APPENDIX 9

BUSHFIRE SIMULATION MODELING REPORT

North Stoneville Structure Plan 34 Lot 48 Stoneville Road, Stoneville

Satterley Property Group

Bushfire Simulation Modelling Report

JBS&G 56850 | 144,615

16 May 2024

We acknowledge the Traditional Custodians of Country throughout Australia and their connections to land, sea and community.

We pay respect to Elders past and present and in the spirit of reconciliation, we commit to working together for our shared future.

Caring for Country The Journey of JBS&G
Artist: Patrick Caruso, Eastern Arrernte

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Abbreviations

Term	Definition
ABCB	Australian Building Codes Board
AEP	Annual exceedance probability
AFAC	Australasian Fire and Emergency Service Authorities Council Limited
AS 3959	Australian Standard 3959 Construction of Buildings in Bushfire-prone Areas
BoM	Bureau of Meteorology
˚C	Degrees Celsius
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DBCA	Department of Biodiversity, Conservation and Attractions
DEC	Department of Environment and Conservation
DEFFM	Dry Eucalypt Forest Fire Model
DEM	Digital elevation model
DFES	Department of Fire and Emergency Services
DPAW	Department of Parks and Wildlife
DPIRD	Department of Primary Industries and Regional Development
DPLH	Department of Planning, Lands and Heritage
ELVIS	Elevation Information System
FBAN	Fire Behaviour Analyst
FFDI	Forest Fire Danger Index
FHR	Fuel hazard rating
FHS	Fuel hazard score
GEV	Generalised Extreme Value
ha	hectare
hr	hour
km	kilometre
LIDAR	Light Detection and Ranging
m	metre
min	minute
RH	Relative humidity
RoS	Rate of spread
SEMC	State Emergency Management Committee
yr	year

Executive Summary

- This report forms part of the evacuation analysis conducted for Amendment 1 to Structure Plan 34 and the area surrounding the structure plan.
- The objective of the bushfire simulation modelling was to determine the time it would take various design bushfires to impact the local public road network and the North Stoneville site. The simulations are depicted in Appendix A.
- The bushfire simulation models use the CSIRO-developed program SPARK, and adopt the following bushfire rate of spread (RoS) models as recommended by the CSIRO publication *A Guide to Rate of Fire Spread Models* (Cruz et al., 2015):
  - Dry Eucalyptus Forest Fire Model or Project VESTA Mark 1 [Cheney et al (2012)]
  - CSIRO grassland fire spread model [Cheney et al (1998)]
- Modelling of embers was determined using the McArthur V spotting model, fitted with a calibration modifier, and code developed by CSIRO.
- Information from past bushfire is useful to inform predicted bushfire behaviour, with review of historical bushfires in the area revealing the following:
  - The peak Forest Fire Danger Index (FFDI) during bushfires in the Perth Hills appears to be no greater than 60, despite FDI in Australian Standard 3959 Construction of Buildings in Bushfire-prone Areas (AS 3959) being 80.
  - The peak observed or reconstructed RoS from past bushfires in the Perth Hills appears to be no greater than 3 km/hr and generally 1.5 to 2 km/hr.
  - Ember spotting appears to be around 500 m ahead of the fire, however can be further where fire is through older fuels.
- Four (4) design bushfire scenarios were simulated, as identified in the Microsimulation Evacuation Modelling Report for the project (Transcore 2024), all which could result in closure of one of the major evacuation corridors (Great Eastern Highway or Toodyay Road):
  - Bushfire approaching on a north-easterly fire run (ignition to the south-west of the site)
  - Bushfire approaching on a south-easterly fire run (ignition to the north-west of the site)
  - Bushfire approaching on a south-westerly fire run (ignition to the north-east of the site)
  - Bushfire approaching on a north-westerly fire run (ignition to the south-east of the site)
- The ignition point used in simulations is a hard coded input in SPARK, which results in an ignition point that is 120 m wide and approximately 11,304 m^2 in area.
- The ignition locations are approximately 6.5 to 7.0 km from the site, to enable the bushfire to impact either Great Eastern Highway or Toodyay Road reasonably quickly after ignition, while still producing head fire widths several kilometres wide at the SP 34 site sufficient to warrant large-scale evacuation of North Stoneville and the surrounding local area.
- Analysis of the bushfire weather using Bickley weather station (Station Number 9240) data was conducted to identify the “worst-credible” bushfire weather, through use of Generalised Extreme Value (GEV) and Moving Average GEV analysis on FFDI, temperature and relative humidity variables. Each of the 4 design bushfire scenarios will be simulated under the following bushfire weather predictions:
  - FFDI 62.1 (1: 50 year event without climate change factored)

- FFDI 74.9 (1:50 year event including 25 year projection of climate change based)

- A 1:50 year recurrence rate for a bushfire event is considered appropriate for a residential subdivision and aligns with the design fire weather specified for Class 1 buildings in accordance the National Construction Code.
- The SPARK simulation environment inputs included the following:
  - A study area of approximately 50 km circular area surrounding the SP 34 site.
  - A suitable digital elevation model (DEM) has been developed from LIDAR for the study area
  - Using the publicly available data sources, the landscape was divided into various classifications of Forest, Built Area, Crops, Grass, Water and Bare Ground
  - The above categories were divided to 3 fuel classifications, namely Forest, Grassland and Built Area, which were assigned consistent fuel characteristics.
- Several trial simulations were conducted, informed by reconstruction of two historical bushfires, namely Parkerville (January 2014) and Wooroloo (February 2021), to calibrate and validate the accuracy of the adopted RoS and spotting models and fuel characteristics, primarily due to the lack of detailed vegetation and land-use data sets available.
  - A Calibration fuel state was derived from the calibration simulations, which are a suite of fuel characteristics that deliver the best alignment with bushfire behaviour from the historical fires, and included the following:
    - Forest – uses VESTA RoS model with fuel characteristics based 10 year old fuels
    - Grassland – uses CSIRO Grassland model adopting grassland condition of eaten out and curing level of 67% for landscapes mapped as Grass or Crops
    - Built Area - used VESTA RoS model with bespoke inputs for total fuel load of 4 t/ha
  - A more onerous suite of fuel characteristics was also developed for use in the time to impact simulations, referred to as the Conservative fuel state, and represents potential for greater availability and fuel loads, and had the following inputs:
    - Forest – uses VESTA RoS model with fuel characteristics based 25 year old fuels
    - Grassland – uses CSIRO Grassland model adopting grassland condition of cut/grazed and curing level of 90% for landscapes mapped as Grass or Crops
    - Built Area – same as Calibration fuel state with total fuel load of 4 t/ha
- The results of the calibration process revealed that two RoS models were required to obtain alignment with both historical fires when using the same Calibration fuel characteristics:
  - Growth RoS model
    - aligned well with the Parkerville fire and the first 7 hours of Wooroloo bushfire, but under-predicted the more mature Wooroloo fire after 7 hours.
    - required a lesser spotting distance to align with the early stage and/or smaller historical bushfires, and is calibrated to 80% of that in the Mature RoS model.
  - Mature RoS model
    - aligned well with the 17 to 25 hours of the Wooroloo bushfire but over-predicted the Parkerville bushfire and the Wooroloo bushfire up to the 7 hour mark.
    - required greater spotting distances to align with more developed or mature bushfires, and is calibrated to 20% greater than the Growth RoS model.

- Reconstructing bushfires using the current simulation tools are unlikely to produce an exact match, however the reconstructed fires do have solid alignment with the historical bushfires, both in terms of RoS and broad shape, when using the Calibration fuel state, in conjunction with the appropriate RoS model (Growth or Mature).

- The Mature RoS model and Conservative fuel characteristics were adopted in the design fire simulations as the most onerous inputs, and are expected to provide relatively reliable representations of expected bushfires.
- To ensure the weather profiles generated for use in the SPARK simulations provided realistic weather variable proportions to achieve the nominated FFDI (i.e. 62.1 and 74.9), both FFDI's were proportionally altered against a "real" weather profile from a high FFDI day that had a sustained FFDI across multiple hours, as well as an onerous combination of temperature, relative humidity and wind speed.
  - A review of the highest historical FFDI days was conducted and the 14th December 2019 was selected as the base weather profile to be prorated against, with the simulations conducted using the time between 1pm and 5pm.
  - The prorating process involved proportionally adjusting the FFDI, temperature and relative humidity to the peaks shown in Table 4, then altering wind speed to achieve the peak FFDI.
- The results of the simulations for each design bushfire scenario (see Appendix A) produce the following range of simulated times to impact the SP 34 site, at each FFDI across all ignition locations:
  - FFDI 62.1 – between 164 min (2.73 hr) and not reaching the site
  - FFDI 74.9 – between 137 min (2.29 hr) and 207 min (3.46 hr)

  Table 10 provides a detailed breakdown of impact times to the site and major roads.
- The assumptions that underpin the simulation modelling ensure that these impact times are suitably conservative as follows:
  - Fuel loads are assumed to be uniform and consistent, and no allowance for any fuel load management (such as prescribed burning) has been made
  - No allowance was made for potential reduction in fuel load due to a drying climate
  - Assumes no suppression activities
  - Wind direction is assumed to be directly at the site for the entire simulation, which while possible, may not always be the case across a 4 hour duration
  - Assumes no impact from the SP 34 development i.e. no development within site to interact with bushfire behaviour
  - Assumes no other changes to land use in the area, which is unlikely over a 50 year period
- Comparative simulations were also conducted adjusting fuel state (Conservative and Calibration) and RoS models (Mature and Growth) and it was found that adjusting either resulted in relatively minor changes in RoS and burn area, however the combination of altering them both, could produce more significant variations in fire speed and extent.
- In order to demonstrate the level of conservatism of the simulated design bushfire scenario outputs, they have been compared with historical bushfires as follows:
  - the quicker average RoS in the first 4 hours of the simulated scenarios of between 1.5 – 2.5 km/hr (FFDI 62.1) and 2 – 3 km/hr (FFDI 74.9) with peak RoS between 3.5 – 4.2 km/hr. This compares favourably to the 1.5 km/hr to 2 km/hr peak average RoS that is historically associated with Perth Hills bushfires, noting that both Parkerville and Wooroloo fires were progressing at about 1 – 1.2 km/hr in the first 2 to 4 hours.

- the significantly greater size associated with the simulated design fires, which have a total burn area after 4 hours of between 1202.5 – 2692.1 ha (FFDI 62.1) and 1713.4 – 3581.1 ha (FFDI 74.9). By comparison, the 4 hour burn area for Parkerville was 333 ha, whereas the Wooroloo bushfire lost 230 ha in the first 4 hours and 1989 ha after 7 hours. The simulated fires are showing far greater size and extent impact than historical bushfires in the first 4 hours.
- comparison against the simulation using the Parkerville weather profile where the rate of spread and fire extents are significantly different after 4 hours show that bushfire behaviour can be substantially affected by lower weather inputs than those used for the design bushfire scenarios.

- Whilst the simulated design bushfire scenarios represent the worst credible case bushfires for a 1:50 year weather event, they do represent a “perfect storm” of conditions that while possible, has historically rarely occurred in unison. On this basis, we are comfortable that there is sufficient conservatism embedded in the model inputs to ensure that an actual bushfire would be slower and smaller than what is being represented in the simulations over the first 4 hours, and likely considerably slower and smaller.

1. Introduction

- This report forms part of the evacuation analysis conducted for Amendment 1 to Structure Plan 34 and the area surrounding the structure plan.
- To inform the evacuation analysis, Strategen-JBS&G, in conjunction with Covey Associates Pty Ltd, have conducted bushfire simulation models of various design bushfires, using the CSIRO-developed program SPARK.
- The objective of the bushfire simulation modelling is to determine the time it would take various design bushfires to impact the local public road network and the North Stoneville site.

1.1 Methodology

- The overall methodology for conducting the bushfire simulations can be broadly divided into the following elements:
  - Determining the design bushfire scenarios
    - Bushfire history review
    - Simulation program selection
    - Rate of spread model selection
    - Scenario development including ignition locations
    - Determining modelling inputs including
      - Land use, vegetation and fuel review
      - Slope analysis
      - Bushfire weather analysis (including allowance for future climate change)
  - Simulation modelling
    - Simulation results and discussion (including time to impact)
- The first element relates to determining the design bushfire scenarios, modelling approach and inputs, with the second involving the actual simulation modelling and determination of the time to impact on the various roads, the SP 34 site and the traffic modelling study area.

1.2 Forest Fire Danger Index (FFDI)

- The concept of Forest Fire Danger index (FFDI) is important to understand as part of this simulation. FFDI is a measure of fire severity in forest or treed landscapes, including potential for elevated rate of spread and intensity, and difficulty of suppression.
- The index is derived from a combination of air temperature, relative humidity, wind speed and long- and short-term drought effects (soil dryness, evaporation, rainfall).
- The raw weather data required to calculate FFDI, is typically obtained from the Bureau of Meteorology (BoM).

2. Bushfire History Review

- Review of past bushfires can be useful to understand historical bushfire behaviour, in particular rate of spread (RoS), bushfire weather and fuel characteristics, which can be used to inform the design bushfire assumptions.
- The following subsections detail some of the findings from historical bushfires in the local area, used to inform this simulation modelling from historical bushfires in the local area.

2.1 2021 Wooroloo Bushfire (1 - 6 February 2021)

- This bushfire occurred in early February 2021, less than 10 km to the north of the North Stoneville SP 34 site. There were 86 homes destroyed, but fortunately no life was lost.
- AFAC (2021) recently released a post bushfire investigation report, which details the following information about the bushfire:
    - The bushfire ignition was approximately midday on 1 Feb 2021, and by 3.45pm had burned out 230 ha.
    - Weather conditions during the daytime were reported as being high temperatures (up to 38°C) with strong winds with FFDI reported as follows:
        - FFDI 53 at Gooseberry Hill
        - FFDI 67 at Gingin Airport
    - In the afternoon of 1 February, firefighters report erratic fire conditions with RoS of between 3-4 km/hr and spotting up to 500 m ahead of the fire front. It is noted that the RoS at 2pm is estimated to be 1.8 km/hr
    - The total burn area was 10,750 ha (over 5 days) with:
        - 230 ha burning in the first 225 mins (3.75 hours)
        - 1989 ha burning after 7 hours, with 28.2 km perimeter (determined from EmergencyWA burnt are mapping)
        - 7300 ha burning after 28 hours, with 80 km perimeter
        - 8000 ha after 30 hours.
- Referring to BoM data from Bickley weather station (Station Number 9240)
    - The FFDI peaked at approximately FFDI 47 at Bickley
    - Peak afternoon average wind speeds were 25-30 km/hr, with gusts of up to 50 km/hr recorded.
- Using burnt area mapping from EmergencyWA website (see 0), an isochrone map was created and used to provide the following broad information on the bushfire:
    - The average Rate of Spread (RoS) appears to be between 1.22 km/hr and 1.78 km/hr
    - The peak average RoS appears to be approximately 3 km/hr (10 km fire spread over 3.3 hours) between 3.45pm and 7.05pm on 1 February 2021.
    - It is acknowledged that the use of the EmergencyWA burnt area maps is not as accurate as isochrone mapping from a post-fire investigation, however as isochrones are not yet publicly available at the time of preparing this report, and as such, this methodology was considered to provide the best guide of the bushfire extent.

2.2 Parkerville bushfire (12 January 2014)

- This bushfire occurred on 12 January 2014, less than 2 km to the south and south-east of the North Stoneville site. The fire destroyed 48 houses and damaged 7 houses, with 25 homes in the survey area suffering no damage. No lives were lost during this fire.
- The State Emergency Management Committee (SEMC) produced a review into the Parkerville Stoneville Mt Helena Bushfire bushfires in June 2014, and detailed the following:
  - The bushfire was reported just prior to 1100hrs on 12 January 2014, and was considered to be contained in the early evening. During this time, the total burn area was assessed as being 386 ha.
  - For the first 60 to 90 minutes, a combination of high fuel loads and weather conditions made the fire difficult to control even though significant ground and aerial resources were deployed
  - Based on the Bickley weather station observations and the Parkerville Spot Weather forecast
    - Temperature were high 30's to low 40's, with an average wind speed of between 17 - 25 km/hr, gusting to from 26-35 km/hr
    - the Forest Fire Danger Index (FFDI) (averaged over 1 hour) peaked between 50 and 60 at Parkerville on and just following the wind change just before 11am, with a secondary peak between 40 and 50 during the early afternoon around 2pm
- DFES (2014) produced a post-fire report on the bushfire behaviour and house loss in which the following was noted:
  - The fuels were basically Eucalypt open forest with a scrub, leaf litter and patches of grass. At the time of the fire the fine fuels were reasonably homogenous in nature in that they had a consistent type and structure of fuel.
  - The fuel load was estimated to average at 15 tonne per hectare (t/ha) with a maximum fuel load estimated at 20 t/ha. These estimates were made from the unburnt pockets within the fire using standard bushfire fuel estimation techniques.
  - For their own modelling, DFES noted that as there is very little actual fuel load data available for the area in which the fire ran, a default forest fuel load of 15 t/ha has been applied.
  - Using their Aurora (Australis) fire prediction modelling, DFES predicted RoS of between 1 to 1.35 km/hr, using the BoM weather data for the 12 January 2014, commencing at 11am.
    - Additional simulations were conducted for 3.00pm, 4.00pm and 4.30pm all predicting RoS of less than 1.15 km.hr. They concluded they obtained a reasonably accurate fire prediction model.
  - One of the significant issues associated with the rate of spread and head fire intensity models is the absence of accurate fuel loads in most areas that this bushfire ran. The rate of spread and head fire intensity determinations are based on field estimations of unburnt pockets and data contained within the DFES data base, but there are significant accurate data gaps particularly on private land.
  - Based on the above, the maximum rate of spread at the Parkerville bushfire appears to be no greater than 2 km/hr.

2.3 Perth Hills bushfire (6 February 2011)

- This bushfire ignited on 6 February 2011 at around 12.30 pm on private property adjacent to the Brookton Highway. The fire resulted in 72 homes destroyed, 37 homes damaged and 32 homes within the survey area suffering no damage. At the time, this was the single biggest house loss in Western Australia to a single bushfire event.

- Within the bushfire inquiry report, Keelty (2011) noted the following:
  - Average rate of spread of approximately 1.5-1.6 km/hr with maximum of up to 3 km/hr
  - Forecast FDI of 60 for 6 February 2011
- DFES (2011) produced a post-fire report on the bushfire behaviour and house loss in which the following was noted:
  - The fuel load was estimated to average 4.5 t/ha in grassland, and 15 t/ha in forest.

2.4 Pickering Brook bushfire (15-25 January 2005)

- The Pickering Brook fire burnt on lands managed by the Department of Environment and Conservation (DEC) east of Karragullen during a ten-day period from 15–25 January 2005.
- Cheney (2010) was a published paper on bushfire behaviour in the Pickering Brook fires and noted the following:
  - Fuels ranged from 1 to 22 years old
  - Observed average rates of spread were no greater than 2 km/hr
  - The predicted maximum rate of spread using the Dry Eucalyptus Forest Fire Model (Project VESTA Mark 1) model was less than 1.8 km/hr, and Cheney concluded it predicted fire spread reasonably well over full range of fuel loads and wind speeds.
  - Fuel characteristics were as summarised below

Table 1

Fuel characteristics assigned to fuels of different ages to predict rate of spread using the FFBT and the Project Vesta equation.

Fuel age (years)	Fuel load[1] (t/ha)	Surface fuel Hazard score	Near-surface Hazard score	Near-surface fuel height (cm)
26 (west)	25	3.5	4	35
20	22.5	3.5	2.9	20
18	21	3.5	2.8	20
16	20	3.4	2.7	20
11	15	3.3	2.5	19
9	13	3.2	2.4	18
8	13	3.1	2.2	17.5
3 (west)	5.5	2.5	1.5	15
3 (east)	5.5	2.5	1.5	15
2 (east)	4	2	1.5	10

[1.] Fuel load taken from Table 6.8 FFBT (Sneeuwjagt and Peet 1985)

  - Spotting was noted to be up to 1 km ahead of the main flame front, however this is when the fire was burning in the 26 year old forest fuels.
  - Fire in 3 year-old fuel spread six times slower and was 20 times less intense than fire in 20 year-old fuel, and that the peak RoS may have been as high as 4.3 km/hr without fuel reduction strategies (prescribed burning).

2.5 Bushfire history review findings

- Review of previous bushfires provides the following information:
  - The peak FFDI during bushfires in the Perth Hills appears to be less than 60, despite FDI in *Australian Standard 3959 Construction of Buildings in Bushfire-prone Areas* (AS 3959) being 80.

- The peak observed or reconstructed RoS from past bushfires in the areas appears to be less than 3 km/hr with potential to be up to 4 km/hr in gusty conditions, but is more typically 1.5 to 2 km/hr. It is noted that the RoS for a bushfire is affected by a number of variables such as fuels, topography and weather conditions especially wind speed, with higher RoS often associated with areas of low height vegetation (grassland, shrubland) and slower RoS in treed areas such as forest.
- Forest fuel loads in the Perth Hills are typically less than the 25 t/ha (for understorey) and 35 t/ha (overall) stipulated in AS 3959.
- Ember spotting appears to be around 500 m ahead of the fire, however could be further especially where fire is through older fuels.

3. Bushfire simulation program

- The bushfire simulation program selected for use in this project is SPARK.
    - CSIRO developed SPARK to take our current knowledge of bushfire behaviour and combine it with state-of-the-art simulation science to produce predictions, statistics and visualisations of bushfire spread.
    - It can incorporate meteorological data and geographic information (e.g. land slope, vegetation and un-burnable areas) into the bushfire models, to predict spread of bushfires through the landscape.
    - SPARK can incorporate various different fire rate of spread models, depending on each fuel type or meteorological properties, with each of these models being fully programmable to permit customisation as required.
- In February 2021, it was announced that a partnership between CSIRO and AFAC, would develop a nationally consistent bushfire modelling and prediction capability. The partnership involves the development of SPARK Operational, a e bushfire simulation tool based on the current SPARK bushfire prediction program.
- Based on the above, SPARK is considered to be the most appropriate bushfire simulation program with which to conduct the modelling.

4. Rate of spread and spotting models

- The bushfire rate of spread (RoS) model selected for use in the SPARK modelling could have a significant impact on the resultant RoS, and therefore the time to impact on roads and the site.
- The 2015 CSIRO publication *A Guide to Rate of Fire Spread Models* (Cruz et al., 2015) currently recommends the use of the following fire spread models, both which have been used in the SPARK simulation modelling:
  - Dry Eucalyptus Forest Fire Model or Project VESTA Mark 1 [Cheney et al (2012)]
  - CSIRO grassland fire spread model [Cheney et al (1998)]
- Modelling of embers is also a required input into the simulation, with Cruz et al. (2015) noting that “spotting is an important, at times dominant, fire propagation process in high intensity fires in eucalypt forests” that can result in an increase in rate of spread.
- To model spotting, the maximum spotting distance was determined using the McArthur V spotting model, fitted with a calibration modifier, and code developed by CSIRO.

4.1 Dry Eucalyptus Forest Fire Model (DEFFM or Project VESTA Mark 1)

- Project VESTA was a fire behaviour study of fire behaviour in dry eucalypt forest (jarrah) fuels of different ages in Western Australia, which aimed to investigate the behaviour of moderate to high-intensity fires. Part of Project VESTA was review of the McArthur Forest Fire Danger Meter model, which was concluded to underpredict rate spread, especially when windspeeds exceeded 12.5 km/hr (McCaw et al, 2007).
- More than 100 experimental fires were conducted in the jarrah forest over three fire seasons to determine the relationship between fire behaviour and wind speed, fuel moisture content, and fuel characteristics.
- There are two fire spread rate variants of the Dry Eucalypt Forest Fire Model (DEFFM) developed by Cheney et al. (2012), one using fuel hazard score (FHS) concept, where a numerical value is used to classify fuels, and the other based on the fuel hazard rating (FHR) concept. The inputs and model calculations for both approaches are depicted in the flow chart below from Cruz et al. (2015), with the fuel hazard scores has been used for the simulation modelling

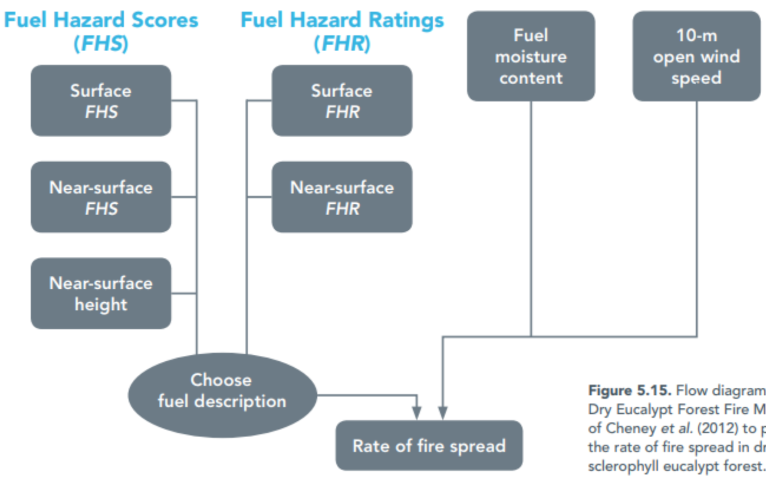


Figure 5.15. Flow diagram for the Dry Eucalypt Forest Fire Model of Cheney *et al.* (2012) to predict the rate of fire spread in dry sclerophyll eucalypt forest.

- Cruz et al. (2015) summarise the VESTA rate of spread calculation as follows:

$$R = \begin{cases} 30 \;\; \Phi M_f & , U_{10} \leq 5\text{km/h} \\ [30 + 1.531\,(U_{10} - 5)^{0.858}\; FHS_s^{0.93}\;(FHS_{ns}\, H_{ns})^{0.637}\, B_1]\; \Phi M_f & , U_{10} > 5\text{km/h} \end{cases}$$

$$\Phi M_f = 18.35\, MC^{-1.495}$$

$$MC = \begin{cases} 2.76 + 0.124\, RH - 0.0187\, T & , \text{Period } 1 \\ 3.60 + 0.169\, RH - 0.0450\, T & , \text{Period } 2 \\ 3.08 + 0.198\, RH - 0.0483\, T & , \text{Period } 3 \end{cases}$$

where Period 1 extends from 12:00 - 17:00 for sunny afternoons from October to March, Period 2 is used otherwise for daylight hours (Table 5.6), and Period 3 is applicable for night-time hours (Table 5.7).

R – rate of spread (m/hr)

U_{10} – 10 m open wind speed (km/hr)

B_1 – bias correction (constant of 1.03)

ØMf – fuel moisture function

FHS – fuel hazard score (NS – near surface, S – Surface)

MC – dead fuel moisture content (% oven-dry weight basis)

RH – Relative Humidity (%)

T – Temperature (°C)

4.1.1 Integration of VESTA into SPARK

- The VESTA rate of spread model is not preloaded into SPARK, and this had to be developed for use on this project.
- Each component/algorithm within the VESTA Mark 1 model was validated by Covey Associates in a controlled simulator environment, where the slope was set at 0° and the fuel load and weather inputs held constant.
- Code was taken from the CSIRO model homepage and the DPAW Fire Behaviour Analyst (FBAN) spreadsheet and input into SPARK in the C coding language.
- Each algorithm output in SPARK was systematically tested against the outputs of the DPAW FBAN spreadsheet and found to be identical.
- The code proven to be working correctly, was then applied into a ‘dynamic’ simulator environment for validation against historical bushfires and for use in this project.

4.2 CSIRO grassland fire spread model [Cheney et al (1998)]

- This model is based on an experimental burning project in the Northern Territory of Australia (with 121 experimental fires) to determine the relative importance of fuel characteristics and fire size on the rate of spread of grassfires.
- The studies developed a quasi-empirical model for predicting the rate of spread of grassland fires that has been used for this simulation modelling, with the inputs and model calculations summarised below from Cruz et al. (2015)

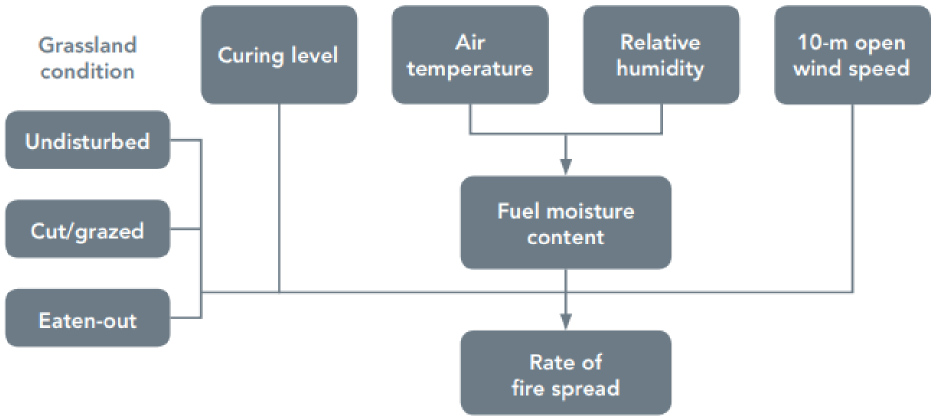


Figure 3.7. Flow diagram for the Cheney *et al.* (1998) grassfire rate of spread model.

- Cruz et al. (2015) summarise the CSIRO Grassland rate of spread calculation as follows:

$$R_{cu} = \begin{cases} (0.054 + 0.209\,U_{10})\,\phi M\,\phi C & ,U_{10} < 5\text{ km/h} \\ (1.1 + 0.715(\,U_{10} - 5)^{0.844})\,\phi M\,\phi C & ,U_{10} \geq 5\text{ km/h} \end{cases}$$

$$\phi M = \begin{cases} exp(-0.108\,MC) & ,MC < 12\,\% \\ 0.684 - 0.0342\,MC & ,MC > 12\,\%, \mathrm{U}_{10} < 10\text{ km/h} \\ 0.547 - 0.0228\,MC & ,MC > 12\,\%, \mathrm{U}_{10} > 10\text{ km/h} \end{cases}$$

$$MC = 9.58 - 0.205\,T + 0.138\,RH$$

$$\phi C = \frac{1.12}{1+59.2\,exp(-0.124(C-50))}$$ or $$\phi C = \frac{1.12}{1+59.2\,exp(-0.124(C-50))}$$

R_{cu} – rate of spread for cut/grazed grassland (km/hr)

U_{10} – 10 m open wind speed (km/hr)

ØM – fuel moisture coefficient

MC – dead fuel moisture content (% oven-dry weight basis)

ØC – curing coefficient

RH – Relative Humidity (%)

T – Temperature (°C)

4.3 McArthur V spotting model

- Due to the importance of spotting in fire propagation, a spotting model was used in the SPARK simulations, instead of relying on pure progressing surface fire front.
- The McArthur V spotting model fitted with a calibration modifier, was adopted in the code and used in conjunction with the VESTA RoS model.
  - It is noted that there is a VESTA spotting model in addition to the RoS model, however it wasn't available for use in CSIRO SPARK at the time of preparing the simulations. Covey Associates did

explore the use of VESTA spotting in SPARK, however were unable to get the VESTA spotting coding to work successfully in the simulation environment.

  - For the reasons above, the McArthur V spotting model (with CSIRO code) was adopted in the simulations, and calibrated with historical local bushfire reconstructions, to confirm appropriateness for use in this landscape.

- The model uses RoS and fuel load as the inputs, with the calibration modifier enabling iterative adjustment in order to produce short to medium range spotting (between 500- 700m) ahead of the main fire front as per official reports and observations at the Wooroloo (AFAC, 2021) and Pickering Brook (Cheney, 2010) fires. The spotting distance in the model was not capped to this distance, and spotting was only used for Forest fuels.
- In this respect, the use of spotting in the model accelerates the rate of spread and improves bushfire simulation performance in comparison to relying only on a surface fire with no spotting.

4.4 Rate of spread build-up (fire growth) phase

- Fire behaviour models aim to predict steady-state RoS as a function of a various fuel, slope and weather inputs, and while short term fluctuations are anticipated, it is expected the predicted average RoS will remain reasonably constant assuming there are no significant changes to the variable inputs.
- Gould (2007), notes that the VESTA fire spread model "…predicts potential quasi-steady state RoS for fires burning in summertime conditions for periods of 30 mins or more after the fire has undergone it growth phase".
- Based on the above, there is typically no consideration of the build-up (fire growth) phase for a bushfire to reach the steady state behaviour predicted by the model, and as such, this needs to be estimated and adjusted as part of the simulation modelling to reflect real bushfire behaviour.

4.4.1 Ignition Point

- The ignition point used in simulations is a hard coded input in SPARK, that adopts a radius 3 times the model resolution.
  - Alternative ignition point sizing approaches were reviewed by Covey Associates, however none were able to be successfully implemented.
- As the resolution for the simulations is 20 m, the resultant ignition point is 120 m wide (60 m radius) and approximately 11,304 m^2 in area (i.e. 60m x 60m x 3.14 [Pi]).

4.4.2 Bushfire build-up review

- Gould and Sullivan (2022) note that ignition and fire build-up is a complex interrelationship of numerous variables including fuel moisture content, fuel surface area and structure (i.e. continuity of understorey fuel strata), combustion rate and burn-out time of fuels, surface wind speeds, atmospheric instability, topography, and the spotting process. They also provide the following comments regarding the initial growth of bushfires:
  - There is currently limited knowledge on the build-up phase of fires from point source ignitions.
  - There are few empirical studies of point source fire growth, and are typically studies in laboratories or experiments under moderate fire behaviour (to avoid igniting an uncontrollable bushfire).
  - There are very few conceptual models for the development of bushfires from ignition, but those that do exist include models proposing:
    - a series of steps or jumps as successive layers of elevated fuel in the forest ignited

  - a more continuous relationship, often asymptotic, with fire growth accelerating early after ignition towards a steady-state RoS
  - a combination of the two relationships, depending on fuel structure, weather and topographic conditions.

- Cheney and Gould (1995) note that the time taken for a point source fire in any fuel to reach steady-state RoS varies considerably, and depends on the rate of development of flame into the fuel bed, the rate of development of a convective plume and the rate of development of head fire width.
  - These processes may occur within a few minutes of ignition in a fine homogenous fuel bed such as grassland, but can take much longer (an hour or more) in deep heterogeneous fuel beds with variable structure and fuel moisture content such as forests
- Gould et al (2003) note the following:
  - Fire in dry eucalypt forest must be wide enough, or allowed to develop to significant size, in order to validate fire spread models designed to predict the fire spread of bushfires at high wind speeds. Factors that may restrict forest fire growth from developing to a sufficient size to produce a steady-state RoS predicted by models include:
    - Fuel structure and continuity (e.g presence of logs, rocky areas and trails) which can restrict the development head fire width, particularly in heavy fuels.
    - Variation of the in-forest wind speed due to differences in overstorey and understorey density, which may restrict fire development
  - Forest fires can maintain steady RoS that are well below their potential RoS (i.e. RoS predicted by model), for several hours during the build-up phase, but can increase in intensity rapidly if conditions change to create a wide head fire (e.g. wind changes).
- Gould and Sullivan (2022) note fire growth patterns in eucalypt fuels to be extremely variable, with fires burning under mild conditions often reaching steady-state spread quickly (i.e. relatively rapid growth to achieve lower RoS) but under more severe burning conditions, the build-up phase to reach steady spread is likely to take longer (i.e. slower relative growth to achieve higher RoS).
- Gould and Sullivan (2022) conducted some preliminary laboratory investigation and analysis of fire growth in dry eucalypt litter from point and line ignition sources under consistent airflow (in a wind tunnel), to investigate fire growth under repeatable burning conditions in order to develop a model to quantitatively predict the time required to reach steady rate of spread.
  - Despite best efforts to avoid variability, the results exhibited a high degree of variability in the observed rate of spread possibly due to changed in temperature, relative humidity in the laboratory, variation in fuel uniformity, and the variable nature of the combustion of natural cellulosic fuels. This resulted in it making it difficult to define what conditions are required to reach steady-state RoS.
  - The insights gained from laboratory studies need to be evaluated and validated against field-scale observations, and the times to reach the steady-state RoS observed in the experiments appears to be inconsistent with field observations where fires burning under more severe conditions and a faster steady-state RoS, took longer to reach steady-state than fires burning under milder conditions with slower steady-state RoS. Potential causes for the inconsistency could include:
    - the highly variable and turbulent winds measured under a forest canopy compared with the laminar and constant direction air flow in the wind tunnel.

- the lack of multilayered fuel strata in the laboratory experiments do not reflect the fuel characteristics of a typical dry eucalypt forest and thus the incremental development of fires through different fuel strata
- The study concluded it is first step to review fire growth in dry eucalypt fuel, and is not a definitive analysis, with further work to be conducted to provide a guideline for estimates for fire growth.

4.4.3 Build-up phase adopted for modelling

- Based on the review above, it is clear that the time taken for a bushfire to progress from ignition to the steady state RoS predicted by the fire behaviour model, is poorly understood and subject of much conjecture, however the following is considered important to note:
    - The DEFFM (or VESTA) fire spread model makes no allowance for the build-up phase
    - The few conceptual models that do exist for fire growth from point source ignition, propose stepped or continuously increasing RoS
    - The growth of a bushfire in forest under severe burning conditions, with a high predicted RoS, is likely to take a longer time to reach the steady-state RoS (often above an hour), and may achieve and maintain a steady state RoS that is less than the predicted RoS for several hours.
    - The build-up phase for fires under mild conditions is still poorly understood, even under controlled laboratory conditions, with no definitive relationship developed yet.
- In addition to the limitations on growth phase understanding detailed above, the size of ignition point required to be used in SPARK is 120 m wide and over 1 ha in area, and is more representative of a fire that has already moved through the growth stage, rather than a point source ignition (e.g. spark, cigarette etc).
    - In the SPARK simulation environment, the ignition point size is approximately 5-6 grid cells, and is similar to proposed "line" ignition across several grid cells.
- Based on the above, the following build up phase characteristics were adopted for these simulations:
    - Time to reach 100% RoS of 45 minutes
        - This is based on the large size of the ignition point (120 m wide; >1 ha in area) already representing a developed bushfire, as well as the uncertainty relating to the build-up time, with literature indicating extended timeframe (over 1 hour but up to several hours) to achieve 100% RoS for high RoS.
    - A continuous linear RoS relationship
        - This is based on the large size of the ignition point as well as the uncertainty associated with the growth phase relationship, especially for forest fires with high RoS. While there may be some asymptotic acceleration, there appears to be limited evidence to support this as a definitive relationship.
        - The linear relationship adopted is based on the build-up phase equation provided by CSIRO for SPARK as follows,

          Speed Factor = 0.1 + 0.9*(time step/total build up phase time)

          Speed Factor is the proportion of maximum RoS

          Time step = time (seconds)

          Total build up phase time = 2700 seconds (45mins)
    - The linear build up phase to achieve 100% RoS is depicted in Plate 1.

- This linear relationship ensures 50% RoS after 22.5 minutes, for modelled peak RoS which are already conservative when compared to the historically peak RoS seen for Perth Hills bushfires in the first few hours.
- The build-up phase is important to incorporate into the simulations to address the unrealistically large ignition point, and also to represent real-life bushfire behaviour as best as possible, which does have a build-up phase in the incipient stage although it is acknowledged this is poorly understood in dry eucalypt forest.
- The build-up phase adopted is considered to represent an appropriate balance between conservatism and reality..

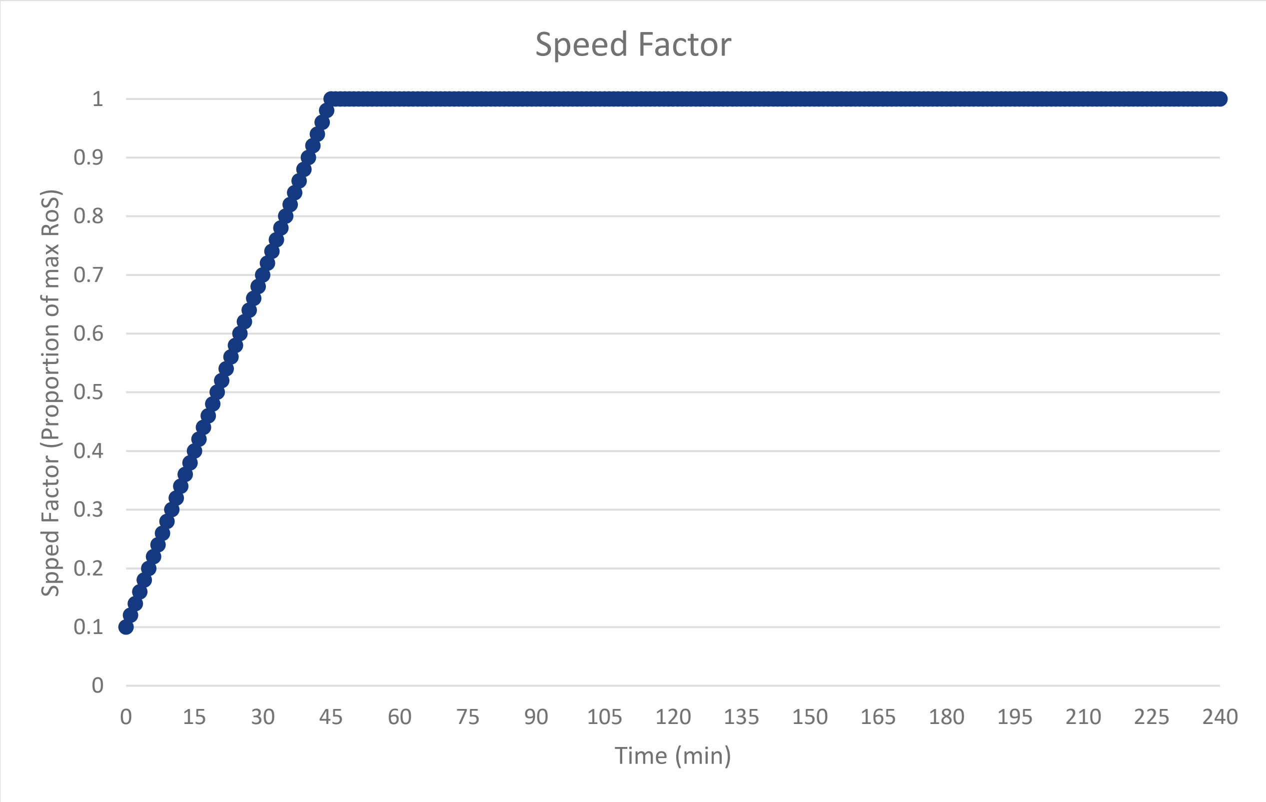


Plate 1: Build up phase

5. Design bushfire scenarios

5.1 Fire run direction and ignition point location

- The objective of the bushfire simulation modelling is to inform the evacuation analysis by determining the time it will take various design bushfires, represent the "worst-credible" bushfire scenarios, to impact both the study area for the traffic modelling (which is bounded by main public roads) and the SP 34 site itself, based on historical, current and projected conditions.
- Transcore (2024) have produced the Microsimulation Evacuation Modelling Report for the project, which identified four (4) bushfire scenarios that could result in closure of one of the major evacuation corridors, namely Great Eastern Highway or Toodyay Road:
  - Bushfire approaching on a north-easterly fire run (ignition to the south-west of the site)
  - Bushfire approaching on a south-easterly fire run (ignition to the north-west of the site)
  - Bushfire approaching on a south-westerly fire run (ignition to the north-east of the site)
  - Bushfire approaching on a north-westerly fire run (ignition to the south-east of the site)
- The ignition locations for each design bushfire scenario need to be sufficiently far from the site, to impact the main public roads of the traffic study area, but also to enable the bushfire to be of sufficient size to warrant full evacuation of North Stoneville and the surrounding local area.
- Based on the above criteria, ignition locations approximately 6.5 to 7.0 km from the SP 34 site, put the fire on the traffic study area boundary for the north-east and south-east scenarios. This would result in bushfire impact to either Great Eastern Highway or Toodyay Road reasonably quickly after ignition, while still producing head fire widths several kilometres wide at the site, sufficient to warrant such large-scale evacuation of North Stoneville and the surrounding local area. These approximate distances for the ignition locations from the SP 34 site, have used to define the south-west and north-west ignition locations.
- The nominated ignition locations and are depicted in 0.
- It is noted that there is potential for significant bushfire behaviour from the east and west of the site, however as fires from these directions would not directly impact the major evacuation roads, these have not been assessed as part of this evacuation analysis.

5.2 Bushfire Weather Recurrence Rate

- The objective is to identify the "worst-credible" bushfire scenario/s likely to impact on the development and road networks, which is achieved by identifying a recurrence period bushfire event based on historical, current and projected conditions.
- A 1:50 year recurrence rate for a bushfire event is considered appropriate for a residential subdivision and aligns with the design fire weather specified for Class 1 buildings in accordance the National Construction Code (ABCB, 2019).
- Each of the 4 design bushfire scenarios will be simulated for the following bushfire weather predictions:
  - 1:50 year projection (without climate change factored)
  - 1:50 year projection (including climate change based on 25 year projection)

6. SPARK modelling inputs

- In order to develop the simulation environment within SPARK, the following inputs were required:
  - Overall study area
  - Land use and vegetation
  - Slope and terrain
  - Fuel characteristics
  - Weather and climate characteristics
- The following sections provide a summary of how these inputs were determined.

6.1 Bushfire modelling study area and resolution

- A study area of approximately 50 km circular area was created surrounding the proposed North Stoneville development site and traffic study area.
- A resolution of 20 m was adopted for the SPARK simulation model.

6.2 Land use and vegetation mapping

- To produce the landscape and vegetation mapping used for the simulations, the following data sets were imported:
  - SENTINEL 2 imagery
    - provides a 10m land use model, classified into 9 classes, differentiating built areas, forest (treed) areas and water features
  - Native vegetation extent (DPIRD-005)
    - Provides current remnant vegetation extent polygons from the mapping of remnant vegetation in Western Australia
  - DBCA Pre-European vegetation (DPIRD-006)
    - Pre-European physiognomic vegetation types, sourced from DBCA, representing an amalgamation of the Beard vegetation mapping into broader vegetation structures/types
  - Urban Forest Mesh Blocks - 2018 (DPLH-073)
    - Uses CSIRO’s Urban Monitor high resolution digital photography, to classify the vegetation cover at a local scale
  - Roads
- Using the data sources above, the mapping has divided the landscape into the following classifications:
  - Jarrah (Eucalyptus marginata), banksia (Banksia spp.) or casuarina (Allocasuarina spp.)
  - Jarrah (Eucalyptus marginata), marri (Corymbia calophylla) and wandoo (E. wandoo)
  - Mainly jarrah (Eucalyptus marginata) and marri (Corymbia calophylla)
  - Built Area (including rural residential land uses)
  - Crops
  - Grass

  - Water
  - Bare ground
- To reflect the observed vegetation classifications more accurately throughout the study area, further processing of the vegetation data sets was conducted to identify areas of tree cover and vegetation:
  - Where vegetation was identified, it was assigned as either Grass or one of the forest classifications, depending on presence of tree cover.
  - Any remaining land is designated Built Area, and while it is the best that could be achieved with the available data sets, it is more aligned with on ground observations.
- The land classification map is attached in 0.

6.3 Slope and terrain analysis

- A suitable digital elevation model (DEM) has been developed for the assessment area using LIDAR data (1 second DEM) obtained from the open-source Elevation Information System (ELVIS; Geoscience Australia).
- The slope analysis plan is depicted on Attachment 4.

6.4 Fuel characteristics

- The VESTA and CSIRO Grassland rate of spread models being used for the simulation require the following inputs relating to the fuels:
  - VESTA (Cheney et al 2012)
    - Surface Fuel (hazard score)
    - Near Surface Fuel (hazard score)
    - Near Surface Fuel height (centimetres)
  - CSIRO Grassland (Cheney et al 1998)
    - Curing level (%)
    - Grassland condition (Undisturbed, Cut/Grazed or Eaten Out)
- The lack of detailed vegetation, fuel load and fuel age data available for the Perth Hills represents a considerable challenge, one recognised by DFES (2014) in the Parkerville post-fire report:

  "one of the significant issues associated with the rate of spread and head fire intensity models is the absence of accurate fuel loads in most areas that this bushfire ran. The rate of spread and head fire intensity determinations are based on field estimations of unburnt pockets and data contained within the DFES data base, but there are significant accurate data gaps particularly on private land".
- This lack of detailed data results in a relatively coarse land classification, which is the best that can be achieved with the information publicly available, and which could only be improved with significant survey or fieldwork over the study area.
- A variety of sources were reviewed in order to assess the most appropriate fuel characteristic inputs for this simulation, and this information is summarised in Table 1.

Table 1: Fuel Characteristic options review

Fuel characteristic	Potential Sources
VESTA (Forest) model inputs	
Surface Fuel (Hazard Score)	• 3.4 Hazard Score (30 years since fire, Tall Shrubby Forest) (Gould et al, 2011) • 3.3 Hazard Score (30 years since fire, Low Shrubby Forest) (Gould et al, 2011) • 3.5 Hazard Score in 26 year old Jarrah fuel(Cheney, 2010) • 14 t/ha steady state surface fuel load (tall shrubby forest) (Gould et al, 2011) • 8 t/ha to 16-17 t/ha in Jarrah Forest (low to high rainfall) (Burrows, 2020)
Near-Surface Fuel (Hazard Score)	• 3 Hazard Score (30 years since fire, Tall Shrubby Forest) (Gould et al, 2011) • 2.8 Hazard Score (30 years since fire, Low Shrubby Forest) (Gould et al, 2011) • 4 Hazard Score in 26 year old Jarrah fuel(Cheney, 2010)
Near-Surface Fuel Height (cm)	• 12cm in 20 year old fuel(Cheney, 2010) • 8cm in 3 year old fuels (Cheney, 2010) • 35cm in long unburnt fuel (Cheney, 2010) • 23cm in 30 year unburnt fuel (Tall Shrubby Forest) (Gould et al, 2011) • 20cm in 30 year old unburnt fuel (Low Shrubby Forest) (Gould et al, 2011) • 35cm in 26 year old unburnt fuel 26 year old Jarrah fuel (Cheney, 2010)
Fuel Load	• Forest 15t/ha (DFES, 2011) • Jarrah and Marri Forest 15t/ha [average] and 20t/ha [max] (DFES, 2014) • Northern Jarrah Forest 7-10t/ha [situational analysis] (DFES, 2014) • Jarrah Forest 25t/ha in 26 year old Jarrah fuel (Cheney, 2010) • 22 t/ha in Jarrah Forest after 20 years (Burrows, 2020) • Forest (understorey) 25t/ha (AS 3959, 2018)
Grassland model inputs	
Curing level	• 70-90% (Cruz et al., 2015) • 80% (Swedosh et al 2018)
Grassland Condition	• Eaten out, Cut/grazed or Undisturbed (Cruz et al., 2015) • Cut/grazed (Swedosh et al 2018)
Overall Fuel Load	• 4.5t/ha (DFES, 2011) and (DFES, 2014)

6.4.1 Calibration simulations

- The information in Table 1 provided a starting point for determining the various fuel characteristic inputs, however given the relative lack of detailed data available, it was also necessary to calibrate against the reconstructed historical bushfires to ensure appropriate inputs were being used in the simulations.
- This was achieved by iteratively refining various fuel characteristic inputs, in conjunction with the RoS models, and comparing the outcome with the isochrones from historical bushfires to ensure a relatively reliable simulation output would be achieved.

- It is important to understand that the 3 land use classifications adopted for the simulations (Forest, Grass and Built Area) are blended classifications that represent the dominant vegetation or land use based on the data available. These 3 classifications will include other vegetation types, or built area, and as such, the input characteristics derived as part of the calibration process, reflects this variable nature.

6.4.2 Adopted fuel characteristics

- The fuel characteristics adopted for the simulation modelling are summarised in Table 2:
  - Calibration fuel state
    - The resultant optimal fuel characteristics from the calibration simulations and is considered to be the most accurate representation of likely fuel characteristics for this land use mapping.
    - This fuel state was used for comparative purposes only
  - Conservative fuel state
    - Adopts more conservative fuel characteristic inputs than the Calibration fuel state (see Table 1) to represent potential for greater available fuels.
    - Assumes greater grass curing and condition than Calibration fuel state, as well as greater forest fuel loads, that could be possible in peak bushfire season.
    - This fuel state is used for the time to impact analysis.

Table 2: Adopted Fuel Characteristics

Fuel Characteristics	Forest	Forest	Grass
Rate of Spread Model	**DEFFM (VESTA)**	**DEFFM (VESTA)**	**CSIRO Grassland**
Land classifications included	Jarrah and Mainly Jarrah	Built Area	Crops, Grass
Calibration Fuel State			
Fuel Age	10 years	N/A	N/A
Spotting	Yes	No	No
VESTA (Forest) model inputs			
Surface Fuel (Hazard Score)	3.3	2.0	N/A
Near-Surface Fuel (Hazard Score)	2.9	1.0	N/A
Near-Surface Fuel Height (cm)	23 cm	2 cm	N/A
Grassland model inputs			
Curing level	N/A	N/A	67%
Grassland Condition	N/A	N/A	Eaten-out
Fuel Load (t/ha)	***21.6 t/ha[1]***	***4 t/ha[2]***	***4.5 t/ha***
Conservative Fuel State			
Fuel Age	25 years	1 year	N/A
Spotting	Yes	No	No

Fuel Characteristics	Forest	Forest	Grass
VESTA (Forest) model inputs			
Surface Fuel (Hazard Score)	3.4	2.0	N/A
Near-Surface Fuel (Hazard Score)	3.0	1.0	N/A
Near-Surface Fuel Height (cm)	23 cm	2 cm	N/A
Grassland model inputs			
Curing level	N/A	N/A	90%
Grassland Condition	N/A	N/A	Cut/grazed
Fuel Load (t/ha)	***22.7 t/ha[3]***	***4 t/ha[2]***	***4.5 t/ha***

The noted understorey fuel loads included the following, which it is noted has no impact on VESTA RoS modelling

[1] 3.5 t/ha for elevated and bark fuels

[2] 1.0 t/ha for elevated and bark fuels

[3] 3.7 t/ha for elevated and bark fuels

6.4.2.1 Forest fuels

- The VESTA rate of spread model was applied to all three (3) jarrah land classifications (see 0).
- All three jarrah classifications were assigned a consistent forest fuel characteristic, rather than trying to assign different fuel characteristics to each classification
- The Calibration fuel state characteristics derived are based on Exponential Model for Tall Shrubby Forest, using 10 year old fuels, from Gould et al (2011).
- The Conservative fuel state characteristics assigned for the forest classification are based on Exponential Model for Tall Shrubby Forest, using 25 year old fuels, from Gould et al (2011).
- Spotting was modelled from forest classification.
- No allowance has been made for potential reduction in fuel accumulation rates and fuel loads due to rainfall decreases in a drying climate (Burrows, 2020).

6.4.2.2 Grassland fuels

- The CSIRO grassland model is applied to areas identified as Grass or Crops, where it was considered likely that unmanaged grassland would exist. The extent of cropping in the fire simulation area is limited.
- The Calibration fuel state characteristics derived for the grassland classification is a condition of Eaten Out with a curing level of 67%.
- The Conservative fuel state characteristics adopted for the grassland classification is a condition of Cut/Grazed and it is assumed that there will be a high-level of summertime curing of 90%. This is consistent with the grassland characteristics used as part of the SPARK evaluation report (Swedosh et al, 2018) which adopted Cut/Grazed condition and 80% curing for its reconstruction of the Pickering Brook bushfire.
- No spotting was modelled from the grassland classification.

6.4.2.3 Built area

- The assignment of fuel characteristics to the Built Areas is a significant challenge, given the diversity of land uses and vegetation types and structures across this classification.
- Several trial calibration simulations were conducted using various fuel inputs as part of the historical reconstructions, to obtain a reasonable level of alignment with the Parkerville and Wooroloo fires.

- The Calibration fuel state characteristics derived for the Built Area classification was based on a bespoke forest fuel load breakdown with an overall fuel load of 4 t/ha, which is considered appropriate given the high-level of non-vegetated elements and significant clearing and vegetation modification, within this land classification.
- The Conservative fuel state characteristics adopted for the Built Area classification are the same as that for the Calibration fuel state, given little is expected to change in this classification.
- No spotting was modelled from the Built Area classification.

6.4.3 VESTA Hazard Scores

- To conduct the SPARK simulations, fuel load data was required to be inputted into SPARK and converted to VESTA Hazard scores. The Exponential fuel model developed by Gould (2011) in Jarrah Forests to determine VESTA Hazard Scores and equivalent t/ha fuel load was adopted for this purpose. An EXCEL calculator was developed to determine the required fuel characteristics (refer to Plate 2) based off age class, with an age of 25 years adopted for forest vegetation (Conservative fuel state).

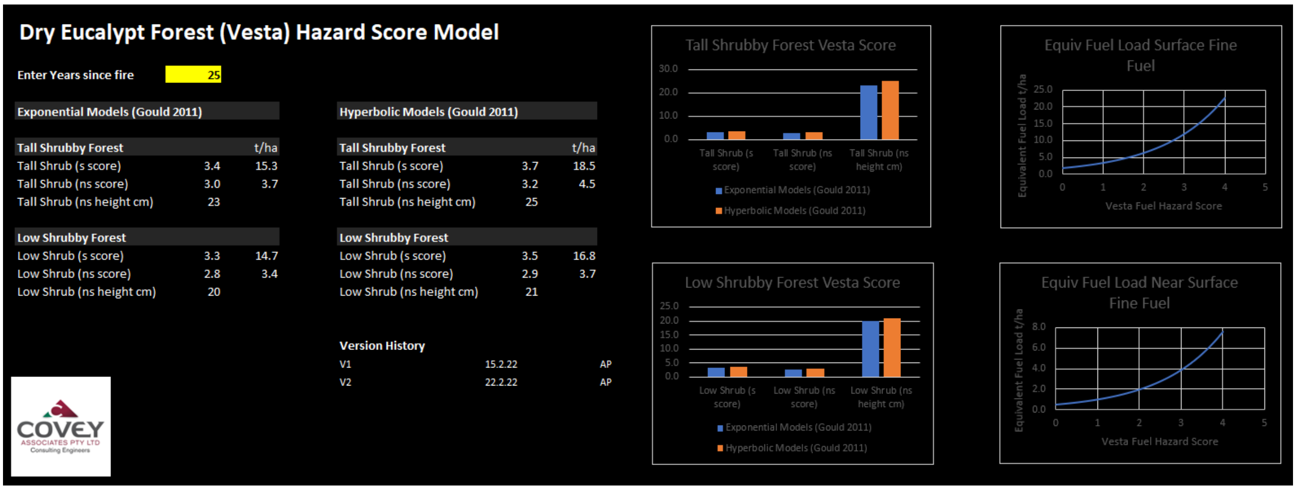


Plate 2: Calculator to determine Vesta Hazard Scores and fuel load based on age class (25yr forest shown)

6.5 Fuel and RoS calibration and validation (bushfire reconstructions)

- Given the lack of detailed vegetation and land-use data sets available to accurately determine fuel characteristics or loads for vegetation in the study area, it was considered that reproducing significant historical bushfires in the area, would be the best method of calibrating and validating that the fuel characteristics adopted for these simulations, in conjunction with the selected RoS models, to determine they would produce a realistic and relatively reliable result.
- The two historical bushfires selected for the reconstructions were Parkerville (January 2014) and Wooroloo (February 2021), given they had occurred relatively recently and near the SP 34 site.
- The calibration process involved iteratively adjusting the preliminary inputs, especially with respect to the Built Area fuel characteristics and spotting distances, to reproduce the two historical bushfires selected as accurately as possible, with focus on:
  - Extent and rate of spread (isochrone comparison)
  - Broad bushfire fire shape, noting that suppression activities will likely have altered the actual bushfire extent
- The results of the calibration process revealed that two RoS models were required to obtain alignment with both historical fires using the same fuel characteristics:

- Growth RoS model
  - aligned well with the Parkerville fire and the first 7 hours of Wooroloo bushfire using the Calibration fuel state.
  - under-predicted the more mature Wooroloo fire after the 7 hour isochrone, where the RoS was slower than the actual bushfire after 17 and 25 hours.
  - required a lesser spotting distance in the modelling to better replicate lesser RoS in the earlier stages of the bushfire, and requires a calibration modifier for spotting of 80% of that of the Mature RoS model.
- Mature RoS model
  - aligned well with the 17 to 25 hours of the Wooroloo bushfire
  - over-predicted the Parkerville and 7 hour Wooroloo bushfires
  - required greater spotting distances in the modelling to better replicate increased RoS, likely driven by greater spotting, and has a calibration modifier for spotting that is 20% greater than Growth RoS.

- While it is noted that reconstructing a bushfire using the current simulation tools is unlikely to produce an exact match, the reconstructed fires do have solid alignment with the historical bushfires, both in terms of extent and rate of spread, when using the Calibration fuel state in conjunction with the appropriate RoS model (Growth or Mature).
- On this basis, the Mature RoS model and Conservative fuel characteristics were adopted in the design fire simulations for the evacuation analysis, and are expected to provide relatively reliable representations of expected bushfires.
  - Given the Growth RoS Model and Calibration fuel state provides the better alignment with historical bushfires in the first 4 hours, some analysis has been conducted using these inputs for comparative purposes.
- The reconstruction simulations are shown in 0 and G, and use the actual BoM weather data from Bickley weather station from the day of the bushfire. Comments on each historical bushfire comparisons, and the overall results, are provided below.

6.5.1 Parkerville bushfire comparison

- The Parkerville isochrone data is obtained from information provided in the DFES (2014) post-fire report, which provided an approximate fire extent at various time- steps as well as intelligence on possible fuel loads at the time of the fire.
- A small 10 degree wind shift was employed to better align the wind direction with the observed fire run direction, in order to better assess the RoS comparison. No other changes where made to the weather inputs.
- Using the Growth RoS model, the simulation performed well, generally matching the direction, overall RoS, burnt area and overall progression of the actual fire.
- The SPARK simulation slightly underpredicts the 1 hour isochrone, and slightly overpredicts at the 2, 3 and 4-hour isochrones, approximately 250 m overprediction at the 4-hour mark, however this is considered to be acceptable on the basis it represents a conservative modelling assumption.
- While the shape of the reconstructed bushfire is wider than the actual fire, likely the impact of suppression activities along the flanks, the overall shape is similar and shows alignment with some of the fingers that spurred from the main fire, albeit not as fully developed in some instances.

- A simulation using the Mature RoS model derived from the latter stages of the Wooroloo fire was also trialled, however the extent of the fire after 4 hours was significantly overpredicted, similar to that for the early stages of the Wooroloo fire.

6.5.2 Wooroloo bushfire comparison

- The Wooroloo isochrone data is obtained from information EmergencyWA, which provided an approximate fire extent at various times. These have been provided in 0 for reference.
  - As previously acknowledged, the use of the EmergencyWA burnt area maps is not as accurate as isochrone mapping from a post-fire investigation, however as isochrones are not yet publicly available at the time of preparing this report, this methodology was considered the best approximation of the bushfire extent.
  - There is limited information regarding the extent of the fire in the initial stages, with the first EmergencyWA fire extent at 7.05 pm. The only information available a statement on Wikipedia that the fire allegedly took 4 hours to burn out the first 230 ha. Assuming this is broadly correct, the fire most likely spread 2-3 km in the first 4 hours, but it is noted this is not confirmed.
- The comparison in the bushfire extent at various timeframes is shown on Table 3:

Table 3: Bushfire extent comparison

Timeframe	Actual bushfire	Reconstructed bushfire (Growth RoS)	Reconstructed bushfire (Mature RoS)
4 hr	2-3 km	6.8 km	8.1 km
7 hr	13.25 km	13.5 km (with spotting to 14.3 km)	16.3 km
17 hr	25.25 km	N/A	23.6 km
25 hr	28.6 km	N/A	28.2 km

- Using the Growth RoS model (same as Parkerville reconstruction)
  - The reconstructed bushfire is certainly quicker in the initial stages shown by the overprediction in RoS in the first 4 hours, which could be a function of poor data on the actual extent of the fire at this stage, but could also be impacted by having a longer build-up phase and/or lesser spotting characteristics.
  - Is well aligned at the 7 hour mark, with the fire extent and shape similar to the actual fire extent, albeit a little further south and the shape slightly wider likely due to lack of simulated suppression impact.
- Using the Mature RoS model
  - The reconstructed fire using this model certainly overpredicts RoS in the first 4 and 7 hours, however is better aligned at the 17 and 25 hour marks.
  - Similar to above, the overall shape is wider, especially at the 25 hours mark, however there is evidence of the various localised effects on the shape, especially at the head of the fire at 25 hour mark, where localised fingers appear at similar positions to the actual fire.
- Both Growth and Mature RoS models provide conservative results up to the 7 hour mark, which overpredict the RoS at both 4 and 7 hours. The use of the Growth RoS model is not considered appropriate after the 7 hour mark where it begins to underpredict RoS once spotting takes a greater

role in fire progression, however the Mature RoS model provides good alignment with the actual bushfire in these later stages.

- Similar to the Parkerville reconstruction, the shape of the reconstructed bushfire is wider than the actual fire, likely the impact of suppression activities, particularly on the southern flank, however the overall shape is considered to be relatively aligned with that of the actual fire. The fire did continue to burn for several days following this reconstruction, which could account for some of the additional burned areas to the north.

6.6 Bushfire Weather analysis

- Bushfire behaviour, including rate of spread, is significantly affected by weather prior to, and during a bushfire.
- The SPARK simulation requires a weather profile of exact weather variables (temperature, relative humidity, windspeed and drought factor) over time steps to be inputted, to enable the rate of spread modelling to be conducted incrementally across the simulation.
- The objective of this bushfire weather analysis is to determine what the predicted 1:50 year weather conditions are, including an allowance for potential climate change impacts, to produce weather profile inputs suitable for the SPARK simulation.
- As defined in Section 1.2, Forest Fire Danger index (FFDI) is a non-dimensional index that represents the weather variables of temperature, relative humidity and wind speed, with the availability of fuel for combustion represented by Drought Factor based on rainfall and evaporation.
- Douglas et al (2014) propose the use of Generalised Extreme Value (GEV) analysis, utilising maximum daily FFDI values derived from site-specific data (e.g BoM weather stations), to establish the annual exceedance probability (AEP) of FFDI (i.e. FFDI at various recurrence rates) for application to bushfire events. This approach can also be applied to other weather variables, such as temperature and relative humidity, to determine likely future peak values for these variables for various recurrence rates (e.g. 1:50 year).
- Douglas and He (2019) details a methodology for using a Moving Average GEV analysis of FFDI, to determine the potential impacts of climate change on future FFDI.

6.6.1 Analysis Methodology

- The following analysis methodology was undertaken to determine the SPARK simulation weather profiles, using BoM data from the Bickley weather station:
  - Calculate daily FFDI using maximum daily temperature, 3 pm relative humidity and wind speed, and the daily Drought Factor. This was used for the GEV analysis of FFDI.
  - Calculate hourly/half-hourly FFDI using temperature, relative humidity and wind speed measured at the time, and the daily Drought Factor. This information is primarily for wind speed analysis.
- Conduct a GEV analysis of the historical daily FFDI across the Bickley data set, to determine the 1:50 year FFDI.
- Conduct a Moving Average GEV analysis of 1:50 year FFDI at Bickley, to determine the impact of climate change on 1:50 year FFDI at 25 year projection.
  - This undertaken by analysing the 1:50 year FFDI trend across 14 moving windows (each window 10 years long) across the 23 year data set.
- Conduct GEV and Moving Average GEV analysis of peak temperature and relative humidity readings, to determine the 1:50 year values for these weather variables.

- Analyse the average wind speeds during times of high FFDI, to gain an understanding of anticipated average wind speeds.
- Use the FFDI, temperature, relative humidity and wind speed analysis, to inform the creation of the weather profiles by using a historical weather profile from a high FFDI day to provide the numerical basis for each weather variable, and enable creation of the future weather stream.

6.6.2 BoM Data

- There are some significant gaps and errors in the Bickley data set as follows:
    - Occasional missing temperature readings
    - Significant numbers of missing relative humidity and wind speed readings
    - Significant number of very low relative humidity readings (1-4%) that are accompanied by very low dew points (typically between -15° and -46°), often not associated with extremely high temperatures, and which are substantially lower than relative humidity readings at Perth Airport (Station Number 9021) at the same time.
- No adjustments were made to the BoM data sets for purposes of gap filling or error correction, however analysis of the relative humidity trends using the Bickley data set was refined, and supplemented by additional analysis using Perth Airport data.

6.6.3 Results

- The bushfire weather analysis and results are provided in 0, with the results summarised below.
- FFDI GEV ***and Moving Average GEV Results (for 1:50 year event)***
    - FFDI 60.6 (1:50 year from GEV with no climate change factored in)
    - FFDI 74.9 (1: 50 year with 25 year climate change projection from MA GEV)
    - The above were calculated using GEV and Moving Average GEV analysis of the daily FFDI.
    - Although the use of the Bickley MA GEV projection has a high level of uncertainty as it is uses 10 year moving windows instead of the recommended 20 year window (Douglas, 2019), and also given the data set is only 23 years long, it is the most appropriate data set to use given its location.
    - While use of the hourly/half hourly FFDI data was not used for the FFDI analysis due to the significant issues with the relative humidity data across the data set (it was calculated for wind speed analysis), the highest credible FFDI result obtained from hourly/half hourly FFDI calculations is FFDI 62.1.
- Temperature GEV and Moving Average GEV Results (for 1:50 year event)
    - 41.8°C (1:50 year from GEV with no climate change factored in)
    - 44.0°C (1: 50 year with 25 year climate change projection from MA GEV)
- Relative Humidity GEV Results (for 1:50 year event)
    - Given the issues with the relative humidity data at Bickley, as outlined above, conducting a GEV or Moving Average GEV analysis across the entire data set was not possible.
    - To provide an indication of anticipated 1:50 year relative humidity, a GEV analysis was conducted using the Bickley relative humidity data from 2017 to 2021 and produce the following:
        - 3.6% (1:50 year)
        - Lowest recorded relative humidity was 6% across these 5 years

  - Given the small data set size, a GEV analysis was also conducted using Perth Airport data from 1999-2021, which is a more reliable data set, and appeared similar to the Bickley readings although typically a little lower on high FFDI days:
    - 3.7% (1:50 year)
    - Lowest recorded relative humidity was 4% across these 23 years
- Windspeed Analysis Results
  - Analysis of windspeeds was conducted using times where the FFDI was greater than FFDI 25, determined using the hourly/half hourly Bickley data set
    - Average windspeed is 21.1 km/hr on days with FFDI >25
    - Average windspeed plus 1 standard deviation is 28.3 km/hr

6.6.4 SPARK Weather Profiles

- The aim of the weather analysis conducted above, was to inform the selected weather profile/s to be used in the SPARK simulations.
- Based on the FFDI analysis results above, the following two scenarios are to be modelled:
  - FFDI 62.1 - 1:50 year event without climate change projection (base case)
    - While FFDI 60.6 was calculated using the daily FFDI results from Bickley, given there has been a FFDI 62.1 actually occur (as determined by hourly/half hourly FFDI calculations) it was decided to use this as peak 1:50 year event as a slightly more conservative approach
  - FFDI 74.9 - 1:50 year event which includes 25 year climate projection (sensitivity case)
    - As calculated using the Moving Average GEV for Bickley
- The challenge with creating future weather streams, is the relative proportion of each of the variables contributing to achieve the nominated FFDI (i.e. 62.1 and 74.9). To overcome this both FFDI's are to be proportionally altered against a "real" weather profile from a high FFDI day, which provided the relative distribution of the variables, while also enabling simulation of a realistic bushfire event, rather than at a constant peak FFDI.
  - The weather profiles of various peak FFDI days were reviewed, to find one that displayed a sustained FFDI across multiple hours, as well as an onerous combination of temperature, relative humidity (and dew point) and wind speed, all on a day with a Drought Factor of 10.
  - A review of the highest historical FFDI days was conducted and:
    - 14th December 2019 (see Table 5) was selected as the weather profile to be prorated against, with the simulations conducted using the time between 1pm and 5pm.
    - 3 February 2007, the day on which the FFDI of 62.1 was recorded, was considered but this day doesn't have a sustained FFDI over several hours (the FFDI either side of the 62.1 are 31.2 and 36.4), and has a low relative humidity of 12%, so it wasn't considered appropriate in this instance.
  - The prorating process involved proportionally adjusting the FFDI, temperature and relative humidity to the peaks shown in Table 4, then altering wind speed to achieve the peak FFDI.

Table 4: Peak weather variables for nominated design bushfire FFDI's

FFDI	Peak Temperature	Peak Relative Humidity	Drought Factor
62.1	39.0°C	6%	10
74.9	42.0°C	4.5%	10

- The prorated weather profile for FFDI 62.1 is depicted on Table 6, with a comparison graph shown on Plate 3.
  - To achieve the target FFDI, given the closeness to the existing 14th December 2019 peak of FFDI 56.7, a small increase in temperature and wind speed is all that is required especially given the relative humidity on the day was already at a record low.
- The prorated weather profile for FFDI 74.9 is depicted on Table 7, with a comparison graph shown on Plate 3.
  - More significant adjustments to the base weather variables are required to achieve the target FFDI of 74.9, compared to that required to achieve FFDI 62.1, which is more of a challenge given the linear regression that derives the FFDI 74.9, doesn't align with the logarithmic regressions for temperature and relative humidity.

- To address this, the analysis conducted for temperature and relative humidity was considered to provide a range as follows, with the objective to use input values that would result in moderate increases in wind speed:
  - Temperature: 41.8°C to 44.3°C
  - Relative Humidity: 3.6% to 6%

Table 5: Weather profile from 11.00 to 18.30 on 14 December 2019

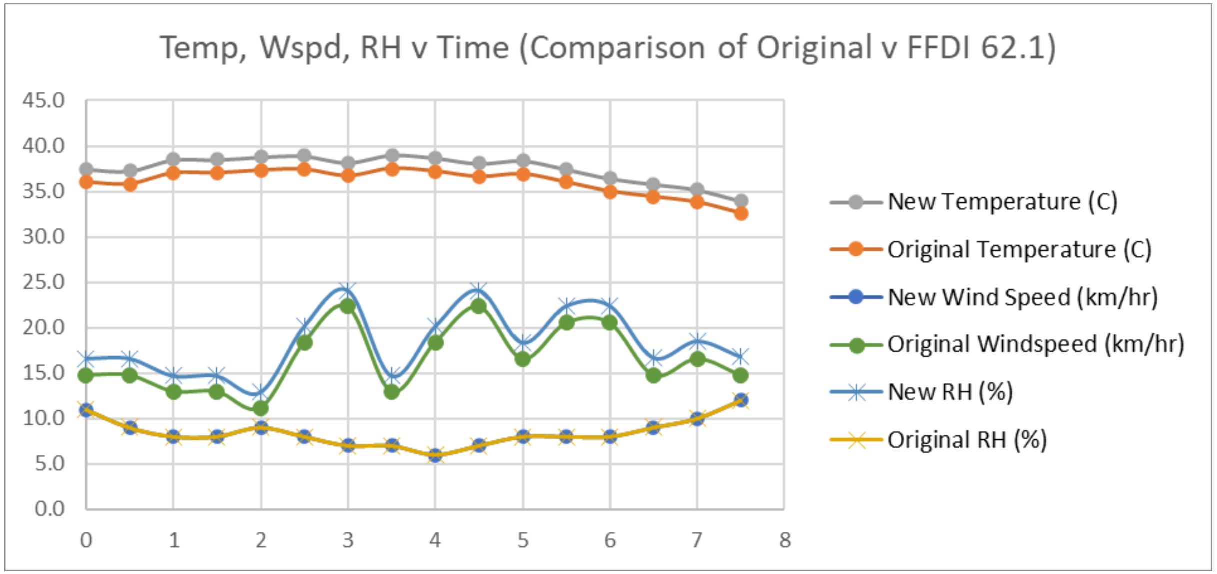
Date	Time	Temperature	Relative Humidity	Dew Pt	Wind Speed (km/hr)	Wind Direction	Drought Factor	FDI
Weather Profile from Original BoM Data from 14 December 2019								
14/12/2019	11:00:00	36	11		14.76	10	10	40.4
14/12/2019	11:30:00	35.8	9		14.76	270	10	43.0
14/12/2019	12:00:00	37	8	-2.7	12.96	280	10	44.4
14/12/2019	12:30:00	37	8	-2.7	12.96	250	10	44.4
14/12/2019	13:00:00	37.3	9	-0.9	11.16	230	10	41.6
14/12/2019	13:30:00	37.4	8	-2.4	18.36	280	10	51.1
14/12/2019	14:00:00	36.7	7	-4.7	22.32	250	10	56.7
14/12/2019	14:30:00	37.5	7	-4.1	12.96	240	10	46.8
14/12/2019	15:00:00	37.2	6	-6.3	18.36	240	10	54.4
14/12/2019	15:30:00	36.6	7	-4.7	22.32	240	10	56.5
14/12/2019	16:00:00	36.9	8	-2.7	16.56	240	10	48.2
14/12/2019	16:30:00	36	8	-3.4	20.52	230	10	51.3
14/12/2019	17:00:00	35	8	-4.1	20.52	230	10	49.5
14/12/2019	17:30:00	34.4	9		14.76	230	10	41.0
14/12/2019	18:00:00	33.8	10		16.56	220	10	40.5
14/12/2019	18:30:00	32.6	12		14.76	220	10	34.8

Table 6: Prorated weather profile for FDI 62.1 using base data from 11.00 to 18.30 on 14 December 2019

Date	Time	New Temp	New RH	New Wind Speed (km/hr)	DF	FDI
Weather Profile bench marked from original BoM data for a peak of FDI 62.1						
14/12/2019	11:00:00	37.4	11	16.6	10	44.3
14/12/2019	11:30:00	37.2	9	16.6	10	47.1
14/12/2019	12:00:00	38.5	8	14.7	10	48.6
14/12/2019	12:30:00	38.5	8	14.7	10	48.6
14/12/2019	13:00:00	38.8	9	12.9	10	45.5
14/12/2019	13:30:00	38.9	8	20.1	10	56.0
14/12/2019	14:00:00	38.2	7	24.1	10	62.1
14/12/2019	14:30:00	39.0	7	14.7	10	51.2
14/12/2019	15:00:00	38.7	6	20.1	10	59.5
14/12/2019	15:30:00	38.1	7	24.1	10	61.9
14/12/2019	16:00:00	38.4	8	18.35	10	52.8
14/12/2019	16:30:00	37.4	8	22.35	10	56.2
14/12/2019	17:00:00	36.4	8	22.4	10	54.3
14/12/2019	17:30:00	35.8	9	16.7	10	44.9
14/12/2019	18:00:00	35.2	10	18.5	10	44.3
14/12/2019	18:30:00	33.9	12	16.8	10	38.1

Table 7: Prorated weather profile for FDI 74.9 using base data from 11.00 to 18.30 on 14 December 2019

Date	Time	New Temp	New RH	New Wind Speed (km/hr)	DF	FDI
Weather Profile bench marked from original BoM data for a peak of FDI 74.9						
14/12/2019	11:00:00	40.3	8.3	16.4	10	53.4
14/12/2019	11:30:00	40.1	6.8	17.2	10	56.9
14/12/2019	12:00:00	41.4	6.0	15.5	10	58.7
14/12/2019	12:30:00	41.4	6.0	15.5	10	58.7
14/12/2019	13:00:00	41.8	6.8	13.3	10	54.9
14/12/2019	13:30:00	41.9	6.0	20.9	10	67.5
14/12/2019	14:00:00	41.3	5.3	25.1	10	74.9
14/12/2019	14:30:00	42.0	5.3	15.8	10	61.8
14/12/2019	15:00:00	41.7	4.5	21.7	10	71.9
14/12/2019	15:30:00	41.0	5.3	25.3	10	74.6
14/12/2019	16:00:00	41.3	6.0	19.2	10	63.7
14/12/2019	16:30:00	40.3	6.0	23.3	10	67.7
14/12/2019	17:00:00	39.2	6.0	23.4	10	65.5
14/12/2019	17:30:00	38.5	6.8	17.4	10	54.2
14/12/2019	18:00:00	37.9	7.5	18.95	10	53.5
14/12/2019	18:30:00	36.5	9.0	16.60	10	46.0



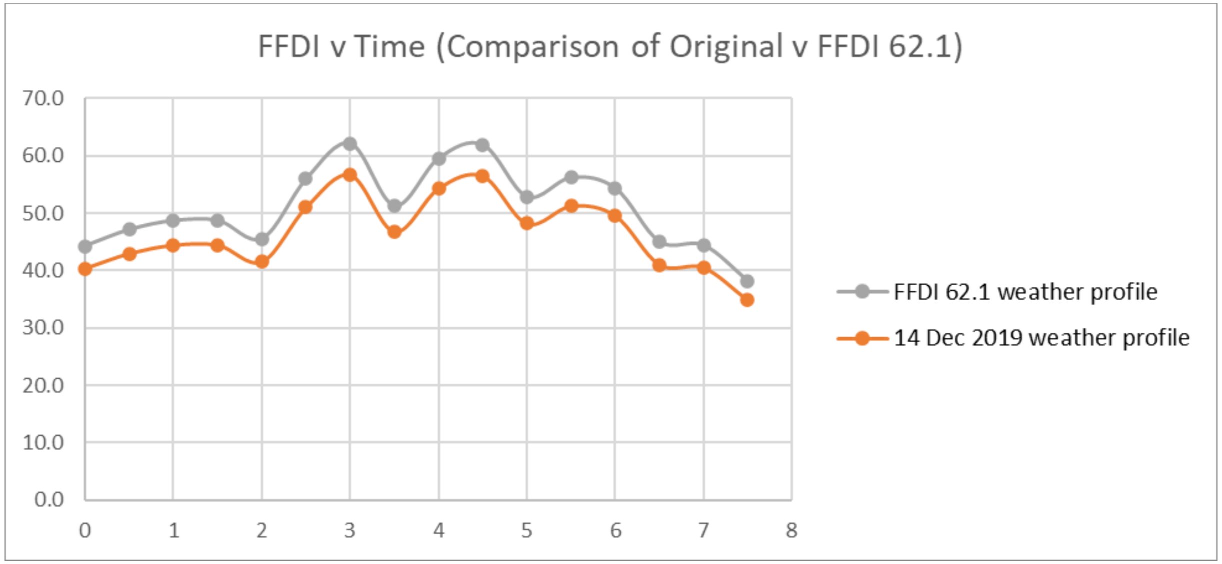
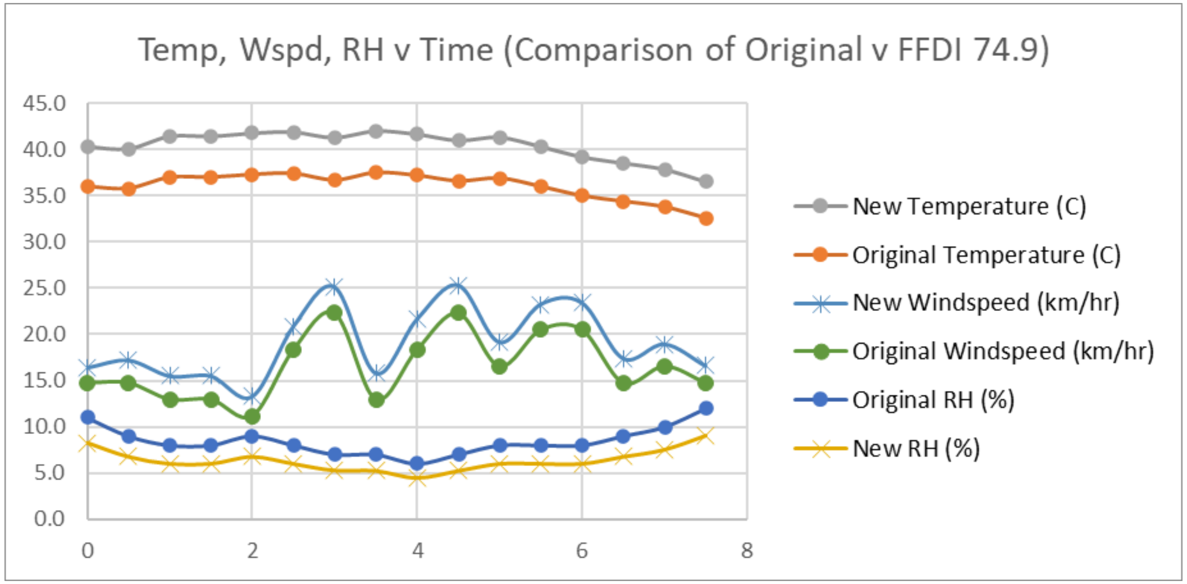


Plate 3: FFDI 62.1 v 14th Dec 2019 comparison



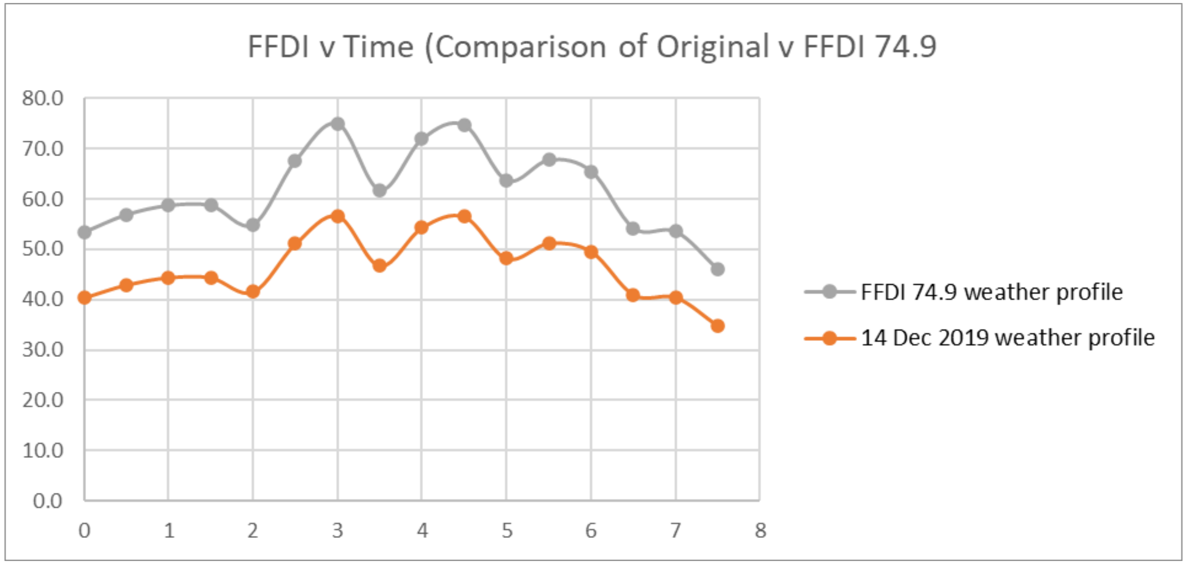


Plate 4: FFDI 74.9 v 14th Dec 2019 comparison

7. SPARK modelling methodology and results

- To inform the evacuation modelling, the time available for safe egress needs to be determined. This is to be achieved by simulating various bushfire scenarios to determine the time taken from initial fire ignition until the fire impacts on the North Stoneville site, as well as key roads that may influence the egress options and therefore timeframe.
- The SPARK simulation inputs are summarised below in Table 8.

Table 8: Summary of modelling inputs

Variable	Input
Rate of Spread Models	• **Mature RoS model (used for all time to impact analysis)** ○ Dry Eucalyptus Forest Fire Model (DEFFM or Project VESTA [Cheney (2012)] – Used for mapped Forest and Built Areas – Same for both Growth and Mature RoS models ○ CSIRO grassland fire spread model [Cheney et al (1998)] – Used for mapped grassland and crop areas – Same for both Growth and Mature RoS models ○ McArthur V spotting model – Uses 20% greater calibration modifier than Growth RoS model (in Forest only) • **Growth RoS model (used for some comparative analysis)** Same inputs as Mature RoS model, other than 20% less calibration modifier for spotting due to reduced role in fire progression (in Forest only)
Scenarios and Ignition Locations	• 4 nominated fire runs and ignition points ○ north-easterly fire run (ignition to the south-west of the site) ○ south-easterly fire run (ignition to the north-west of the site) ○ south-westerly fire run (ignition to the north-east of the site) ○ north-westerly fire run (ignition to the south-east of the site) Ignition 6.5 km to 7.0km from site to ensure disruption of major roads while achieving sufficient size to warrant full-scale evacuation
Slope	Digital Elevation Model (from ELVIS)
Fuel characteristics	• As defined in Table 2 • Conservative Fuel State ○ Forest assigned a 25 year fuel age with fuel load of 22.7 t/ha ○ Grass assigned cut/grazed condition with 90% curing and fuel load of 4.5 t/ha ○ Built Area assigned bespoke fuel characteristics with fuel load of 4 t/ha • Calibration Fuel State ○ Forest assigned a 10 year fuel age with fuel load of 21.6t/ha ○ Grass assigned eaten out condition with 67% curing and fuel load of 4.5 t/ha Built Area assigned bespoke fuel characteristics with fuel load of 4 t/ha
FFDI and Weather profiles	• FFDI used for simulations ○ FFDI 62.1 (1:50 year recurrence period with no climate change projection) ○ FFDI 74.9 (1:50 year recurrence period with 25 year climate change projection) SPARK weather profile developed for each FFDI through benchmarking against 14 December 2019 weather data.

7.1.1 Simulation Assumptions

- In addition to the modelling inputs identified in Table 8. the simulation modelling for each of the nominated design bushfire scenarios also includes the following assumptions:
  - The effects of the SP 34 development are not depicted (i.e. land is currently undeveloped) and there is no further intensification of land use in the traffic study area other than the current land uses (i.e. additional vegetation modification and removal as part of future land uses).
  - A 45 min build up phase from ignition to reaching 100% rate of spread
  - Data from the Bickley weather station is representative of local weather conditions influencing the design bushfire scenarios
  - A constant wind direction toward the site
  - No road disruptions based on the road network were included in the SPARK simulations
    - The use of road disruptions was explored during the calibration process, however removal from the simulations reduced problematic interactions with the bushfire that was preventing good alignment with the historical bushfires.
  - No weather/fire feedback such as fire interaction with upper atmosphere
  - No topography effects such as gully effects
  - No near field/ fire coalescence effects
  - No specific suppression activities were included that might affect the fire extent or rate of spread.
    - Assumes first attack/early containment of the fire was unsuccessful
    - Assumes no impact on overall fire extent from successful suppression, primarily along flanks
    - Assumes no reduction in spread from successful aerial attack.
  - A soft-self extinguishment nested model was adopted
    - Uses a self-extinguishment threshold of 0.004m/s.
    - The soft-extinguishment approach enables the fire to reignite in that cell, where the conditions allow for a RoS exceeding the threshold criteria
  - No allowance has been made for potential reduction in fuel accumulation rates and fuel loads due to rainfall decreases in a drying climate.

7.1.2 Key impact points

- Table 9 provides a summary of the key impact points required for the evacuation modelling, including major public roads, with Great Eastern Highway and Toodyay Road forming the outer boundaries of the traffic study area and the SP 34 site. Where possible, other minor public roads have also been included as impact points.

Table 9: Distances to key impact points

Slope / Model	Distance from ignition point (km)	
Scenario	Impact point	Distance (km)
South-west (North-easterly fire run)	Great Eastern Hwy (west) – Traffic Study Area boundary	2.5 km
	Roland Road (south)	5.0 km
	North Stoneville site boundary	6.7km

Slope / Model	Distance from ignition point (km)	
Scenario	Impact point	Distance (km)
North-west (South-easterly fire run)	Toodyay Rd (west) – Traffic Study Area boundary	3.6 km
	Roland Road (north) and North Stoneville site	6.6 km
North-east (South-westerly fire run)	Toodyay Rd (east) – Traffic Study Area boundary	0 km
	Stoneville Road (north)	3.2 km
	North Stoneville site	6.9 km
South-east (North-westerly fire run)	Great Eastern Hwy (west) – Traffic Study Area boundary	0.5 km
	Riley Road and Stoneville Road (south)	4.1 km
	North Stoneville site	6.5 km

7.2 SPARK Modelling Results

- The results of the simulation modelling are presented as isochrone maps for each design bushfire scenario at FFDI 62.1 and FFDI 74.9.
- The isochrone maps are attached in Appendix A.

7.2.1 Time to impact results

- An important output is also the time to impact the North Stoneville site, as well as key roads surrounding the site.
- Table 10 summarises the time for the head fire to impact key locations (in minutes), from time of ignition. It should be noted that while this provides a time for the head fire to impact, in terms of public safety, any road closures would be expected to occur ahead of the head fire arriving at the road.

Table 10: Time to impact at key locations (minutes)

Scenario	Impact Point	Time to impact (FFDI 62.1)	Time to impact (FFDI 74.9)
South-west (NE fire run)	Great Eastern Hwy (west) – Traffic Study Area boundary	69 min (1.15 hr)	61 min (1.1 hr)
	Roland Road (south)	216 min (3.6 hr)	181 min (3.02 hr)
	North Stoneville site	Doesn't reach site[1]	207 min (3.46 hr)
North-west (SE fire run)	Toodyay Rd (west) – Traffic Study Area boundary	86 min (1.44 hr)	68 min (1.14 hr)
	Roland Road (north) and North Stoneville site	164 min (2.73 hr)	137 min (2.29 hr)
North-east (SW fire run)	Toodyay Rd (east) – Traffic Study Area boundary	0 min (0 hr)[2]	0 min (0 hr) [2]
	Stoneville Road (north)	80 min (1.33 hr)	68 min (1.13 hr)
	North Stoneville site	Doesn't reach site[3]	208 min (3.46 hr)
South-east (NW fire run)	Great Eastern Hwy east) – Traffic Study Area boundary	17 min (0.28 hr)	15 min (0.25 hr)

Scenario	Impact Point	Time to impact (FFDI 62.1)	Time to impact (FFDI 74.9)
	Riley Road and Stoneville Road (south)	184 min (3.06 hr)	161 min (2.68 hr)
	North Stoneville site	226 min (3.76 hr)	189 min (3.15 hr)

[1] Fire ends within 80 m of SP 34 south-west boundary, so impact can be assumed to be approximately 4 hrs

[2] Ignition point for this scenario is adjacent to Toodyay Road, so the bushfire has potential to impact immediately.

[3] Fire ends within 50 m of SP 34 north-east boundary, so impact can be assumed to be approximately 4 hrs

7.2.2 Rate of Spread results

- To review the rate of spread of each of the design bushfire scenarios (Mature RoS model and Conservative fuel state), Table 11 states the maximum distance travelled and corresponding peak RoS, since fire ignition and over each 1 hr time step.

Table 11: Maximum Rate of Spread for Design Bushfire Scenarios

Scenario	Time since ignition (Time step)	Maximum distance travelled (km) since ignition	Maximum distance travelled (km) during time step	Peak RoS (km/hr) since ignition	Peak RoS (km/hr) during time step
FFDI 62.1					
South-west (North-easterly fire run)	1.0 hr (1hr)	2.0 km	2.0 km	2.0 km/hr	2.0 km/hr
	2.0 hr (1hr)	3.0 km	1.0 km	1.5 km/hr	1.0 km/hr
	3.0 hr (1hr)	4.5 km	1.5 km	1.5 km/hr	1.5 km/hr
	4.0 hr (1hr)	7.15 km	2.65 km	3.15 km/hr	2.65 km/hr
North-west (South-easterly fire run)	1.0 hr (1hr)	2.25 km	2.25 km	2.25 km/hr	2.25 km/hr
	2.0 hr (1hr)	4.4 km	2.15 km	2.2 km/hr	2.15 km/hr
	3.0 hr (1hr)	7.9 km	3.5 km	2.63 km/hr	3.5 km/hr
	4.0 hr (1hr)	10.9 km	3.0 km	2.72 km/hr	3.0 km/hr
North-east (South-westerly fire run)	1.0 hr (1hr)	2.0 km	2.0 km	2.0 km/hr	2.0 km/hr
	2.0 hr (1hr)	3.8 km	1.8 km	1.9 km/hr	1.8 km/hr
	3.0 hr (1hr)	5.1 km	1.3 km	1.7 km/hr	1.3 km/hr
	4.0 hr (1hr)	6.4 km	1.3 km	1.6 km/hr	1.3 km/hr
South-east (North-westerly fire run)	1.0 hr (1hr)	1.0 km	1.0 km	1.0 km/hr	1.0 km/hr
	2.0 hr (1hr)	2.7 km	1.7 km	1.35 km/hr	1.7 km/hr
	3.0 hr (1hr)	4.9 km	2.2 km	1.63 km/hr	2.2 km/hr
	4.0 hr (1hr)	7.2 km	2.3 km	1.8 km/hr	2.3 km/hr
FFDI 74.9					
South-west (North-easterly fire run)	1.0 hr (1hr)	2.4 km	2.4 km	2.4 km/hr	2.4 km/hr
	2.0 hr (1hr)	3.6 km	1.2 km	1.8 km/hr	1.2 km/hr
	3.0 hr (1hr)	6.25 km	2.65 km	2.08 km/hr	2.65 km/hr
	4.0 hr (1hr)	9.15 km	2.9 km	2.29 km/hr	2.9 km/hr
North-west (South-easterly fire run)	1.0 hr (1hr)	2.7 km	2.7 km	2.7 km/hr	2.7 km/hr
	2.0 hr (1hr)	5.6 km	2.9 km	2.8 km/hr	1.9 km/hr
	3.0 hr (1hr)	9.8 km	4.2 km	3.27 km/hr	4.2 km/hr
	4.0 hr (1hr)	12.0 km	2.2 km	3.0 km/hr	2.2 km/hr

Scenario	Time since ignition (Time step)	Maximum distance travelled (km) since ignition	Maximum distance travelled (km) during time step	Peak RoS (km/hr) since ignition	Peak RoS (km/hr) during time step
North-east (South-westerly fire run)	1.0 hr (1hr)	2.3 km	2.3 km	2.3 km/hr	2.3 km/hr
	2.0 hr (1hr)	4.3 km	2.0 km	2.15 km/hr	1.0 km/hr
	3.0 hr (1hr)	5.6 km	1.3 km	1.86 km/hr	1.3 km/hr
	4.0 hr (1hr)	8.0 km	2.4 km	2.0 km/hr	2.4 km/hr
South-east (North-westerly fire run)	1.0 hr (1hr)	1.1 km	1.1 km	1.1 km/hr	1.1 km/hr
	2.0 hr (1hr)	3.25 km	2.25 km	1.62 km/hr	2.25 km/hr
	3.0 hr (1hr)	6.1 km	2.85 km	2.03 km/hr	2.85 km/hr
	4.0 hr (1hr)	9.5 km	3.4 km	2.37 km/hr	3.4 km/hr

7.2.3 Design bushfire extent

- In addition to the bushfire spread distances detailed above, Table 12 provides approximate information on the extent of the bushfires, using bushfire burn areas as a guide to bushfire size.
- The measurements have been provided for each design bushfire after 2 and 4 hours, to depict the fire progression prior to reaching the SP 34 site, and the spread once the fire is fully-developed.

Table 12: Design bushfire burn area measurements

Scenario	FFDI 62.1 (2hrs)	FFDI 62.1 (4hrs)	FFDI 74.9 (2hrs)	FFDI 74.9 (4hrs)
South-west (NE fire run)	321.7 ha	1202.5 ha	372.1 ha	1713.4 ha
North-west (SE fire run)	654.2 ha	2692.1 ha	790.5 ha	3228.0 ha
North-east (SW fire run)	611.5 ha	2677.0 ha	799.5 ha	3581.0 ha
South-east (NW fire run)	353.5 ha	1919.6 ha	476.6 ha	2672.0 ha

- While some information is provided on the burn area for the Wooroloo and Parkerville bushfires, some approximate measurements were taken from actual fire extent for the purposes of comparison:
    - Parkerville (actual)
        - 56.7 ha area (after 2 hours)
        - 333 ha area (after 4 hours)
        - 386 ha area (final fire extent)
    - Wooroloo (actual)
        - 1989 ha area (after 7 hours)
- A comparative analysis figure is provided in Appendix I.

7.3 Parkerville weather profile comparison

- The design bushfires simulated depict worst credible case scenarios, based on number of conservative assumptions.
- To provide a more realistic bushfire scenario, a simulation has been conducted for the worst design bushfire scenario of ignition to the north-west of the SP 34 site, but using the weather profile from the Parkerville bushfire in January 2014, with ignition occurring at exactly the same time of 11.00 am (see Table 13 with simulation times highlighted in green).

- On the day, the peak FFDI was approximately FFDI 53, however this occurred in the hour prior to ignition (10am to 11am), with the peak FFDI in the 4 hours from 11.00 am being FFDI 43.2. Notwithstanding, the temperatures and wind speed were high during this period (34°C – 38.3°C and wind up to 28 km/hr), with the higher relative humidity (17% - 25%) preventing the FFDI from being overly high.
- This simulation is shown as the final one in Appendix A, and has time to impact and average RoS as follows:
  - Toodyay Road (west): 114 min at 1.89 km/hr
  - North Stoneville site Doesn't reach site within 4 hours
- The extent of the bushfire is as follows:
  - After 2 hours, has spread 3.8 km with average RoS of 1.9 km/hr, and has a burn area of 314.8 ha
  - After 4 hours, has spread 5.8 km with average RoS of 1.45 km/hr and has a burn area of 799.7 ha.
- In comparison to the times and average RoS stated in Table 10, under the Parkerville weather conditions, the simulated bushfire would have taken 24-44 mins more to reach Great Eastern Highway (depending on FFDI), and approximately 2-3 hours more to reach the SP 34 site under Parkerville weather conditions. This highlights how the fire weather at the time of the bushfire can significantly alter the amount of time for evacuation, and clearly shows the design bushfire scenarios represent conservative events.

Table 13: Bickley weather profile from 10.00 to 16.00 on 12 January 2014 (Parkerville Bushfire)

Date	Time	Temperature	Relative Humidity	Wind Speed (km/hr)	Wind Direction	Drought Factor	FDI
12/01/2014	10:00:00	38.7	11	22.32	340	10	52.8
12/01/2014	11:00:00	38.3	17	16.56	290	10	37.0
12/01/2014	12:00:00	38	18	16.56	290	10	35.4
12/01/2014	13:00:00	37.2	19	27.72	250	10	43.2
12/01/2014	13:48:00	35.4	18	27.72	260	10	42.1
12/01/2014	14:00:00	35.4	19	27.72	250	10	40.7
12/01/2014	15:00:00	33.9	25	20.52	250	10	26.6
12/01/2014	16:00:00	33	27	24.12	250	10	26.2

7.4 Growth RoS model and Calibration fuel state comparisons

- Similar to the reasoning for conducting the Parkerville weather stream comparison above, the following comparative simulations have also been conducted for the worst of the design bushfire scenarios which is the fire igniting in the north-west and spreading to the south-east, for FFDI 74.9:
  - Mature RoS Model with Calibration fuel state
    - Depicts the difference in RoS resulting from changing fuel state from Conservative to Calibration with no alteration to RoS model
    - This scenario reaches the SP 34 site in 152 min, which is slightly slower than the 140 min using Conservative fuels, and spreads 5.6 km and 11.3 km after 2 and 4 hrs respectively,

compared to the 5.6 km and 12.0 km when Conservative fuels are adopted. The burn area after 4 hours is 2885.9 ha, compared to the 3228 ha for the Conservative fuels.

- Growth RoS Model with Conservative fuel state
  - Depicts the difference in RoS resulting from changing RoS model from Mature to Growth
  - This scenario reaches the SP 34 site in 161 min, which is slower than the 140 min using Mature RoS, and spreads 5.3 km and 11.3 km after 2 and 4 hrs respectively, compared to the 5.6 km and 12.0 km when Mature RoS (and Conservative fuels) are adopted. The burn area after 4 hours is 3020.4 ha, compared to the 3228 ha for the Conservative fuels.
- Growth RoS Model with Calibration fuel state
  - Depicts the difference in RoS resulting from changing fuel state from Conservative to Calibration, and the RoS model from Mature to Growth
  - Given this model and fuel state aligns best with the nearby Parkerville bushfire and early stages of the Wooroloo fire, it is considered this likely provides the most accurate prediction of bushfire behaviour in the first 4 hours.
  - This scenario reaches the SP 34 site in 166 min, which is slower than the 140 min using Mature RoS, and spreads 5.0 km and 9.8 km after 2 and 4 hrs respectively, compared to the 5.6 km and 12.0 km when Mature RoS (and Conservative fuels) are adopted. The burn area after 4 hours is 2440.2 ha, compared to the 3228 ha for the Conservative fuels.

- The comparative simulations above provide the following insight:
  - The change in fuel state from Calibration to Conservative has only a slight affect on the RoS of the simulated bushfires, with some slowing of the RoS and reduction in burn area.
  - Similarly, the change from Mature to Growth RoS models, also appears to have a slight affect on RoS and reduction in burn area, however it is likely that this would be more pronounced later in the fire as spotting takes a more significant role in fire progression.
  - The combination of changing fuels states and RoS model has a more marked affect, with more of significant slowing of the RoS and final burn area after 4 hours.

7.5 Simulation Results Discussion

- The simulation results for each design bushfire scenario are to be used to inform the evacuation analysis.
- The simulated design bushfire scenarios represent the worst credible case bushfires with sufficient conservatism embedded, to ensure that an actual bushfire event would be slower than the simulations.
- The assumptions that underpin the simulation modelling, such as uniform and high fuel loads, consistent wind directions, no suppression activities (see further discussion below) and no changes to land use, ensure that the bushfire behaviour in the simulated design bushfire scenarios is suitably conservative in comparison to historical fires (see Appendix I) which is demonstrated by the following:
  - The quicker average RoS in the 4 scenarios:
    - for FFDI 62.1 scenarios, 1.35 – 2.25 km/hr after 2 hours, and 1.6 – 3.15 km/hr after 4 hours, with peak RoS over a 1 hour period of up to 3.5 km/hr but more typically between 1.5-2.5 km/hr
    - for FFDI 74.9 scenarios, 1.62 – 2.8 km/hr after 2 hours, and 2.0 – 3.0 km/hr after 4 hours, with peak RoS of up to 4.2 km/hr but more typically between 2-3 km/hr
    - with the FFDI 62.1 scenarios, the simulated bushfires have a slightly quicker RoS in comparison to the 1.5 km/hr to 2 km/hr typical with historical bushfires in the area, with a

comparable peak RoS of 3-4 km/hr. The FFDI 74.9 scenarios represent a more substantial increase to an average RoS over 4 hours of 2.0 – 3.0 km/hr with peak RoS slightly higher.

  - While the RoS increases may not appear as substantial as could be expected, it is necessary to consider that these RoS are occurring in the first 2 to 4 hours of the simulated bushfire, which have historically been slower, with both Parkerville and Wooroloo fires not spreading much faster than 1 – 1.2 km/hr in the first 2 to 4 hours.

- The significantly greater burn areas associated with the simulated design fires, over those of actual historical bushfires in the initial stages of the fire:
  - for FFDI 62.1 scenarios, the fire was between 321.7 – 654.2 ha in area after 2 hours, and between 1202.5 – 2692.1 ha after 4 hours.
  - for FFDI 74.9 scenarios, the fire was between 372.1 – 799.5 ha in area after 2 hours, and between 1713.4 – 3581.1 ha after 4 hours.
  - In comparison, the actual burn areas for Wooroloo and Parkerville bushfires where substantially smaller than the simulated design bushfires, with Parkerville being approximately 56.7 ha and 333 ha in area after 2 and 4 hours respectively, while Wooroloo was reportedly 230 ha in area in the first 4 hours and 1989 ha after 7 hours.
  - The simulated design bushfires are of significantly greater size than historical bushfires in the first 4 hours, and while this is evidence of conservatism, it is also acknowledged that the simulated fires assume greater bushfire weather inputs and don't include the impacts of suppression effort unlike the historical fires, which can impact the overall burnt area. Notwithstanding, both historical fires did develop into significant bushfires, and it is unlikely the suppression efforts in the first few hours, were particularly impactful on the fire extent as resources were deployed to the fire.
- The weather profile inputs for the design bushfires are also conservative which is demonstrated by the comparison of the design bushfire scenario from the north-west (at FFDI's 62.1 and 74.9) against the simulation using the Parkerville weather profile.
  - The average RoS of the Parkerville weather profile is between 1.45-1.9 km/hr is significant slower than those from the simulated design bushfires which are generally averaging between 2.2 - 3 km/hr (depending on FFDI).
  - The extent of the Parkerville weather profile bushfire is significantly smaller, having area of 314.8 ha (after 2 hours) and area of 799.7 ha (after 2 hours). The simulated north-west design bushfires are 2 – 4 times greater in area.
  - The reason for the reduction in bushfire behaviour for the Parkerville weather profile is mainly associated with the dropping FFDI throughout the afternoon as temperature drops and relative humidity increases. While the design bushfire simulations assume an elevated peak FFDI, this comparison depicts how more typical weather conditions (that occurred during a significant bushfire) can impact the bushfire behaviour, in particular RoS and bushfire extent.

7.5.1 Potential Bushfire Suppression Impact

- Firefighting suppression activities, especially in the early stages of the bushfire, could reduce the extent of the fire through containment of the flanks, but may also have some impact on the rate of spread while the fire is smaller. Given the high FFDI associated with the design bushfires, it is reasonable to expect that fire and emergency services would be at an elevated state of readiness to combat the bushfire threat on these days. While it can be expected that on these days that ignition of a fire may readily escalate to steady-state behaviour, it is also reasonable to assume that there would likely be heightened local surveillance, rapid notification and quick response and turnout by fire brigade appliances, both vehicles and aerial appliances. By being onsite early, this potentially allows firefighting containment and suppression activities to be more effective in reducing the impact of the fire, by slowing its spread and reducing the extent at the flanks, especially in areas of greater development (e.g. rural residential land), where there is less contiguous fuel loads and greater vehicular access.

- An example of the likely effectiveness of fire containment and suppression is visible on the Wooroloo reconstruction (see 0), where the southern extent from the simulated bushfire is significantly larger than that of the actual fire. Some level of successful suppression along the southern flank, likely due to the more fragmented rural residential land, has limited the spread in this direction and resulted in a more linear fire shape than the reconstruction predicts. It is hard to determine how successful the suppression activities where on arresting RoS, however the reconstruction appears to overpredict the likely RoS in the first 4 hours, which could potentially due to initial firefighting efforts on the day.

- While firefighting activities can provide significant impact on the fire spread and extent, it should also be noted that on such high-risk bushfire days, there may also be more than one bushfire in the area, and resources could become more stretched across various firegrounds, and may not be able to respond as quickly to the fire. Additionally, there would be more of a focus on warning occupants and life safety concerns in the early stages of the fire, with the evacuation of the area also likely to fill the public roads with egressing vehicles, all of which could also hamper fire appliance access and suppression response, although it is noted that the intent is there is very few public vehicles near the fireground
- Given the uncertainty of the impact on bushfire behaviour and extent that would result from fire containment and suppression activities, it is reasonable to assume no impact as part of the simulation, however it is also reasonable to expect that firefighters will have some impact especially in more developed areas where there is more managed and fragmented vegetation as well as better vehicular access and water supplies.

7.5.2 Bushfire Likelihood Comments

- The likelihood of the design bushfire scenarios igniting and developing to steady-state bushfire behaviour that could threaten lives and homes, is based on a variety of factors such as ignition sources, fuel loads, structure and continuity, topography (which can often also affect access to enable suppression) and weather conditions.
- Given the numerous factors that affect the likelihood of a bushfire impacting the site, it is difficult to quantify this, however one variable does provide some guidance is that of wind direction.
- A broad analysis of wind direction on days with FFDI>25 is depicted on Table 27 and Plate 11 (see 0). These show that the predominant wind direction during days of elevated FFDI is from the east (28.5%), south-east (17.9%) and north-east (14.1%), with winds from the south-west (10.1%) and north-west (6.2%) occurring far less frequently. One reason for this, especially for the relatively common south-west seabreeze, is the temperature drop, humidity increase and overall FFDI drop that would be associated with coastal winds. In the case of the north-west wind, this is not a typical summertime wind direction for Perth, and this is likely reflected in the low occurrence at high FFDI.
- While the wind direction analysis in no way excludes bushfires from the south-west or north-west, but it does highlight a lesser likelihood of winds from these directions, especially the north-west. The design bushfire from the south-west is still considered a likely scenario given it is a common summertime afternoon wind direction, and while FFDI may have dropped, it could fan conditions of an ignited fire. The design bushfire from the north-west is considered to be less likely given this is not typically a summertime wind direction, but it can't be excluded as not possible at all given winds can occur from this direction.

8. Conclusion

- To inform the evacuation modelling, simulations of 8 design bushfire scenarios (4 directions at both FFDI 62.1 and 74.9) have been conducted, to calculate the time of likely bushfire impact at key roads and the site. This information will be used to determine whether there is sufficient time available for people at the North Stoneville site to conduct safe egress.
- The simulated time to impact the SP 34 site of at each FFDI across all ignition points is as follows:
  - FFDI 62.1 – between 164 min (2.73 hr) and not reaching the site
  - FFDI 74.9 – between 137 min (2.29 hr) and 207 min (3.46 hr)
- The assumptions that underpin the simulation modelling ensure that these impact times are suitably conservative as follows:
  - Fuel loads are assumed to be consistent, and no allowance for any fuel load management (such as prescribed burning) has been made
  - No allowance has been made for potential reduction in fuel load due to a drying climate
  - Assumes no specific suppression activities are undertaken
  - Wind direction is assumed to be directly at the site for the entire simulation, which while possible, may not always be the case across a 4 hour duration
  - Assumes no impact from the SP 34 development
  - Assumes no other changes to land use in the area, which is unlikely over a 50 year period
- The level of conservatism with the simulated design bushfire scenarios is depicted by the:
  - the quicker average RoS in the first 4 hours of the simulated scenarios of between 1.5 – 2.5 km/hr (FFDI 62.1) and 2 – 3 km/hr (FFDI 74.9) with peak RoS between 3.5 – 4.2 km/hr. This compares favourably to the 1.5 km/hr to 2 km/hr peak average RoS that is historically associated with Perth Hills bushfires, noting that both Parkerville and Wooroloo fires were progressing at about 1 – 1.2 km/hr in the first 2 to 4 hours.
  - the significantly greater size associated with the simulated design fires, which have a total burn area after 4 hours of between 1202.5 – 2692.1 ha (FFDI 62.1) and 1713.4 – 3581.1 ha (FFDI 74.9). By comparison, the 4 hour burn area for Parkerville was 333 ha, whereas the Wooroloo bushfire lost 230 ha in the first 4 hours and 1989 ha after 7 hours. The simulated fires are showing far greater size and extent impact than historical bushfires in the first 4 hours.
  - comparison against the simulation using the Parkerville weather profile where the rate of spread and fire extents are significantly different after 4 hours show that bushfire behaviour can be substantially affected by lower weather inputs than those used for the design bushfire scenarios.
- Whilst the simulated design bushfire scenarios represent the worst-case bushfires, they do represent a "perfect storm" of conditions, that while is a possibility, has historically rarely occurred in unison. On this basis, we are comfortable that there is sufficient conservatism embedded in the model inputs to ensure that an actual bushfire would be slower and smaller than what is being represented in the simulations over the first 4 hours, and likely considerably slower and smaller.

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10. Limitations

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This report ("the report") has been prepared by JBS&G in accordance with the scope of services set out in the contract, or as otherwise agreed, between the Client and JBS&G. In some circumstances, a range of factors such as time, budget, access and/or site disturbance constraints may have limited the scope of services. This report is strictly limited to the matters stated in it and is not to be read as extending, by implication, to any other matter in connection with the matters addressed in it.

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Appendix A Stoneville isochrome maps from SPARK simulations

Design Bushfire Scenarios (for time to impact analysis)

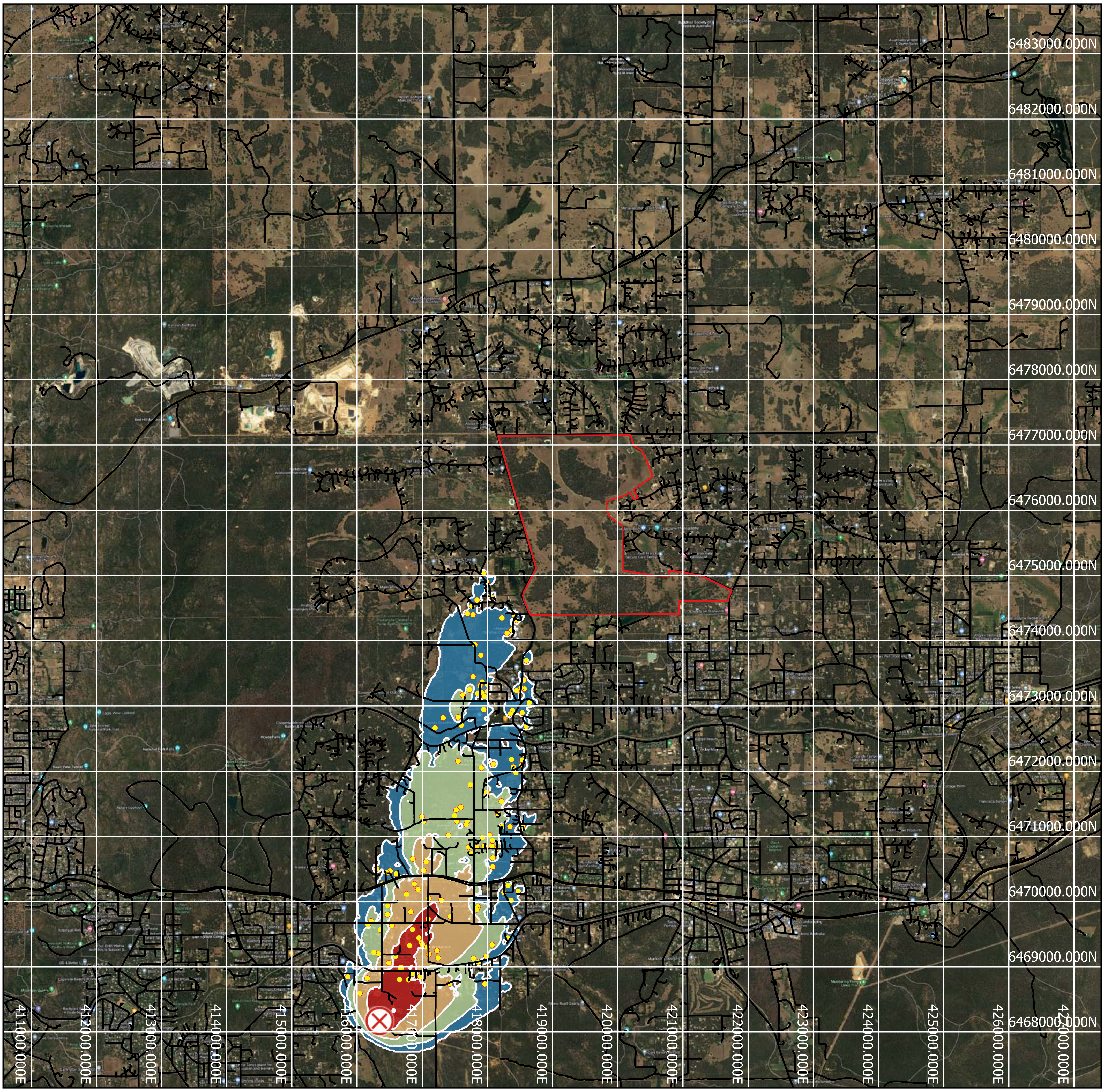
- North-easterly fire run (ignition to the south-west of the site)
  - FFDI 62.1 - Conservative Fuel State with Mature RoS
  - FFDI 74.9 - Conservative Fuel State with Mature RoS
- South-easterly fire run (ignition to the north-west of the site)
  - FFDI 62.1 - Conservative Fuel State with Mature RoS
  - FFDI 74.9 - Conservative Fuel State with Mature RoS
- South-westerly fire run (ignition to the north-east of the site)
  - FFDI 62.1 - Conservative Fuel State with Mature RoS
  - FFDI 74.9 - Conservative Fuel State with Mature RoS
- North-westerly fire run (ignition to the south-east of the site)
  - FFDI 62.1 - Conservative Fuel State with Mature RoS
  - FFDI 74.9 - Conservative Fuel State with Mature RoS

Comparison Bushfire Scenarios (for comparative purposes)

- North-easterly fire run (ignition to the south-west of the site)
  - Parkerville weather profile (FFDI 43.2) - Conservative Fuel State with Mature RoS
  - FFDI 74.9 -Calibration Fuel State with Mature RoS
  - FFDI 74.9 - Conservative Fuel State with Growth RoS Model
  - FFDI 74.9 - Calibration Fuel State with Growth RoS Model

North Easterly Fire Run Approaching Stoneville

Conservative Fuels, FFDI-62.1, Mature RoS



The presented 4 hour bushfire spread simulation was developed using the following information:
Bushfire Simulation: SPARK
Resolution: 20m
ROS Model: Vesta Mark 1 & CSIRO Grassland
Fire History: No
Disruptions: None
Spotting: Yes
Build-up Phase: 45 mins
Ignition Time: 13:00 hrs

0 1,000 2,000 m

CRS: 7850
Scale: 1:60,000 @ A3
Drawn by: AP
Date: 9.12.2022
Model 4k, Issue: A

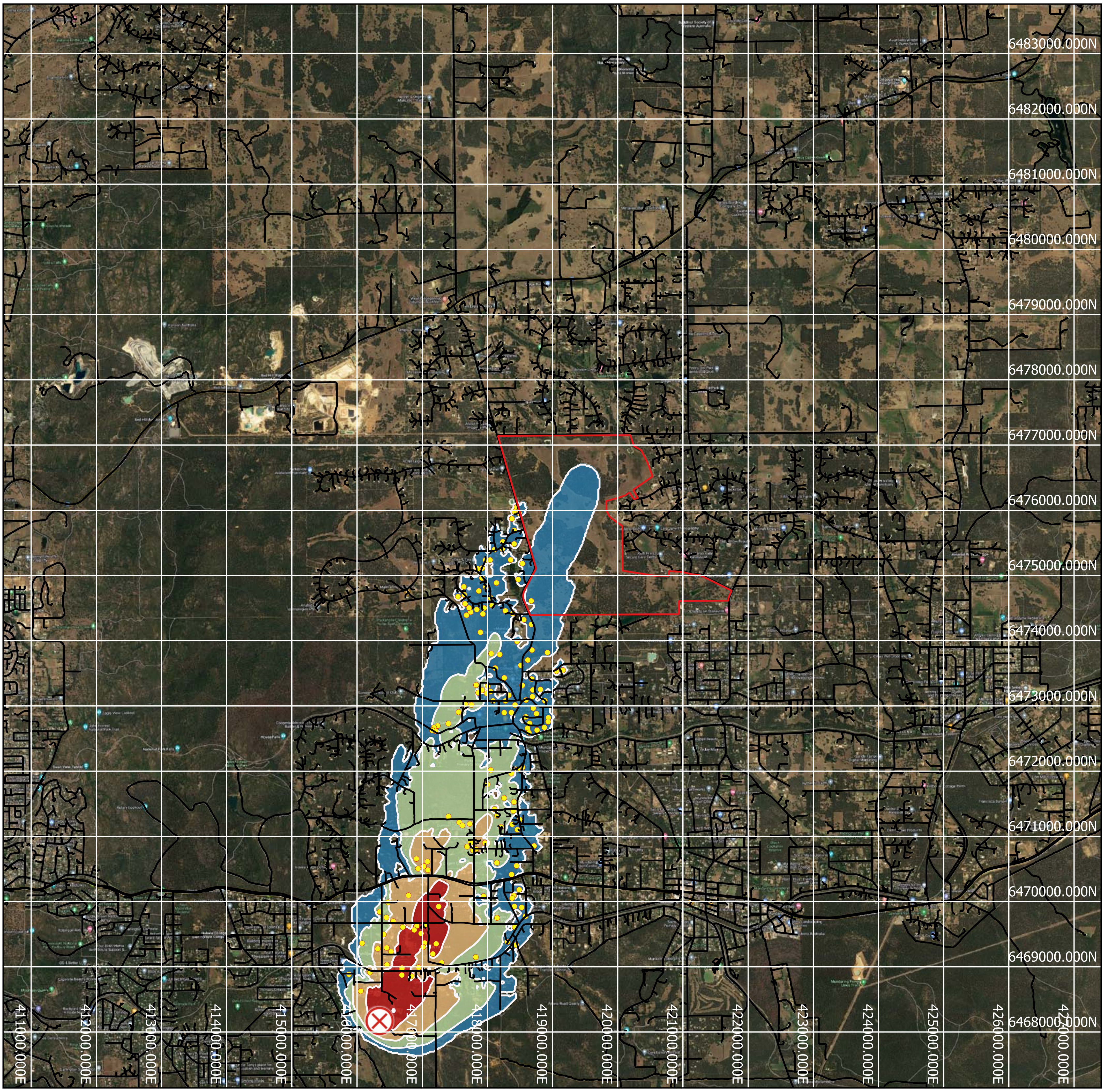
Legend

- Stoneville Site
- Road Network
- Ignition Location
- 1 hour isochrones
- Spot fires

Arrival Time
- 0 to 1 hour
- 1 to 2 hours
- 2 to 3 hours
- 3 to 4 hours

North Easterly Fire Run Approaching Stoneville

Conservative Fuels, FFDI-74.9, Mature RoS



The presented 4 hour bushfire spread simulation was developed using the following information:
Bushfire Simulation: SPARK
Resolution: 20m
ROS Model: Vesta Mark 1 & CSIRO Grassland
Fire History: No
Disruptions: None
Spotting: Yes
Build-up Phase: 45 mins
Ignition Time: 13:00 hrs

0 1,000 2,000 m

Legend

- Stoneville Site
- Road Network
- Ignition Location
- 1 hour isochrones
- Spot fires

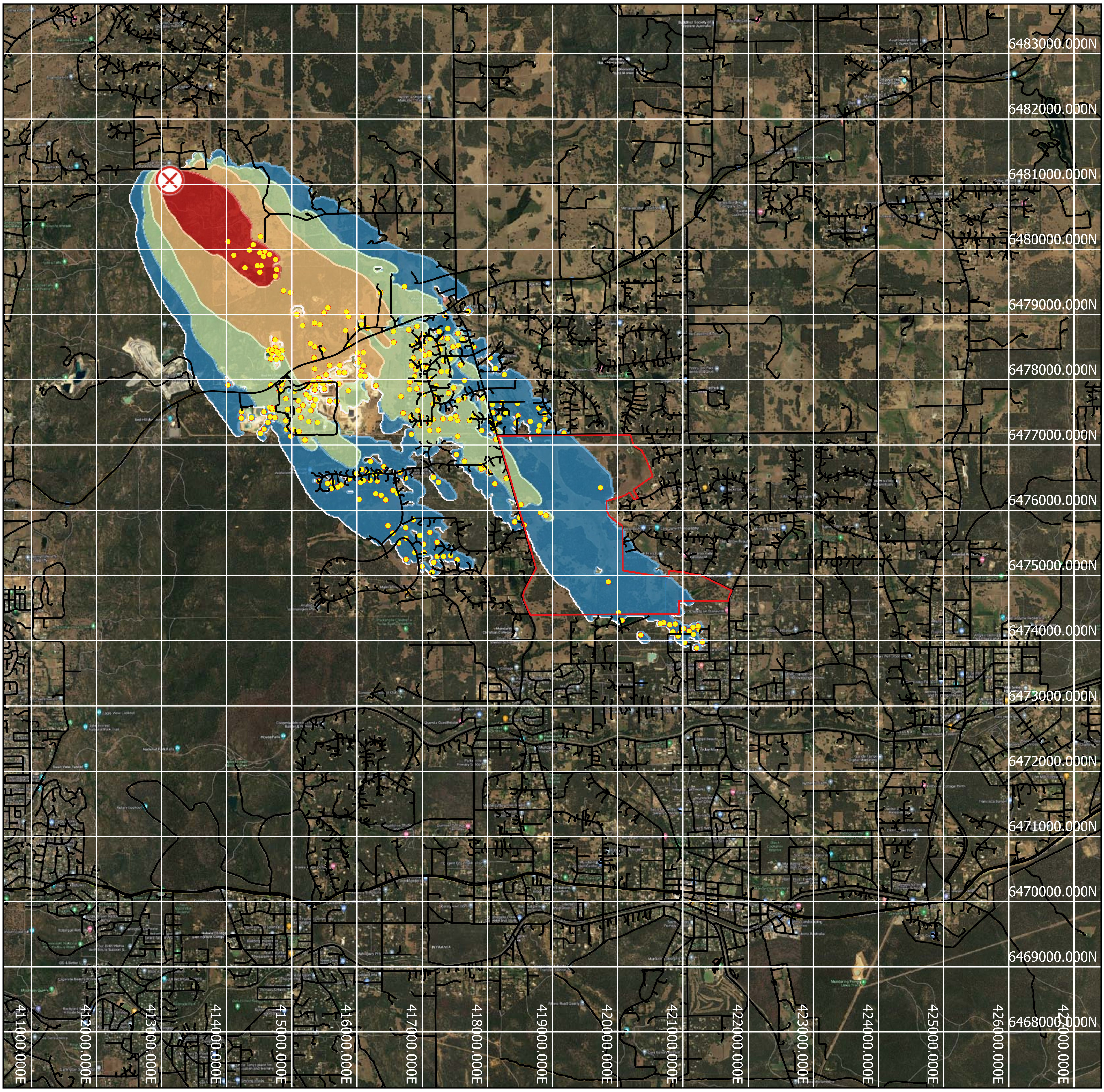
Arrival Time

- 0 to 1 hour
- 1 to 2 hours
- 2 to 3 hours
- 3 to 4 hours

CRS: 7850
Scale: 1:60,000 @ A3
Drawn by: AP
Date: 9.12.2022
Model 4j, Issue: A

South Easterly Fire Run Approaching Stoneville

Conservative Fuels, FFDI-62.1, Mature RoS



The presented 4 hour bushfire spread simulation was developed using the following information:
Bushfire Simulation: SPARK
Resolution: 20m
ROS Model: Vesta Mark 1 & CSIRO Grassland
Fire History: No
Disruptions: None
Spotting: Yes
Build-up Phase: 45 mins
Ignition Time: 13:00 hrs

0 1,000 2,000 m

Legend

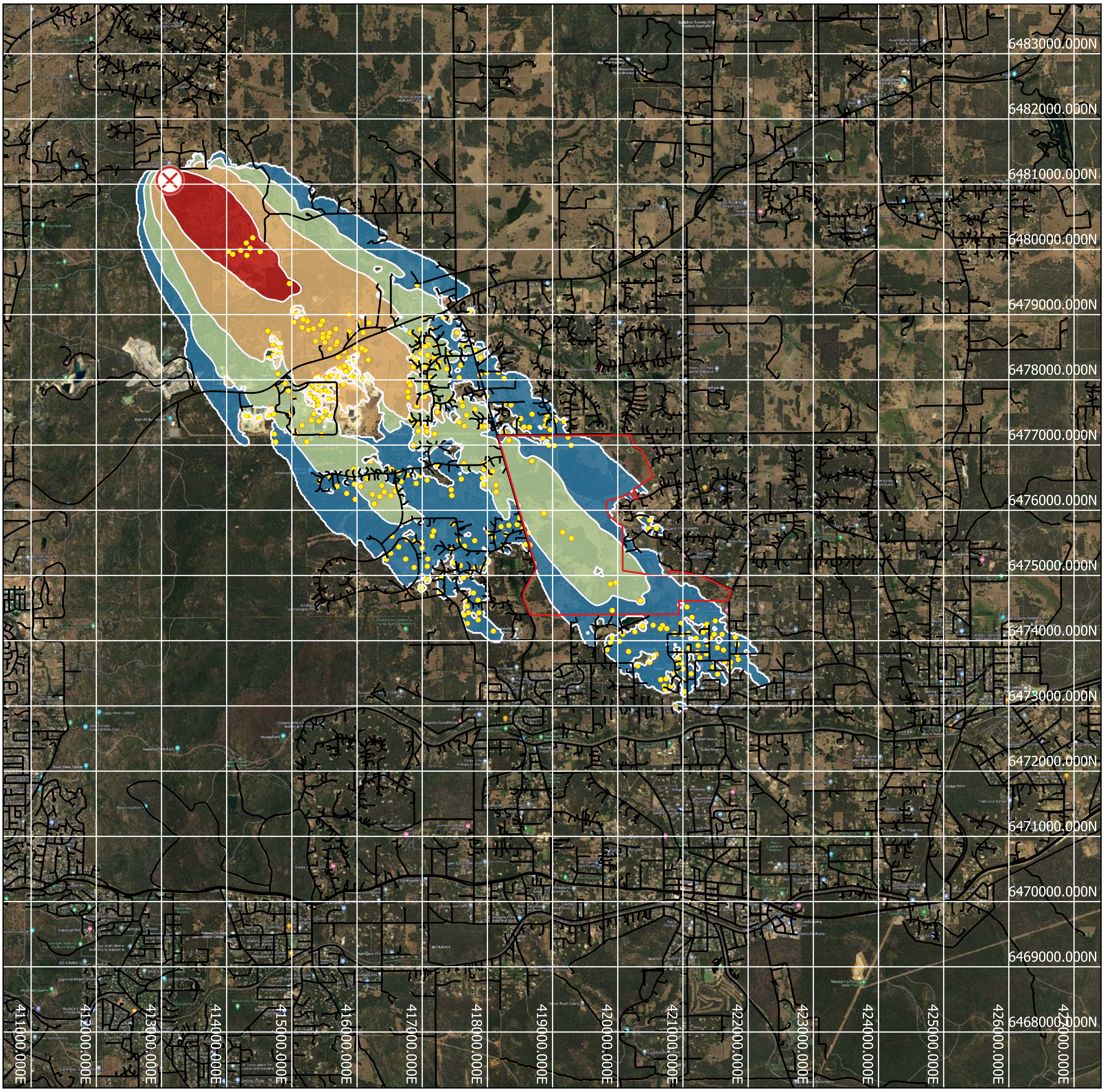
- Stoneville Site
- Road Network
- Ignition Location
- 1 hour isochrones
- Spot fires

Arrival Time
- 0 to 1 hour
- 1 to 2 hours
- 2 to 3 hours
- 3 to 4 hours

CRS: 7850
Scale: 1:60,000 @ A3
Drawn by: AP
Date: 8.12.2022
Model 4b, Issue: A

South Easterly Fire Run Approaching Stoneville

Conservative Fuels, FFDI-74.9, Mature RoS



The presented 4 hour bushfire spread simulation was developed using the following information:
Bushfire Simulation: SPARK
Resolution: 20m
ROS Model: Vesta Mark 1 & CSIRO Grassland
Fire History: No
Disruptions: None
Spotting: Yes
Build-up Phase: 45 mins
Ignition Time: 13:00 hrs

0 1,000 2,000 m

CRS: 7850
Scale: 1:60,000 @ A3
Drawn by: AP
Date: 8.12.2022
Model 4a, Issue: A

Legend

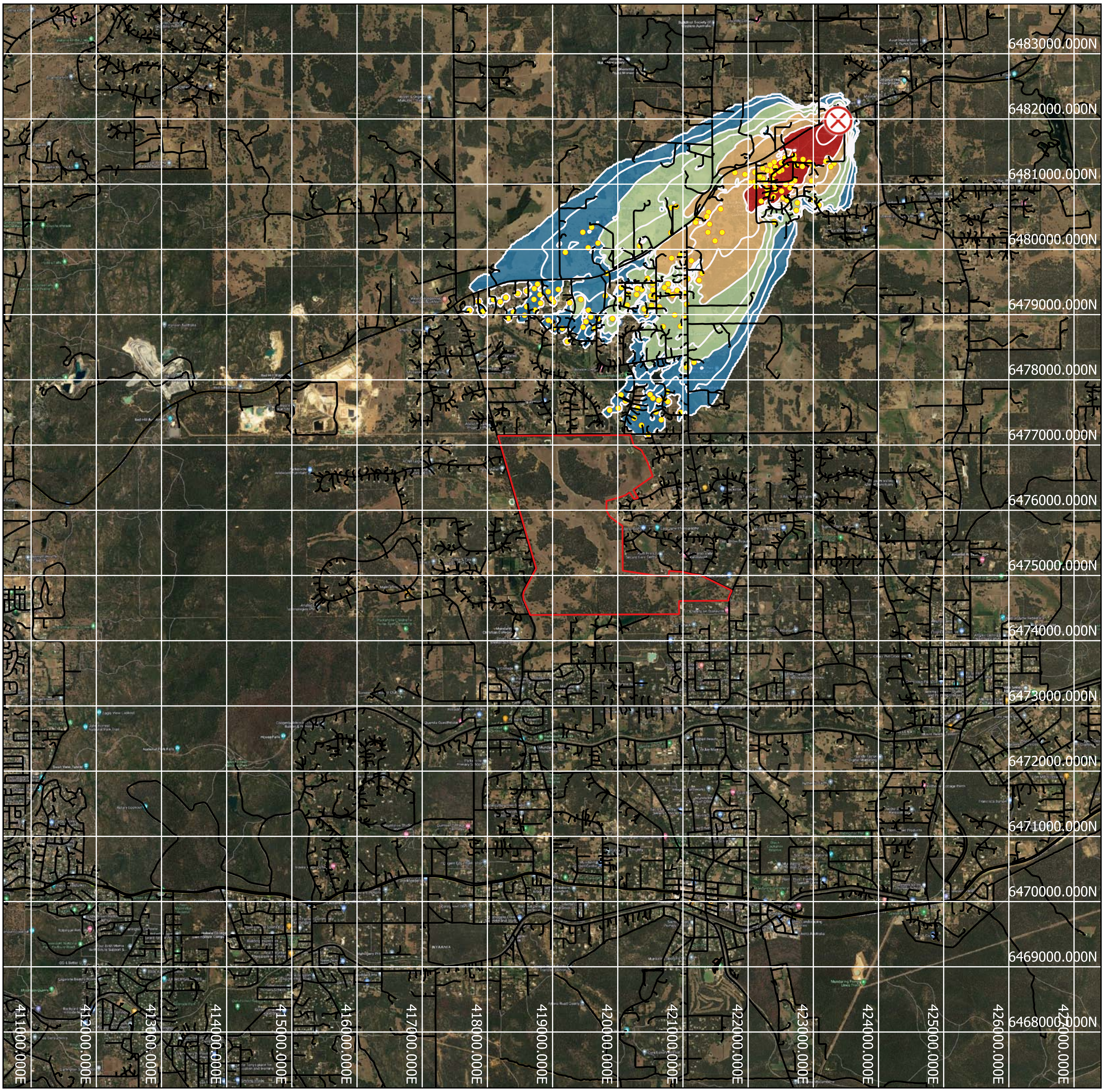
- Stoneville Site
- Road Network
- Ignition Location
- 1 hour isochrones
- Spot fires

Arrival Time

- 0 to 1 hour
- 1 to 2 hours
- 2 to 3 hours
- 3 to 4 hours

South Westerly Fire Run Approaching Stoneville

Conservative Fuels, FFDI-62.1, Mature RoS



The presented 4 hour bushfire spread simulation was developed using the following information:
Bushfire Simulation: SPARK
Resolution: 20m
ROS Model: Vesta Mark 1 & CSIRO Grassland
Fire History: No
Disruptions: None
Spotting: Yes
Build-up Phase: 45 mins
Ignition Time: 13:00 hrs

0 1,000 2,000 m

Legend

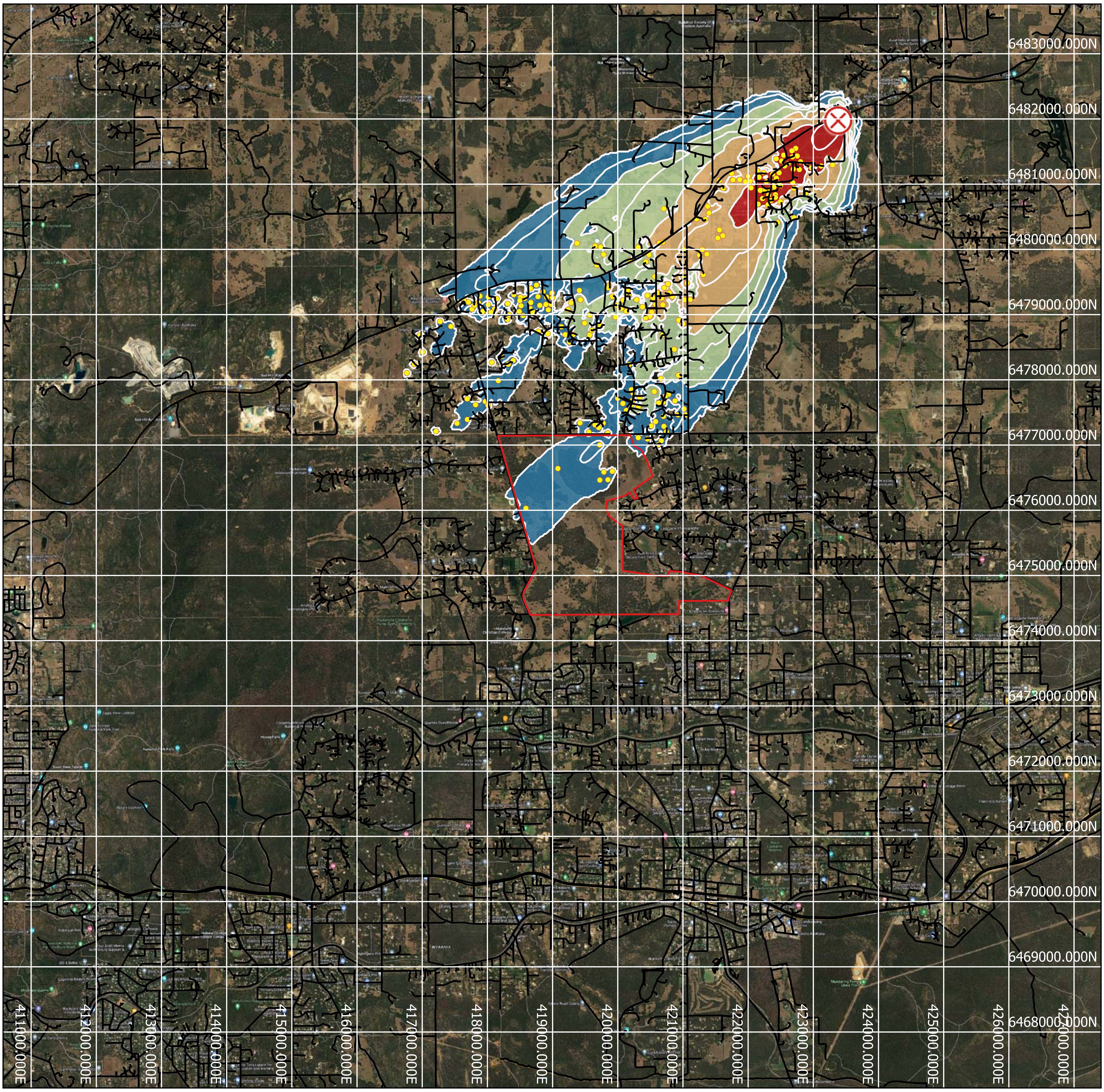
- Stoneville Site
- Road Network
- Ignition Location
- 1 hour isochrones
- Spot fires

Arrival Time
- 0 to 1 hour
- 1 to 2 hours
- 2 to 3 hours
- 3 to 4 hours

CRS: 7850
Scale: 1:60,000 @ A3
Drawn by: AP
Date: 9.12.2022
Model 4o, Issue: A

South Westerly Fire Run Approaching Stoneville

Conservative Fuels, FFDI-74.9, Mature RoS



The presented 4 hour bushfire spread simulation was developed using the following information:
Bushfire Simulation: SPARK
Resolution: 20m
ROS Model: Vesta Mark 1 & CSIRO Grassland
Fire History: No
Disruptions: None
Spotting: Yes
Build-up Phase: 45 mins
Ignition Time: 13:00 hrs

0 1,000 2,000 m

Legend

- Stoneville Site
- Road Network
- Ignition Location
- 1 hour isochrones
- Spot fires

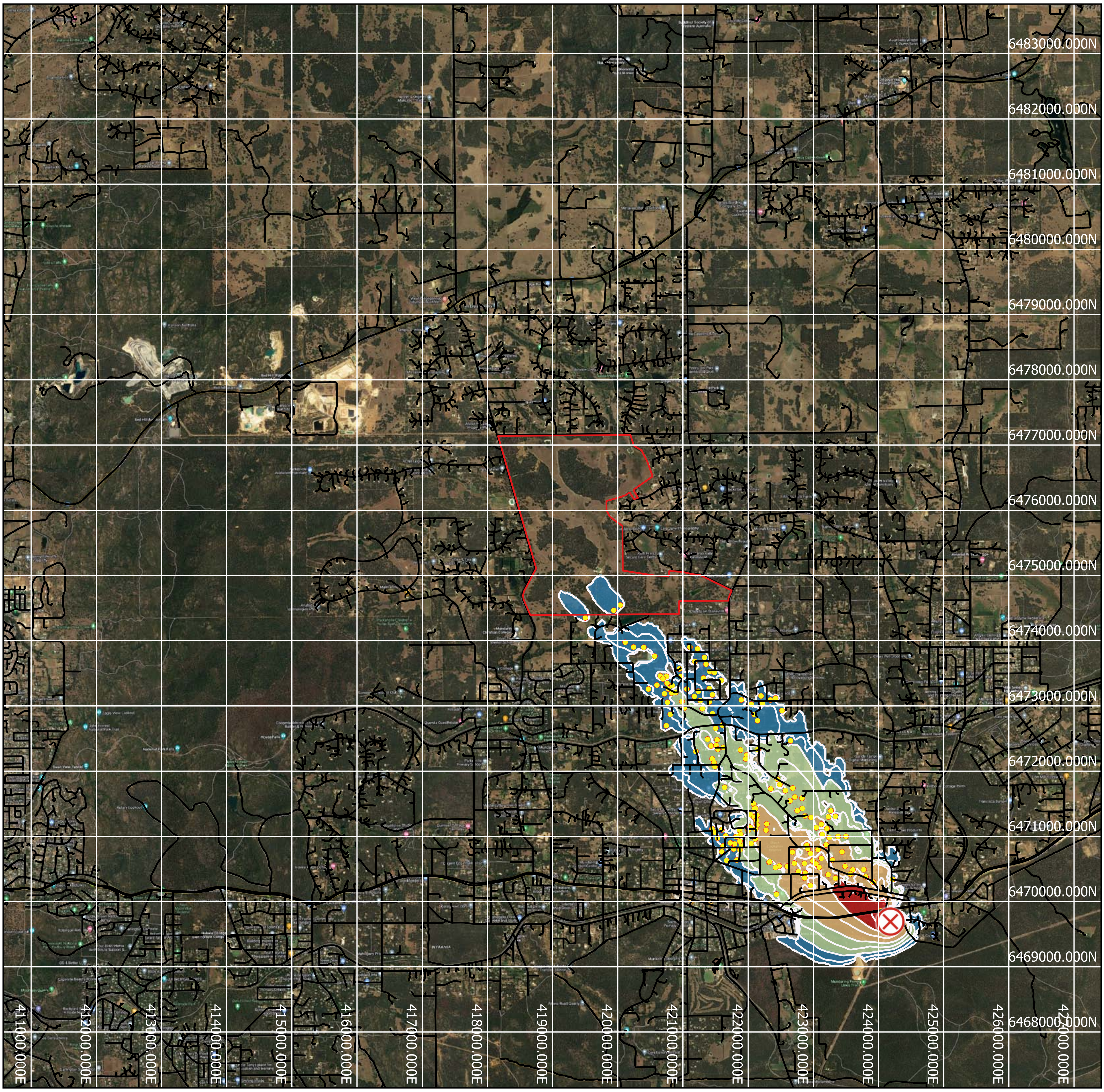
Arrival Time

- 0 to 1 hour
- 1 to 2 hours
- 2 to 3 hours
- 3 to 4 hours

CRS: 7850
Scale: 1:60,000 @ A3
Drawn by: AP
Date: 9.12.2022
Model 4n, Issue: A

North Westerly Fire Run Approaching Stoneville

Conservative Fuels, FFDI-62.1, Mature RoS



The presented 4 hour bushfire spread simulation was developed using the following information:
Bushfire Simulation: SPARK
Resolution: 20m
ROS Model: Vesta Mark 1 & CSIRO Grassland
Fire History: No
Disruptions: None
Spotting: Yes
Build-up Phase: 45 mins
Ignition Time: 13:00 hrs

0 1,000 2,000 m

Legend

- Stoneville Site
- Road Network
- Ignition Location
- 1 hour isochrones
- Spot fires

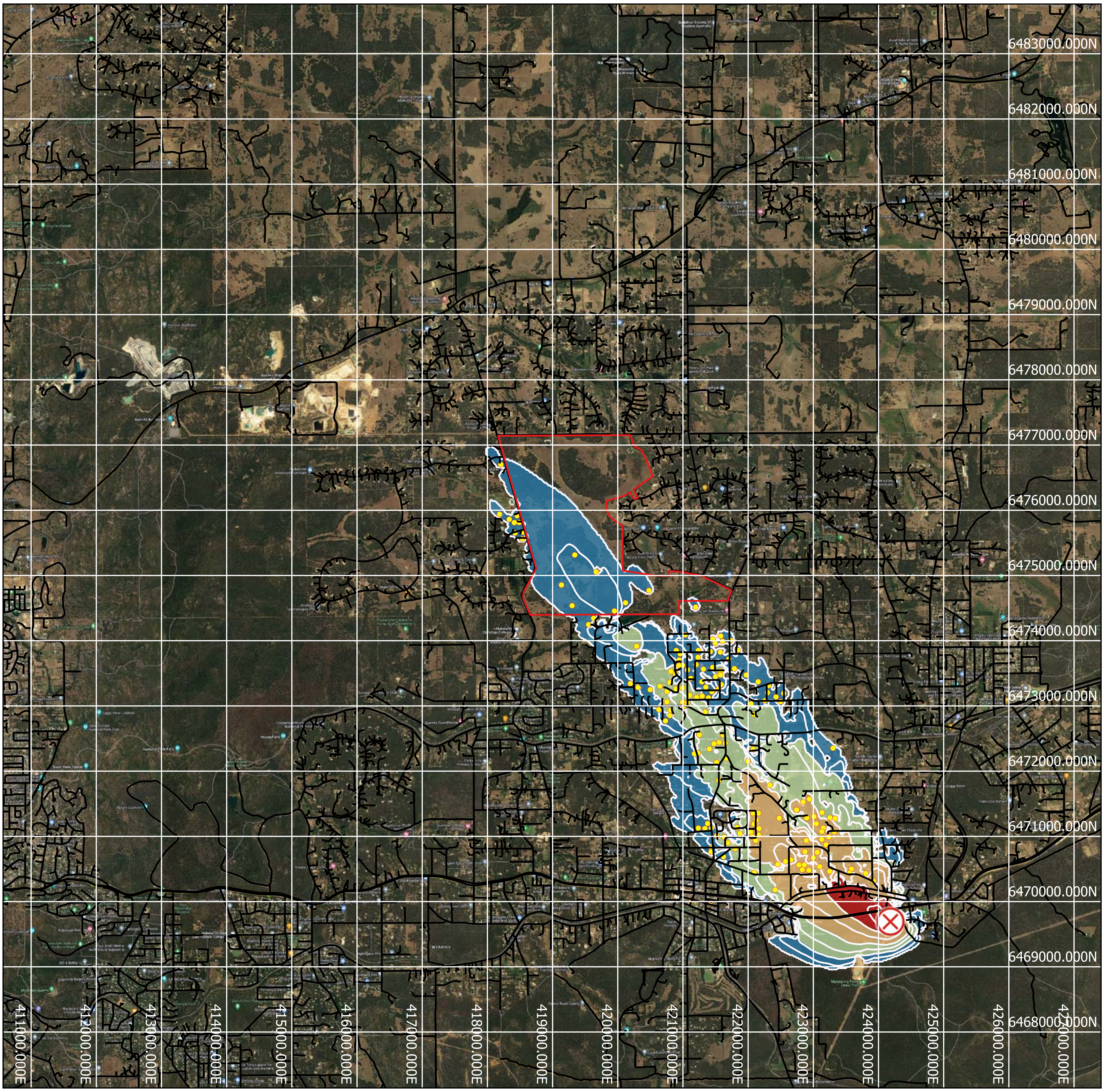
Arrival Time

- 0 to 1 hour
- 1 to 2 hours
- 2 to 3 hours
- 3 to 4 hours

CRS: 7850
Scale: 1:60,000 @ A3
Drawn by: AP
Date: 9.12.2022
Model 4q, Issue: A

North Westerly Fire Run Approaching Stoneville

Conservative Fuels, FFDI-74.9, Mature RoS



The presented 4 hour bushfire spread simulation was developed using the following information:
Bushfire Simulation: SPARK
Resolution: 20m
ROS Model: Vesta Mark 1 & CSIRO Grassland
Fire History: No
Disruptions: None
Spotting: Yes
Build-up Phase: 45 mins
Ignition Time: 13:00 hrs

0 1,000 2,000 m

CRS: 7850
Scale: 1:60,000 @ A3
Drawn by: AP
Date: 9.12.2022
Model 4p, Issue: A

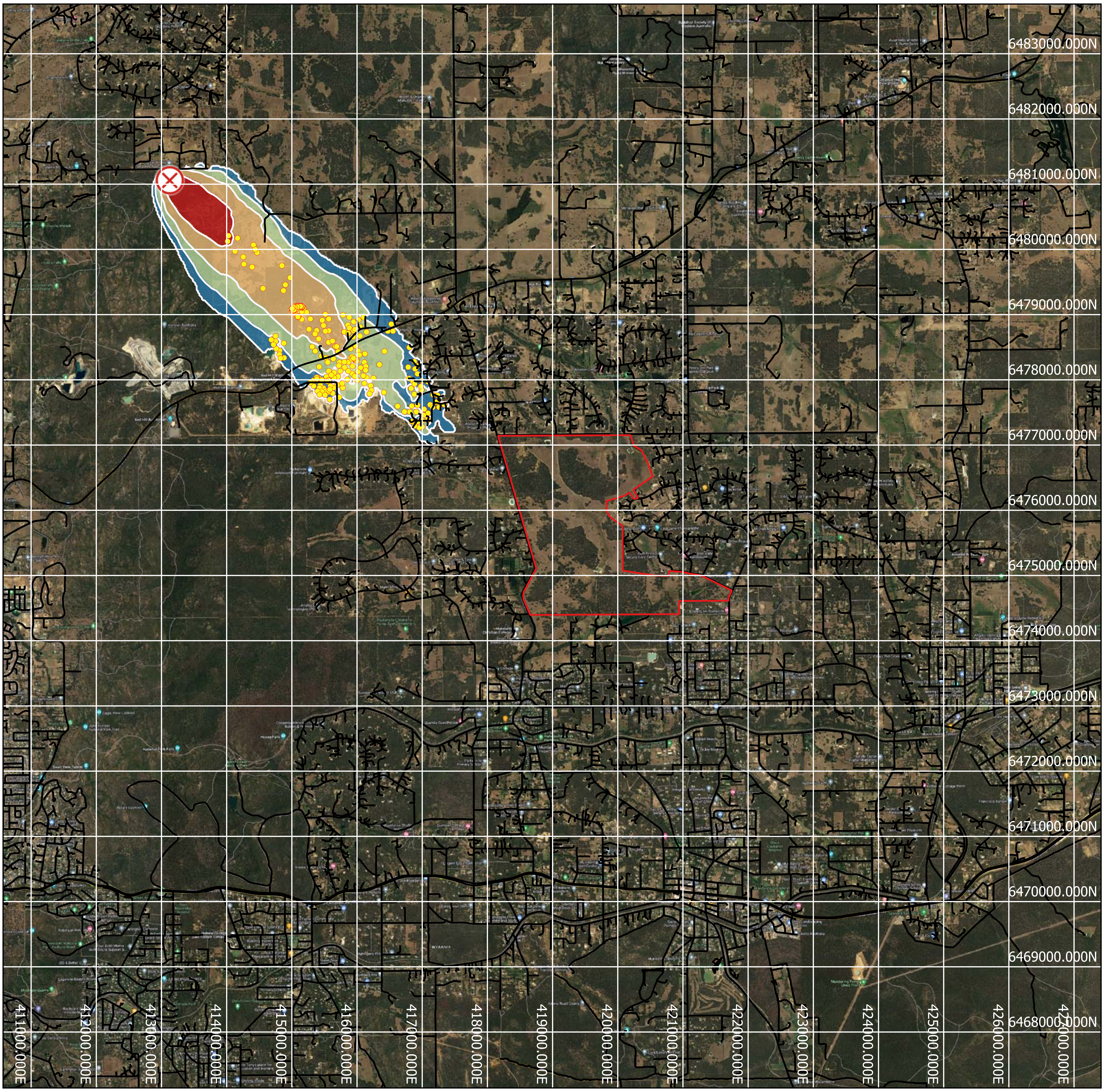
Legend

- Stoneville Site
- Road Network
- Ignition Location
- 1 hour isochrones
- Spot fires

Arrival Time
- 0 to 1 hour
- 1 to 2 hours
- 2 to 3 hours
- 3 to 4 hours

South Easterly Fire Run Approaching Stoneville

Conservative Fuels, Parkerville Fire Weather (FFDI 43.2), Mature RoS



The presented 4 hour bushfire spread simulation was developed using the following information:
Bushfire Simulation: SPARK
Resolution: 20m
ROS Model: Vesta Mark 1 & CSIRO Grassland
Fire History: No
Disruptions: None
Spotting: Yes
Build-up Phase: 45 mins
Ignition Time: 13:00 hrs

0 1,000 2,000 m

Legend

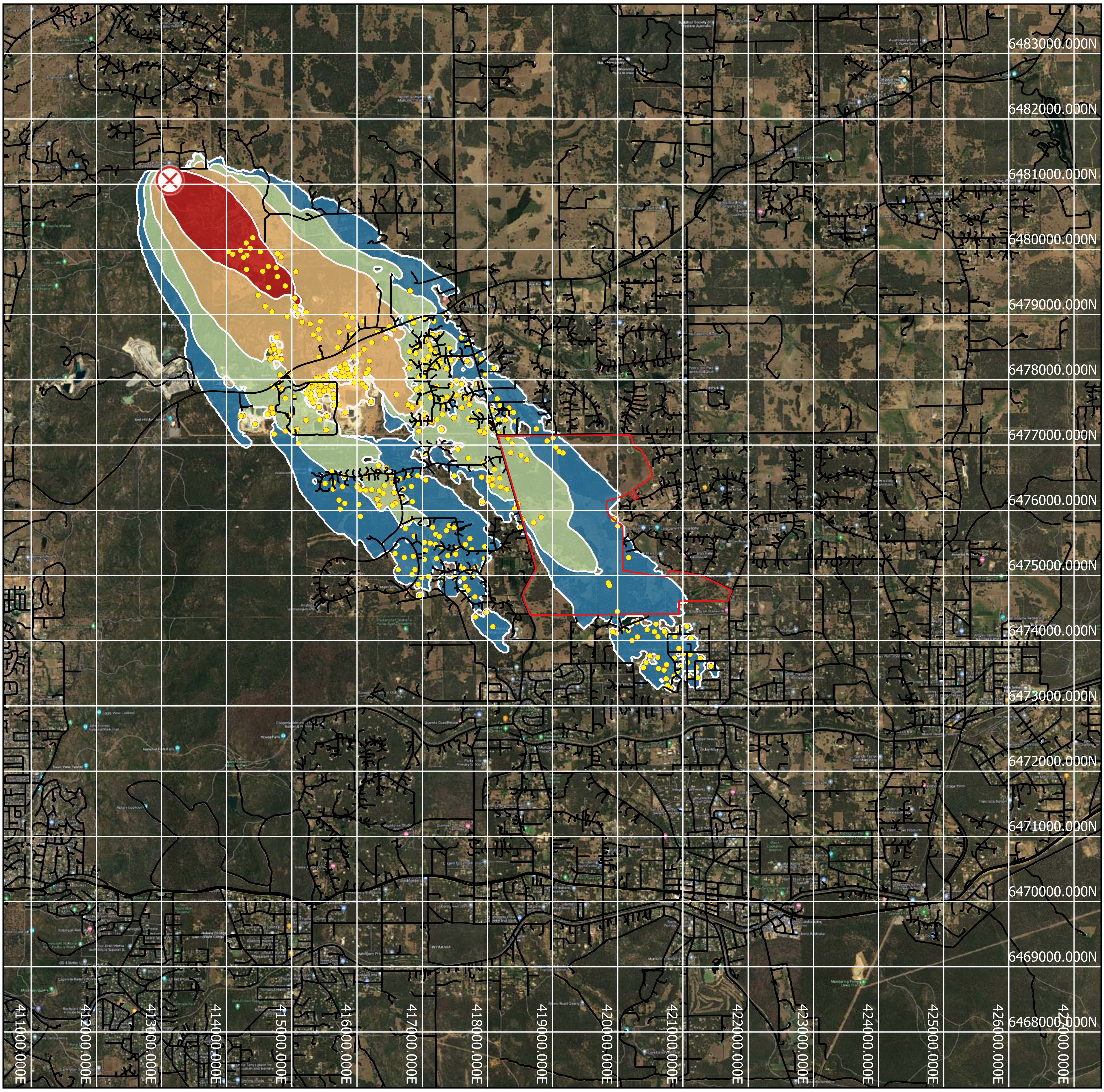
- Stoneville Site
- Road Network
- Ignition Location
- 1 hour isochrones
- Spot fires

Arrival Time
- 0 to 1 hour
- 1 to 2 hours
- 2 to 3 hours
- 3 to 4 hours

CRS: 7850
Scale: 1:60,000 @ A3
Drawn by: AP
Date: 9.12.2022
Model 4u, Issue: A

South Easterly Fire Run Approaching Stoneville

Calibration Fuels, FFDI-74.9, Mature RoS



The presented 4 hour bushfire spread simulation was developed using the following information:
Bushfire Simulation: SPARK
Resolution: 20m
ROS Model: Vesta Mark 1 & CSIRO Grassland
Fire History: No
Disruptions: None
Spotting: Yes
Build-up Phase: 45 mins
Ignition Time: 13:00 hrs

0 1,000 2,000 m

CRS: 7850
Scale: 1:60,000 @ A3
Drawn by: AP
Date: 8.12.2022
Model 4c, Issue: A

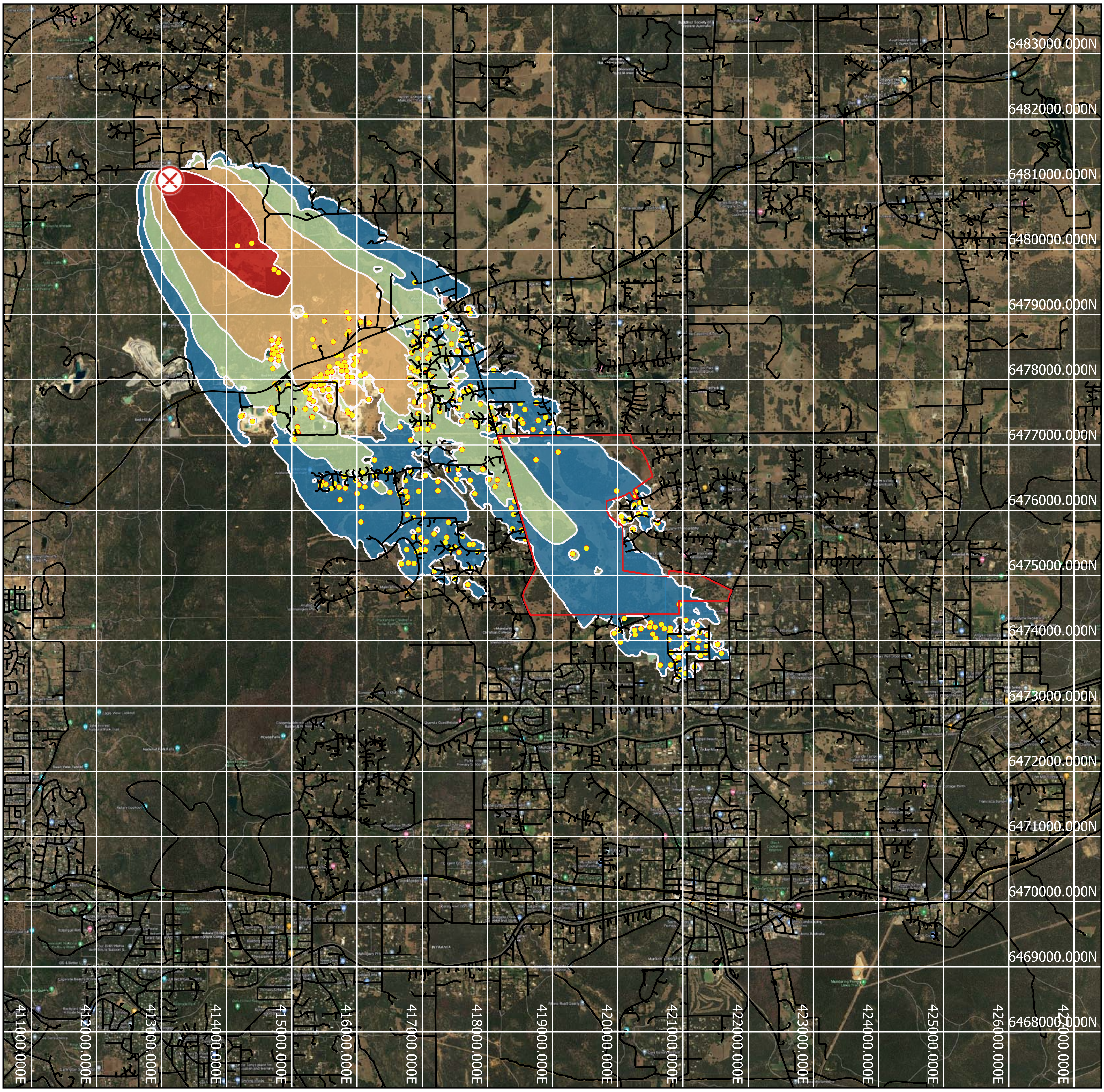
Legend

- Stoneville Site
- Road Network
- Ignition Location
- 1 hour isochrones
- Spot fires

Arrival Time
- 0 to 1 hour
- 1 to 2 hours
- 2 to 3 hours
- 3 to 4 hours

South Easterly Fire Run Approaching Stoneville

Conservative Fuels, FFDI 74.9, Growth RoS



The presented 4 hour bushfire spread simulation was developed using the following information:
Bushfire Simulation: SPARK
Resolution: 20m
ROS Model: Vesta Mark 1 & CSIRO Grassland
Fire History: No
Disruptions: None
Spotting: Yes
Build-up Phase: 45 mins
Ignition Time: 13:00 hrs

0 1,000 2,000 m

Legend

- Stoneville Site
- Road Network
- Ignition Location
- 1 hour isochrones
- Spot fires

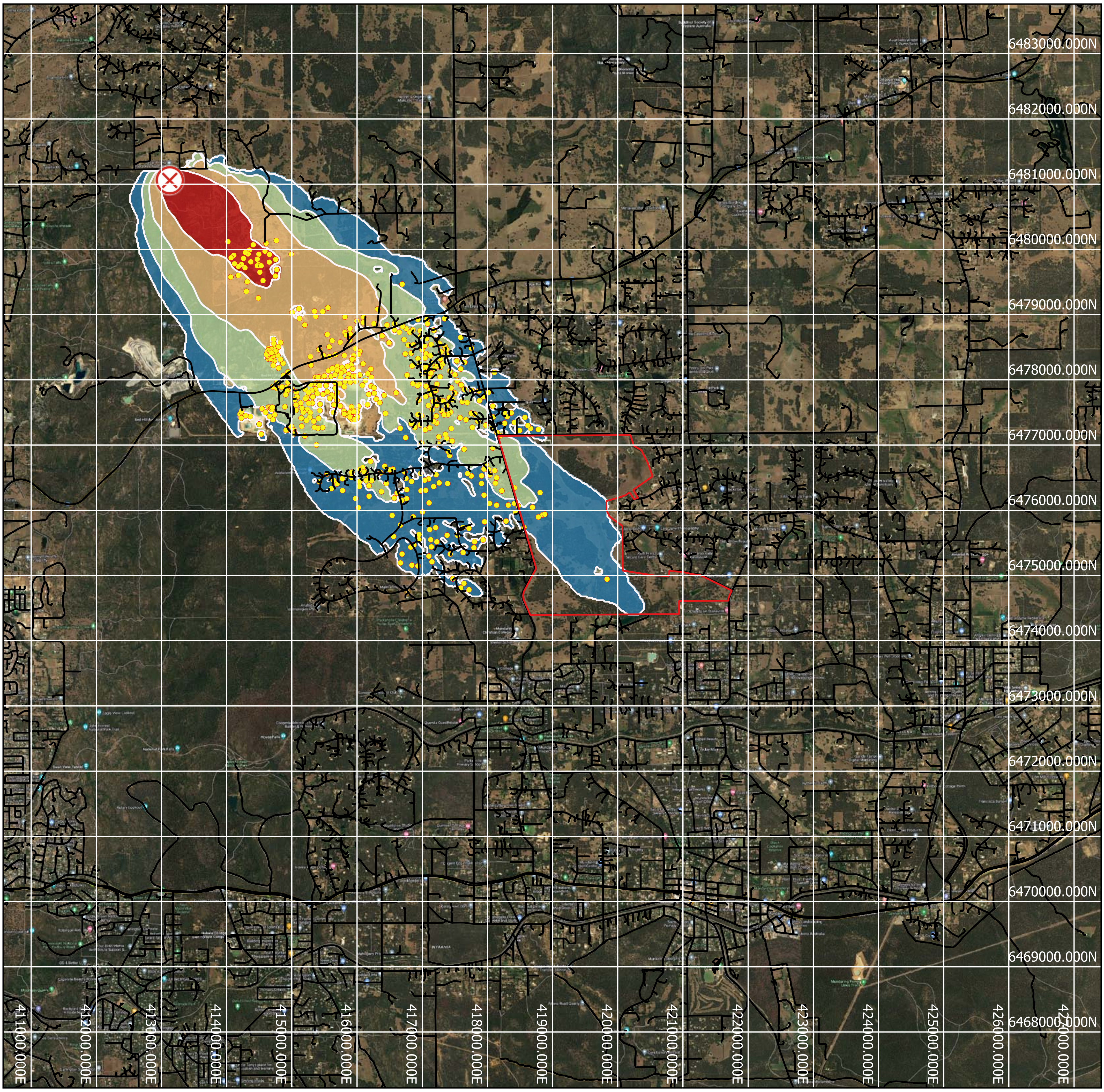
Arrival Time

- 0 to 1 hour
- 1 to 2 hours
- 2 to 3 hours
- 3 to 4 hours

CRS: 7850
Scale: 1:60,000 @ A3
Drawn by: AP
Date: 9.12.2022
Model 4v, Issue: A

South Easterly Fire Run Approaching Stoneville

Calibration Fuels, FFDI-74.9, Growth RoS



The presented 4 hour bushfire spread simulation was developed using the following information:
Bushfire Simulation: SPARK
Resolution: 20m
ROS Model: Vesta Mark 1 & CSIRO Grassland
Fire History: No
Disruptions: None
Spotting: Yes
Build-up Phase: 45 mins
Ignition Time: 13:00 hrs

0 1,000 2,000 m

Legend

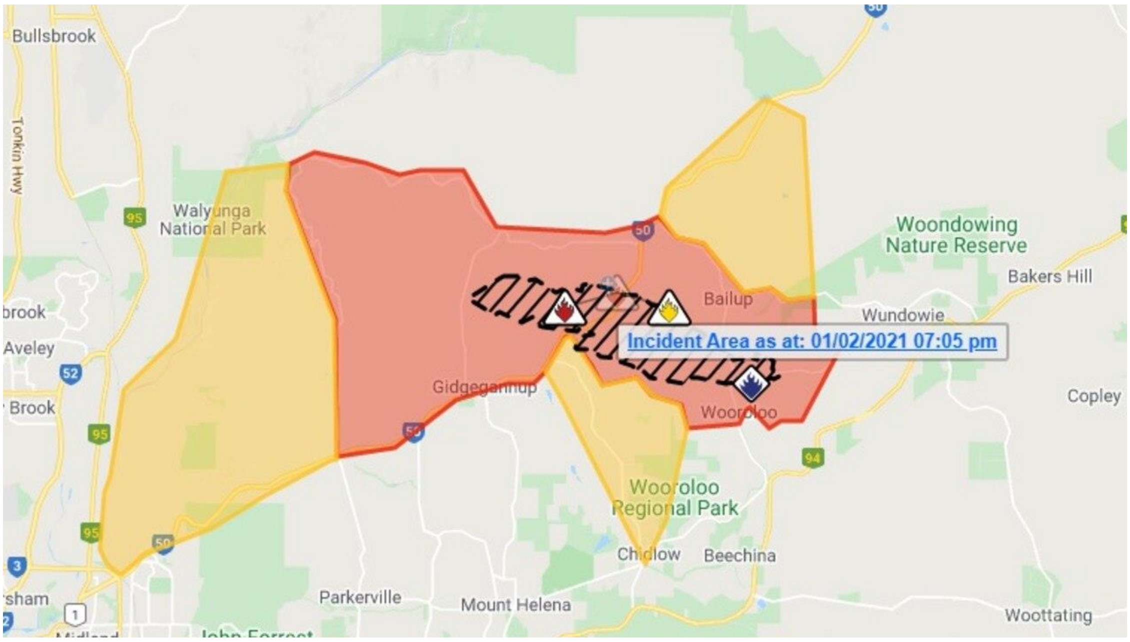
- Stoneville Site
- Road Network
- Ignition Location
- 1 hour isochrones
- Spot fires

Arrival Time
- 0 to 1 hour
- 1 to 2 hours
- 2 to 3 hours
- 3 to 4 hours

CRS: 7850
Scale: 1:60,000 @ A3
Drawn by: AP
Date: 8.12.2022
Model 4e, Issue: A

Appendix B Wooroloo Burnt Area Maps

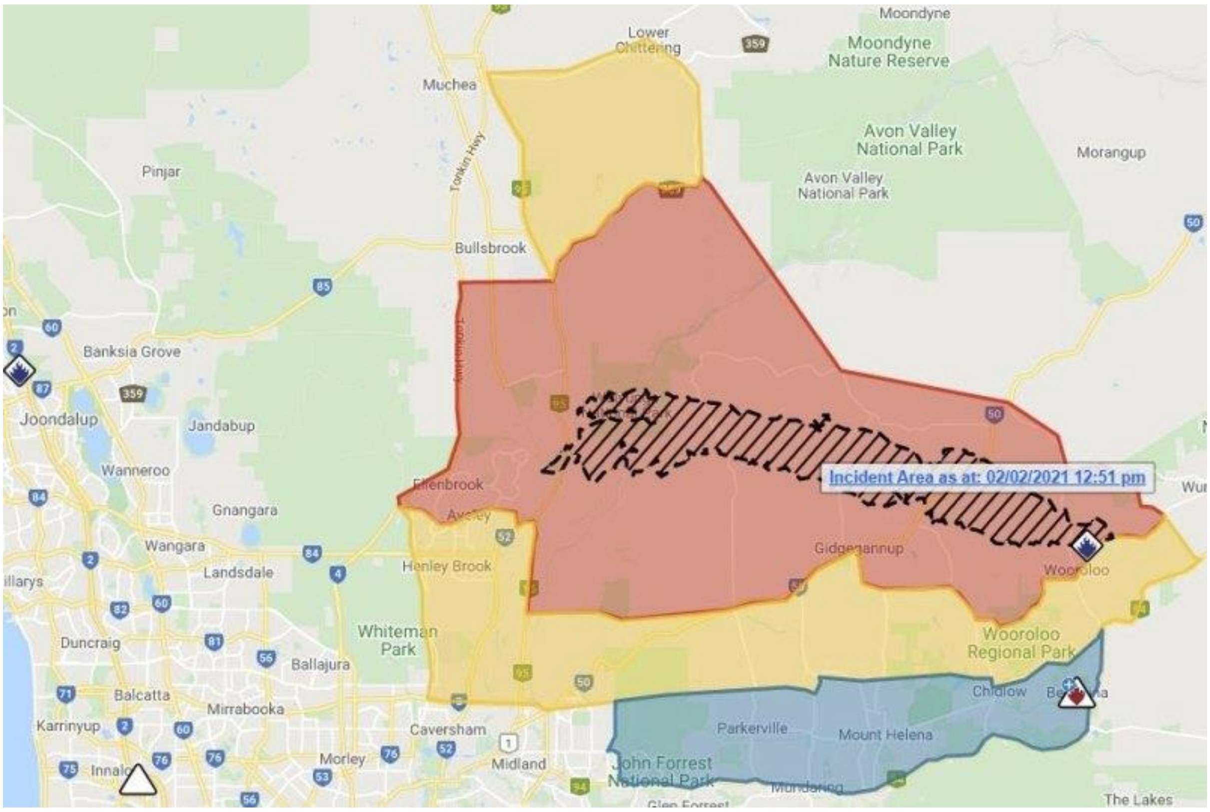
1 February 2021 – 7:05pm (approx. 7hrs since ignition)



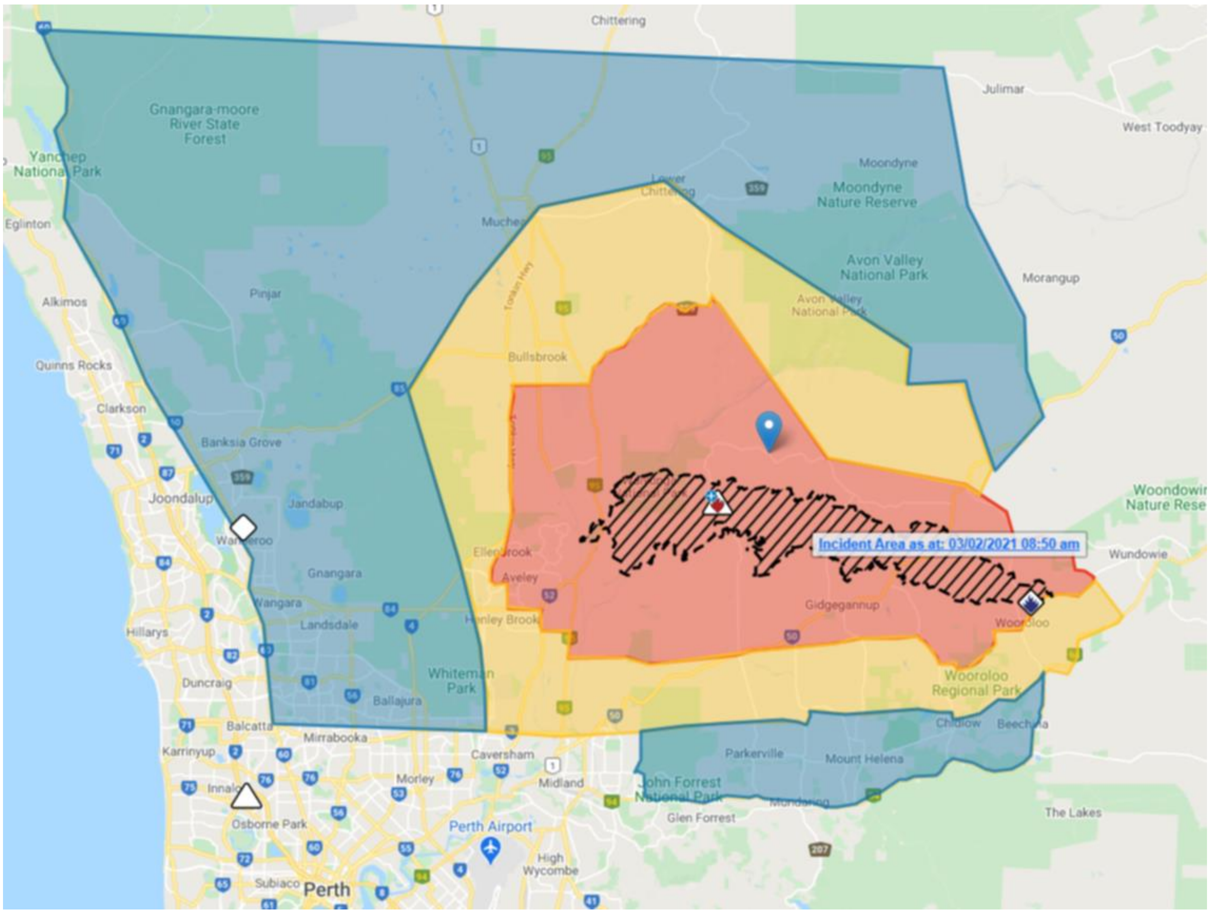
2 February 2021 – 5.10am (approx. 17hrs since ignition)

- Black hatch: Bushfire incident area
- Red: Emergency bushfire warning extent
- Yellow: Watch and Act bushfire warning extent
- Blue: Advice warning bushfire extent

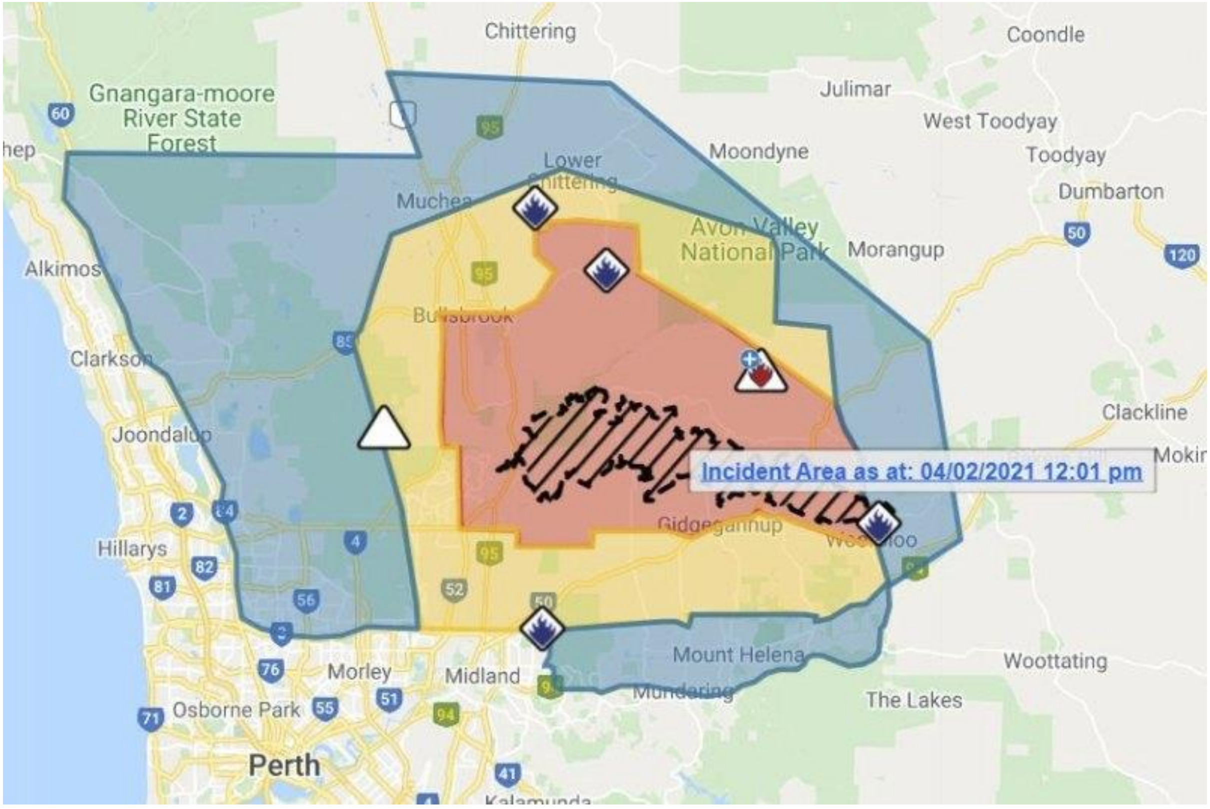
2 February 2021 – 12.51pm (approx. 25hrs since ignition)



3 February 2021 – 8.50am (approx. 45hrs since ignition)

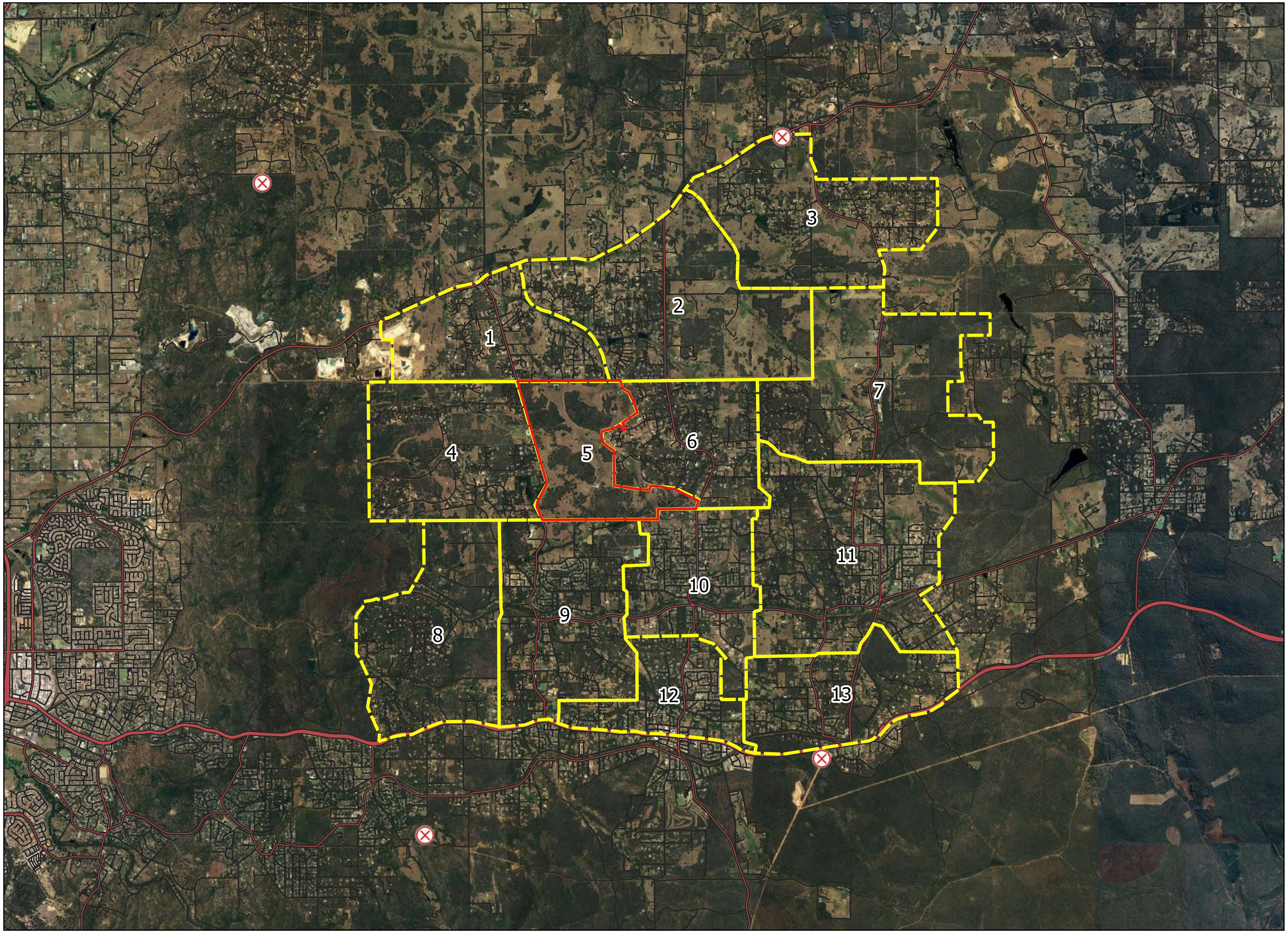


4 February 2021 – 12.01pm



Appendix C Ignition locations

Stonveille District Ignition Scenarios Map



Legend

Ignition Locations
Site Boundary
Road Network
Traffic Zones

Notes

Scale: 1:75,000 @ A3
Drawn: AP
Date: 22.4.22

0 5 10 km

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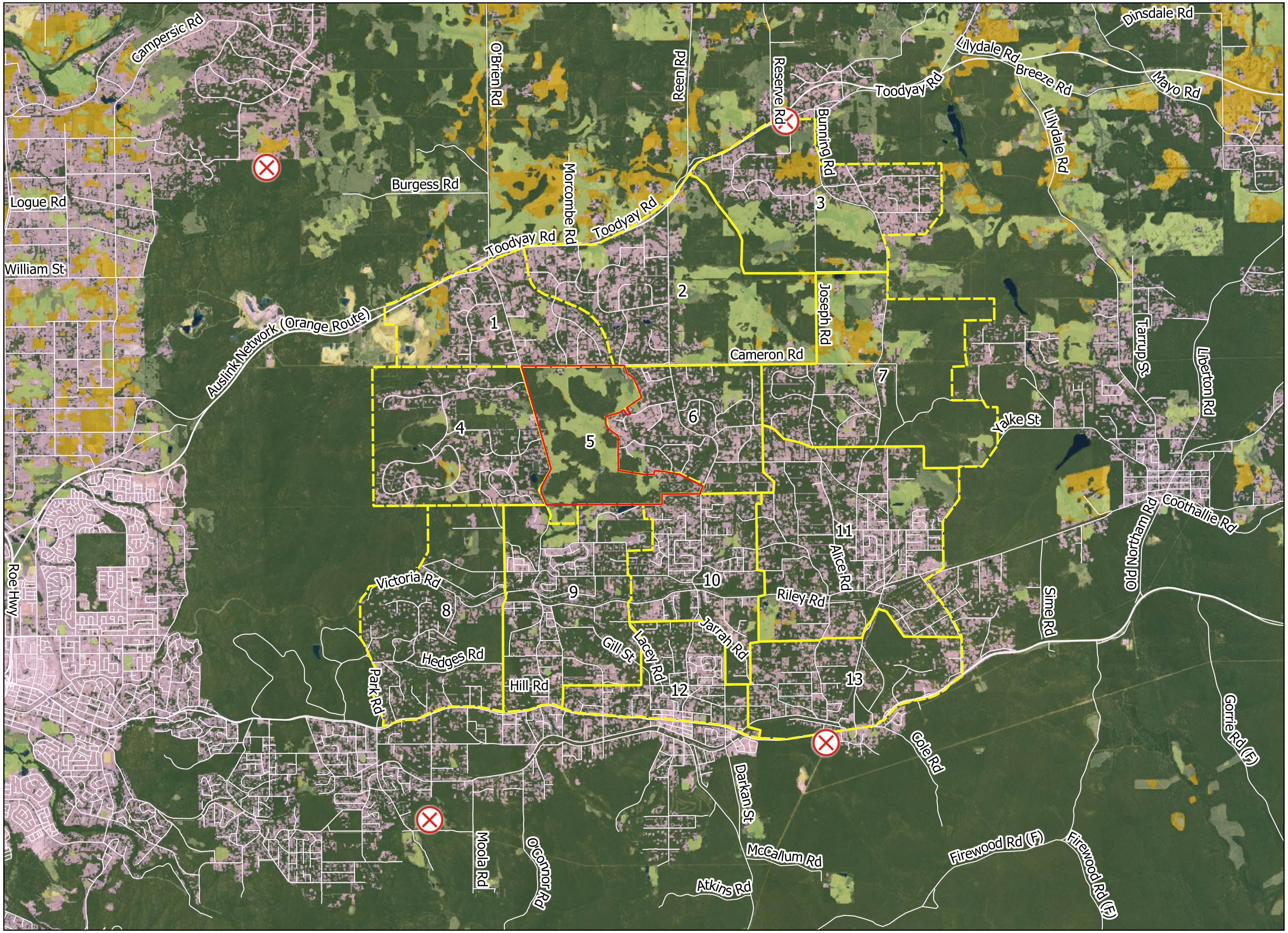
Consulting Engineers

Appendix D Land classification map

Stoneville & District Land Classification Map for SPARK Modelling



Legend

- Stoneville Site
- Roads
- Traffic Zones
- Ignition Scenario Locations

Land Classification

- Jarrah and Marri Forest
- Woodland
- Crops
- Grassland
- Built-up Areas
- Bare Ground
- Open Water

Notes
* Derived from Esri Annual Land Use & Cover Maps 2022
Scale: 1:75,000 @ A3
Drawn: AP
Date: 12.12.22
Issue: B

0 5 10 km

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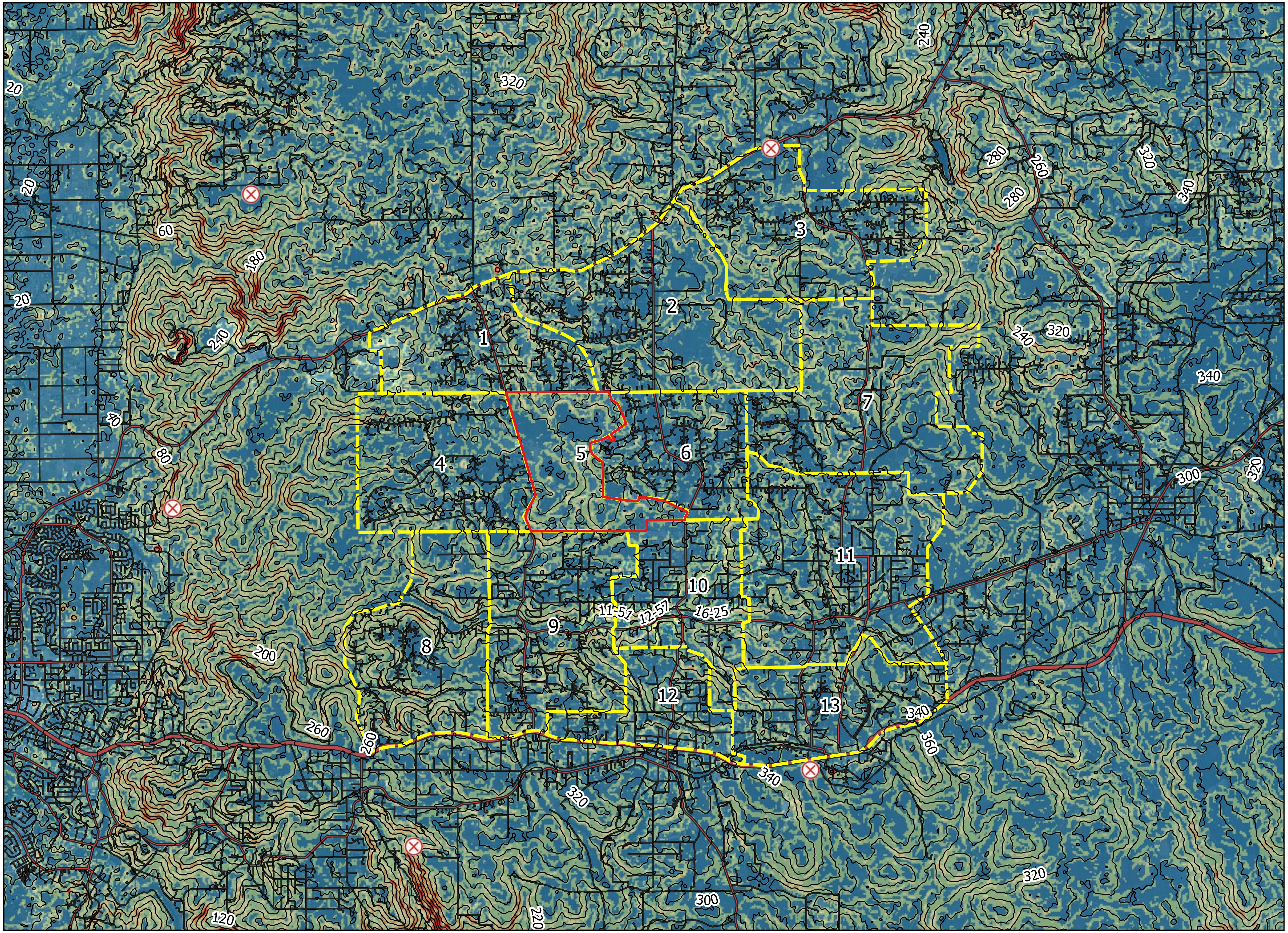
Appendix E Slope Analysis

Stonveille District Slope Analysis Map



Legend

- Ignition Locations
- Site Boundary
- Road Network
- Contour (20m CI)

Slope Analysis (degrees)

- 0-5
- 5-10
- 10-15
- 15-20
- 20+
- Traffic Zones

Notes
* Slopes derived from 1s DEM
* DEM Source Elvis Lidar
Scale: 1:75,000 @ A3
Drawn: AP
Date: 18.5.22
Issue: B

0 5 10 km

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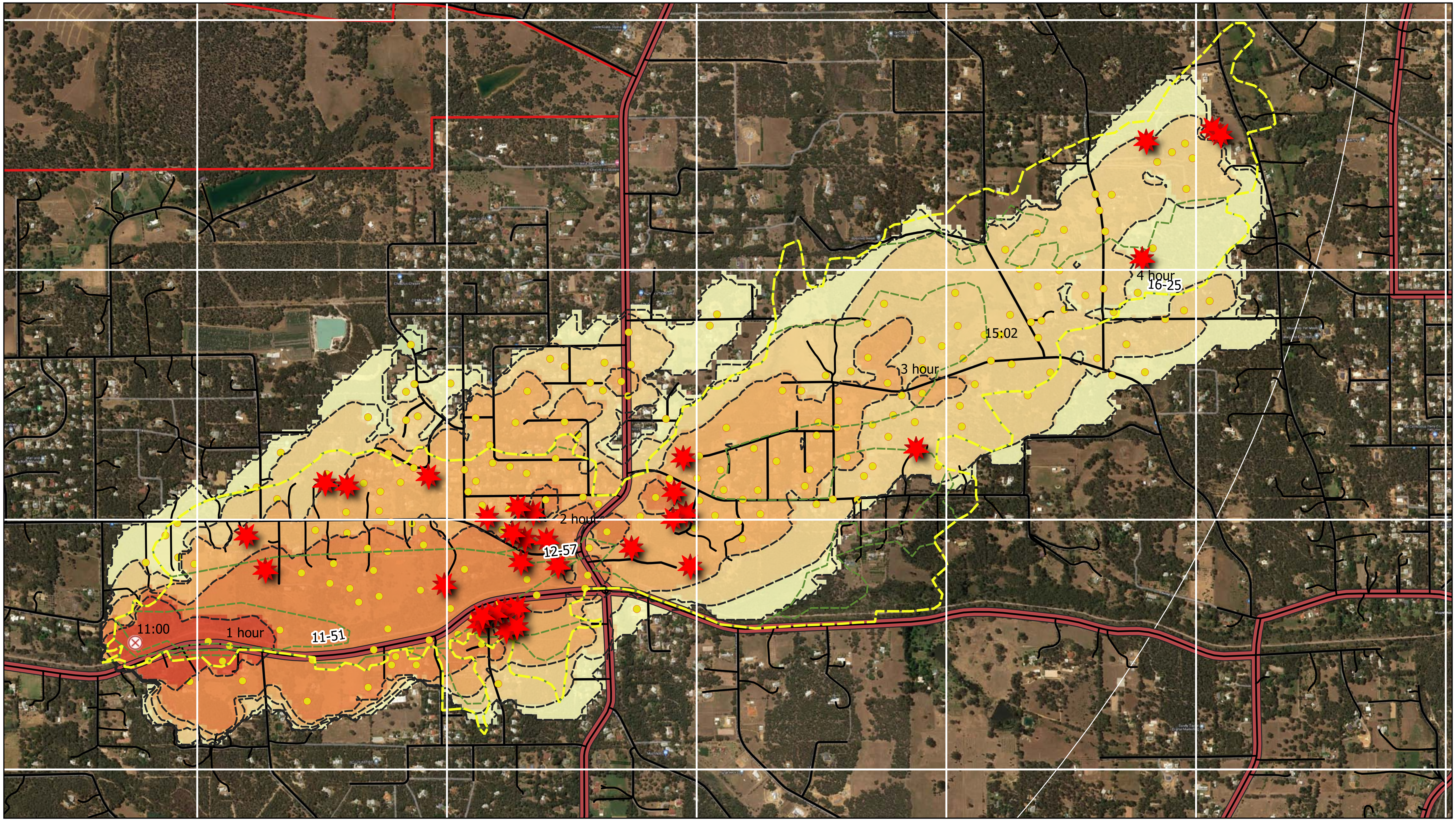
Consulting Engineers

Appendix F Parkerville bushfire reconstruction plan

Growth RoS model

Parkerville Fire Simulation, 12 Jan 2014, Peak FFDI 43.2, Growth RoS



0 0.5 1 km

CRS: 7850
Scale: 1:15,000 @ A3
Drawn by: AP
Model Shown: 3q
Date: 28.11.22
Issue: E

Simulation Notes
Model Resolution: 20m
ROS Model: Vesta Mk 1
Duration: 5 hours
Weather: Bickley AWS + 10 degree wind shift
Suppression: No
Fire History: No
DEM: 25m
Land Class: derivsed from 2021 Sentinel
Hist Isochrones: derived from DFES report
Build-Up Phase: 20 mins

Legend

Sim Arrival Time (hours)
- 1 hour
- 2 hours
- 3 hours
- 4 hours
- 5 hours

Sim Isochrones (1 hour)
Ignition Location (11:00hrs)
Sim Spot Fires
Structure Loss
Final Perimeter
Est. Perimeter (DFES)
Roads
Stoneville Site Bdy

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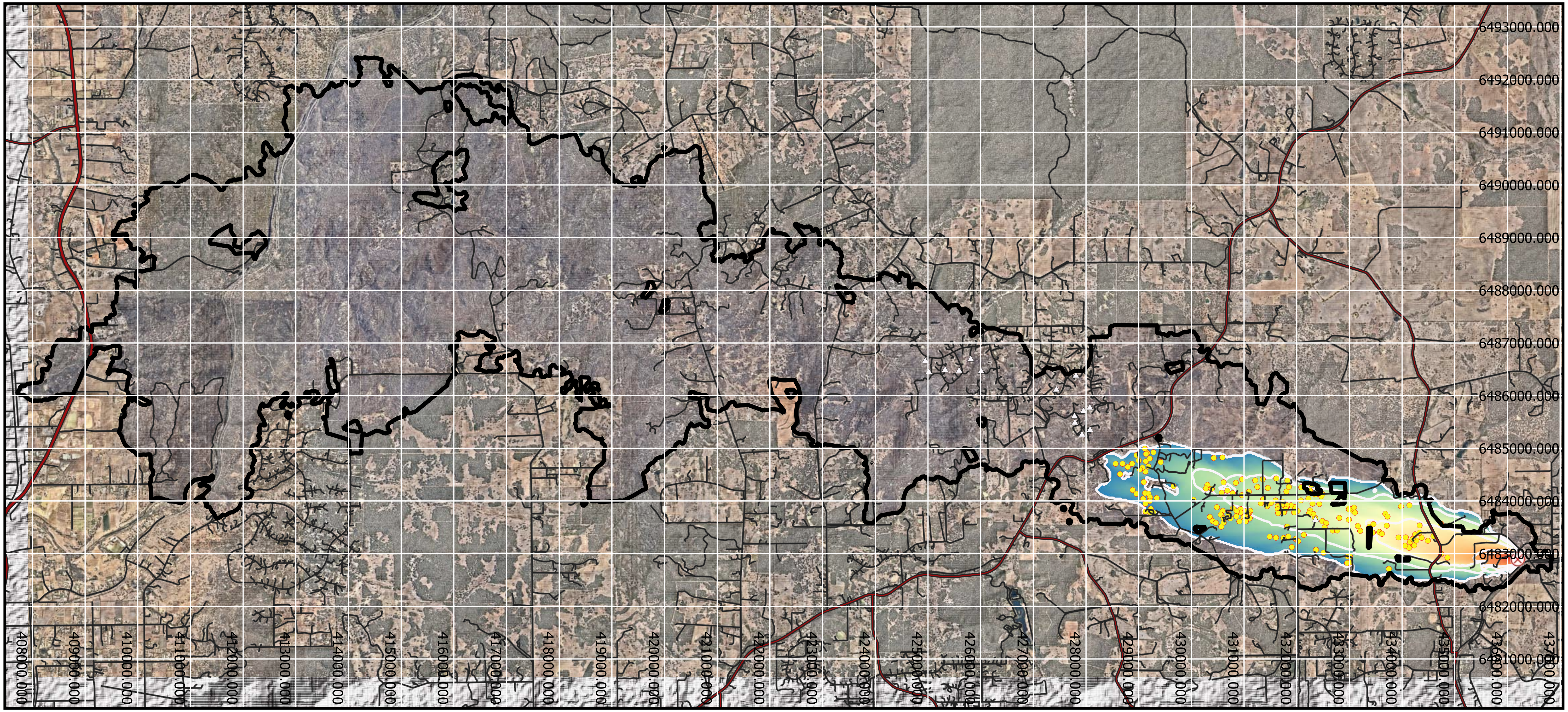
Appendix G Wooroloo bushfire reconstruction plan

Mature RoS model

Growth RoS model

Wooroloo Fire Simulation, 1 Feb 2021 (Peak FFDI 47.4), Mature RoS, Approx. 15:50 (4-hours)



Legend

- Final Fire Perimeter
- Identified Lost Building
- Major Roads
- Other Roads
- Ignition Location
- Sim Spots
- Sim Iso (1 hr)

Sim Arrival Time

- Time 0
- 1 hour
- 2 hours
- 3 hours
- 4 hours

0 5 10 km

Notes

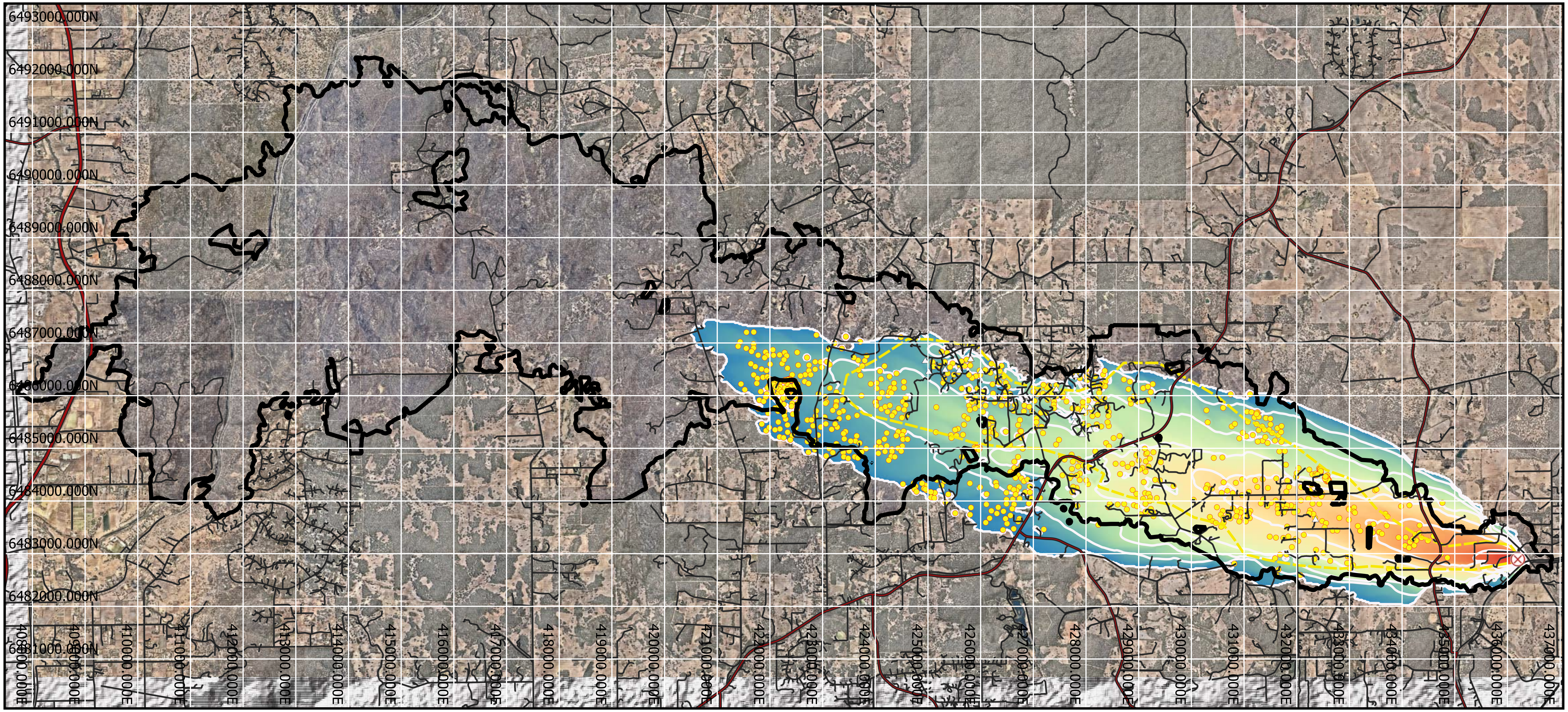
Model Resolution: 20m
ROS Model: Vesta Mk 1
Weather: Bickley AWS
Fuels: 10 Years
Fire Area: tbc

Suppression: No
Spotting: Yes (mature)
Fire History: No
Build-up: 45 mins

DEM: 25m
Land Class: drived from 2021 Sentinel
Hist Isochrones: derived from Wiki site
Disruptions: No

CRS: 7850
Scale: 1:75,000 @ A3
Drawn by: AP
Date: 9 Dec 2022
Map Grid: 1km

Wooroloo Fire Simulation, 1 Feb 2021 (Peak FFDI 47.4), Mature RoS, Approx. 19:05 (7-hours)



Legend

- Final Fire Perimeter
- Identified Lost Building
- Major Roads
- Doc. Per. (approx 7 hrs)
- Other Roads
- Ignition Location
- Sim Spots
- Sim Iso (1 hr)

Sim Arrival Time

- Time 0
- 1 hour
- 2 hour
- 3 hour
- 4 hour
- 5 hour
- 6 hour
- 7 hour

0 5 10 km

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Notes

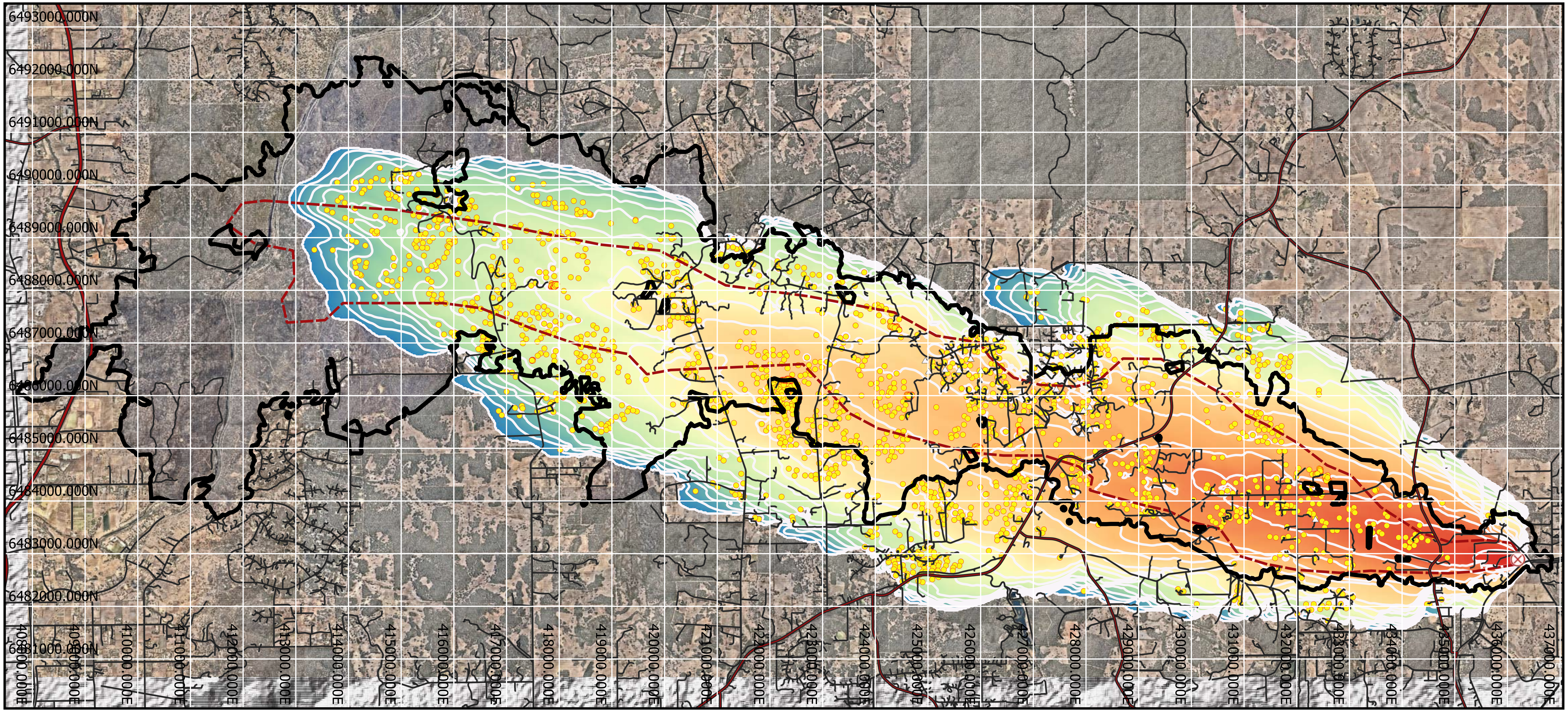
Model Resolution: 20m
ROS Model: Vesta Mk 1
Weather: Bickley AWS
Fuels: 10 Years
Fire Area: tbc

Suppression: No
Spotting: Yes (mature)
Fire History: No
Build-up: 45 mins
Curing: 67%

DEM: 25m
Land Class: drived from 2021 Sentinel
Hist Isochrones: derived from Wiki site
Disruptions: No

CRS: 7850
Scale: 1:75,000 @ A3
Drawn by: AP
Date: 9 Dec 2022
Map Grid: 1km

Wooroloo Fire Simulation, 1 Feb 2021 (Peak FFDI 47.4), Mature RoS, Approx. 05:10 (17-hours)



Legend

Final Fire Perimeter	Other Roads	Sim Iso (1 hr)	2 hours	6 hours	10 hours	14 hours
Identified Lost Building	Ignition Location	Sim Arrival Time	3 hours	7 hours	11 hours	15 hours
Major Roads	Sim Spots	Time 0	4 hours	8 hours	12 hours	16 hours
Doc. Per. (approx 17 hrs)		1 hour	5 hours	9 hours	13 hours	17 hours

0 5 10 km

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Notes

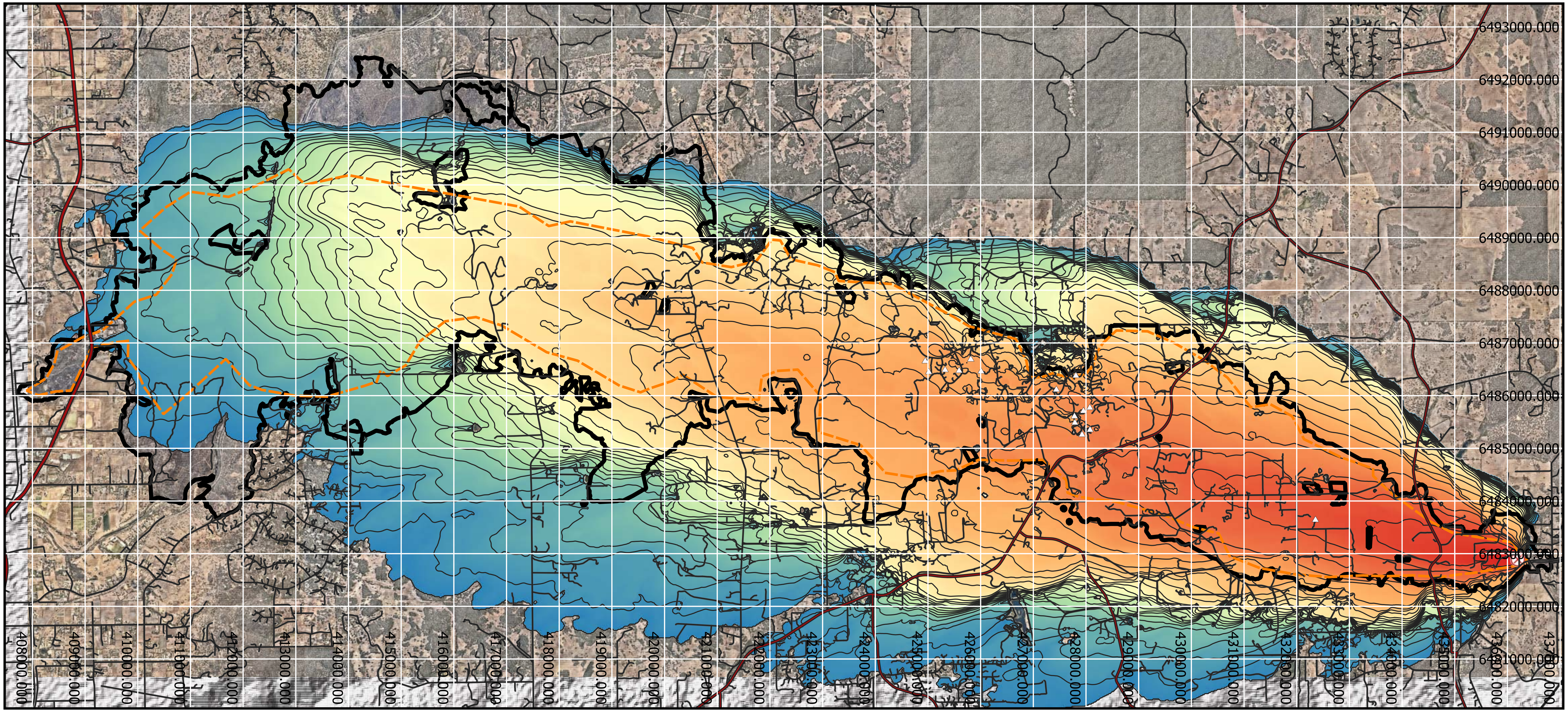
Model Resolution: 20m
ROS Model: Vesta Mk 1
Weather: Bickley AWS
Fuels: 10 Years
Fire Area: tbc

Suppression: No
Spotting: Yes (mature)
Fire History: No
Build-up: 45 mins
Curing: 67%

DEM: 25m
Land Class: drived from 2021 Sentinel
Hist Isochrones: derived from Wiki site
Disruptions: No

CRS: 7850
Scale: 1:75,000 @ A3
Drawn by: AP
Date: 9 Dec 2022
Map Grid: 1km

Wooroloo Fire Simulation, 1 Feb 2021 (Peak FFDI 47.4), Mature RoS, Approx. 12:51 (25-hours)



Legend

Final Fire Perimeter	Sim Iso (1 hr)	3 hours	8 hours	13 hours	18 hours
Identified Lost Building	Sim Arrival Time	4 hours	9 hours	14 hours	19 hours
Major Roads	Time 0	5 hours	10 hours	15 hours	20 hours
Other Roads	1 hour	6 hours	11 hours	16 hours	21 hours
Doc. Per. (approx 25 hrs)	2 hours	7 hours	12 hours	17 hours	22 hours

23 hours
24 hours
25 hours

0 5 10 km

Notes

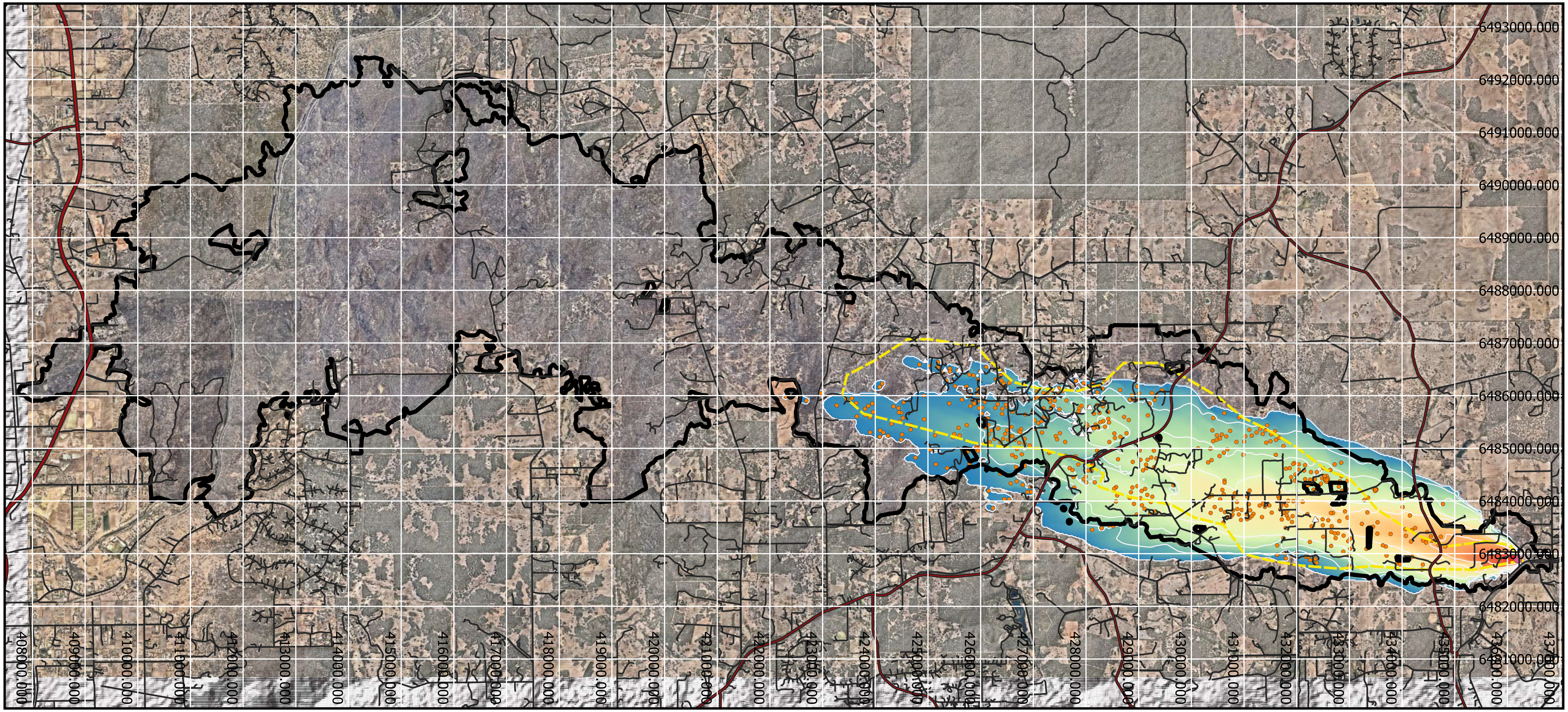
Model Resolution: 20m
ROS Model: Vesta Mk 1
Weather: Bickley AWS
Fuels: 10 Years
Fire Area: tbc

Suppression: No
Spotting: Yes (mature)
Fire History: No
Build-up: 45 mins

DEM: 25m
Land Class: drived from 2021 Sentinel
Hist Isochrones: derived from Wiki site
Disruptions: No

CRS: 7850
Scale: 1:75,000 @ A3
Drawn by: AP
Date: 9 Dec 2022
Map Grid: 1km

Wooroloo Fire Simulation, 1 Feb 2021 (Peak FFDI 47.4), Growth RoS, Approx. 19:00 (7-hours)



Legend

Final Fire Perimeter	Major Roads	Sim Iso (1 hr)	2 hours
Doc. Per. (approx 7 hr)	Other Roads	Sim Arrival Time	3 hours
Identified Lost Building	Sim Spots	Time 0	4 hours
		1 hour	5 hours
			6 hours
			7 hours

0 5 10 km

Notes

Model Resolution: 20m
ROS Model: Vesta Mk 1
Weather: Bickley AWS
Fuels: 10 Years
Fire Area: 2,975.6 ha

Suppression: No
Spotting: Yes
Fire History: No
Build-up: 45 mins

DEM: 25m
Land Class: drived from 2021 Sentinel
Hist Isochrones: derived from Wiki site
Disruptions: No

CRS: 7850
Scale: 1:75,000 @ A3
Drawn by: AP
Date: 2 Dec 2022
Map Grid: 1km

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Appendix H Bushfire Weather Analysis

Weather Data for FFDI calculation purposes

- Site-specific FFDI information for locations around Western Australia is not readily available.
- Bureau of Meteorology (BoM) also have access to a national historical fire weather dataset developed by Lucas (2010), that analysed daily 3pm weather data, in conjunction with daily drought factor, to calculate the FFDI from 1972 to present day. Whilst this dataset is often useful, it is only available for a few locations, the nearest being Perth Airport.
- To address the limitations relating to the national historical fire weather dataset including the lack of a nearby location in the Perth Hills and the temporal factors in the FFDI calculation, an FFDI analysis has been conducted using raw weather data and the calculated ground moisture data from BoM, to produce a FFDI calculation for the project area that is both as close to the project area as possible, whilst also providing a more accurate calculation of the peak daily FFDI at the locality.
- The data set were obtained from BoM for the Bickley weather station (Station Number 9240) located less than 14 km south of the project area, and included the following:
    - Hourly weather station information
        - hourly air temperature (°C)
        - hourly relative humidity (%)
        - hourly wind speed and direction
        - 10 min and 24 hour rainfall (up to 9:00 am day prior)
    - Ground Moisture Module (GMM)
        - Daily Drought Factor
- Both data sets (hourly weather and GMM) are available from 21 July 1999 to 15 December 2021 to enable calculation of the daily and hourly FFDI over this 23 year period.
- There are some significant gaps and errors in the data sets, typically relating to missing or obviously incorrect relative humidity data and missing windspeeds values, however there were also some missing temperature values.
    - Occasional missing temperature readings
    - Significant numbers of missing relative humidity and wind speed readings
    - Significant number of very low relative humidity readings (1-4%), that are accompanied by very low dew points (typically between -15 and -46°), often not associated with extremely high temperatures, and are significantly lower than relative humidity readings at Perth Airport (Station Number 9021) at the same time.
- No adjustments were made to the BoM data sets for purposes of gap filling or error correction, however analysis of the relative humidity trends using the Bickley data set was refined, and supplemented by additional analysis using Perth Airport data.
- Table 14 below provides a summary of the station information for each of the BoM weather stations used as part of this analysis, namely Bickley and Perth Airport.
    - A key difference between the two stations is the elevation, with Bickley located approximately 370 m higher, despite being located approximately 16 km apart. This likely explains the higher temperatures but lower relative humidity readings that tend to be recorded at Perth Airport in comparison to those at Bickley.

Table 14: Bickley and Perth Airport BoM Station information

BoM Weather Station	Bickley	Perth Airport
BoM Station Number	9240	9021
BoM District Name	Central Coast (WA)	Central Coast (WA)
Latitude/Longitude	32°0'26"S / 116°8'13"E	31°55'39"S / 115°58'35"E
Station Height (Barometer Elevation)	384 m (385 m)	15.4 m (20 m)

FFDI calculation

- FFDI is calculated using the following equation:

  $$FFDI = 2\exp(-0.450 + 0.987 \ln D - 0.0345H + 0.0338T + 0.0234V) \qquad [1]$$

  where:

  D = drought factor,

  H = relative humidity (%),

  V = wind speed (kph) at 10 m reference height and

  T = air temperature (°C)

  The drought factor is derived from Keetch-Byram Drought Index or KBDI.

- Using hourly weather data and daily ground moisture data from the local BoM weather station at Bickley, FFDI has been calculated as follows:
  - Daily FFDI
    - Maximum temperature
    - 3pm Relative Humidity and Wind Speed
    - Daily Drought Factor
  - Hourly/half-hourly FFDI
    - Temperature, Relative Humidity and Wind Speed measured at the specific time
    - Daily Drought Factor

Generalised Extreme Value (GEV) Calculation

- Using extreme value statistical techniques is common for determining design conditions for other natural events, with an example being in the National Construction Code of Australia where annual exceedance probabilities for extreme events is used to determine the importance level for structural design.
- Douglas et al (2014) propose the use of Generalised Extreme Value (GEV) analysis, utilising maximum FFDI values derived from site-specific data, to establish the annual exceedance probability (AEP) of FFDI for application to bushfire events.
- Douglas et al (2014) describes the GEV analysis as follows:
  - Assume that M number of values of a given parameter, y, are available for n years.
  - The data points are ranked according to their values in the descending order.
  - The return period or recurrence *R* for the *m*th ranked data point, *ym*, is then evaluated from:

$R(ym) = (n + 1)/m$ [2]

The so obtained set of M data pairs (ym, Rm) (m=1, 2, 3, …, M) can be plotted on a log-linear graph.

- The resultant curve usually follows a log function of the form:

  $y = a \ln R + b$ [3]

  where b is the intersect with the one year recurrence or return period.

  Eq. [3] can be used to extrapolate the return periods beyond the data period.

FFDI GEV Analysis

- The 24 highest daily FFDI values obtained from the Bickley weather station (see Table 15) were used to conduct the GEV analysis of the recurrence period.
  - 330 results were missing from this analysis, primarily due to missing relative humidity readings.
- These FFDI values were plotted *vs* return period *R*, with a regression line of best-fit determined using the log-linear function as expressed in Eq. [3] as shown on Plate 5. From the calculated regression, the FFDI can be calculated for the various recurrence periods (see Table 16)
  - The calculated 1:50 year FFDI at Bickley is FFDI 60.6

Table 15: Highest FFDI values for Bickley (9240) from 1999 to 2021

Rank	Recurrence	FFDI
1	24	55.5
2	12	55.0
3	8	54.3
4	6	53.9
5	5	53.4
6	4	52.3
7	3	52.2
8	3	52.0
9	3	52.0
10	2	50.1
11	2	49.8
12	2	48.9
13	2	48.8
14	2	47.9
15	2	47.7

Rank	Recurrence	FFDI
16	2	47.7
17	1	47.6
18	1	47.4
19	1	47.3
20	1	46.8
21	1	46.4
22	1	46.3
23	1	46.1
24	1	46.1

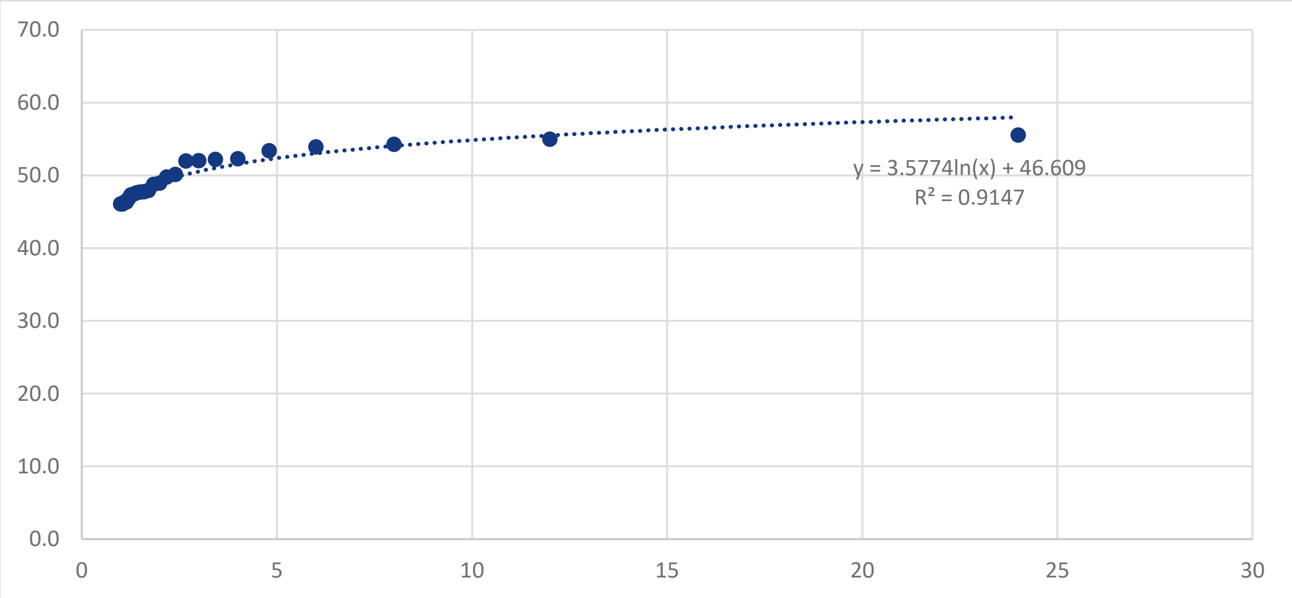


Plate 5: FFDI GEV analysis for Bickley (9240) from 1999 to 2021

Table 16: FFDI for various recurrence periods for Bickley (9240)

Recurrence period (years)	FFDI
1	46.6
20	57.3
25	58.1
50	60.6
100	63.1

Moving Average FFDI GEV Analysis

- This methodology was detailed in Douglas and He (2019), and seeks to analyse the potential impacts of climate change on future FFDI.
- It requires conducting the GEV FFDI analysis over the available data set, but using a moving window across time steps, rather than considering the entire data set as a single entity.
  - Douglas and He (2019) recommend that 20 year moving windows are used and this was confirmed with Grahame Douglas (per comm.). The reason is that using a lesser timeframe increases the potential error, with a 20 year window considered to have 5% error, but a 10 year moving window increase to at least 10% error.
- Based on the available data sets from Bickley weather station, GEV analysis of the 1:50 year FFDI was conducted over 14 moving windows
  - each 10 year window used to calculate 1:50 year FFDI as shown in Table 17
  - various regressions were applied to the graphed data to determine the best fit. In this case the linear relationship was best fit with a R2 of 0.6159 (see Plate 6)
  - The 1:50 year FFDI is revised based on the linear relationship to account for 25 year and 50 year climate change projections (see Table 18)
- As the data set is not over a sufficiently long enough timeframe to use 20 year moving windows, it will contain inherent errors

Table 17: Moving Average 1:50 year FFDI for Bickley (9240) in 10 year windows

Window	Window Sequence	1: 50 yr FFDI
1	1999 - 2008	61.1
2	2000 – 2009	61.2
3	2001 – 2010	59.5
4	2002 – 2011	59.5
5	2003 – 2012	58.9
6	2004 – 2013	59.1
7	2005 – 2014	59.8
8	2006 – 2015	59.8
9	2007 – 2016	62.4
10	2008 – 2017	63.3
11	2009 – 2018	63.3
12	2010 – 2019	65.1
13	2011 – 2020	64.3
14	2012 – 2021	64.9

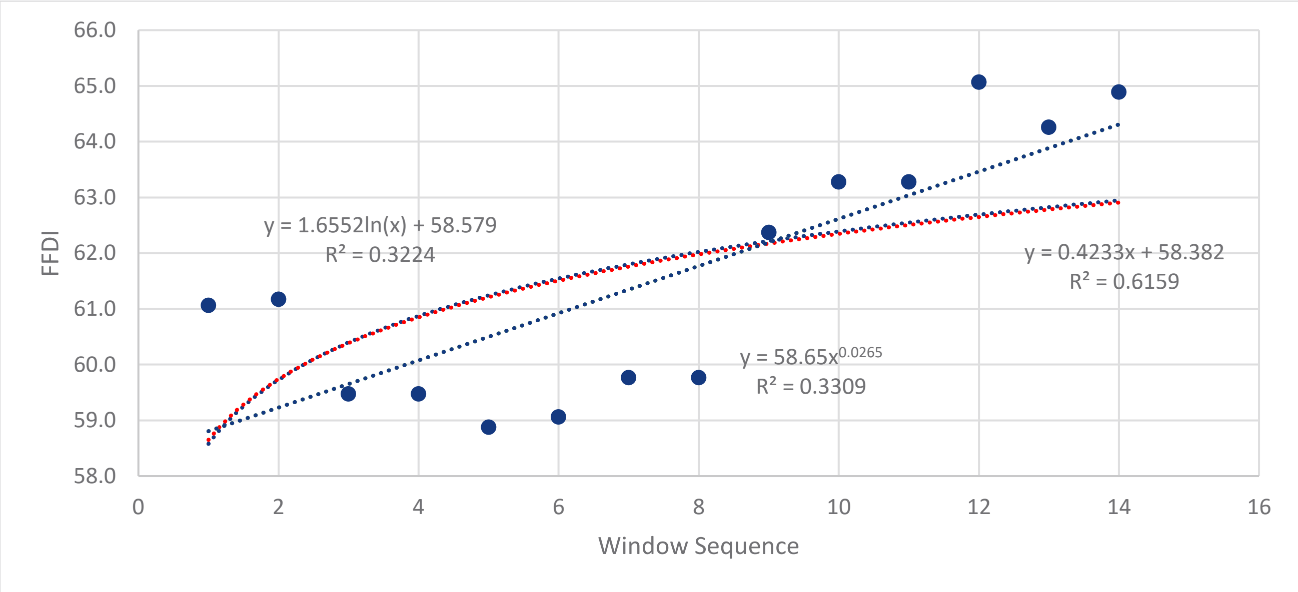


Plate 6: Moving Average FFDI GEV analysis for Bickley (9240)

Table 18: 1:50 year FFDI for 25yr and 50yr climate change projections

Projection (years)	FFDI (1:50 year)
39 [25 year]	74.9
64 [50 year]	85.5

<u>Temperature and Relative Humidity GEV Analysis</u>

- In order to develop the weather profile information to input into SPARK, and understanding of likely peak temperature and relative humidity is also required.
- Similar to FFDI, a GEV analysis was also conducted of temperature over the Bickley weather station data set, to provide an indication of expected future peak temperatures
    - Using maximum temperatures at Bickley (see Table 19), a GEV analysis of the peak temperature was conducted (see Plate 7) to determine the peak temperatures as various recurrence rates (see Table 20)
- Using a 10 year moving window (see Table 21) of the 1:50 year temperature, a Moving Average GEV analysis was conducted (see Plate 8), to provide an indication of likely climate change impact on temperature (see Table 22)

Table 19: Highest Temperature values for Bickley (9240)

Rank	Recurrence	Temperature (°C)
1	24	41.6
2	12	40.8
3	8	40.3
4	6	40.3

Rank	Recurrence	Temperature (°C)
5	5	39.9
6	4	39.9
7	3	39.9
8	3	39.8
9	3	39.8
10	2	39.6
11	2	39.6
12	2	39.5
13	2	39.3
14	2	39.3
15	2	39.3
16	2	39.3
17	1	39.2
18	1	39.2
19	1	39.6
20	1	39.6
21	1	39.2
22	1	39.1
23	1	39
24	1	39

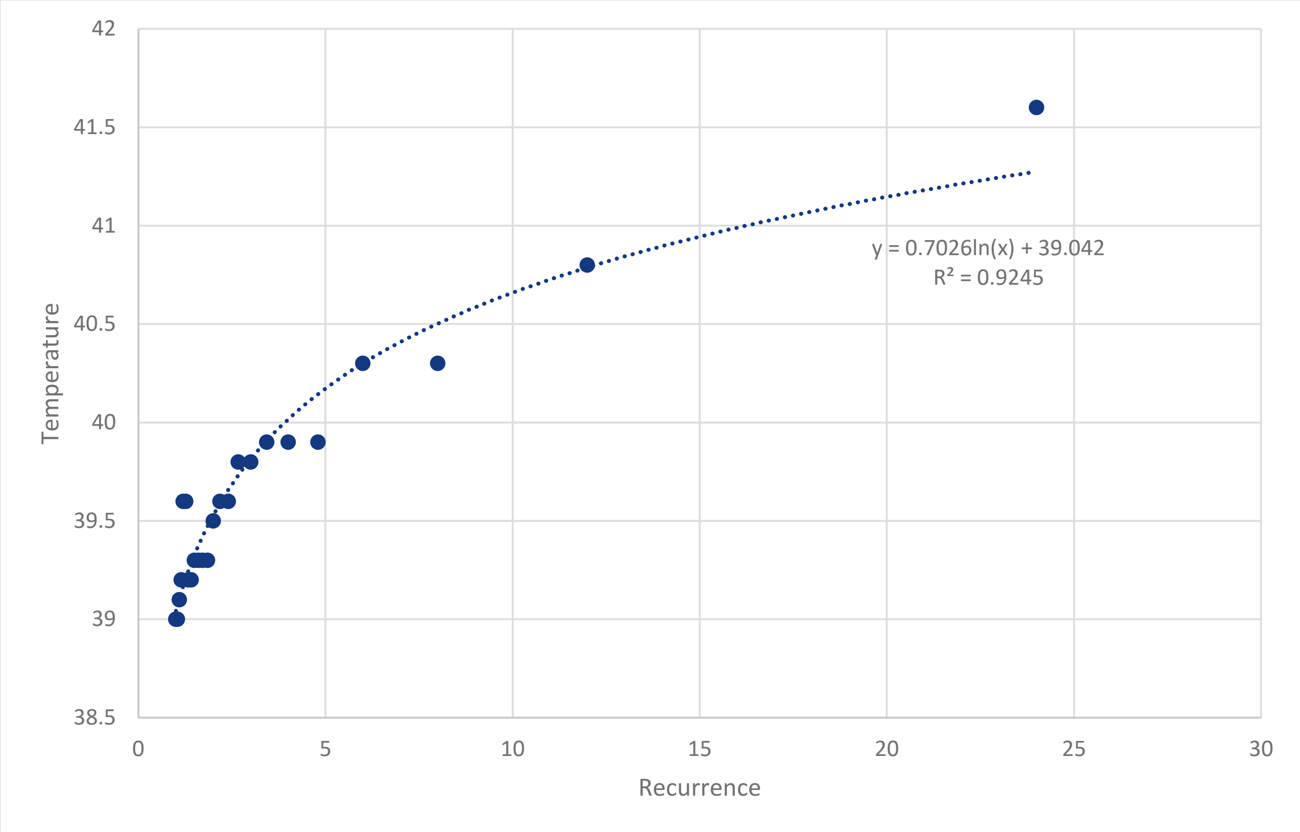


Plate 7: Temperature GEV analysis for Bickley (9240)

Table 20: Temperature for various recurrence periods for Bickley (9240)

Recurrence period (years)	FFDI
1	39.0
20	41.1
25	41.3
50	41.8
100	42.3

Table 21: Moving Average 1:50 year Temperature for Bickley (9240) in 10 year windows

Window	Window Sequence	1: 50 yr Temperature
1	1999 - 2008	41.7
2	2000 – 2009	41.7
3	2001 – 2010	42.8
4	2002 – 2011	42.8
5	2003 – 2012	42.9
6	2004 – 2013	43.0

Window	Window Sequence	1: 50 yr Temperature
7	2005 – 2014	42.9
8	2006 – 2015	43.4
9	2007 – 2016	43.2
10	2008 – 2017	43.4
11	2009 – 2018	43.5
12	2010 – 2019	43.4
13	2011 – 2020	42.5
14	2012 – 2021	42.5

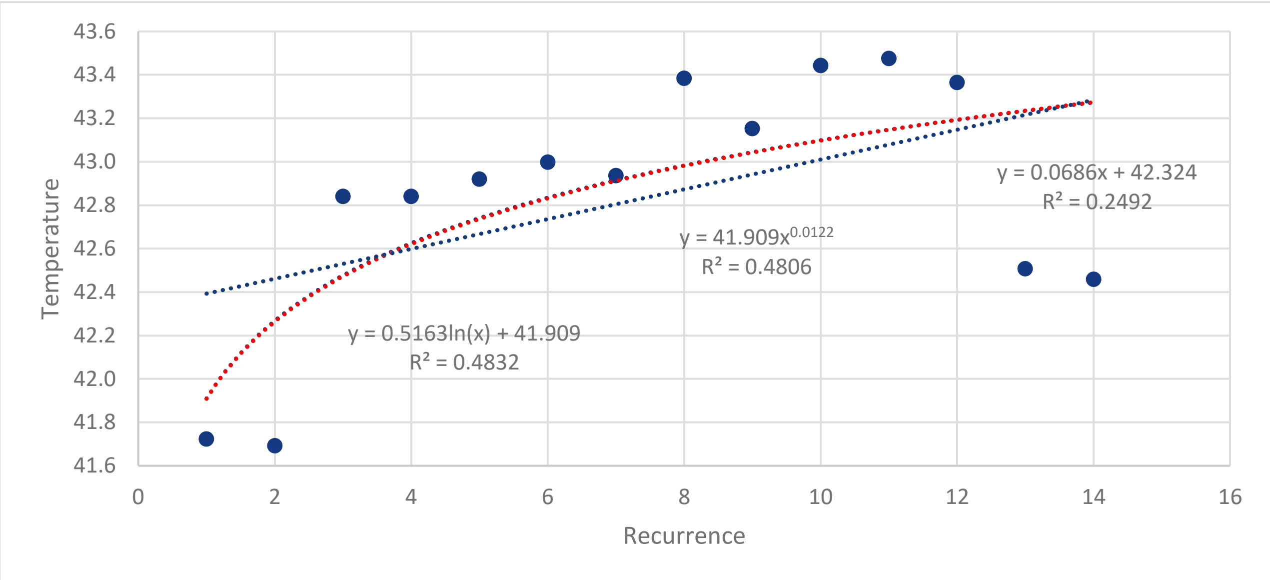


Plate 8: Moving Average Temperature GEV analysis for Bickley (9240)

Table 22: 1:50 year Temperature for 25yr and 50yr climate change projections

Projection (years)	Temperature (1:50 year)
39 [25 year]	44
64 [50 year]	44.3

<u>Relative Humidity GEV Analysis</u>

- A GEV analysis was also conducted of relative humidity over the Bickley and Perth Airport weather station data sets, to provide an indication of expected future peak temperatures
  - As previously detailed, the Bickley data set has a significant number of missing relative humidity values and also has a significant number of very low humidity readings with dew points <-15 °C.
  - On that basis, the lowest relative humidity values from 2017 to 2021 (see Table 23) were used to conduct a GEV analysis for Bickley (see Plate 9) to determine the 1:50 year relative humidity (see

Table 24). Given the very limited dataset, and the R^2 of 0.7746, this would be considered an indicative relative humidity at best.

- To address the limited reliable data set at Bickley, the relative humidity values from Perth Airport from 1999 to 2021 (see
- Table 25) were used to conduct a GEV analysis (see Plate 10) to determine the 1:50 year relative humidity value (see Table 26).
- Given the issues with the recorded Relative Humidity readings, given the stable readings since 2017, a GEV was conducted from the lowest readings obtained from 2017 to 2021 (see Table 19). The Perth Airport relative humidity readings over this period, do not have the issues with extremely low dew points and missing readings that appear on the Bickley data set, and provide a way of confirming the GEV from the limited Bickley data set.

Table 23: Lowest Relative Humidity values for Bickley (9240) from 2017 to 2021

Rank	Recurrence	Temperature (°C)
1	6	6
2	3	6
3	2	7
4	2	7
5	1	7
6	1	8

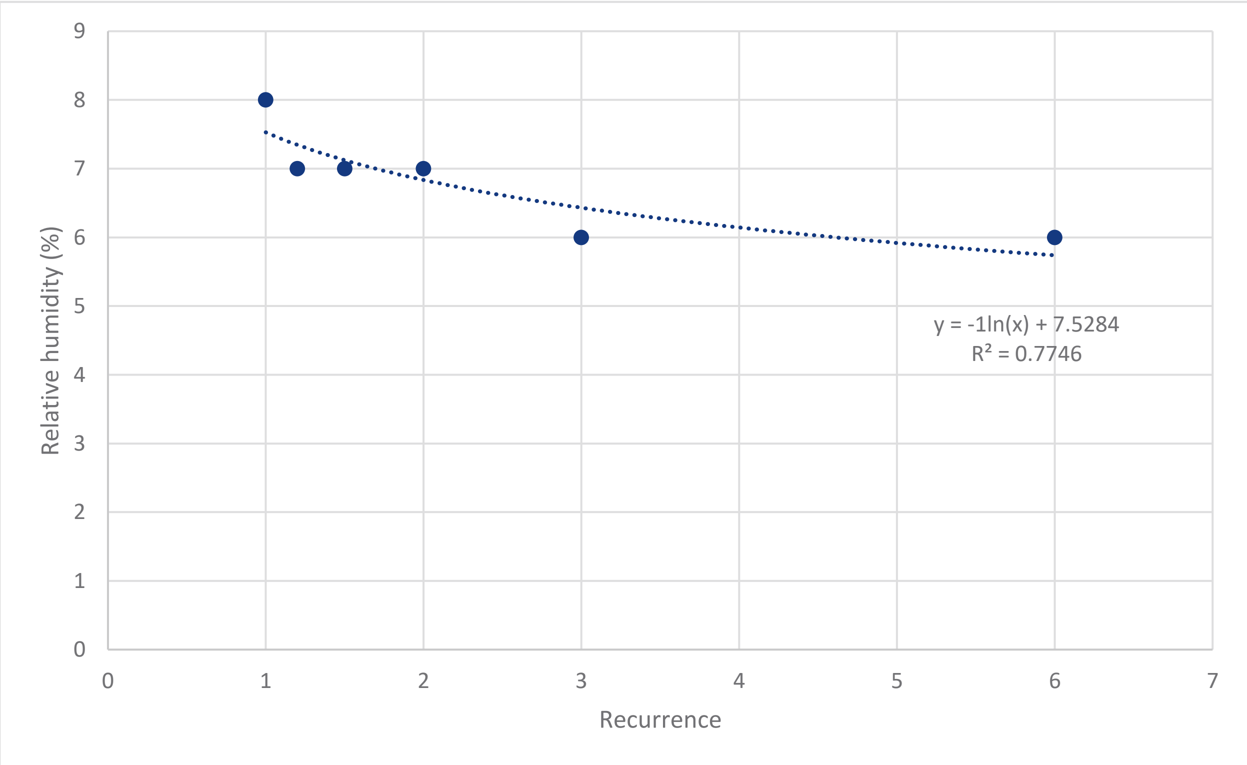


Plate 9: Relative Humidity GEV analysis for Bickley (9240) from 2017 to 2021

Table 24: Relative Humidity for various recurrence periods for Bickley (9240) from 2017 to 2021

Recurrence period (years)	Relative Humidity (%)
1	7.5
20	4.5
25	4.3
50	3.6
100	2.9

Table 25: Lowest relative humidity values for Perth Airport (9021) from 1999 to 2021

Rank	Recurrence	Temperature (°C)
1	24	4
2	12	5
3	8	5
4	6	5
5	5	5
6	4	5
7	3	5
8	3	5
9	3	5
10	2	6
11	2	6
12	2	6
13	2	6
14	2	6
15	2	6
16	2	6
17	1	6
18	1	6
19	1	6

Rank	Recurrence	Temperature (°C)
20	1	6
21	1	6
22	1	6
23	1	6
24	1	6

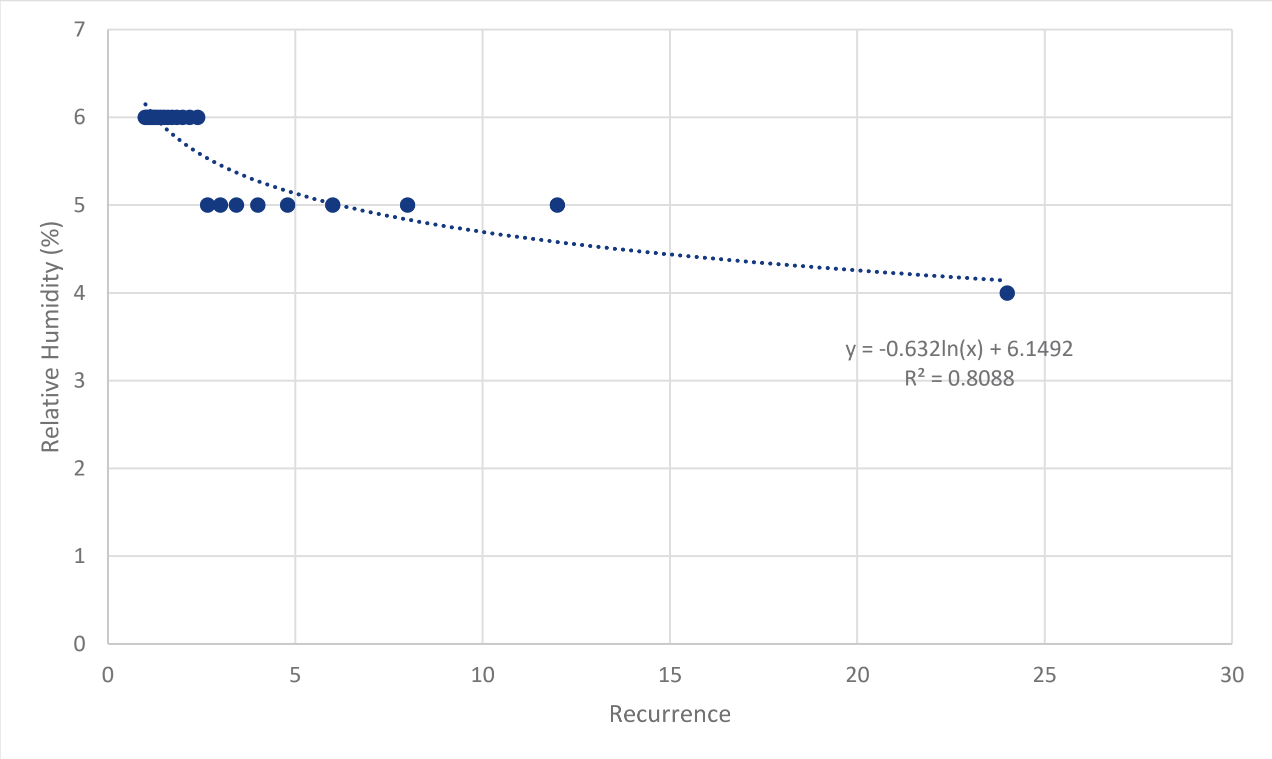


Plate 10: Relative Humidity GEV analysis for Perth Airport (9021) from 1999 to 2021

Table 26: Relative Humidity for various recurrence periods for Perth Airport (9021) from 1999 to 2021

Recurrence period (years)	Relative Humidity (%)
1	6.1
20	4.3
25	4.1
50	3.7
100	3.2

Wind speed and Direction Analysis

- Wind speed is not considered to be impacted by climate change, however some analysis was required to understand what the likely windspeed was during days with higher FFDI.
- An analysis was conducted of wind speeds and directions using the FFDI calculated over the hourly/half hour, however only when the FFDI exceeded 25 in order to restrict the wind speed analysis to times when the FDR was Very High and above.
- Table 27 summarises the average windspeed on days with FFDI >25 from various wind directions, and shows the average to be less than 21.1 km/hr and less than 28.3 with 1 standard deviation.

Table 27: Windspeed analysis (FDI>25)

Direction	N	NE	E	SE	S	SW	W	NW
% of values	5.5%	14.1%	28.5%	17.9%	4.8%	10.1%	12.7%	6.2%
Ave Windspeed (km/hr)	13.9	17.3	21.1	20.5	13.1	16.5	17.5	16.5
Standard Deviation	5.4	6.4	7.2	7.8	4.4	4.9	5.0	6.0
Ave + 1 Standard Dev	19.3	23.7	28.3	28.2	17.5	21.5	22.5	22.5

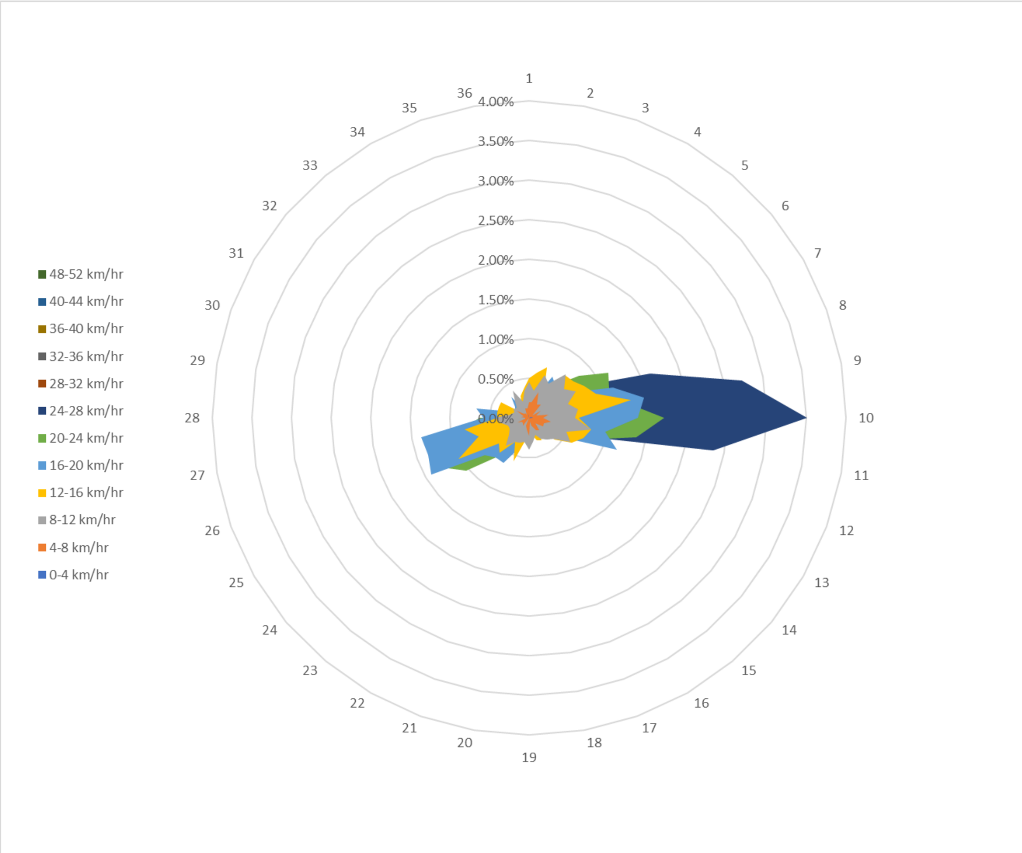


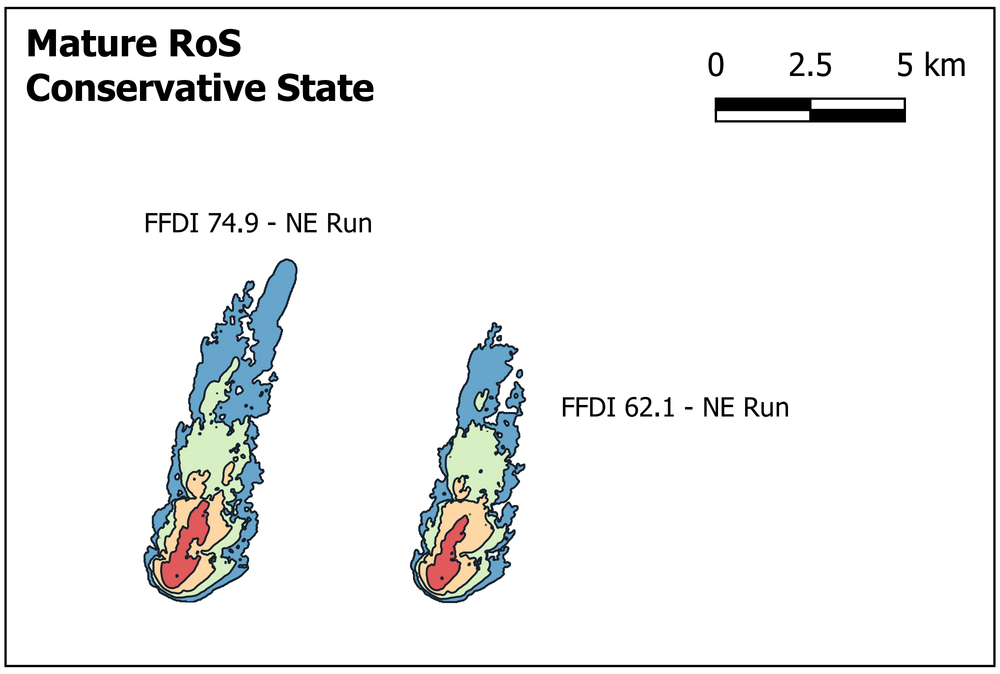
Plate 11: Wind rose (speed and direction) for FFDI exceeding 25

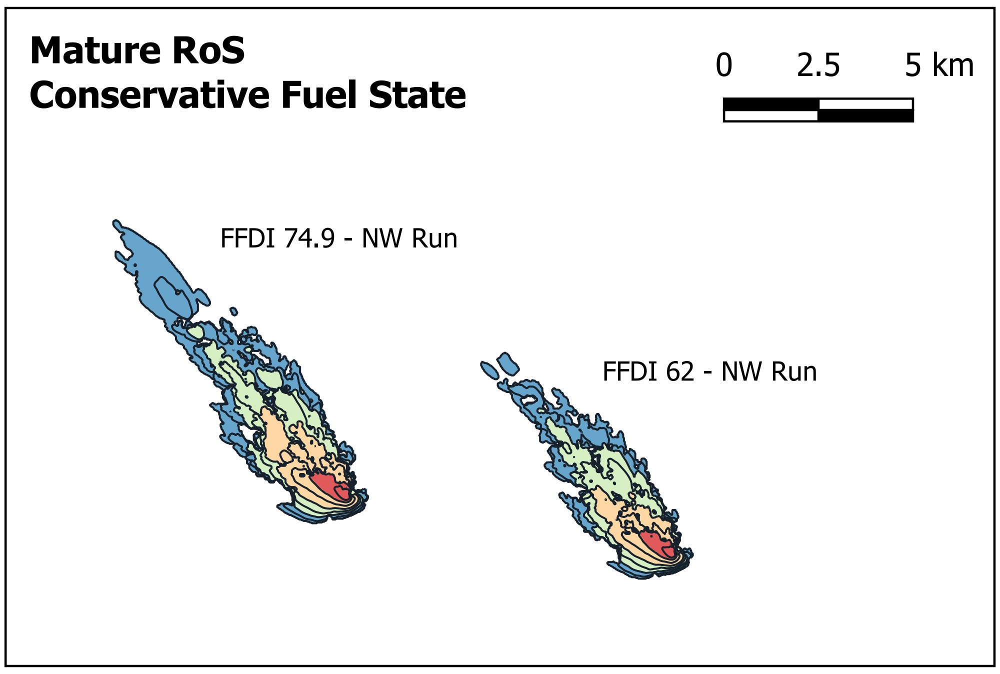
Drought Factor

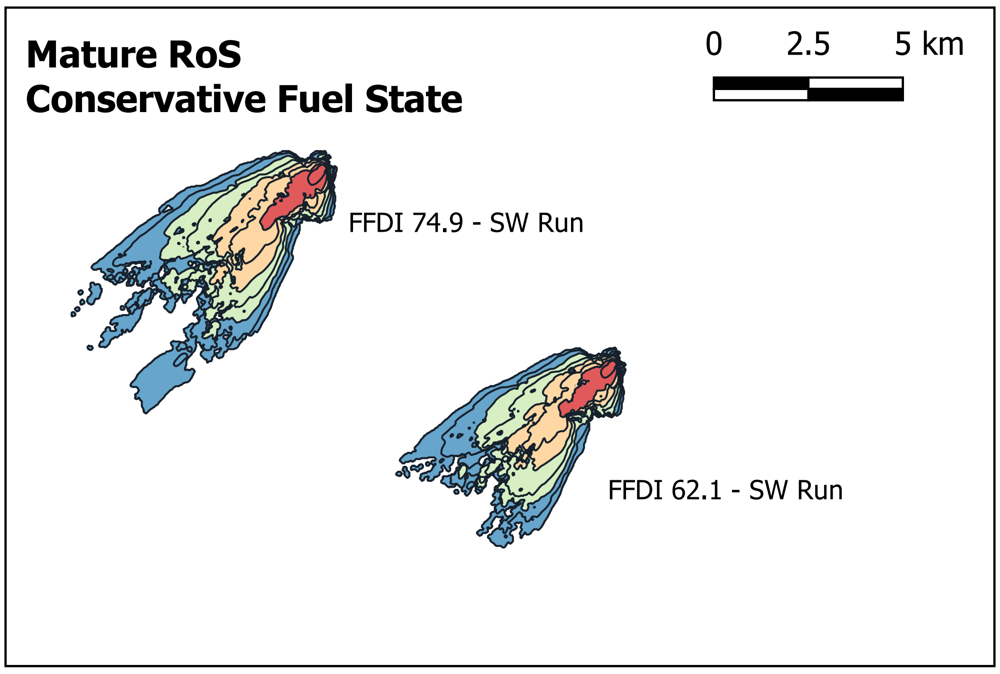
- Drought factor was assumed to be a maximum of 10

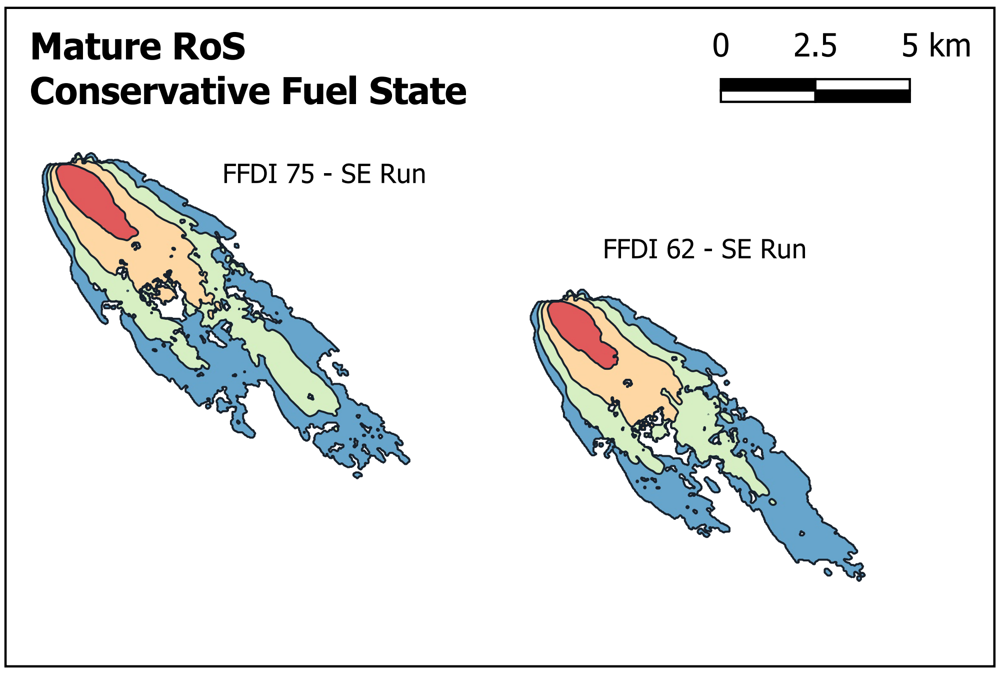
Appendix I Design and comparative bushfire simulations against actual bushfire extent

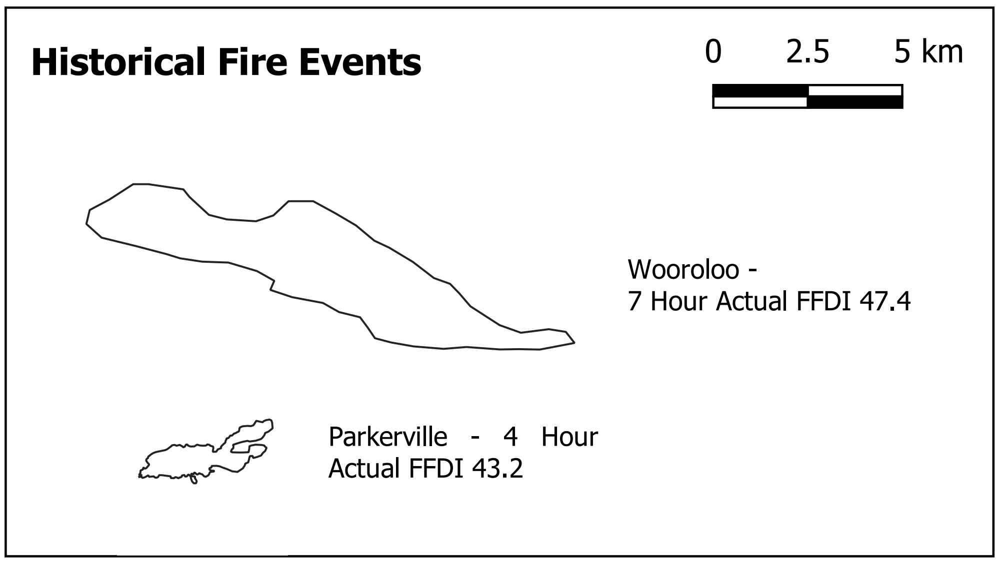
Design and Comparative Bushfire Simulations against Actual Fire Extent

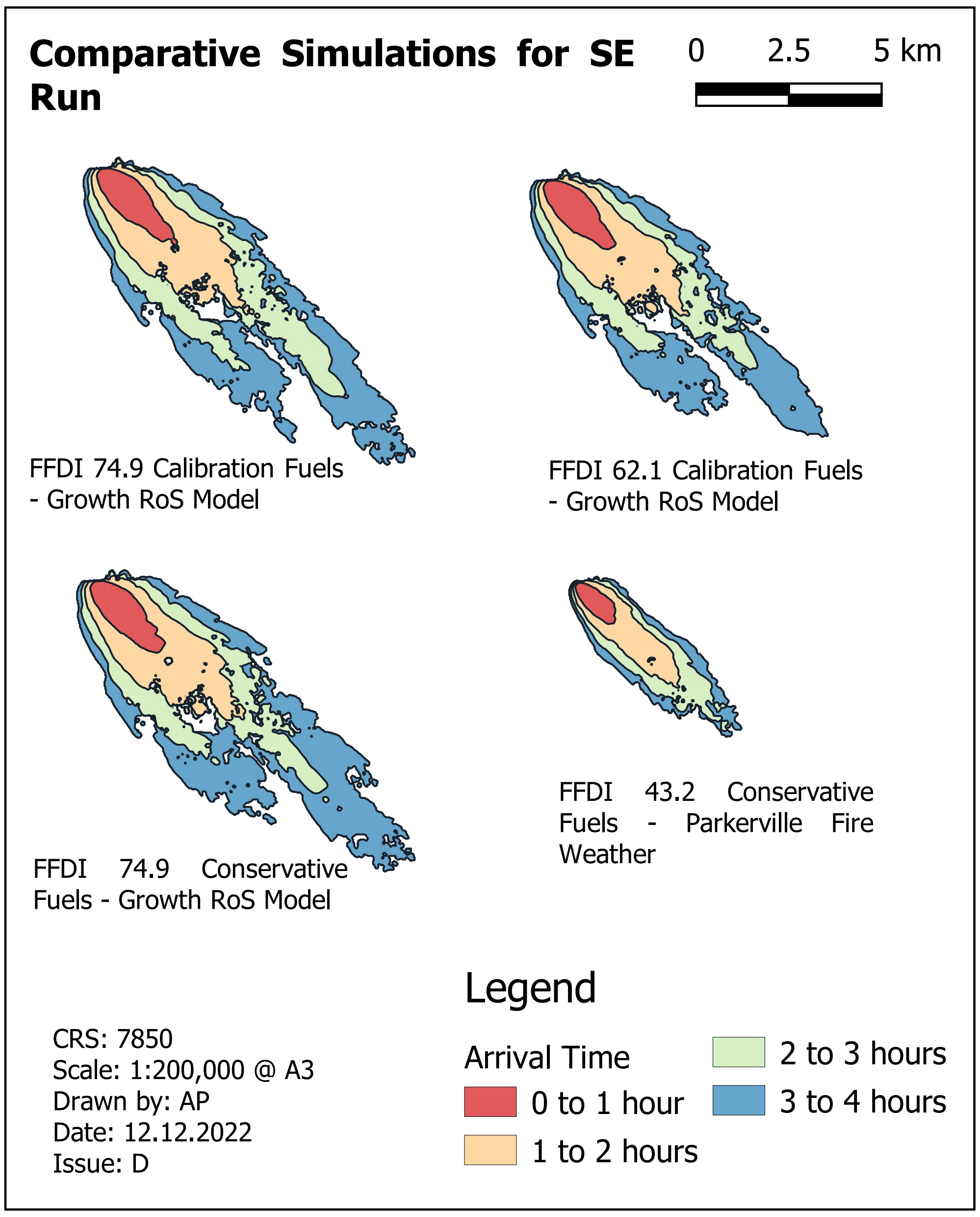












Fire/Sim	Peak FFDI	Duration (hrs)	Fuel State	RoS Model	Fire Area (ha)
NE Run	74.9	4	Conservative	Mature	1713.4
NE Run	62.1	4	Conservative	Mature	1202.5
NW Run	74.9	4	Conservative	Mature	2672
NW Run	62.1	4	Conservative	Mature	1919.6
SW Run	74.9	4	Conservative	Mature	3581
SW Run	62.1	4	Conservative	Mature	2677
SE Run	74.9	4	Conservative	Mature	3228
SE Run	62.1	4	Conservative	Mature	2692.1
SE Run	74.9	4	Calibration	Mature	2885.9
SE Run	74.9	4	Calibration	Growth	2440.2
SE Run	74.9	4	Conservative	Growth	3020.4
SE Run (Parkerville)	43.2	4	Conservative	Mature	799.7
Wooroloo Actual	47.4	7	n/a	n/a	1988.6
Parkerville Actual	43.2	4	n/a	n/a	333

1.1.1.1 Document Status

Report version	Rev No.	Purpose	Author	Reviewed and Approved for Issue	
				Name	Date
Draft Report	Rev A	For review	Linden Wears (BPAD 19809, Level 3)	Darren Walsh	4 April 2022
Draft Report	Rev B	For review	Linden Wears (BPAD 19809, Level 3)	Darren Walsh	22 April 2022
Final Report	Rev 0	For issue to SAT	Linden Wears (BPAD 19809, Level 3)	Darren Walsh	19 May 2022
Final Report	Rev 1	For issue to SAT	Linden Wears (BPAD 19809, Level 3)	Darren Walsh	13 December 2022
Final Report	**Rev 2**	**For issue to SAT**	**Linden Wears (BPAD 19809, Level 3)**	**Darren Walsh**	**15 December 2022**
Final Report	**Rev 3**	**For issue to SAT**	**Linden Wears (BPAD 19809, Level 3)**	**Darren Walsh**	**9 February 2023**
Final Report	**Rev 4**	**For issue**	**Linden Wears (BPAD 19809, Level 3)**	**Linden Wears (BPAD 19809, Level 3)**	**16 May 2024**

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