# Kangaroo Valley FRMSP

## Flood Study Revision

W4960

Prepared for
Shoalhaven City Council

September 2013

Cardno
Shaping the Future

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# Executive Summary

Shoalhaven City Council have commissioned Cardno to undertake a Floodplain Risk Management study for the Kangaroo Valley Township and its surrounds.

The previous flood study was revised to incorporate updated hydraulic modelling of the study area in 2D. This report details the outputs of the revised flood study, namely:

- Flood behaviour in various AEP events;
- Provisional Hazard and Hydraulic Mapping; and,
- Sensitivity Assessment.

The results presented in this report will form the existing scenario for the subsequent Floodplain Risk Management Study and Plan for Kangaroo Valley.

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# Glossary

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|---|---|
| Annual Exceedence Probability (AEP) | Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded each year; it would occur quite often and would be relatively small. A 1%AEP flood has a low probability of occurrence or being exceeded each year; it would be fairly rare but it would be relatively large. |
| Australian Height Datum (AHD) | A common national surface level datum approximately corresponding to mean sea level. |
| Average Recurrence Interval (ARI) | The average or expected value of the periods between exceedances of a given rainfall total accumulated over a given duration. It is implicit in this definition that periods between exceedances are generally random |
| Cadastre, cadastral base | Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc. |
| Catchment | The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream. |
| Creek Rehabilitation | Rehabilitating the natural 'biophysical' (i.e. geomorphic and ecological) functions of the creek. |
| Design flood | A significant event to be considered in the design process; various works within the floodplain may have different design events. E.g. some roads may be designed to be overtopped in the 1 in 1 year or 100%AEP flood event. |
| Development | The erection of a building or the carrying out of work; or the use of land or of a building or work; or the subdivision of land. |
| Discharge | The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving. |
| Flash flooding | Flooding which is sudden and often unexpected because it is caused by sudden local heavy rainfall or rainfall in another area. Often defined as flooding which occurs within 6 hours of the rain which causes it. |
| Flood | Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences. |
| Flood fringe | The remaining area of flood-prone land after floodway and flood storage areas have been defined. |

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| Flood hazard | Potential risk to life and limb caused by flooding. |
| Flood-prone land | Land susceptible to inundation by the probable maximum flood (PMF) event, i.e. the maximum extent of flood liable land. Floodplain Risk Management Plans encompass all flood-prone land, rather than being restricted to land subject to designated flood events. |
| Floodplain | Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land. |
| Floodplain management measures | The full range of techniques available to floodplain managers. |
| Floodplain management options | The measures which might be feasible for the management of a particular area. |
| Flood planning area | The area of land below the flood planning level and thus subject to flood related development controls. |
| Flood planning levels | Flood levels selected for planning purposes, as determined in floodplain management studies and incorporated in floodplain management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also take into account the social, economic and ecological consequences associated with floods of different severities. Different FPLs may be appropriate for different categories of land use and for different flood plains. The concept of FPLs supersedes the "Standard flood event" of the first edition of the Manual. As FPLs do not necessarily extend to the limits of flood prone land (as defined by the probable maximum flood), floodplain management plans may apply to flood prone land beyond the defined FPLs. |
| Flood storages | Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. |
| Floodway areas | Those areas of the floodplain where a significant discharge of water occurs during floods. They are often, but not always, aligned with naturally defined channels. Floodways are areas which, even if only partially blocked, would cause a significant redistribution of flood flow, or significant increase in flood levels. Floodways are often, but not necessarily, areas of deeper flow or areas where higher velocities occur. As for flood storage areas, the extent and behaviour of floodways may change with flood severity. Areas that are benign for small floods may cater for much greater and more hazardous flows during larger floods. Hence, it is necessary to investigate a range of flood sizes before adopting a design flood event to define floodway areas. |
| Geographical Information Systems (GIS) | A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data. |
| High hazard | Flood conditions that pose a possible danger to personal safety; evacuation by trucks difficult; able-bodied adults would have difficulty wading to safety; potential for significant structural damage to buildings. |

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| Hydraulics | The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity. |
| Hydrograph | A graph that shows how the discharge changes with time at any particular location. |
| Hydrology | The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods. |
| Low hazard | Flood conditions such that should it be necessary, people and their possessions could be evacuated by trucks; able-bodied adults would have little difficulty wading to safety. |
| Mainstream flooding | Inundation of normally dry land occurring when water overflows the natural or artificial banks of the principal watercourses in a catchment. Mainstream flooding generally excludes watercourses constructed with pipes or artificial channels considered as stormwater channels. |
| Management plan | A document including, as appropriate, both written and diagrammatic information describing how a particular area of land is to be used and managed to achieve defined objectives. It may also include description and discussion of various issues, special features and values of the area, the specific management measures which are to apply and the means and timing by which the plan will be implemented. |
| Mathematical/computer models | The mathematical representation of the physical processes involved in runoff and stream flow. These models are often run on computers due to the complexity of the mathematical relationships. In this report, the models referred to are mainly involved with rainfall, runoff, pipe and overland stream flow. |
| Overland Flow | The term overland flow is used interchangeably in this report with “flooding”. |
| Peak discharge | The maximum discharge occurring during a flood event. |
| Probable maximum flood | The flood calculated to be the maximum that is likely to occur. |
| Probability | A statistical measure of the expected frequency or occurrence of flooding. For a fuller explanation see Annual Exceedance Probability. |
| Risk | Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. For this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment. |
| Runoff | The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess. |
| Stage | Equivalent to 'water level'. Both are measured with reference to a specified datum. |
| Stage hydrograph | A graph that shows how the water level changes with time. It must be referenced to a particular location and datum. |

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| Stormwater flooding | Inundation by local runoff. Stormwater flooding can be caused by local runoff exceeding the capacity of an urban stormwater drainage system or by the backwater effects of mainstream flooding causing the urban stormwater drainage system to overflow. |
| Topography | A surface which defines the ground level of a chosen area. |

* Terminology in this Glossary have been derived or adapted from the NSW Government Floodplain Development Manual, 2005, where available.

# Abbreviations

| | |
|---|---|
| AAD | Average Annual Damage |
| AEP | Annual Exceedance Probability |
| ARI | Average Recurrence Intervals |
| BoM | Bureau of Meteorology |
| DCP | Development Control Plan |
| FPL | Flood Planning Levels |
| FRMP | Floodplain Risk Management Plan |
| FRMS | Floodplain Risk Management Study |
| GIS | Geographic Information System |
| ha | Hectare |
| IFD | Intensity Frequency Duration |
| km | Kilometres |
| $km^2$ | Square kilometres |
| LEP | Local Environment Plan |
| LGA | Local Government Area |
| m | Metre |
| $m^2$ | Square metre |
| $m^3$ | Cubic Metre |
| mAHD | Metres to Australian Height Datum |
| mm | Millimetre |
| m/s | Metres per second |
| NSW | New South Wales |
| OEH | Office of Environment & Heritage |
| PMF | Probable Maximum Flood |
| PMP | Probable Maximum Precipitation |
| SES | State Emergency Service |

# 1 Introduction

This report details the outcomes of the flood study revision for the Kangaroo Valley region. The report defines the existing flooding behaviour of the study area for a range of flood events, and determines provisional hazard and hydraulic category regions.

The setup and calibration of the hydrological and hydraulic models for Kangaroo Valley were detailed in the *Kangaroo Valley Floodplain Risk Management Study and Plan: Model Calibration and Verification Report* (Cardno, 2013).

This report details the results of the modelling of the design events for Kangaroo Valley.

The findings of this report will form the base for the subsequent Floodplain Risk Management Study and Plan.

## 1.1 Study Context

The NSW Floodplain Management process progresses through 6 steps in an iterative process:

1. Formation of a Floodplain Management Committee
2. Data Collection
3. Overland Flow / Flood Study
4. Overland Flow / Floodplain Risk Management Study
5. Overland Flow / Floodplain Risk Management Plan
6. Implementation of the Overland Flow / Floodplain Risk Management Plan

This document revises work undertaken as part of Stage 3 of the process.

# 2 Catchment Description

The Kangaroo River is a tributary of the Shoalhaven River, on the south coast of New South Wales. The river originates from within the Budderoo National Park, from where it flows across the western escarpment, through the township of Kangaroo Valley, and discharges into Lake Yarrunga. Lake Yarrunga is formed by Tallowa Dam, constructed immediately downstream of the confluence of the Kangaroo River and the Shoalhaven River.

The land use of the catchment is predominately forest and pasture, with isolated areas of urban development. The terrain is varied; steep ranges surround the catchment on the northern, eastern and southern sides, formed by the eastern escarpment. In the centre of these ranges are open alluvial flats.

The study area of the Kangaroo Valley Floodplain Risk Management Study and Plan is located mid-way along the Kangaroo River on the central flats, comprising the area of the Kangaroo Valley Township, within the Shoalhaven City Council LGA.

The Kangaroo River catchment area and the study area are shown in **Figure 2-1**.

The township of Kangaroo Valley is located on the southern side of Kangaroo River. The main road, Moss Vale Road, crosses the Kangaroo River at Hampden Bridge, west of the township.

The key features of the study area are shown in **Figure 2-2**.

The township is located on the southern side of the Kangaroo River, with most development located on the high ground at the foot of the adjacent ranges. Commercial areas are predominately along Moss Vale Road, with residential properties located on the hills to the south. A number of dairy farms are located across the central alluvial plain.

The township has experienced historical flooding, with significant events occurring in 2005, 1999, 1991, 1990, 1978 and 1975. Roads have been reported cut during flood events, in some instances by depths of over 2m.

# 3 Existing Case Flood Modelling Results

## 3.1 Extents and Flood Depths

Flood modelling of design storms was undertaken for the 20%, 10%, 2%, 1% and 0.5% AEP events and the PMF event.

Flood extents for the design storms are shown in **Figure 3.1** to **Figure 3.6**.

The peak flood depths for the design storms are shown in **Figure 3.7** to **Figure 3.12**.

## 3.2 Provisional Flood Hazard & Hydraulic Categories

### 3.2.1 Provisional Flood hazard

Provisional flood hazard is determined through a relationship developed between the depth and velocity of floodwaters and is based strictly on hydraulic considerations (Appendix L; NSW Government, 2005). The Floodplain Development Manual (NSW Government, 2005) defines two categories for provisional hazard – high and low.

The model results were processed using an in-house developed program, which utilises the model results of flood level and velocity to determine hazard. Provisional hazard was prepared for 6 design events, namely PMF, 0.5%, 1%, 2%, 10%, and 20% AEP.

Hazard is calculated for each grid cell at each time step based on velocity, depth and velocity x depth, with the highest value giving the hazard rating for the cell.

The provisional hazard is shown in **Figure 3.13** to **Figure 3.18**.

### 3.2.2 True Flood Hazard

Provisional flood hazard categorisation based around the hydraulic parameters described above in **Section 3.2.1**, does not consider a range of other factors that influence the "true" flood hazard. In addition to water depth and velocity, other factors contributing to the true flood hazard include the:

- Size of the flood
- Effective warning time
- Flood readiness
- Rate of rise of floodwaters
- Duration of flooding
- Ease of evacuation
- Effective flood access
- Type of development in the floodplain

True flood hazard will be assessed as part of the Floodplain Risk Management Study and Plan.

## 3.3 Hydraulic Categories

Hydraulic categorisation of the floodplain is used in the development of the Floodplain Risk Management Plan. The Floodplain Development Manual (2005) defines flood prone land to be one of the following three hydraulic categories:

- Floodway - Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- Flood Storage - Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood Storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10%.
- Flood Fringe - Remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant effect on the flood pattern or flood levels.

Floodways were determined for the 1% AEP event by considering those model branches that conveyed a significant portion of the total flow. These branches, if blocked or removed, would cause a significant redistribution of the flow. The criteria used to define the floodways are described below (based on Howells et al, 2003).

As a minimum, the floodway was assumed to follow the creekline from bank to bank. In addition, the following depth and velocity criteria were used to define a floodway:

- Velocity x Depth product must be greater than 0.25 $m^2/s$ and velocity must be greater than 0.25 m/s; OR
- Velocity is greater than 1 m/s.

Flood storage was defined as those areas outside the floodway, which if completely filled would cause peak flood levels to increase by 0.1 m and/or would cause peak discharge anywhere to increase by more than 10%. The criteria were applied to the model results as described below.

Previous analysis of flood storage in 1D cross sections assumed that if the cross-sectional area is reduced such that 10% of the conveyance is lost, the criteria for flood storage would be satisfied To determine the limits of 10% conveyance in a cross-section, the depth was determined at which 10% of the flow was conveyed. This depth, averaged over several cross-sections, was found to be 0.2 m (Howells et al, 2003). Thus the criteria used to determine the flood storage is:

- Depth greater than 0.2m
- Not classified as floodway.

All areas that were not categorised as Floodway or Flood Storage, but still fell within the flood extent, where the depth is greater than 0.1 m, are represented as Flood Fringe.

The hydraulic categories for the design events are shown in **Figure 3.19** to **Figure 3.24**.

Combined hazard and hydraulic categories for the design events are shown in **Figure 3.25** to **Figure 3.30**.

# 4 Sensitivity Analysis

A sensitivity analysis was undertaken on the SOBEK model for the 1% AEP. The analysis was undertaken by:

- Varying the downstream boundary by +/- 20%
- Varying 1D and 2D roughness values by +/- 20%
- Varying the rainfall intensity by +/- 20%

The peak water level differences for the downstream boundary assessment are shown in **Figure 4-1** and **Figure 4-2**.

The peak water level differences for the roughness assessment are shown in **Figure 4-3** and **Figure 4-4**.

The peak water level differences for the rainfall intensity assessment are shown in **Figure 4-5** and **Figure 4-6**.

A summary of the differences observed in the sensitivity assessments are provided in **Table 4-1**.

**Table 4-1 Summary of Sensitivity Assessment – change in peak flood level (m)**

| Location | DS Boundary +20% | DS Boundary -20% | Roughness +20% | Roughness -20% | Rainfall + 20% | Rainfall -20% |
|---|---|---|---|---|---|---|
| Hampden Bridge | -0.86 | 1.22 | 0.38 | -0.38 | 1.33 | -1.51 |
| Caravan Park | -0.30 | 0.56 | 0.44 | -0.47 | 1.26 | -1.31 |
| Barrengarry Ck confluence | -0.35 | 0.62 | 0.44 | -0.46 | 1.32 | -1.46 |
| Upper Kangaroo River Rd bridge | -0.30 | 0.57 | 0.43 | -0.45 | 1.27 | -1.22 |
| Nugents Ck confluence | -0.27 | 0.52 | 0.44 | -0.48 | 1.21 | -1.18 |

The results show a similar amount of change across the catchment. This is likely due to the fact that the flooding of the valley is storage driven, and that at the peak of the flood event, the study area is behaving like a large basin, with similar flood levels occurring throughout. Smaller changes were observed in the tributaries, than in the main reach.

The smallest differences were observed for changes in roughness values, which resulted in average peak water level differences of approximately +0.43 and -0.46m for increases and decreases in roughness respectively.

The model was more sensitive to changes in the downstream boundary, particularly to reductions in the boundary. Average differences in peak levels of -0.3m and +0.6m where observed for increases and decreases to the boundary discharge throughout the study area. The observed differences were more pronounced in the vicinity of the boundary, with differences of -0.9m and +1.2m at Hampden Bridge.

The greatest model sensitivity was observed for changes in rainfall intensity, with average peak water level differences of +1.28m and -1.34m for increases and decrease in rainfall intensity respectively.

Due to the nature of the terrain within the study area there was minimal horizontal expansion of the flood extents even for the larger variations. The largest variation, the 1.28m increase as a result of the 20% rainfall increase, resulted in a horizontal extent change of typically less than 10m across the study area, and less than 5m adjacent to the Township.

# 5 Blockage Sensitivity

The blockage rates adopted for the design events was based on the blockage guidelines provided in the AR&R Project 11 Stage 2 Report (Engineers Australia, 2013).

Due to the inherent uncertainty of the blockage assessment approach, a sensitivity analysis has been conducted to assess the impact of increased blockage rates. The blockage adopted for the sensitivity assessment aligns with the 'severe blockage' as outlined in the AR&R report, and accounts for a blockage that is 'improbable but possible'.

This blockage rate results in all of the culverts in the study area being fully blocked.

The bridges within the study area however, even under the severe blockage scenario, still have a 0% blockage due to their large opening widths (60m in the case of Hampden Bridge) and the fact that they are full span bridges, with no central piers that may collect debris.

In addition to the severe blockage rates suggested in the AR&R report (Engineers Australia, 2013), a blockage rate of 10% has been applied to all bridges in the catchment area, in order to assess the models sensitivity to the blockage of these structures. A summary of the blockage rates adopted are provided below in **Table 5-1**.

The results of the blockage assessment are shown in **Figure 5.1**.

**Table 5-1 Blockage Factors**

| Structure Opening Width | Design Event Blockage Rates | Severe Blockage Rates | Adopted Sensitivity Blockage Rates |
|---|---|---|---|
| Less than 3m | 50% | 100% | 100% |
| 3m to 9m | 10% | 50% | 50% |
| Greater than 9m | 0% | 0% | 10% |

The results show that culvert blockages have a minimal impact on flood behaviour. The blockage of culverts crossing Mount Scanzi Road resulted in increases immediately upstream of 1.4m for the two western culverts, extending 100m upstream from the culvert. These impacts did not affect properties. The blockage of the eastern culvert resulted in increases of 0.15m extending 60m upstream of the culvert, which may result in additional property flooding. This will be further assessed following the collection of the floor level survey data.

The blockage of the culvert crossing Moss Vale Rd to the east of the caravan park resulted in localised increase of 0.05m extended 20m upstream of the culvert. The increase impacted flooding of residential lots, but not of buildings.

The 10% blockage applied to bridges resulted in a flood level increase of 0.22m within the Kangaroo River adjacent to the Township. This reduces to an increase of 0.19m at the Nugents Creek confluence. Immediately upstream of Hampden Bridge, the increase was 0.42m.

Increases extended up the Kangaroo River 4.1km

# 6 Discussion on Existing Flooding

## 6.1 Kangaroo River

The Kangaroo River is the major flowpath in the study area. It runs east to west through the study area, and has one crossing within the study area; Hampden Bridge, located downstream of the Kangaroo Valley township.

It is a high hazard flow path, due to both depths and velocities, which reach 16m and 4.5m/s in the 1% AEP event.

In events as small as the 20% AEP event, the Kangaroo River breaks its northern banks and inundates the floodplain in the centre of the study area. The southern bank rises higher than the northern bank and prevents overtopping in events smaller than the 10% AEP. In events greater than the 10% AEP event, the river breaks its southern banks, which impacts properties between the river and Moss Vale Rd.

## 6.2 Barrengarry Creek

Barrengarry Creek enters the study area in the north, and joins with the Kangaroo River immediately downstream of the Kangaroo Valley Township

It is a high hazard flow path, due to both depths and velocities, which reach 16m and 2.5m/s in the 1% AEP event.

In events above the 20% AEP event, it breaks over the eastern bank, and contributes to flooding within the central floodplain. In larger events, flooding along the reach within the study area is largely governed by flooding in the Kangaroo River; the central floodplain is fully inundated, and the levels along Barrengarry Creek are controlled by the large volume of flood water passing down the Kangaroo River.

## 6.3 Nugents Creek and Jarretts Creek

Nugents and Jarretts Creeks are two tributaries of the Kangaroo River that join it upstream of the Township.

The upper reaches of the creeks are typically well contained within the creek banks for events up to the 2% AEP. Flooding within the downstream extents of the creek however are controlled by the Kangaroo River, and backwater flows break creek banks in events as small as the 10% AEP event.

Creek flow is classified as high hazard as a result of velocities of up to 2.5m/s. The overbank flooding is typically low hazard, with depths of up to 0.4m in the 1% AEP event.

## 6.4 Town Creek and Myrilla Creek

Town and Myrilla Creeks are two tributaries of the Kangaroo River that join it within the Township. Similar to the Nugents and Jarretts Creeks, upstream reaches are typically contained within the creek banks, whilst downstream reaches are controlled by flood levels in the Kangaroo River.

Creek velocities and depths reached 1.8m and 0.6m/s respectively, resulting in regions of high hazard within the creek. The overbank flooding is low hazard, with depths of 0.3m.

## 6.5 Flow Timings

Each of the flowpaths responds at a different rate to storm events. Shown below in **Table 6-1** are the times to peak flow in each flowpath from the start of the storm event for the 10% and 1% AEP events.

The table shows that the smaller creeks peak first, approximately 7 hours after the storm starts. The larger Barrengarry Creek peaks next, approximately 1 hour later. The Kangaroo River does not reach its peak until 11 hours after the storm commences.

It should be noted that the flow timings for the creeks only translate to peak flood level timings for the upper reaches of the creeks. Downstream, peak flood levels are governed by Kangaroo River flooding, and peak flood levels occur during the peak of the Kangaroo River flow. Within Barrengarry Creek for instance, the peak inflow occurs at 8 hours, but creek levels continue to rise after this time, as the flood levels are controlled by the downstream level in the Kangaroo River.

It should also be noted that the reported timings are for the critical 9 hour event. A more detailed assessment of timings for a range of durations will be undertaken as part of the Floodplain Risk Management Study and Plan.

**Table 6-1 Time to Peak Flow in the 100yr ARI (hours from start of storm event)**

| Flowpath | 10% AEP | 1% AEP |
|---|---|---|
| Kangaroo River - Hampden Bridge | 11 | 11 |
| Barrengarry Creek | 8 | 8 |
| Nugents Creek | 7 | 7 |
| Jarretts Creek | 7 | 7 |
| Town Creek | 7 | 7 |
| Myrilla Creek | 7 | 7 |

## 6.6 Road Overtopping

There is one primary road, Mona Vale Road, which runs through the Kangaroo Valley Township. In events above the 10% AEP event, it is cut in multiple locations by overtopping depths greater than 0.2m. Summarised in **Table 6-2** are the overtopping characteristics in the 2% and 1% AEP events at a number of locations along Mona Vale Road.

The table shows that overtopping occurs via two distinct mechanisms. The first, which applies at Nugents and Jarretts Creeks, is that upstream creek flow overtops the road due to insufficient culvert capacity. This overtopping is characterised by relatively shallow flow depths, and short overtopping durations, resulting from the quick flooding response of the upstream catchment.

Overtopping at the tennis courts and Myrilla Creek however are governed by backwater from the Kangaroo River. This overtopping is characterised by significantly greater overtopping depths and much longer durations.

The timings of the overtopping mechanisms also vary. Creek driven overtopping occurs 1 to 2 hours before the river driven overtopping occurs.

**Table 6-2 Road Overtopping Behaviour**

| Location | 2% AEP Overtopping Depth (m) | 2% AEP Overtopping Duration (hours) * | 1% AEP Overtopping Depth (m) | 1% AEP Overtopping Duration (hours) * |
|---|---|---|---|---|
| Moss Vale Rd at Nugents Creek crossing | 0.26 | 1.5 | 0.36 | 2.0 |
| Moss Vale Rd at Jarretts Creek crossing | 0.07 | - | 0.08 | - |
| Moss Vale Rd at tennis courts | 2.97 | > 5.0 | 3.89 | > 5 |
| Moss Vale Rd at Myrilla Creek crossing | 1.20 | 4.5 | 2.17 | > 5 |

* Duration times reported for when depth is greater than 0.2m

# 7 Conclusion & Next Steps

Flood modelling has been undertaken for the Kangaroo Valley Township in order to describe the existing flood behaviour, as part of the NSW Floodplain Management Process.

The calibrated hydrologic and hydraulic models were used to asses a range of design events, namely:

- 20% Annual Exceedence Probability (AEP);
- 10% AEP;
- 2% AEP;
- 1% AEP;
- 0.5% AEP and,
- The Probable Maximum Flood (PMF)

Peak water levels, depth and velocities, as well as provisional flood hazards and hydraulic categories were determined for each AEP event.

The outcomes of this investigation will form the basis for the subsequent Floodplain Risk Management Study and Plan for the Kangaroo Valley study area.

# 8 Qualifications

This report has been prepared by Cardno for Shoalhaven City Council and as such should not be used by a third party without proper reference.

The investigation and modelling procedures adopted for this study follow industry standards and considerable care has been applied to the preparation of the results. However, model set-up and calibration depends on the quality of data available. The flow regime and the flow control structures are complicated and can only be represented by schematised model layouts.

Hence there will be a level of uncertainty in the results and this should be borne in mind in their application.

The report relies on the accuracy of the survey data and pit and pipe date provided.

Study results should not be used for purposes other than those for which they were prepared.

Flood Study Revision

# FIGURES

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Shaping the Future

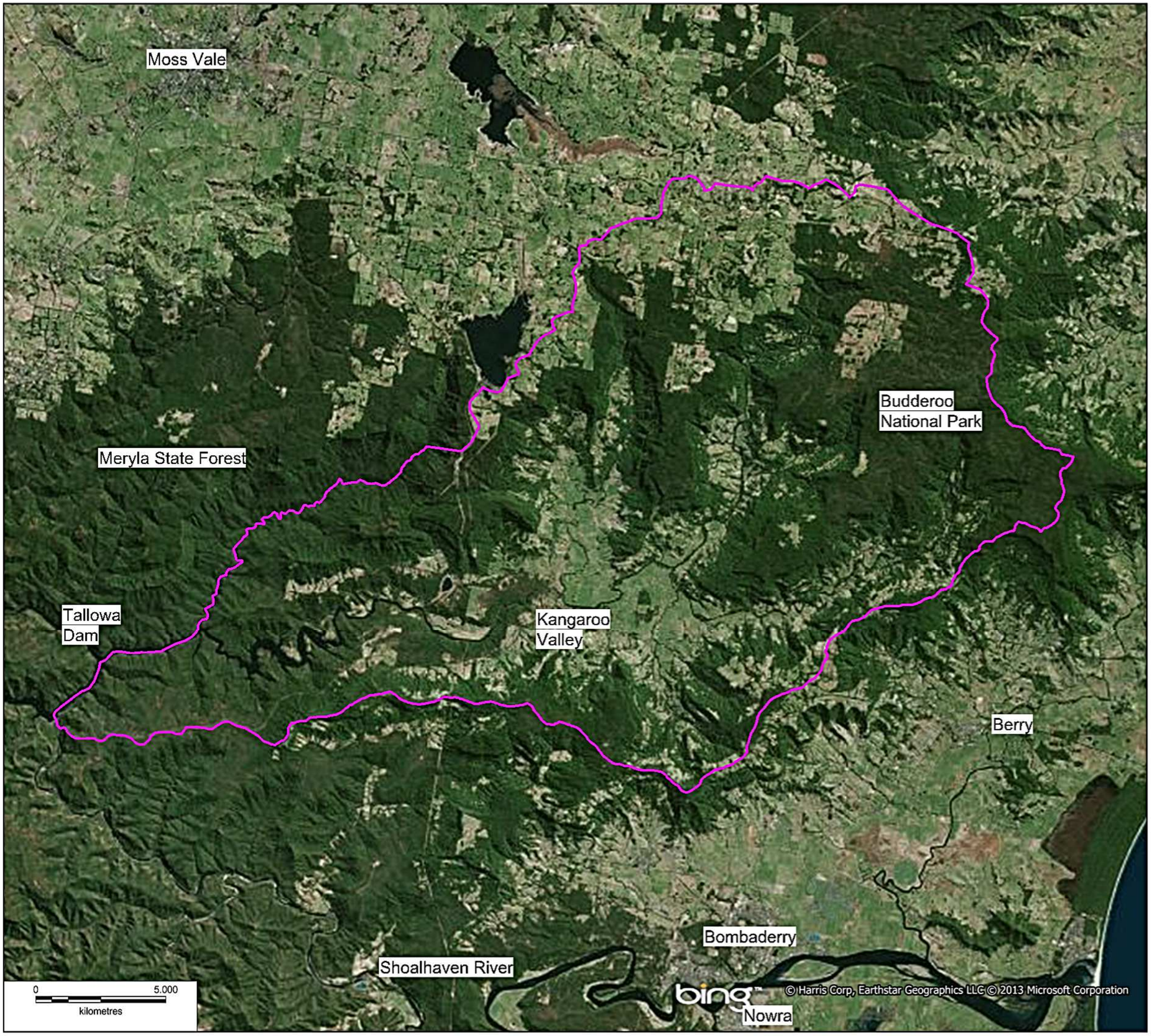


**Figure 2-1**

**Catchment Area**

Kangaroo Valley FRMSP
Flood Study Revision

Catchment Area

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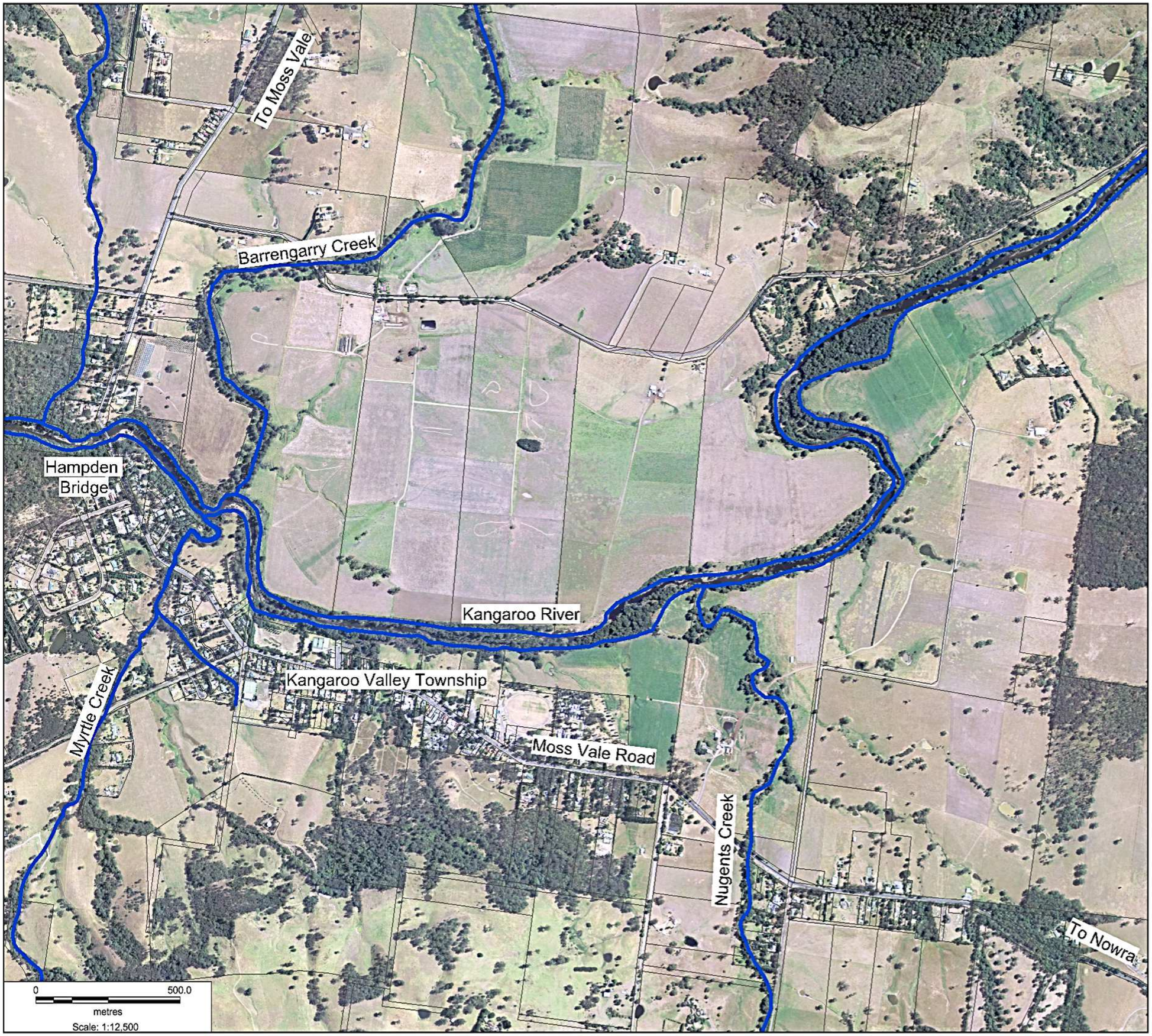


**Figure 2-2**

**Study Area Features**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre
Waterways

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**Figure 3-1**

**20% AEP Flood Extent**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Flood Extent

N
W
E
S

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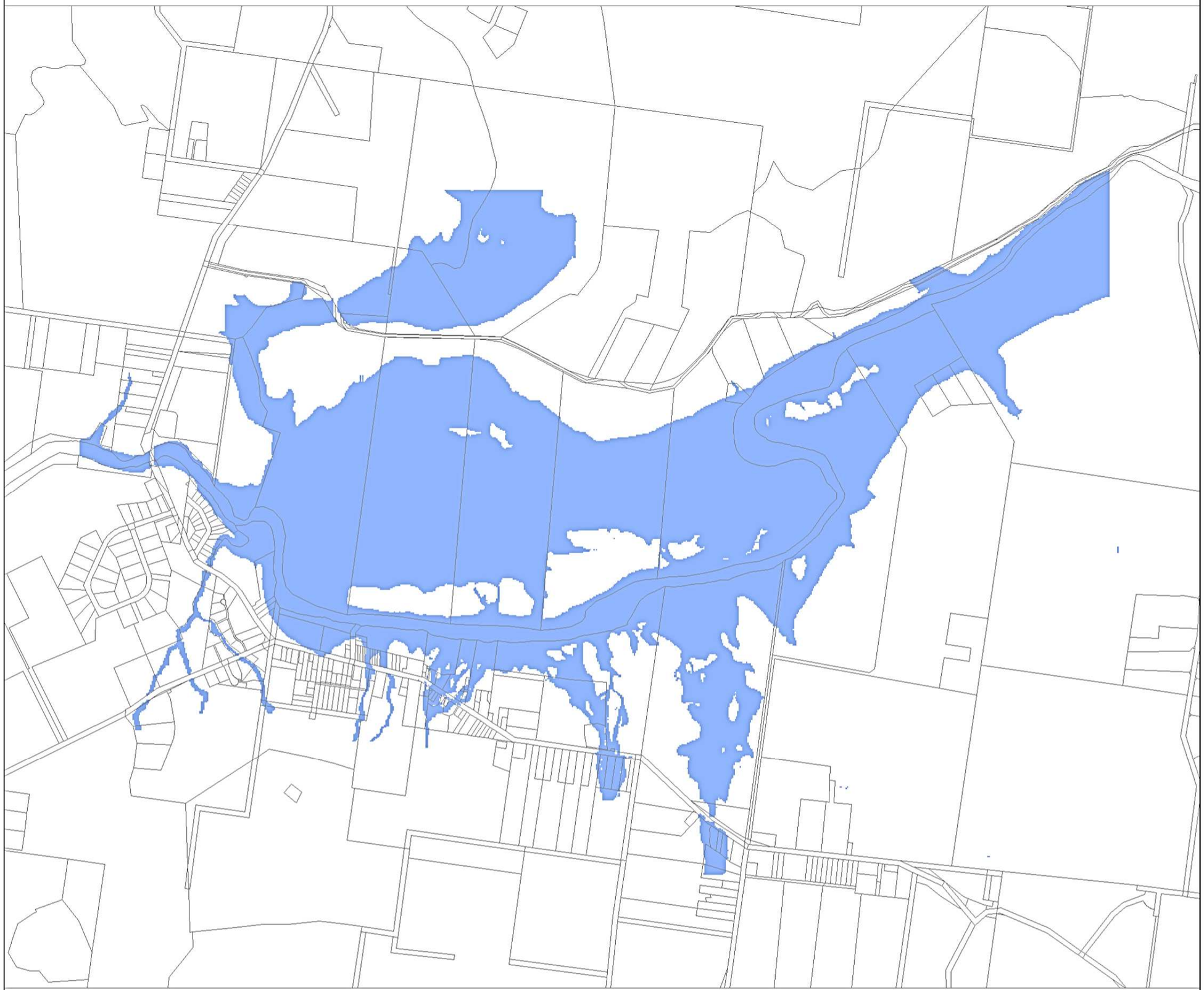


**Figure 3-2**

**10% AEP Flood Extent**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Flood Extent

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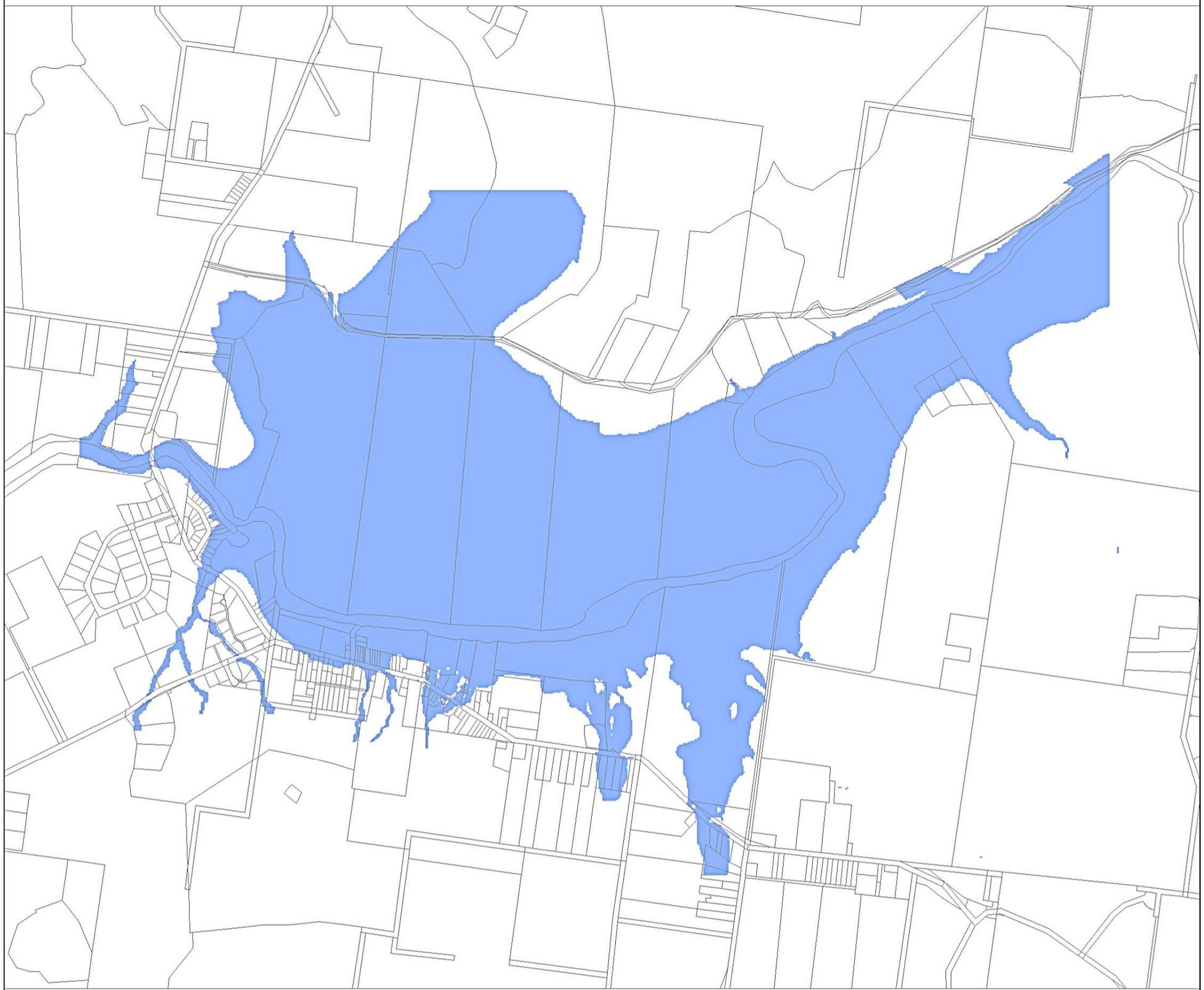


**Figure 3-3**

**2% AEP Flood Extent**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Flood Extent

N
W
E
S

Cardno

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# Figure 3-4

## 1% AEP Flood Extent

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Flood Extent

0 1,000

metres

Scale: 1:15,000

N

W E

S

Cardno

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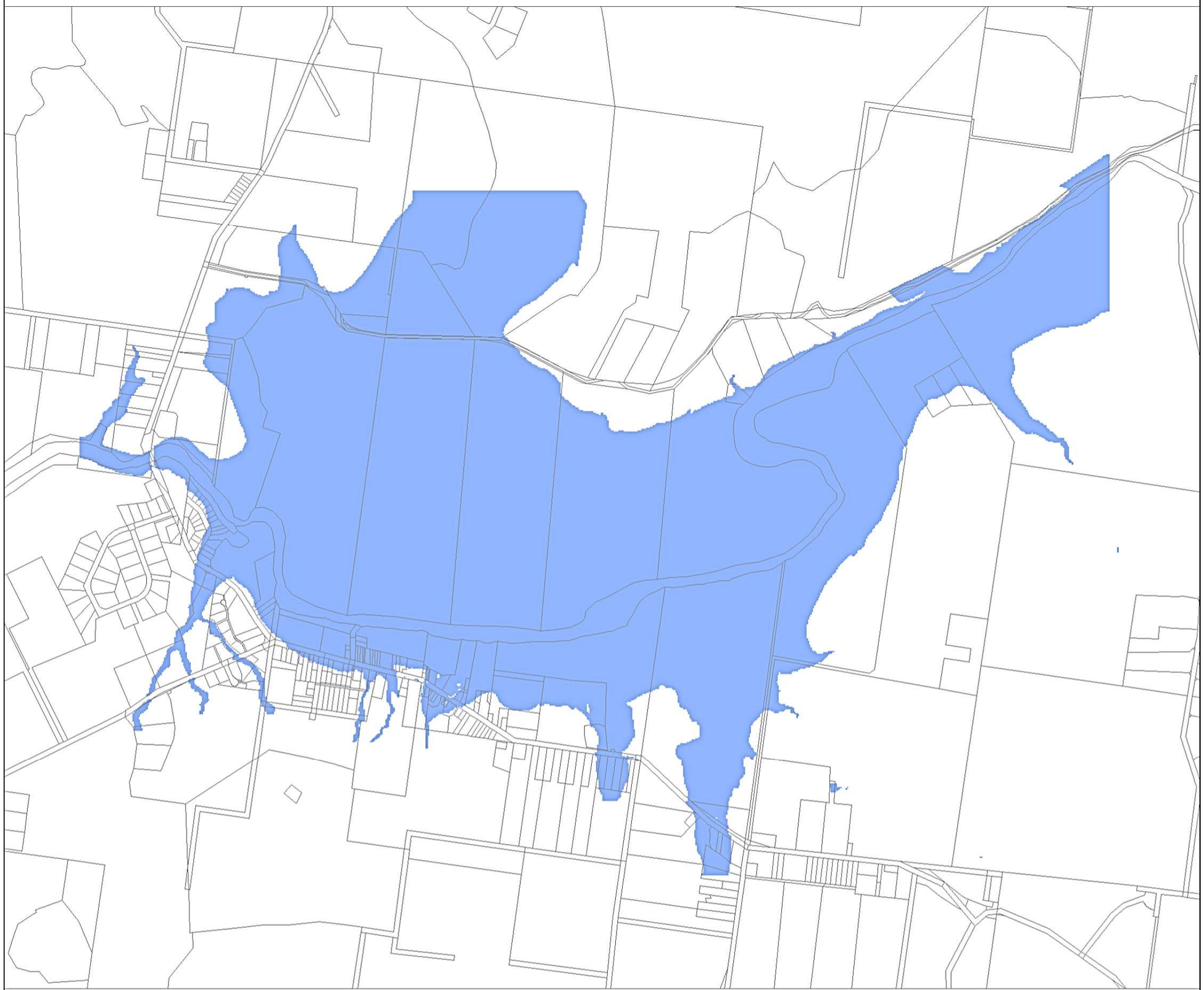


**Figure 3-5**

**0.5% AEP Flood Extent**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Flood Extent

N
W
E
S

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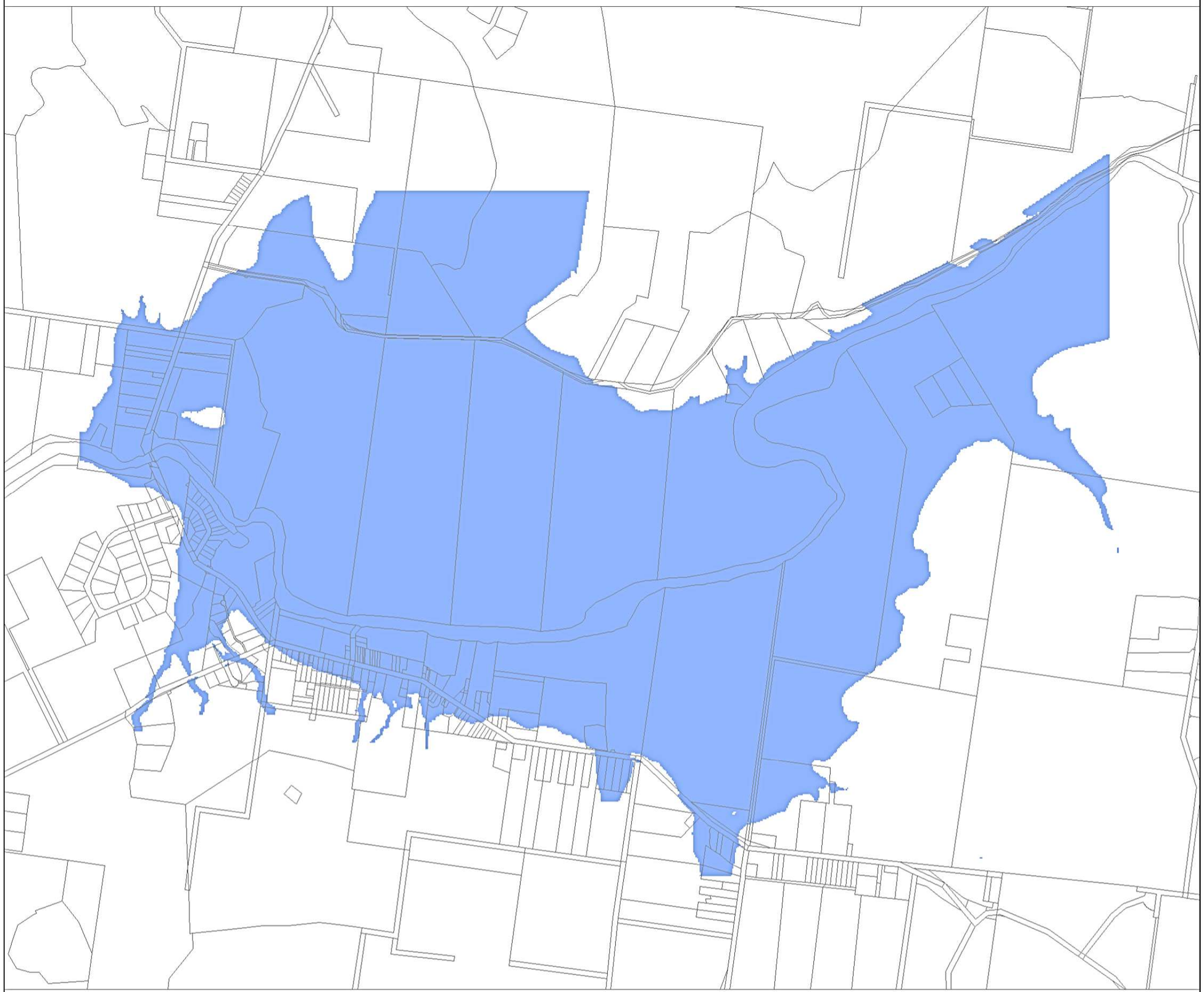


**Figure 3-6**

**PMF Peak Flood Extent**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Flood Extent

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**Figure 3-7**

**20% AEP Flood Depth**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Depth (metres)

- 0.0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- 2.0 - 5.0
- 5.0 - 10.0
- > 10.0

N
W E
S

Cardno

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0 1,000
metres
Scale: 1:15,000

**Figure 3-8**

**10% AEP Flood Depth**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Depth (metres)

- 0.0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- 2.0 - 5.0
- 5.0 - 10.0
- > 10.0

N
W
E
S

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0 1,000
metres
Scale: 1:15,000

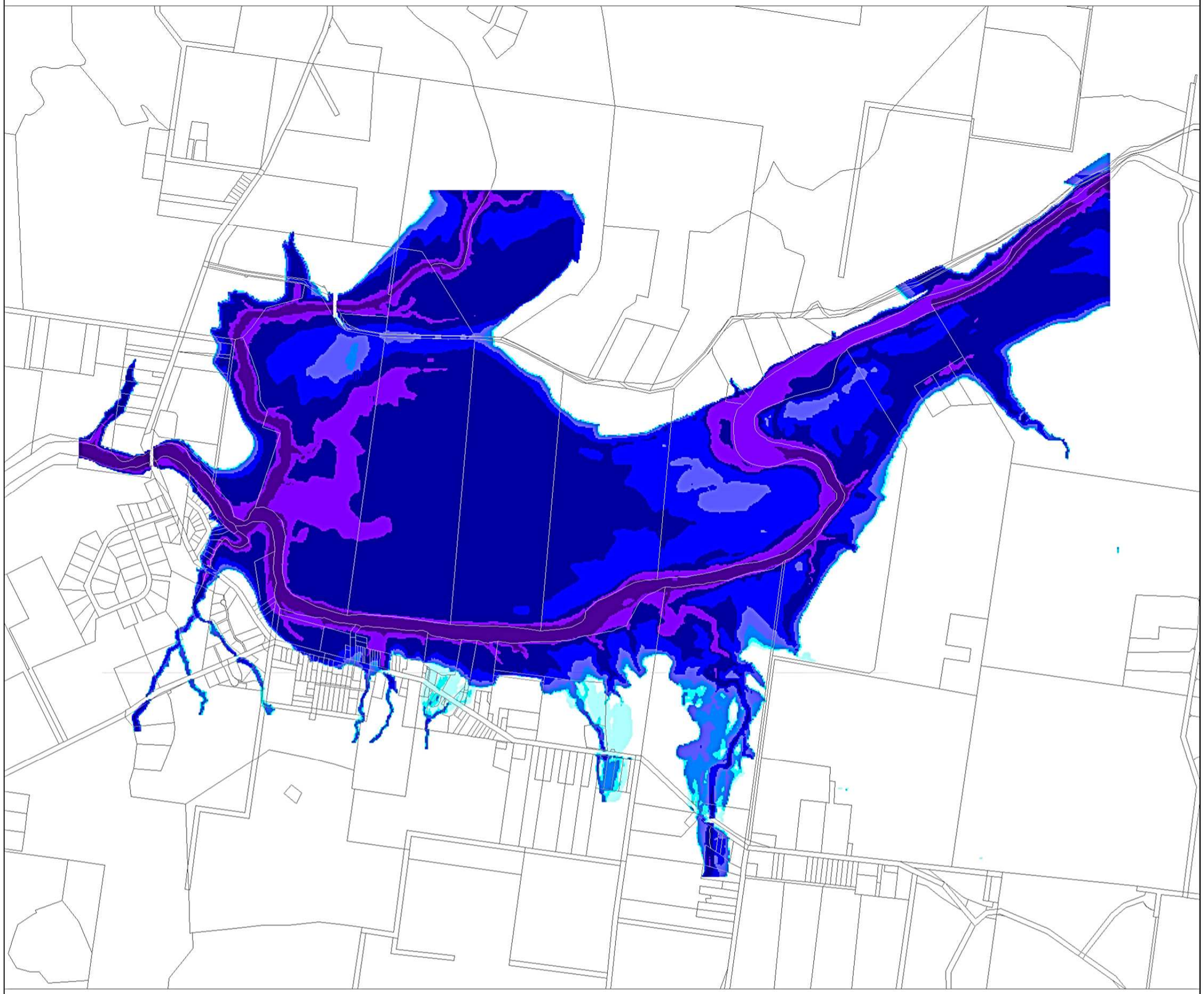


**Figure 3-9**

**2% AEP Flood Depth**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Depth (metres)

- 0.0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- 2.0 - 5.0
- 5.0 - 10.0
- > 10.0

N
W
E
S

Cardno

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**Figure 3-10**

**1% AEP Flood Depth**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Depth (metres)

- 0.0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- 2.0 - 5.0
- 5.0 - 10.0
- > 10.0

N
W
E
S

Cardno

0 1,000
metres
Scale: 1:15,000

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**Figure 3-11**

**0.5% AEP Flood Depth**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Depth (metres)

- 0.0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- 2.0 - 5.0
- 5.0 - 10.0
- > 10.0

0 1,000
metres
Scale: 1:15,000

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# Figure 3-12

## PMF Peak Flood Depth

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Depth (metres)

- 0.0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- 2.0 - 5.0
- 5.0 - 10.0
- > 10.0

N
W
E
S

0 1,000
metres
Scale: 1:15,000

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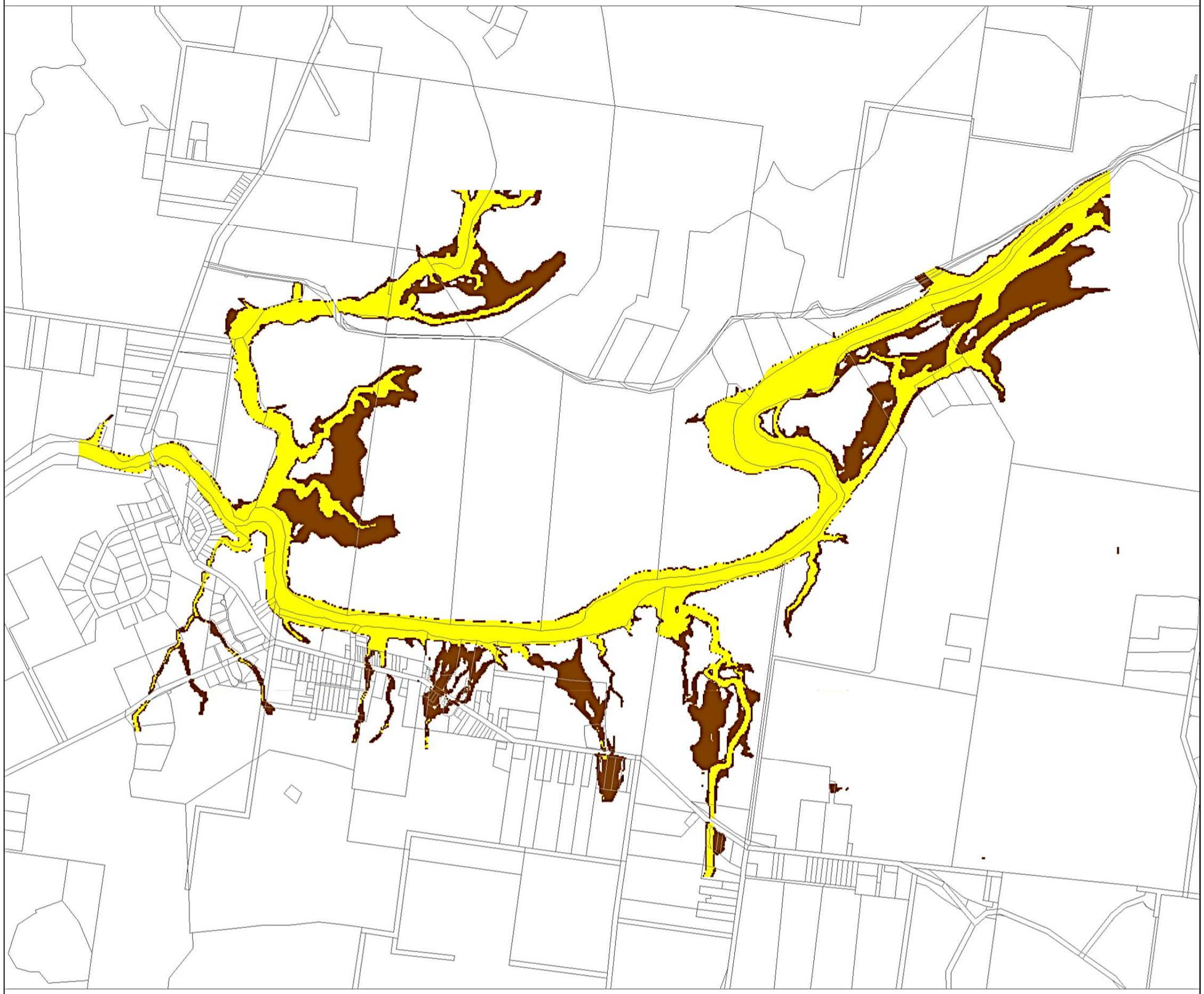


**Figure 3-13**

**20% AEP Provisional Flood Hazard**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Provisional Flood Hazard

High

Low

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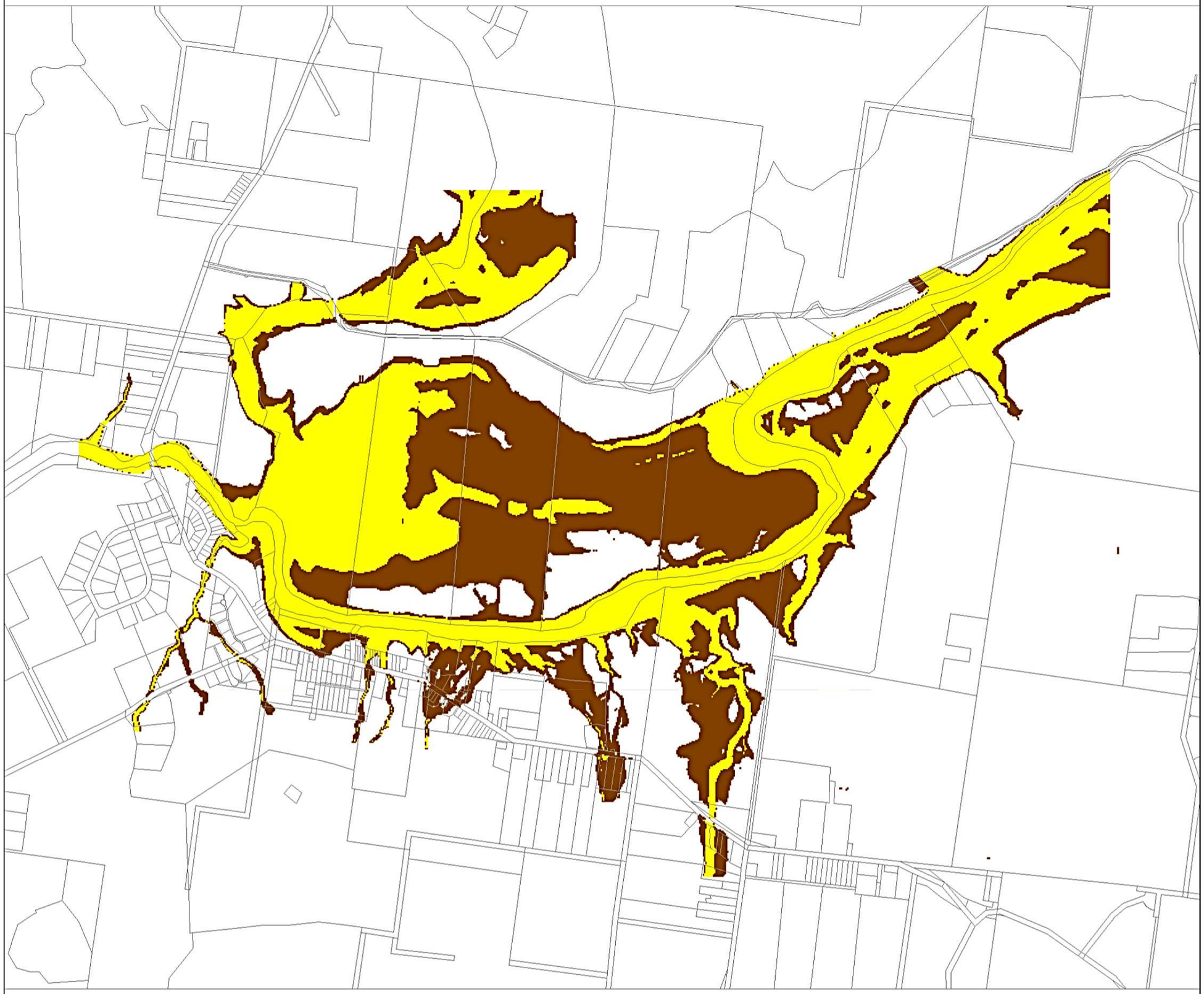

0 1,000
metres
Scale: 1:15,000

**Figure 3-14**

**10% AEP Provisional Flood Hazard**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Provisional Flood Hazard

High

Low

N
W E
S

Cardno

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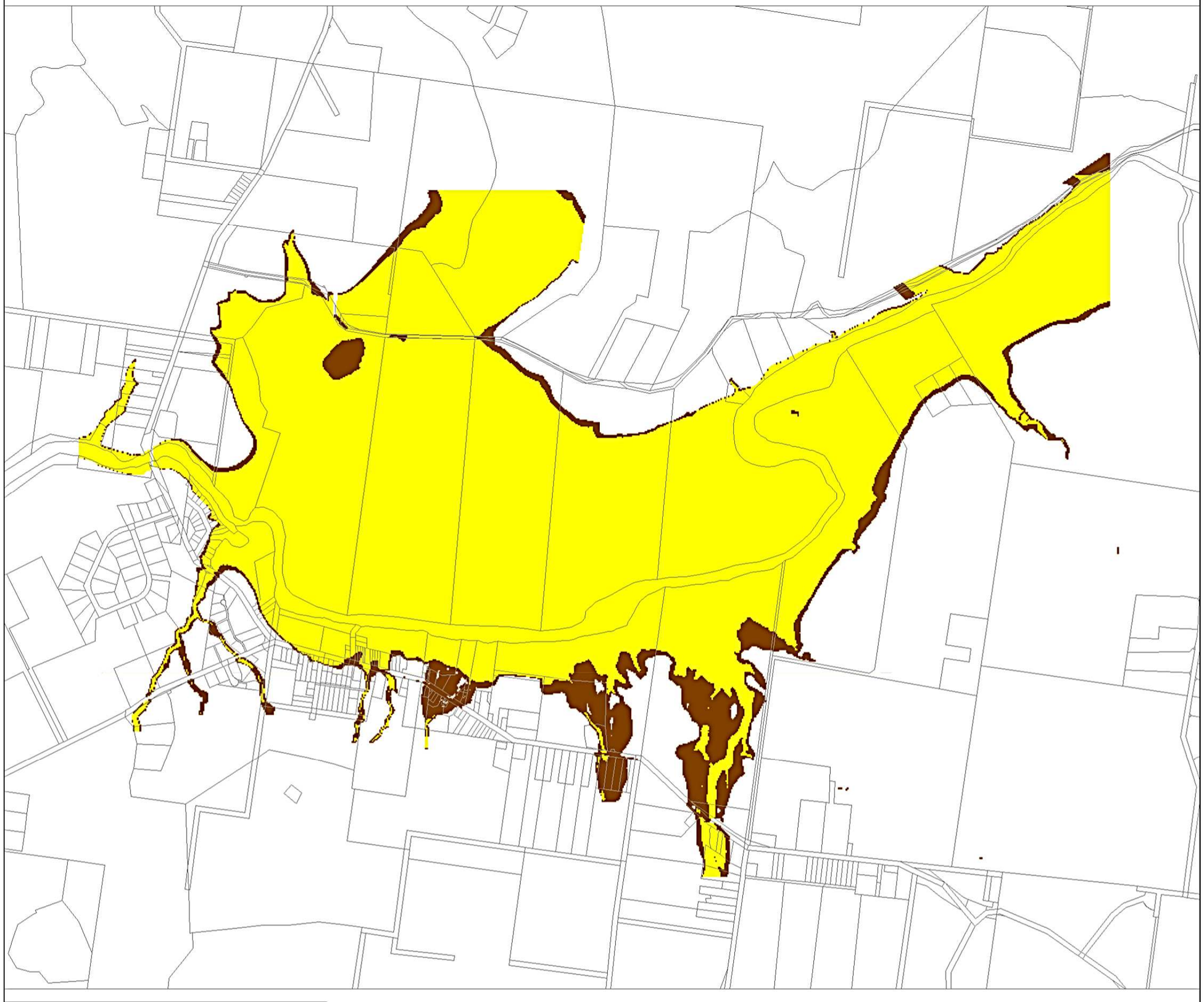

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**Figure 3-15**

**2% AEP Provisional Flood Hazard**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Provisional Flood Hazard

High

Low

N
W E
S

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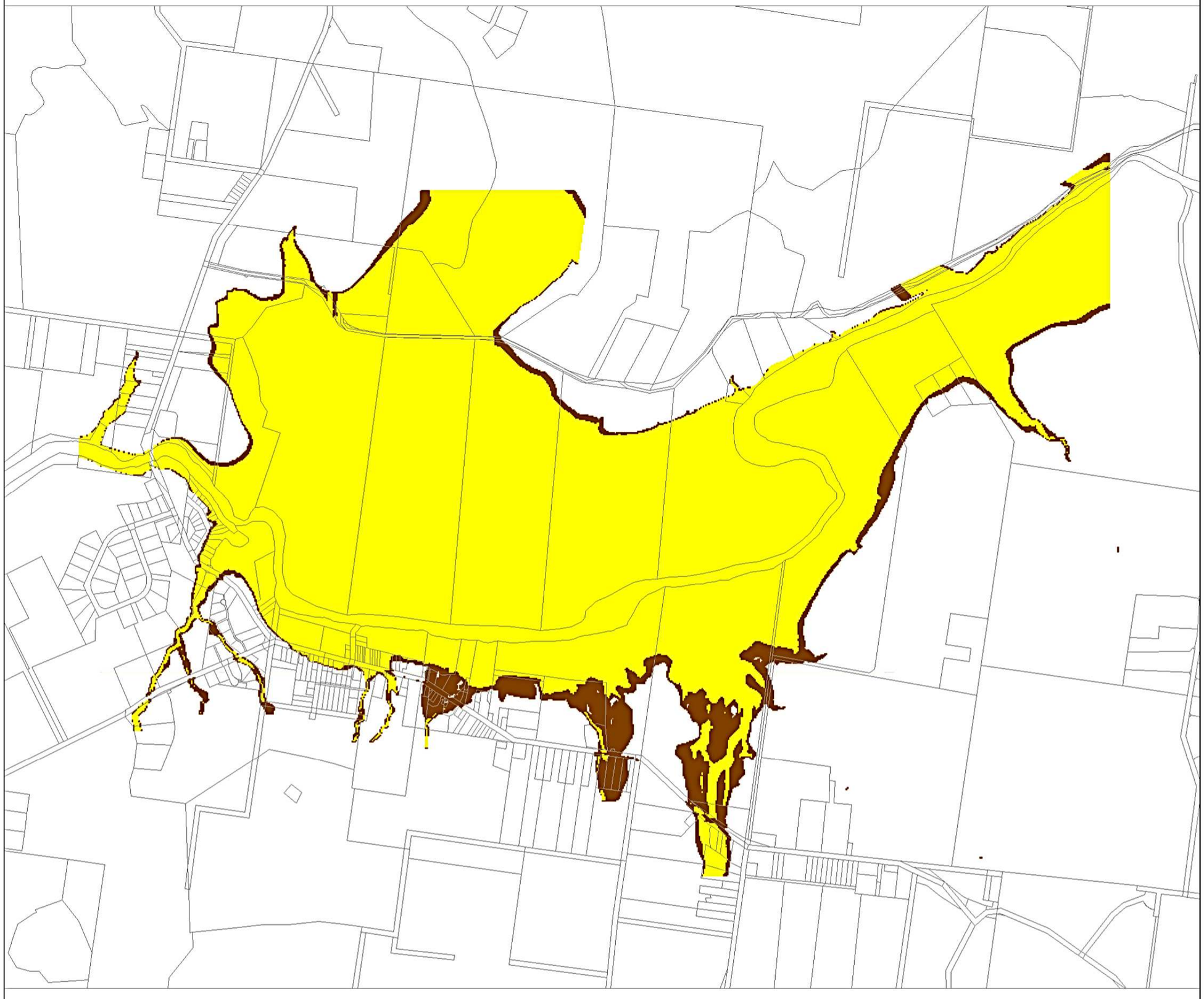

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**Figure 3-16**

**1% AEP Provisional Flood Hazard**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Provisional Flood Hazard

High

Low

N
W E
S

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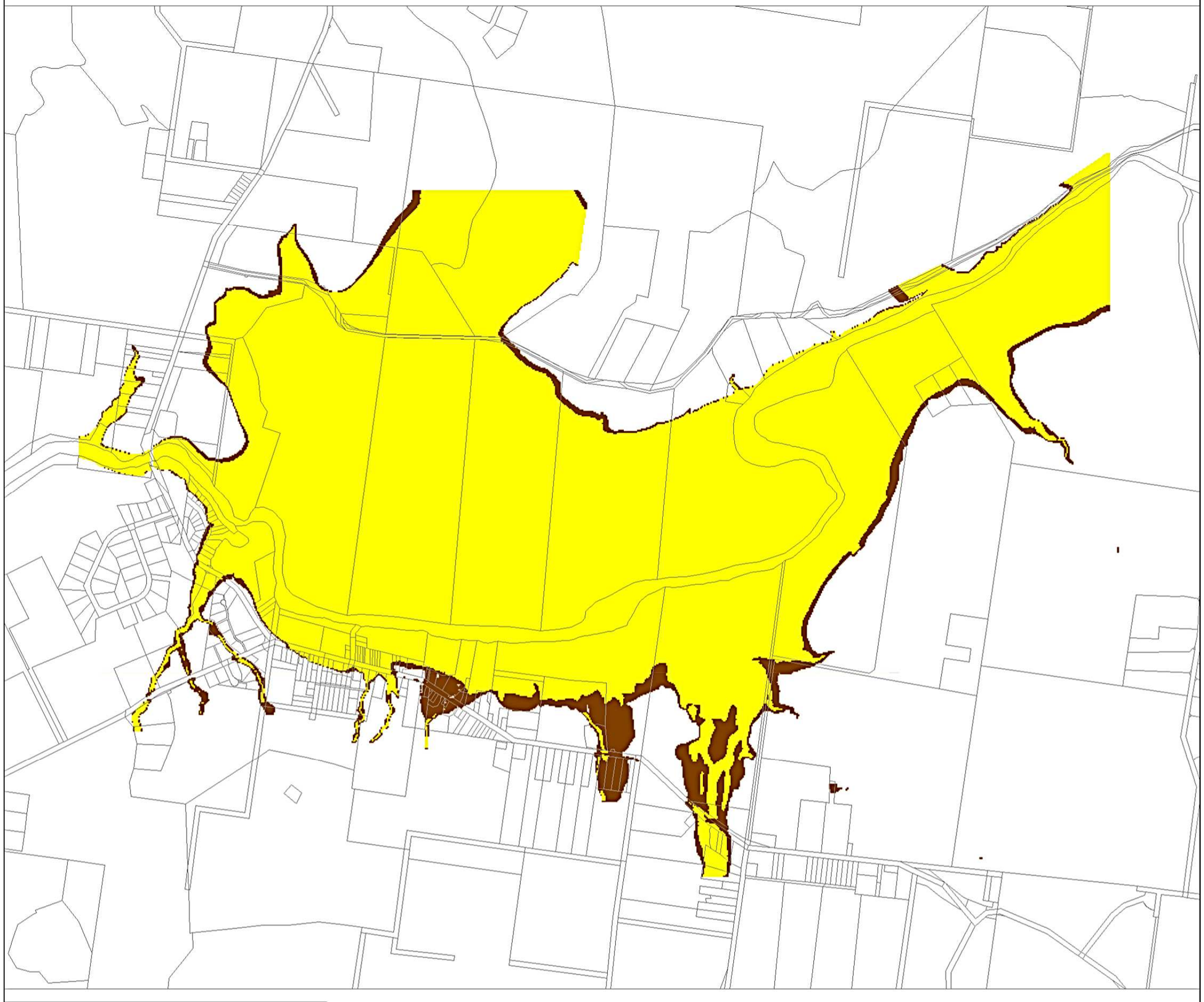

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metres
Scale: 1:15,000

**Figure 3-17**

**0.5% AEP Provisional Flood Hazard**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Provisional Flood Hazard

High

Low

N
W E
S

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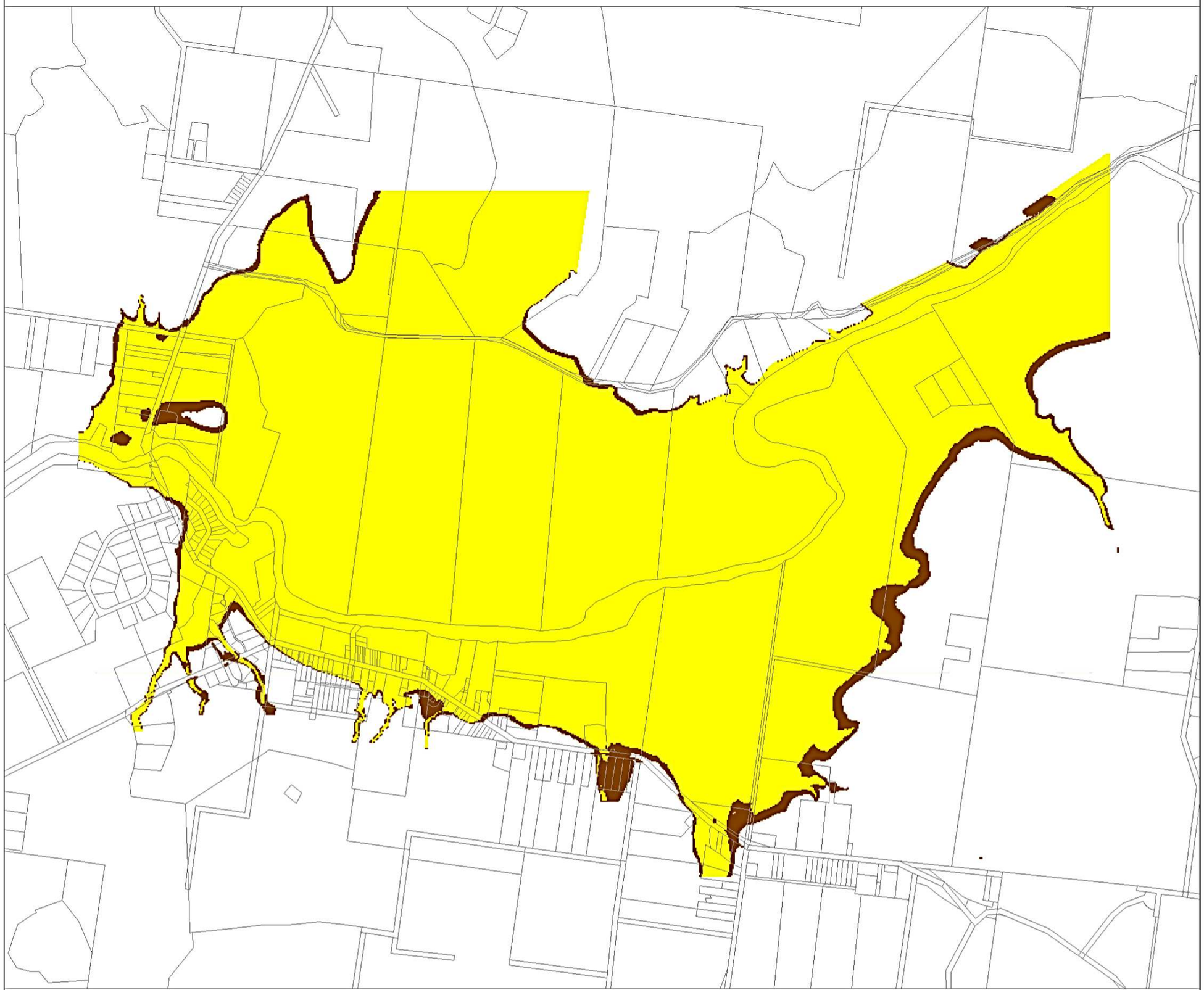

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metres
Scale: 1:15,000

**Figure 3-18**

**PMF Peak Provisional Flood Hazard**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Provisional Flood Hazard

High

Low

N
W E
S

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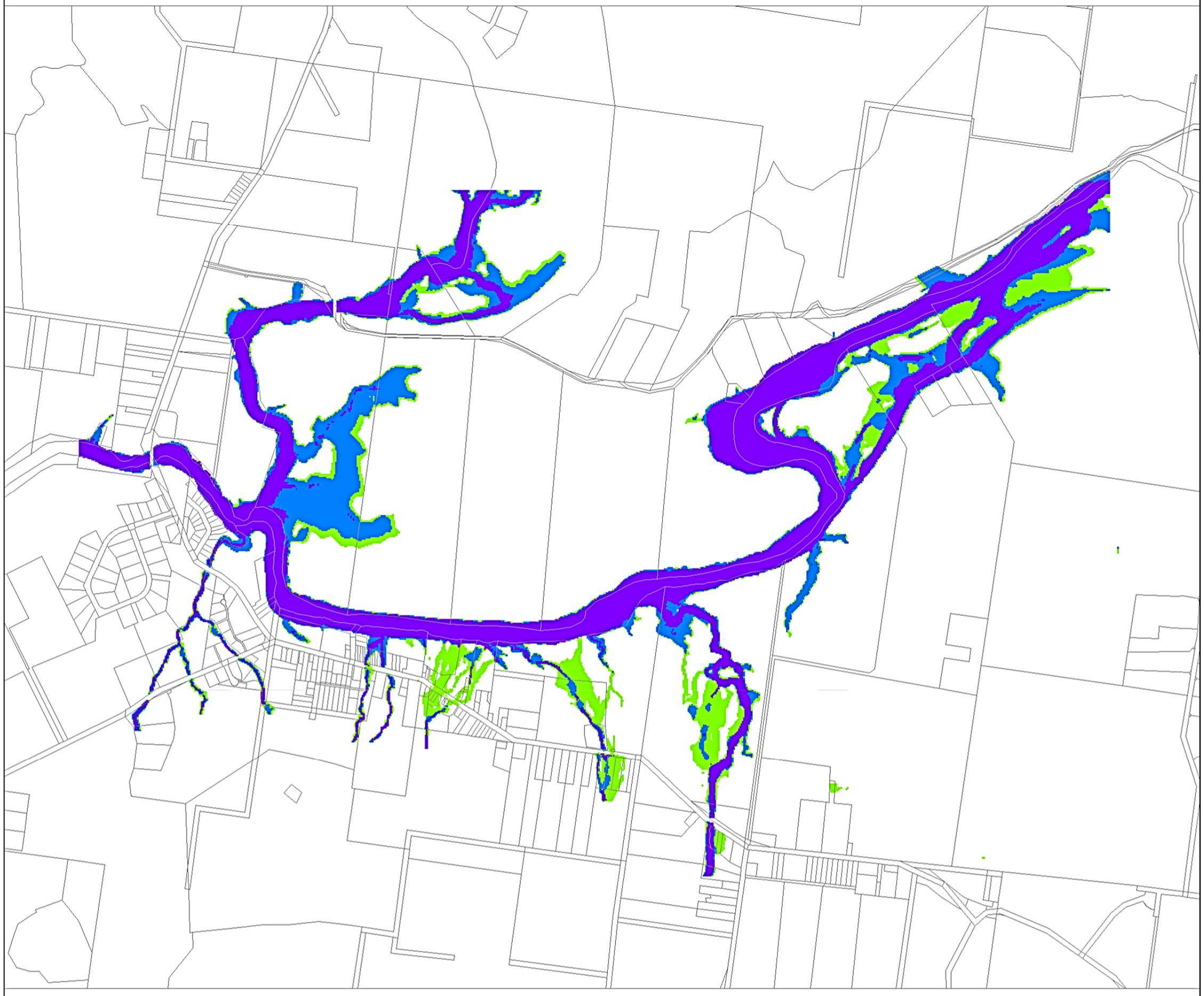

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metres
Scale: 1:15,000

**Figure 3-19**

**20% AEP Hydraulic Categories**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Provisional Flood Hazard

- Floodway
- Flood Storage
- Flood Fringe

N
W E
S

Cardno

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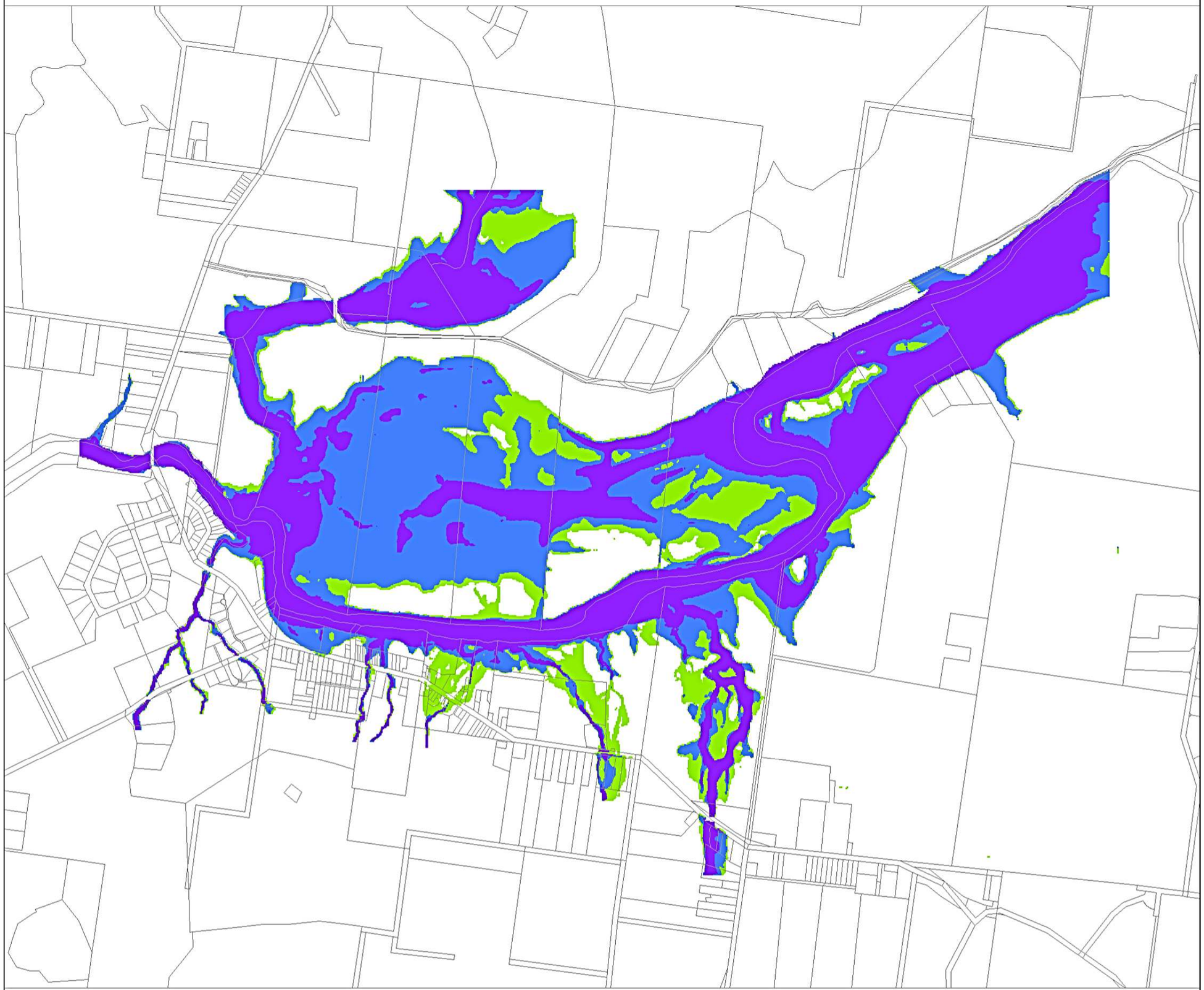


**Figure 3-20**

**10% AEP Hydraulic Categories**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Provisional Flood Hazard

Floodway

Flood Storage

Flood Fringe

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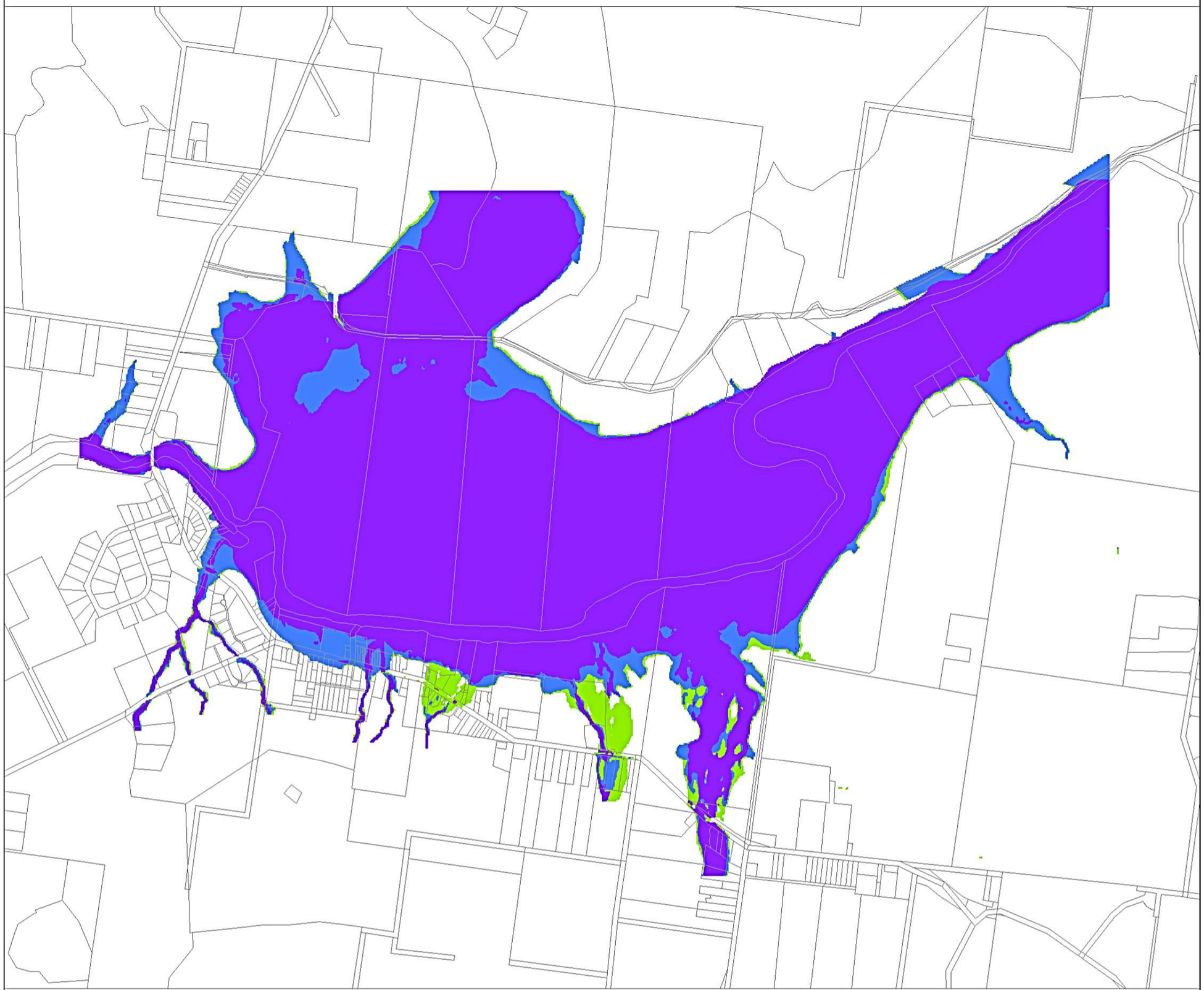


**Figure 3-21**

**2% AEP Hydraulic Categories**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Provisional Flood Hazard

Floodway

Flood Storage

Flood Fringe

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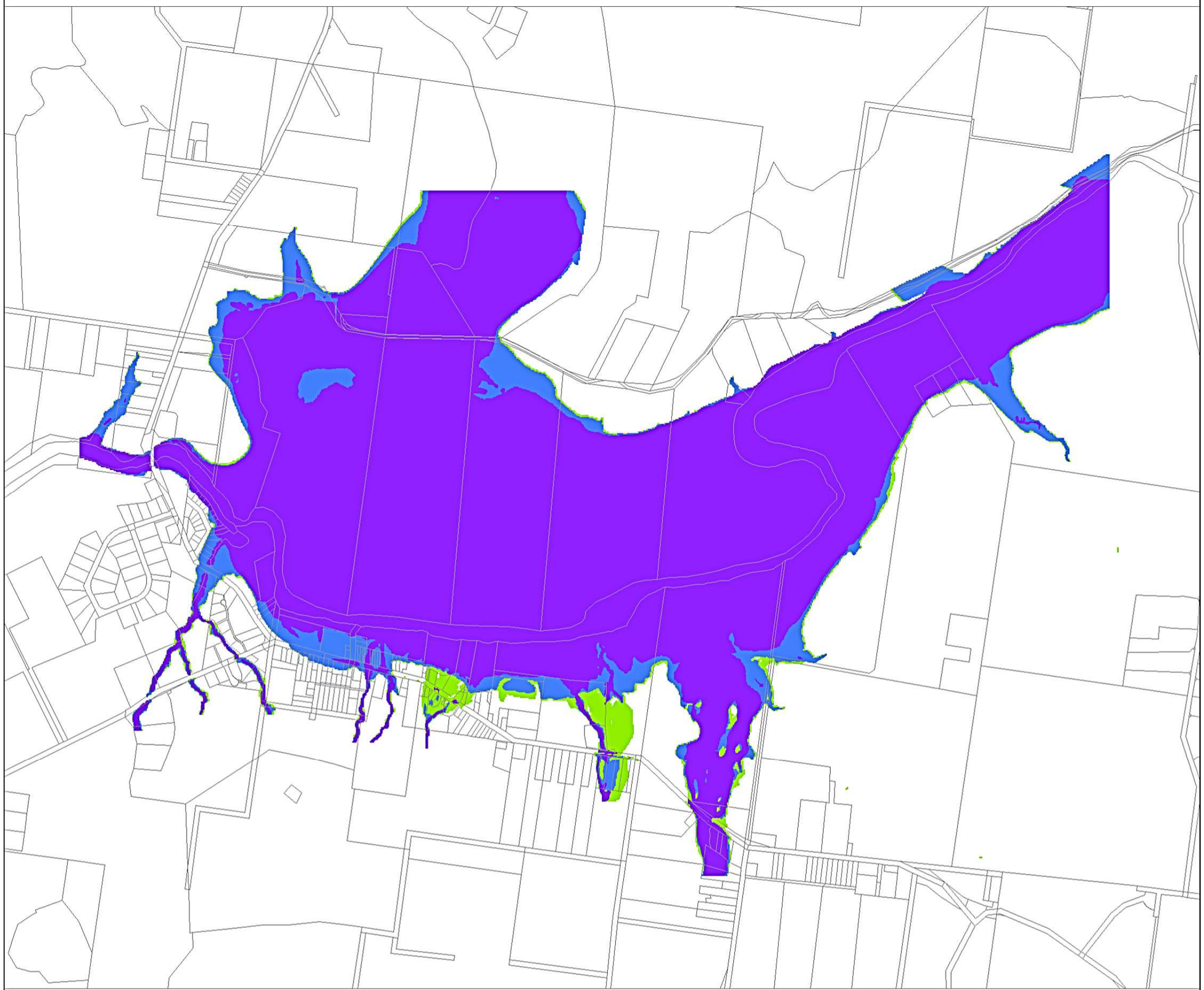


**Figure 3-22**

**1% AEP Hydraulic Categories**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Provisional Flood Hazard

Floodway

Flood Storage

Flood Fringe

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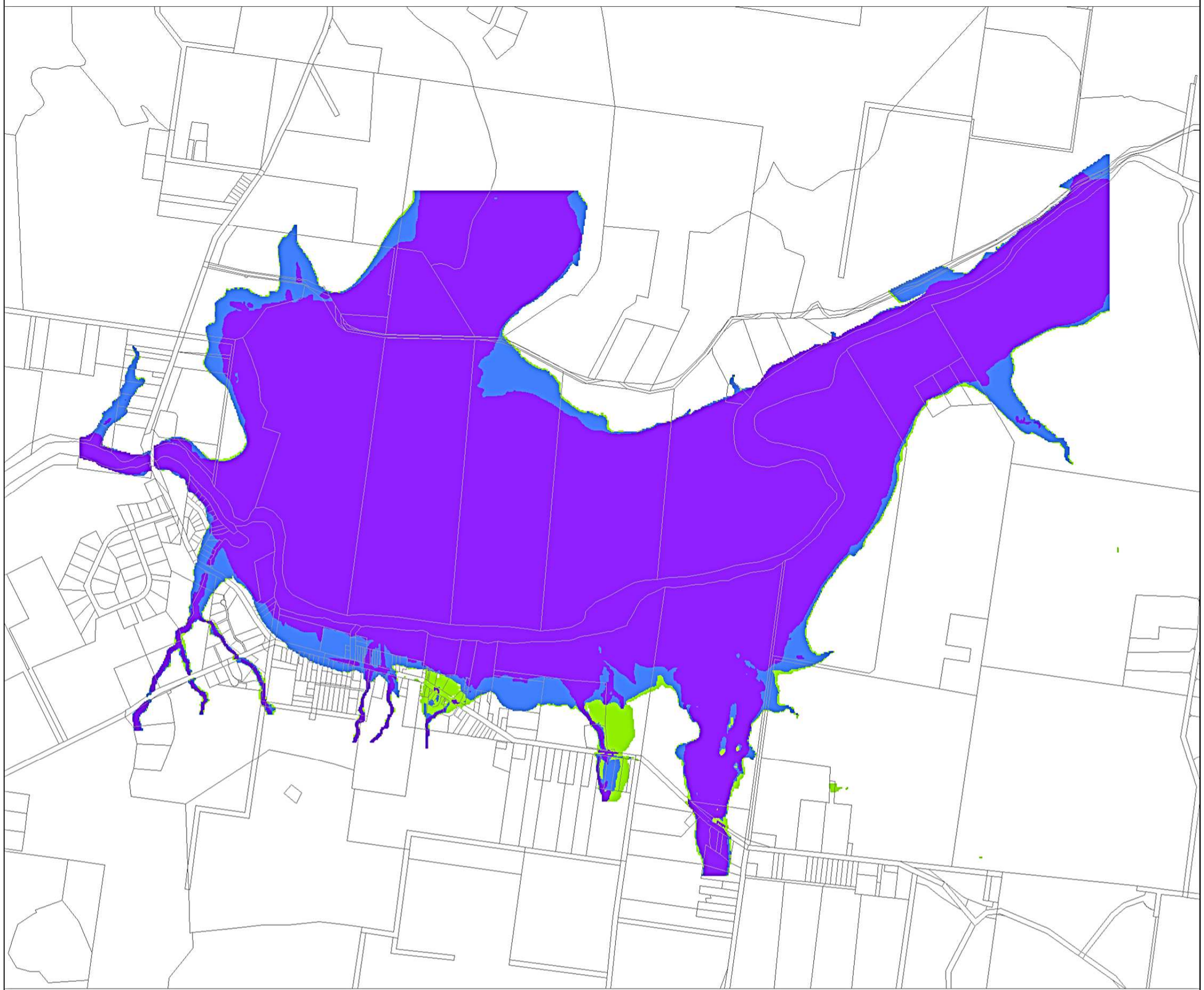


**Figure 3-23**

**0.5% AEP Hydraulic Categories**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Provisional Flood Hazard

Floodway

Flood Storage

Flood Fringe

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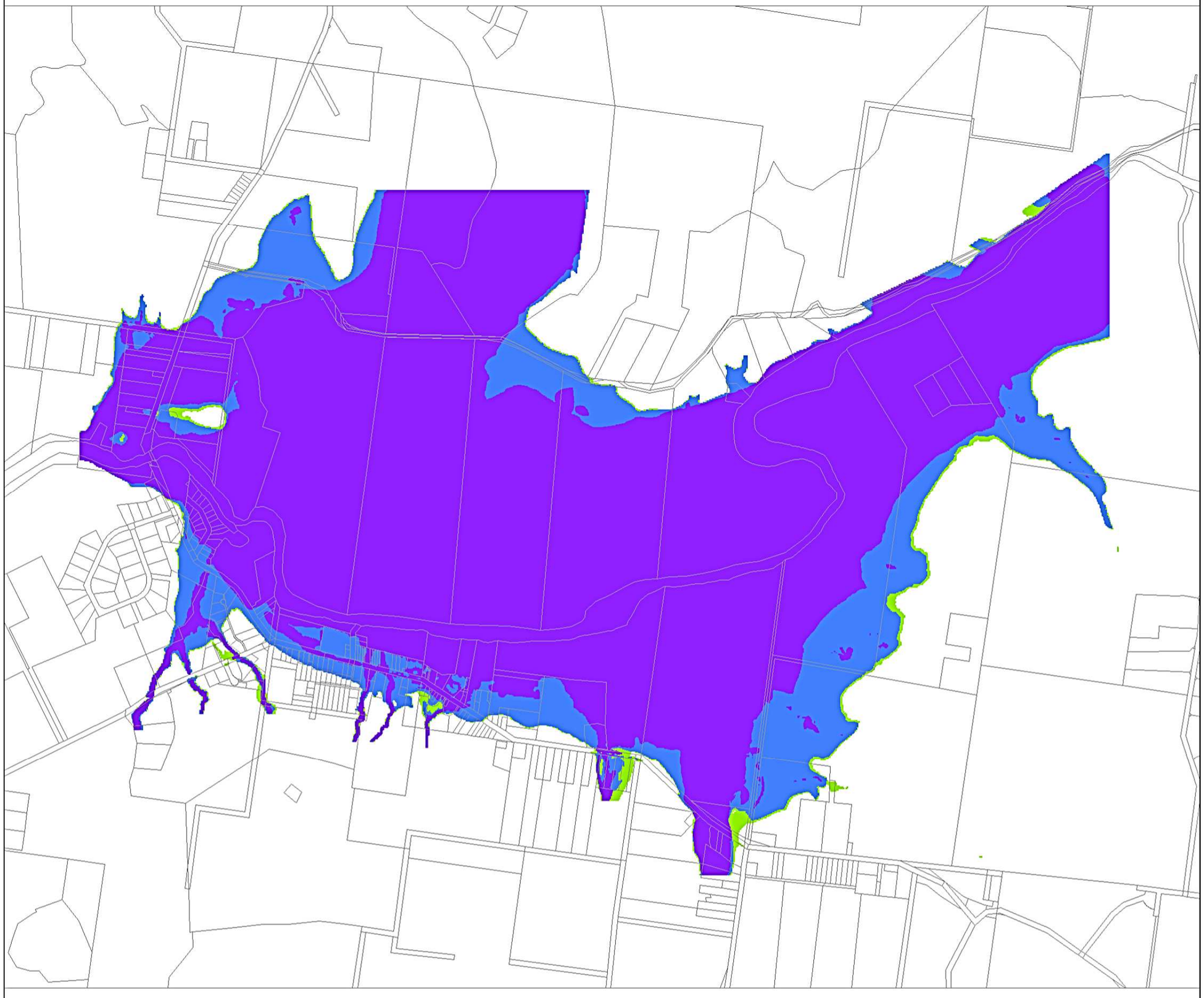


**Figure 3-24**

**PMF Peak Hydraulic Categories**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Provisional Flood Hazard

- Floodway
- Flood Storage
- Flood Fringe

N
W
E
S

Cardno

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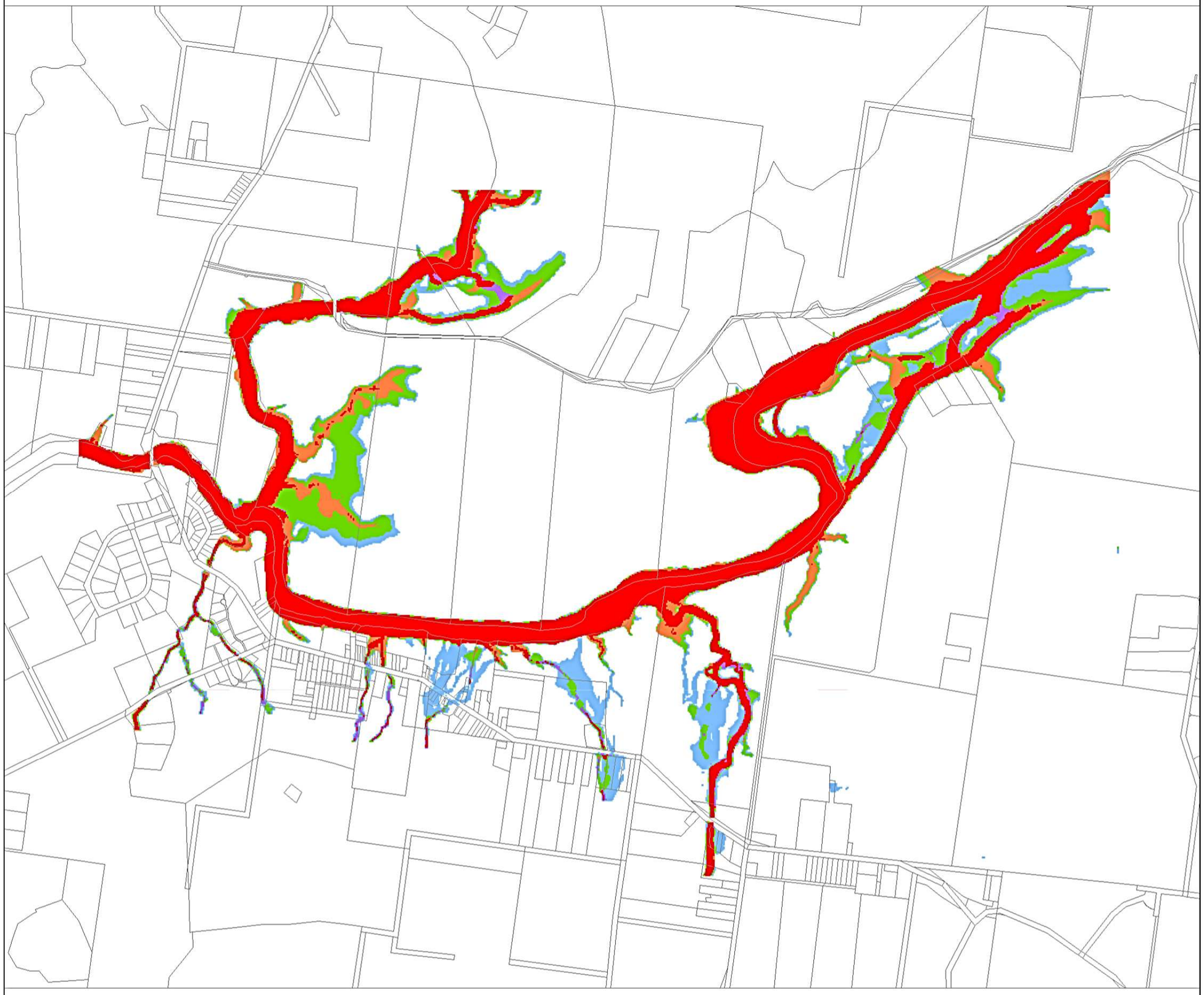


**Figure 3-25**

## 20% AEP Hazard & Hydraulic Categories

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Hydraulic Categories

- Floodway High Hazard
- Floodway Low Hazard
- Flood Storage High Hazard
- Flood Storage Low Hazard
- Flood Fringe High Hazard
- Flood Fringe Low Hazard

N
W
E
S

Cardno

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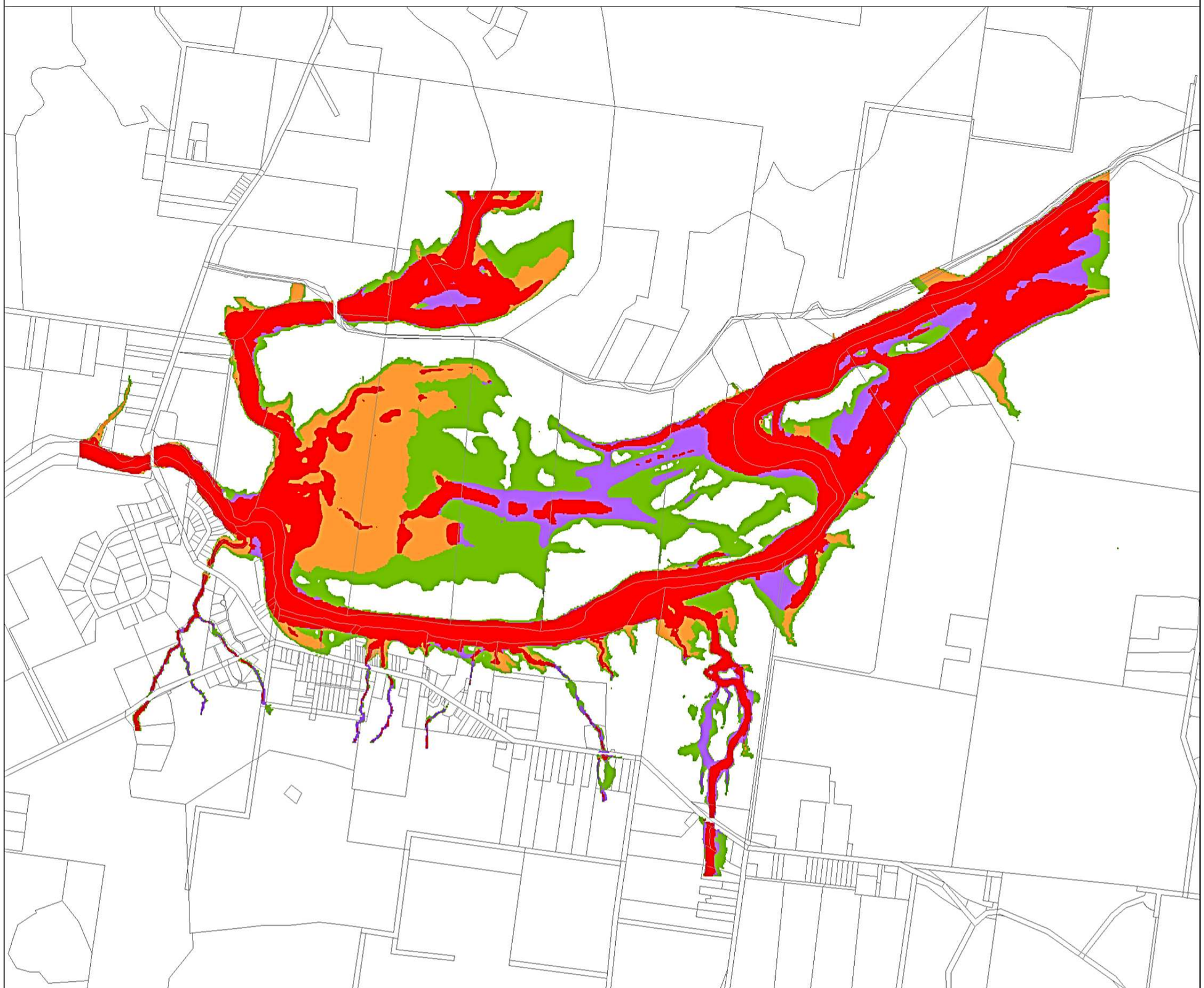

0 1,000
metres
Scale: 1:15,000

**Figure 3-26**

## 10% AEP Hazard & Hydraulic Categories

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Hydraulic Categories

- Floodway High Hazard
- Floodway Low Hazard
- Flood Storage High Hazard
- Flood Storage Low Hazard
- Flood Fringe High Hazard
- Flood Fringe Low Hazard

N
W E
S

Cardno

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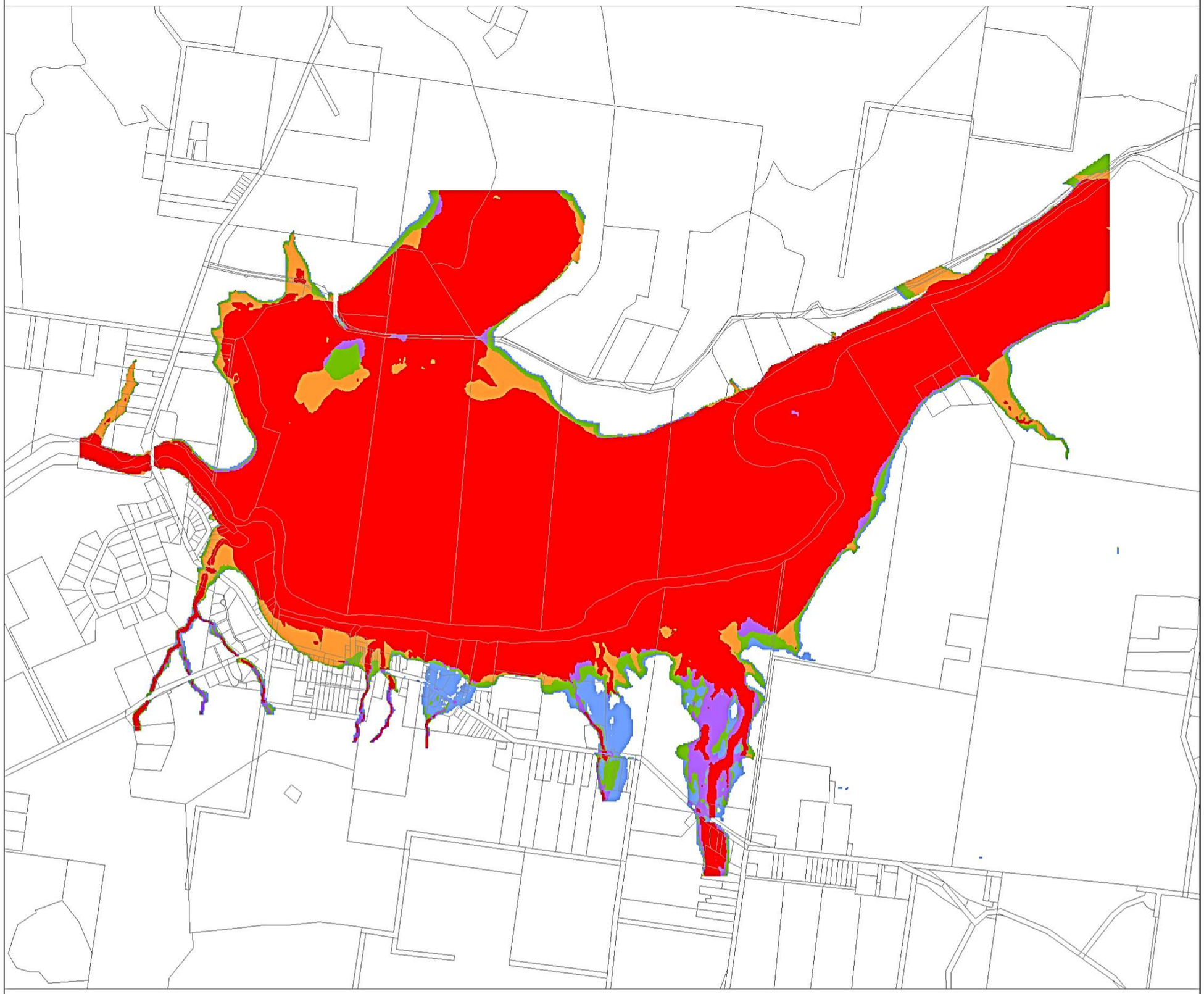


**Figure 3-27**

## 2% AEP Hazard & Hydraulic Categories

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Hydraulic Categories

- Floodway High Hazard
- Floodway Low Hazard
- Flood Storage High Hazard
- Flood Storage Low Hazard
- Flood Fringe High Hazard
- Flood Fringe Low Hazard

N
W
E
S

Cardno

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Coordinate System: MGA Zone 56


**Figure 3-28**

## 1% AEP Hazard & Hydraulic Categories

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Hydraulic Categories

- Floodway High Hazard
- Floodway Low Hazard
- Flood Storage High Hazard
- Flood Storage Low Hazard
- Flood Fringe High Hazard
- Flood Fringe Low Hazard

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**Figure 3-29**

**0.5% AEP Hazard & Hydraulic Categories**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Hydraulic Categories

- Floodway High Hazard
- Floodway Low Hazard
- Flood Storage High Hazard
- Flood Storage Low Hazard
- Flood Fringe High Hazard
- Flood Fringe Low Hazard

N
W
E
S

0 1,000
metres
Scale: 1:15,000

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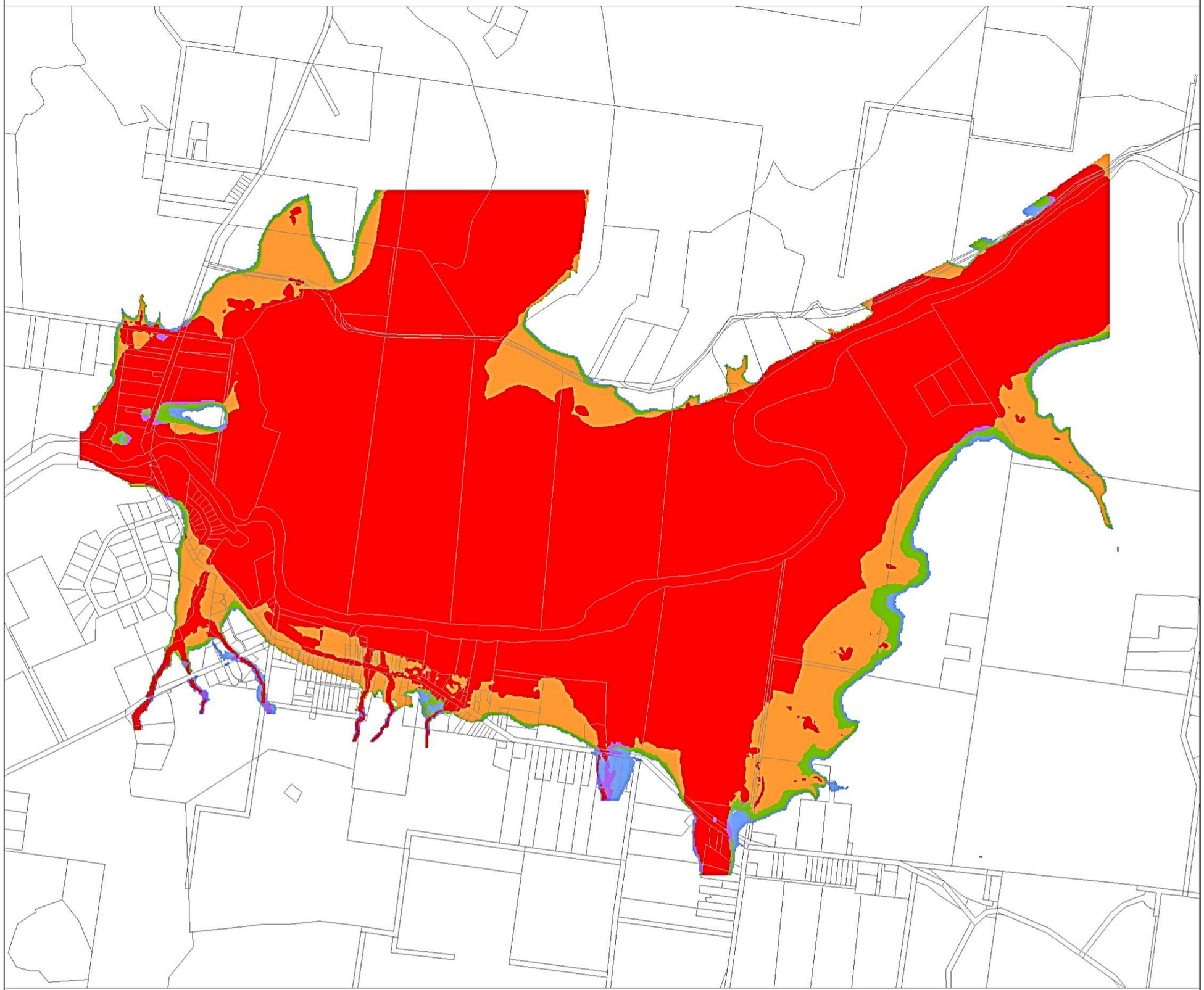


**Figure 3-30**

**PMF Peak Hazard & Hydraulic Categories**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Hydraulic Categories

- Floodway High Hazard
- Floodway Low Hazard
- Flood Storage High Hazard
- Flood Storage Low Hazard
- Flood Fringe High Hazard
- Flood Fringe Low Hazard

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Coordinate System: MGA Zone 56

# Figure 4-1

## Sensitivity Assessment Boundary Increase

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Peak Water Level Difference
metres

- > 0.5
- 0.4 to 0.5
- 0.3 to 0.4
- 0.2 to 0.3
- 0.1 to 0.2
- 0.01 to 0.1
- -0.01 to 0.01
- -0.01 to -0.1
- -0.1 to -0.2
- -0.2 to -0.3
- -0.3 to -0.4
- -0.4 to -0.5
- <-0.5

N
W E
S

Cardno

0 1,000
metres
Scale: 1:15,000

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# Figure 4-2

## Sensitivity Assessment Boundary Decrease

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Peak Water Level Difference
metres

- > 0.5
- 0.4 to 0.5
- 0.3 to 0.4
- 0.2 to 0.3
- 0.1 to 0.2
- 0.01 to 0.1
- -0.01 to 0.01
- -0.01 to -0.1
- -0.1 to -0.2
- -0.2 to -0.3
- -0.3 to -0.4
- -0.4 to -0.5
- <-0.5

N
W E
S

Cardno

0 1,000
metres
Scale: 1:15,000

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**Figure 4-3**

**Sensitivity Assessment**
**Roughness Increase**

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Peak Water Level Difference
metres

- > 0.5
- 0.4 to 0.5
- 0.3 to 0.4
- 0.2 to 0.3
- 0.1 to 0.2
- 0.01 to 0.1
- -0.01 to 0.01
- -0.01 to -0.1
- -0.1 to -0.2
- -0.2 to -0.3
- -0.3 to -0.4
- -0.4 to -0.5
- <-0.5

N
W E
S

Cardno

0 1,000
metres
Scale: 1:15,000

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# Figure 4-4

## Sensitivity Assessment Roughness Decrease

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Peak Water Level Difference
metres

- > 0.5
- 0.4 to 0.5
- 0.3 to 0.4
- 0.2 to 0.3
- 0.1 to 0.2
- 0.01 to 0.1
- -0.01 to 0.01
- -0.01 to -0.1
- -0.1 to -0.2
- -0.2 to -0.3
- -0.3 to -0.4
- -0.4 to -0.5
- <-0.5

N
W E
S

Cardno

0 1,000
metres
Scale: 1:15,000

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# Figure 4-5

## Sensitivity Assessment Rainfall Increase

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Peak Water Level Difference
metres

- > 0.5
- 0.4 to 0.5
- 0.3 to 0.4
- 0.2 to 0.3
- 0.1 to 0.2
- 0.01 to 0.1
- -0.01 to 0.01
- -0.01 to -0.1
- -0.1 to -0.2
- -0.2 to -0.3
- -0.3 to -0.4
- -0.4 to -0.5
- <-0.5

0 1,000
metres
Scale: 1:15,000

Cardno

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# Figure 5-1

## Blockage Assessment 1% AEP Event

Kangaroo Valley FRMSP
Flood Study Revision

Cadastre

Peak Water Level Difference
metres

- > 0.5
- 0.4 to 0.5
- 0.3 to 0.4
- 0.2 to 0.3
- 0.1 to 0.2
- 0.01 to 0.1
- -0.01 to 0.01
- -0.01 to -0.1
- -0.1 to -0.2
- -0.2 to -0.3
- -0.3 to -0.4
- -0.4 to -0.5
- <-0.5

N
W E
S

Cardno

0 1,000
metres
Scale: 1:15,000

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