FIRE INVESTIGATION REPORT

19/06/2019

ABSTRACT

This vegetation fire, which occurred opposite [redacted] Pigeon Valley Road, Nelson, New Zealand, was ignited on 5 February 2019. It destroyed or damaged around 2000 hectares of pine forest, destroyed one home, multiple outbuildings, fences, shelter belts and pastures, and caused the evacuation of around 2500 people. This report covers the investigation process into the fire's origin and cause.

Investigator:

Jamie Cowan

Wildfire Management Specialist/Wildfire Investigator

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PO Box 2775, Wakatipu, Queenstown 9349

[redacted]

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ABBREVIATIONS

FCP	Forward Control Point
FFMC	Fine Fuel Moisture Code
HFI	Head Fire Intensity
ICP	Incident Control Point
MC	Moisture Content
OA	Origin Area
RH	Relative humidity
SOA	Specific Origin Area
FENZ	Fire and Emergency New Zealand
PPE	Personal Protective Equipment
PRFO	Principal Rural Fire Officer

1 EXECUTIVE SUMMARY

1.1 Fire Authority Name

Fire and Emergency New Zealand

1.2 Report by

Jamie Cowan

Wildfire Management Specialist/Wildfire Investigator

[redacted]

1.3 Fire Name

Pigeon Valley Fire, F2704034

1.4 Location

Opposite [redacted] Pigeon Valley Road, Nelson, NZ

1.5 Date of Ignition

5 February 2019

1.6 Time of Ignition

Around 14:10 (111 call at 14:15)

1.7 Date of Investigation

5 February 2019 to 28th March 2019

1.8 Area (ha)

Approximately 2300

1.9 Origin Area

Within 4m of waypoint 1601608E, 5420589N NZTM

1.10 Impact of Fire on Environment & Property

This fire destroyed or damaged around 2000 hectares of pine forest, destroyed one home, multiple outbuildings, fences, shelter belts, pastures, and caused the evacuation of around 2500 people. This fire resulted in a local state of emergency and disrupted the lives of thousands of people. This was New Zealand's largest wildfire in several decades.

1.11 Cause of Ignition

Based on the evidence available at the time of this investigation, the cause of this fire is believed to be the result of an agricultural soil preparation operation using a set of disc harrows. The discs striking a stone or rubbing on the scrapers, has resulted in a spark(s) or created a hot surface that has contacted and ignited the fine fuels. The classification of this incident should be recorded as 'Accidental' and caused by 'Equipment use'.

2 WILDFIRE INVESTIGATING OFFICER

2.1 Name

James Patrick Cowan

2.2 Qualifications

Unit Standard 10615 Investigate Origin and Cause of Vegetation Fires (2011)

Unit Standard 20392 Protect and Preserve a Fire Scene (2010)

National Certificate 'Fire and Rescue Services' (Vegetation) L4 (2011)

New Zealand Fire Service 'F1, Structure Fire Investigation Course' (2017)

Canberra Institute of Technology PUAFIR501B, 'Conduct Fire Investigation and Analysis' (2017)

Wildfire Investigator L2

2.3 Significant Fires Investigated

7-Mile Fire (2010)

Closeburn Road Fire (2011)

Queenstown Hill Fire (2011)

Rob Roy Lane Fire (2012)

Mount Rosa Fire (2012)

The Stack Fire (2012)

Matukituki Fire (2013)

Northburn Fire (2014) fatality

Waitaki Rail Fires (2015)

Saddle Hill Fire (2015)

Waitaki Island Fire (2016)

Rat Point Fire (2017)

Piha Fires (2017)

Early Valley Fire, Port Hills (2017)

Marley's Hill Fire, Port Hills (2017)

Tiwai Fire (2018)

Burnside Fire, Dunedin (2018)

Makara Fire, Chatham Is (2018)

Hawea Fire (2018)

Rabbit Island Fire - Nelson Complex (2019)

Atawhai Fire - Nelson Complex (2019)

3 PROCESS OF INVESTIGATION (This section identifies the steps and process involved in the investigation)

3.1 Introduction

3.1.1 On 5 February 2019, at around 14:10, a passing motorist noticed smoke coming from a paddock where an agricultural tractor was working. The fire built very quickly in the tinder-dry conditions and spread to the adjacent forestry block where it advanced upslope under a moderate westerly wind. By morning, the fire had covered around 1900 hectares, destroyed one home, caused extensive damage to forestry assets and rural residential properties, and sparked multiple evacuations. The fire continued to advance over the next few days, necessitating the evacuation of Wakefield and growing to its final extent of 2316 ha (26/02/19). A local state of emergency was declared, and this was reported to be the largest vegetation fire in NZ since 1955.

3.1.2 Hundreds of fire fighters supported by heavy machinery and up to 24 aircraft fought the fire at its peak. Crews worked for a month to completely extinguish the fire. Most evacuees were allowed back to their homes from Monday 11 February.

3.1.3 The Nelson/Tasman district was in a PROHIBITED fire season at the time of this fire. The fire danger on this day was EXTREME.

3.1.4 A state of emergency was declared for the Nelson area on Wednesday 6 February and expired on Wednesday 27 February.

3.2 Process

3.2.1 05 February 2019

3.2.1.1 At approximately 19:00, I was contacted by Manager Rural Fire, Tim Mitchell and asked if I could carry out a Fire Investigation for the Pigeon Valley fire. I agreed and advised him that I would be on site around 11:30 in the morning. Terms of reference were drafted.

3.2.1.2 At 19:50, I called Witness [redacted] We discussed how and when the fire was observed and potential ignition sources. Witness [redacted] provided me with photos of the fire in its early stages.

3.2.2 06 February 2019

3.2.2.1 11:45, I arrived at the Richmond Incident Control Point (ICP) and was directed out to the Forward Control Point (FCP) on Moutere Highway.

3.2.2.2 12:30, I arrived at the FCP, gathered a map and was briefed by Fire and Emergency NZ (FENZ) Liaison Mark Boere. I then departed the scene for Pigeon Valley.

3.2.2.3 13:00, I called Witness [redacted]. He informed me of the name of the person driving the tractor at the time of the fire and we agreed to meet on site at 14:00.

3.2.2.4 13:30 approx., I arrived on site, opposite [redacted] Pigeon Valley Road.

3.2.2.5 I was given a phone number of a person who apparently knew about the fire in its early stages. I phoned this person, and it turned out they had only seen a post on Facebook. This person sent me the Facebook picture and identified the person who took the photo as [redacted]

3.2.2.6 13:50 approx., Witness [redacted] arrived. He brought with him Witness [redacted].

3.2.2.7 13:58, I interviewed Witness [redacted] and took a statement. This witness was nearby when the fire started and saw it when it was approximately 20m x 20m. This witness physically showed me where the fire was thought to have started. [redacted]

3.2.2.8 I interviewed Witness [redacted] who was phoned by Witness [redacted] at 14:19 on the day of the fire and arrived on site at around 14:50 to see the fire in a well-advanced state. This witness arranged for a mechanic to assess the discs and tractor and agreed to me attending this inspection.

3.2.2.9 14:24, I started the external examination, GPS tracking, and my Photo Log. I spoke to the Division Commander via radio and advised the fire fighters to stay out of the area.

3.2.2.10 15:03, Witness [redacted] returned with Witness [redacted] who showed me where the fire was thought to have started. He noted that on his arrival, the fire was on both sides of the disc tracks and was around 20m x 20m in size. I interviewed Witness [redacted] and took a statement.

3.2.2.11 15:35, I continued my scene examination and taped off the now identified Origin Area. I had to adjust my camera timestamp as it was 1 hour and 5 minutes behind the correct time.

3.2.2.12 15:44, I was advised of the Rabbit Island fire starting and was asked to attend. Given I had to leave the scene, I took a series of photographs of the entire Origin Area and marked the fire pattern indicator vectors electronically with Fire Mapper.

3.2.2.13 16:00, I took weather readings and departed the scene at 16:05.

3.2.3 07 February 2019

3.2.3.1 09:00, I arrived at Witness [redacted] workshop where he and I were joined by a mechanic who carried out an inspection on the discs and tractor. No obvious signs of damage or mechanical problems were identified. Photos were taken. (Appendix 6: Maintenance records/Documents.)

3.2.3.2 Witness [redacted] supplied me with work logs and maintenance records for the tractor. These show that the engine bay had been accessed by an auto electrician on 29 January, an engineer on 30 January and again on 4 February by the driver to top up hydraulic oil after a fitting repair. These checks are relevant as any birds' nests or similar under the bonnet that may have caused or contributed to a fire would have been found. I departed at 10:00.

3.2.3.3 10:45, I arrived back at the Origin Area and was met by Witness [redacted]. This witness saw the fire as a "hint of blue smoke" whilst driving past and called Rural Fire first, before calling 111 at 14:15. This witness showed me where the fire was on his arrival [redacted]. I interviewed this witness and took a statement.

3.2.3.4 10:57, Witness [redacted] departed, and I continued the scene examination. I took another weather reading, carried out magnet sampling and flagged, mapped, and GPS'd the Specific Origin Area (SOA). I removed the barrier tape and departed the scene at 13:50 and went to work at the ICP as part of the Incident Management Team.

3.2.4 13 February 2019

3.2.4.1 06:15, I returned to Nelson to meet with investigators appointed by insurance companies and to show them the Origin Area. (I had been advised on 12/02/19, by Manager Rural Fire Tim Mitchell, that I was able to share scene information and to discuss the origin but not to provide samples, photographs, ICADS, statements, or other information collected by FENZ or myself.)

3.2.4.2 11:00 approx., I met with the Operations Manager, Safety Officer and the Planning and Intelligence Manager and advised them of my plans for the day.

3.2.4.3 12:00, Meeting with insurance assessors and wildfire investigators held in the Sabine room of Tasman District Council. I advised them of the SOA waypoint and provided a map of the fire.

3.2.4.4 13:30, Accompanied by the insurance assessors and fire investigators, we arrived at the Origin Area after stopping at the FCP to sign in. A scene examination was carried out. Weather readings taken. Origin was GPS'd again. Magnet samples taken. Aerial overflight conducted. (N.B. investigators wanted to fly drones to photograph site; I asked the Air Division Commander and we decided to use a helicopter instead for safety reasons.) Departed the scene around 19:00.

3.2.5 14 February 2019

3.2.5.1 09:00, I joined the insurance assessors and investigators to reassess the discs and tractor.

3.2.5.2 11:00, Sign in at FCP and return to Origin Area to complete scene examination.

3.2.5.3 15:00 approx., Departed the scene, signed out, and travelled back to Queenstown.

3.2.6 18 February to 19 June 2019

3.2.6.1 Phone calls to Tim Mitchell to discuss investigation.

3.2.6.2 Phone calls to PRFO Ian Reade to update him on the investigation.

3.2.6.3 Emails to Simon Cox and Scion requesting scientific papers on mechanical sparking.

3.2.6.4 Emails to/from FENZ re Official Information requests.

3.2.6.5 Phone calls to Witness 1 and 3 for further discussions.

3.2.6.6 Preparation of 1st draft of report (completed 28/3/19).

3.2.6.7 Peer review and final publication.

4 SCENE EXAMINATION (This section identifies the process and findings of the scene examination)

4.1 External Examination

4.1.1 06 and 07 February 2019

4.1.1.1 As identified in the 'Process' above, [redacted] had given me several photos of the fire in its early stages, indicating where the General Origin Area was. I walked the perimeter of the General Origin Area and surrounds, used a helicopter to view and photograph the scene from above and observing the following:

4.1.1.2 Very rocky ground. From my previous experience working in the agriculture/horticulture industries I was surprised it had been disced it was so rocky.

4.1.1.3 Multiple strike marks on rocks where the discs had passed. The strike marks ran across the rocks in the direction of travel of the discs and, in several cases, metal was smeared onto the rocks.

4.1.1.4 Freeze on foliage at the General Origin Area showing a wind direction at the time of the fire from the north-west. (This was closer to a WNW.)

4.1.1.5 A macro scale 'V' pattern leading from the disced paddock up into the forestry block.

4.1.1.6 Fire Pattern Indicator categories 'protection' and 'grass stems' were observed.

4.1.1.7 90% to 100% cured grass around 15cm high.

4.1.1.8 I recreated the first photo taken by [redacted] to help identify the SOA.

4.1.1.9 No obvious sources of ignition were found.

4.1.1.10 As part of the external examination, a mechanic was tasked to examine the tractor and discs to determine if any faults or damage were present that may have contributed to the fire.

(Appendix 6 Maintenance records/Documents.) I was present during this examination and a subsequent examination carried out on the 14/02/19. The following was observed:

4.1.1.10.1 No sign of any birds' nests or build-up of grass under the bonnet that could have ignited and fallen to the ground whilst the tractor was being operated.

4.1.1.10.2 No damage to the exhaust system or any other component on the tractor.

4.1.1.10.3 No damage to the wheel bearings or disc bearings.

4.1.1.10.4 No sign of any mechanical fault or defect that could have caused a spark or hot particle ignition on the tractor or discs.

4.1.1.10.5 Maintenance records for the tractor and daily log sheets for the discing operations were provided by the owner. These show the tractor being well serviced and checked. (Alternator was repaired by an auto electrician on 29 January 2019, an engineer carried out welding on 31 January and the driver filled hydraulic oil after a fitting fault on 4 February.) The disc bearings were checked around midday on the day of the fire and were fine. (See Witness 4 statement.)

4.1.1.10.6 Some rub marks showing that at least one of the scrapers (metal blades that keeps the discs free of debris) has come in contact with a disc during operations. This has the potential to cause a hot surface and/or sparks. (Photo Log, 10.)

4.1.1.10.7 A disc and scraper (third from the end on the front right gang) were removed by the insurance investigators for further testing.

4.2 Internal Examination

4.2.1 07 February 2019

4.2.1.1 A detailed scene examination of the SOA identified multiple fire pattern indicators and vectors. These were identified, photographed and flagged. (See Appendix 3: Photo Log) I was able to narrow down the SOA an area approximately 8m long by 4 m wide.

4.2.1.2 I identified all the "stone strikes" (18 significant strikes) in the SOA, these were marked and photographed. Some of these strikes showed a significant amount of steel smeared onto the rocks. (Photo Log, 13.)

4.2.1.3 I prepared a magnet to test the area around the strikes by putting it into a plastic bag. Magnet tests around the strikes showed significant amounts of metallic filings and particles (Photo Log, Photo 10.) To ensure these were not generally found throughout the area I carried out four separate magnet tests outside of the disced area, all tests found no magnetic particles. Further samples of the metal smeared onto the rocks was also collected outside of the burnt area. (Photo Log, 15.)

4.2.1.4 No metallic objects apart from the small filings and particles were found in the Ignition Area. (This was reconfirmed with a metal detector on 14/2/19.)

4.2.1.5 No ignition sources were found in the Ignition Area.

4.2.1.6 Further weather readings were taken. The Ignition Area was photographed, flagged, GPS'd, and mapped using FireMapper.

4.3 General, Specific or Origin Area

4.3.1 The Specific Origin Area was narrowed down to an area within 4m of waypoint 1601608E, 5420589N NZTM. (Photo Log, 21.)

4.4 Main fire runs

4.4.1 The initial fire run was briefly wind driven over a distance of around 7 metres to the east-southeast before it encountered the 15-degree slope and ran upslope to the east-southeast. Shortly after ignition, the wind moved to more of a south-westerly.

4.5 Spot fires

4.5.1 Multiple spot fires were observed during the fire's main run, however, no spot fires were identified in the SOA.

5 INDICATED CAUSE (This section identifies hypotheses formed from the scene examination.)

5.1 From the site examinations, photos, and witness reports, the following hypotheses were formed:

5.1.1 **Hypothesis 1.** The discs striking a stone or rubbing on the scrapers, has created a spark(s) that has ignited the fine fuels.

5.1.2 **Hypothesis 2.** A component or bearing on the discs or tractor has been damaged or failed, thus creating sparks or hot material that has fallen to the ground, igniting the fine fuels.

5.1.3 **Hypothesis 3.** A build-up of grass or fine fuels has occurred under the tractor's bonnet or around the exhaust, ignited and fallen to the ground, igniting the fine fuels.

5.1.4 **Hypothesis 4.** The scrapers have come in contact with the discs creating a hot surface that fuel has been trapped/rested against, igniting the fine fuels.

6 IGNITION FACTORS (This section tests the indicated cause hypotheses against empirical and factual data.)

6.1 Weather Factors

6.1.1 Weather observations from the Dovedale weather station 4 km to the northwest of the Origin Area, at the time of ignition. (14:10) (Appendix 2: Fire Weather)

Temp.	Relative Humidity	Wind Direction	Wind Speed	Rain last 24 hours	
26	33%	WSW	15km/h	0mm	
FFMC	**DMC**	**DC**	**ISI**	**BUI**	**FWI**
89	96	451	10	125	32 **Extreme**

6.1.2 Weather readings (three samples over three days) taken at the Origin Area compared to the Dovedale station show the weather at the Origin Area to be approximately 2°C higher in temperature, with 10% less humidity (minimum) and wind of similar direction but a speed of 5 km/h less.

6.1.3 Therefore, the weather and adjusted indices at the time of ignition should be considered as:

Hourly adjusted FFMC	Temperature	Relative Humidity (RH)	Wind Direction	Wind Speed
90	28°C	23%	WSW	10km/h

6.1.4 How the above readings and indices relate to the potential fire cause hypotheses are as follows:

6.1.4.1 The moderate wind speed, high Fine Fuel Moisture Code (FFMC) and low relative humidity (RH) at the time of ignition were conducive to an ignition for all four of the identified hypotheses. Looking at these weather factors separately we find the following:

6.1.4.1.1 **Wind** – Many studies have covered the effect that wind has on ignition temperatures, or the role wind plays in the transition from smouldering to flaming ignition. Pitts (2007) found that when testing the ignition temperature of tall fescue and cheat grass against a hot metal plate, ignitions were achieved between 340ºC to 380ºC. With wind at up to 2.5m/s (9 km/h), ignition temperature dropped to between 310ºC and 350ºC, depending on the grass curing. Much like blowing on a glowing ember, wind plays an important role in the ignition temperature required to achieve flaming combustion.

Ignition of Cellulosic Fuels by Heated and Radiative Surfaces. Pitts 2007

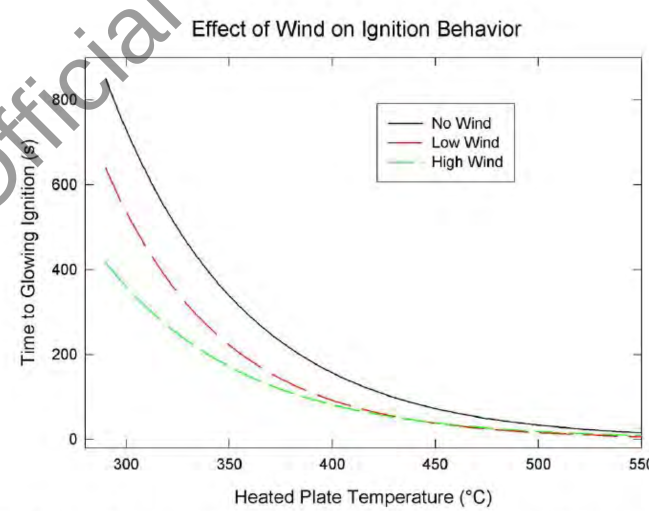


Figure 76. Results of exponential least squares curve fits of experimental ignition times as a function of heated plate temperature for seven fuels are shown for no wind, low wind, and high wind cases.

6.1.4.1.2 **Fine Fuel Moisture Code, Moisture Content & Relative Humidity** – The FFMC is derived from the relationship between temperature, humidity and rainfall readings taken daily at 12:00 LST. These readings are then calculated to represent the FFMC for the peak fire conditions at around 16:00 LST. Using the humidity (RH) at the time of the fire, we can adjust this 16:00 FFMC to better represent the time of ignition (14:00). In this case, the FFMC has been adjusted to 90. FFMC does not directly correlate to the Moisture Content (MC) of the fine fuels, however, we can use previous studies to give an indicative value of MC from the FFMC. Bianchi and Defosse (2015) concluded that for a FFMC of 89 the

MC was between 6% and 11%. Van Wagner (1987) concluded that an FFMC of 91 equates to an MC of 10%. For the purpose of this investigation, we will assume a MC of around 10%. This is in the extreme range where it is much easier to ignite most fine fuels and, in particular, grass. This very low MC is a very important factor in this investigation as it means that very small sparks or particles that would not normally be associated with an ignition relevant to this situation may now be considered as a competent ignition source.

6.1.4.1.3 The above is highlighted in the findings of Wakelin (2010), "Fuel MC is a highly significant variable affecting the ignition thresholds of fuels. In many studies it is the single most important variable (Wilson, 1985; de Groot et al., 2005; Plucinski & Anderson, 2008; Anderson & Anderson, 2010; Dimitrakopoulos et al., 2010)".

Wang et al. *(2016)* graphed their results showing the effect of particle size and MC on ignition as follows:

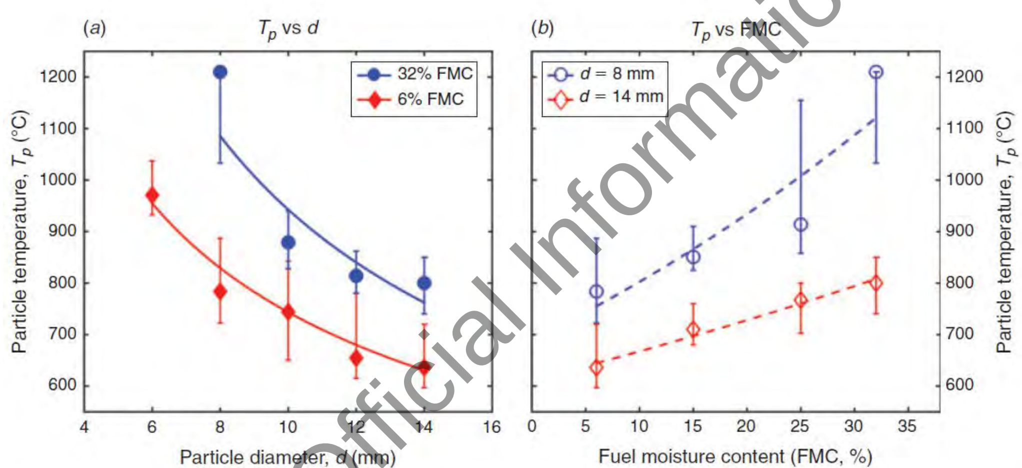


Fig. 4. The measured critical particle temperature $T_{p,crt}$ as a function of (*a*) particle size *d* (solid lines); and (*b*) FMC (dashed lines), with 2-m s^{-1} wind. The error bars are bounded by the 5 and 95% ignition probability.

6.1.5 Hypothesis 1 and 2 relate to an ignition by a spark or hot particle, where 3 and 4 relate to an ignition by radiation or conduction as the fine fuel is ignited by prolonged contact with a hot surface. Each hypothesis is examined for additional weather factors as follows:

6.1.5.1 **Hypothesis 1 –** The discs striking a stone or rubbing on the scrapers, has created a spark(s) that has ignited the fine fuels.

6.1.5.1.1 Cheney and Sullivan (2008) state that grass fuels can only ignite from metal sparks if the dead fuel MC is less than 6%. This is refuted by Wakelin (2010) who proved, using a grinder, that a shower of sparks would ignite grasses, with a 54% probability of ignition at 35% MC. Antunez (2018) also proved that sparks from a grinder against high carbon steel (similar to our discs), would ignite grass fuels at higher fuel moistures. The relevance of Wakelin (2010) to this investigation is that, at 10% MC, the ignition probability from grinder sparks was 89%. The correlation between ambient temperature and ignition by sparks was investigated by Salvador Antunez. His study, *Ignition Capability of Mechanically Generated Sparks Landing in Fuel Beds* (2018), shows that 290°C is a critical spark/particle temperature, with anything above that allowing grass fuels to ignite much easier. From the above studies, it is clear that no single factor controls spark ignitions and the relevance to this investigation is that there may have been a spark or string of sparks similar to those caused by a grinder as the discs rotated against the scraper or scraped along a stone. I acknowledge that their most certainly would not have been as many sparks as created by a grinder running at full speed however, the mechanism of a rotating disk contacting the scraper or a stone is the same. There also existed a very low MC.

6.1.5.1.2 **Conclusion –** For this hypothesis I have concluded that the weather and indices are conducive to an ignition of this type.

6.1.5.2 **Hypothesis 2 –** A component or bearing on the discs or tractor has been damaged or failed, thus creating sparks or hot material that has fallen to the ground igniting the fine fuels.

6.1.5.2.1 **Comments relating to Hypothesis 1 are relevant for this hypothesis.**

6.1.5.2.2 **Conclusion –** For this hypothesis I have concluded that the weather and indices are conducive to an ignition of this type.

6.1.5.3 **Hypothesis 3 –** A build-up of grass or fine fuels has occurred under the tractors bonnet or around the exhaust, ignited and fallen to the ground igniting the fine fuels.

6.1.5.3.1 Wakelin (2010) studied the ignition potential of exhaust systems to ignite grass fuels. In this study it was determined that grass with a MC of 10% has around a 50% chance of ignition when held in contact with a heated surface of 400°C. This rises to 88% probability at 425°C. The results suggested that grass fuels can ignite at temperatures as low as 390°C. Pitts (2007) found that when testing the ignition temperature of Tall Fescue and Cheat Grass against a hot metal plate with MC of between 6% and 14%, ignitions were achieved between 310°C to 350°C with 2m/s wind depending on MC. A temperature of around 530°C achieved flaming ignition in cheat grass within 25s.

6.1.5.3.2 Exhaust temperatures vary in temperature but, as reported by many studies (Heisler (1999); Cole (2001); DeHaan (2002)), these are in the range of 500°C to 550°C and higher if a turbocharger is present (it was in this instance). The above studies are relevant because in this investigation there was a MC of 10% and the exhaust temperature on the tractor would have been greater than 500°C.

6.1.5.3.3 **Conclusion –** For this hypothesis I have concluded that the weather and indices are conducive to an ignition of this type.

6.1.5.4 **Hypothesis 4 –** The scrapers have come in contact with the disc creating a hot surface that fuel has been trapped/rested against, thus igniting the fine fuels.

6.1.5.4.1 Comments relating to Hypothesis 3 are relevant for this hypothesis.

6.1.5.4.2 **Conclusion –** For this hypothesis I have concluded that the weather and indices are conducive to an ignition of this type.

6.2 Fuel Factors

6.2.1 The fuel in and around the Ignition Area was 90% to 100% cured partially grazed grass and weeds. (Photo Log 20.) These fuels were extremely dry and, as such, easily ignited. Cured dead grass is considered to be much easier to ignite than most cellulosic fuels, such as needles and leaves (Hogenbirk & Sarrazin-Delay (1995); Pitts (2017)).

6.2.2 I have discussed the fuel moisture content in Weather Factors above.

6.2.3 **Conclusion –** Given that all four of the identified hypotheses relate to the same fuel and similar ignition methods, I have concluded that the fuel type was conducive to an ignition of all or any of these types.

6.3 Topographical Factors

6.3.1 The SOA is on a flat piece of ground open to the west and the north. It would have had some shade early in the morning as the sun is below the hill to the east. This means that the ignition site would receive all the maximum heat of the sun during the peak burn period each day and so would have been very dry and warm. As such, fuels would have been preheated and would be more receptive to an ignition than a south facing or shaded site.

6.4 Other Factors

6.4.1 Other factors that are relevant to each hypothesis are as follows:

6.4.1.1 **Hypothesis 1 –** The discs striking a stone or rubbing on the scrapers has created a spark(s) that has ignited the fine fuels – The following studies and literature are relevant to this investigation as they relate to the ability of very small particles to create ignitions if they are hot enough;

6.4.1.1.1 NFPA 27.15.6.3 states that mechanical sparks are a "minimally-viable source of ignition", this is contradicted in part by NFPA 27.4.4 that highlights the ability for sparks created by metal to metal or metal to road (such as a wheel falling off a vehicle) to be as hot as 1200°C and in the table 5.7.1.1 as hot 1400°C.

6.4.1.1.2 The study *An Assessment of Hot Metal Fragments From Heavy Mechanical Equipment as a Potential Ignition Source For Forest Litter*, Howitt (2015), uses a bulldozer to create sparks by running it over rocks in a forest situation. Howitt concludes that the relationship between the makeup, (thermal conductivity, density) size of the particle and the energy required to fracture it from its parent substance equates to its temperature and the amount of energy it can transfer to the fuel bed. The minimal energy required to ignite the fuel is interpreted as a minimal thermal fluence. For cellulose sheets this equated to 80kJ/m2. (Martin 1963) Howitt concludes that the bulldozer created sparks to a maximum of 550°C that due to their makeup could only deliver a thermal fluence of up to 19.4kJm/2 and as such could not be considered a competent ignition source. This theory relating to the energy content of a particle has been critiqued by Babrauskas V (2003) *Ignition Handbook* and Hadden, Scott, Lautenberger, Fernado-Pello (2010) where they conclude that the ignition potential was governed not only by the energy of the particle but also its temperature and size. In the study *Ignition of Combustible Fuel Beds by Hot Particles*, Hadden, Scott, Lautenberger, Fernado-Pello (2010), hot spot ignition theory is used to determine the particle size-temperature relationship required for ignition of a cellulose fuel bed. This study concludes that to get flaming ignition (a flaming ignition is more relative to this investigation given the speed in which the fire ignited and began to spread) from a particle as low as 650°C, a particle size (spheroid) of 19.1mm was required and for particles more relevant to this investigation (very small), 1200°C was required to get flaming ignition from a particle size of 2.4mm. (The steel particles we found during the investigation are better described as spheroids, chips or slivers ranging from <1mm up to approximately 4mm wide and <1mm thick.)

Ignition of Combustible Fuel Beds by Hot Particles – Hadden, Scott, Lautenberger, Fernado-Pello (2010)

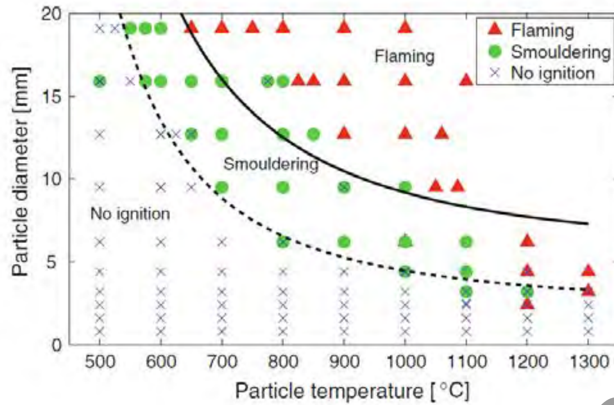


Figure 4. Ignition propensity of dry cellulose using heated steel spheres.

6.4.1.1.3 How hot were the particles in this instance? The following studies and literature are relevant to determining the maximum temperature and ignition potential of very small particles. These studies don't align exactly with a set of disks however the mechanism that created the spark/s is similar. I.E An impact or friction with enough force to fracture particles of steel from the parent object.

(a) In a study by Hawksworth et al. (2006), when assessing the ignition potential of mechanical equipment, it was found that the probability of ignition was dependent on the power, load, speed, size, and coefficient of friction produced by the equipment. So, a higher speed of impact of the discs onto a rock is likely to produce a spark of higher energy/temperature.

(b) The study, *An Assessment of Hot Metal Fragments from Heavy Mechanical Equipment as a Potential Ignition Source For Forest Litter*, Howitt (2015), uses a bulldozer to create sparks by running it over rocks in a forest situation. Howitt concludes that the Bulldozer created sparks to a maximum of 550°C at a maximum speed of 10km/h (similar speed to our discs).

(c) Finney et al. (2013) found that when a rifle was fired into a sheet of steel, the corresponding very small sparks and projectile particles could reach 800°C and frequently caused ignitions.

(d) Nikiforev et al. (2017) found that when spherical droplets or spheroids were formed during the spark forming process, the metal chip had reached its melting point, the surface temperature had risen above the surface oxides melting point and combustion had occurred. (See Image 1 below.) They also found that the higher the carbon content of the alloy the higher the temperature of the spark. The discs involved in this investigation are made of high carbon steel. Many steel fragments where found in the SOA during this investigation. The fragments varied in size and shape and most were irregular in shape, however, some spherical droplets or spheroids (<1mm in diameter, Photo Log, 17& 18) were found, showing that some of the sparks created by the discs impacting on the rocks or from the scraper contacting the discs were in the range of 1400°C to 1455°C. (The sparks may have come from the softer steel that the scrapers are made of and in that case may have been closer to 1350°C.)

Image 1. Spheroid formation Nikiforev et al. (2017)

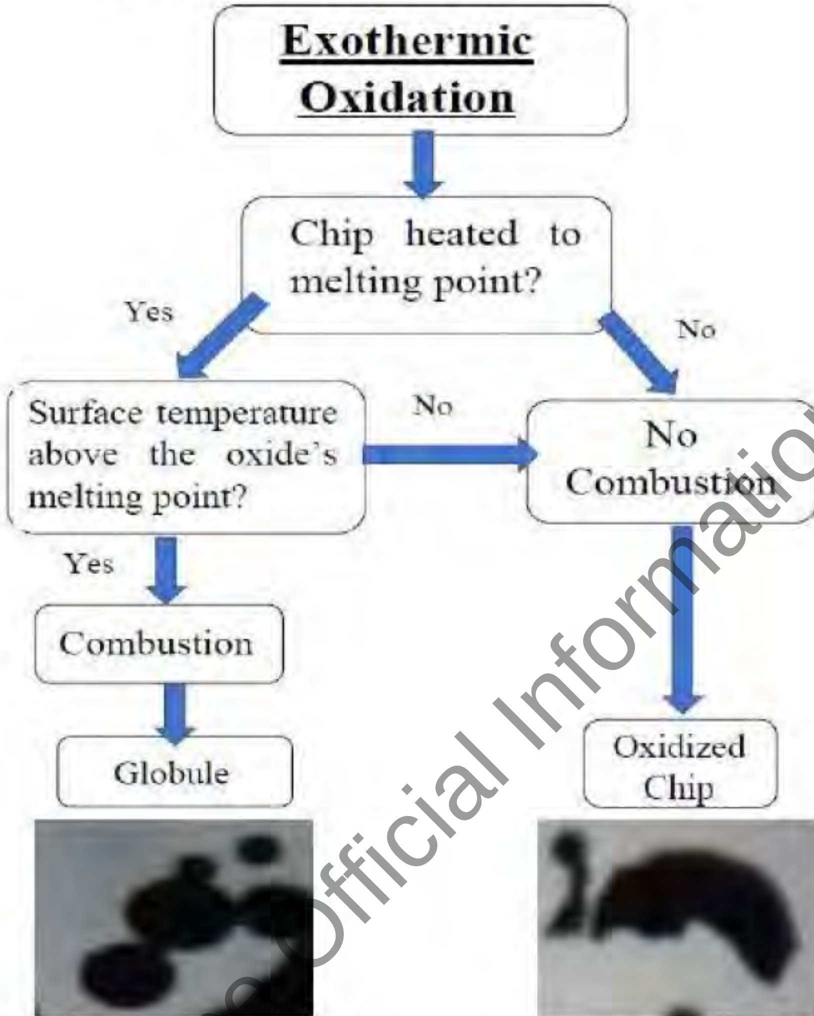


Figure 3.3 Algorithm (adopted from Nikiforov *et al.*, 2017) for Determining Final Form of Metal Chip. Where globules are the cooling spherical metal droplets produced during the spark production from a metal, and metals chips are produced due to the lack of combustion of the metal particle.

6.4.1.1.4 **Conclusion –** In this instance the particles were around 1400°C degrees and studies have shown that small particles over 1200°C can cause ignitions in cellulosic fuels. For this hypothesis I have concluded that this is a competent ignition source.

6.4.1.2 **Hypothesis 2 –** A component or bearing on the discs or tractor has been damaged or failed, thus creating sparks or hot material that has fallen to the ground igniting the fine fuels.

6.4.1.2.1 Comments relating to Hypothesis 1 are relevant for this hypothesis, where they relate to the temperature of any sparks formed. The SOA and the areas immediately around it were searched with magnets and with a metal detector. The only magnetic particles or objects found were very small and matched the description of what small sparks or pieces fractured off hardened steel might look like (Antunez (2018)). (Photo Log, 14, 15, 16.). As no ball bearings or bearing case parts were found we can conclude that no significant part failure has occurred.

6.4.1.2.2 As mentioned in the 'Process' section of this investigation, a mechanic was asked to inspect the tractor and the discs and no sign of any damage or failed part was found on the discs or the tractor. The bearings on the discs were specifically checked. As part of this investigation, I collected maintenance records from the owner of the tractor and daily check sheets from the driver. These showed a well-checked and maintained tractor and discs. There was no reason to suspect that a part or bearing had failed or been damaged on the day of the fire. Further to this, as part of his statement, Witness [redacted] stated that he had checked the axles on the discs around lunchtime on the day of the fire and they were fine. ("Spun nicely.")

6.4.1.2.3 **Conclusion –** I have concluded that this hypothesis is not valid.

6.4.1.3 **Hypothesis 3 –** A build-up of grass or fine fuels has occurred under the tractors bonnet or around the exhaust, ignited and fallen to the ground igniting the fine fuels.

6.4.1.3.1 NFPA 27.15.6.2 identifies hot surfaces such as exhausts as competent ignition sources. As mentioned under Hypothesis 2 above, the mechanic checked under the bonnet with both Witness 3 and me present and we found no reason to suspect that grass had been allowed to build up under the bonnet or around the exhaust. We specifically discussed the possibility of birds' nests occurring and determined that it was too late in the season for nesting birds. The maintenance records provided by Witness [redacted] show that the engine bay had been accessed by an auto electrician on 29 January, an engineer on 30 January, and again on 4 February by the driver to top up hydraulic oil after a fitting repair. These instances don't include the daily checks by the driver. Any build-up of grass or birds' nests should have been found. NFPA 27.15.4.3 highlights the relevance of collecting maintenance records to determine if maintenance may have any relevance to the origin or cause of an equipment fire.

6.4.1.3.2 **Conclusion –** For this hypothesis I have concluded that it is unlikely the fire was caused in this manner.

6.4.1.4 **Hypothesis 4 –** The scrapers have come in contact with the disc, creating a hot surface that fuel has been trapped/rested against, thus igniting the fine fuels.

6.4.1.4.1 As referenced previously, we can expect grass at a MC of 10% to ignite above 310°C if held against a hot surface for a length of time and it is likely to achieve flaming ignition if the surface is above 530°C.

6.4.1.4.2 NFPA 27.15.4.2 identifies the risk of vegetative debris collecting around rotating shafts (such as on the discs) and leading to ignition by frictional heating.

6.4.1.4.3 How hot could the disc and scraper get if they were rotating against each other? The temperature created by friction between a disc and the scraper is a function of velocity and friction. We do not know what amount of friction pressure could be applied as the scraper was not in contact with the disc when I observed it, however, it did show fresh signs of rubbing against the disc (fresh metal that had not oxidised fully). (Photo Log, 10.) The velocity is relative to the speed that the discs are towed at and, in this case, we are assuming around 2m/s or 7km/hr. In the study *Formation of Mechanical Sparks in Sliding Metal Contacts*, Wenzel et al. (2009), it was found that stainless steel under friction generated more heat than mild steel. This may be relevant to this investigation as the discs are made from hardened steel that more closely aligns with stainless steel than mild steel.

That said, we cannot determine if the sparks or heat source came from the disc or the softer, mild steel scraper. At relatively slow friction speeds (2m/s), Wenzel was able to observe temperatures up around 700°C as is seen in the graph below.

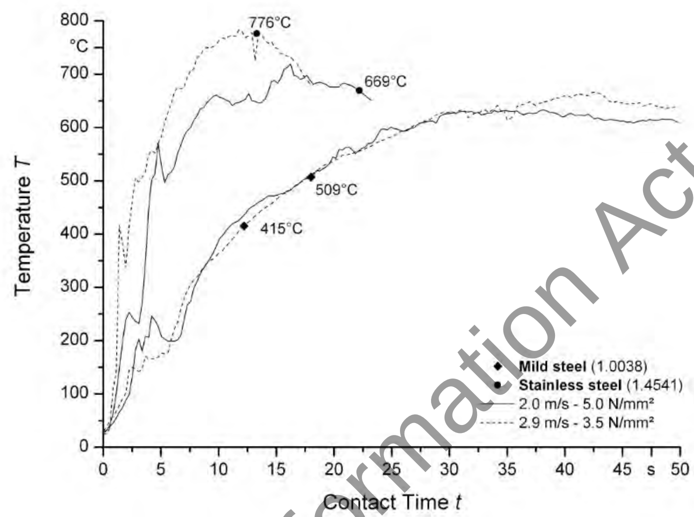


Figure 3: Temperature rise in sliding steel contacts

6.4.1.4.4 In the study *Hot Surfaces Generated by Sliding Metal Contacts and Their Effectiveness as an Ignition Source*, Meyer, Beyer and Krause (2015), it was determined that at relatively slow speeds (2m/s), temperatures up to 600°C were observed, as graphed below.

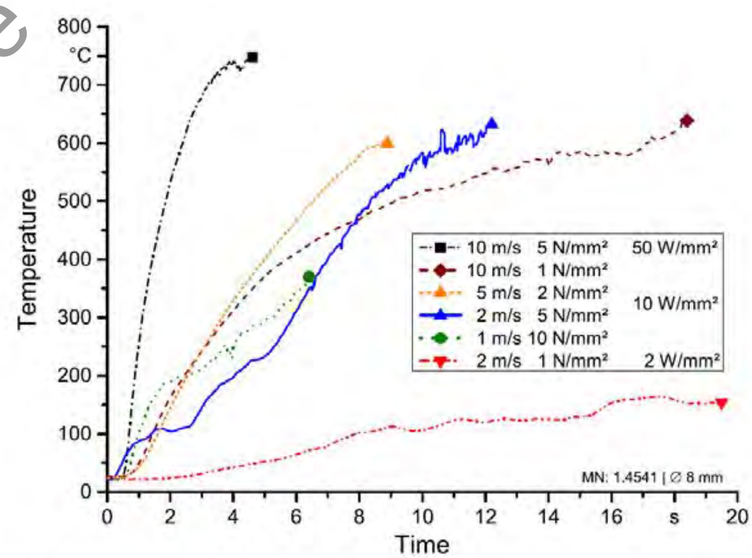


Fig. 6. Temperature evolution of stainless steel (MN: 1.4541) at different power densities.

6.4.1.4.5 Even though the scraper was not sitting against the disc when I observed it some 40 hours after the fire, there is evidence to show that the disc had been rotating against the scraper in the immediate past. Having had some personal experience discing paddocks and as confirmed by Witness 3 during phone conversations, it is common for the scrapers to come in contact with the discs as part of normal operations on rough ground. They are knocked by rocks or debris into contact with the discs and can be knocked back in the same manner or fixed with a kick during maintenance checks.

6.4.1.4.6 **Conclusion –** For this hypothesis I have concluded that this is a competent ignition source.

6.5 Burn and Char Patterns/Pattern Indicators

6.5.1 As described and photographed in the external and internal examinations. See the Photo Log for detailed photographs and notations of the fire pattern indicators and vectors.

7 FIRE BEHAVIOUR (This section identifies the expected and observed fire behaviour and how this relates to the cause hypotheses.)

7.1 Predominant fuels in the SOA include 90 to 100% cured partially grazed grass and weeds. (Photo Log 20). As mentioned in the fuel section of this report, these fuels are easy to ignite and will burn and spread quickly under moderate wind or the effects of a moderate slope. The fire only had to travel around 2m before it crossed the fence into long rank grass and 7m before it encountered a 15 degree slope and the fuel changed to light forestry slash, long rank grass, and weeds. I have classified this fuel as 'Pine second rotation'. Rates of spread for these fuels are as follows:

7.1.1 Grazed grass at 0.2m high, 90% cured, wind of 10km/h, temp 28, RH 23% – Forward Rate of Spread (F-ROS) is calculated at around 1000m/h, (0.27 m/s) with flame length of 1.6m. Fuel load is around 1.6 t/ha and Head Fire Intensity (HFI) is around 1,000kw/m.

7.1.2 Pine, 1-4 years second rotation – F-ROS is calculated at around 2340m/h, with flame length of 10m. Fuel load is around 36 t/ha and HFI is around 42,000kw/m.

7.1.3 As can be seen by the calculations above, this fire would have developed extremely quickly and been nearly impossible to stop once it had crossed the fence and entered the forestry block.

7.1.4 The tractor and discs had carried on an additional 191m past the SOA before the driver saw the fire. Based on an approximate rate of travel of 7km/h or 2m/s (Witness 3 mentioned that the tractor was likely to have been going slower than this when on very rocky sections of the paddock and then speeding up when it had moved past these patches) and depending on how soon the ignition occurred in relation to the discs and tractor passing, the fire could have been burning for up to 95 seconds and probably longer as the tractor had to back up at one stage to get into a corner further up the paddock (Photo Log, 3). This correlates well with the driver's recollection of maybe 2 minutes from the time he passed the Origin Area to when he saw the fire.

7.1.5 The tractor driver reported the fire as being around 20m x 20m in size and 5m up the hill when he got to it.

8 SUMMARY WITNESS STATEMENTS/OBSERVATIONS (See Witness Identification Log Appendix 8 for personal contact details.)

8.1 Witness [redacted]

8.1.1 [redacted]

8.1.2 This witness saw a puff/hint of blue smoke by a tractor in a roadside paddock.

8.1.3 This was seen from around 300m away to the west. The tractor was discing and was parked by the fire. (Witness was not sure if the tractor was parked by the fire when he first saw it, but it was there within 10 to 20 seconds, once he had pulled up at the driveway.)

8.1.4 This witness [redacted] called a number that he had for Rural Fire. His call was not answered so he called 111. He then spoke to the tractor driver and notified the driver that he had called 111. He [redacted] of the fire in its early stages. (At 14:17.) [redacted] on the day of the fire (5/2/19).

8.1.5 This witness physically showed me where the fire was when it was first seen. I recreated his [redacted] to help identify the SOA. (Photo Log, 2.)

8.2 Witness [redacted]

8.2.1 [redacted]

8.2.2 This witness had [redacted]

8.2.3 He was at a neighbour's home around 400m to the south when he saw the fire. He struggled to identify it as a fire as it was so small. He instructed the neighbour to call 111 and he went to investigate. On arrival, the fire was around 20m x 20m and heading upslope quickly. This witness physically showed me where the fire was when he arrived on the scene. When asked what he thought had started the fire, he said it may have been stone strike, tractor exhaust or similar, or a mechanical issue with the discs. He had no definite idea on the exact cause.

8.3 Witness [redacted]

8.3.1 [redacted]

8.3.2 This witness was called by Witness [redacted] and advised of the fire at 14:19 hours. He travelled to the site and arrived around 14:50. At this stage the fire was well advanced and up the hill. This witness arranged for a mechanic to come and assess the tractor and discs and invited me to attend. This witness provided me with maintenance records and a daily check sheet for the tractor. This witness told me that Witness [redacted] does not smoke.

8.3.3 Subsequent discussions with this witness have included discussions around the speed of the tractor when discing (as low as 3 km/h on very rocky ground and up to 10km/h in perfect conditions) and how common it is for scrapers to come into contact with the discs when discing rough ground. ("Very common.")

8.4 Witness [redacted]

8.4.1 [redacted]

8.4.2 This witness had been directed to disc the paddocks leased by Witness [redacted]. He had been discing since early in the morning and had disced several paddocks to the north before starting on the piece over the creek where the fire started. He had been discing for about 2 to 3 minutes before noticing smoke where he had previously disced, around 2 minutes before. He lifted the discs and drove around 100m to the fire. He attempted to put the fire out with the discs and a fire extinguisher, but the fire was too hot. He parked the tractor and went to call 111 but had no cellphone reception. He walked out to the west and was met by Witness [redacted] who advised him that he had already called 111. They had a discussion on moving the tractor to avoid the fire and opening the gates for access by emergency vehicles. This witness noted that Witness [redacted] arrived shortly after ignition. Witness [redacted] told me that he had found no signs of mechanical issues with the discs or tractor. He had checked all the axles on the discs around lunchtime and no issues were found. The discs "Spun nicely". He physically showed me where the fire was on arrival and noted that it was on both sides of his disc tracks when he first got to it. The fire was described as around 20m x 20m on arrival and 5m uphill.

8.5 Witness Conclusions

8.5.1 These witness statements support the location of the SOA. Information (statements, maintenance logs and daily check sheets) provided by Witnesses [redacted] point to the unlikely nature of a mechanical failure or fault contributing to the ignition.

9 VISUAL AND PHYSICAL EVIDENCE

9.1 Visual Images

9.1.1 Photos and videos were taken by myself and Witness [redacted].

9.1.2 My cameras time stamp was incorrect and had to be adjusted by 1 hour and 5 minutes.

9.1.3 A sample of the more relevant photos are attached in the Photo Log – Appendix 3.

9.2 Physical Site Evidence

9.2.1 Magnetic samples taken by myself and by insurance investigator [redacted]

9.2.2 Scraper and Discs as removed and taken by insurance investigator [redacted].

9.2.3 Rock sample as taken by insurance investigator [redacted].

10 ORIGIN (Determination of the Specific Origin Area)

10.1 Witness statements, photos and fire pattern indicators all point to a SOA within 4m of waypoint 1601608E, 5420589N NZTM.

10.2 This area can be described as: inside the disc tracks within 2m of the fence along the forestry block edge.

11 CAUSE(S)

11.1 Possible causes that were eliminated or identified:

11.1.1 Power Lines – No power lines were present in the Origin Area (OA).

11.1.2 Lightning – No lightning was detected in the greater Nelson area between the first and tenth of February. (MetService)

11.1.3 Cigarettes – No cigarette remains, matches, or other sources of open flame were found in the SOA. Given the distance from any road or other access and the fact that the tractor driver did not smoke, we have no reason to suspect that a cigarette ignition is possible.

11.1.4 Campfires – No evidence of campfires in the OA.

11.1.5 Debris/burning – No evidence of any burn-offs in the OA.

11.1.6 Children – No evidence of children at play (fire play) was found in the OA. School had resumed earlier that week, the fire was in the middle of the day and the site was not easily accessible.

11.1.7 Miscellaneous causes – No evidence of any other ignition source or activities including, but not limited to, fireworks, cutting/welding/grinding, firearms, or spontaneous combustion.

11.1.8 Incendiary/Arson – This area is on private land and has no public access. No other persons were observed on the site by any of the witnesses. No evidence of arson was found, and we have no reason to suspect that arson is a factor in this fire.

11.1.9 Equipment use – Equipment was being used on this site, where we have proven the existence of sparks around 1400ºC. Studies show that at these high temperatures it is possible to get ignition in cellulosic fuels by a single hot particle. We know there was more than one very hot particle, very low fuel moistures, high ambient temperatures, very low humidity, and significant wind. All of the above factors have been proven to make ignitions by hot particles and/or hot surfaces more likely.

11.2 Cause or most likely cause of fire

11.2.1 After testing the four hypotheses against the Weather, Fuel, and Other Factors, Witness Statements, Fire Behaviour Factors, and available literature, I have eliminated Hypotheses 2 and 3 and modified/combined Hypotheses 1 and 2 to form the following hypothesis:

> **"The discs striking a stone or rubbing on the scrapers, has resulted in a spark(s) or a hot surface that has contacted and ignited the fine fuels."**

11.2.2 Given the evidence available and identified as part of this investigation it is my conclusion that the above hypothesis is the most likely cause of this fire and, as such, this fire should be classified as 'Accidental' and caused by 'Equipment Use'.

12 CONCLUSIONS

12.1 I am confident this fire was caused by the operation of the discs in very stony ground on a hot, very dry windy day.

12.2 To determine if it was a spark from the disc or scraper, or the hot surface created when the disc and scraper have come together is a question I cannot answer. I believe this report has proven both to be competent ignition sources. Combined with the 'swiss cheese effect' of perfect weather and fuel conditions, a fire from a source not historically considered a fire risk has occurred.

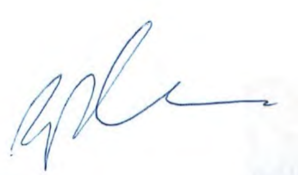
13 RECOMMENDATIONS (This section identifies any risk reduction initiatives identified by the investigator that may warrant consideration)

13.1 Discing should be considered a low risk for potential ignitions in most circumstances, however, under extreme fire conditions discing should be subject to best practice 'trigger points' that identify when the risk for ignition is high and operations should stop or fire risk mitigating factors be employed.

13.2 Given the similar mechanism for ignition as in chainsaw use and other heavy machinery (sparks and hot surfaces) used in forestry operations, the best practice trigger points developed for the forestry industry may be suitable for general agricultural machinery use.

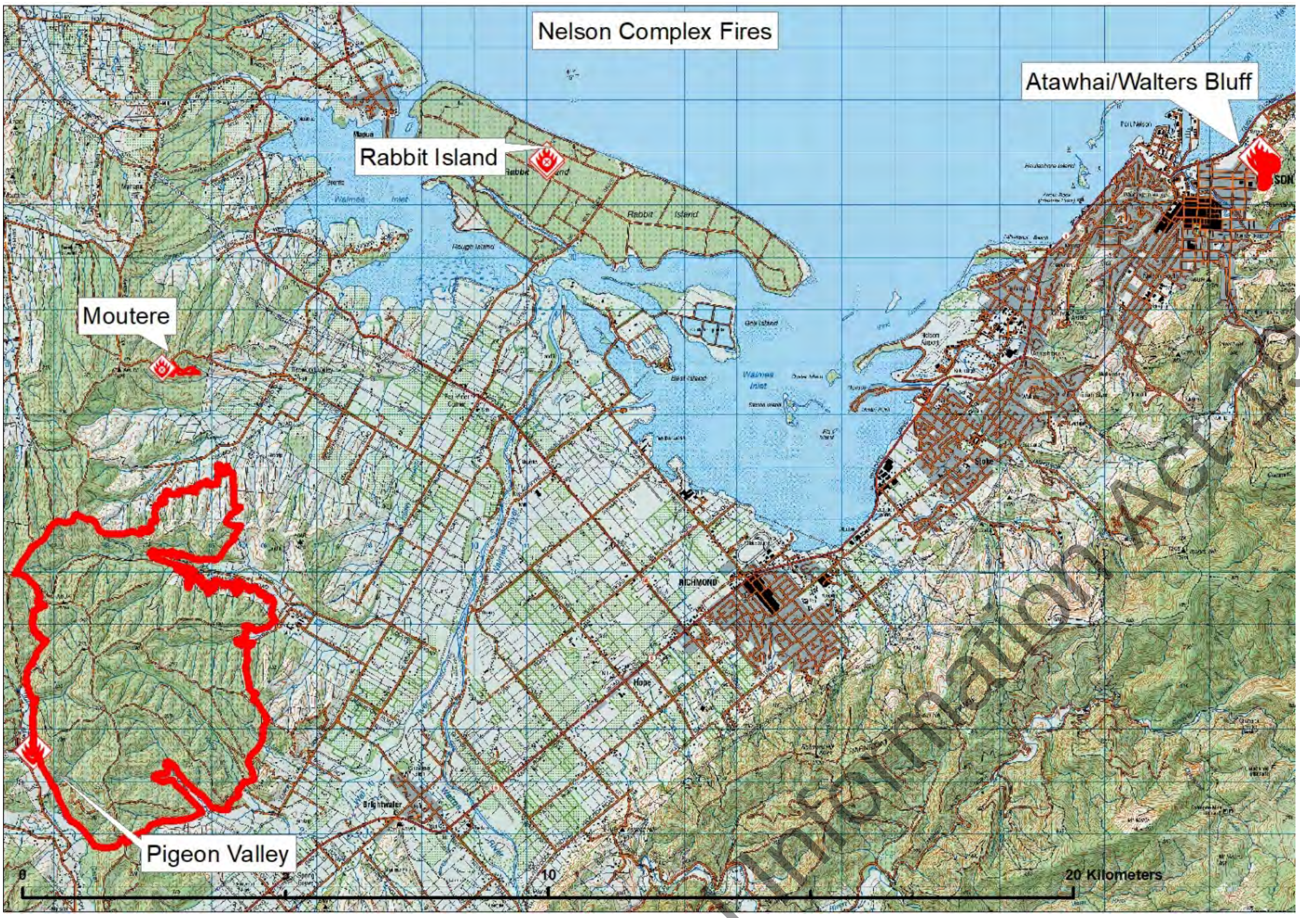
13.3 These guidelines or trigger points could be supported by some basic precautions such as discing a break around the outside of a paddock to prevent fire spread if an ignition does occur, discing rocky ground in the morning and having larger fire extinguishers or another portable water source/water cart on hand during extreme fire days when discing has to continue. Further mitigation could include modifying discs so that the scrapers cannot contact the discs or manufacturing them out of a different compound that will not cause sparks.

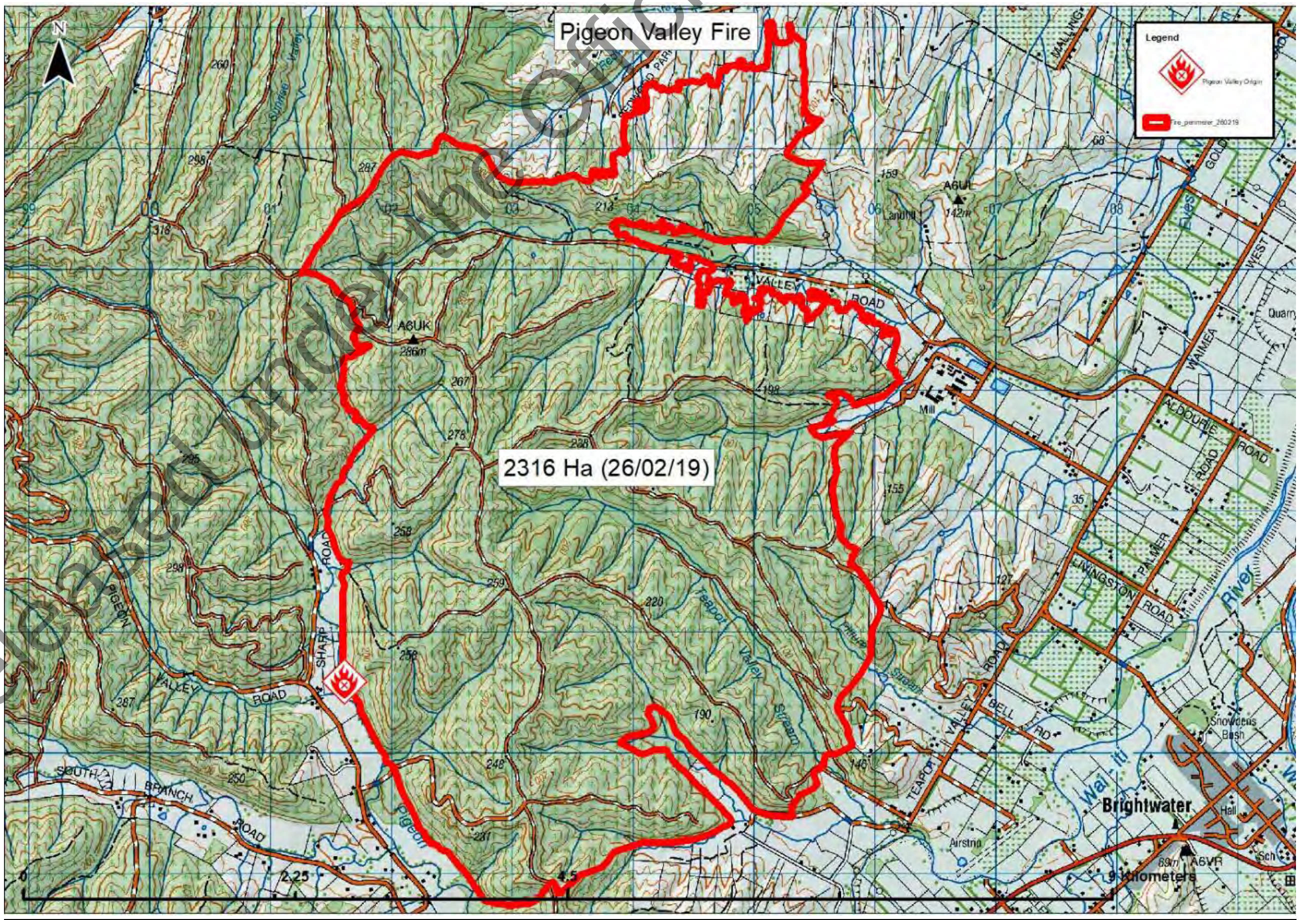
Investigation and report published on the 19/06/2019 by

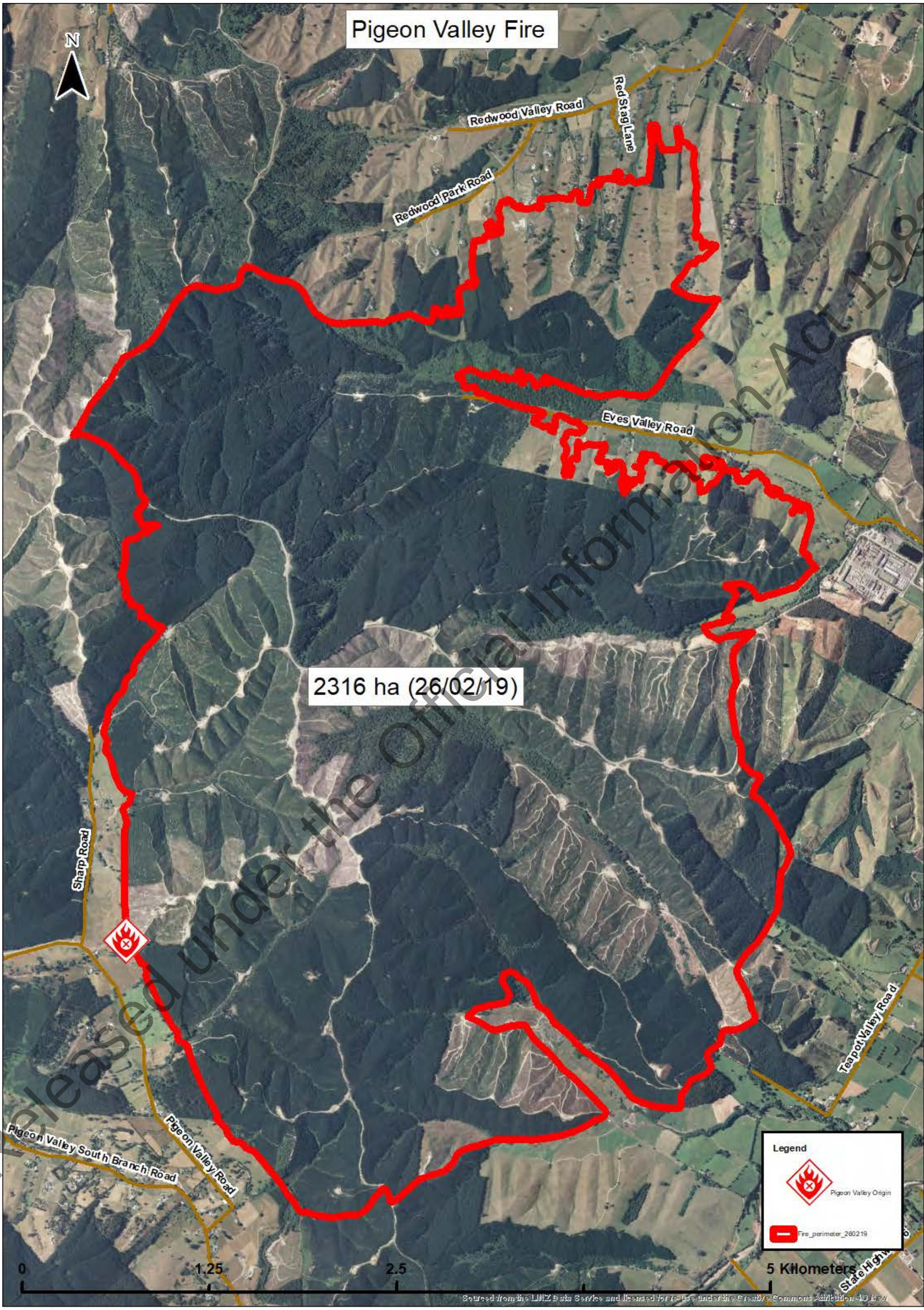


Jamie Cowan
Wildfire Management Specialist/Wildfire Investigator L2
Wildfire Management NZ
[redacted]

Appendix 1 MAPS. Overview Maps

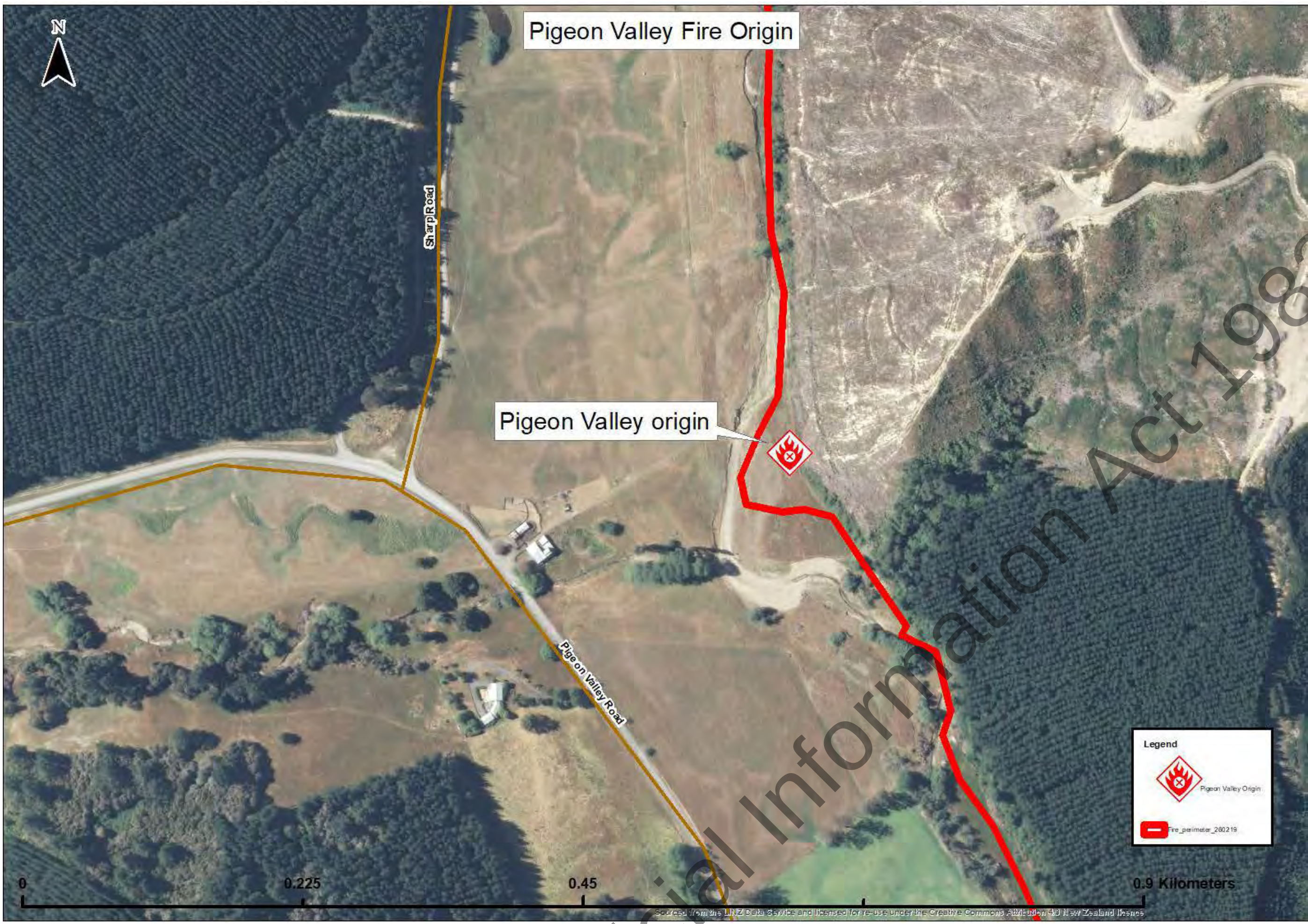


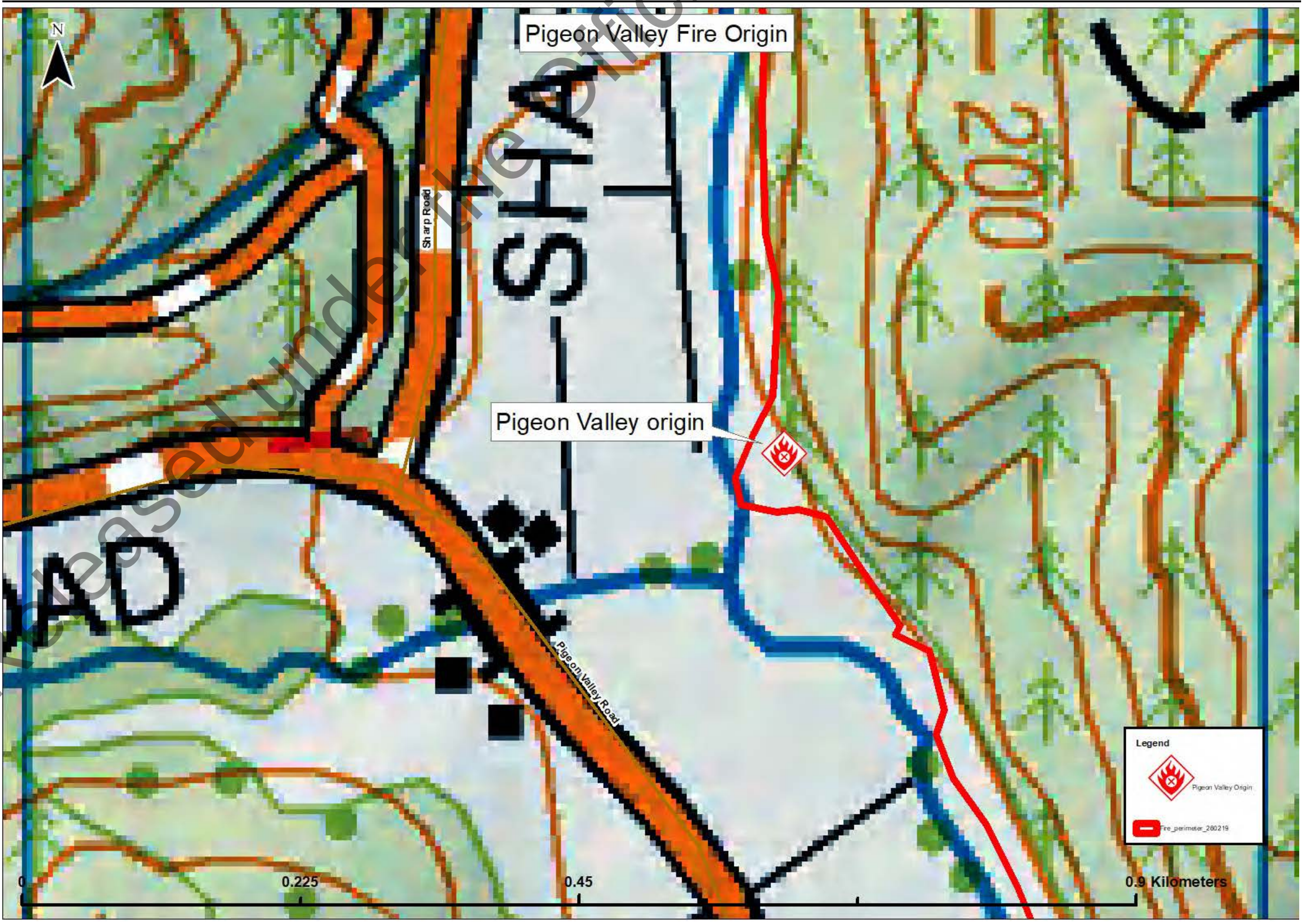




Pigeon Valley Fire
N
Redwood Valley Road
Red Stag Lane
Redwood Park Road
Eves Valley Road
2316 ha (26/02/19)
Sharp Road
Teapot Valley Road
Pigeon Valley South Branch Road
Pigeon Valley Road
State Highway
Legend
Pigeon Valley Origin
Fire_perimeter_260219
0
1.25
2.5
5 Kilometers
Sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 4.0 New

Pigeon Valley Origin Maps





Appendix 2 Fire Weather

Nelson-Marlborough																Tuesday, 05 February 2019
STATION NAME	FOREST	SCRUB	GRASS	FFMC	DMC	DC	ISI	BUI	FWI	TEMP	RH	DIR	WSP	RN24	GC%	STAT
Takaka Aerodrome	E	E	V	92	65	355	25.4	89	54.3	29.6	32	277	29	0.0	65	Aut
Kenepuru Head	E	E	H	89	54	322	15.5	76	36.9	25.5	45	293	29	0.0	65	Aut
Big Pokororo 2	E	E	V	91	93	386	20.8	116	53.8	26.6	36	283	28	0.0	70	Aut
Rai Valley	E	E	H	89	61	327	11.6	84	31.9	26.6	44	303	22	0.0	65	Aut
Hira	H	E	H	90	78	426	5.8	107	22.4	26.3	42	267	6	0.0	70	Aut
Nelson	E	E	V	90	74	444	17.3	105	46.0	27.1	39	217	27	0.0	70	Aut
Dovedale	E	E	H	91	96	451	11.6	125	38.1	24.9	36	249	18	0.0	70	Aut
Koromiko	E	E	H	92	92	352	10.8	111	34.7	28.5	34	213	14	0.0	55	Aut
Onamalutu	E	E	H	92	85	327	12.3	103	36.7	28.0	32	290	15	0.0	70	Aut
Lower Wairau	E	E	H	93	86	434	14.4	115	42.6	29.3	30	280	17	0.0	65	Aut
Western Boundary	E	E	H	90	64	303	17.8	83	42.1	20.5	45	195	28	0.0	60	Aut
Landsdowne	E	E	E	93	120	495	31.9	150	75.6	26.9	27	257	30	0.0	80	Aut
Awatere Valley	E	E	E	94	93	377	37.0	115	76.1	29.9	25	281	32	0.0	80	Aut
Cape Campbell	M	E	M	84	35	299	5.3	54	14.5	20.9	70	150	21	0.0	65	Aut

Dovedale RAWS Observation

Validity time (local)	air temperature (°C)	relative humidity (%)	wind direction (10m) (°T)	wind speed (10m) (km/h)
Tue 05-02-2019 13:20	26.1	35	223	10.08
Tue 05-02-2019 13:30	25.2	36	256	15.84
Tue 05-02-2019 13:40	25.6	36	250	15.48
Tue 05-02-2019 13:50	25.6	35	253	15.48
Tue 05-02-2019 14:00	25.8	34	250	16.92
Tue 05-02-2019 14:10	26.4	33	245	12.24
Tue 05-02-2019 14:20	25.6	35	239	13.68
Tue 05-02-2019 14:30	25.9	36	268	20.16
Tue 05-02-2019 14:40	25.6	36	252	15.84
Tue 05-02-2019 14:50	25.6	36	253	16.2
Tue 05-02-2019 15:00	26.1	35	262	18.36
Tue 05-02-2019 15:10	26.3	35	266	21.24
Tue 05-02-2019 15:20	26.4	35	266	23.4
Tue 05-02-2019 15:30	25.8	36	261	19.44
Tue 05-02-2019 15:40	25.6	37	266	23.04
Tue 05-02-2019 15:50	25.6	37	264	21.6
Tue 05-02-2019 16:00	25.9	38	263	19.8
Tue 05-02-2019 16:10	26.3	37	267	19.44
Tue 05-02-2019 16:20	25.8	39	263	21.96
Tue 05-02-2019 16:30	26.1	38	270	23.04
Tue 05-02-2019 16:40	25.4	40	263	23.76
Tue 05-02-2019 16:50	25.3	41	264	21.24
Tue 05-02-2019 17:00	25.2	42	267	24.12
Tue 05-02-2019 17:10	24.8	43	261	16.92
Tue 05-02-2019 17:20	23.4	46	258	19.08
Tue 05-02-2019 17:30	23.1	47	240	21.6
Tue 05-02-2019 17:40	23.6	46	244	21.24
Tue 05-02-2019 17:50	23.9	46	245	19.08
Tue 05-02-2019 18:00	23.7	46	248	18.72

Appendix 3 Pigeon Valley photo log. Index.

1. Series of Photos taken by the [redacted] at 14:15. Timestamp is highlighted in photo title
2. Blow up of photo taken by Witness [redacted] against my re-created photo 799 (was taken from slightly different angle, however I have counted posts to align) (note grass curing at 90% to 100%)
3. Photo 410A5340 [redacted]). Origin and discing area over the creek.
4. Photo 410A5343 ([redacted]). Origin and circular pattern believed to be created by discs when arriving at origin. (Witness [redacted] talked about trying to put out fire with discs)
5. Photo 792. Fendt tractor that was pulling discs at the time of ignition.
6. Photos 20190214-092250. Under bonnet of tractor showing exhaust manifold and turbo.
7. Photo 795. Fendt tractor and discs.
8. Photo 795. Close up of discs and scrapers. (Note scrapers are bent and out of alignment, this shows the wear and tear on scrapers as part of normal operations.
9. Photos 20190214-091241,-091301,-094037. Close up of discs and scrapers. (Note scrapers are at different distances from discs and in some cases very close.
10. Photos 20190214-094156,-094208,-104817,-102140. Close up of fresh abrasion to scraper and corresponding scratches in disc. (3rd disc and scraper set in from front right gang)
11. Photo 797. Close up of discs showing wear and tear on cutting edge.

12. Photo 762. Note the very rocky nature of the area being disced. The origin is the rockiest area disced along the eastern edge of this block.
13. Photos 829 to 837. Showing some of the 18 stone strikes photographed in the origin area.
14. Photos 20190213-153053, -150838, -150632. Examples of the amount of metal smeared onto rocks by the discs outside of the origin area.
15. Photo 825. Magnet test showing magnetic particles from within the Origin Area. No particles were found from multiple tests outside the disced area.
16. Photos 20190214-120055, -121214. Further examples of magnet tests carried out by insurance investigator [redacted] (Note large flake on the left hand picture)
17. Photo Spheroid 1 ([redacted]). Magnified picture of magnetic samples showing the presence of spheroids. (0.3mm) These occur once steel sparks have reached their melting point.
18. Photo Spheroid 2 ([redacted]). Magnified picture of magnetic samples showing the presence of spheroids. (0.2mm, 0.1mm)
19. Photos 20190214-191705. Fire extinguisher used by tractor driver. We did not find the pin when searching the origin area.
20. Photos 20190214-142329, -142351. Example of the fuel type just outside of the origin area. (Note, it was variable depending on location)
21. Photo 849 – Taken from above the Origin Area (taped off) showing flagging.
22. Photo 850 – Close up of flagging and rock strike markers.

23. FireMapper 2- Shows the electronic flagging of fire pattern vector indicators. Photos of these indicators to follow.
24. Photo 768 – Freeze at Origin showing wind direction from the north west
25. Photo 803, 805 – Backing vector indicators. Grass stems present and facing origin
26. Photo 806 – Backing vector indicators. Has backed under thistle. Grass stems present, protection and sooting at rock.
27. Photo 807, 808 – Advancing vector indicators. Protection in lee of rock and clean burn line on advancing side.
28. Photo 811, 812, 813 – Advancing vector indicators. Protection in lee of rock. Protection under rock with clean burn line on advancing side.
29. Photo 816, 817, 818 – Lateral vector indicators. Protection in lee of rock. Protection under rock with clean burn line on advancing side. Staining on lateral advancing side of rock
30. Photo 819, 820 – Lateral vector indicators. Grass stem remains as fire has flanked under them. Note the intensity and colour of the burning is much lighter than the advancing vectors from the previous pictures.

1, Series of Photos taken [redacted] at 14:15. Timestamp is highlighted in photo title

Photo 20190205-141718

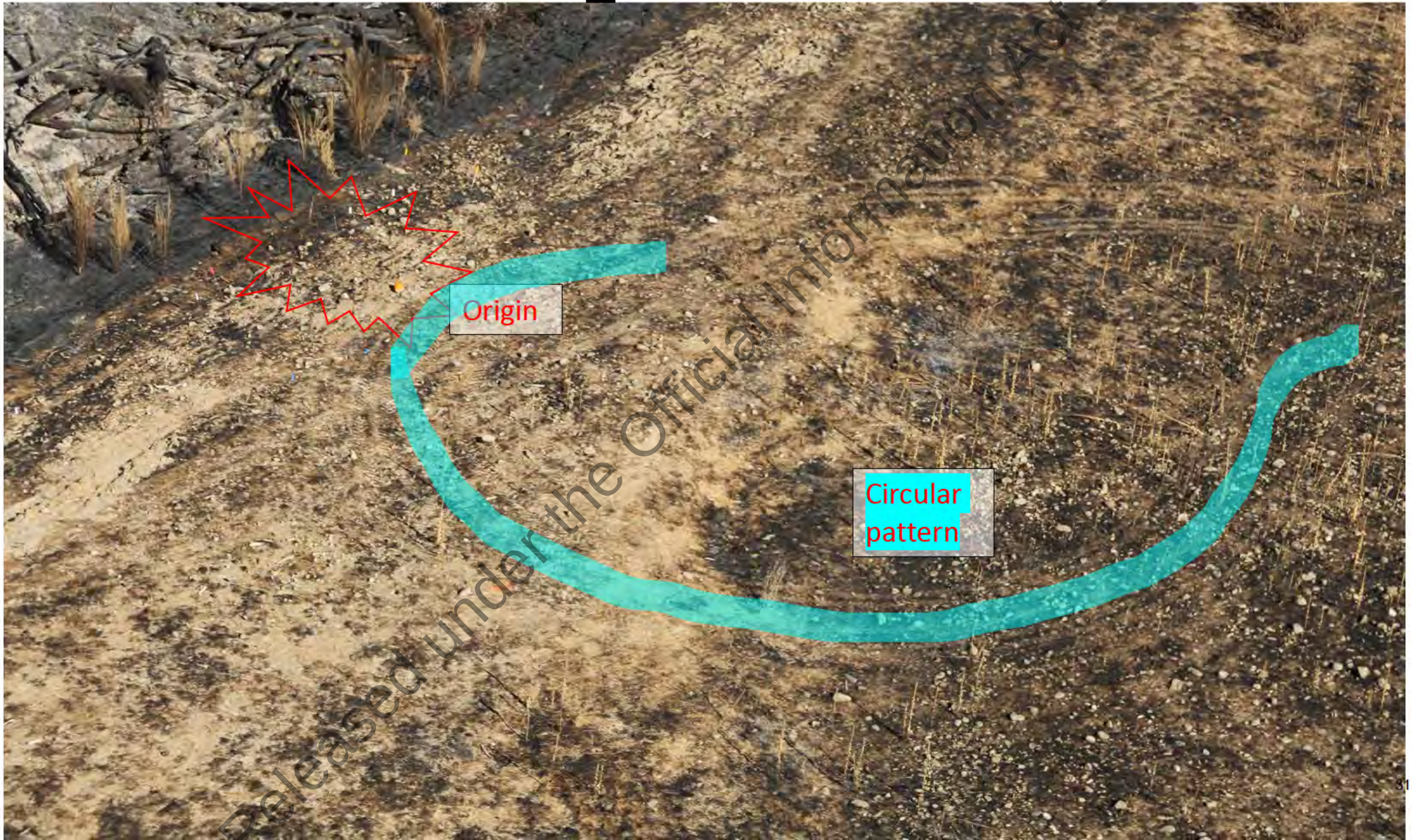
Photo 20190205-142208

Photo 20190205-143821

2, Blow up of photo taken by [redacted] against my re-created photo 799 (was taken from slightly different angle, however I have counted posts to align) (note grass curing at 90% to 100%)

3, Photo 410A5340 ([redacted]). Origin and discing area over the creek.

4, Photo 410A5343 ([redacted]). Origin and circular pattern believed to be created by discs when arriving at origin. (Witness [redacted] talked about trying to put out fire with discs)

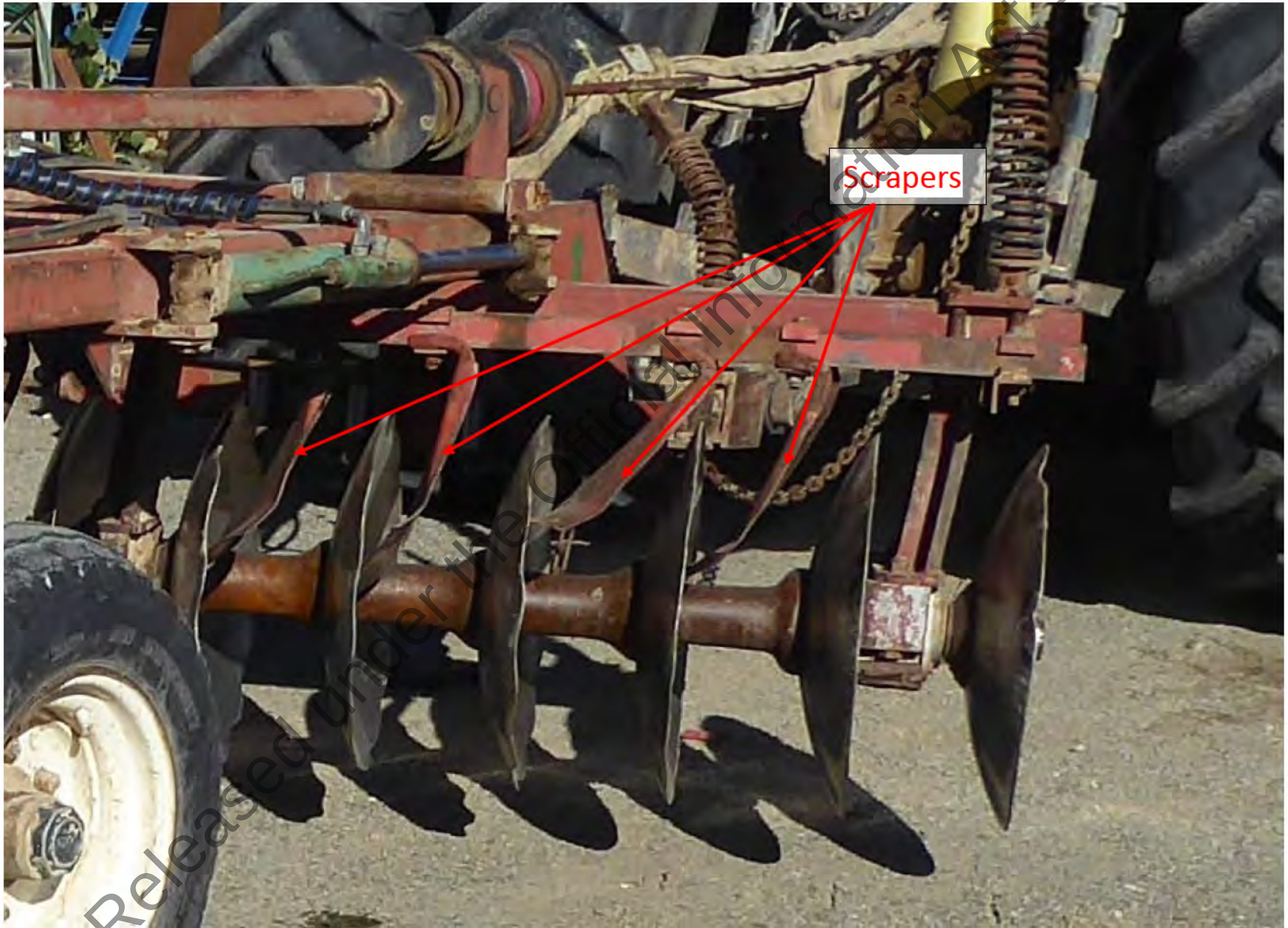


5, Photo 792. Fendt tractor that was pulling discs at the time of ignition.

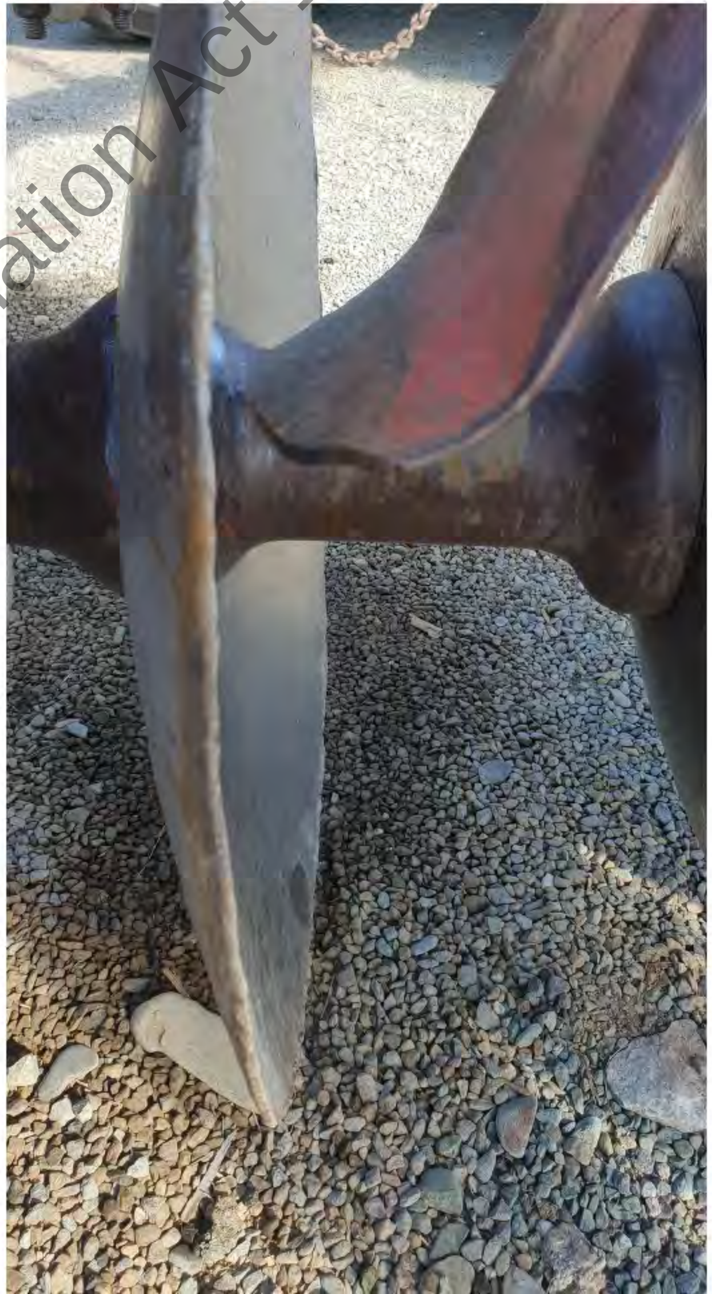
6, Photos 20190214-092250. Under bonnet of tractor showing exhaust manifold and turbo.

7, Photo 795. Fendt tractor and discs.

8, Photo 795. Close up of discs and scrapers. (Note scrapers are bent and out of alignment, this shows the wear and tear on scrapers as part of normal operations.



9, Photos 20190214-091241,-091301,-094037. Close up of discs and scrapers. (Note scrapers are at different distances from discs and in some cases very close.



10, Photos 20190214-094156,-094208,-104817,-102140. Close up of fresh abrasion to scraper and corresponding scratches in disc. (3rd disc and scraper set in from front right gang)

11, Photo 797. Close up of discs showing wear and tear on cutting edge.

12, Photo 762. Note the very rocky nature of the area being disced. The origin is the rockiest area disced along the eastern edge of this block.