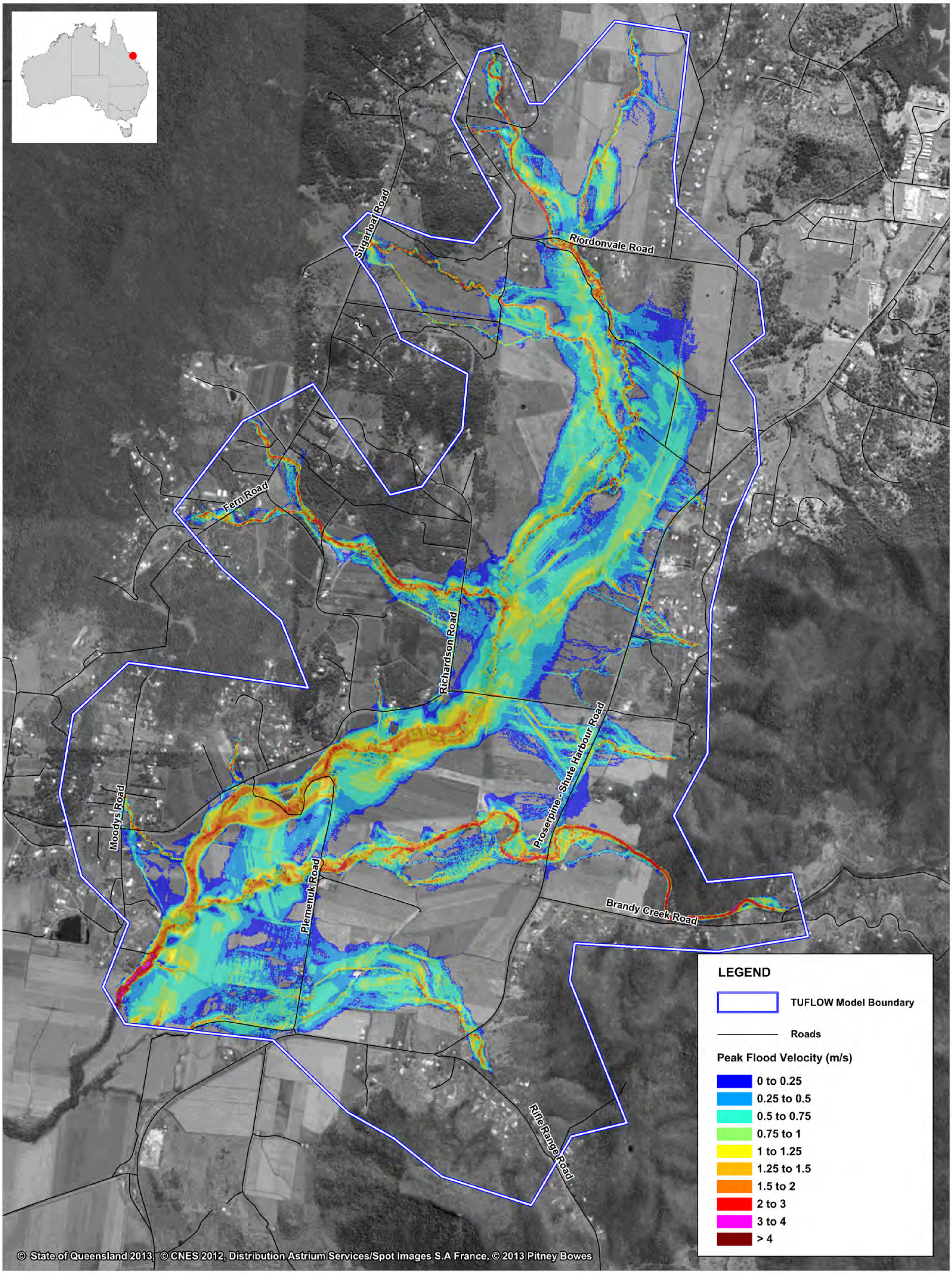
0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\Crofton\FLD_006_170912_PeakFloodDepths_Crofton.wor




Title:
**Crofton Creek Peak Flood Velocities**

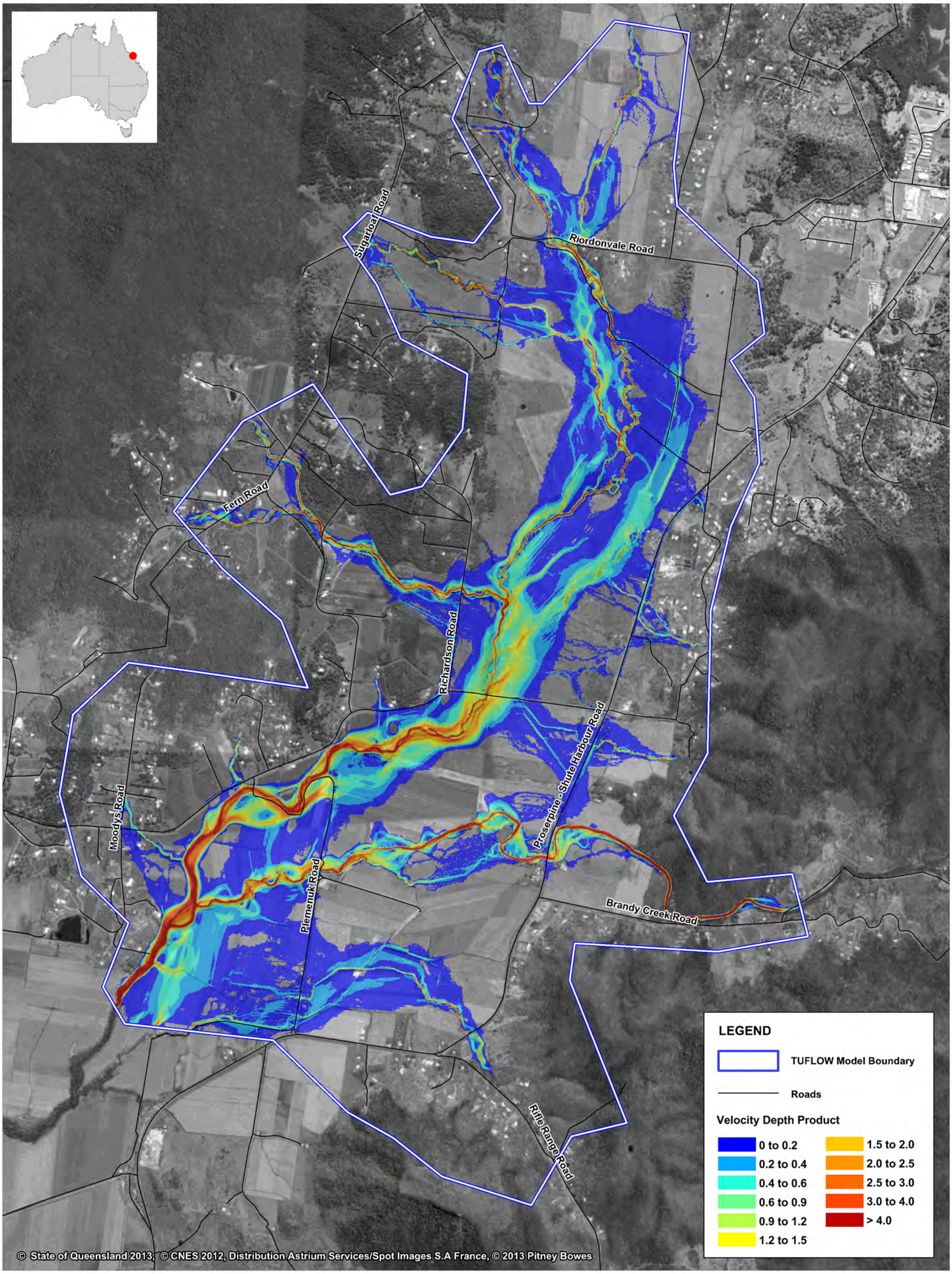
Figure: **F-7**

Rev: **A**



BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\Crofton\FLD_007_170912_PeakFloodVelocities_Crofton.wor






Title:
**Crofton Creek Depth Velocity Product**

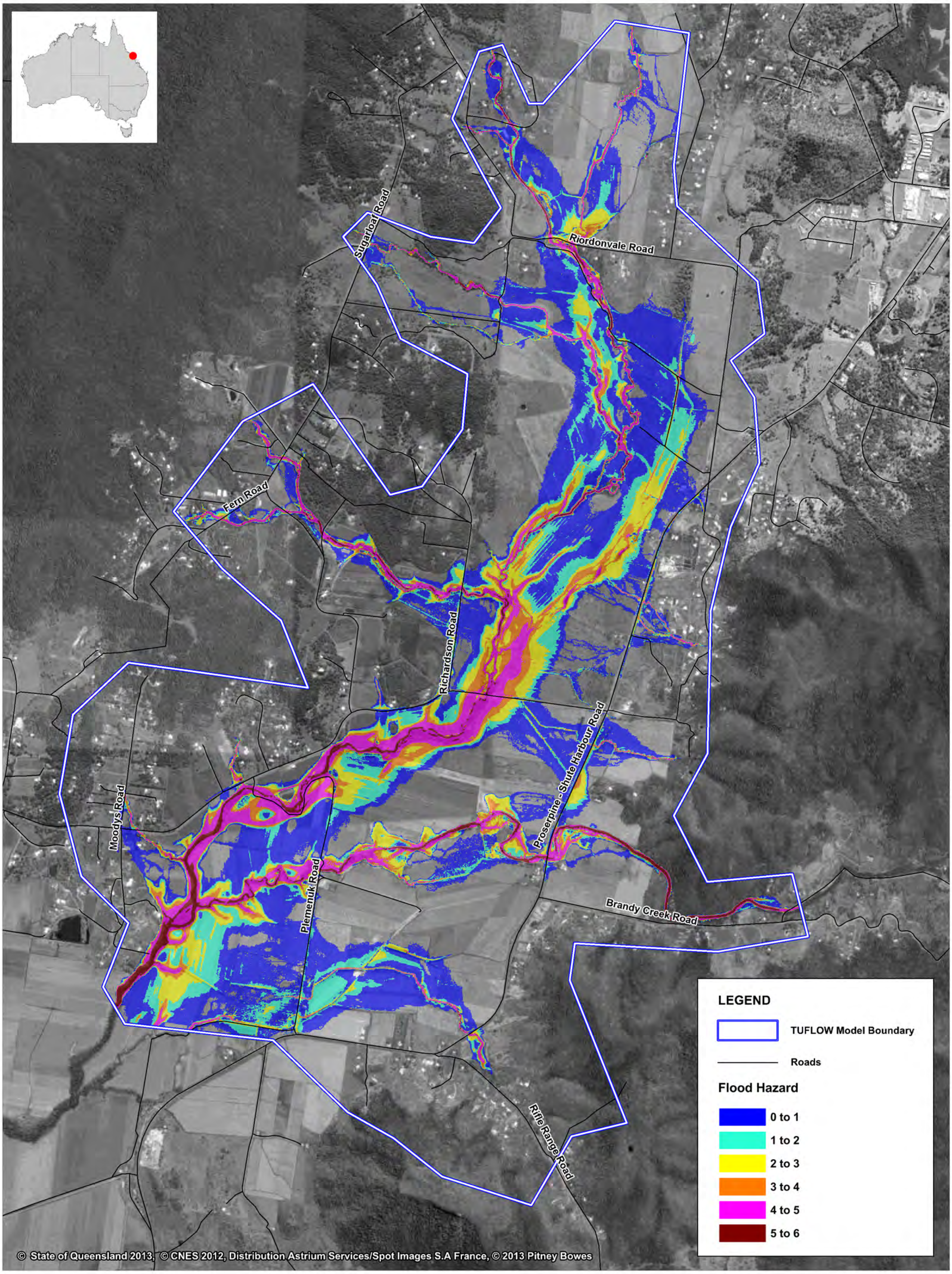
Figure: **F-8**

Rev: **A**



BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\Crofton\FLD_008_170912_DepthVelocityProduct_Crofton.wor

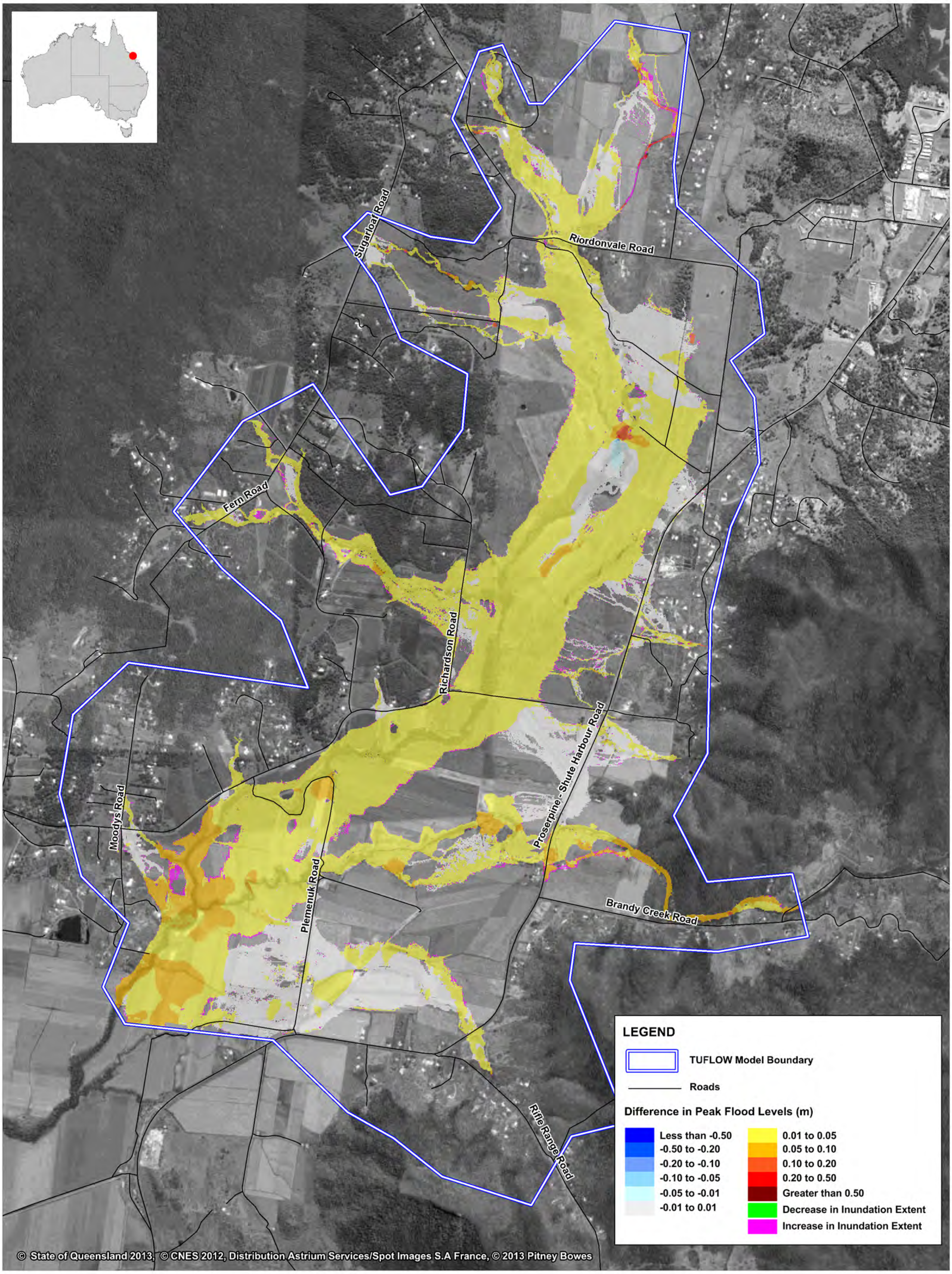



| Title: | Figure: | Rev: |
|---|---|---|
| **Crofton Creek Flood Hazard** | **F-9** | **A** |



BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\Crofton\FLD_009_170912_FloodHazard_Crofton.wor




Title:
**Crofton Creek Climate Changee 2050 - Peak Flood Level Impact**

Figure: **F-10**

Rev: **A**



N

0 0.5 1km
Approx. Scale

BMT WBM
www.bmtwbm.com.au

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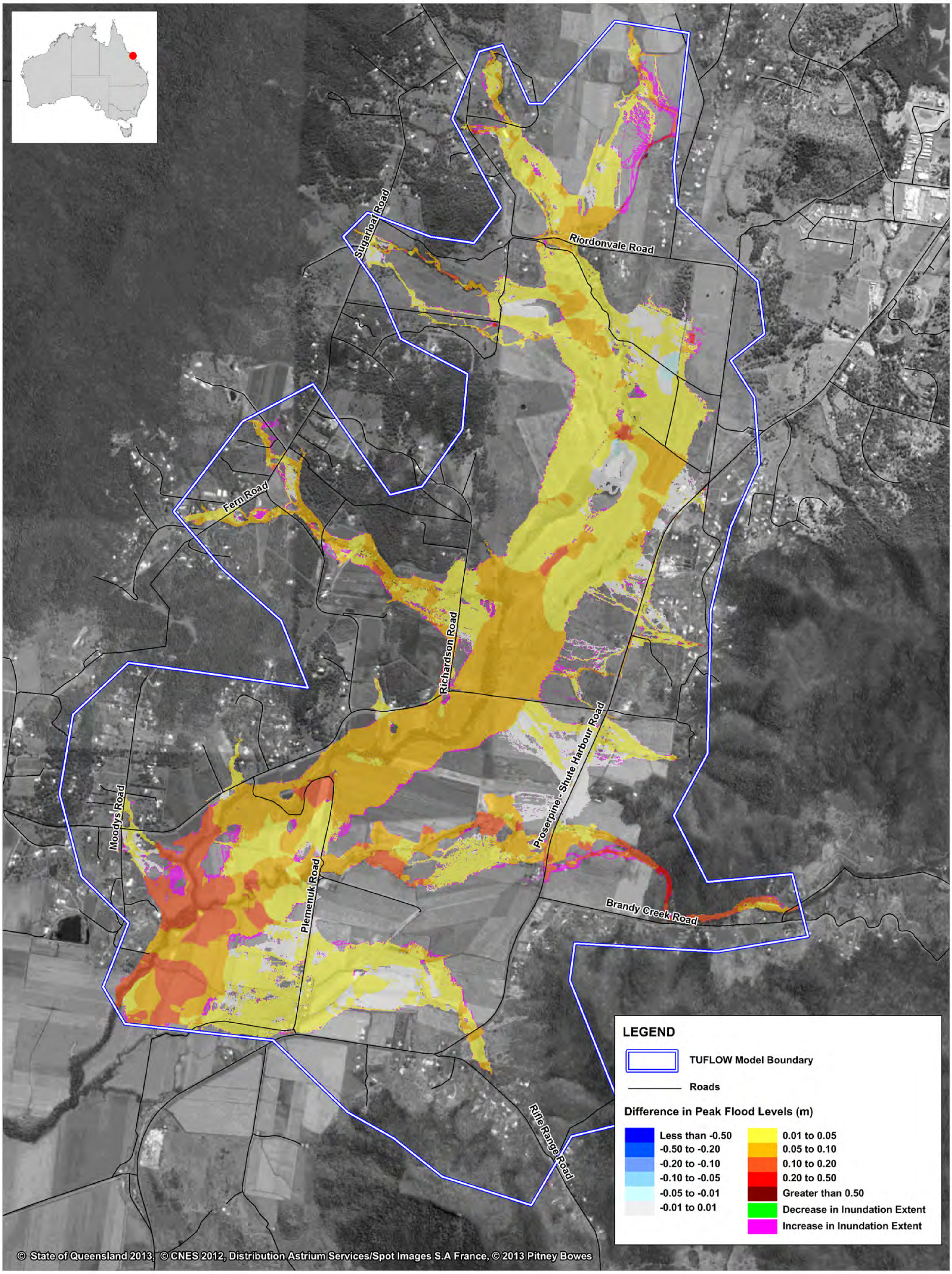



Title:
**Crofton Creek Climate Changee 2100 - Peak Flood Level Impact**

Figure:
**F-11**

Rev:
**A**



N

0 0.5 1km

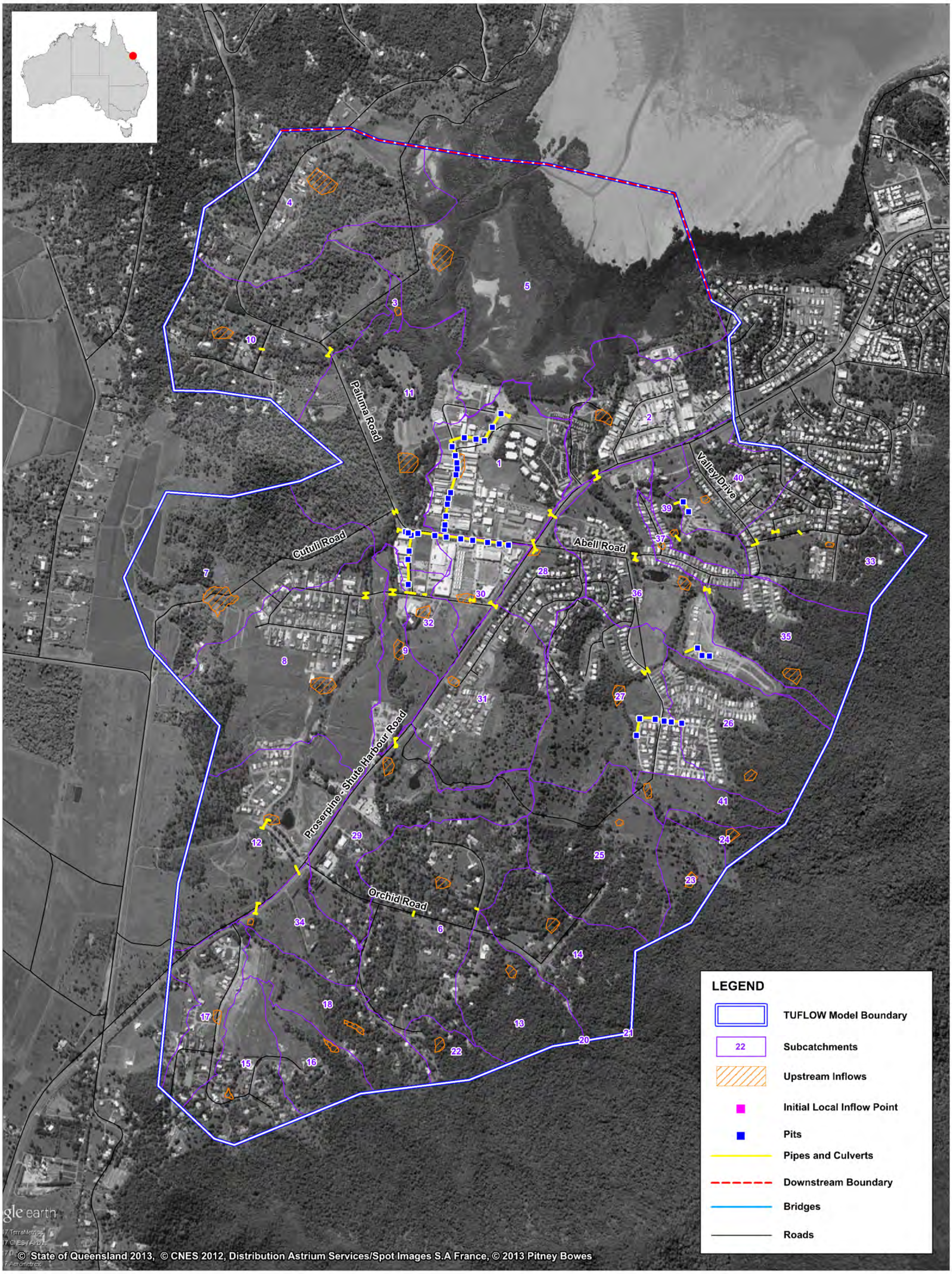
Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\Crofton\FLD_011_170912_2100_CC_FloodLevelImpact_Crofton.wor

# Appendix G Galibraith and Waite Creeks




Title:

**Galibraith and Waite Creeks Model Layout**

Figure: **G-1**

Rev: **A**



N

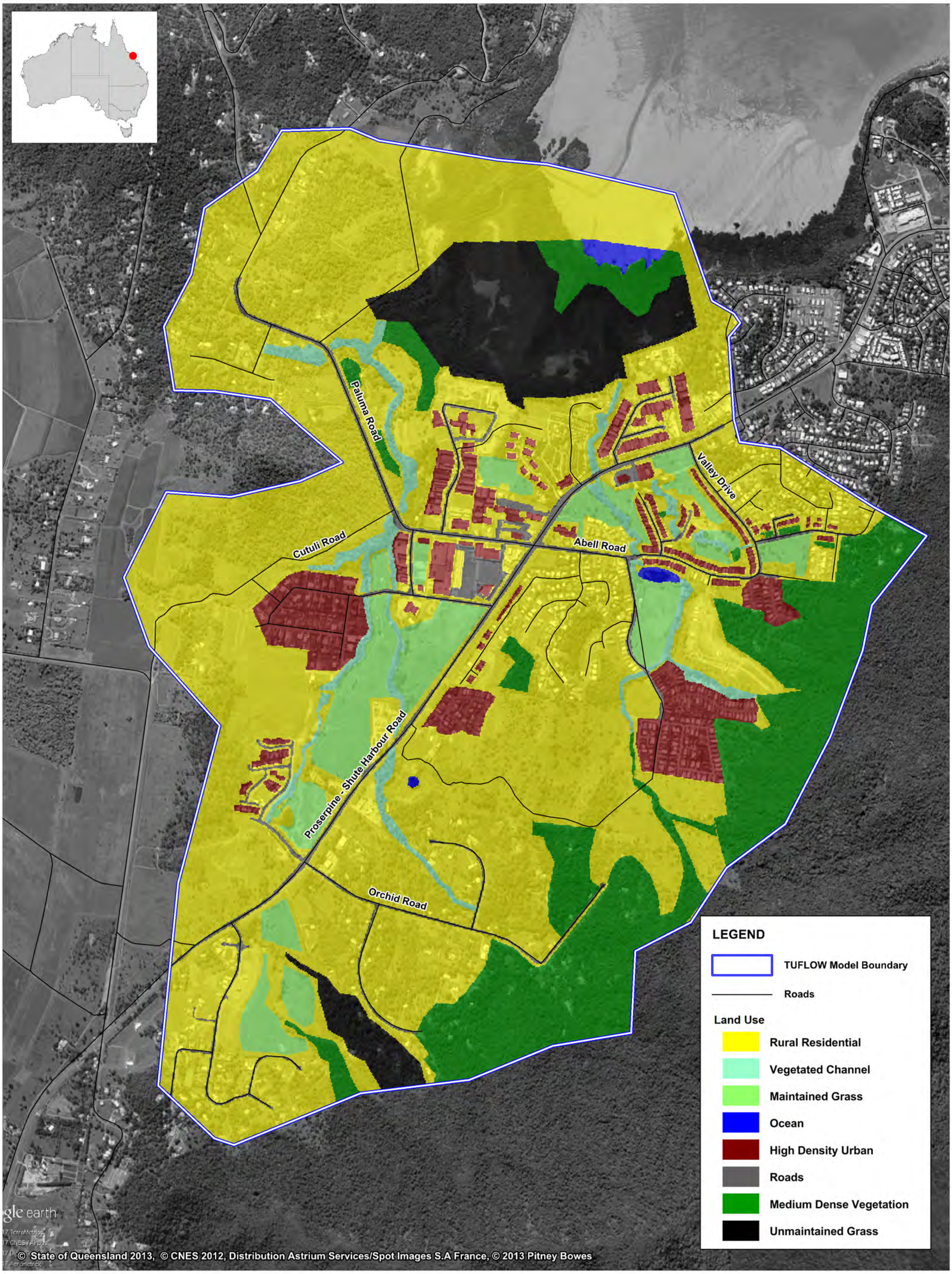
0 400 800m

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\Galbraith\FLD_001_170908_Model Inputs_Galbraith.wor






Title:

**Galbraith and Waite Creeks Land Use Map**

Figure: **G-2**

Rev: **A**



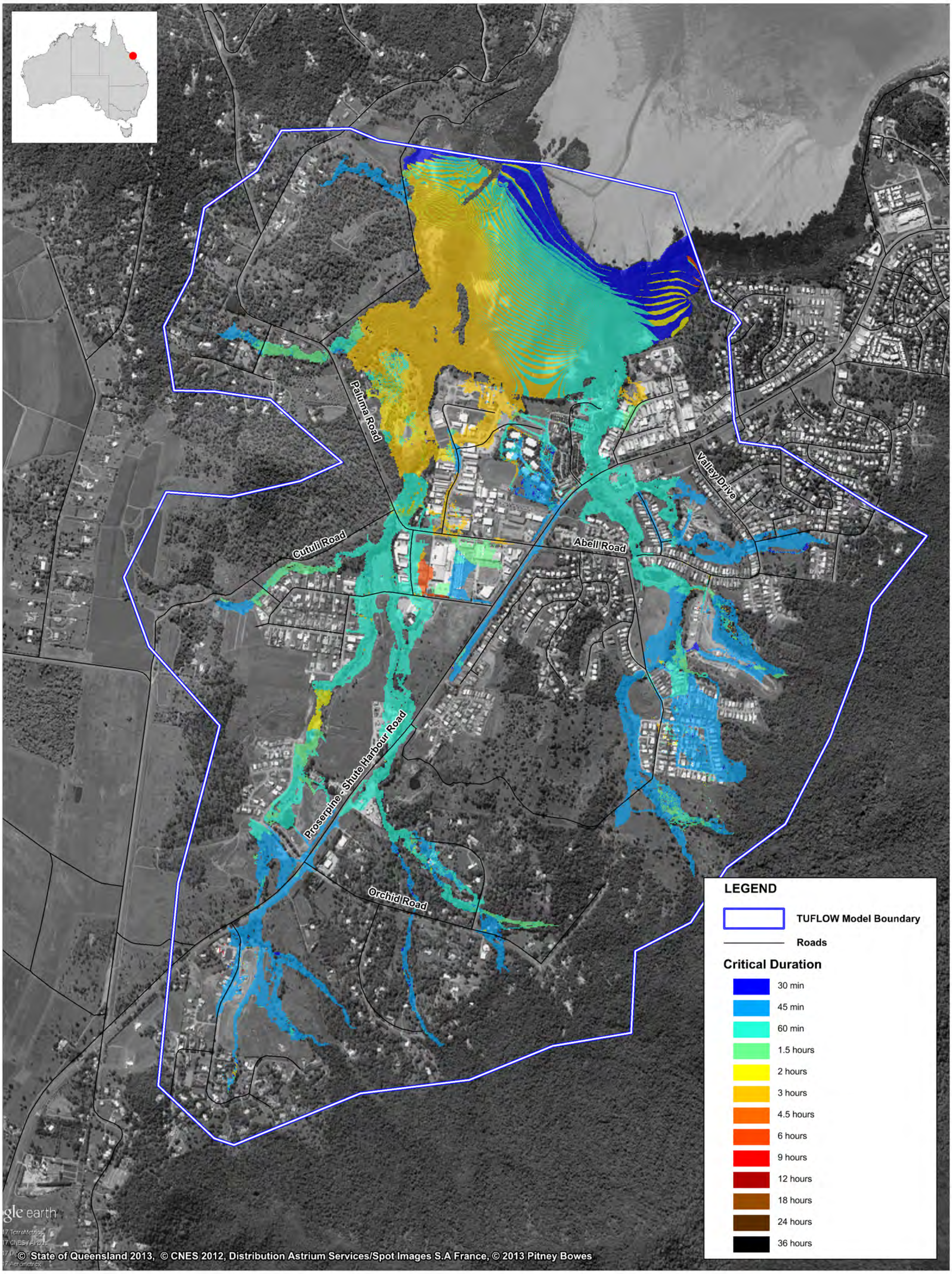
N

0 400 800m

Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\Galbraith\FLD_002_170911_Land Use_Galbraith.wor




Title:

**Galbraith and Waite Creeks Critical Duration Assessment**

Figure: **G-3**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

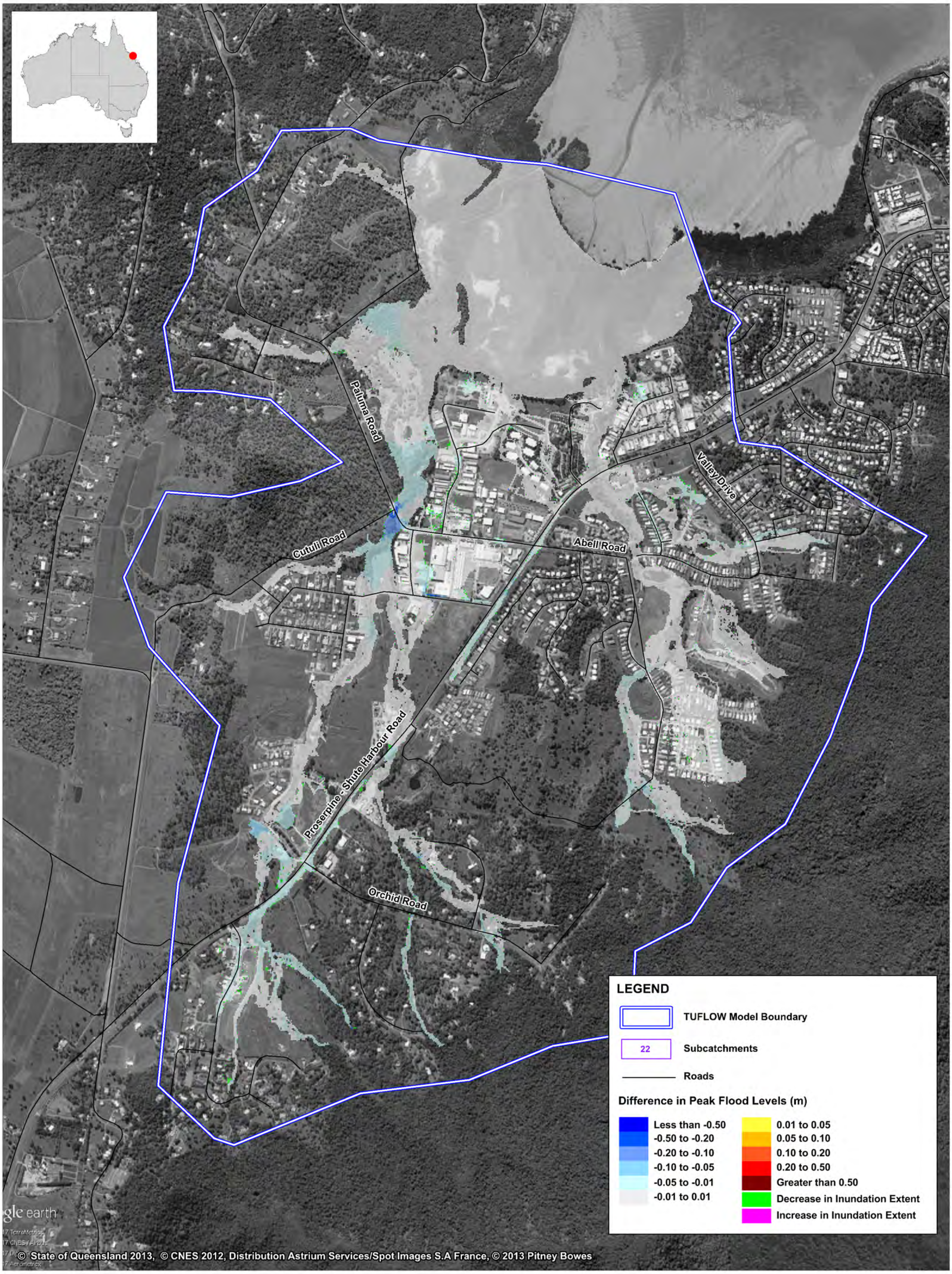
N

0 400 800m

Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\Galbraith\FLD_003_170911_CriticalDuration_Galbraith.wor




Title:

**Galbraith and Waite Creeks Difference in Peak Flood Levels**

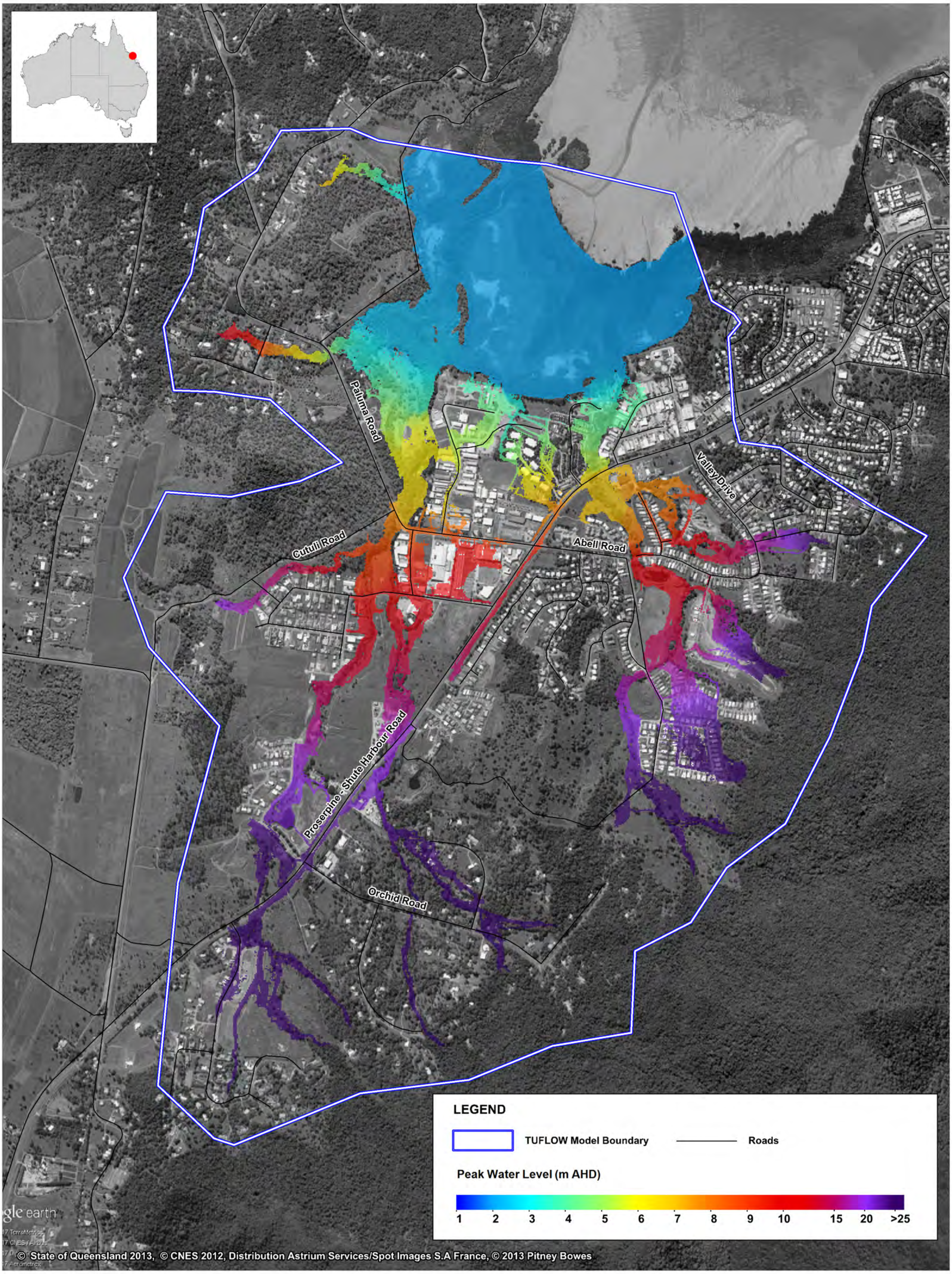
Figure: G-4

Rev: A



BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\Galbraith\FLD_004_170911_PeakFloodLevel_Diff_Galbraith.wor




Title:

**Galbraith and Waite Creeks Peak Flood Levels**

Figure: **G-5**

Rev: **A**



N

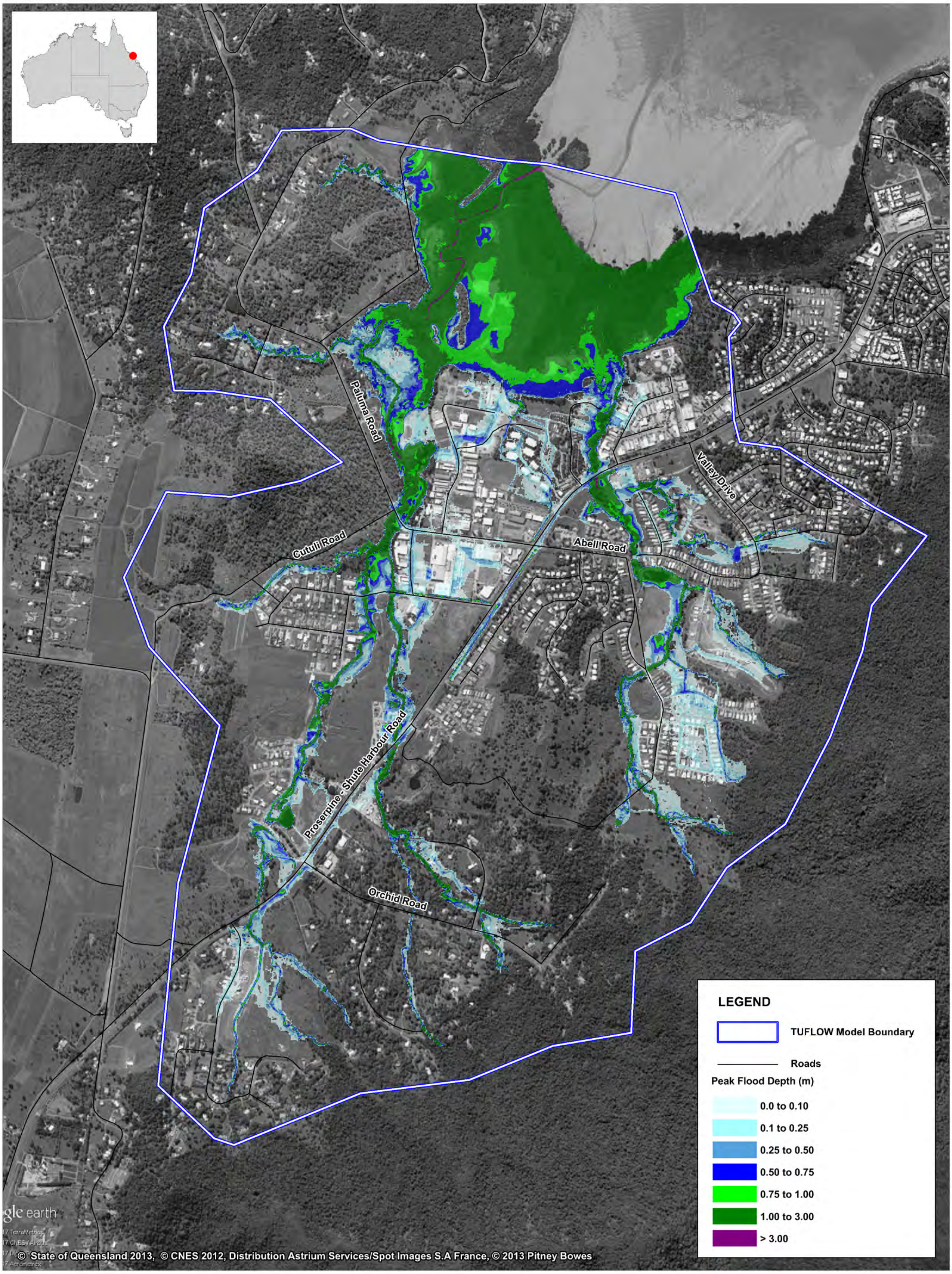
0 400 800m

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\Galbraith\FLD_005_170911_PeakFloodLevels_Galbraith.wor




Title:
**Galbraith and Waite Creeks Peak Flood Depths**

Figure: **G-6**

Rev: **A**



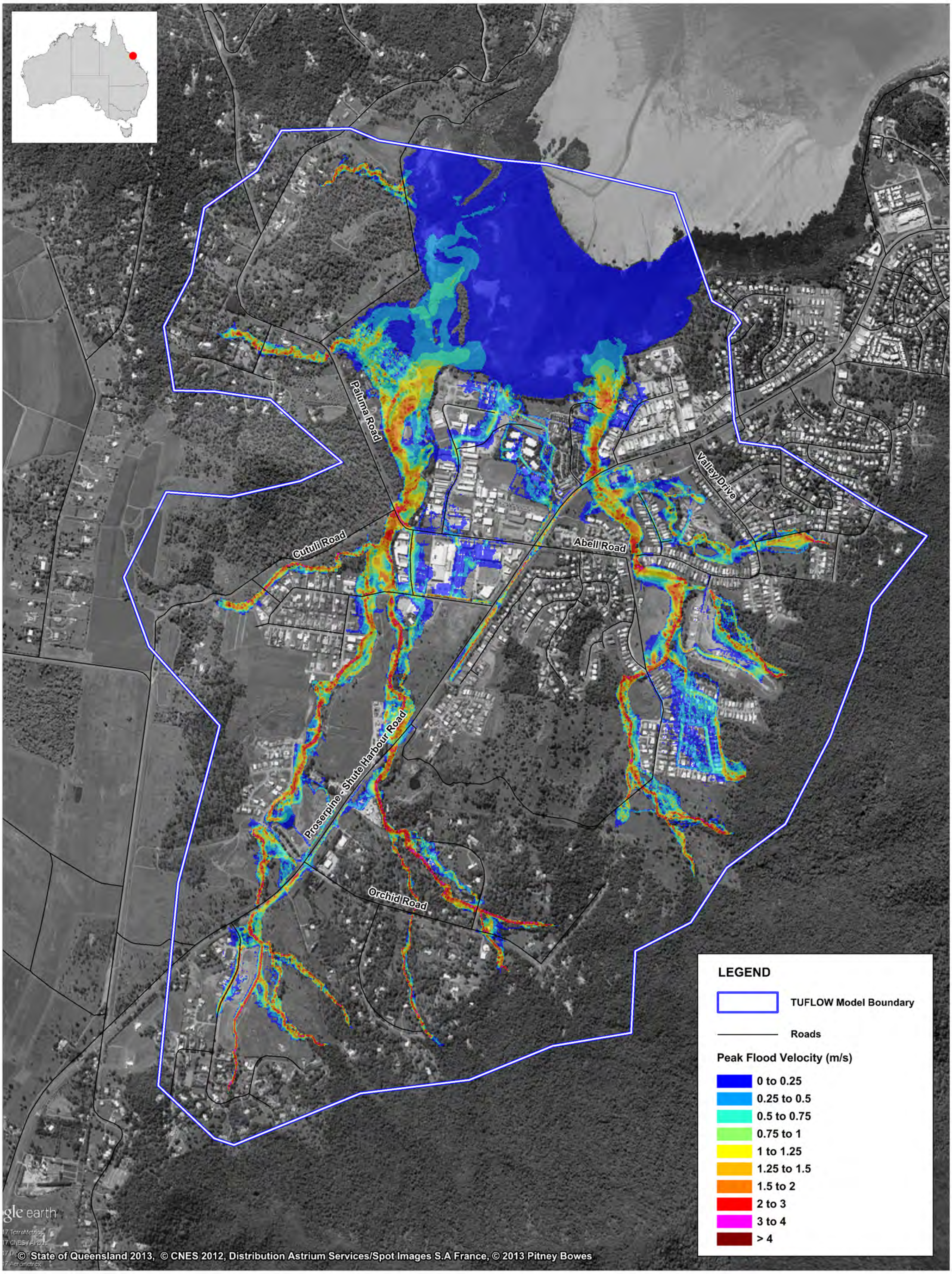
N

0 400 800m

Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\Galbraith\FLD_006_170911_PeakFloodDepth_Galbraith.wor




Title:
**Galbraith and Waite Creeks Peak Flood Velocities**

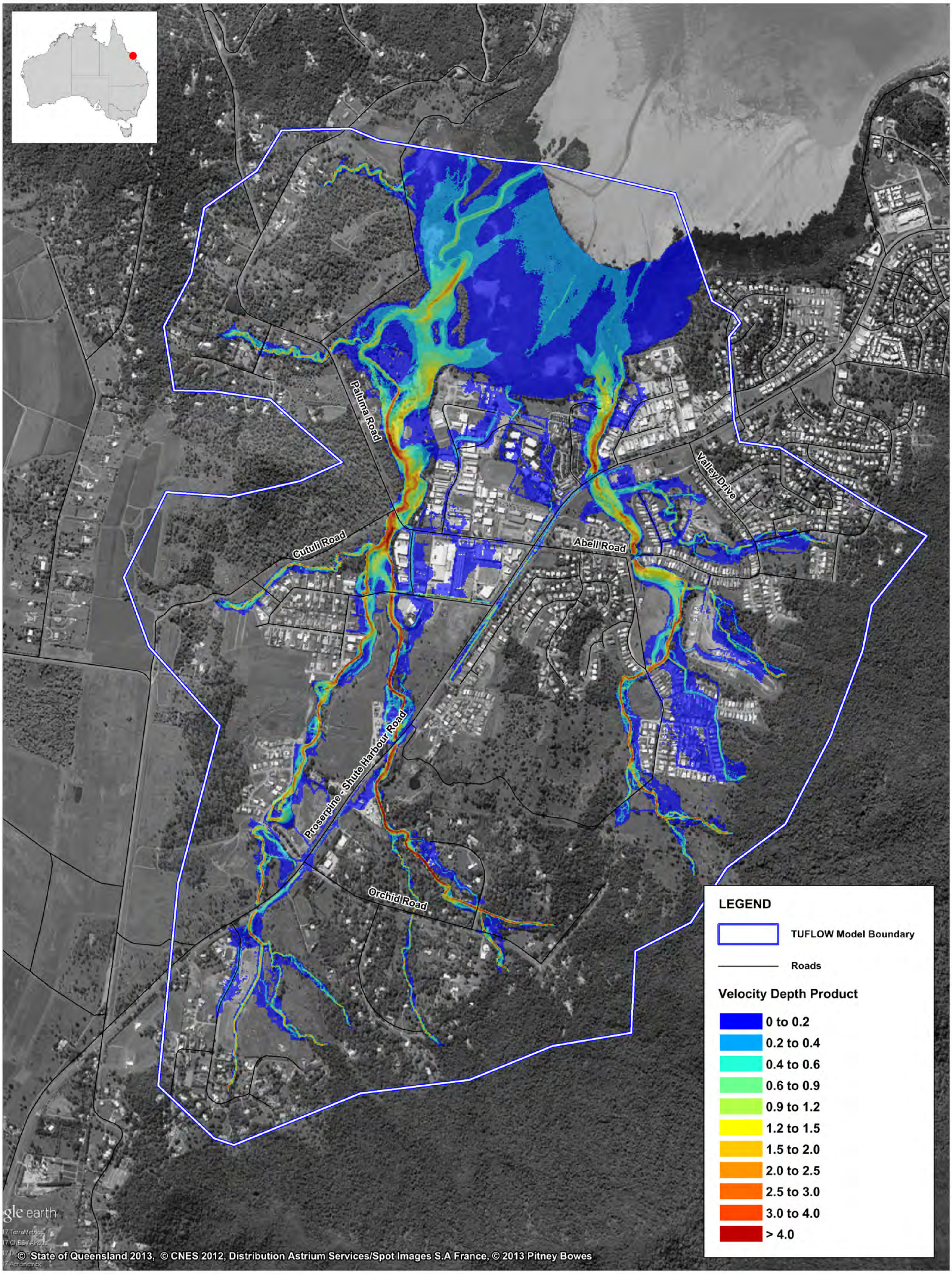
Figure: **G-7**

Rev: **A**



BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\Galbraith\FLD_007_170911_PeakFloodVelocities_Galbraith.wor




Title:
**Galbraith and Waite Creeks Depth Velocity Product**

Figure: **G-8**

Rev: **A**

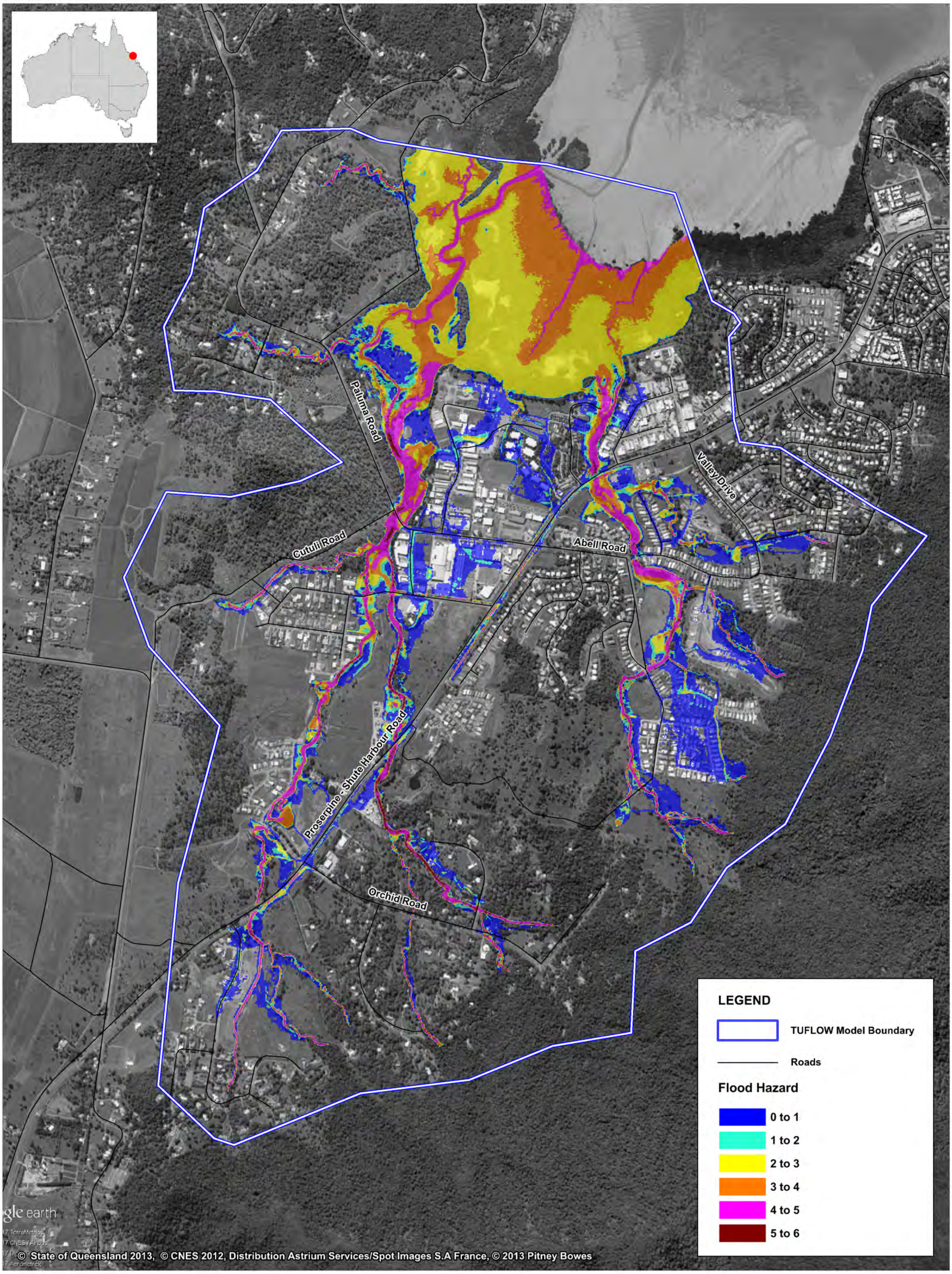


N

0 400 800m
Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\Galbraith\FLD_008_170911_DepthVelocityProduct_Galbraith.wor




Title:

**Galbraith and Waite Creeks Flood Hazard**

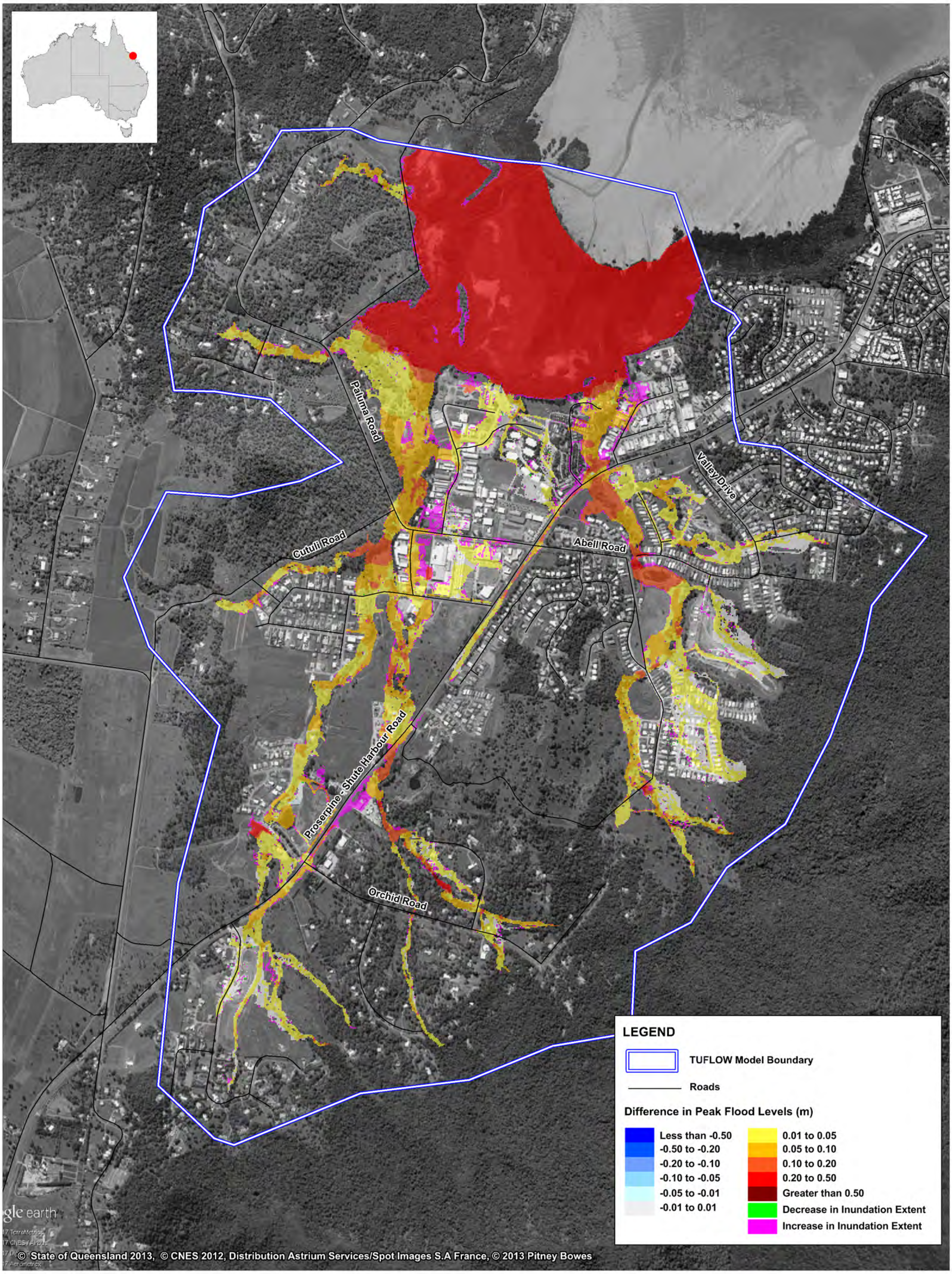
Figure: **G-9**

Rev: **A**



BMT WBM
www.bmtwbm.com.au

Filepath: I:\B22591_I_ak_TOWDS\DRG\Galbraith\FLD_009_170911_FloodHazard_Galbraith.wor




Title:
**Galbraith and Waite Creeks Climate Change 2050 - Peak Flood Level Impact**

Figure: **G-10**

Rev: **A**

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N

0 400 800m
Approx. Scale

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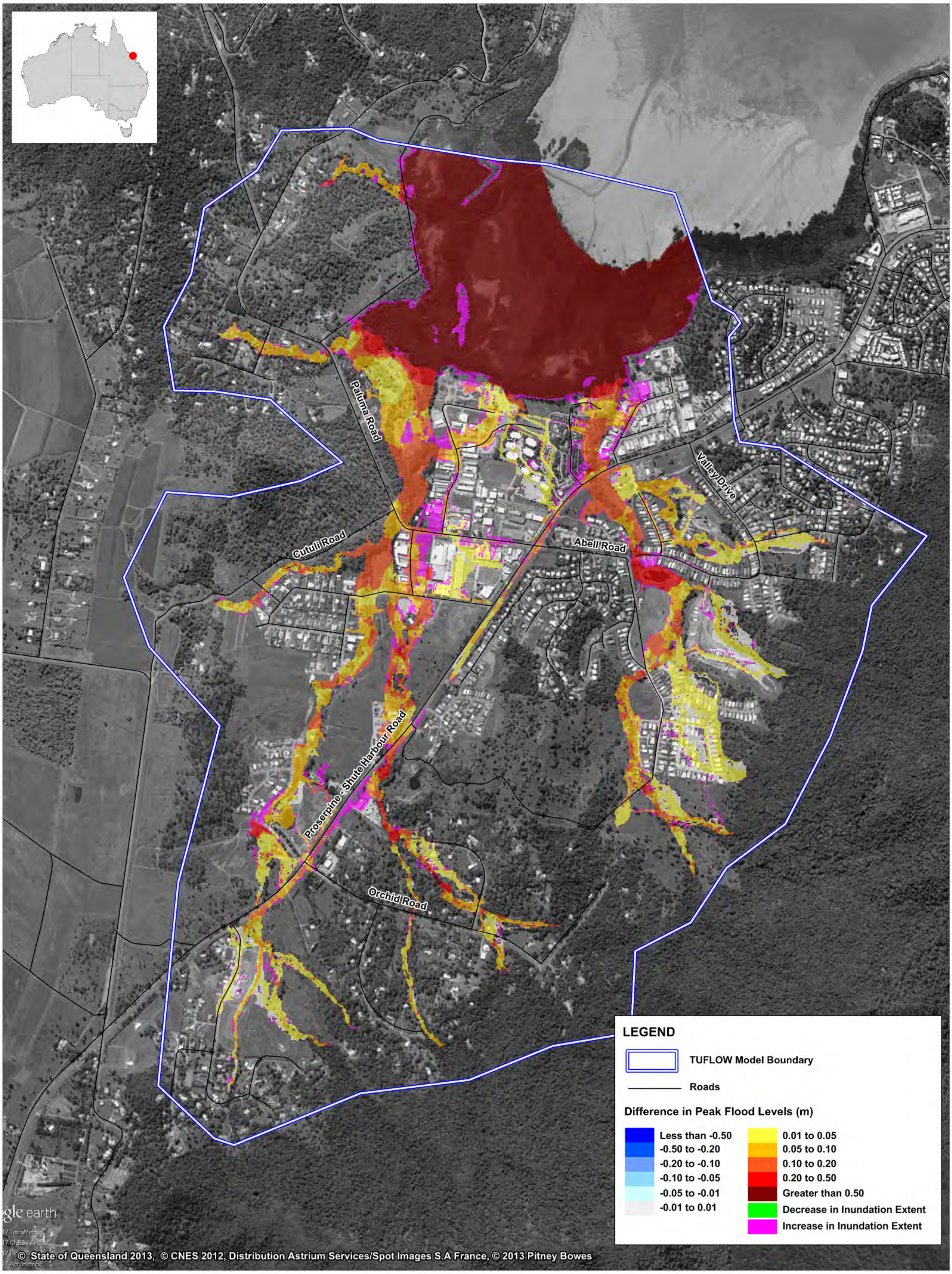
Filepath: I:\B22591_I_ak_TOWDS\DRG\Galbraith\FLD_010_170911_2050_CC_FloodLevelImpact_Galbraith.wor






Title:
**Galbraith and Waite Creeks Climate Change 2100 - Peak Flood Level Impact**

Figure: **G-11**

Rev: **A**



N

0 400 800m

Approx. Scale

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