Queensland Government

DEPARTMENT OF NATURAL RESOURCES AND MINES

Mine Safety and Health - Explosives Inspectorate

Explosives Act 1999

INVESTIGATION REPORT

TO

CHIEF INSPECTOR OF EXPLOSIVES

on the **AMMONIUM NITRATE EXPLOSION**

at

Angellala Creek, Charleville Queensland Australia

on 5 September 2014

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Prepared by	Accepted by
sch4p4(6) Personal information	sch4p4(6) Personal information
26 May 2016	26 May 2016
Ryan Brogden	Noel Erichsen
Principal Inspector of Explosives	Chief Inspector of Explosives

1 Executive summary

1.1 The incident

At approximately 2054 on Friday 5 September 2014, a vehicle carrying 52.8 t of ammonium nitrate was involved in a single vehicle incident. The vehicle was transporting 44 flexible intermediate bulk containers (IBCs) each carrying 1.2 t of ammonium nitrate.

The ammonium nitrate transported was classified as UN 1942, manufactured by Orica Australia Pty Limited (Orica) at Yarwun, Queensland. The load was being transported by Kalari Pty Limited (Kalari) to an iron ore mine in South Australia.

The vehicle left the road on approach to the road bridge over Angellala Creek on the Mitchell Highway, approximately 30 km south of Charleville. It came to rest in the creek bed adjacent to the road bridge. The prime mover caught fire. A local man driving south from Charleville arrived at the crash scene soon after the incident and rendered assistance to the injured driver.

The driver of a truck that arrived from the south provided further assistance to the injured driver. The local man left the crash scene to contact emergency services at a nearby Station. A short time later another truck driver arrived from the north and rendered assistance to the injured driver.

Queensland Fire and Emergency Services (QFES) and Queensland Police Service (QPS) from Charleville responded. The first fire truck arrived at the incident scene at approximately 2203. They started first aid on the injured driver and assessed the vehicle fire.

At approximately 2210 – 2211 an explosion occurred. The QFES officers decided to evacuate. At 2212 a larger explosion occurred while the QFES officers were in the process of evacuating the area.

There were no fatalities; however eight people were injured, some seriously. The injuries included burns, lacerations, internal bruising, bleeding of organs, eardrum perforation and bleeding from the ears.

The Kalari vehicle, two fire vehicles, a police car and both the rail and road bridges over Angellala Creek were either destroyed or sustained significant structural damage.

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1.2 Cause

The cause of the fire and explosion could not be determined. A number of possible causes have been discussed in the report. Some possible causes have been eliminated based on analysis of the evidence.

1.3 Key findings

1.3.1. The vehicle was mechanically sound and was regularly maintained (section 7.9.2).

1.3.2. The prime mover contained a large amount of combustible material, including fuel, and various metals (section 4.4.4).

1.3.3. A diesel fuel injector line has failed during the fire event after the crash (section 5.5.3.1).

1.3.4. The GSM signal from the prime mover was lost approximately 15 km north of the incident site and the satellite signal had not been acquired at the time of the incident. The crash occurred approximately 10 minutes after the GSM signal was lost (section 4.4.1.1).

1.3.5. Some ammonium nitrate IBCs were dislodged from the trailers during the crash and scattered along the vehicle pathway from the start of the bridge to the resting point of the prime mover (section 5.5.1).

1.3.6. Ammonium nitrate samples from the site showed the appearance of being molten and contaminated with organic substances and metals (section 7.6.2.3).

1.3.7. Following the crash the fire burned for over one hour, engulfing the prime mover, first trailer and a quantity of the load before reducing to a small fire on the prime mover immediately prior to the explosion (section 6.2.3).

1.3.8. There was a diesel spill from the vehicle across the site from the north bank to the south bank of the creek that would have contributed to the fire (section 7.6.2.3).

1.3.9. There are hot surfaces, particularly the engine exhaust that are in close proximity to where spilled diesel would be found as a result of the crash (section 7.5.3.1).

1.3.10. An electrical arc has occurred from the batteries electrical cabling (section 7.5.3.2).

1.3.11. Molten ammonium nitrate and molten aluminium and copper were found at the site, indicating an intense fire in excess of 1000°C (section 6.2.2).

1.3.12. The first explosion occurred approximately one hour and fifteen minutes after the estimated time of the vehicle crash (section 7.7.1).

1.3.13. The first explosion did not appear to have a significant blast overpressure or projections and caused no structural damage (section 7.7.3).

1.3.14. A second explosion occurred approximately one hour and seventeen minutes following the estimated time of the vehicle crash (section 7.7.1).

1.3.15. Post blast analysis estimated the size of the explosion involved approximately 40 to 45 t of ammonium nitrate which equates to approximately 10 to 15 t TNT (section 7.8).

1.3.16. Debris from the Kalari vehicle and other infrastructure was found up to one kilometre away from the site of the vehicle crash (section 7.7.4).

1.3.17. Eight people were injured in the explosion, some seriously. (section 7.8).

1.3.18. All explosions involving ammonium nitrate in transport have occurred on flat deck type trailers (section 7.1.2).

1.3.19. The vehicle crash rendered the driver semi-conscious and unable to take control of the incident site. He was able to convey some emergency response information to external parties (section 6.2.3).

1.3.20. The manifest, emergency procedure guide (EPG), placards and Emergency Information Panel's (EIPs) were destroyed by the fire, preventing communication of the hazards to first responders (section 7.9.1).

1.3.21. There was no phone signal at the site for people to call and alert emergency services of the incident (section 5.3).

1.3.22. Guide 50 in SAA/SNZ HB76:2010 *Dangerous Goods – Initial Emergency Response Guide* (HB76) for response to an ammonium nitrate incident is not specific in some cases, for example when to respond and when to evacuate an ammonium nitrate incident involving a fire and the safe evacuation distances (section 7.9.3).

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1.3.23. At the time of the incident, the Hazchem Code in the *Australian Code for the Transport of Dangerous Goods by Road and Rail 7th Edition (*ADGC) for ammonium nitrate was 1Z and did not address the explosion risk of ammonium nitrate (section 11.2).

1.4 Key conclusions

1.4.1 Cause of vehicle crash

The vehicle crash was part of the police investigation that concluded the cause of the vehicle leaving the road could not be determined.

1.4.2 Cause of vehicle fire

There was no conclusive determination on what caused the initial fire, or at what location, on the vehicle. Witness accounts indicate the fire was large, consuming the prime mover and first trailer. A number of possible fire scenarios have been proposed.

The most probable scenarios for initiating the fire on the vehicle include:

1. Spilt fuel contacting the engine exhaust and igniting;
2. Electrical arcing igniting the leaking fuel; or
3. Wheel rim being heated by friction and igniting leaking fuel.

1.4.3 Cause of first explosion

The cause of the first explosion could not be clearly determined. This explosion had no overpressure or significant projections and did not cause any structural damage. A number of probable scenarios for this first explosion have been proposed based on the preceding fire.

The probable scenarios leading to this first explosion include:

1. A pressurised piece of equipment (for example a tyre or air tank reservoir) has burst possibly as a result of fire;
2. A gas or thermal explosion from the decomposition of ammonium nitrate as a result of heating has caused a low order explosion;
3. Molten aluminium contacting either a water source or molten ammonium nitrate causing a violent reaction.

1.4.4 Cause of second explosion

The cause of the second explosion could not be clearly determined. The size of the explosion was estimated to be between 10 – 15 t trinitrotoluene (TNT) equivalence, causing significant destruction to infrastructure and blast injuries to the people at the site. No link could be found between the first and second explosions. A number of probable scenarios for the second explosion have been proposed based on a preceding fire.

The probable scenarios leading to this second explosion include:

1. Thermal explosion (cook off);
2. Deflagration under pressure (heat conduction and chemical reaction);

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3. Detonation (shock wave driven) – either direct shock detonation transition or deflagration detonation transition; or
4. Water hammer/ concerted void collapse (i.e. hot spot).

1.4.5 Design of vehicles

The current accepted design of vehicles does not provide controls to reduce the risk of abnormal conditions such as vehicle crash or fire.

All of the previous incidents worldwide where an explosion has occurred on a vehicle transporting ammonium nitrate have been following an intense fire that has involved the ammonium nitrate. All of these explosions have occurred on flat deck type trailers. If the risk of fire is eliminated, controlled or isolated, the chance of an explosion of ammonium nitrate during transport operations is negligible.

To stop this type of incident occurring again there is a need to:

1. Reduce the chance of a fire occurring on transport vehicles by improving the safety design and including fire mitigation controls for if and when a fire does occur.
2. Segregate ammonium nitrate from the prime mover and other large sources of contamination and heat through effective risk management practices.
3. Ensure first responders to an incident site can quickly identify and treat incident according to the hazards present.

1.5 Recommendations

1.5.1. A steel vertical and horizontal firescreen be fitted to flat deck trailers transporting ammonium nitrate to isolate the ammonium nitrate load from a fire on the vehicle.

1.5.2. Reduce the quantity of combustible material on a vehicle, particularly in proximity to ignition sources.

1.5.3. Regulators and industry representatives to develop appropriate design criteria for vehicles transporting ammonium nitrate that includes safety design features to prevent, reduce and isolate a fire.

1.5.4. Increase the fire extinguisher capacity and provide additional water on vehicles transporting ammonium nitrate to respond adequately to an initial fire scenario.

1.5.5. Review the appropriate hazard information on vehicles, including documentation and vehicle marking, and systems to alert external parties to an incident involving ammonium nitrate.

1.5.6. Communicate ammonium nitrate transport routes to emergency services and remote communities for pre-planning of emergency response.

1.5.7. Update the initial emergency response guide SAA/SNZ HB76:2010 *Dangerous Goods – Initial Emergency Response Guide* (HB76) to reflect the appropriate initial response and evacuation response to an ammonium nitrate fire.

1.5.8. Conduct further research into the causes of initiation of an ammonium nitrate explosion in a transport incident, particularly the interaction of molten metals with molten ammonium nitrate in large loads.

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2 Introduction

2.1 Foreword

The Explosives Inspectorate of the Department of Natural Resources and Mines (DNRM) is the regulator of explosives in Queensland. The Explosives Inspectorate supports safety and security in the explosives industries to protect the community and explosives workers from the hazards of explosives through:

- Monitoring explosives activities to ensure compliance with the *Explosives Act 1999* (the Act) and the Explosives Regulation 2003 (the Regulation);
- Ensuring there are standards for the safe handling, transport and use of explosives;
- Responding effectively to explosives incidents; and
- Administering government magazines for the storage, distribution and disposal of explosives.

2.2 Investigation team members

The investigation team comprised three Inspectors of Explosives, along with support staff and incident responders. Their duties and responsibilities were as follows:

- Ryan Brogden, Principal Inspector of Explosives – Lead Investigator
- Chris Donovan, Senior Inspector of Explosives – Investigator
- Haydn Isaac, Principal Inspector of Explosives – Investigator
- Andy Bruce, Principal Project Officer – Investigator assisting
- Lionel Gainey, Senior Inspector of Explosives – Incident response; Exhibit Registrar
- Bruce Symmans, Senior Inspector of Explosives – Incident response
- Jim Fowler, Principal Inspector of Explosives - Incident response; Exhibit Registrar
- Ray Belleville, Senior Inspector of Explosives- Incident response
- Paul White, Senior Inspector of Explosives- Incident response
- Matt O'Shea, Senior Inspector of Explosives- Incident response
- Ian Ellison, Senior Inspector of Mines – ICAM facilitator
- Audrey Nolan, Executive Support Officer
- Lydia Spataro, Administration support
- Paula Deacon, Project Officer

2.3 Acknowledgement

DNRM acknowledge the injured persons who have been adversely affected by this event. It is hoped that this investigation will help to ensure a safer industry for the transport of ammonium nitrate.

DNRM wish to thank Queensland Fire and Emergency Services, Queensland Police Service, the State Emergency Service, Department of Transport and Main Roads and the DNRM Charleville office for their assistance with the on-site investigation by providing staff and resources to assist the Explosives Inspectorate investigation.

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3 Aim and scope of the investigation

3.1 Aim

The aim of the investigation by the DNRM Explosives Inspectorate was to establish the nature and cause of the fire and explosion at Angellala Creek, and to prepare a report about the incident that includes recommendations to prevent this type of incident from occurring again.

3.2 Scope

The investigation examined the following:

- Activities leading up to and at the time of the incident
- The cause and effect of the fire at the site
- The explosion and cause of the explosion

3.3 Other agencies with specific jurisdiction into the incident

3.3.1 Queensland Police Service (QPS)

QPS have conducted an investigation into the cause of the vehicle crash.

3.3.2 Department of Transport and Main Roads (DTMR)

DTMR regulate heavy vehicles and fatigue law. RoadTek, a section of DTMR, manages road construction and maintenance.

3.3.3 Queensland Fire and Emergency Services (QFES)

QFES are responsible for emergency response, including hazardous materials (Hazmat) management.

3.3.4 Workplace Health and Safety (WHS)

WHS under Work Health and Safety legislation covers regulation of the work place.

Note: The investigations undertaken by these agencies are outside the scope of the Explosives Inspectorate's investigation. The details surrounding the vehicle crash, fatigue management and various agency responses to the incident may be discussed; however findings regarding these events will not be made in this report.

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3.4 Abbreviations used in the report

Abbreviation	Term
The Act	Explosives Act 1999
AdBlue	Urea based additive to decrease nitrous gas emissions from diesel engines
ADGC	Australian code for the transport of dangerous goods by road and rail – 7th edition, version 7.3
AEC	Australian code for the transport of explosives by road and rail – 3rd edition
AEISG	The Australian Explosives Industry Safety Group
AN	Ammonium nitrate (solid prilled ammonium nitrate)
ARTSA	Australian Road Transport Suppliers Association
AS2809	Australian Standard 2809–2008 Road tank vehicles for dangerous goods
BK1	Sheeted bulk container (see section 6.8.2 of ADGC for definition)
BK2	Closed bulk container (see section 6.8.2 of ADGC for definition)
BOM	Bureau of Meteorology
DDT	Deflagration to detonation transition
DNRM	Department of Natural Resources and Mines (Queensland)
DTMR	Department of Transport and Main Roads (Queensland)
EI	Explosives Inspectorate (Queensland)
EIP	Emergency information panel
FCP	Forward control point
GPS	Global positioning system
GSM	Global system for mobile communications
GVM	Gross vehicle mass
HB76	SAA/SNZ HB 76:2010 Dangerous Goods - Initial Emergency Response Guide
IBC	Intermediate bulk container
iROS	Intelligent roll over system
JMP	Journey management plan
MOU	Memorandum of understanding
MPU	Mobile processing unit
NHVAS	National Heavy Vehicle Accreditation Scheme
OEM	Original equipment manufacturer
QAS	Queensland Ambulance Service
QFES	Queensland Fire and Emergency Services
QHFSS	Queensland Health Forensic and Scientific Services
QLD	Queensland
QPS	Queensland Police Service
The Regulation	Explosives Regulation 2003
SDT	Shock to detonation transition
SIMTARS	Safety In Mines Testing and Research Station
SSAN	Security sensitive ammonium nitrate
TNO	Netherlands Organisation for Applied Scientific Research
TOC	Total organic carbon
WHS	Workplace Health and Safety
UN	United Nations

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4 Introduction

4.1 Background

4.1.1 Orica Australia Pty Ltd

Orica produces commercial explosives and blasting systems for the mining and construction markets. Orica manufactures prilled ammonium nitrate at their Yarwun manufacturing plant near Gladstone, Queensland. At the time of the incident, Orica contracted Kalari Pty Ltd to transport of ammonium nitrate from Yarwun to Peculiar Knob Iron Ore Mine in South Australia.

4.1.2 Kalari Pty Ltd

Kalari is a transport bulk logistics provider to many different industries, in particular the mining and resources sector. Kalari own all vehicles in their fleet and employs their own drivers.

4.2 Authorities

4.2.1 Orica Australia Pty Ltd

At the time of the incident, Orica held a current authority issued by the Department of Natural Resources and Mines (DNRM) enabling the company to manufacture ammonium nitrate at Yarwun (Annex 1). The Licence to Manufacture Explosives was issued on 12 April 1999 (licence number

(7)(1)(c) Business/commercial/professional/financial affairs

4.2.2 Kalari Pty Ltd

At the time of the incident, Kalari possessed a current authority issued by DNRM to transport ammonium nitrate issued as a Licence to Transport Explosives (Annex 2). The licence was issued on 2 October 2013 (licence number sch4p4(7)(1)(c) Business/commercial/professional/financial affairs). This licence is for the prime mover involved in the incident (registration number sch4p4(7)(1)(c) Business/commercial/professional/financial affairs) to transport explosives of Division 5.1 including security sensitive ammonium nitrate (SSAN). SSAN includes ammonium nitrate prill.

This authority is issued under section 13 of the Act to transport explosives. Kalari must comply with the requirements of the Act and the Regulation, particularly Parts 3 and 9 of the Regulation and all conditions of their licence (Annex 2).

4.3 Driver Information

At the time of the incident, sch4p4(6) Personal information was employed by Kalari as a heavy vehicle driver sch4p4(7)(1)(c) Business/commercial/professional/financial affa

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4.4 Vehicle Information

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4.4.1 Prime mover

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4.4.1.1 Global positioning system (GPS) tracking of prime mover

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4.4.2 Trailers and converter dolly

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4.4.3 Vehicle metal components

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4.4.4 Vehicle combustible components

The vehicle involved in the incident contained a large amount of combustible material (Table 2). In a fire, these combustible materials readily burn. Pure ammonium nitrate does not burn, but when mixed with sufficient combustible material, can become a Class 1 explosive. Combustible material mixed with ammonium nitrate will significantly intensify a fire and increase the probability of an explosion.

Table 2 – Combustible material found on vehicle involved in incident and typical uses.

Combustible material	Use
Diesel and oil	Fuel for prime mover, oil for engine, transmission, drive axles and hydraulics
Fibreglass	Prime mover cabin and bonnet
Rubber and plastic	Tyres on prime mover, dolly and trailers, engine hoses, conduit for electrics, material in cabin, suspension, IBC bags containing the ammonium nitrate, rope and straps
Canvas	Covering for ammonium nitrate load
Aluminium (combustible when heated above 660°C)	Decking for trailers, prime mover body and fuel tanks, wheel rims for prime mover, trailers and dolly.

4.4.5 Cargo – Ammonium Nitrate

The cargo being carried on the trailers was UN1942 ammonium nitrate. The product is generically authorised as an explosive under the Act by the Chief Inspector of Explosives as security sensitive ammonium nitrate (SSAN) of Division 5.1.

The load configuration consisted of 44 IBCs weighing 1.2 t each. There were 22 IBCs per trailer loaded in two rows of eleven. The load was restrained using 22 ratchet tie down straps anchored from one side to the other across two IBCs (Figure 4). Each trailer load was covered by a canvas tarp secured by synthetic rope.

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Figure 4 – Typical 1.2 tonne flexible IBC strapped on a trailer.



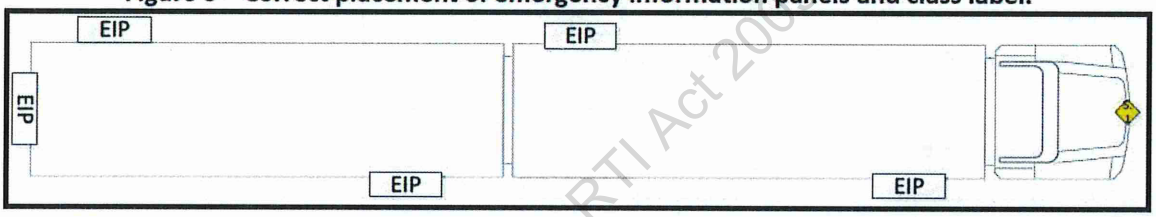
The two trailers displayed polyvinyl emergency information panels (EIP) for ammonium nitrate (Figure 5) on each side of each trailer and one on the rear of the second trailer (Figure 6) as required by the *Australian Code for the Transport of Dangerous Goods by Road and Rail 7th Edition* (ADGC).

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Figure 5 – Typical EIP for ammonium nitrate.



Figure 6 – Correct placement of emergency information panels and class label.



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4.4.6 Chemical properties of ammonium nitrate

Ammonium nitrate is a dangerous good of Division 5.1 (oxidising substance). An oxidising substance is a chemical that supports oxidation by providing oxygen to the reaction. The ADGC definition states:

> *Substances which, while in themselves not necessarily combustible, may, generally by yielding oxygen, cause, or contribute to, the combustion of other material. Therefore when a combustible material is mixed with ammonium nitrate, a fire can be sustained in the absence of oxygen from the air.*

In accordance with the ADGC, the ammonium nitrate in the incident was classified as UN1942. To be considered UN1942, the ammonium nitrate must pass Test Series 1 and 2 in the Manual of Tests and Criteria (in accordance with Special Provision 306 from ADGC) and contain no more than 0.2 % total combustible material, measured as carbon. When ammonium nitrate does not pass Test Series 1 or 2 or it contains more than 0.2 % carbon, it is considered to be a Class 1 explosive. The analysis and determination of classification for the ammonium nitrate prill involved in the incident is discussed in section 7.6.2.1.

sch4p4(7)(1)(c) Business/commercial/professional/financial affairs

The ammonium nitrate of UN1942 is a porous low density prill designed to absorb a fuel oil to form ANFO (ammonium nitrate fuel oil) for use in blasting. While ammonium nitrate is also manufactured as a fertiliser, the ammonium nitrate in the incident was manufactured specifically for use in the mining industry for blasting. The typical physical properties of the ammonium nitrate (Nitropril) involved in the incident are detailed in Table 3 (Annex 12).

Table 3 – Physical properties of ammonium nitrate (Nitropril).

Physical state	Granular Solid / Prills
Colour	White to Off-white
Specific Gravity	0.72 - 0.78 g/cm^3 (bulk density)
Solubility	Soluble in water
Solubility in water (g/L)	190 g/100 mL at 20 °C
Melting Point/Range (°C)	160 – 169 °C
Boiling Point/Range (°C)	Decomposes (approx. 210 °C)
Decomposition Point (°C)	210°C (approx.)
pH	4.5 - 5.2 (10 % solution @ 20 °C)
Mean Prill diameter	1.6 - 2.4 mm
Total organic content	Not greater than 0.2 %

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According to the Orica safety data sheet for Nitropril (Annex 12), ammonium nitrate is known to be incompatible with the following substances:

Tetranitromethane, dichloroisocyanuric acid, trichloroisocyanuric acid, any bromate, chlorate, chlorite, hypochlorite or chloroisocyanurate or any inorganic nitrite and combustible materials that include organic materials, reducing agents, metal powders, strong acids, nitrites, chlorates, chlorides and permanganates.

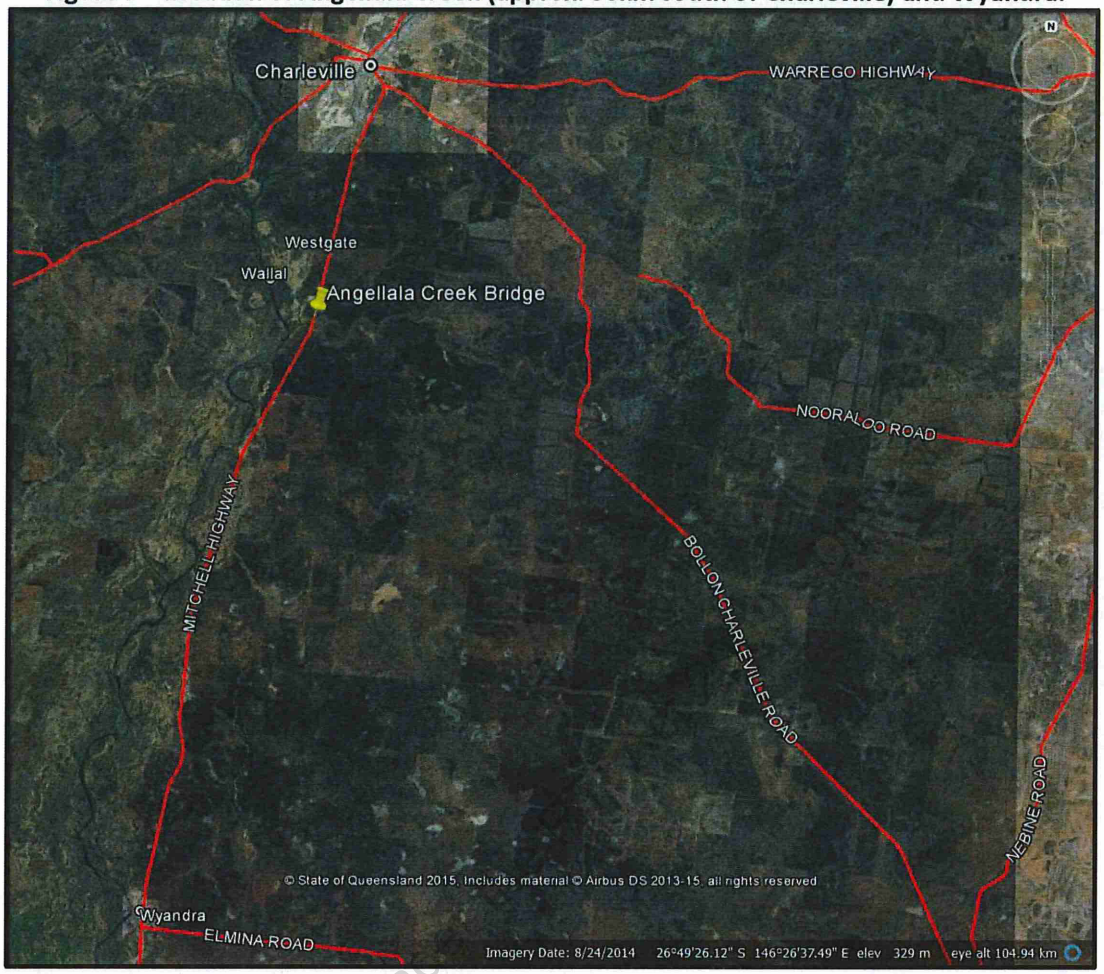
When ammonium nitrate is mixed with these incompatible substances, a violent and uncontrollable reaction can occur that may result in an explosion.

4.5 Incident site details

4.5.1 Incident location

The Angellala Creek Bridge on the Mitchell Highway is located at Bakers Bend, approximately 30 km south of Charleville. Charleville is approximately 700 km west of Brisbane. This is a remote rural area with cattle stations and a few residences being the only populated areas in the vicinity to the site (Figure 7). The GPS location of the bridge is: 26^{0}39'13.55"S 146^{0}10'33.03"E.

Figure 7 – Location of Angellala Creek (approx. 30km south of Charleville) and Wyandra.



4.5.2 Mitchell Highway road and bridge construction

The road leading up to and over the bridge was a typical 8m wide sealed bitumen road. Figure 8 shows the approach to the bridge pre-incident looking south in the direction the Kalari vehicle was travelling prior to the crash.

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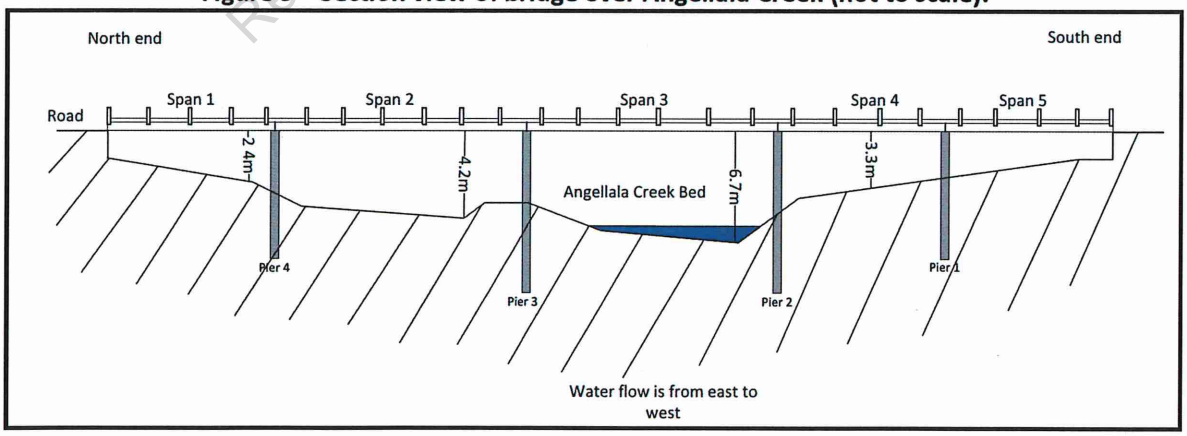
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Figure 8 – Angellala Creek Bridge, Mitchell Highway (Photo taken in 2002 by DTMR Inspector).



The Angellala Creek road bridge (Figure 9) was constructed in 1973. It was a concrete bridge consisting of five concrete spans. Spans 1, 4 and 5 were 10.5 m long and weighed 97.6 t each. Spans 2 and 3 were 13.7 m long and weighed 145.1 t each. The bridge had a precast prestressed concrete deck and asphaltic wearing surface. There were two abutments and four piers supporting the decks which were prestressed reinforced concrete sections. Railings running the length of the bridge on each side comprised two end reinforced concrete posts and 22 evenly spaced reinforced concrete posts with a steel pipe attached.

Figure 9 – Section view of bridge over Angellala Creek (not to scale).



A concrete kerb ran the length of the bridge along both sides. The bridge was 8.5 m wide from kerb to kerb. The road was continuous leading to and over the bridge and consisted of a bitumen surface.

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The northern left hand side approach consisted of a 20 m long steel guard railing mounted on steel posts set in concrete. The railing was approximately 1 m off the edge of the road and 0.7 m high. The 50 m approach to the bridge was compacted gravel concrete mix 0.5 m wide and sloping off the road at an approximately 50 degree angle over 1 m width. Refer to Main Roads Department, Murweh Shire Plan No. 115 182 (approved by Chief Engineer 02.08.72) Angellala Creek Bridge design for further information (Annex 14).

Previous DTMR inspection reports indicate the bridge was in a good condition prior to the incident (Annex 15).

A cross section of the creek bed at the bridge site illustrates the water channel profile and spot depths from the road level to the creek bed (Figure 9). The approximate distance (deepest section) from road level to creek bed is approximately 6.7 m. Note: These distances were accurate at the time of the last known survey of the creek bed at the time the bridge was constructed in 1973.

4.5.3 Angellala Creek

The creek is a narrow channelled non-perennial freshwater creek which flows from east to west. The creek is clay based and topsoiled with sand and gravel. The creek banks and surroundings are heavily vegetated with large coolabah trees and small shrubs. At the time of the incident it is understood that the creek bed was dry, except for a body of water under the bridge.

Jon Bundy, Bridge Inspector with DTMR, advised that a small body of water 5m in diameter and 1m to 2 m deep is always present under the bridge about span/pier two (Annex 16).

Vegetation in the vicinity of the bridge is typical open savannah comprising grasses, small shrubs, eucalypts (iron bark, poplar box and coolabah) and acacia (mulga).

4.5.4 Environmental conditions

The weather conditions at 2100 on 5 September 2014 measured at the Charleville weather station were 13.9 °C, 30 % relative humidity, wind 9 km/h from a south easterly direction with zero precipitation (Annex 17). The weather at the time of the incident at the Angellala Creek site was assumed to be similar to the readings taken from Charleville.

Prior to the incident the last recorded rain event was from 14 to 17 August 2014 where 76.4 mm fell at Bakers Bend weather station (Annex 18). The incident occurred almost three weeks after this last recorded rain event, supporting the likelihood that the creek channel was dry (except under the bridge) at the time of the incident.

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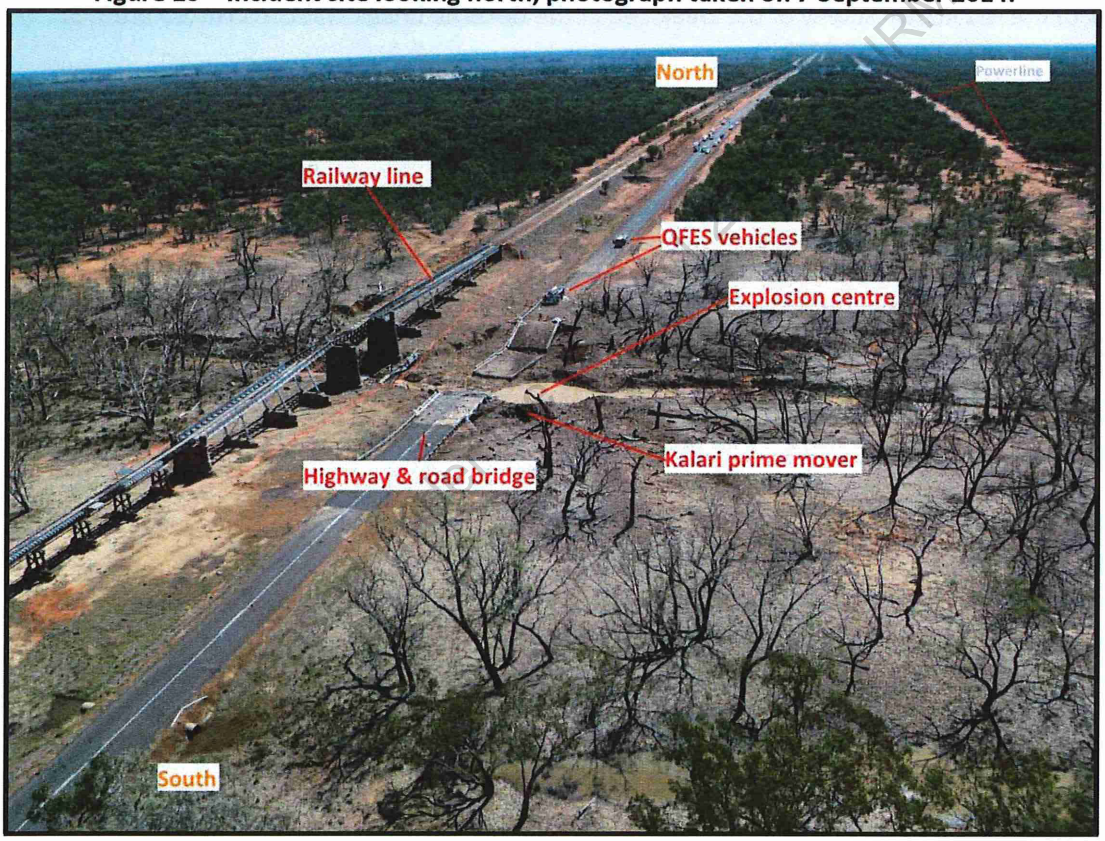
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5 Course of events

5.1 Angellala Creek incident

On Friday 5 September 2014 an explosives incident occurred on the Mitchell Highway at Angellala Creek, 30 km south of Charleville. A Type 1 road train had a single vehicle incident. The vehicle caught fire and an explosion involving the load of ammonium nitrate occurred. The driver suffered serious injuries from the crash, fire and explosion. Seven other people were injured from the explosion; two truck drivers rendering voluntary assistance, four fire officers and a police officer responding to the emergency. The road bridge, rail bridge and vegetation destruction was extensive, as shown in Figure 10.

Figure 10 – Incident site looking north, photograph taken on 7 September 2014.



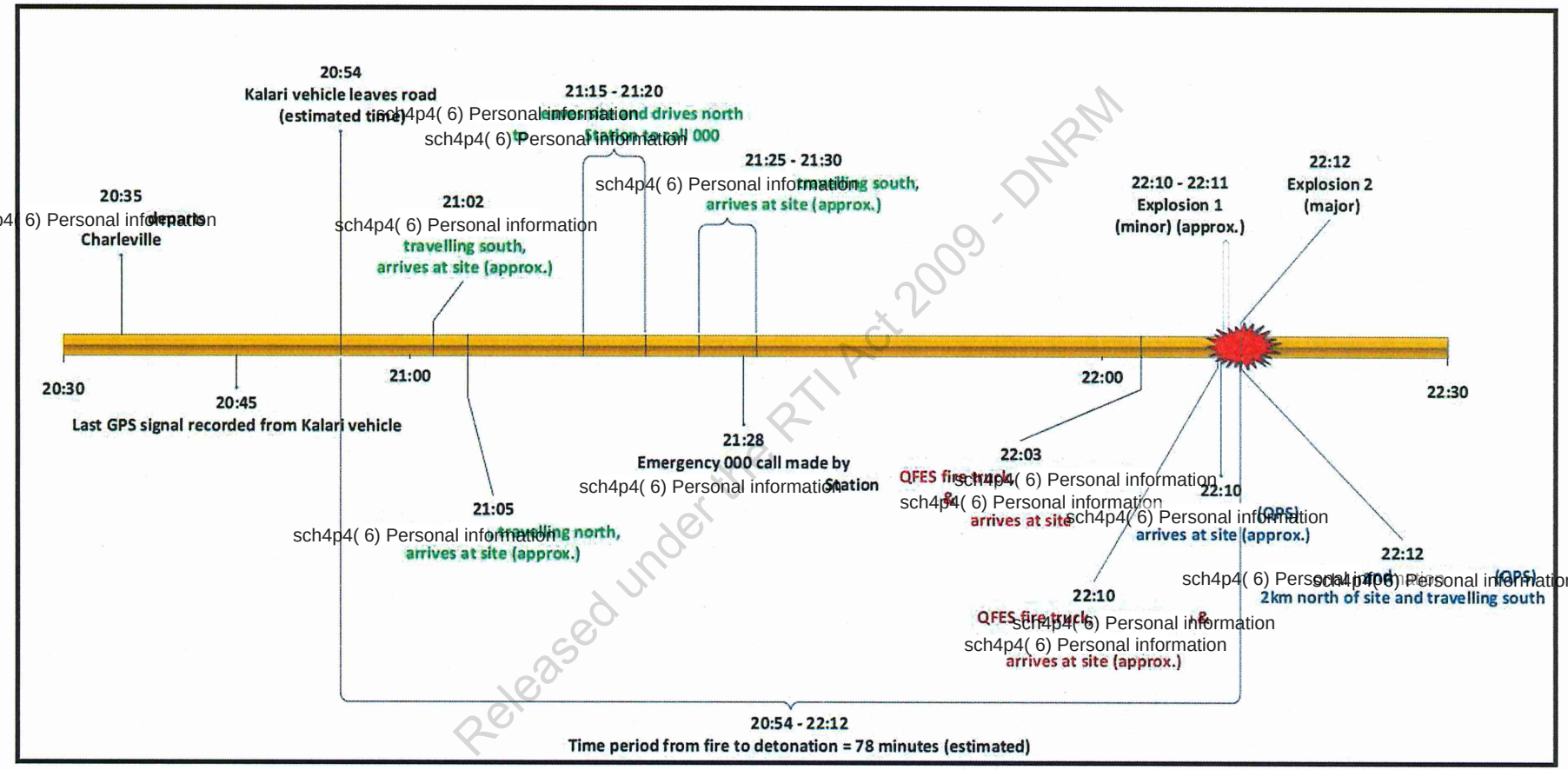
5.2 Timeline of events

This investigation focussed on the events involving the driver, vehicle and load of ammonium nitrate from 72 hours prior to the incident. The timeline in Annex 19 provides an illustration of the events leading up to the vehicle crash.

The timeline in Figure 11 provides a summary of the events that occurred from just prior to the vehicle crash to the explosion. The timeline in Annex 20 provides further detail of the events from the time of the crash to the explosion.

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Figure 11 – Timeline of events from the vehicle leaving Charleville to the explosion at Angellala Creek.



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5.3 Initial incident response

The crash occurred at approximately 2054. Following the vehicle crash, sch4p4(6) Personal information sch4p4(6) Personal information sch4p4(6) Personal information He scrambled up the creek bank on the southern side and onto the bridge. He started walking north along the bridge where he was met by sch4p4(6) Personal information a passing motorist who had stopped north of the bridge. sch4p4(6) Personal information lay down on the roadway at the northern approach to the bridge. He talked to sch4p4(6) Personal information alerting him to the load containing ammonium nitrate and the need to evacuate to a safe distance of 1000 m.

Truck driver sch4p4(6) Personal information arrived at the location in a vehicle driven from the south at about 2105. He parked the truck on the road about 170 m to the south of the road bridge and walked north towards sch4p4(6) Personal information sch4p4(6) Personal information sch4p4(6) Personal information. He spoke to sch4p4(6) Personal information asking him to drive and call emergency services as there was no phone or radio reception at the site. sch4p4(6) Personal information left the site, driving north back towards Charleville. sch4p4(6) Personal information remained with sch4p4(6) Personal information sch4p4(6) Personal information arrived at sch4p4(6) Personal information Station, approximately sch4p4(6) Personal information of the incident site. He alerted the occupant of the house who called emergency services.

Truck driver sch4p4(6) Personal information arrived around 2130 in a vehicle driven from the north. He parked the truck off the road about 400 metres to the north of the road bridge and walked south to sch4p4(6) Personal information The two men remained with sch4p4(6) Personal information

QFES officers Firefighter sch4p4(6) Personal information and Firefighter sch4p4(6) Personal information arrived at the site at 2203 and parked the fire truck angled across the road adjacent to sch4p4(6) Personal information and the truck drivers and about 50 m from the vehicle which was still on fire. The officers initiated first aid on sch4p4(6) Personal information

A second QFES vehicle with Firefighter sch4p4(6) Personal information and Firefighter sch4p4(6) Personal information arrived at about 2210 and parked behind the first fire truck. Firefighter sch4p4(6) Personal information and Firefighter sch4p4(6) Personal information walked up to the site and talked with the sch4p4(6) Personal information truck drivers and other QFES officers. They established that ammonium nitrate was being transported on the crashed vehicle and it had been exposed to fire. As this was occurring, QPS officer Sergeant sch4p4(6) Personal information was arriving in a police car, and parked approximately 200 m north of the road bridge.

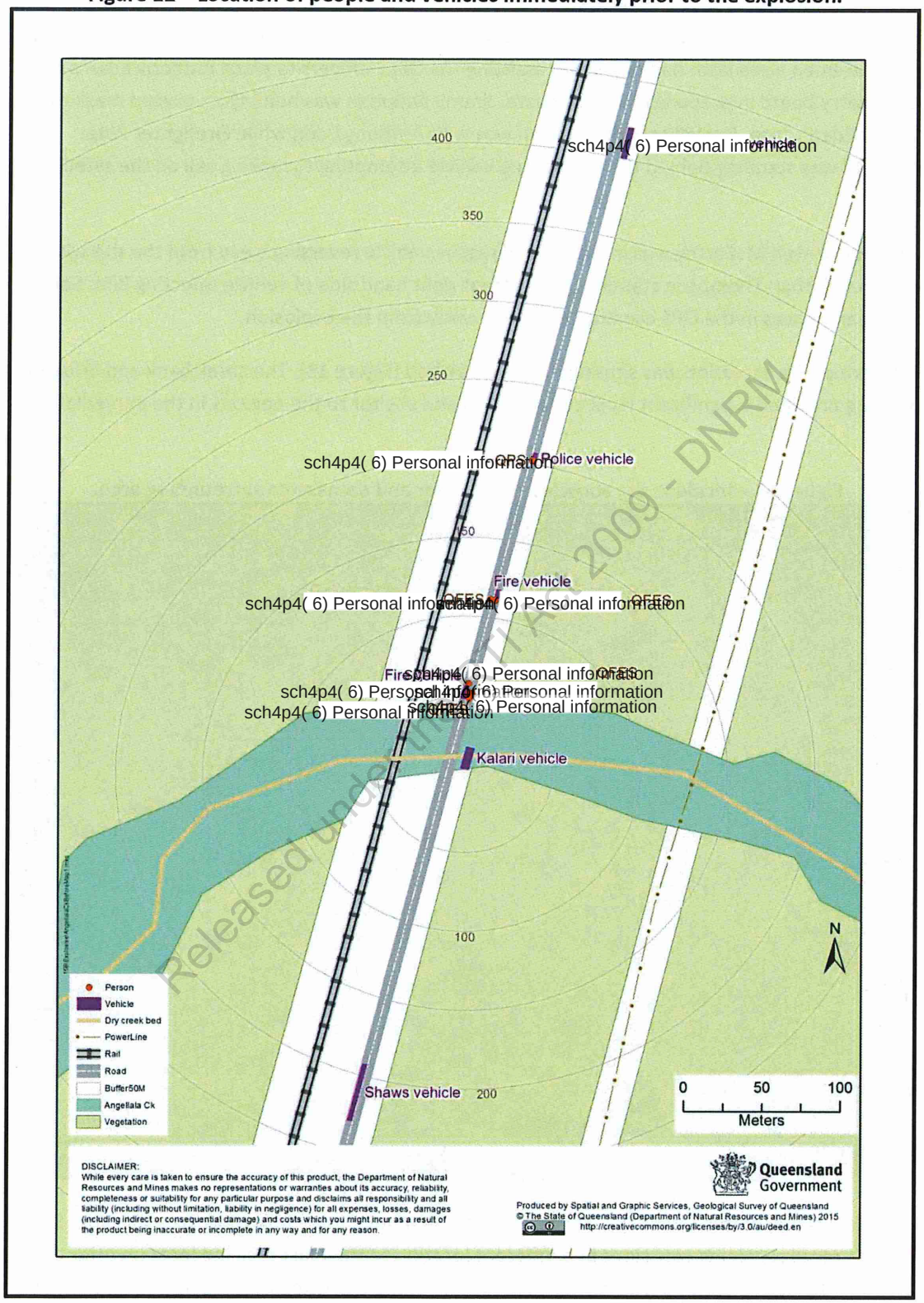
QPS officers Senior Constable sch4p4(6) Personal information and Constable sch4p4(6) Personal information received instruction from Roma Communications to attend the site. They left Charleville in a vehicle and travelled south to the crash site.

Figure 12 shows the location of the vehicles and people at the site immediately prior to the explosion.

At approximately 2210 - 2211 the first explosion occurred. It had no blast overpressure, no significant projections and caused no major damage to infrastructure, vehicles or people. Following the first explosion, the QFES officers gave directions to evacuate from the site. At 2212 the second explosion occurred, causing significant damage to infrastructure and vehicles at the site and injuring the people close to the creek.

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Figure 12 – Location of people and vehicles immediately prior to the explosion.



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5.3.1 Secondary incident response

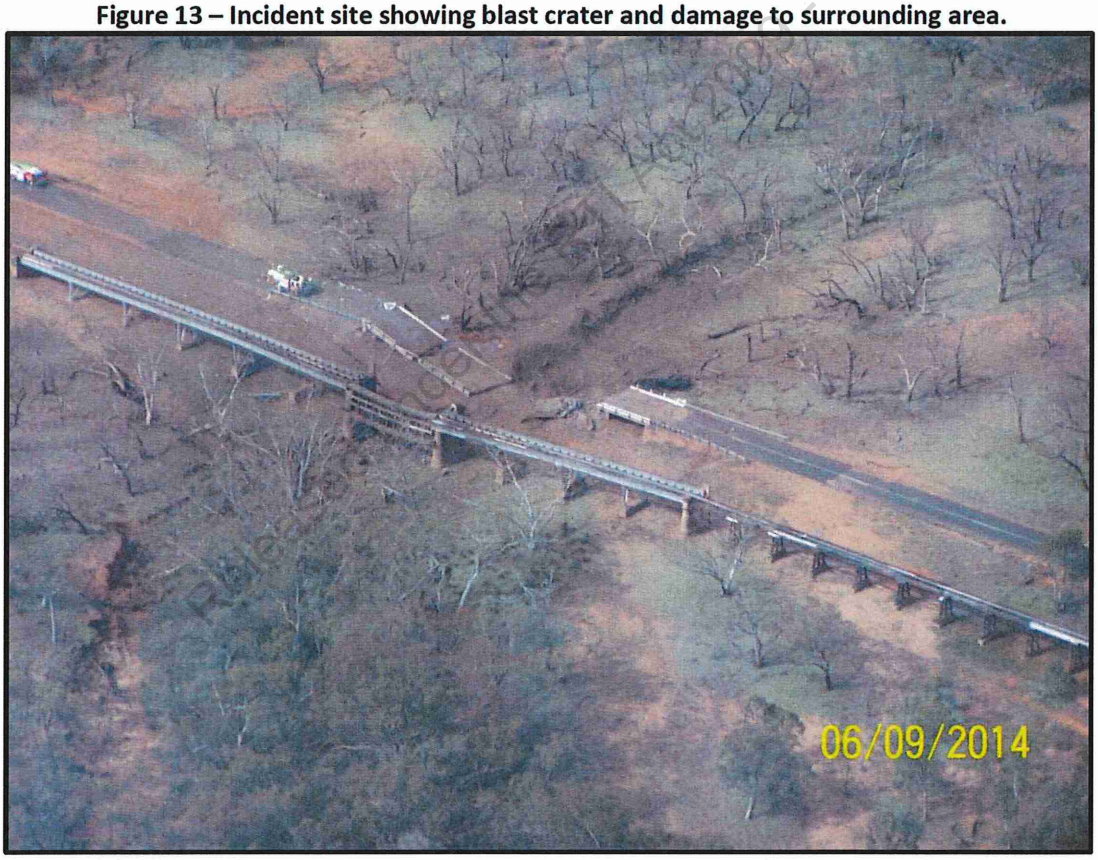
At the time of the second larger explosion, sch4p4(6) Personal information were both bending down assisting the QFES officers to place sch4p4(6) Personal information on a patient carry board in preparation to evacuate.

sch4p4(6) Personal information was standing behind the first rescue vehicle attempting to make a call on the satellite phone.

Firefighter sch4p4(6) Personal information was in the second rescue vehicle reversing away from the site with Firefighter sch4p4(6) Personal information standing by the front right hand side of vehicle directing him. Sergeant sch4p4(6) Personal information was in the QPS car situated 200 m away from the explosion.

The centre of the explosion was situated in the creek bed (Figure 13). The creek bank and bridge mounding provided a significant level of protection and shelter to the persons in the immediate area.

Figure 13 – Incident site showing blast crater and damage to surrounding area.



The exact location of the injured cannot be determined immediately following the explosion. Some witnesses recall regaining conscious in a different location to their last recalled location prior to the explosion. They were either blown a short distance from the explosion or have no recollection of moving from their original position due to the effects of shock.

Following the explosion, Sergeant sch4p4(6) Personal information turned his vehicle around and headed back in the direction of Charleville in the damaged police vehicle. He was stopped by Constable sch4p4(6) Personal information and Senior Constable sch4p4(6) Personal information who were travelling towards the site. QAS Officers sch4p4(6) Personal information and sch4p4(6) Personal information arrived from Charleville to the Forward Control Point (FCP), set up by QPS north of the site following the explosion. They provided assistance to Sergeant sch4p4(6) Personal information

Senior Constable sch4p4(6) Personal information and Constable sch4p4(6) Personal information then travelled from the FCP to the incident site and located four QFES Officers and sch4p4(6) Personal information They transported them back to the FCP in their police vehicle for treatment by the QAS Officers.

Senior Constable sch4p4(6) Personal information and Constable sch4p4(6) Personal information again returned to the incident site, locating sch4p4(6) Personal information and the Kalari driver sch4p4(6) Personal information located a QAS Officer while Senior Constable sch4p4(6) Personal information remained with sch4p4(6) Personal information Constable sch4p4(6) Personal information and QAS Officer sch4p4(6) Personal information returned to the site to assist sch4p4(6) Personal information and sch4p4(6) Personal information returned to the FCP and sch4p4(6) Personal information

sch4p4(6) Personal information sch4p4(6) Personal information sch4p4(6) Personal information the four QFES Officers and Sergeant sch4p4(6) Personal information were all transported to Charleville Hospital for initial treatment. Some of the injured were transported to Toowoomba or Brisbane for further assessment and treatment.

5.4 Details of the injured

The Explosives Inspectorate made requests to the injured people for access to their medical records detailing the injuries sustained. For those who gave consent for access to their records, a detailed description is provided. For those where no consent was provided, a summary based on statements and observations will be used to estimate the injuries. (Annex 21).

sch4p4(6) Personal information

sch4p4(6) Personal information

away from the explosion, suffered blast type injuries. These included lacerations, eardrum perforation, fractures, internal and external bruising.

5.5 Description of the site after the explosion

5.5.1 Ammonium nitrate cargo

About four to five damaged IBCs, some burnt, were found adjacent to the tree hit by the vehicle (Figure 14). These IBCs contained residual amounts of ammonium nitrate, either partially recrystallised from melting or still as solid prill (Figure 15). The plastic coverings of the IBCs and other combustible material, such as tree and leaf material, burned for some time following the explosion. The remainder of the ammonium nitrate burned with combustible material, decomposed to form nitrous gases, or had been scattered across the site from the crash.

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Figure 14 – Ammonium nitrate Nitropril bag located at the site.

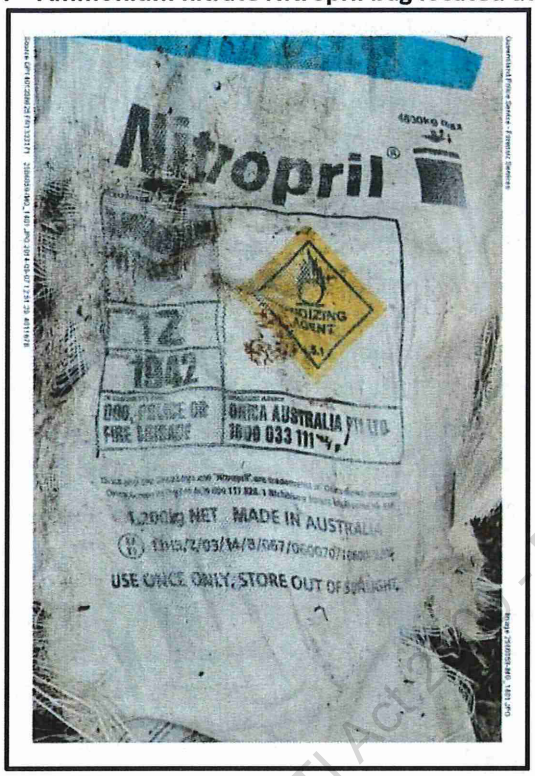


Figure 15 – Partially burnt IBCs of ammonium nitrate near tree hit by vehicle.



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Figure 16 shows evidence of ammonium nitrate under the road bridge found on the northern bank. This prill was found across the site following the path of the vehicle during the crash, buried by soil deposited from the blast crater.

Figure 16 – Evidence of ammonium nitrate (white particles) under span 2 of the road bridge.



5.5.2 Damage to structures from the explosion

5.5.2.1 Mitchell Highway roadway and bridge

The bridge was completely destroyed. Spans 1 and 2 (from the northern end) remained in location however had collapsed to the ground due to the piers being displaced in the explosion. Spans 3 and 4 were subjected to significant blast damage with a large portion of span 3 striking the rail bridge and segments of half of the bridge being blown up to 250 m to the west from its original location. Span 5 has remained standing in position; however suffered structural damage (Figure 17). Three of the four piers were destroyed (Figure 18).

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Figure 17 – Looking north along the road bridge, span 5, in the foreground, remaining in place.



Figure 18 – Span 1 and 2 of the road bridge on northern bank.



5.5.2.2 Rail Bridge

The heritage rail bridge was constructed around 1885 and consisted of 7 x 12 m steel spans, later upgraded and strengthened with additional steel in 1994. The rail bridge was located 30 m west of the road bridge, running north-south parallel with the Mitchell Highway.

Extensive damage has occurred to the rail bridge (Figure 19). A section of span 3 from the road bridge struck the centre rail span dislodging it off of its concrete piers (Figure 20). Damage to other areas included steel supporting piers being dislodged totally from their position under the bridge, while others have been broken and distorted. The rail lines showed evidence they had been raised and dropped into offset position from their original position.

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Figure 19 – Rail bridge showing explosion damage.



Figure 20 – Rail bridge with section of road bridge span 3.



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5.5.2.3 Power lines

The high voltage transmission lines operated by Powerlink run parallel to the Mitchell Highway, 145 m to the east of the road bridge (Figure 12). These power lines and poles appeared to be undamaged.

5.5.2.4 Gas pipeline

APA Group's Ballera – Roma – Brisbane natural gas pipeline runs in a north east to south west direction past the incident site. The pipeline crosses underneath the Mitchell Highway 1150 m to the north of the incident site. The closest point of the pipeline to the Angellala Creek Bridge is 930 m to the north-west. Large metal fragments of trailer debris were found on the surface of the pipeline corridor that is cleared of vegetation.

5.5.2.5 House at Station

s6 4p4(6) Personal information

A lowset timber and fibreboard house at Station, approximately s6 4p4(6) Personal information s6 4p4(6) Personal information of Angellala Creek, sustained damage to a number of its internal fibreboard walls, possibly a result of the ground shock following the explosion as no glass breakage to external windows was evident (Figure 21).

Figure 21 – Crack in an internal wall of the house at [redacted] Station



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5.5.3 Damage to vehicles from the fire and explosion

5.5.3.1 Damage to Kalari vehicle

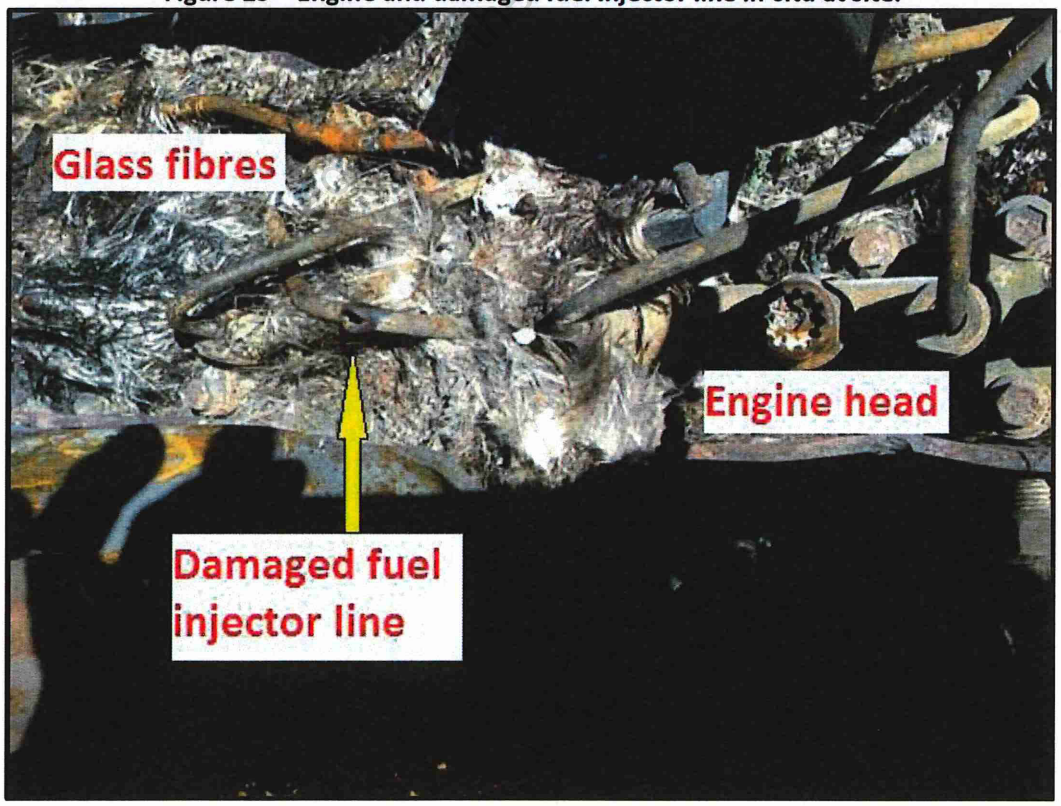
The Kalari prime mover suffered severe damage in the fire and was destroyed in the explosion (Figure 22). The prime mover was inspected at the incident site by DNRM Inspector Chris Donovan. The vehicle was found to be resting on the top of the southern bank facing toward to the north-west. It is likely the prime mover was moved to this position during the explosion.

The engine had a damaged fuel injector line with no other visual defects other than effect of heating from a fire (Figure 23). The bonnet, vehicle cabin and support frames were missing. Fire affected heavy gauge electrical wiring was present. The aluminium gearbox bell housing was missing and appeared to have melted during the fire.

Figure 22 – Remnants of the Kenworth prime mover after the fire and explosion.



Figure 23 – Engine and damaged fuel injector line in-situ at site.



The second drive axle weighing approximately 1300 kg was not attached to the prime mover; it had been dislodged at the suspension components. This second drive axle was located 170 m south east of the prime mover (Figure 24).

Figure 24 – second drive axle of prime mover in-situ at site.



The driver side fuel tanks and the mounting brackets on the driver's side were damaged by fire and did not show signs of significant impact damage (Figure 25). The AdBlue tank was still present and located in its normal mounted location and showed minimal signs of heat interaction.

The fuel tank on the passenger side of the prime mover (left hand side) was heavily impacted and dislodged as a result of the vehicle crash. Its mounting brackets showed signs of forceful lateral impact damage (Figure 26). This fuel tank was separated from the vehicle and was not affected by fire.

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Figure 25 – Fuel tank and AdBlue tank on driver side of prime mover in situ at site.

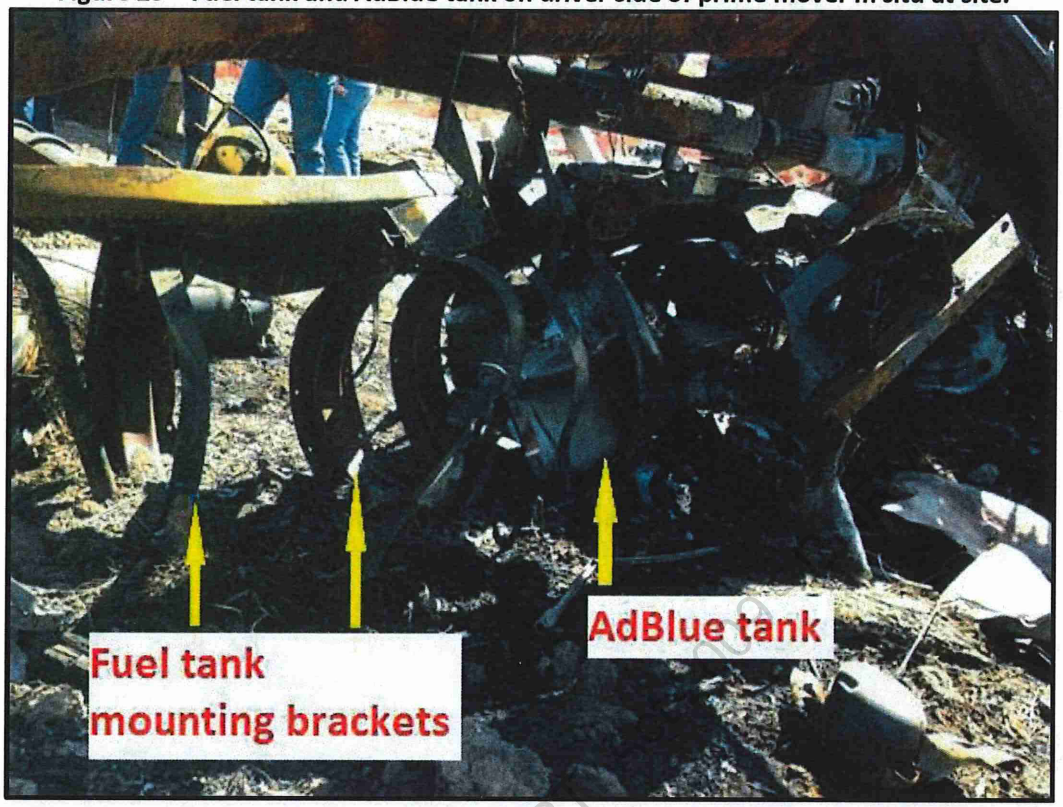
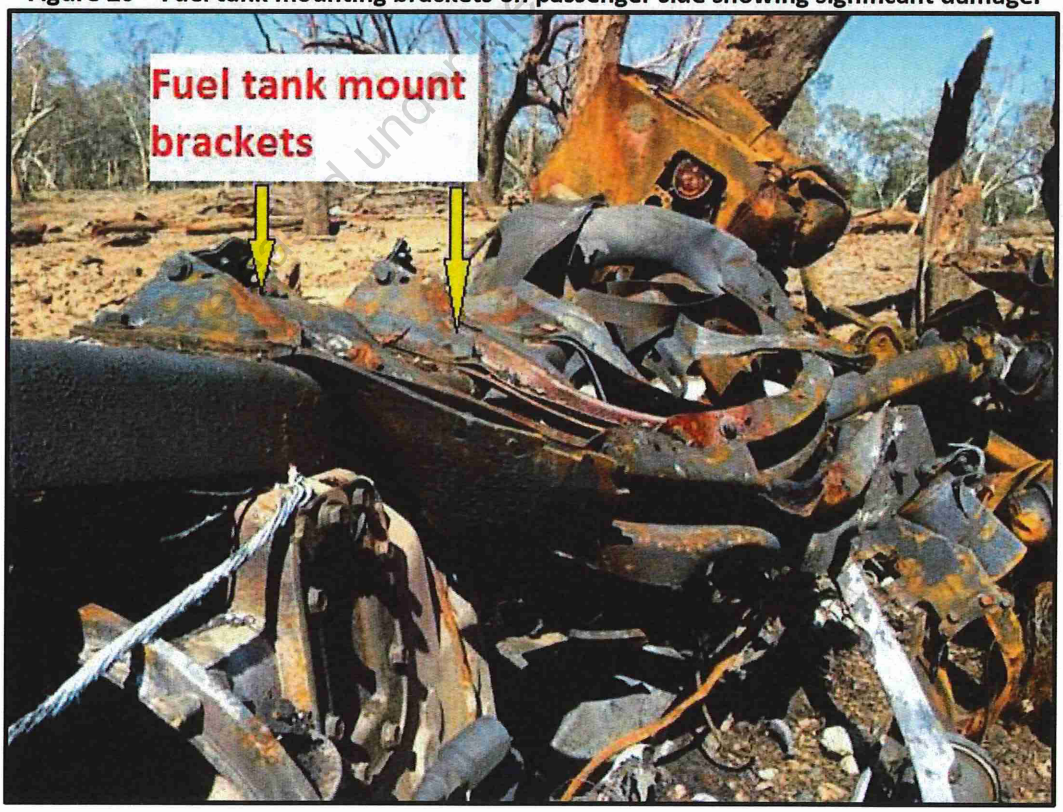


Figure 26 – Fuel tank mounting brackets on passenger side showing significant damage.



The battery box immediately to the rear of the passenger side fuel tank was detached during the crash. The sleeper cabin icepack system was mounted in its normal location and was affected by fire.

The first trailer and converter dolly components were destroyed. Their remains, along with components of the prime mover, were collected from a 1 km radius from the blast site and relocated to the Helidon Explosives Reserve for further detailed investigation. These collected components showed signs of fire and blast damage.

The second trailer was partially destroyed, with half of the second trailer recovered mainly intact (Figure 27). This section showed signs of impact and blast damage only with the aluminium decking missing. The front axle was detached and was located beside the trailer with the remaining two axles still attached but damaged.

The collected vehicle parts were further inspected by Explosives Inspectors, QPS Officers (Annex22, Annex 23), Bipin Parmar (Annex 24), Theo Kahl (25) and Bill Kennedy (Annex 26) at the Helidon Explosives Reserve.

Figure 27 – Remnants of second (rear) trailer removed from under bridge span 1.



5.5.3.2 Damage to the QFES vehicles

Extensive damage occurred to the two QFES fire trucks, a 1999 Mitsubishi and a 2011 Isuzu. The first fire truck sustained extensive structural damage due to the blast pressure and flying debris (Figure 28). The vehicle roof was removed from the cabin frame. The front windscreen and all other windows were missing. All four doors were twisted and bent backwards. Both front outer door skins had started to separate from their frame. All front driving lights and auxiliary warning lighting was missing. There was extensive damage to the primary cabin and rear module which were twisted and structurally deformed.

Figure 28 – QFES vehicle Isuzu registration 1201QF.



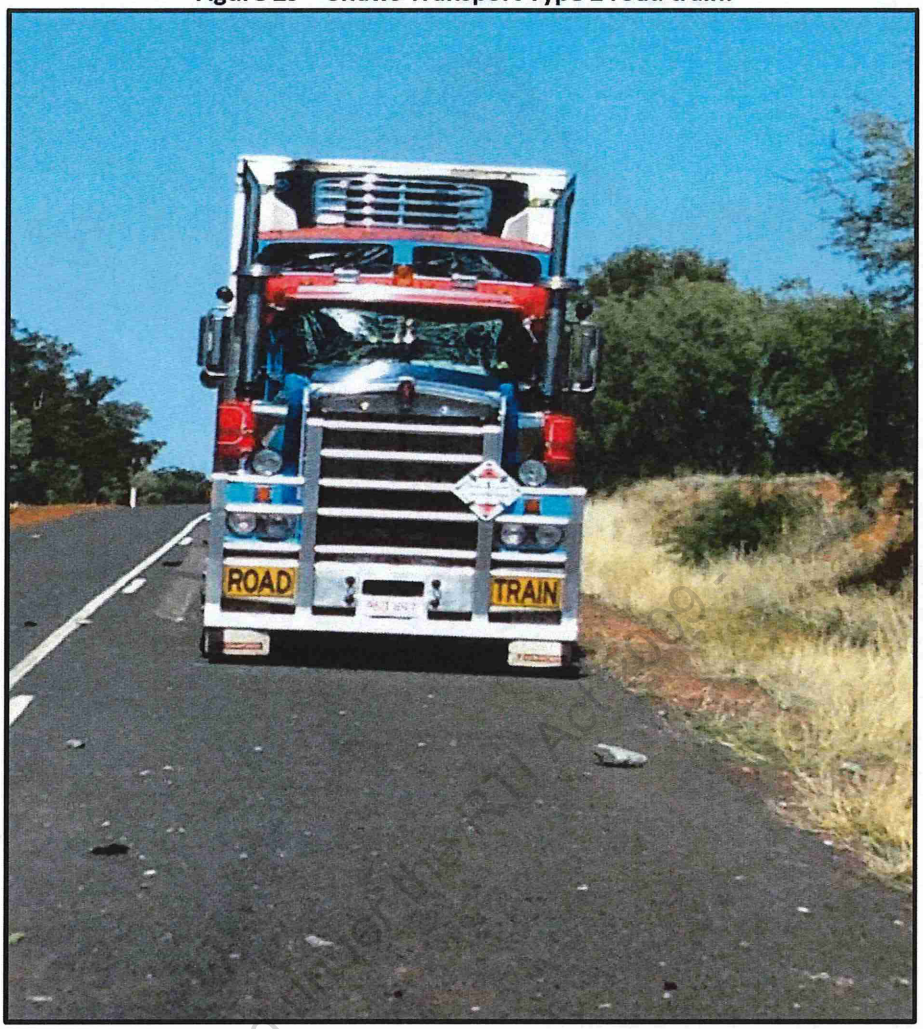
The second fire truck attending the site sustained damage from the blast overpressure and flying debris. The vehicle showed damage along both sides to all roller door shutters and dents to all doors. The front windscreen and all side windows were missing. The cabin roof was distorted upward and the driver seat was dislodged from its mounts.

5.5.3.3 Damage to Shaws Transport vehicle

A visual only inspection at the site of the Type 2 road train driven by [redacted] revealed damage to its entire forward facing cabin and sleeper berth glass panels from blast overpressure and debris from the blast crater, including parts of the Kalari vehicle and road bridge (Figure 29). The first trailer of the vehicle was also damaged by metal pieces projected from the Kalari vehicle. The Shaws vehicle was parked to the south of the site about 180 m away from the Angellala Creek Bridge and was surrounded by debris.

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Figure 29 – Shaws Transport Type 2 road train.



5.5.3.4 Damage to vehicle

A visual only inspection at the site of the Type 1 road train owned and driven by Sch 4p4(6) Personal information did not indicate any visual damage to the vehicle. This vehicle was parked about 400 m to the north of the road bridge and surrounded by debris.

5.5.3.5 Damage to the QPS vehicle

A QPS Toyota Hilux four wheel drive suffered a damaged front windscreen and dents to the roof and side doors on both sides. This vehicle was positioned behind the second QFES fire truck to the north of the site about 200 m from the bridge.

5.5.4 Effect of explosion on surrounds

Extensive damage occurred to the flora in the immediate area (approximately 200–300 m from the blast centre) including trees and bushes being stripped of leaves and branches broken. Tree fragments were found scattered over the site up to a distance of 600 m to the west and 800 m to the south east. No animal remains were found at the site.

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5.6 Incident notification

At 0155 on Saturday, 6 September 2014, Inspector Chris Donovan received a phone call from sch4p4(6) Personal information sch4p4(6) Personal information sch4p4(6) Personal information of Kalari called the Explosives Inspectorate emergency response number from the Kalari Moranbah depot to advise the Explosives Inspectorate of an explosives incident. sch4p4(6) Personal information advised that at around 2235 a Kalari owned Type 1 road train was involved in a single vehicle incident on the Mitchell Highway 30 km south of the township of Charleville, Queensland.

sch3(10)(3) Information compelled under investigation of contravention of the law

sch3(10)(3) Information compelled under investigation of contravention of the law Inspector Chris Donovan advised Sergeant McDonald to keep a 1.5 km exclusion zone in place and to preserve the site.

Inspector Chris Donovan then called Inspector Haydn Isaac and informed him of the events. Inspector Isaac then contacted Chief Inspector of Explosives Geoff Downs. Inspector Chris Donovan then sent an internal email to Inspector Isaac with the discussed incident details (Annex 27).

Written email advice of an incident was later provided to the Chief Inspector of Explosives Downs on 19 September 2014 by Kalari General Compliance Manager sch4p4(6) Personal information (Annex 28).

Written confirmation of the incident was provided by Orica to Chief Inspector of Explosives Downs on 25 September 2014 (Annex 29).

5.7 Response to the incident

Chief Inspector Downs assigned a team to attend the incident site. The nominated lead investigator was Inspector Ryan Brogden and the investigators were Inspector Chris Donovan, Inspector Lionel Gainey and Inspector Bruce Symmans. The investigation team was established to respond to the transport incident and to commence an investigation (Annex 30).

Inspector Lionel Gainey and Inspector Bruce Symmans travelled from Brisbane and arrived at the site at 1630 on 6 September 2014. The site was under control of the police and a cordon was in place 500 m north and south of the incident site. Inspector Lionel Gainey and Inspector Bruce Symmans remained at the site and provided advice to QPS and QFES. Fire and smoke could still be observed across the site and no entry to the site was allowed. Inspector Ryan Brogden and Inspector Chris

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Donovan left Brisbane, arriving in Charleville at 2130 on 6 September 2014 and were briefed by Inspector Lionel Gainey and Inspector Bruce Symmans (Annex 31).

On the morning of 7 September 2014, Inspector Lionel Gainey and Inspector Bruce Symmans travelled to the incident site at 0600 to provide assistance to QPS and QFES. The traffic incident site was still under the control of the QPS when Inspectors arrived. Police were maintaining a cordon on Mitchell Highway 500 m to the north and south of the incident site.

Inspector Ryan Brogden and Inspector Chris Donovan attended a briefing at 0730 on 7 September 2014 at QFES Charleville with QPS and QFES officers. Due to the site safety risk, control of the site was handed to QFES. It was decided that QFES Scientific Branch would enter the site to determine if it was safe for investigators to enter. Inspector Ryan Brogden and Inspector Chris Donovan travelled to the incident site, arriving at 0930 on 7 September 2014.

At 1225 on 7 September, QFES Scientific Branch declared the site safe for entry and allowed access for the Explosives Inspectorate to begin the site investigation. At 1245 a number of people from QPS, QFES and the Explosives Inspectorate accessed the incident site and took photographs and site observations.

Observations taken at this time included:

1. Upon approach to the site from the north, the roadway was littered with dirt, tree branches, and large concrete and steel pieces.
2. A Type 1 road train was parked off the roadway to the left hand side about 400m to the north of the road bridge.
3. A fire truck was positioned in the left side lane facing south toward the bridge which had extensive structural damage.
4. A second fire truck positioned on the right side of the roadway closest to the bridge facing south also showed extensive structural damage.
5. The left side bridge guard rail was damaged with its mounting posts flattened horizontally facing towards the bridge.
6. Adjacent to the damaged guard rail medical equipment, a blanket and a dried pool of blood were found.
7. The road bridge showed extensive damage with collapsed decking covered in dirt and metal debris.
8. The centre bridge deck was to the west of the bridge under the adjacent rail bridge.
9. The rail bridge to the west of the road bridge showed extensive damage, including cracked piers and dislodged rail lines.
10. A large tree to the east of the bridge approach showed impact damage and was smouldering around its base.
11. White pieces of IBC bags were present around the base of this tree.
12. To the south, across the creek, there was a large blast crater.
13. Beyond the crater were the blackened structural remains of the prime mover.
14. Under a collapsed bridge deck smoke was rising which had a strong chemical odour.
15. A Type 2 road train could be seen to the south of the bridge parked in the left side lane facing north.

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16. Loose soft soil, concrete, timber and metal pieces were scattered over the immediate area.
17. Concrete and bitumen sections and vehicle components were visible in further surrounds.
18. The area was rain affected.

Dr Michael Logan and Firefighter Gordon Hemphrey from QFES Scientific Branch and Senior Sergeant Andrew Rowan from QPS Scientific Branch took samples of ammonium nitrate from the incident site with the assistance of Inspector Ryan Brogden and Inspector Chris Donovan. Senior Sergeant Rowan took possession of these samples and delivered them to Queensland Health Forensic Science Service (QHFSS) in Brisbane for scientific analysis.

At 1630 on 8 September 2014, QFES officially handed the site over to the Explosives Inspectorate to undertake an investigation in accordance with the Act. QPS managed the outer cordon at the site, with Altus Traffic maintaining the cordon on the Mitchell Highway 500 m north and south of incident site under the control of QPS. Altus maintained a record of who had entered and left the outer cordon. This cordon remained in place until Explosives Inspectors left the site on the evening of 12 September 2014.

The Explosives Inspectorate maintained access to the inner cordon beyond the forward command. Inspector James Fowler attended site on 9 September 2014 to maintain the inner cordon, recording who entered and left the site. Inspector Paul White and Inspector Matt O'Shea arrived on 11 September 2014 to assist with the site investigation. Inspector Ryan Brogden provided a briefing at the start of each day and a debrief at the end of each day for all personnel at the site.

On the evening of 12 September 2014, the site was handed to RoadTek, DTMR to begin the road diversion and bridge reconstruction (Annex 32 and 33). Inspector Ryan Brogden, Inspector Chris Donovan, Inspector Bruce Symmans, Inspector Lionel Gainey and Inspector Jim Fowler all left Charleville on the morning of 13 September 2014. Inspector Paul White and Inspector Matt O'Shea left Charleville in the afternoon of 13 September 2014.

From the 7 September to 13 September, the following activities were conducted by the Explosives Inspectorate at the site:

- Photograph and document the incident site including vehicles, road and rail bridges and vehicle debris
- Locate, collect and document over 2500 pieces of explosion debris up to a 1km radius from the blast site with assistance from QPS, QFES, State Emergency Services (SES) and DNRM Charleville staff
- Interview available witnesses involved in the incident
- Maintain control of the site and co-ordinate activities with other government agencies
- Co-ordinate the transfer of evidence from site to the Helidon Explosives Reserve or QHFSS in Brisbane for scientific analysis

RoadTek provided heavy equipment to assist with moving large pieces of debris and removing the bridge segments to recover sections of the second trailer from under the collapsed bridge.

Following the initial site investigation, Inspector Bruce Symmans, Inspector Lionel Gainey and Inspector Matt O'Shea attended the site on 27 to 30 September 2014 to document and collect

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debris further from the incident site. The debris was sent to Helidon Explosives Reserve for storage and further assessment.

Inspector Chris Donovan, Inspector Lionel Gainey and Inspector Bruce Symmans returned to the site on 10 April 2015 to collect debris that was contained within the rail bridge corridor. This evidence could not be removed earlier due to safety issues identified by Queensland Rail with the unstable bridge. Once the rail bridge was demolished, the remaining evidence was documented and collected. This debris was also sent to the Helidon Explosives Reserve for further investigation.

At Helidon Explosives Reserve, a purpose built shed was constructed to house the collected debris from the site. This debris was sorted and the identified pieces of the truck were placed in their position prior to the explosion to re-create the original construction of the vehicle prior to the explosion.

5.7.1 Control of evidence at the site

The size and location of the incident area made site control difficult. The known debris field extended up to 1km radius from the blast site. In consultation with Charleville QPS, it was decided to maintain the cordon on the highway north and south of the incident site, initially with a police officer and then Altus (traffic control) staff, 24 hours a day from the time of the incident to the time the site was handed over to DTMR on 12 September 2014. Samples of ammonium nitrate collected at the site were prioritised and collected as soon as access to the site was available. The final collection of debris was undertaken seven months after the incident occurred due to the unsafe access to the rail corridor. Access was given to inspectors after contractors had dismantled the rail bridge. Table 4 describes the evidence collected from the site and the description of the transfer of evidence from site. Annex 34 contains the debris database which is the documented evidence list of over 2500 pieces of debris and ammonium nitrate samples collected from the incident site.

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Table 4 – Evidence transfer summary.

Evidence	Date collected	Transferred from to
AN samples from site	07-12 September 2014	Incident site to QHFSS by Inspector Ryan Brogden
AN samples manufactured at Orica Yarwun	08, 09 & 14 September 2014	Yarwun plant to Bajool to Helidon Reserve by Inspector Haydn Isaac
AN samples manufactured at Orica Yarwun from Cudeco	11 September 2014	Cudeco site Inspector Ian Tutt to Inspector Haydn Isaac to Helidon Explosives Reserve
Debris from site	07-13 September 2014	Incident site to Helidon Explosives Reserve by Kalari. Items transported in security sealed containers.
Debris from site	27-30 September 2014	Incident site to Helidon Explosives Reserve by Kalari. Items transported in security sealed containers.
Debris from site	10 April 2015	Incident site to Helidon Explosives Reserve. Items transported by Inspector Bruce Symmans and Inspector Lionel Gainey.

5.7.2 Preliminary report

A preliminary report was written on 28 October 2014 by Inspector Brogden. This report documented a description of the injuries and extent of damage, cargo involved, licensing and entities involved and contributors to the event (Annex 35).

5.7.3 Explosives safety alert

A safety alert was developed and released once the initial information and evidence had been gathered and to communicate any important information to the public and authority holders. This was released as the Explosives Safety Alert 86 Ammonium nitrate explodes during transport incident on 9 October 2014 (Annex 36).

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6 Investigation methodology

6.1 Investigation plan

Under section 58 of the Act, the Chief Inspector of Explosives made the decision to investigate the explosives incident to find the cause of the fire, explosion, and injury to people and damage to property.

An investigation plan was established (Annex 37) that contained:

- Summary of event, date, time and place
- Involved entities
- Incident details
- Scope of the investigation
- Investigation team, leader and decision maker
- Persons involved in the incident
- Stakeholders affected by the incident and investigation outcomes
- Tasks that require completion and timeframes

Methodologies adopted to conduct the investigation included the following processes and tools:

- Conducting an Incident Cause Analysis Method (ICAM) study
- Examination of all the collected physical evidence, observations, photographs, statements, interviews and version of events
- Development and examination of a blast debris database and production of evidence diagrams
- Diagram of the incident site based on the examinations of the physical evidence
- Scientific testing of the evidence and expert analysis
- Literature review of historical explosions when transporting ammonium nitrate

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6.2 Evidence gathered during the investigation

6.2.1 Data collection

Initial identification of data that needed to be collected was identified and listed in the Data Collection checklist (PEEPO) (Annex 38). This included items relevant to people involved and witnesses, the environmental conditions leading up to and at the time of the incident, the equipment including structures that were involved in the incident, applicable and relevant procedures, documentation or records and Kalari and Orica organisational system management policies.

6.2.2 Physical evidence

Physical items were photographed in situ, logged with GPS location and the item given a unique number for identification. Individual cameras used for this were also logged. A large number of photos were taken at the site by the different agencies including QPS Forensics.

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The debris database (Annex 34) provides the list of evidence collected from the site. It contains the field identification number, DNRM identification number, GPS location, photo reference, and description of the item, when the item was collected and by whom. Certain pieces of debris that were of interest were inspected further and weighed at the Helidon Explosives Reserve.

The location of the items of debris collected at the site was mapped to show the spread of debris from the explosion. Figure 30 maps the location of the debris collected at the site. It is worth noting the amount of debris in close proximity to the blast crater and the directional debris concentration in a west to north west direction and an east to south east direction. This concentration of debris indicates both the orientation of the vehicles at the time of the blast and the direction of the blast pressure.

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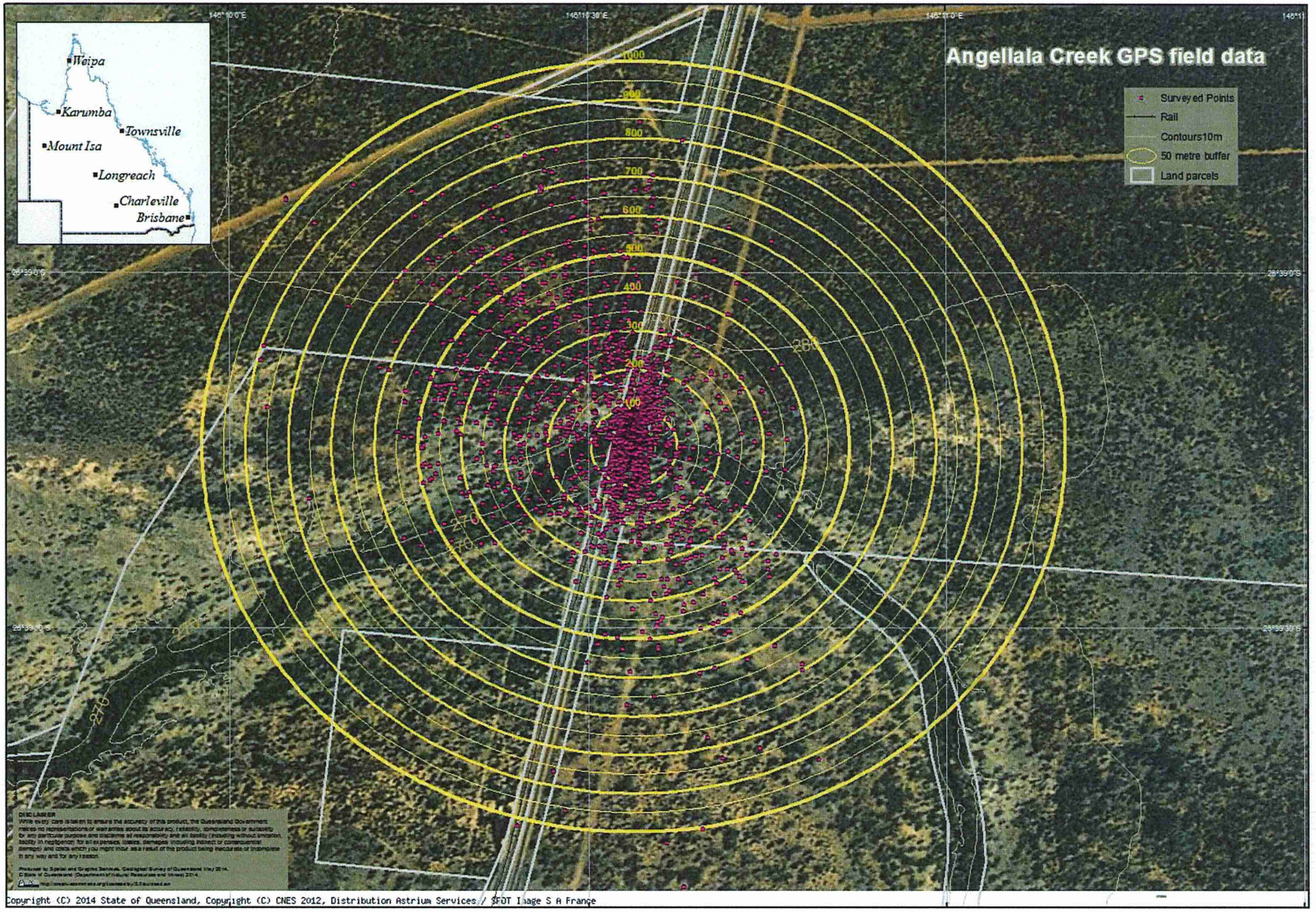
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Figure 30 – Debris map showing all debris collected from the incident site.



6.2.3 Statements and interviews

A number of people were interviewed, including those injured at the site, people directly associated with the incident, responsible people from Kalari and Orica and other relevant people identified throughout the investigation (Table 5).

Table 5 – Statements and interviews from people associated with the incident.

Surname	Given Name	Involvement	Injured	Employer	Statement / Interview	Annex
sch4p4(6) Personal information		Truck Driver and bystander	Yes	Owner Driver	Interview	39
		Charleville Area Commander	No	QFES	Statement	40
		Truck Driver and bystander	Yes	Shaw's Transport	Statement	41
		Witness – first on site	No	Passer by	Interview	42
		Truck Driver of Kalari vehicle	Yes	Kalari Pty Ltd	Interview (x2)	5 and 43
		Firefighter	Yes	QFES	Interview & Statement	45 and 46
		Paramedic	No	QAS	Version of events	47
		Site Services Manager	No	Orica Yarwun	Interview	48
		Police Officer	No	Charleville Police	Version of events	49 and 50
		Witness who called 000	No	sch4p4(6) Personal information Station	Version of events	51
		Superintendent S/W Region	No	QFES	Interview	52
		Firefighter	Yes	QFES	Statement	53
		SHEC Manager	No	Orica Yarwun	Interview	54
		Supervisor Gladstone	No	Kalari Pty Ltd	Interview	55
		Yardman	No	Kalari Pty Ltd	Interview	56
		Police Officer	Yes	Charleville Police	Statement & Version of events	57 and 58
		Laboratory Assistant	No	Orica Yarwun	Interview	59
		Firefighter	Yes	QFES	Interview & Version of events	60 and 61
		Firefighter	Yes	QFES	Interview	62
		Paramedic	No	QAS	Version of events	63

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6.2.4 Inspection of similar Kalari vehicles

The Kalari vehicle was destroyed by the fire and explosion. sch4p4(7)(1)(c) Business/commercial/professional/financial affairs

sch4p4(7)(1)(c) Business/commercial/professional/financial affairs

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6.2.5 External technical supporting reports

The following reports to assist with the investigation and provide further expert and technical assistance were provided upon request to the Explosives Inspectorate. These reports include:

- Electrical analysis of fire causes – Bipin Parmar, SIMTARS (Annex 24).
- Crash and fire causes – Bill Kennedy, Kennedy's Engineering and Forensic. (Annex 26).
- Metallurgy report for fire temperature, electrical arcing, fuel pipe and crash – Theo Kahl, DNRM (Annex 25 and appendices to report in Annex 69, 70, 71 and 72).
- Chemical analysis of ammonium nitrate samples – Paul Venz, QHFSS (Annex 73 and 74).
- Literature review and ammonium nitrate explosion analysis – Ron Peddie and Dr Martin Braithwaite (Annex 75).

7 Analysis and evaluation

This section analyses the evidence gathered from the site, additional information collected from the licence holders and interviews conducted with the witnesses from the site. Various experts were contracted to provide advice regarding elements of the investigation. The results of their investigations will be discussed in this section.

7.1 Analysis of previous ammonium nitrate transport incidents

All explosives transport authority holders were asked to provide vehicle movement figures for the 2014 period to the Explosives Inspectorate for ammonium nitrate transport in Queensland. The feedback provided indicated there were approximately 32,000 vehicle movements in Queensland for the 2014 calendar year. The vast majority of these movements composed of ammonium nitrate loads with multiple trailers, either in IBCs or bulk containers. These figures show about 1.8 million tonnes of ammonium nitrate were transported throughout Queensland in 2014 (note: ammonium nitrate may have more than one journey in Queensland).

During 2014 the only reported ammonium nitrate vehicle incident in Queensland was the Angellala Creek incident. Nationally there was one recorded transport fire event involving ammonium nitrate, caused by a mechanical failure.

7.1.1 Discussion of previous ammonium nitrate transport incidents involving fires

Significant ammonium nitrate transport events involving a fire in Australia since 2004 are listed in Table 6. These incidents have all been the result of a vehicle crash or mechanical failure. The Queensland data is sourced from the Explosives Inspectorate incident database. Information on incidents in other jurisdictions has been taken from publicly available information. The list in Table 6 may not be a comprehensive record of the actual number of incidents around Australia in that time.

A review of the cause of fire on these vehicles from Table 6 shows the majority of the non-crash related fires on ammonium nitrate vehicles have been a result of a brake or bearing failure. The main recommendation in these cases was to review vehicle maintenance. The cause of fire from the crash incidents was not provided for any of the incidents.

A further analysis of the incidents in Table 6 shows the effect of fire on a number of different vehicle types. In most cases the fire initiated in the prime mover and the prime mover was destroyed by the fire. The three trailer types (flat deck, BK1 and BK2) each provided a differing level of protection to the load of ammonium nitrate.

In the case of vehicles with flat deck trailers, all fires directly involved the load of ammonium nitrate on the trailer. Most ammonium nitrate remained as solid prill with the tarps and bags burning. Ammonium nitrate on the surface melted, with large amounts of pooling and some contamination of the molten ammonium nitrate (Figure 31).

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Table 6 – Recent ammonium nitrate transport incidents involving a fire.

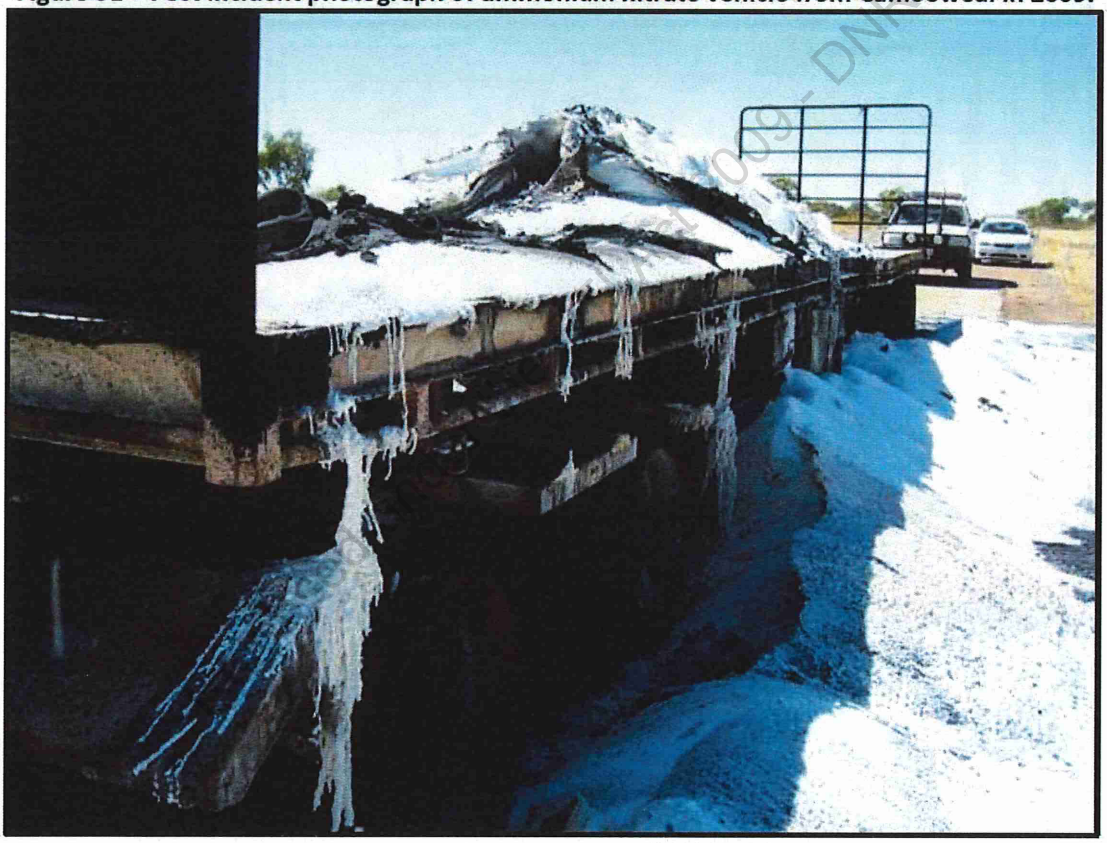
Year	Location	Description
2004	Glenden, Queensland	Type 1 road train (two trailers), each trailer carrying a BK2 container with ammonium nitrate in bulk, had a bearing failure on the steer wheel of the prime mover that led to a tyre fire burning the prime mover and first trailer. The container on the first trailer protected the load from the fire. A small amount of molten ammonium nitrate leaked from the front and rear of the container (Figure 33).
2008	Duaringa, Queensland	A-B triple combination (three trailers), each trailer carrying a BK2 container with ammonium nitrate in bulk, collided with an oncoming light vehicle causing a fire that burnt the prime mover and heat affected the BK2 bulk container on first trailer. Some ammonium nitrate leaked from the container top hatches. The container protected the load from the external fire (Figure 32).
2009	Mt Isa, Queensland	Type 2 road train (three trailers), with IBCs of ammonium nitrate on the first two trailers protected by steel vertical and horizontal steel firescreens and a third trailer with an ANE tank, collided with an oncoming light vehicle that led to a fire burning the prime mover and front trailer carrying ammonium nitrate. Large amounts of molten ammonium nitrate around trailer (Figure 34).
2009	Camooweal, Queensland	Type 1 road train (two trailers), each trailer a flat deck carrying IBCs of ammonium nitrate under tarps, had a fire from a wheel bearing failure on the second trailer that led to a tyre fire. The fire affected the load on both trailers. Majority of ammonium nitrate spilled from IBCs and molten ammonium nitrate found near rear trailer on road (Figure 31).
2011	Fort Cooper (Nebo) , Queensland	B-Double road train (two trailers), each trailer containing an aluminium BK1 open sheeted bulk containers with ammonium nitrate in bulk, had a failure of the prime mover wheel bearing leading to a fire on the prime mover. The first trailer was affected by fire, with minimal ammonium nitrate leaking from the trailer and some molten ammonium nitrate on the ground near the front of the first trailer.
2012	Emerald, Queensland	B-Double road train (two trailers), each trailer containing an aluminium BK1 open sheeted bulk containers containing ammonium nitrate in bulk, had a fire in the engine bay of the prime mover due to an air conditioning compressor failure. The ammonium nitrate was not affected by fire. Minor cosmetic fire damage to prime mover bonnet.
2013	Curragh Coal Mine, Queensland	A B triple combination (three trailers), each trailer with a BK2 container holding ammonium nitrate in bulk, had a brake failure to the rear wheel of the prime mover that led to smoking of the rim and no fire. No ammonium nitrate leaked or was affected by heat.

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Year	Location	Description
2013	Wubin, Western Australia (Annex 76)	Type 2 road train (two trailers), each trailer a flat deck carrying IBCs of ammonium nitrate with no tarp, had a collision with an oncoming light vehicle that led to a fire burning on the prime mover and first trailer. Two fatalities from vehicle crash. Molten ammonium nitrate on road and solid ammonium nitrate prill spilled.
2015	Ti Tree, Northern Territory (Annex 77)	Type 1 road train (two trailers), each trailer a flat deck carrying IBCs of ammonium nitrate under tarps, had a likely brake failure on the rear trailer that led to a fire that consumed the rear trailer. Prime mover and first trailer decoupled and moved away from fire. Molten ammonium nitrate on road and solid ammonium nitrate prill spilled.

Figure 31 – Post incident photograph of ammonium nitrate vehicle from Camooweal in 2009.



In the case of BK1 containers (open at the top) and BK2 containers (closed), the ammonium nitrate showed a minor effect from heating. The container acted as a heat shield to dissipate and protect the ammonium nitrate from excessive heating (Figure 32 and Figure 33). In the case of the Mt Isa incident in 2009, there was a steel head board and steel deck on the flat deck trailer that acted as a fire screen providing protection to the ammonium nitrate load (Figure 34). Peddie and Braithwaite provided further analysis of the benefit of heat shielding in their report (Annex 75).

It must be noted that new vehicles transporting ammonium nitrate are being built with aluminium rims, aluminium decks, fibreglass and aluminium coverings on the prime mover to decrease the

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weight of the vehicle. This assists transporters to reduce transport costs or increase the load capacity of the vehicle. This addition of aluminium and fibreglass provides more fuel to the vehicle to intensify a fire and adds more metal that is potentially incompatible with molten ammonium nitrate.

Another factor in review of the incidents is the frequency of incidents involving fires on ammonium nitrate vehicles. Based on the data in Table 6, since 2008 in Australia there is on average almost one incident involving a significant fire on an ammonium nitrate vehicle every year.

Figure 32 - Post incident photograph of ammonium nitrate vehicle from Duaringa in 2008.



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Figure 33 – Post incident photograph of ammonium nitrate vehicle from Glenden in 2004.



Figure 34 – Post incident photograph of ammonium nitrate vehicle from Mt Isa in 2009.



7.1.2 Analysis of ammonium nitrate transport explosions from around the world

Significant worldwide ammonium nitrate transport incidents where a fire and explosion have occurred over the past 60 years are listed in Table 7. Common conditions for these incidents include:

- they were all flat deck type trailers (Some trailers had enclosures; however they provided no protection to the load from a fire)
- the high fuel load on the vehicle has led to a high temperature uncontrolled fire
- the fire has burned for a significant time, usually 30 minutes to one hour before the explosion
- there was enough time for spectators or emergency crews to arrive (and in some cases tragically become casualties)
- a large quantity of ammonium nitrate has been in direct contact with the heat source
- it seems unlikely that the entire load of ammonium nitrate had melted prior to an explosion

The ammonium nitrate involved in the incidents was either high density ammonium nitrate for fertiliser use or low density ammonium nitrate for use in blasting.

There is little information available regarding the cause of fire and explosion for these incidents. On this basis, it is difficult to learn from these incidents to prevent a similar incident from happening again.

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Table 7 – Ammonium nitrate transport incidents resulting in explosion (Annex 75).

Date	Location	Event	Fatalities
1959	Oregon, USA	Truck carrying dynamite and ammonium nitrate caught fire and exploded	14
1972	Taroom, Australia	Truck carrying low density ammonium nitrate had electrical fault in cabin leading to a fire and explosion	3
1997	Brazil	Fire and collision of trucks, one carrying ammonium nitrate and one carrying gasoline; ammonium nitrate exploded	17
2004	Barracas, Spain	Truck collision, leading to fire and ammonium nitrate explosion	2
2004	Mihailesti, Romania	Truck carrying bagged ammonium nitrate overturned, fire resulted, then exploded	18
2007	Pernik, Bulgaria	Truck carrying ammonium nitrate caught fire and exploded	0
2013	Drevja, Norway	Mobile processing unit carrying ammonium nitrate and ammonium nitrate emulsion, fire from electrical fault resulted in explosion	0

There is one common theme in all reported transport incidents where an explosion involving ammonium nitrate has occurred; every explosion has been the outcome of an uncontrolled fire (Table 7).

The only other recorded explosion of ammonium nitrate during transport in Australia occurred near Taroom, Queensland in 1972 (Figure 35). The recommendations from this investigation were to install fire extinguishers on the vehicle and move the fuel tanks forward of the trailers.

Figure 35 – Photo showing site after the truck explosion at Taroom in 1972.



7.2 Discussion of crash

The investigation relating to the traffic crash was conducted by the Queensland Police Service (QPS). The QPS inspection of the crash site and completed report are found in Annex 78.

7.2.1 Kalari vehicle crash

The vehicle was travelling south at approximately 90 km/h. This speed is calculated from the average vehicle speeds recorded by the vehicle GPS up to 15 km north of the incident site, where the GPS signal was lost. It is assumed the vehicle was using cruise control and maintaining a consistent speed at the accident site. At approximately 2054, the vehicle travelled off the road to the eastern side on approach to the Angellala Creek road bridge on the Mitchell Highway. The vehicle made contact with the left side guard rail (Figure 36) on approach to the bridge and then contacted a large tree (Figure 37). The prime mover and trailers have departed the road into the creek, striking the far creek bank where the vehicle has abruptly come to rest (Figure 38).

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Figure 36 – Bridge guard rail and tree showing evidence of impact.



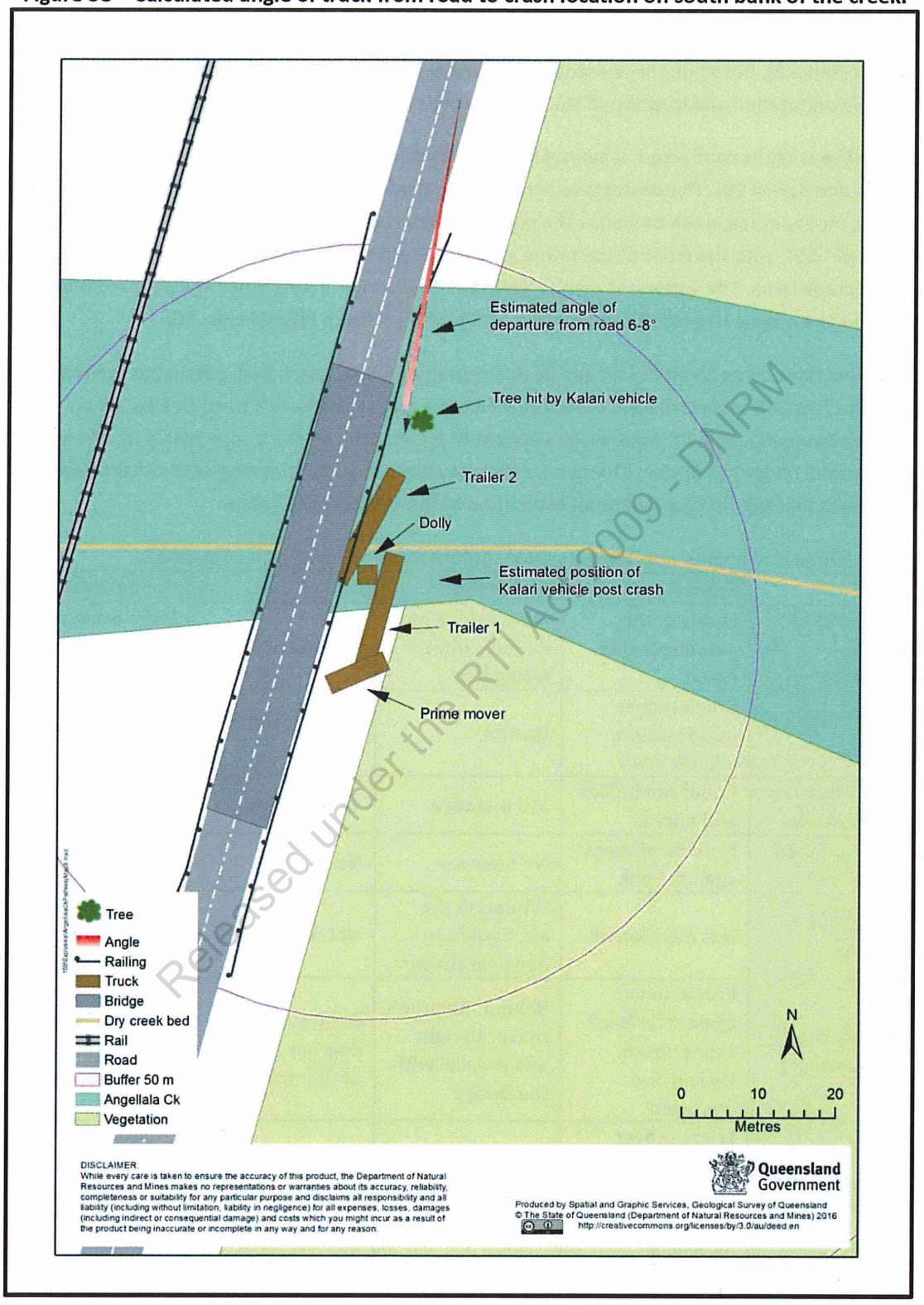
Figure 37 – Tree showing strike marks on nearest side to the road bridge.



As the vehicle has left the road and struck the tree adjacent to the bridge, the impact likely tore the tarp, tie-down straps and dislodged some IBCs of ammonium nitrate (Annex 78).

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Figure 38 – Calculated angle of truck from road to crash location on south bank of the creek.



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7.2.2 Orientation of the vehicle post-crash

Witness accounts vary regarding the orientation of the vehicle after the crash and prior to the explosion (Table 8). Based on these accounts and other observations from site, the following is the most likely orientation and location of the vehicle post-crash and prior to the explosion.

Based on the analysis conducted, it cannot be determined if the iROS device activated (Annex 24, Annex 25 and Annex 26). The device was consumed in the fire and was not recovered. The angle of the prime mover in the creek bed after the crash was estimated on its passenger side at an angle between 45°-55°, with the front of the prime mover facing a south westerly direction ascending the southern creek bank. The witnesses do not describe the engine running when they arrived on site. It is probable the engine has cut out at the time of the crash or soon after (Annex 26).

Both trailers have come to rest in an upside down position in the creek bed, parallel to the road bridge. The first and second trailers are estimated to be angled to the left hand side based on witness statements (Table 8). Both trailers appear to be adjacent to the bridge with part of one trailer possibly under the bridge. The two trailers may have been overlapping each other following the vehicle crash. Figure 38 provides an estimation of the vehicle orientation.

Table 8 – Witness accounts regarding position and orientation of vehicle post-crash.

Person	Prime mover	Trailer one	Dolly	Trailer two
sch4p4(6) Personal information interview (version 1)	Facing south, passenger side down	From bridge on its side, wheels facing him	Nil observation	From bridge on its side, wheels facing him
sch4p4(6) Personal information EI interview	Prime mover upside down, wheels in air	Unsure	Upright near the bridge	Unclear
sch4p4(6) Personal information QPS interview	Could see bulbar and engine	No memory	No memory	Rear trailer upside down
sch4p4(6) Personal information EI interview	Far side of creek against bank	No memory	No memory	No Memory
sch4p4(6) Personal information EI Interview	Not mentioned	Wheels in the air. Could see hay bale shapes	Not mentioned	Wheels in the air. Could see hay bale shapes
sch4p4(6) Personal information QFES interview	Prime mover against far bank facing south. Heavily fire damaged	Behind the prime mover upright and parallel with the bridge	Dolly at 90 degrees to east of first trailer	Concertinaed with the front end of the trailer out to the east. Upright
sch4p4(6) Personal information QPS statement	Prime mover against far bank facing south. Heavy fire damaged	Not mentioned	Not mentioned	Not mentioned
sch4p4(6) Personal information QFES Statement	Parallel to the bridge and upside down against far bank	Parallel to the bridge and upside down	Parallel to bridge and upside down between trailer 1 and trailer 2	Parallel to the bridge and upside down. Behind dolly

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7.3 Witness observations of the fire on the Kalari vehicle

It is difficult to establish where the fire initiated and the pathway the fire spread through the vehicle. Witnesses have minimal recollection, as detailed in Table 9, of the location, size and characteristics regarding the fire. A credible pathway for the fire could be initially from the prime mover cabin, motor cowling and diesel on the ground spreading rearward to the combustible elements on the first trailer. The fire reduced in size as the combustible material was consumed. There was little evidence of combustible material left from the prime mover or first trailer post explosion.

Table 9 – Witness observations of the location, size and characteristics of the fire.

	Location of fire	Size of fire	Fire characteristics
sch4p4(6) Personal information first Explosives Inspectorate interview	sch4p4(6) Personal information front of prime mover on fire. Fire engulfing entire prime mover	Fire had 'gone out' once QFES arrived	Dodging 12-24 small (200 mm) fires when walking north over the bridge
sch4p4(6) Personal information Explosives Inspectorate interview	Massive fire at bridge when arrived. Prime mover on fire	Massive fire	Red flames
sch4p4(6) Personal information QPS interview	Flames and smoke at the creek. Truck on fire. Cab melted and well alight. 15-30 minutes later flames spread to trailers	Flames 6-10 m high	Reddy/orange. Black smoke. Flames and fire appeared smaller than earlier. first explosion – heard a loud explosion
sch4p4(6) Personal information Explosives Inspectorate interview	Within 4-5 km saw a fire. Fire lit up the area. Fire up the front in the motor front of the cab and bonnet	No mention	Orange flames first explosion – 'massive explosion went off'
sch4p4(6) Personal information Explosives Inspectorate Interview and version of events	5 km out was just a glow. Getting closer flames died down. Small fire on Prime mover	Small, bit larger than a 44 gallon drum typical fire.	Orange flames, normal fire. First explosion, thought it looked like fireworks, big bang into the sky. No debris. Little white diamonds coming down spreading everywhere, slowly falling down, slower than you would expect
sch4p4(6) Personal information self-first account, version of events	On prime mover	Small fire 44 gallon drum 1-2 m high flame,	Normal orange flames, first explosion – no blast – pure white snow flake sparkles cloud, little sparkler type
sch4p4(6) Personal information QFES Statement	Approximately 1/3 of the trailer long	Fire tame 2 m high flames	One small explosion followed by a larger one

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7.4 Temperature profile of fire across the vehicle

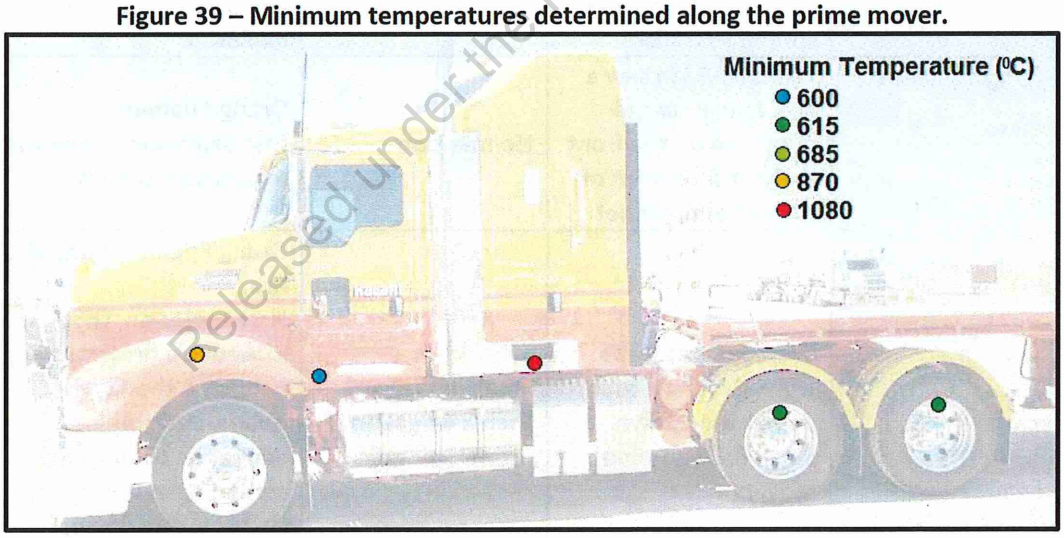
Samples of metal components from the vehicle were selected and analysed to confirm the temperature profile along the vehicle (Annex 70, 71 and 72). It is likely the maximum temperatures measured were reached as a result of the fire before the explosion. Table 10 and Figure 39 show the temperature profile along the prime mover and the first trailer (Annex 25). Different temperatures were reached across the prime mover, the highest being around 1080 °C. These temperatures are near or in excess of the melting point of copper (1080 °C) and aluminium (660 °C). Different temperatures were reached across the first trailer, the highest being around 685 °C. This temperature is in excess of the melting point of aluminium (660 °C).

Table 10 – Temperature ranges for samples analysed.

Sample #	Description	Estimated Minimum Temperature Range (Average) (°C)	Colour coding for Figure 9
TKC1	Molten metal found in chassis rail (Ex Engine Mounting)	550-650 (600)	Blue
TKC4	Rims on both rear axles (Sample from another rim that didn't melt)	580-650 (615)	Green
TKC6	Axle U-bolt (Unknown axle) on 1st trailer	650-720 (685)	Light Green (Not shown in Figure 39)
TKC8	Molten battery cable	1080	Red
TKC10	Failed injector pipe	870	Yellow

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Figure 39 – Minimum temperatures determined along the prime mover.



From the observations and analysis it can be confirmed that:

- the fire burned for over one hour
- the fire was very intense for a sustained period of time
- a significant amount of combustible material on the truck has burned
- the prime mover and first trailer sustained significant heat, reaching temperatures in excess of 1000 °C on the prime mover and up to 720 °C on the first trailer
- molten copper and aluminium were found at the site in proximity to the prime mover

Release

7.5 Discussion regarding the cause of fire on the Kalari vehicle

7.5.1 Vehicle fire

It is highly likely that the prime mover caught fire between it impacting the bridge guard rail and coming to rest in the creek bed. The prime mover and first trailer have been engulfed by fire. The fire intensified over a period of time causing extensive fire damage to both the prime mover, first trailer and a quantity of the ammonium nitrate load. It is likely the fire would have consumed a volume of the ammonium nitrate prior to the explosion, either from mixing with combustible material or from decomposition due to heating.

7.5.2 Known heavy vehicle fire causes

The following is a summary of common causes of fire on heavy vehicles (Annex 79):

1. Arc on ignition or battery cable or the positive feed into the cabin igniting combustible material.
2. Flammable material contacting the turbo charger or the exhaust.
3. Rubbing of fuel lines that result in leaks and then a fuel mist in the engine compartment.
4. Turbo charger failures that cause excessive temperatures in the exhaust.
5. Electrical arcs at terminals or connectors resulting from hot terminals that cause insulation to melt and catch fire.
6. Addition of heavy add-on loads onto a circuit not intended for it. If the fuse rating is increased, the wiring may not be adequately protected.
7. Tyres catching fire because they are deflated or are rubbing on hard surfaces creating friction.
8. Wheel bearing failures resulting in bearing grease catching fire.
9. Overheated brakes resulting in bearing grease or tyre catching fire.
10. Road debris that catches under vehicles and is combustible.
11. Engine oil contacting a hot surface.
12. An electrical fault in the vehicles engine bay or cabin.

Each of the above causes of fire shall be examined in this section with the aim to determine an initial cause of fire for the incident. Scenarios 2, 3, 4, 6, 10, 11 and 12 listed above could not be determined as a cause due to insufficient evidence. Scenarios 7, 8 and 9 were considered unlikely due to examination of the vehicle showing no evidence to support the scenario. Scenarios 1 and 6 were considered credible in the incident, along with other causes identified by external experts engaged to review the evidence to determine a cause of fire.

Many of the scenarios above will occur during normal operating conditions due to mechanical failure. It should be noted that when a vehicle crash occurs, the likelihood of a vehicle fire increases, due to the possible damage to electrical wires and the rupture of fuel tanks.

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7.5.3 Cause of fire on Kalari vehicle

The cause of fire and time the fire started could not be determined. Significant fire and explosion damage has destroyed evidence that would assist in determining a cause of fire. A number of credible fire scenarios have been proposed based either on evidence found at the site and from review of the collected debris.

sch4p4(6) Personal information

sch4p4(6) Personal information (Annex 43).

The third fuel injector pipe from the front of the fuel system's common rail was found to be burst open (Figure 23). It was subjected to metallurgical investigation to determine the cause of rupture. The injector pipe failed as a result of internal pressure at high temperature. It is likely that the high pressure was caused by the fire heating the fuel within the fuel system after the crash. The possibility of leakage from a small hole in this injector pipe (pre-incident) was considered, but found to be highly unlikely (Annex 25 and 26).

Based on evidence and analysis, the following scenarios are considered credible:

- The exhaust system or other hot surface on the vehicle has ignited spilt diesel fuel.
- A battery or electrical cabling has been damaged during the crash causing an arc event igniting spilt diesel fuel or other combustible material.
- Molten grinding metals could have ignited spilt diesel fuel from friction experienced during the process of grinding the rims on the roadway.

These events shall be discussed in further detail below in sections 7.5.3.1, 7.5.3.2 and 7.5.3.3.

When the vehicle came to rest, the fire intensity is likely to have escalated quickly due to the amount of available combustible material including diesel fuel, engine, gear and hydraulic oils, plastics, rubber, fibreglass, timber, dry grass and aluminium. Witnesses confirm that the fire spread from the prime mover to the load on the first trailer and amplified in a short period of time. The fire burnt for more than one hour before it had reduced to a small fire towards the rear of the prime mover.

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7.5.3.1 Fuel in contact with a hot surface

An operating prime mover has a number of hot surfaces capable of exceeding the auto ignition temperature of diesel (240 °C). The turbo in the engine can achieve 800 °C and the exposed exhaust system can operate between 400-600 °C. There are rubber fuel hoses that pass under the exhaust system with minimal protection. It is possible that a diesel hose ruptured in the crash and/or diesel from the ruptured fuel tanks could have made contact with the turbo or the exhaust system leading to a fire (Annex 25 and 26) (Figure 40 and Figure 41).

Figure 40 – Fuel lines and exhaust piping under prime mover driveline.

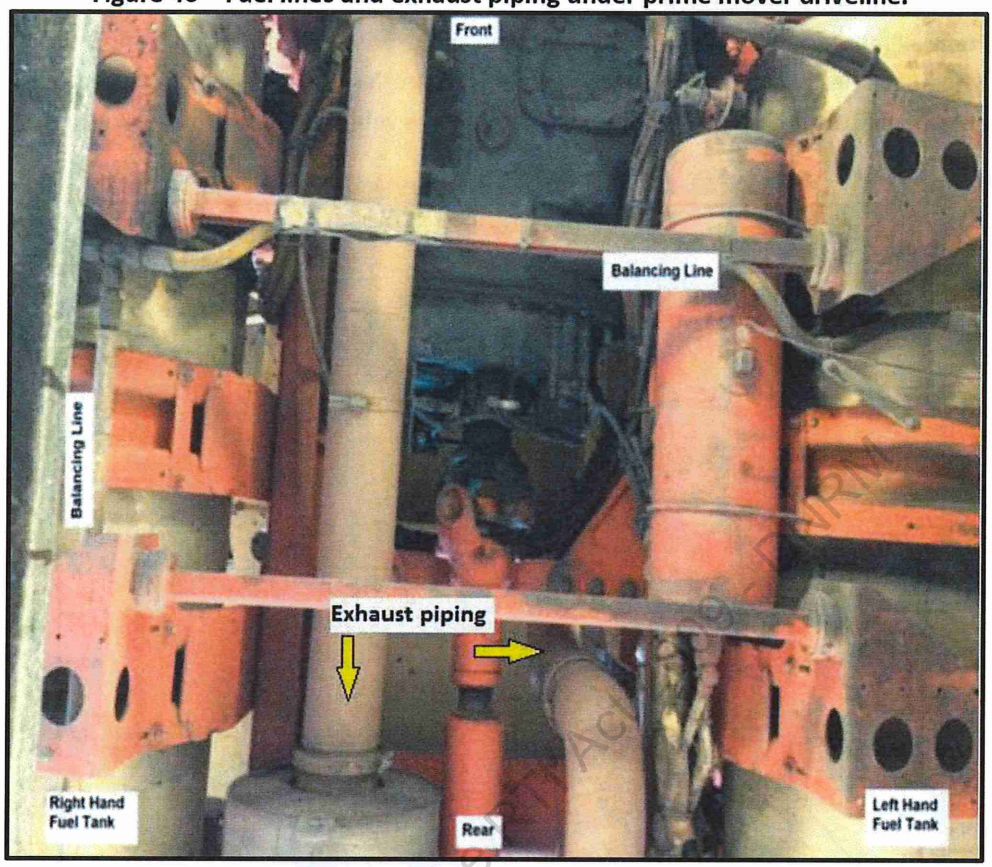
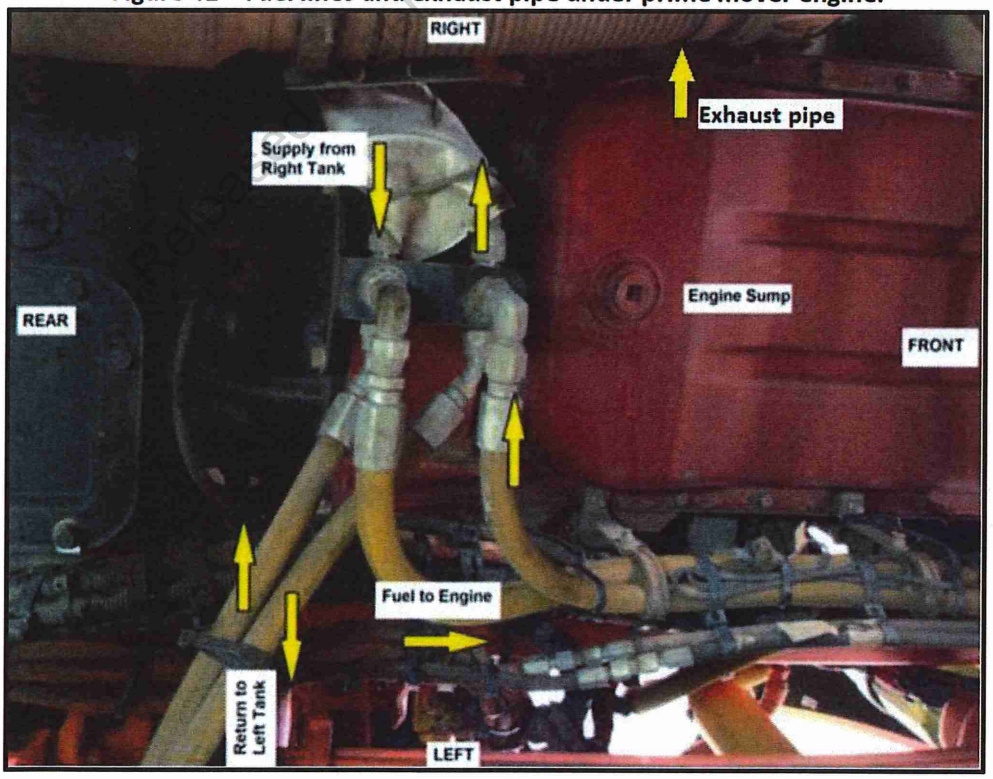


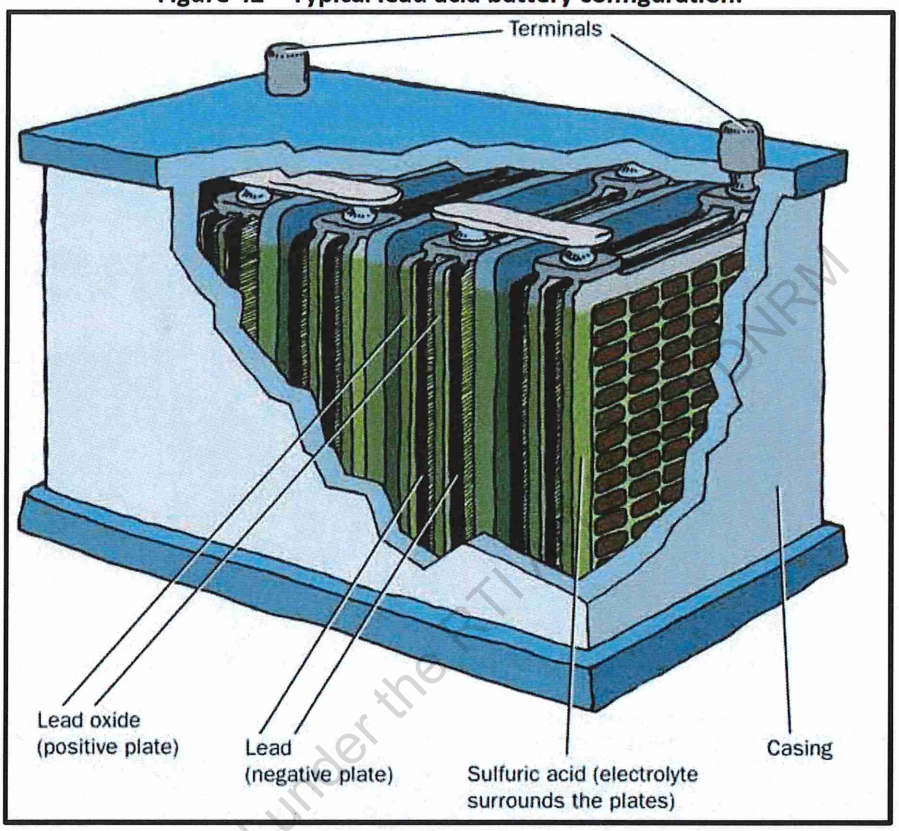
Figure 41 – Fuel lines and exhaust pipe under prime mover engine.



7.5.3.2 Arc event with fuel source

Due to the proximity of the batteries to the fuel tank and exposure to an external impact (Figure 3), it is likely the batteries and the cable connected to the batteries were severely damaged as a result of the vehicle crash. Figure 42 shows the typical design of a vehicle lead acid battery.

Figure 42 – Typical lead acid battery configuration.



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It is postulated that at the point of impact the fuel tank has ruptured, spilling fuel and possibly dislodging some of the four batteries from the housing. An instantaneous battery short circuit current would be in the order of several thousand amperes (Each battery is rated at 600 cold crank amperes and there were four batteries wired in a parallel circuit).

Battery cables were dislodged and could come in contact with the negative polarity of the prime mover or other adjacent negative copper cables. A battery cable was analysed by QHFSS and confirmed an arc event occurred on a battery cable that was part of the starter motor/ignition circuit (Figure 43). The battery cables were inspected and it was noted that the copper strands of the cable had fused together (Figure 43). This indicates temperatures in excess of 1000 °C (Note: The melting point of pure copper is 1085°C.).

Figure 43 – Evidence of electrical arc on starter motor battery cable.



There was dislodgement of the battery cables from the terminal in the battery box and likely the batteries were dislodged (Annex 24). These two events could lead to an arc event within the battery box. It should be noted that substantial force is required to pull the cable from a crimped lug as shown in Figure 44(a). The battery casing or terminal lugs were not located after the fire and explosion. The cable still has some insulation remaining; however the strands of the cable show signs of stretching and burning as shown in Figure 44(b). It should be noted that there was no evidence or trace of the corrugated plastic electrical conduit, likely burned in the fire (Annex 24).

Given the likely spread of diesel from the ruptured fuel tank and other fuel sources, such as plastic insulation around the battery cables, it is possible that an arc event initiated a fire (Annex 24 and 25).

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Figure 44 – Copper cable showing (a) pulling and stretching (b) separation from battery terminal.

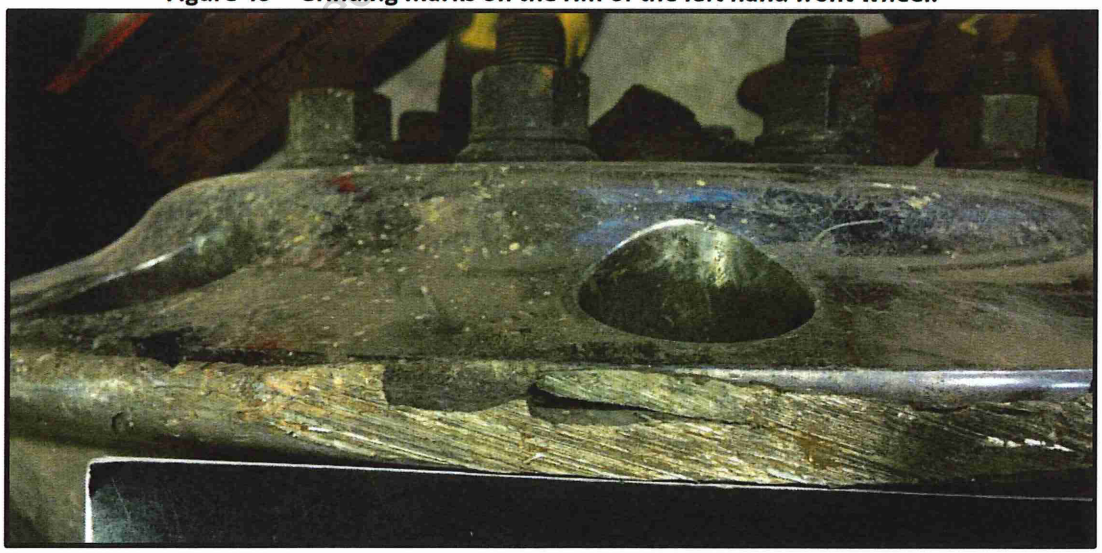


7.5.3.3 Friction with fuel source

The left hand front wheel rim showed signs of grinding on the edge of the rim (Figure 45). These marks are at an angle of about 15 degrees to the direction that the wheels would normally be travelling on a straight road.

The aluminium has a relatively low melting point of about 660 °C. An auto-ignition temperature of 760 °C has been reported for aluminium powder. Potentially the powdered/molten grinding products could have ignited from friction experienced during the process of grinding the rims.

Figure 45 – Grinding marks on the rim of the left hand front wheel.



With the presence of diesel it is possible this may have been an ignition source for a fire. Given the location of the diesel tanks and expected speed of approximately 90 km/h that the truck was

travelling at the time of the crash, it is unlikely that diesel would have been in the vicinity of the tyre rim while the heat was sufficient to cause auto ignition of the diesel (i.e. above 240 °C). Hot and molten grinding products could have travelled back towards the location of spilt diesel fuel. See section 3.2 of the report by Inspector Theo Kahl in Annex 25 for a further description.

7.5.3.4 Other possible causes of fire

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7.6 Scientific testing by Queensland Health Forensic Science Services

7.6.1 Samples of ammonium nitrate

A number of ammonium nitrate samples were collected from the incident site in the days after the vehicle crash and explosion. These samples were collected from visual observation of substances that appeared to be ammonium nitrate or melted ammonium nitrate that had recrystallised.

Samples of the ammonium nitrate manufactured at the Orica Yarwun plant were collected from the same production batch runs (28 August to 2 September 2014 and 2 to 6 September 2014) to the ammonium nitrate involved in the incident.

Table 11 details the ammonium nitrate samples collected from the Angellala Creek site. Figure 46 shows the location each sample was taken from at the Angellala Creek site. The last four entries in Table 11 details the exemplar samples taken from Orica Yarwun and an Orica storage site at the Cudeco Mine in Queensland.

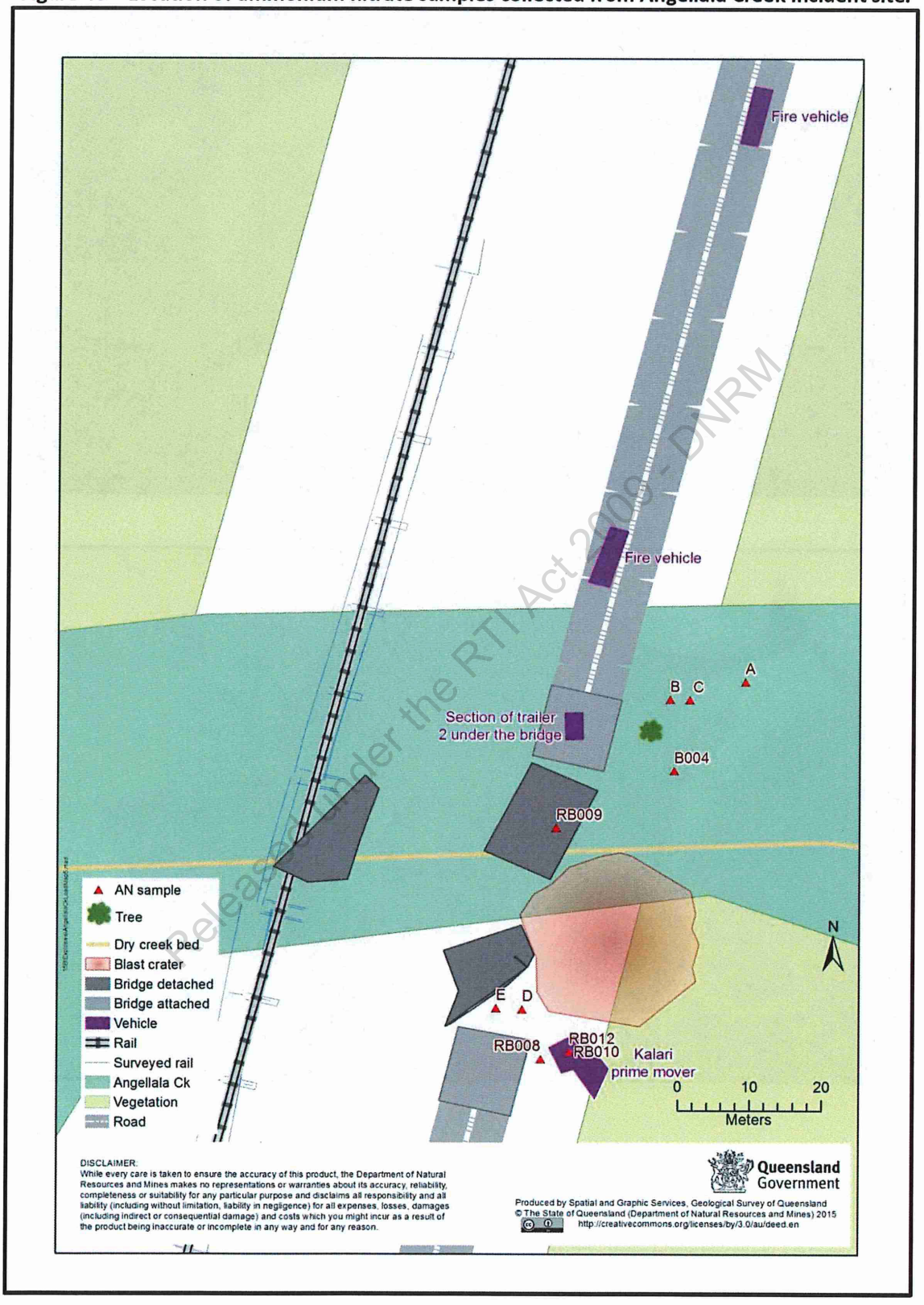
All samples were sealed in plastic buckets or bags and later sent under continuity receipts to Queensland Health Forensic Science Services (QHFSS) for chemical analysis to confirm the presence of ammonium nitrate and any contaminants contained within each sample of ammonium nitrate.

Table 11 – Ammonium nitrate samples collected from the Angellala Creek site.

Sample ID	Collected by	Date collected	Description
A (541682236)	Andy Rowan (QPS); Michael Logan (QFES)	07/09/14	AN prill contained inside white outer IBC bag, not fire affected (Figure 47)
B (541682245)	Andy Rowan (QPS) ; Michael Logan (QFES)	07/09/14	AN prill inside white bag white outer IBC bag, fire affected (Figure 48)
C (541682254)	Andy Rowan (QPS) ; Michael Logan (QFES)	07/09/14	AN prill partially melted under fire damaged tree east of bridge, fire affected (Figure 49)
D (541682263)	Andy Rowan (QPS) ; Michael Logan (QFES)	07/09/14	Solidified AN prill west of bridge and crater, fire affected (Figure 50)
E (541682272)	Andy Rowan (QPS) ; Michael Logan (QFES)	07/09/14	Solidified AN prill west of bridge and crater, fire affected (Figure 51)
B004	Bruce Symmans; Lionel Gainey	07/09/14	AN next to fire damaged tree hit by vehicle on north bank of creek, fire affected (Figure 52)
RB008	Chris Donovan	10/09/14	AN from southern bank of Angellala creek between bridge and prime mover, not fire affected (Figure 54)
RB009	Chris Donovan	12/09/14	Soil and AN from under bridge and 500 mm of soil, not fire affected (Figure 16)
RB010	Chris Donovan	10/09/14	Soil and AN next to bridge and prime mover, not fire affected (Figure 53)
RB011	Chris Donovan	10/09/14	Soil and AN next to bridge and prime mover, not fire affected (Figure 53)
RB012	Chris Donovan	10/09/14	Soil and AN next to bridge and prime mover with part of poly woven bag, not fire affected (Figure 53)
RB013	Chris Donovan	10/09/14	Soil and possible AN found approximately 200 m south east of the blast site adjacent to burnt out tree
RB014	Chris Donovan	10/09/14	Soil and possible AN found approximately 200 m south east of the blast site adjacent to burnt out tree
RB015	Chris Donovan	10/09/14	Soil and possible AN found approximately 200 m south east of the blast site adjacent to burnt out tree
4754A	Haydn Isaac	08/09/14	Sample from Orica Yarwun (Batch 02-06/09/14)
4754C	Haydn Isaac	08/09/14	Sample from Orica Yarwun (Batch 08/09/14)
4755	Haydn Isaac	10/09/14	Sample from Orica Yarwun (Batch 10/09/14)
6415	Ian Tutt	11/09/14	Sample from Cudeco Cloncurry manufactured at Orica Yarwun (Batch 02-06/09/14)

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Figure 46 – Location of ammonium nitrate samples collected from Angellala Creek incident site.



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Figure 47 – Ammonium nitrate sample A (541682236).



Figure 48 – Ammonium nitrate sample B (541682245).

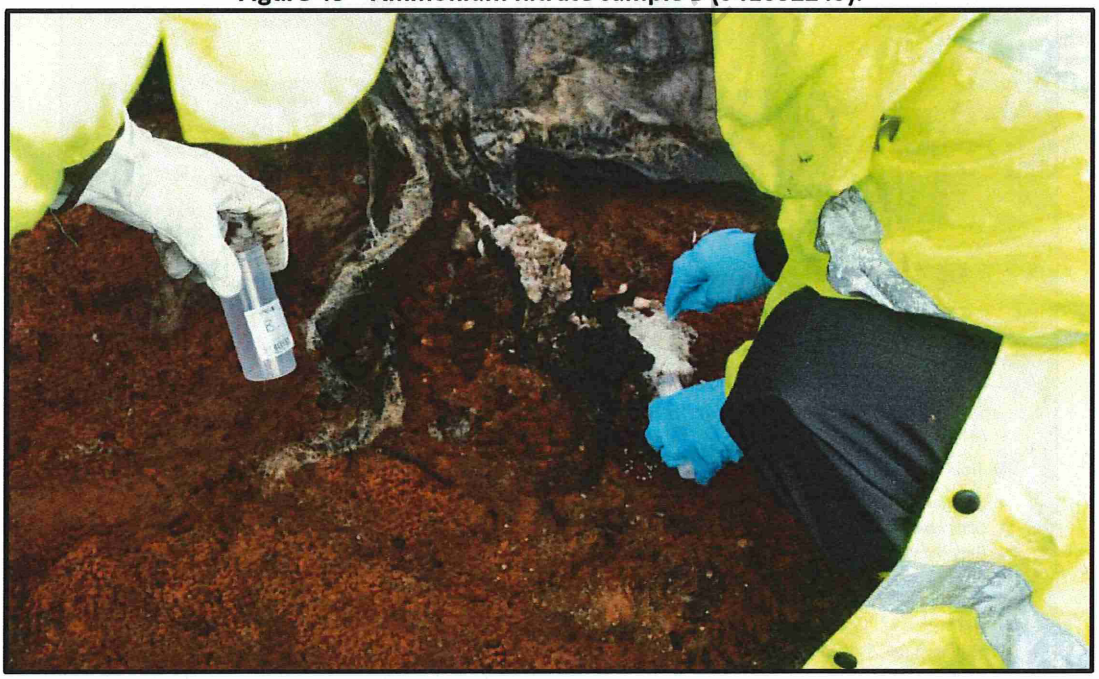


Figure 49 – Ammonium nitrate sample C (541682254).



Figure 50 – Ammonium nitrate sample D (541682263).



Figure 51 – Ammonium nitrate sample E (541682272).



Figure 52 – Ammonium nitrate sample B004 contained in buried IBC uncovered during excavation.



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Figure 53 – Ammonium nitrate samples RB10, RB011 and RB012 under prime mover (white areas).



Figure 54 – Ammonium nitrate sample RB008 near bridge on southern bank (white areas).



A series of soil samples were collected from near the blast crater at locations away from potential contamination from the ammonium nitrate on the vehicle, the fire or subsequent explosion. These soil samples were used for comparison purposes to the ammonium nitrate samples collected and contaminated with soil. Table 12 details the location from which each soil sample was taken.

Approximately 5 kg of soil was taken from just below the surface to remove the effect of any plants and excess organic material.

Table 12 – Soil samples and location taken from Angellala Creek.

Sample ID	Collected by	Date collected	Description
SOIL1	Ryan Brogden	27/10/14	North east top of creek 40 m east of blast site
SOIL2	Ryan Brogden	27/10/14	North east top of creek 50 m east of blast site
SOIL3	Ryan Brogden	27/10/14	North east creek bed 40 m east of blast site
SOIL4	Ryan Brogden	27/10/14	South east top of creek 60 m east of blast site
SOIL5	Ryan Brogden	27/10/14	South east creek bed 40 m east of blast hole
SOIL6	Ryan Brogden	27/10/14	South east top of creek 30 m east of blast site

7.6.2 Discussion of chemical analysis results

The samples collected from Orica and at the site were analysed by a chemist at QHFSS to:

- determine the presence of ammonium nitrate
- confirm the ammonium nitrate from Orica Yarwun is Division 5.1, classified as UN1942
- detect any contamination of the ammonium nitrate samples collected from the site

Possible contaminants at the site may include organic (diesel, urea, rubber or plastic) and inorganic substances (metals and ionic salts).

Samples 4754A and 6415 (Table 11) were both manufactured during the same batch run as the samples collected at the site from the truck involved in the incident. Samples 4754A and 6415 will be used for comparison purposes to confirm contamination of samples at the site.

The detailed chemical analysis report is attached in Annex 73 and 74 and is summarised in 7.6.2.1 and 7.6.2.2.

Firstly, the analysis was conducted to confirm the presence of ammonium nitrate in the samples. These results are provided in Table 13 and confirm the samples contained a majority of ammonium nitrate. The lower results for some samples collected from site (RB009 and RB010) are due to the presence of insoluble material from the incident site contaminating the sample.

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Table 13 – Chemical analysis results for contaminated samples of ammonium nitrate.

Sample	Ammonium nitrate (%w/w)	Insoluble (%w/w)	Total organic carbon (%w/w)	Diesel present (Yes/No)
4754A	97.43	0.09	0.03	No
4754C	97.50	0.11	0.03	No
4755	96.81	0.10	0.03	No
6415	96.41	0.09	0.03	No
A	94.47	0.50	0.31*	No
B	93.72	0.43	0.04	No
C	90.73	2.02	0.04	No
D	93.20	1.41	-	**Yes**
E	95.45	1.54	-	**Yes**
B004	97.50	0.54	-	No
RB008	97.65	1.59	-	**Yes**
RB009	75.24	20.77**	-	**Yes**
RB10	88.40	9.00**	-	**Yes**
RB11	93.84	1.35		**Yes**
RB12	92.94	-	-	**Yes**

*Insufficient sample to analyse

**Large amount of insoluble material

sch4p4(7)(1)(c) Business/commercial/professional/financial affairs

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7.6.2.1 Samples of ammonium nitrate from Yarwun manufacturing plant

Secondly, to confirm the ammonium nitrate as a Division 5.1 oxidising substance classified as UN1942, the results of the analysis of samples 4754A, 4754C, 4755 and 6415 (see section 13.1 of the QHFSS report in Annex 74) did not show any contamination from the known chemicals that are incompatible with ammonium nitrate. The amount of total organic carbon, measured as a percentage of carbon (% C) was measured as 0.03 %w/w for each sample and less than the 0.2 %w/w total combustible material required to be considered UN1942 ammonium nitrate.

Orica upon request supplied a number of reports relating to self-completed UN testing conducted on the Yarwun manufactured ammonium nitrate prill. The reports included total organic carbon (TOC) testing, UN compliance testing, Test Series 2a testing and Test Series 2b testing (Annex 81, 82, 83). The result of all tests conducted by Orica confirmed the ammonium nitrate manufactured at Yarwun is classified as Division 5.1, UN 1942 ammonium nitrate, *with not more than 0.2% total combustible material, including any organic substance, calculated as carbon to the exclusion of any other added substance*.

The Test Series 2 results that confirm ammonium nitrate is not a Class 1 explosive (i.e. Gap test, Koenen test etc.) were not performed on the ammonium nitrate sampled from the Yarwun plant by the Explosives Inspectorate, as the results discussed in this section did not confirm any contamination of the ammonium nitrate; the percentage of carbon was below the threshold of 0.2 %; and the results for Test Series 2 provided by Orica were considered valid for the batch

involved in the incident. Sufficient samples of the ammonium nitrate from the Yarwun plant have been retained by the Explosives Inspectorate if Test Series 2 analysis is considered in the future.

Orica also perform a number of tests for internal quality assurance of the ammonium nitrate. An onsite laboratory is utilised to test the ammonium nitrate prill for pH, friability, size conformity, oil absorption, thermal cycling, caking and hardness, coating agent by [redacted] (c) Business/commercial/professional/financial affairs determination. These tests are collated on a daily composite work sheet that identifies the minimum and maximum parameters required for the prill to remain within specification (Annex 84).

On the basis of these results, it can be considered there was no contamination of the ammonium nitrate manufactured at the Orica Yarwun plant for the batch run 2 to 6 September 2014, which correlates to the same batch of ammonium nitrate on the truck involved in the incident at Angellala Creek.

7.6.2.2 Testing of ammonium nitrate from the incident site

The third part of the chemical analysis was to confirm any contamination of the ammonium nitrate samples collected from the incident site after the explosion event. Table 11 shows the date the samples were collected at the site. Some days had passed between the incident on the 5 September 2014 and the collection of the samples due to a number of circumstances, including the site being isolated under the control of QFES to deal with the toxic gases being released after the explosion from spot fires that appeared to include ammonium nitrate near the blast crater. This led to a delay in handover of the site to the Explosives Inspectorate. Further delays in sampling occurred due to documentation and mapping of the site and clearing of structures and debris where ammonium nitrate was found buried.

There was rain at the site after the incident on 6, 7 and 8 September prior to collection of some ammonium nitrate samples (Table 14). The samples A, B, C, D and E were collected before the rain event occurred and are considered to not be effected by water dilution (Note – ammonium nitrate is extremely hydroscopic and absorbs water if exposed to a humid atmosphere).

The remaining samples from the site in Table 11 were sampled after the rain event, however these samples were either buried under soil, the prime mover or located under the remaining bridge and there was no observation of effect from water or moisture in the samples at these locations, due mainly to their protection from the rain by soil or other structures. If water had reached these samples, it is highly likely the ammonium nitrate would have dissolved, due to its high solubility (190 g/100 g water at 20 °C) and potentially diluted through the soil making the presence of the ammonium nitrate impossible to visually detect.

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Table 14 – Rainfall measured from nearby Bureau of Meteorology weather recording stations.

Station name	Distance from Incident site	Station number	Latitude	Longitude	Elevation	Rainfall total 6-8 Sept 2014
Bakers bend AL	14 km	044233	26.71 °S	146.11 °E	261 m	11.4 mm
Charleville Aero	28 km	044021	26.41 °S	146.26 °E	302 m	7.6 mm
Binnowee AL	16 km	044230	26.48 °S	146.09 °E	200 m	39 mm

7.6.2.3 Results of analysis of samples from the incident site

The results of the contamination of ammonium nitrate samples collected from the incident site are detailed in section 13.3 of the QHFSS report (Annex 74). The results for samples A, B,C and B004 located on the northern bank adjacent to the tree that the vehicle hit show no contamination of the ammonium nitrate by inorganic or organic substances.

There are some slight elevations in the amount of nitrite, chloride, calcium and iron for some samples analysed (Item C, sample 3; Item E, sample 1; Item RB009; Item RB10, Aggregate; Item RB011, Prill), however these correlate with a significant amount of insoluble material contaminating the sample (i.e. soil/ground substrate, described in section 13.2 of the report in Annex 74 as sand and/or clay and/or black carbonaceous material) of between 15.70 to 25.13 % across these samples. It is highly likely these elevated levels of nitrite, chloride, calcium and iron are attributed to the soil contamination.

Sample A also shows an elevated TOC level, described in the report in Annex 74 as being due to the minimal amount of material available for the TOC analysis, being heavily contaminated with soil and plant matter that could not be separated from the ammonium nitrate and having only single replicate analysis. This TOC result provided in the QHFSS report for Sample A is considered invalid and is therefore not considered as part of the results in this discussion.

Sample D and E appeared to be a recrystallised form of molten ammonium nitrate with significant contamination of an unknown origin. These samples were found in the area of ground where span 4 of the road bridge adjacent to the blast hole was located prior to the explosion (Figure 46). After the explosion span 4 of the bridge was no longer in its original position.

The results for sample D and E (Annex 74) show increased levels for copper and zinc. The source of the copper and zinc is likely from the Kalari vehicle involved in the fire. There are no other known sources of these metals that were in proximity to the load of ammonium nitrate. The temperature of the fire on the prime mover and evidence (Annex 25) confirms that both copper and zinc from the prime mover or trailers would have been in the molten phase and could have mixed with the molten ammonium nitrate.

Samples D and E (Table 13) also indicate the presence of diesel type (distillate-range) hydrocarbons that would be consistent with diesel and differentiated from the heavy mineral oils, waxes, long

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chain fatty acid salts and fatty acid amines found in the coating agent of the ammonium nitrate prill. The concentration of the diesel type hydrocarbons was not determined in these samples. The only credible source of diesel from the site was the spilt fuel from the Kalari prime mover involved in the incident.

The ammonium nitrate samples collected adjacent to or directly under the prime mover (RB008, RB010, RB011 and RB012) will be discussed together with sample RB009. These samples were found under the northern section of bridge that had collapsed from the explosion (Figure 16). Table 13 provides the results from section 13.4 of the report (Annex 74). Certain samples contained prill or an aggregate of both prill and recrystallised ammonium nitrate. All of these samples were mixed with soil.

In terms of inorganic contamination, samples RB009, RB010, RB011 and RB012 found in close proximity to the prime mover all showed very slightly elevated levels of [redacted]. Given the ammonium nitrate samples from Yarwun (4754, 4755 and 6415) was these samples from site (RB009, RB010, RB011 and RB012) show contamination from [redacted] in addition to the [redacted] from the manufacture of the prill. The source and form of the [redacted] in the mixture is not known. The only known source of [redacted] at the site was the Kalari vehicle that had [redacted] for the body of the prime mover.

The samples RB008, RB009, RB010, RB011 and RB012 were all contaminated with diesel type hydrocarbons that would be consistent with diesel and differentiated from the heavy mineral oils, waxes, long chain fatty acid salts and fatty acid amines found in the coating agent of the ammonium nitrate prill. The concentration of the diesel type hydrocarbons was not determined in these samples. The only credible source of diesel from the site was the fuel tanks of the Kalari prime mover involved in the incident.

On the basis of the diesel contamination in the ammonium nitrate samples, it is estimated that the spread of diesel from the crash was across the site from the northern bank to the southern bank where the prime mover was resting after the crash. This would be consistent with the diesel tanks being ruptured when the vehicle left the road, hit the crash barrier and the final impact with the creek bank on the south side. Any diesel that did not burn in the fire would have absorbed into the soil and the more volatile components evaporated over a period of time.

Samples RB013, RB014 and RB015 were sent for analysis however the results confirmed these samples did not contain ammonium nitrate. On further review of the residues and the photos of the location the samples were collected from, it was confirmed the white residue was wood ash from a fire involving a tree. It is unknown if this fire was related or unrelated to the incident. The tree was located approximately 200 m to the south east away from the blast site. It is possible a hot or burning fragment landed in or near the tree and started a fire involving the tree, however this cannot be confirmed.

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7.7 Analysis of the explosion

7.7.1 Description of explosions

Loud "bangs" and bursting noises were reported by witnesses to come from the burning Kalari vehicle over a period of time with very high and bright flames which were engulfing part of the bridge.

Approximately one hour and fifteen minutes after the vehicle crash, at approximately 2210-2211, a small but loud explosion occurred with what was described as having firework-like effects seen falling from the sky.

Approximately one minute later, at 2212, a much larger explosion occurred, causing serious injuries to the people and extensive damage to the infrastructure and vehicles nearby.

Witnesses at the incident site described two explosions occurring about one minute apart. Explosions involving ammonium nitrate in previous transport incidents in Brazil, Canada and Romania mention a small explosion before the major explosion (Annex 75). No evidence was found in these incidents to link the two explosions together.

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7.7.2 Theory regarding the pathway for ammonium nitrate to detonation

The review conducted by Peddie and Braithwaite (Annex 75) provided the following mechanisms for an explosion or detonation to develop in ammonium nitrate:

- Thermal explosion (cook off) – caused by exothermic reaction due to external heat source. These reactions are typically fast.
- Deflagration (heat conduction and chemical reaction) – requires ignition and contaminated AN or very high pressure. These reactions are typically slow.
- Detonation (shock wave driven) – either direct shock detonation transition (SDT) or via deflagration to detonation transition (DDT). This reaction is typically supersonic.
- Water hammer/ concerted void collapse (hot spot) – gassed media at or near thermal explosion condition. This reaction is typically fast.

Solid ammonium nitrate is considered an insensitive substance. It requires a very large input of energy to detonate unless it changes from its solid state. A transport incident, such as a vehicle crash, will not provide enough energy to cause an explosion of the ammonium nitrate. When ammonium nitrate is continuously heated it starts to melt at around 169 °C and decompose around 210 °C, producing gas voids which lower the density. The molten gas in ammonium nitrate requires much less energy to detonate and has a much smaller critical diameter compared to solid ammonium nitrate (Annex 75).

Netherlands Organisation for Applied Scientific Research (TNO) has published a fault tree analysis describing the known pathways to detonation for ammonium nitrate. Peddie and Braithwaite added the possibility of a reaction with metals (Figure 55).

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Figure 55 – Fault tree analysis showing possible pathways leading to an explosion of ammonium nitrate (TNO).

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What is not well understood in the literature is the initiation method for the detonation to occur. It is possible a small explosion in the gassed and molten ammonium nitrate has occurred, leading to a larger explosion of the hot solid product and then the ambient temperature product. In normal explosives use this is referred to as the explosives train, i.e. a small initiator detonates a sensitive and powerful explosive charge that detonates the large insensitive explosive.

The initiation of the explosion could be caused from the following (Annex 75):

- Shock to detonation transition or impact (SDT) to molten ammonium nitrate with sufficient energy
- Deflagration to detonation transition (DDT)
- Interaction of molten ammonium nitrate with molten metals such as aluminium, zinc, copper (possibly forming tetramine cupric nitrate complex) and chromium creating a very sensitive explosive.

These scenarios are difficult to replicate in experiments and while attempts have been made, initiation of ammonium nitrate via these mechanisms has not been consistently achieved and the quantities used in experiments have been very small compared to the quantities involved in actual incidents.

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7.7.3 Analysis of first explosion at Angellala Creek

The first explosion occurred at approximately 2210 and was described by witnesses as having no overpressure shock (Table 9). This may indicate the explosion was not large or did not involve a detonation. The first explosion was described as having bright white sparks burning and slowly falling from the sky following the explosion; described as a firework effect. This is possibly due to burning metal, such as aluminium, or another combustible material that was thrown into the air from the explosion.

The cause of the first explosion is unknown. There was no evidence found at the site that could be linked to this first explosion. A number of scenarios have been considered for the first explosion and they shall be described briefly. No further analysis was conducted due to the lack of physical evidence. The possible scenarios include:

1. A pressurised piece of equipment (for example a tyre or air receiver) has burst possibly as a result of fire and thrown molten or burning debris into the air
2. A gas or thermal explosion from the decomposition of ammonium nitrate has caused a low order explosion
3. There has been an explosion involving ammonium nitrate that has been small and not involved the larger load of ammonium nitrate
4. Molten aluminium contacting either a water source or molten ammonium nitrate causing an explosion (Annex 85).

7.7.4 Analysis of second explosion at Angellala Creek

The second explosion occurred at 2212, confirmed by Geosciences Australia as reaching 2.1 on the Richter scale at the location of the explosion (Annex 86). The explosion was catastrophic. The Kalari vehicle involved in the crash was destroyed, along with the road bridge. The vehicles in near vicinity

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to the explosion were significantly damaged. The people near the explosion were seriously injured, sustaining blast type injuries from the overpressure blast wave and projected blast debris.

The explosion consumed the ammonium nitrate remaining after the vehicle crash and fire. It was estimated from observations at the site that approximately 6 to 8 IBCs (7.2 to 9.6 t) of ammonium nitrate were dislodged from the trailers during the crash. Five part IBCs with ammonium nitrate were found near the tree that the vehicle hit during the crash. Some of this material had burned with combustible material over a 24 hour period following the vehicle crash and only small amounts of ammonium nitrate were collected from the IBCs.

Ammonium nitrate was also spread across the site in a fine layer as a result of the crash. During excavation of the surface of the creek bed under the bridge, this layer of ammonium nitrate was found about 100mm below the soil that was ejected from the blast crater and deposited over the area surrounding the blast crater following the explosion (Figure 16). Bags containing small quantities of unburnt prill were found during excavation near the tree hit by the vehicle (Figure 52).

The fire that burned on the vehicle would have consumed an amount of the ammonium nitrate due to decomposition into nitrous oxide gases when heated above the decomposition temperature of 210 °C. Given that some metal parts of the trailer were measured as having reached a temperature in excess of 600 °C, it can be reasonably assumed part of the ammonium nitrate load would have exceeded the decomposition temperature.

Based on the loss of ammonium nitrate from the vehicle during the crash, there may have been approximately 40 to 45 t of ammonium nitrate left on the trailers from the original 52.8 t following the crash.

It is likely ammonium nitrate was in contact with or very close to the first trailer and the front half of the second trailer, as the remains of these parts of the trailers were scattered across a 1 km radius from the blast site. Most of these trailer components showed significant fire and blast damage. The rear half of the second trailer was not affected by fire and was still mainly intact, with the rear two axles and suspension still attached (Figure 27). The aluminium decking was missing from this part of the trailer. This would indicate that the quantity of ammonium nitrate and the blast pressure was not as significant on the rear of the second trailer. There were no recognisable parts of the converter dolly found. This indicates the dolly may have been near the middle of the blast and small parts of the dolly were scattered across the wider site.

It is thought that part of the load of ammonium nitrate may have been under and around the rear of the prime mover before the second explosion, as this rear differential was found 170 m south east of the blast site. This rear differential weighs approximately 1300 kg and would require significant energy to be projected that distance.

Based on an observation of the blast crater, it is possible that the two trailers were overlapping each other (Figure 56). A detailed analysis of the blast crater profile was not undertaken as this is unlikely to provide an accurate assessment of the orientation of the load prior to the explosion or an accurate assessment of the size of the explosion.

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Figure 56 – Blast crater with original creek bed profile in top left.



7.8 Assessment of blast effects

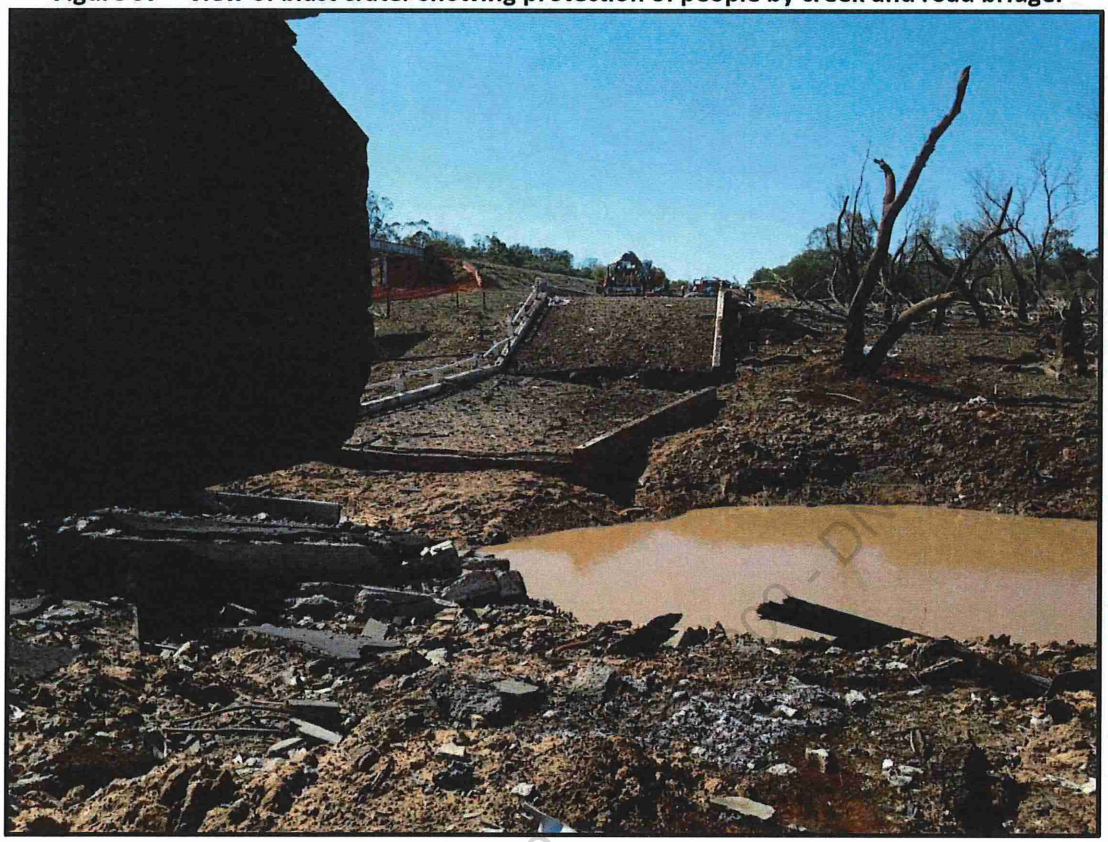
The estimation of the blast size based on crude analysis was between 10 to 15 t of TNT. In Queensland, the acceptable TNT equivalence for ammonium nitrate is 0.32. Based on this TNT equivalence, this would equate to a mass of 31 to 47 t of ammonium nitrate involved in the explosion. This correlates to all of the expected mass of 40 to 45 t of ammonium nitrate that was anticipated to be in the blast crater being consumed in the explosion.

It is astonishing there were no fatalities as a result of the explosion. Five of the injured were in the open, approximately 50 m to 60 m away from the blast. One person was in the open and one person in a fire vehicle approximately 70 m away from the blast. Another person was approximately 200 m away inside a police vehicle. Considering the injuries sustained, it is estimated that they received a blast overpressure of 21-70 kPa, based on 70 kPa being considered a 100% chance of fatality to a person in the open (Annex 87). If the Kalari vehicle was in direct sight of the people 50-60 m from the blast, it could be assumed that most of the seven would have been killed.

The only reasonable consideration for their survival could be due to there being no direct line of sight between the ammonium nitrate load that exploded and the people due to the natural contour of the creek bed and protection by the road bridge (Figure 57).

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Figure 57 – View of blast crater showing protection of people by creek and road bridge.



7.9 Explosives Act 1999 and Explosives Regulation 2003 requirements for transport of ammonium nitrate

7.9.1 Documents to be kept with vehicle during transport

There are a number of documents that must be kept in the vehicle during the transport of ammonium nitrate, including the dangerous goods transport document, emergency procedure guide, emergency response card, copy of licence to transport explosives, Kalari letter of endorsement for sch4p4(6) Personal information and the driver log book for recording work hours. These documents were not found at the site. They were most likely consumed in the fire and explosion.

Copies of previous vehicle pre-starts indicate that the appropriate documentation was carried on previous occasions. Observations made on similar vehicles owned by Kalari at Port Pirie and Gladstone showed the appropriate safety equipment and documentation on the vehicles.

7.9.2 Vehicle maintenance

Kalari has in place a maintenance program for the prime mover and its trailing equipment. This maintenance system is developed from the manufacturer's maintenance schedules, standards and specifications, best industry practice and from a national maintenance program known as the National Heavy Vehicle Accreditation Scheme (NHVAS).

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A post incident inspection of the remains of the prime mover found no physical defects that could have contributed to the cause of the incident.

Records of vehicle pre-starts, driver defect reports, servicing, scheduled maintenance logs, breakdown and manufacture warranty work records have been reviewed and presented no inherent or ongoing defects. These records demonstrate a pattern of frequent and thorough maintenance.

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Figure 58 – Vehicle repairs undertaken on prime mover involved in the incident.

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7.9.3 Initial emergency response guide

An initial emergency response guide, SAA/SNZ HB76:2010 *Dangerous Goods – Initial Emergency Response Guide* (HB76) is a guidebook for first responders responding to a dangerous goods or hazardous materials transportation incident. It is used by the driver and emergency response personnel such as firefighters. Chapter 11.2 of ADGC requires emergency information to be carried by a vehicle transporting dangerous goods that may include HB76.

One of the initial actions when responding to a vehicle fire involving its cargo is to identify what the product/s are on fire or imminently involved in the fire to determine what hazards are posed by the load so appropriate precautions can be taken.

Following this incident, QFES have undertaken a review of the HB76 Guide 50 that details the requirements for responding to an ammonium nitrate incident. These changes have been submitted to Standards Australia for an update to HB76 (Annex 90).

7.9.4 Hazchem code for ammonium nitrate

The HAZCHEM emergency action code provides first responders and emergency services personnel with information on the correct initial action to be taken to prevent the escalation of an incident. It is shown on EIPs on the vehicle and IBCs of ammonium nitrate, as required by the ADGC (Figure 5).

On the date of the incident the HAZCHEM code for ammonium nitrate UN1942 was 1Z, which is defined as 1 = Coarse Spray and Z = Breathing apparatus and fire kit AND Contain (see Appendix C of ADGC). 1Z is not the correct Hazchem code to use for ammonium nitrate as it does not consider the explosive potential of ammonium nitrate in an incident.

Following this incident, the Queensland Explosives Inspectorate submitted a proposal to the National Transport Commission (NTC), who publish the ADGC, to change the Hazchem code for ammonium nitrate of UN 1942 to 1Y. 1Y is defined as 1 = Coarse Spray and Y = substance can be violently or even explosively reactive, including combustion AND Breathing apparatus and fire kit AND Contain (see ADGC Version 7.4 at http://www.ntc.gov.au/heavy-vehicles/safety/australian-dangerous-goods-code/).

The NTC have updated the ADGC as recommended by the Explosives Inspectorate. There is currently a transition period in place to change from 1Z to 1Y for ammonium nitrate of UN 1942. This transition period expires on 31 December 2016 where 1Y will be the mandatory Hazchem code for ammonium nitrate of UN 1942.

7.9.5 Review of Kalari risk management for Kalari transport of ammonium nitrate

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7.9.6 Kalari risk assessment for transport

A risk assessment for the transport of ammonium nitrate was provided by Kalari.

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8 Findings

The findings are focussed on the fire and explosion involving the vehicle and ammonium nitrate that affected the people, vehicles and infrastructure at the site. Where there are discussions of other factors in the report, they will not be incorporated into the findings section of this report.

8.1 Orica

8.1.1 Activity for manufacture of ammonium nitrate at Yarwun by Orica was licensed by the Explosives Inspectorate (section 4.2.1).

8.1.2

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8.2 Ammonium nitrate at time of manufacture

8.2.1 The ammonium nitrate involved in the incident was manufactured at Orica Yarwun in Queensland (section 7.6.2.1).

8.2.2 The ammonium nitrate manufactured by Orica was tested and confirmed to be classified as UN1942 (section 7.6.2.1).

8.2.3 There was ongoing quality control to ensure the manufactured ammonium nitrate maintained the correct classification prior to transport (section 7.6.2.1).

8.3 Kalari

8.3.1 The activity of transport by Kalari was licensed by the Explosives Inspectorate (section 4.2.2).

8.3.2

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8.3.3

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8.4 Kalari vehicle

8.4.1 The vehicle met the requirements of the ADGC including safety equipment, marking and documentation (section 7.9).

8.4.2

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8.4.3 The vehicle was mechanically sound and was regularly maintained (section 7.9.2).

8.4.4 The exact speed of the vehicle at the time of the vehicle crash could not be determined. The estimated speed of the vehicle at the time of the incident was 90 km/h (section 7.1).

8.4.5 The diesel fuel tank on the passenger side was damaged in the crash (section 5.5.3.1).

8.4.6 The battery compartment on the passenger side was impacted and damaged in the crash (section 5.5.3.1).

8.4.7 The prime mover contained a large amount of combustible material, including fuel, and various metals (section 4.4.4).

8.4.8 The trailer decking consisted of aluminium (section 4.4.2).

8.4.9 A diesel fuel injector line failed during the fire event after the crash (section 5.5.3.1).

8.5 sch4p4(6) Personal information

8.5.1

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8.5.2

8.5.3 The driver was injured as a result of the vehicle crash, fire and explosion (section 5.4).

8.6 Communication

8.6.1

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8.6.2

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8.7 Crash

8.7.1 The vehicle left the roadway to the left hand side while travelling in a southerly direction (section 7.2.1).

8.7.2 The vehicle impacted the left hand side (eastern) guard rail on the approach to the bridge (section 7.2.1).

8.7.3 The combination continued on its southerly course impacting a tree and then came to a rest in the creek bed in an overturned state (section 7.2.1).

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8.8 Cargo

8.8.1 Torn segments of the IBCs were located at the site that indicated UN1942 ammonium nitrate was on the load (section 5.5.1).

8.8.2 Some ammonium nitrate IBCs were dislodged from the trailers during the crash (section 5.5.1).

8.8.3 Some ammonium nitrate was scattered along the vehicle pathway from the start of the bridge to the resting point of the prime mover (section 5.5.1).

8.8.4 There was no contamination of ammonium nitrate found in the samples from the incident site that were still contained in their packaging (section 7.6.2.3).

8.8.5 Ammonium nitrate samples from the site showed the appearance of being molten and contaminated with organic substances and metals (section 7.6.2.3).

8.9 Fire

8.9.1 Following the crash the fire burned for over one hour, engulfing the prime mover, first trailer and a quantity of the load before reducing to a small fire on the prime mover immediately prior to the explosion (section 6.2.3).

8.9.2 There was a diesel spill from the vehicle across the site from the north bank to the south bank of the creek that is likely to have contributed to the fire (section 7.6.2.3).

8.9.3 There were hot surfaces, particularly the engine exhaust that are in close proximity to where spilled diesel would be found as a result of the crash (section 7.5.3.1).

8.9.4 An electrical arc has occurred from the batteries electrical cabling (section 7.5.3.2).

8.9.5 Molten ammonium nitrate and molten aluminium and copper were found at the site, indicating an intense fire in excess of 1000°C (section 6.2.2).

8.10 Explosion

8.10.1 The first explosion occurred approximately one hour and fifteen minutes after the estimated time of the vehicle crash (section 7.7.1).

8.10.2 The first explosion did not appear to cause any structural damage and had no overpressure (section 7.7.3).

8.10.3 A second explosion occurred approximately one hour and seventeen minutes following the estimated time of the vehicle crash (section 7.7.1).

8.10.4 Post blast analysis estimated the size of the explosion at approximately 10 to 15 t trinitrotoluene (TNT) equivalence, which would equate to approximately 31 to 47 t of ammonium nitrate (section 7.8).

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8.10.5 Debris from the Kalari vehicle and other infrastructure was found up to one kilometre away from the site of the vehicle crash (section 7.7.4).

8.10.6 Eight people were injured in the explosion, some seriously. Four people were located approximately 50 metres away from the explosion, one person 55 metres away behind a fire truck, one person approximately 70 metres away inside a fire truck and another person outside adjacent to the fire truck. One person was in a police car approximately 200 metres away (section 7.8).

8.10.7 The mechanism for initiation of ammonium nitrate is complex and prior research has not been able to replicate actual incidents (section 7.7.2).

8.10.8 All explosions involving ammonium nitrate in transport have occurred on flat deck type trailers (section 7.1.2).

8.11 Hazard communication

8.11.1 The vehicle crash rendered the driver semi-conscious and unable to take control of the incident site. He was able to convey some emergency response information to external parties (section 6.2.3).

8.11.2 The manifest, emergency procedure guide, placards and EIPs were destroyed by the fire, making communication of the hazards difficult (section 7.9.1).

8.11.3 There was no phone signal at the site for people to call and alert emergency services of the incident (section 5.3).

8.12 Emergency response

8.12.1 Guide 50 in SAA/SNZ HB76:2010 *Dangerous Goods – Initial Emergency Response Guide* (HB76) for response to an ammonium nitrate incident is not specific in some cases, for example when to respond and when to evacuate an ammonium nitrate incident involving a fire and the safe evacuation distances (section 7.9.3).

8.12.2 At the time of the incident, the Hazchem Code in the *Australian Code for the Transport of Dangerous Goods by Road and Rail 7th Edition* (ADGC) for ammonium nitrate was 1Z and did not address the explosion risk of ammonium nitrate (section 11.2).

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9 Analysis of findings

This section shall detail the investigation of the root causes of the incident using the Incident Cause Analysis Method (ICAM) and discuss ways the deficiencies identified in the ICAM and the investigation could be addressed.

9.1 ICAM process

ICAM is an investigation tool used by DNRM when conducting nature and cause investigations. It aims to identify both local factors and systemic failures within the broader organisation and systems that contributed to the incident. Consideration is given to identifying deficient organisational factors such as communication, training, operating procedures, incompatible goals, risk management, change management, plant design and organisational culture. Through the analysis of information gathered from the investigation process, ICAM assists with identifying what went wrong and to make recommendations on necessary remedial actions to reduce risk and build error-tolerant defences against future incidents.

An ICAM of the incident was conducted on 24 and 25 August 2015 to provide the department with information to identify possible causes of the event and further explore these causes.

The following outcomes were identified:

- Exposed fuel lines and electrical cabling on the prime mover were damaged
- Vehicle construction components include a large amount of combustible material
- Inappropriate segregation of ammonium nitrate from combustible materials
- Risk assessments not considering all hazards for the transport of ammonium nitrate
- Emergency responders not having the information about the ammonium nitrate load prior to arrival at the site to prepare for correct response

The ICAM analysis (Figure 59) identified contributing factors to the above defences that included:

- Vehicle not designed to incorporate effective risk reduction in a crash
- Acceptance by users of minimum standards in standards and codes
- Most hazards are identified, however the hazard of an explosion during transport of ammonium nitrate is not considered
- Lack of placarding due to the damage as a result of the crash and fire
- Ammonium nitrate movements are not monitored within the state
- Ammonium nitrate characteristics are not fully understood where a fire disrupts the normal transport conditions.

9.2 Vehicle design to control fire and explosion hazards

As discussed in section 7.1.2, all previous transport incidents where an explosion has occurred have been the result of a prolonged fire. Therefore the vehicle design should firstly consider controls to eliminate a fire (section 9.2.1). Where a fire cannot be eliminated, controls should be implemented to reduce the intensity of a fire (section 9.2.2). In addition to reducing the intensity of the fire, the ammonium nitrate load should be isolated from any fire (section 9.2.3). If such controls are

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implemented, there will be a negligible chance of an explosion during the transport of ammonium nitrate, unless a deliberate act of sabotage is involved.

The concept of layers of protection analysis (LOPA) is considered to be an effective tool to prevent an explosion involving ammonium nitrate. This technique relies on an adequate number of protective layers that must be breached for a final catastrophic outcome, in this case an explosion. When discussing the controls in the following sections, the concept of LOPA should be considered.

In terms of controlling the risk, the hierarchy of risk controls is an accepted practice for determining the suitability of controls to implement to ensure risk is as low as reasonably practicable (ALARP). The highest control in the hierarchy is elimination of the hazard. The controls decrease in effectiveness through substitution, engineering controls, administration controls and personal protective equipment as the lowest level control. This concept is utilised in the following sections to discuss vehicle design considerations for the transport of ammonium nitrate.

Controls for the prevention of a crash are not discussed here and may be considered as part of the risk assessment or design standard for ammonium nitrate transport generally.

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9.2.1 Design of vehicles to prevent a fire

The following controls may be considered to reduce the risk of a fire during the transport of ammonium nitrate. The prevention of a fire will require the elimination of either the ignition source or the fuel.

9.2.1.1 Electrical system

- Relocate the prime mover batteries away from the fuel tanks and to a location protected from impact.
- Review the layout of electrical wiring to increase protection from impact in a crash.
- Install impact and thermal resistant wiring conduit for copper cabling in all vehicles to minimise fire initiation from an electrical short.
- Use sufficient current carrying capacity electrical wiring in conduit and ensure all circuits are protected with adequate fuses or circuit breakers.

9.2.1.2 Fuel system

- Install a shield or lagging between the vehicle engine turbo and diesel fuel lines in close proximity to the turbo to protect the turbo from direct contact with diesel or oil from a fuel line rupture.
- Review the positioning of the engine exhaust system to isolate it from diesel fuel lines.
- Provide shielding between diesel fuel lines in close proximity to the exhaust pipe to prevent diesel from contacting the exhaust in the event of a fuel line rupture.
- Provide additional structural protection for fuel tanks to prevent a rupture of the fuel tank. Consider use of a rubber type bladder, or open cell foam core inside the fuel tank to prevent or reduce spillage of diesel in the event of a vehicle crash.
- Review fuel system installation to protect against an external impact that would release diesel.

9.2.1.3 Fuel load on vehicle

- Reduce the amount of combustible material on the vehicle, including fibreglass and aluminium.
- Use fire retardant packaging and load covers.
- Reduce the use of aluminium alloys including semi-trailer decks, wheel rims and prime mover body components to reduce the combustible fuel load.

9.2.1.4 Fire prevention system

- Install a system to monitor tyre and wheel temperature with an in-cabin display to alert the driver of overheating of a tyre prior to a fire.

9.2.1.5 Other controls

- Fit all vehicles transporting ammonium nitrate with battery rollover protection and battery isolation, as required for transport of Class 1 explosives, ammonium nitrate emulsion and dangerous goods in bulk.
- Segregation of ammonium nitrate from a fire by use of steel bulk container.

9.2.2 Design of vehicles to reduce fire intensity

Regardless of the number and effectiveness of controls to prevent a fire, a fire on a vehicle transporting ammonium nitrate must be considered and appropriate controls put in place to reduce the risk of a fire. The fire could be the result of a failure of equipment during normal operations or from a crash. A failure of equipment during normal operations could include: brake seizure, bearings failure or electrical fault. During a crash at speed, fuel lines and electrical wiring are likely to be damaged that may lead to or intensify a fire.

A number of controls can be put in place to reduce the risk in a fire situation. The following is a list of controls to consider that will reduce the risk:

- Install a fire detection system in the engine bay and cabin that will detect smoke or a fire and alert the driver and external party to a fire.
- Install a fire suppression system in the engine bay, turbo and exhaust system to mitigate or reduce the intensity of a small fire.
- Increase the minimum fire extinguisher capacity for ammonium nitrate vehicles to be consistent with other dangerous goods in accordance with ADGC (i.e. 1x60B or 2x30B per trailer and one 10B in the cabin).
- Install a pressurised water system that can be used to reduce the heat from brakes or bearings or extinguish a fire involving the tyres before it has spread to the load. This will address the emergency procedure guide requirement to have adequate water supply to put out a vehicle fire.

9.2.3 Design of vehicles to isolate fire and contamination from ammonium nitrate

Where a fire occurs on a vehicle transporting ammonium nitrate, the isolation of the fire and contaminants, including combustibles and metals, from the ammonium nitrate will decrease the potential for ammonium nitrate to explode considerably. The likelihood of solid prill, as discussed previously, to detonate in a transport incident is almost impossible.

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Typically the transport of ammonium nitrate in Australia is via three methods:

1. IBCs on flat top trailers
2. BK1 (open at the top) containers as a bulk load
3. BK2 (closed) containers either in IBCs or bulk load

The construction of BK1 and BK2 bulk containers provide some degree of a barrier between the ammonium nitrate and potential fire sources on the prime mover or trailer.

It must be stated again that the recorded explosions of ammonium nitrate prill worldwide have been on flat deck trailers, not in BK1 or BK2 type trailers.

For transport on flat deck trailers, in addition to the controls listed in the previous sections, a vertical fire barrier should be considered between the prime mover and first trailer and a horizontal fire screen should be considered for each trailer. Chapter 6.4.2 of AEC3 provides the requirements for a vertical and horizontal fire screen that should be considered for the transport of ammonium nitrate.

9.2.4 Other design considerations

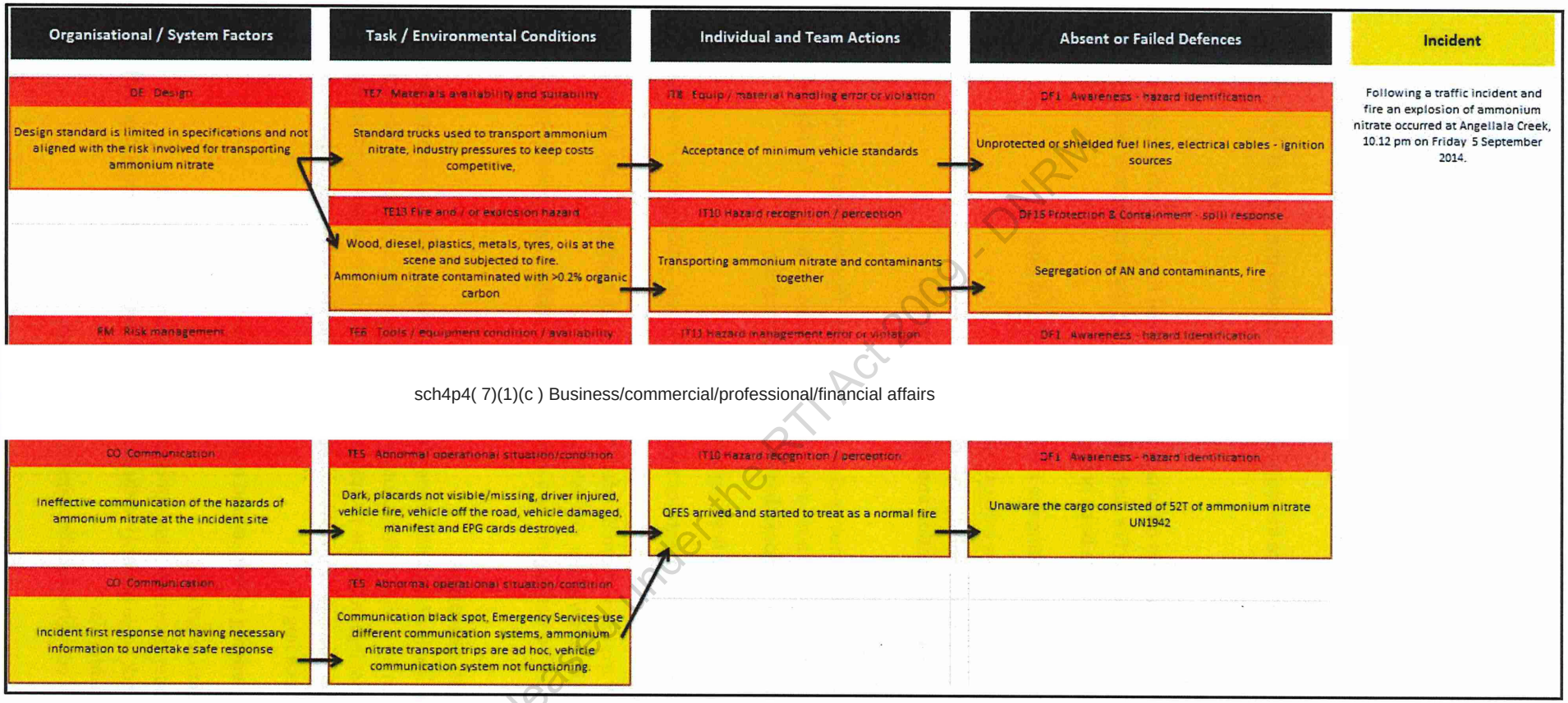
Where a vehicle crash or a fire occurs, the following controls should be considered:

- A fire-proof and blast-proof black box to record video, communications, GPS data and vehicle monitoring systems. This information may be useful to determine the cause of the accident.
- More rapid automated response to overturned trucks including automated G-Force and rollover duress to an external party. This could also alert the company transporting the ammonium nitrate of the incident and they may provide initial technical advice to the emergency services responding to the incident.

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Figure 59 – ICAM chart.



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10 Conclusions

10.1 Cause of incident

10.1.1 Cause of vehicle crash

The vehicle crash was part of the police investigation that concluded the cause of the vehicle leaving the road could not be determined.

10.1.2 Cause of vehicle fire

There was no conclusive determination on what caused the initial fire, or at what location, on the vehicle. Witness accounts indicate the fire was large, consuming the prime mover and first trailer. A number of possible fire scenarios have been proposed.

The most probable scenarios for initiating the fire on the vehicle include:

1. Spilt fuel contacting the engine exhaust and igniting;
2. Electrical arcing igniting the leaking fuel; or
3. Wheel rim being heated by friction and igniting leaking fuel.

10.1.3 Cause of first explosion

The cause of the first explosion could not be clearly determined. This explosion had no overpressure or significant projections and did not cause any structural damage. A number of probable scenarios for this first explosion have been proposed based on the preceding fire.

The probable scenarios leading to this first explosion include:

1. A pressurised piece of equipment (for example a tyre or air tank reservoir) has burst possibly as a result of fire;
2. A gas or thermal explosion from the decomposition of ammonium nitrate as a result of heating has caused a low order explosion;
3. Molten aluminium contacting either a water source or molten ammonium nitrate causing a violent reaction.

10.1.4 Cause of second explosion

The cause of the second explosion could not be clearly determined. The size of the explosion was estimated to be between 10 – 15 t trinitrotoluene (TNT) equivalence, causing significant destruction to infrastructure and blast injuries to the people at the site. No link could be found between the first and second explosions. A number of probable scenarios for the second explosion have been proposed based on a preceding fire.

The probable scenarios leading to this second explosion include:

1. Thermal explosion (cook off);
2. Deflagration under pressure (heat conduction and chemical reaction);
3. Detonation (shock wave driven) – either direct shock detonation transition or deflagration detonation transition; or
4. Water hammer/ concerted void collapse (i.e. hot spot).

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10.1.5 Design of vehicles

The current accepted design of vehicles does not provide controls to reduce the risk of abnormal conditions such as vehicle crash or fire.

All of the previous incidents worldwide where an explosion has occurred on a vehicle transporting ammonium nitrate have been following an intense fire that has involved the ammonium nitrate. All of these explosions have occurred on flat deck type trailers. If the risk of fire is eliminated, controlled or isolated, the chance of an explosion of ammonium nitrate during transport operations is negligible.

To stop this type of incident occurring again there is a need to:

1. Reduce the chance of a fire occurring on transport vehicles by improving the safety design and including fire mitigation controls for if and when a fire does occur.
2. Segregate ammonium nitrate from the prime mover and other large sources of contamination and heat through effective risk management practices.
3. Ensure first responders to an incident site can quickly identify and treat incident according to the hazards present.

10.2 Other contributing factors

There were a number of contributing factors that lead to the fire initiating and propagating the explosion as follows.

10.2.1 Engineering standards

Vehicles used in Queensland to transport ammonium nitrate are generally standard equipment supplied by the manufacturer. sch4p4(7)(1)(c) Business/commercial/professional/financial affairs

sch4p4(7)(1)(c) Business/commercial/professional/financial affairs

4(7)(1)(c) Business/commercial/professional/financial affairs The vehicle has many combustible elements making up its construction and the trailers had aluminium decks. For flat deck trailers, there is no isolation of the load from the prime mover or other fire sources, such as a fire screen.

10.2.2 Risk management effective implementation

Previous ammonium nitrate transport incidents where explosions have occurred have all involved a fire on vehicles with a flat deck trailer transporting IBCs. The manufacturer of ammonium nitrate is aware of risks involved with ammonium nitrate; sch4p4(7)(1)(c) Business/commercial/professional/financial affairs

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A causal connection between the explosion in this incident and risk management processes could not be established. The efficacy of risk mitigation can be significantly disrupted in the event of a vehicle incident.

10.2.3 Communication

Ammonium nitrate trailers are marked with hazardous chemical labels to let public and incident responders identify the vehicles contents. However where the information is lost or the driver is

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unable to provide assistance, public and first responders are uninformed and not made aware of the potential risk involved.

Systems are in place where a vehicle can be monitored through GSM or GPS networks. However they are ineffective where they are travelling through blackspots or are not being monitored live by the company or contracted to an external agency.

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11 Actions already taken

As a result of the incident, a number of actions have already been taken to prevent an incident like this from occurring again. The following actions have been taken:

11.1. On 9 October 2014, the Explosives Inspectorate released an Explosives Safety Alert 86 *Ammonium nitrate explodes during transport incident* in response to the incident at Angellala Creek

11.2. The Explosives Inspectorate proposed a change to the ADGC for the Hazchem code for ammonium nitrate of UN 1942 from 1Z to 1Y to consider the risk of an explosion. The NTC has implemented this change in the current version 7.4 of ADGC that was implemented on 1 January 2016, with a 12 month transition period.

11.3. The NTC is reviewing the fire extinguisher requirements for ammonium nitrate loads in the ADGC to increase the capacity on each trailer from 30B to 60B and require a 10B fire extinguisher in the cabin of the vehicle. This will be considered for version 7.5 of the ADGC that is planned for release on 1 January 2017.

11.4. QFES has recommended changes to Standards Australia for Guide 50 in the emergency procedure guide HB 76. The Explosives Inspectorate supports these changes to improve the response to an ammonium nitrate incident.

11.5. The Explosives Inspectorate has met with the Transport Industry Liaison Group (TILG), a group facilitated by the Explosives Inspectorate, to discuss potential vehicle design improvements to prevent fires on ammonium nitrate vehicles.

11.6. The Explosives Inspectorate has been involved with an ammonium nitrate transport company to review the use of tyre pressure and temperature monitoring devices to detect an overheating tyre prior to a fire.

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12 Recommendations

Based on the findings and conclusions in this investigation, a number of recommendations are detailed in this section.

12.1. A steel vertical and horizontal firescreen be fitted to flat deck trailers transporting ammonium nitrate to isolate the ammonium nitrate load from a fire on the vehicle.

12.2. Reduce the quantity of combustible material on a vehicle, particularly in proximity to ignition sources.

12.3. Regulators and industry representatives to develop appropriate design criteria for vehicles transporting ammonium nitrate that includes safety design features to prevent, reduce and isolate a fire.

12.4. Increase the fire extinguisher capacity and provide additional water on vehicles transporting ammonium nitrate to respond adequately to an initial fire scenario.

12.5. Review the appropriate hazard information on vehicles, including documentation and vehicle marking, and systems to alert external parties to an incident involving ammonium nitrate.

12.6. Communicate ammonium nitrate transport routes to emergency services and remote communities for preplanning of emergency response.

12.7. Update the initial emergency response guide SAA/SNZ HB76:2010 *Dangerous Goods – Initial Emergency Response Guide* (HB76) to reflect the appropriate initial response and evacuation response to an ammonium nitrate fire.

12.8. Further research should be conducted into the initiation of an ammonium nitrate explosion in a transport incident, particularly the interaction of molten metals with molten ammonium nitrate in large loads.

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13 Annex list

1. Orica - Licence to Manufacture Explosives # [redacted] (eDOCS document #4108745)
2. Kalari - Licence to Transport Explosives # [redacted] (eDOCS document #4109073)
3. [redacted] - Training and Induction documents (eDOCS document #4162991)
4. Dangerous goods driver licence application for [redacted] with dangerous goods driver medical (eDocs document #4154018)
5. [redacted] - Interview transcript (eDOCS document #3315286)
6. [redacted] - Record of Current Jobs (eDOCS document #4162981)
7. Kalari - Prime Mover Proof of Purchase (eDOCS document #4202593)
8. Kalari - Trailers Specification (eDOCS document #4161895)
9. Kalari - Dolly Specification (eDOCS document #4161941)
10. Kalari - Statement of Similar truck Specifications (eDOCS document #4415461)
11. Orica - [redacted] email (eDOCS document #4447525)
12. Orica - SDS Nitropril (eDOCS document #3322462)
13. Orica - SDS Armoflo (eDOCS document #4447524
14. DTMR - Main Roads Department, Murweh Shire Plan No. 115 182 (eDOCS document #3227642)
15. DTMR - Level 2 Inspection Report of Angellala Creek Bridge (eDOCS document #3227667)
16. DTMR - Water under Angellala Creek bridge Jon Bundy (eDOCS document #4264407)
17. BOM - Half-hourly weather observations for Charleville Aero 5 September 2014 (eDOCS document #3408313)
18. BOM - Daily rainfall record for Bakers Bend 2014 (eDOCS document #4403036)
19. Timeline of events leading up to the crash (eDocs document #4485549)
20. Timeline for events from the crash to the explosion (eDocs document #4485551)
21. Details of injured people and injuries sustained (eDOCS document #4485550)
22. QPS - Forensic Report (eDOCS document #3225951)
23. QPS - Mechanical Inspection (eDOCS document #3220870)
24. SIMTARS - Electrical Investigation Report (eDOCS document #4405243)
25. Kahl - Metallurgy Technical Evaluation Report rev H (eDOCS document #4405517)
26. Kennedy's - Engineering & Forensic Examination of Prime Mover Report (eDOCS document #4405153)
27. Chris Donovan internal email to Isaac - incident notification from Kalari (eDocs document #4010295)
28. Letter from [redacted] from Kalari providing written confirmation of incident (eDocs document #4445095)
29. Email from [redacted] from Orica providing written notification of incident (eDocs document #4445196)
30. CIE - Assign Incident response team (eDOCS document #4399794)
31. Ryan Brogden notebook entries (eDocs document #4494933)
32. DNRM - Release of Incident Site to DTMR (eDocs document #3228249)
33. DNRM - Release of Incident Site to DTMR – Maps (eDocs document #3228260)
34. Blast Debris Database (eDOCS document #4494215)

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35. Preliminary Report Angellala Creek Investigation (eDOCS document #3327257)
36. Explosives Safety Alert 86 Ammonium nitrate explodes during transport incident (eDOCS document #4405831)
37. Angellala Creek nature and cause investigation plan (eDocs document #3253081)
38. PEEPO data collection (eDOCS document #3406075)
39. Record of Interview transcript (eDOCS document #3315477)
40. Statement (QFES) (eDocs document #3280350)
41. Statement (QPS) (eDOCS document #3219269)
42. Record of interview transcript (eDOCS document #3315481)
43. Re-interview transcript (eDOCS document #4163758)
44. Version of events 9.9.14 14:00 (eDOCS document #3220347)
45. Record of Interview transcript 16.9.14 (eDOCS document #3280366)
46. Statement 5.9.14 (eDOCS document #3219272)
47. Version of events (eDocs document #4494737)
48. Record of interview transcript (eDocs document #4053919)
49. Version of events 9.9.14 (eDOCS document #3220333)
50. and Interview (QPS) (eDOCS document #4098870)
51. Version of Events (eDOCS document #3220326)
52. Record of Interview transcript (QFES) (eDocs document #3280367)
53. Statement 9.9.14 (QPS) (eDOCS document #4223941)
54. Record of interview transcript (eDocs document #4053915)
55. Record of interview transcript (eDocs document #3299951)
56. Record of interview transcript (eDocs document #3299950)
57. Statement (eDOCS document #3320875)
58. Version of events 8.9.14 12:00 (eDOCS document #3227666)
59. Record of interview transcript (eDocs document #4053910)
60. Record of interview transcript (QFES) (eDOCS document #4223969)
61. Version of events 10.9.14 (eDOCS document #3220315)
62. Record of interview transcript (QFES) (eDOCS document #3303681)
63. Version of events (eDocs document #3220338)
64. Kalari - Proof of Purchase of 3 similar vehicles to (eDOCS document #4202593)
65. Kalari - Details of inspections of the similar trucks to (eDOCS document #4541925)
66. Kalari - New Trailer Job Specification (eDOCS document #4161895)
67. Kalari - Dealer Truck Purchase Order for (eDOCS document #4161885)
68. Kalari - Details of inspections of Similar Trucks to (eDOCS document #4541884)
69. Kahl - Metallurgy Report Appendix D Electrical Circuit (eDOCS document #4405511)
70. UQ - Materials Performance Metallurgy Report 04.03.15 stage 1 (eDOCS document #4051432)
71. UQ - Materials Performance Metallurgy Report 28.05.15 stage 2 (eDOCS document #4051437)

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72. UQ - Materials Performance Metallurgy Report 04.01.16 stage 3 (eDOCS document #4405474)
73. QHFSS - Statement of Witness 20.03.15 (eDOCS document #4040391)
74. QHFSS - Addendum Statement of Witness 20.04.15 (eDOCS document #4040381)
75. R Peddie and M Braithwaite – Literature background review of issues arising from the explosion at Angellala Creek (eDOCS document #4494945)
76. http://www.watoday.com.au/wa-news/two-men-dead-in-wubin-truck-crash-20130522-2k26l.html (eDOCS document #4479802)
77. http://www.abc.net.au/news/2014-11-19/ammonium-nitrate-truck-catches-fire-on-stuart-highway-in-nt/5901878 (eDOCS document #4479791)
78. QPS - Traffic Report (eDOCS document #4098881)
79. ARTSA Report – Why trucks catch fire (eDOCS document #4207585)
80. Kalari - GPS tracking data for [redacted] mover (0845) (eDOCS document #4162986)
81. Orica – UN Compliance testing of Yarwun manufactured Nitropril 1st June 2012 (eDOCS document #3322336)
82. Orica – YWAN2131112 Test Series 2a Testing of Yarwun AN2 Nitropril for WA 31st March 2014 (eDOCS document #3322386)
83. Orica – YWAN2131113 Test Series 2a Testing of Yarwun AN2 Nitropril for WA 31st March 2014 (eDOCS document #3322396)
84. Orica – Certificate of analysis and quality for ammonium nitrate manufactured 02-06/09/2014 (eDocs document #3219342)
85. Peterson, Warren. Molten aluminium – ammonium nitrate explosions. Light Metals (1997), pg. 1195 - 1198 (eDocs document #3496279)
86. Seismic record from Geoscience Australia (email Spiro Spiliopoulos (eDOCS document #4004998)
87. Hazardous Industry Planning Advisory Paper No 4 – Risk Criteria for Land Use Planning, Table 7: Effects of Explosion Overpressure, page 22 (eDocs document #4448671)
88. Kalari - Mechanics Competency Letter (eDOCS document #4409023)
89. Kalari - Service History for [redacted] (fleet number 0845) (eDOCS document #4162993)
90. Correspondence from Michael Logan, QFES regarding updated to Guide 50 in HB76 for ammonium nitrate (eDocs document #4479956)
91. Kalari work instruction for risk assessment / hazard management Version 5 dated 26/02/2007 (eDocs document #4202647)
92. Kalari - JHA Safe handling, storage and transport of SSAN Product 20.02.2015 (eDOCS document #4162999)
93. Kalari - Letter stating previous Risk Assessment / [redacted] (eDOCS document #4412614)

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