Australian Government
Australian Transport Safety Bureau

Office of Transport Safety Investigations

Derailment of freight train 4BM4

Nana Glen, New South Wales, on 25 February 2021

ATSB Transport Safety Report
Rail Occurrence Investigation (Systemic)
RO-2021-004
Final – 6 June 2023

Cover photo: Fire and Rescue NSW

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Addendum

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Executive summary

What happened

On 24-25 February 2021, freight train 4BM4 operated by Pacific National (PN) was scheduled to travel from Brisbane, Queensland to Melbourne, Victoria. The train was crewed by two drivers and consisted of three locomotives and 37 wagons.

During the journey, the crew of train 4BM4 experienced heavy rainfall that became more intense the further south they travelled into New South Wales (NSW).

The driver of 4BM4 reported that after departing Kungala (between Grafton and Coffs Harbour in NSW) there was heavy rain and large amounts of water around the rail corridor. After passing Glenreagh they noticed water approaching the rail line that was building up near the rail head about 1-1.5 km before the derailment site. They had recently passed a freight and passenger service that had been through the area but had not been advised of any issues so continued. On exiting a curve on approach to Nana Glen, a section ahead of the train had been washed away at 643.800 km. The drivers did not see the washaway but due to speed and sighting distance they would not have been able to stop if they had.

At 0137, the train passed over the washaway while travelling at approximately 59 km/h and derailed. The first and third locomotives derailed with the third locomotive coming to rest on its side. Ten wagons derailed, some of the wagons entered floodwaters on both sides of the rail line. During the derailment, the second driver received minor injuries and the fuel tank on the second locomotive was damaged and leaked. There were dangerous goods on the train, but they were not involved in the derailment.

There was significant damage to the rail line, rolling stock and freight. The rail line reopened after nine days once flood water had receded, rolling stock was removed and the track was repaired.

What the ATSB found

The network users were not aware of the extent of the severe weather event and had not been advised of an amber alert issued by the weather monitor Early Warning Network (EWN) prior to the derailment. Australian Rail Track Corporation (ARTC) and PN did not provide guidance for train crew on how to respond to extreme wet weather events or floodwater in the rail corridor. There was no guidance for when trains should stop or report if there was water on the track formation, covering the ballast, sleepers or the rail. Neither driver of two previous trains which passed through the section at 0054 and 0110 reported a condition affecting the network (CAN), relating to the poor weather conditions in the vicinity of Nana Glen, to the ARTC network controller. And, although visibility was severely affected, the drivers of all involved services did not slow their trains which reduced their opportunity to sight potential obstructions and safely traverse level crossings.

The culvert located nearest to the derailment at 643.849 km did not have sufficient capacity to discharge the runoff from the rain event on the night of 24-25 February 2021. Floodwater built up on the southern side of the embankment before overtopping the track and washing away the ballast at 643.800 km. The culvert at 643.849 km and numerous other culverts along the Mid North Coast rail network had been identified as far back as 1995, as susceptible to overtopping leading to an increased risk of track washing away.

The driver of 4BM4 observed water in and around the rail corridor after passing Glenreagh but continued close to track speed (between 60-70 km/h) towards Nana Glen. On exiting a right-hand bend, train 4BM4 derailed at a washaway at 643.800 km.

Although ARTC had procedures in place for monitoring and responding to extreme weather events, the process had significant limitations. The mechanism (email) for alerting operational personnel required to respond to amber alerts did not ensure that alerts were always identified or actioned in a timely manner. Furthermore, the actions specified for amber and red alerts were insufficient to respond to escalating rainfall and flooding events, both forecast and actual.

It was also found that ARTC could not reliably determine the risk of flooding along the Telarah to Acacia Ridge corridor or the risks associated with inadequate capacity cross drainage systems. While remote weather monitoring stations were being installed, ARTC had not undertaken formal assessments to determine the need for these stations or the locations where they should be installed to detect extreme weather events that could affect the integrity of its rail infrastructure.

In addition, the weather alerts issued by the EWN did not reliably meet the requirements of ARTC's extreme weather monitoring procedure or the service agreement under which the information was provided. This likely impacted the expectations of ARTC users who relied on these warnings to inform their response.

What has been done as a result

The following proactive safety actions have been communicated by ARTC as being completed, in progress or planned:

- Installed an additional 20 remote weather stations along the Telarah to Acacia Ridge corridor, with plans to install an additional 50 remote weather stations and 500 stream flow monitors across their network in the next two years.
- Developed and implemented a work instruction for the management of flooding and special locations. Introduced an enterprise-wide special locations register (to capture infrastructure such as non-standard culverts) which is maintained through their asset management system.
- In December 2022, ARTC released a safety bulletin which increased the rainfall and flooding alerts by one category (i.e. red alerts treated as black alerts) as a preventative measure based on the cumulated conditions impacting on the network including saturated catchments and the La Niña weather pattern.
- Initially reviewed the contract with the Early Warning Network (EWN) to revise inconsistencies between the contract and extreme weather monitoring procedure (OPE-PR-014) and ensured that monitoring for the Hunter Valley commenced.
- In December 2022, ARTC awarded a new weather monitoring contract to a different provider that incorporated additional requirements for monitoring rainfall near flooding special locations, and flood warnings for specific locations along their network. The service agreement acknowledged the safety-criticality of the information being provided and the contract was prepared in line with the requirements of ARTC procedure OPE-PR-014.
- ARTC also engaged a consultant to undertake a hydrology review of their network. The hydrology review will identify the theoretical hydraulic capacity of all of ARTC culverts along the length of its network. This will determine what the culverts are capable of handling and then use a risk analysis to prioritise the locations for installation of monitors and consideration for upgrading to a greater hydraulic capacity. The hydrology review is being informed by the results of analysis by separate consultant on the effects of climate change focussing on the Brisbane to Albury corridor.
- ARTC advised that they are undertaking a formal review of their extreme weather monitoring procedure. ARTC have initiated a project and engaged a consultant to develop a risk model to support real-time decision-making on operational responses to extreme wet weather events. The first stage of this project is to understand ARTC's current operational responses to extreme wet weather events, and to assess the strengths, weaknesses and opportunities for improvement, having regard to contemporary wet weather incidents and current industry practice. Later project stages will involve the development of a risk model, along with the proposal of strategies to leverage the risk model to better inform ARTC's management of extreme wet weather events.

ARTC also advised it had discussed with PN investigating improvements to the processes and actions required by train drivers and network controllers when flood water is observed in the corridor. PN advised they supported discussion between Rail Operators and the Network Operator with regards to the development of guidance material to support the CAN network rule. The ATSB welcomes the intention by ARTC and PN, however, has issued recommendations to both parties to develop guidance for train crew to respond to and report extreme wet weather events or floodwater in the rail corridor.

The EWN advised that they revised their rainfall alert system and added all ARTC's rainfall monitoring gauges. The locations of ARTC's flooding special locations were added to trigger amber alerts should rainfall exceed the defined threshold. Additionally, monitoring of rainfall depths for the Hunter Valley corridor had been setup and was being performed.

Safety message

Extreme weather events pose a significant risk to the rail network and are likely to increase in frequency and intensity into the future. These events can affect the integrity and exceed the design of rail infrastructure. Rail infrastructure managers must ensure that they have sufficient processes in place to actively identify, monitor and manage foreseeable risks in relation to extreme weather. These processes should be frequently reviewed to ensure that they remain adequate and appropriate.

Both rail infrastructure managers and rolling stock operators must also ensure that they provide guidance and operational procedures to enable consistent responses to conditions that may adversely affect the integrity of rail infrastructure and operational safety.

Contents

The occurrence

Events prior to the derailment

On 24 February 2021, freight train 4BM4 operated by Pacific National (PN) was scheduled to travel from Brisbane Freight Terminal (BFT), Queensland to Melbourne, Victoria. Train 4BM4 consisted of three locomotives (NR43, AN3 and NR39) and 37 wagons with a length of 1459 m and a total mass of 2422 t. The train was carrying dangerous goods located in the 20th, 23rd, 30th and 31st wagons.

At 1750,[1] driver A and driver B commenced their shift at the BFT and departed at approximately 1820. Driver A operated the train from BFT to Kyogle, New South Wales (NSW) where the drivers changed position, and driver B operated the train to Grafton. At Grafton the drivers changed positions again and driver A operated the train towards Nana Glen (Figure 1).

Figure 1: Main north coast rail line

Source: Geoscience Australia, annotated by OTSI

At 0112[2] on 25 February 2021, train 4BM4 travelling in the Up[3] direction diverted into the loop at Kungala (Figure 2) to allow freight train 3MB4 travelling in the Down direction to pass.

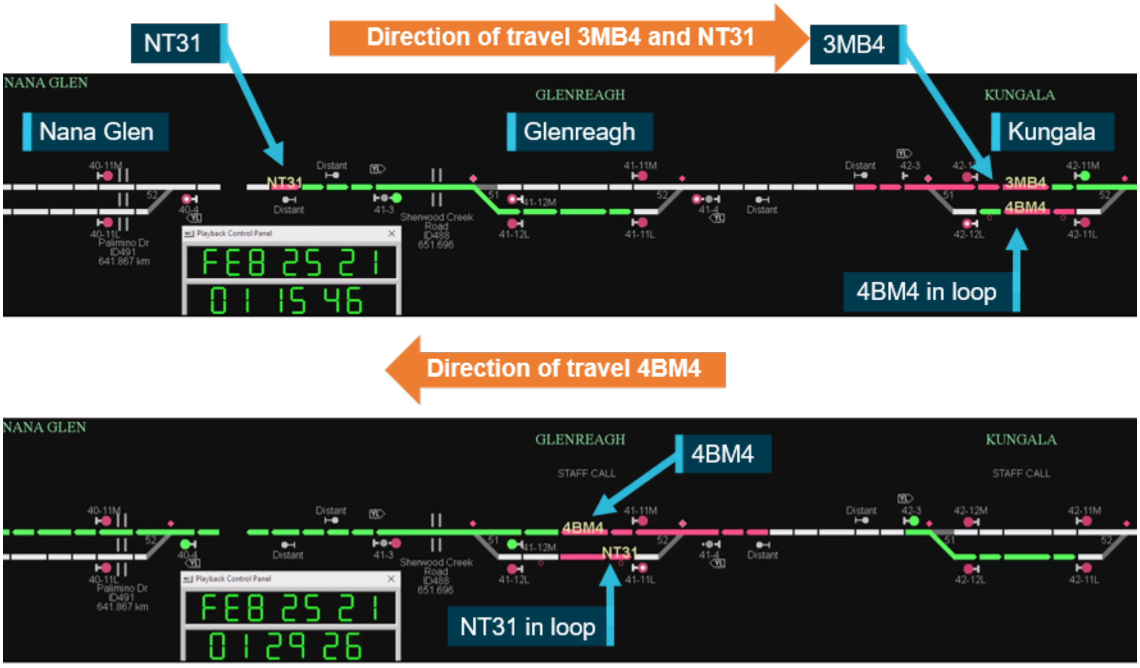
Train 3MB4 was travelling from Melbourne to Brisbane and was operated by PN. This service was followed by the XPT passenger service NT31 that was travelling to Brisbane.

1 Time shown as 24-hour time as Australian Eastern Standard Time (AEST).
2 Times shown in 24-hour time as Australian Eastern Daylight Time (AEDT) for the remainder of this report.
3 The Up direction refers to the direction of travel for trains heading towards Sydney. The Down direction refers to trains heading away from Sydney.

Train 3MB4 passed 4BM4 at 0115 at Kungala and a roll-by inspection[4] was performed. The driver of 3MB4 recalled speaking with 4BM4 by radio and being advised their train was intact.

Following the passage of 3MB4, train 4BM4 departed Kungala at 0120 and operated at around 70 km/h towards Glenreagh. At 0129 train 4BM4 passed an XPT passenger service NT31 that was standing in the loop at Glenreagh (Figure 2). There was no communication between the two trains on passing.

Figure 2: Train crossing movements



The train paths of 3MB4 and NT31 are shown travelling in the Down direction (north) with 4BM4 travelling in the Up direction (south) with crossing movements shown at Kungala and Glenreagh. The upper image shows the trains passing at Kungala at 0115 and the lower shows the trains passing at 0129 at Glenreagh.
Source: ARTC, annotated by OTSI

At interview the driver of 3MB4 advised that they experienced extremely heavy rain from Coffs Harbour onwards and that the windscreen wipers were struggling to cope. They reported that as they reached the top of Red Hill (618.990 km) the rain became more intense and continued as they passed through Coramba and Nana Glen. They recalled noticing rainwater runoff in the corridor during the journey but did not see any floodwater at Nana Glen and continued.

The driver of NT31 reported at interview that between Coramba and Glenreagh the force of the rain was obstructing their visibility. They advised that they did not notice any water in the rail corridor when passing through Nana Glen.

There were no speed restrictions through the area and no track circuit faults at the time of the incident or in the previous 24 hours.

The derailment

Train 4BM4 passed through Glenreagh at 71 km/h and continued towards Nana Glen. The train's speed decreased to 66 km/h by 646.010 km. It gradually decreased to 56 km/h by 644.510 km and was powering in throttle notch 5 to increase speed.

[4] Roll-by inspections were a visual inspection of moving rail traffic to identify equipment, loading security or other defects or failure.

The driver of 4BM4 reported after passing Glenreagh they noticed water in the rail corridor and approaching the rail line. The front of train (FOT) footage showed water built up near the rail and water was visible primarily on the left-hand side of the track (Figure 3). On exiting a 300 m radius curve, the FOT footage showed a section of track that had been washed away a short distance ahead of the train at 643.800 km (Figure 4 and Figure 5).

Figure 3: Floodwater on approach to Nana Glen

The front of train footage showed an accumulation of water in the cess and on the formation primarily on the left-hand side about 130 m prior to the washaway.
Source: Pacific National, annotated by OTSI

Figure 4: Approaching the washaway

The image shows the front of train footage with the section of track immediately ahead of the locomotive.
Source: Pacific National, annotated by OTSI

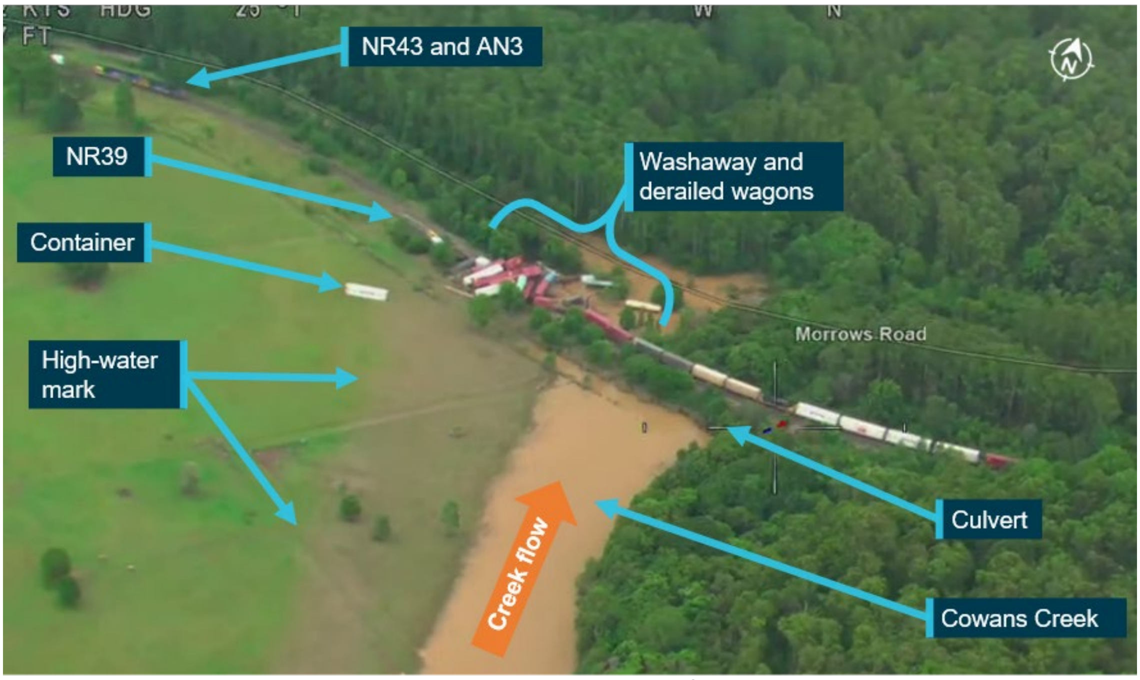
Figure 5: Washaway

The image shows two sections washed away just prior to the train passing over. The floodwater was flowing from left to right.
Source: Pacific National, annotated by OTSI

At 0137 the train passed over the washaway while travelling at approximately 59 km/h. The lead locomotive dipped as it passed over the section of track and derailed, before bouncing out of the washaway and continuing. Both drivers reported they were thrown into the air when they passed over the washaway. Driver A was uninjured and driver B reported that at the time they felt some discomfort in their neck and shoulder.

The first locomotive derailed the first and sixth axles and the second locomotive did not derail. Both locomotives remained upright and came to a stand approximately 360 m from the point of derailment (Figure 6). The train separated between the second and third locomotive with the third locomotive (NR39) coming to rest on its left-hand side in the direction of travel (Figure 7). The first 10 wagons in the consist derailed and concertinaed to the left and right of the rail line as the train came to a stand. A number of wagons entered the floodwaters on the Orara River (northern side) and one container came to a rest in the field on the southern side near the high-water mark (Figure 6).

Figure 6: Derailment site



The image was captured by a helicopter at 1528 on 25 February almost 14 hours after the derailment. At 1530 the river height at Glenreagh (6.48 km north west of the derailment site) was recorded at 10.02 m with water from the Orara River visible on the northern side of the derailment site. The location of the washaway and resting place of the locomotives and wagons are shown. Cowans Creek ran towards the Orara River and drained through a culvert at 643.849 km. The grass was stained with a high-water mark visible where the water had receded.
Source: NSW Rural Fire Service, modified and annotated by OTSI

Figure 7: Third locomotive NR39 derailed

NR39 shown laying on the side with wagons derailed behind. The topography of the area can be seen to rise behind the derailment site.
Source: OTSI

Events post-derailment

Following the derailment driver B contacted the Australian Rail Track Corporation (ARTC) North Coast B Network Controller (NCO) to advise they had derailed. The NCO sought further information and arranged emergency services. Driver A left the lead locomotive to inspect the consist and reported that there were multiple wagons derailed. They were prevented from inspecting further due to floodwaters. The train crew could not confirm if the wagons containing the dangerous goods were involved in the derailment.

Driver B shut down the second locomotive (AN3). The crew left the lead locomotive running so they could keep the headlights on and make it easier to be spotted by emergency services. While inspecting the derailment site further, the crew identified the fuel tank on AN3 was leaking but were unable to block the leak.

A short time later driver B identified a small fire on the air compressor of lead locomotive (NR43) which the crew successfully extinguished with a portable fire extinguisher.

Extensive flooding in the local area prevented vehicle access to the derailment site for several hours. The train crew reported that police arrived approximately two hours following the derailment after walking in on foot. The police remained with them until maintenance personnel arrived around 0630 by road rail vehicle (RRV).

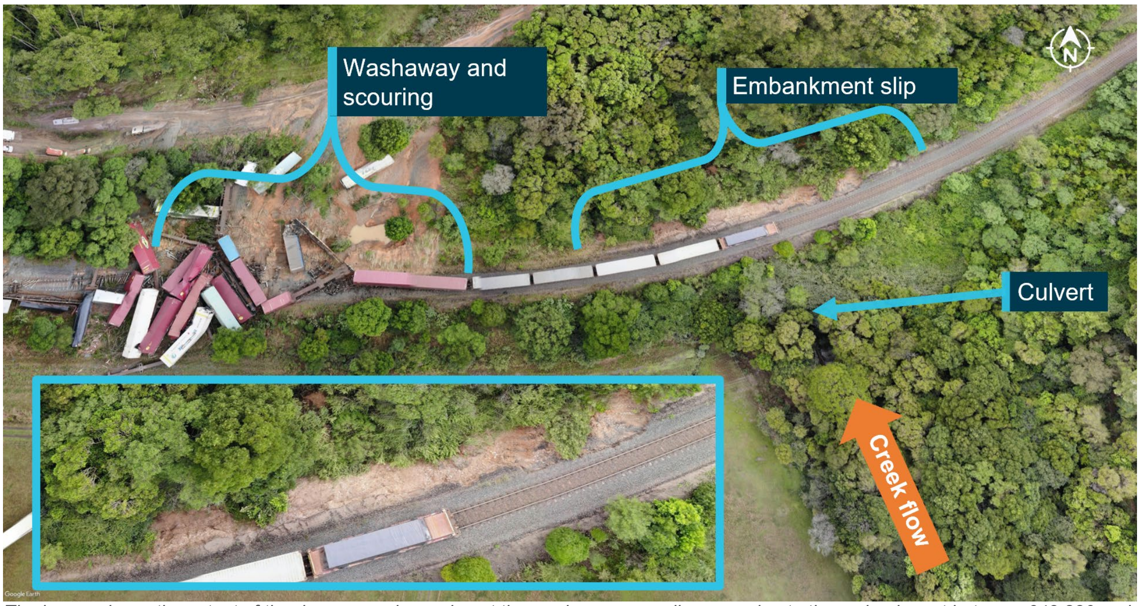
The train crew were evacuated from site shortly after and conveyed to Coramba before being transferred to Coffs Harbour, to be assessed by ambulance officers. The crew were then conveyed back to Brisbane by the operator arriving around 1400.

Post-incident drug and alcohol testing was not conducted as it could not be performed within the required three-hour timeframe.

While AN3, the second locomotive did not derail, the fuel tank cracked during the derailment. Approximately 10,000 L of fuel was believed to have leaked due to a crack in the underside of the fuel tank. Fire and Rescue NSW responded to the site and plugged the damaged fuel tank to prevent further diesel leaking. Containment booms were also used to limit the spread of fuel and oil on the site.

There was damage to the track and embankment at the area of the washaway and derailment. There was scouring[5] on the downstream side of the embankment at the washaway due to the flow of water, with scouring to the toe of the embankment. A land slip had also affected a section of the embankment on the northern side between 643.820 and 643.900 km (Figure 8). The slip came within about 1 m of the end of the sleepers.

Figure 8: Post derailment site



The image shows the extent of the damage and scouring at the washaway as well as scouring to the embankment between 643.820 and 643.900 km. The inset image shows the proximity of the slip to the rail line and sleepers.
Source: Fire and Rescue NSW and Google Earth, modified and annotated by OTSI

The rail line was closed following the incident until the flood waters receded, rolling stock was removed and repairs could be completed. Approximately 140 m of track required repairs to the formation[6] and replacement of rail, sleepers, and ballast. Additionally, about 180 sleepers beyond the washaway also required replacement. The slip along the embankment and near the culvert outlet was repaired using geofabric and rock fill to stabilise the embankment. The rail line reopened with a temporary speed restriction at 2036 on 6 March 2021.

The cost of repairs to the site were estimated to be $1.07 million, and damage to rolling stock and recovery of the wagons estimated at $4.05 million. The cost of the rail line closure, damaged freight, emergency services response and environmental impact were not assessed but would likely have been significant.

[5] Scour: The removal of soil and rocks around a structure though erosion.

[6] Formation: The full width of the top of embankments or the bottom of cuttings upon which the track is constructed. Refer to Figure 21 for graphical representation.

Context

Involved parties

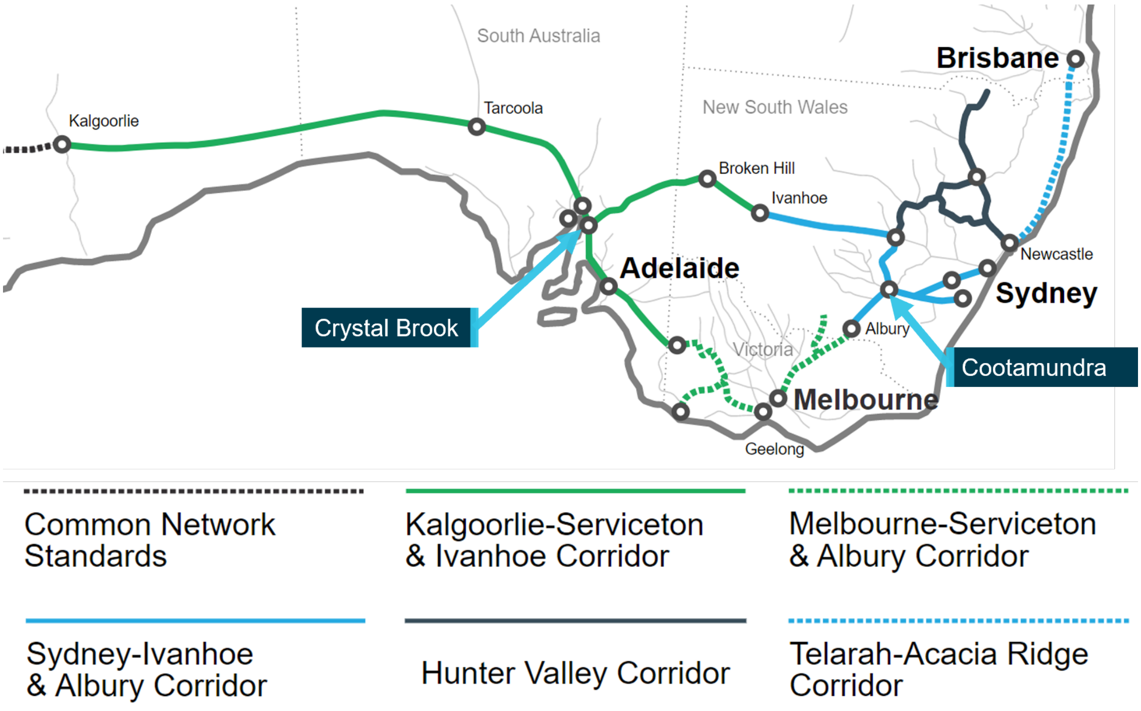
Australian Rail Track Corporation

The Australian Rail Track Corporation (ARTC) was a rail infrastructure manager (RIM) and managed 8500 km of rail network across five states (Figure 9). ARTC owned or leased most of the Defined Interstate Rail Network (DIRN).[7] ARTC divided the DIRN into the east-west and north-south corridors:

- east-west – Cootamundra, NSW to Kalgoorlie, Western Australia (WA) and Crystal Brook, South Australia (SA) to Melbourne, Victoria.
- north-south – Telarah, NSW to Acacia Ridge, QLD and Melbourne to Macarthur (near Sydney).

These corridors were further divided into separate corridors as shown in Figure 9.

Figure 9: ARTC rail network



Map showing the ARTC network and separate corridors.
Source: ARTC, modified and annotated by OTSI

Within NSW, the DIRN and Hunter Valley (HV) corridor were leased to ARTC in September 2004 under a 60-year lease from the NSW Government.[8] The rail assets were transferred to ARTC from the State Rail Authority (SRA) and Rail Infrastructure Corporation (RIC).

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[7] The Defined Interstate was the standard gauge interstate rail line linking the mainland capital cities (except Darwin) and the regional centres of Alice Springs, Darwin, Whyalla, Port Kembla and Newcastle.

[8] The original lease was between the State Rail Authority (SRA), Rail Infrastructure Corporation (RIC) and Australian Rail Track Corporation. In 2007, the assets held or owned by SRA were transferred to RIC. RIC was rebranded in 2010 as Country Rail Infrastructure Authority (CRIA). In 2012 the CRIA was abolished and control of all regional assets, rights and liabilities were transferred to Transport for NSW (TfNSW).

In NSW, ARTC managed the rail network from:

- Islington Junction to North Star/Camurra Junction
- Goobang Junction to Gulgong via Dubbo and Merrygoen
- Telarah to Loadstone
- Macarthur to Albury
- Parkes to Broken Hill
- The Sydney Metropolitan Freight network (MFN).

Pacific National

Services 3MB4 and 4BM4 were both operated by Pacific National (PN) with their own train crew. PN was a privately owned rail freight operator with rail safety accreditation to operate across mainland Australia.

NSW Trains

Passenger service NT31 was operated by NSW Trains, an agency of Transport for NSW (TfNSW).[9] NSW Trains provided rail and coach services for regional NSW, including intercity, regional and interstate train services and a network of connecting coach services.

NSW Trains was a rolling stock operator with rail safety accreditation to operate in NSW, Victoria and Queensland. NSW Trains operated a fleet of electric and diesel hauled rolling stock.

Early Warning Network

Early Warning Network (EWN) was a provider of services relating to adverse weather events, alerts, forecasting, climate risk and other climate related issues. EWN were engaged by ARTC for their weather services through a contract.

Rail line information

Telarah to Acacia Ridge

The Telarah to Acacia Ridge (TAR) corridor was 776 km long and ran from 194.92 km at Telarah to 971.136 km at Acacia Ridge, Queensland. This rail line was also referred to as the main north or north coast rail line as it joined Sydney and Brisbane. The rail line was a standard gauge (1435 mm) single line with loops located along the line to allow passing movements for services travelling in opposite directions, or to allow faster services to pass freight services.

The derailment occurred at Nana Glen which was located about 25 km north-west of Coffs Harbour on the Mid North Coast of NSW.

The TAR corridor was susceptible to East Coast Lows (ECL)[10] which could produce gale force winds, and heavy rain leading to flash flooding and major river flooding. ECL could be difficult for forecasters to accurately predict where they would occur along the east coast and could intensify rapidly.

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9 An NSW Government agency constituted by the Transport Administration Act 1988 Part 1A Section 3C.

10 East Coast Lows (ECL) are intense low pressure systems which occur, on average, several times each year off the eastern coast of Australia, in particular southern Queensland, NSW and eastern Victoria. Although they can occur at any time of the year, they are more common during autumn and winter with a maximum frequency in June. East Coast Lows will often intensify rapidly over a period of 12-24 hours making them one of the more dangerous weather systems to affect the eastern coast. Source: BoM

Coffs Harbour to Kungala

From Coffs Harbour the rail line ran in a north-westerly direction rising up Red Hill to Landrigans before it gradually descended towards Glenreagh. The track speed for freight services in the Up direction varied between 70-100 km/h and 70-125 km/h for passenger services. In the Down direction the speed for freight services was between 60-80 km/h and 75-110 km/h for passenger services.

The track speed for freight services between Glenreagh and Nana Glen was 70 km/h in both the Up and Down direction. The XPT was permitted to travel between 75-95 km/h in that section and through the derailment site the track speed was 75 km/h.

Between Coramba and Glenreagh there were 18 level crossings with the first at 624.727 km and the last at 651.600 km just before the loop at Glenreagh. Only four of those crossings had active protection with the remaining fitted with passive stop signs.

Between Karangi (622.906 km) and Kungala (664.460 km) the rail line ran in close proximity to the Orara River and crossed a number of other rivers and creeks. The Orara River drained to the Clarence River at Grafton and was subject to flooding.[11]

Nana Glen

At Nana Glen there was a loop located at 641 km. The rail line passed over several creeks including Bucca Bucca and Cowans Creek that joined the Orara River. There were a number of curves and the rail line was built on a freestanding embankment at the derailment site. The rail was 60 kg/m and was fastened to concrete sleepers by heavy duty resilient clips. The ballast depth was approximately 300 mm below the sleepers. The subgrade material comprised of clay material from the adjacent cutting.

Train information

4BM4

Train 4BM4 was an interstate freight service operating from Brisbane Freight Terminal (BFT) to Melbourne Freight Terminal. The train consisted of three locomotives, NR43 (leading), AN3 and NR39 and 37 wagons. The train had a total mass of 2422 t and a length of 1459 m.

The wagons were a mixture of containerised freight on single flat top wagons, 5 packs[12] and one well wagon (2 pack). As the train passed over the washaway, the leading portion of the train derailed and divided between the second and third locomotive. When the train separated, the brake pipe was broken, resulting in an emergency brake application along the length of the train.

The following locomotives and wagons derailed or were damaged in the derailment:

- NR43 – derailed the first and sixth axle and remained upright
- AN3 – did not derail, fuel tank damaged and leaked approximately 10,000 L diesel, remained upright
- NR39 – derailed and on rolled on left-hand side, no fuel leaks
- 1st wagon – RCQY00715K

[11] The river height gauge at Glenreagh had recorded moderate flooding (9 m) on 31 occasions between 1972 and February 2021. Of those, 16 moderate floods were recorded between 2007 and 2021. Major flooding exceeding 13 m was also recorded in 2009 and 2013.

[12] An articulated wagon comprising five platforms, the adjacent ends of individual units being supported on a common bogie and permanently connected by a device which permits free rotation in all planes. Note, these do not always consist of five units; they could be 2-packs, 3-packs etc.

- 2nd wagon – RQHY07037G
- 3rd wagon – RRAY07253E
- 4th wagon – RQJW60037P
- 5th wagon – RRQY07306A
- 6th wagon – RQSY34446R
- 7th wagon – NQGY34470Q
- 8th wagon – RQFY00111K
- 9th wagon – RQSY34427K
- 10th wagon – RQJY60000U.

The three locomotives were repaired following the derailment. The 10 wagons derailed were made up of two 5-packs and eight wagons (18 platforms in total). Nine out of the 10 wagons that derailed were damaged beyond repair and scrapped. The cost associated with the damaged rolling stock and recovery of the wagons was estimated at $4.05 million.

There were dangerous goods[13] on the consist but they did not derail and were undamaged. The dangerous goods were located in the following wagons:

- 20th wagon – RRQY08343 – 23,000 L resin solution, flammable – UN No. 1866
- 23rd wagon – RQSY35042 – 40,000 L environmentally hazardous substance,[14] liquid, N.O.S.[15] (wastewater) in two tanks – UN No. 3082
- 30th wagon – RQFY00126 – 23,000 L resin solution, flammable – UN No. 1866
- 31st wagon – RQPW60078F
  - 12,000 kg aerosols, 288 kg paint or paint related material and 224 L paint or paint related material – UN No. 1263.
  - 40 kg flammable liquid, N.O.S (ink) – UN No. 1993.

The combination and quantity of the dangerous goods posed a risk to the train crew and surrounding environment if they had derailed.

Fuel tanks

During the derailment, the fuel tank on AN3 was damaged, causing an 18 mm crack on the underside of the tank. The contents of the 10,800 L tank leaked from the crack. There was other damage to the tank although no other leaks.

The fuel tank on NR39 had several impacts but remained intact during the derailment and when the locomotive rolled over.

The fuel tanks on both NR39 and AN3 were sealed, excluding the vents (breather pipes). The vents had a ball within the valve designed to close the valve in the event of a roll over. This design prevented the fuel from NR39 spilling into the floodwaters and reduced the hazards on site.

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13 Australian Dangerous Goods Code (2020), Australian Code for the Transport of Dangerous Goods by Road & Rail, Edition 7.7. The code details the classification and designation of dangerous goods, including the allocation of UN numbers.

14 The environmentally hazardous substance designation was for substances and mixtures which were dangerous to aquatic environments.

15 N.O.S: not otherwise specified (N.O.S) is the designation for substances not specified elsewhere as per the Australian Dangerous Goods Codes.

NT31

Train NT31 was the scheduled 1441 Sydney to Brisbane XPT passenger service operated by NSW Trains. The train consisted of two locomotives (power cars) and six trailer cars.[16] At the time of passing through Nana Glen at 0109, there were six train crew and 36 passengers on board. The train crew consisted of one driver and five on-board staff.

3MB4

Train 3MB4 was an interstate freight service operating from Melbourne Freight Terminal to Brisbane Freight Terminal. The train consisted of three locomotives and 37 wagons. The train had a total mass of 3327.91 t and a length of 1477.80 m.

There were dangerous goods on two wagons consisting of 27,000 kg of sulphur (molten), 1400 kg aerosols, 96 kg of flammable liquid (corrosive) and 250 kg of paint or paint related material.

Train crew information

4BM4 – Driver A

Driver A of 4BM4 was an experienced rail worker and appropriately qualified train driver. They were employed with PN for over nine years and had worked as a train driver for about six years.

Driver A commenced duty at 1750 on 24 February 2021, at their home depot in Brisbane, to operate train 4BM4 from Brisbane, Queensland to Taree, NSW with a co-driver (driver B). Driver A recalled being fit for duty and feeling refreshed after rostered days off. They were familiar with and experienced on the route, conducting one to two trips per week over the prior 15 months, with most duties at night. They had driven with driver B previously, although they were not the co-driver they would normally drive with.

The train departed the Brisbane Freight Terminal (BFT) at 1820. Driver A stated that the journey was uneventful, up until the period immediately preceding the derailment. They reported that they were not provided with any adverse weather advice, before commencing or during the trip.

Driver A and driver B conducted changeovers in driving duty during the trip. Driver A operated from Brisbane to Kyogle, NSW before handing over to driver B, who operated from Kyogle to Grafton. Driver A resumed driving from Grafton up to the occurrence location.

The train stopped at Kungala, NSW to cross train 3MB4, then continued once clear. The train also crossed train NT31 at Glenreagh, standing in the loop.

Driver A reported that after departing Kungala, there was heavy rain and large amounts of water located around the rail corridor.

Driver A also reported observing rainwater building up in the rail corridor from Glenreagh, and that it was raining steadily. They recalled water mainly on the left side of the train (in the direction of travel), between the ballast and wall of the cutting, with the depth increasing towards the rail head, about 1-1.5 km before the derailment. The water appeared to be stationary, not fast moving.

Driver A reported that they had the locomotive's headlights on but that it was dark, with reduced visibility due to rain. They stated that if they had observed water over the rail head, they would have stopped the train. At the time, they considered that the depth and position of the water, in proximity to the rail, did not meet the criteria for reporting to the Network Controller (NC).

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[16] NT31 consisted of the following carriages, XP2013 (leading), XAM2178, XL2230, XBR2152, XF2203, XF2220, XFH2106 and XP2004 (trailing).

Driver A recalled thinking that it was safe to proceed given two other trains (3MB4 and an XPT) had already travelled through the area, and the drivers of the other services and the NC had not advised them of any issues.

Driver A later reported that on approaching Nana Glen, they noticed the water on the side of the track encroaching towards the rail, with no water visible on the rail. It was dark with heavy rain. Driver A operated the train at around 65 km/h through that section where the maximum permissible speed was 70 km/h in that location.

Driver A stated that as the train travelled around the right curve (direction of travel) at Nana Glen, there appeared to be no indication of any track issues. Suddenly, the lead locomotive dipped and dropped about half a metre into water, before bouncing back up, jolting the drivers around in their seats. Driver A applied the emergency brake but believed the consist may have already separated and waited for the train to stop. The train crew then checked with one another that they were uninjured. Driver A was uninjured. Driver B reported feeling a twinge in their shoulder at the time.

Driver B notified network control while driver A left the cabin with a torch to survey the situation. Driver A observed that a locomotive was on its side, and wagons derailed to the left and right of the track. They were surrounded by water on the left and a significant drop in the topography on the right. A short time after the derailment, the train crew observed a small fire on the lead locomotive. Driver B extinguished the fire using a portable fire extinguisher.

The train crew were evacuated from the site about 0700 on 25 February 2021 by a road rail vehicle. They were then transferred to Coffs Harbour where they were checked by ambulance officers. The train crew were then transferred back to Brisbane by PN.

Driver A roster

In the 14-day period prior to and including the occurrence shift, driver A worked six shifts. They were rostered off from duty for 60 hours before commencing duty on 24 February 2021 (Table 1). Their roster was in accordance with the operator’s fatigue management requirements and there were no identified issues.

Table 1: Actual duty times for driver A for 14-day period

Date	Duty start	Duty end	Duty time	Time free (of duty) before next shift
11 February 2021	1400	2149	7 hours 49 minutes	
12 February 2021	Rostered off			
13 February 2021	Rostered off			
14 February 2021	Rostered off			
15 February 2021	Rostered off			
16 February 2021	Rostered off			
17 February 2021	2015	0900	11 hours 45 minutes	12 hrs 15 minutes
18 February 2021	2115	0702	9 hours 47 minutes	13 hrs 58 minutes
19 February 2021	2300	0600	7 hours	40 hours
20 February 2021	Rostered off			
21 February 2021	2200	0549	7 hours 49 minutes	60 hours 1 minute
22 February 2021	Rostered off			
23 February 2021	Rostered off			
24 February 2021	1750	1340	19 hours 50 minutes	

4BM4 – Driver B

The co-driver of 4BM4 (driver B) was an experienced rail worker and appropriately qualified train driver. They were employed with PN for over nine years as a train driver.

Driver B commenced duty at 1750 on 24 February 2021, at their home depot in Brisbane, to operate as a co-driver for train 4BM4 from Brisbane, Queensland to Taree, NSW with driver A. Driver B recalled being fit for duty at sign on for the occurrence shift. They were familiar and experienced on the route, having operated the service during night shift only.

Driver B reported that the departure of 4BM4 was delayed on 24 February 2021, due to a loading issue. They then proceeded as normal, with driving duties shared with driver A.

Driver B recalled that it had been raining during the trip, with the rainfall intensifying after leaving Grafton. Approaching Nana Glen, they experienced heavy rainfall, which resulted in reduced visibility from the cab. At that time, the locomotive air conditioner malfunctioned, and condensation was building up on the cab windscreen. They reported they did not see any water on the rail.

Driver B reported that during the occurrence trip, there were no weather alerts or condition affecting the network (CAN)[17] issued.

Driver B recalled that they approached the occurrence site at about 65 km/h. The lead locomotive dropped down then bounced out of a dip, up to the other side. Driver B sustained minor musculoskeletal injuries and items in the cab were dislodged. Driver B reported that they did not observe the track washout before the occurrence.

After coming to a stop, Driver B recalled driver A went out with a torch to assess the situation. Driver B notified network control of the derailment and advised that further information would be provided when available. Driver A then advised driver B, via radio, that the lead and second locomotive were separated from the rest of the train, with the third locomotive on its side and the wagons derailed behind.

Driver B continued with further calls to initiate the internal emergency response. The train crew then surveyed the site with torches, to determine if there were any immediate hazards to be managed. The second locomotive was shut down and the lead locomotive left running, to provide lighting from the headlights and visual reference for emergency responders.

The train crew returned to the lead locomotive and secured it. Driver B isolated the electrically driven compressor, which was making significant noise. About 20 minutes later, driver B identified that the compressor’s low oil light was illuminated and went to visually inspect it. The compressor was on fire. Driver B went back to the cab to alert driver A and get the portable fire extinguisher. Driver B then successfully extinguished the fire.

The train crew then identified a fuel spill from the second locomotive, which they reported to emergency services, who were in contact to determine the crew’s location and whether there were any dangerous goods on the train.

The first emergency responders were police officers on foot. Other emergency services and responders arrived after.

Driver B roster

In the 14-day period prior to and including the occurrence shift, driver B worked three night shifts. They were rostered off from duty for over 17 hours before commencing duty on 24 February 2021

[17] Refer to *Condition affecting the network* on page 44.

(Table 2). Their roster was in accordance with the operator's fatigue management requirements and there were no identified issues.

Table 2: Actual duty times for driver B for 14-day period

Date	Duty start	Duty end	Duty time	Time free (of duty)
11 February 2021	2245	0840	9 hrs 55 minutes	
12 February 2021	Rostered off			
13 February 2021	Rostered off			
14 February 2021	Rostered off			
15 February 2021	Sick certificate			
16 February 2021	Sick certificate			
17 February 2021	Rostered off			
18 February 2021	Rostered off			
19 February 2021	Rostered off			
20 February 2021	Rostered off			
21 February 2021	Rostered off			
22 February 2021	Rostered off			
23 February 2021	1400	0022	10 hours 22 minutes	17 hours 28 minutes
24 February 2021	1750	1340	19 hours 50 minutes	

NT31 – Driver C

The driver of NT31 (driver C) was an appropriately qualified regional passenger train driver for NSW Trains, based at Grafton for about 4 years at the time of the occurrence. They had worked as a passenger train driver for about 12 years and employed with NSW Trains as a driver for over 5 years. They were experienced and familiar with the route operated by NT31 between Taree and Grafton, for both day and night operations.

On 24 February 2021, driver C was called out to operate passenger service NT31 from Taree, in place of a rostered duty out of Grafton. They recalled being fit for duty. Driver C was transferred via taxi from their home to Taree Station. NT31's scheduled departure from Taree was at 2008. However, that night the service was delayed by about 80 minutes. Driver C relieved the outgoing driver of NT31 at Taree and continued operating the service to Grafton.

Driver C reported that the weather conditions on the night of the occurrence from Coramba to Glenreagh, were the worst that they had encountered in their driving career. They reported at interview that visibility was significantly reduced ahead, with no visibility to the left or right of the cab, due to intense rainfall. Driver C stated that they did not observe any water in the vicinity of the tracks, noting that the visibility was limited. The train's headlights provided reduced lighting of the track ahead, with the cab windscreen wipers operating at maximum setting. Driver C recalled that they operated through that section from about 0058 to 0120 on 25 February 2021. They had driven a service through the same section two days earlier and there were no noticeable differences between services.

From Coffs Harbour to the distant signal at Glenreagh, NT31 had all green signals. At Glenreagh, the signal indicated that NT31 was to enter the crossing loop. A freight train passed NT31, which Driver C later learned was 4BM4.

NT31 then proceeded towards Kungala, where the NCO informed driver C that there was a derailment at Nana Glen due to the line washing away. The NCO advised they would hold NT31 at the home signal (42-3) at Kungala, so that a freight service could enter the loop. After being held at Kungala for about 30 minutes, NT31 proceeded to Grafton Station where driver C was relieved of duty as planned.

Driver C recalled that they did not make or receive any communication from other train drivers during that duty. They reported that typically, there would only be communications with the freight train crews if they observed any issues with the freight train, or to assist by advising the drivers when their train was clear in a crossing situation.

Driver C reported that they had not received any weather advice or alerts either prior to commencing duty on 24 February, or during that shift. They reported that they were surprised there was no weather alert issued by network control. Driver C was personally aware of a period of ongoing rainfall of about two weeks prior to the occurrence date, as they lived in the region. In their experience, they had previously observed floodwater in the Nana Glen showgrounds area (near 640.500 km) where the loop was located, when there was heavy rainfall. They had not seen water encroach the rail corridor and could not see the area on the night due to the conditions.

Driver C stated that if they observed floodwater in the rail corridor near the rail, they would advise network control. They considered that water approaching the rail head would constitute a CAN.

3MB4 – Driver D

The driver of 3MB4 (driver D) was an appropriately qualified train driver with over 17 years' experience as a freight train driver operating between Melbourne and Brisbane, with the majority of their duties conducted at night.

Train 3MB4 was the last freight train to pass through the occurrence site about 43 minutes before the derailment of 4BM4.

Driver D recalled that while operating 3MB4, the weather slowly deteriorated as the train travelled north. There was no weather advice or alerts received from network control. Driver D also recalled that they received communication from network control about a requirement to maintain 3MB4 ahead of a following XPT service. Driver D reported operating on schedule and driving in accordance with the speed boards.

After departing Coffs Harbour, the rainfall became more intense approaching the top of the range, at Red Hill. Train 3MB4 continued through Coramba towards Nana Glen. Around Nana Glen, there was heavy rainfall, with the maximum speed of the locomotive cab windscreen wipers unable to keep the windows clear, due to the intensity of the rain. They travelled through Nana Glen at 0053 on 25 February, and through the incident site at about 0054. Driver D stated that they did not experience any abnormal line conditions at that time but noted that there was very heavy rainfall.

Driver D reported that they observed water starting to accumulate near the rail line through the section, but not near the level of the rail head. Due to the heavy rain, there were small streams of water runoff in the cess.[18] However, driver D also reported that the amount of rainwater water runoff was not as extensive as they had observed in the past, when operating through the same area. Trees adjacent to the line were hanging low and heavy from the rain, with 3MB4 hitting some low branches as the train travelled through. Driver D noted that the conditions were comparable to those resulting from a thunderstorm and not unusual.

After travelling through Nana Glen, train 3MB4 passed the stationary 4BM4 in the loop at Kungala at 0115. Driver D recalled they communicated with 4BM4, that their train was intact, and they could see the end of train marker as they passed, which was normal procedure. There was no

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[18] Cess: the area between the outermost rail and the boundary of the rail corridor.

other communication between the drivers. Driver D reported that radio coverage to communicate with other trains was limited once they were more than a train length apart. If they needed to communicate further, it would need to be via network control.

Driver D continued and they reported being unaware of the derailment at Nana Glen until their arrival in Brisbane.

Driver D reported at interview that trains would be stopped when water was above the rail head as water would then contact the locomotive traction motors, leading to faults. If water was running across the track, driver D would notify network control. Conditions on 25 February 2021 experienced by driver D did not meet these criteria. Driver D recalled that they had experienced such conditions previously, operating in a southerly direction on that line at Red Hill, towards Sydney, and had notified network control on that occasion.

Environment and weather

Forecast

The EWN provided the daily TAR corridor forecast to ARTC at 0809 on 24 February with the three-day look ahead, the daily forecast stated:

> North of Coffs Harbour, isolated to scattered showers and isolated storms will be possible about the corridor over the course of today as an upper trough combines with onshore winds. Activity will mostly remain weak however there is the low chance of some severe storms occurring between Coffs Harbour and Grafton, and the moderate chance of severe activity north of Grafton to Acacia Ridge. Mostly the risk of damaging wind gusts is expected though the impacts of this will remain quite localised with rainfall rates remaining below the thresholds of concern. Storm activity is unlikely to occur today south of Coffs Harbour with showers expected across the remainder of the corridor.
>
> Tomorrow will see showers and storms develop across the entire corridor as a broad area of instability extends along the eastern coastline of NSW. Expect the highest risk of severe storms to occur between Newcastle and Kempsey though rainfall rates will remain below the thresholds of concern. North of Kempsey, activity will tend more isolated with showers with activity largely remaining weak (though the risk of damaging winds cannot be ruled out).

Associated with the forecast was a colour coded geographical breakdown of the TAR corridor between Woodville Junction, NSW and Acacia Ridge, Queensland. The section NSW/QLD Border and Acacia Ridge were coded as amber[19] with a moderate risk (30-50 per cent) of severe storms. Between Coffs Harbour and Grafton it noted low risk (10-30 per cent) of severe storms and they were colour coded as green (Figure 10). The forecast for the three days (Thursday to Saturday) ahead were also colour coded as green.

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[19] Amber refers to ARTC's classification of the risk associated with the weather. See Weather monitoring and response on page 37 and Table 9 for further details relating to the colour coding of weather alerts.

Figure 10: EWN TAR corridor forecast 24 February 2021

	Past 24hrs Rainfall	Next 24hrs Rainfall	Forecast Wind Speed	Max Temperature	Min Temperature	Existing Severe Weather Alerts & Comments	External Alerts
Woodville Junction (Newcastle Nobbys)	7mm	3-7mm	5-20km/h	25	19	-	-
Telarah (Maitland AP)	1mm	3-7mm	5-15km/h	24	17	-	-
Taree	15mm	4-8mm	5-15km/h	24	19	-	-
Kempsey	18mm	3-7mm	5-15km/h	25	19	-	-
Coffs Harbour	42mm	10-25mm	5-20km/h	25	20	Low risk severe storms	-
Grafton	56mm	15-35mm	5-15km/h	25	19	Low risk severe storms	-
NSW/QLD Border (Casino)	56mm	20-40mm	5-15km/h	26	19	Moderate risk severe storms	-
Acacia Ridge (Archerfield)	12mm	10-25mm	5-20km/h	29	21	Moderate risk severe storms	-

Colour coded geographical breakdown of the TAR corridor with rainfall recorded in the previous 24 hours and predicted rainfall for the next 24 hours. Nana Glen was between Coffs Harbour and Grafton.
Source: Early Warning Network

The Bureau of Meteorology (BoM) provided two forecasts on 24 February 2021 for the Mid North Coast district, with the first issued at 0515 stating:

> Weather Situation - A low pressure system lies near New Zealand, while a ridge of high pressure across Victoria extends an onshore flow across the eastern districts of New South Wales. A trough lies across inland New South Wales, and is likely to promote unsettled weather in many central and eastern districts over the coming days.
>
> Forecast for the rest of Wednesday 24 February - Cloudy. High (80%) chance of showers. The chance of a thunderstorm during this afternoon and evening.

The second forecast was issued at 1630 and contained the same notes for the weather situation and the forecast noted 'High (80%) chance of showers. The chance of a thunderstorm'.

NSW Trains utilised the BoM forecasts as well as any warnings from various rail network operators to inform their network services weather alerts. On 24 February these alerts were communicated at 0830 and 1800 to their operational personnel and were posted at train crewing sign on areas.

PN advised that their personnel within Integrated Planning Services (IPS) monitored the BoM website during extreme weather events. There was also a dedicated television screen that displayed the weather radar to monitor weather events. PN advised that use of some of this information was reliant on receiving weather alerts or reports of issues from either trains or network operators. In relation to defining if it was safe to operate trains, PN relied on ARTC as the rail infrastructure manager (RIM) to monitor and respond to extreme weather events.

Weather warnings and alerts

At 2152 on 24 February 2021 the BoM issued the following severe thunderstorm warning:

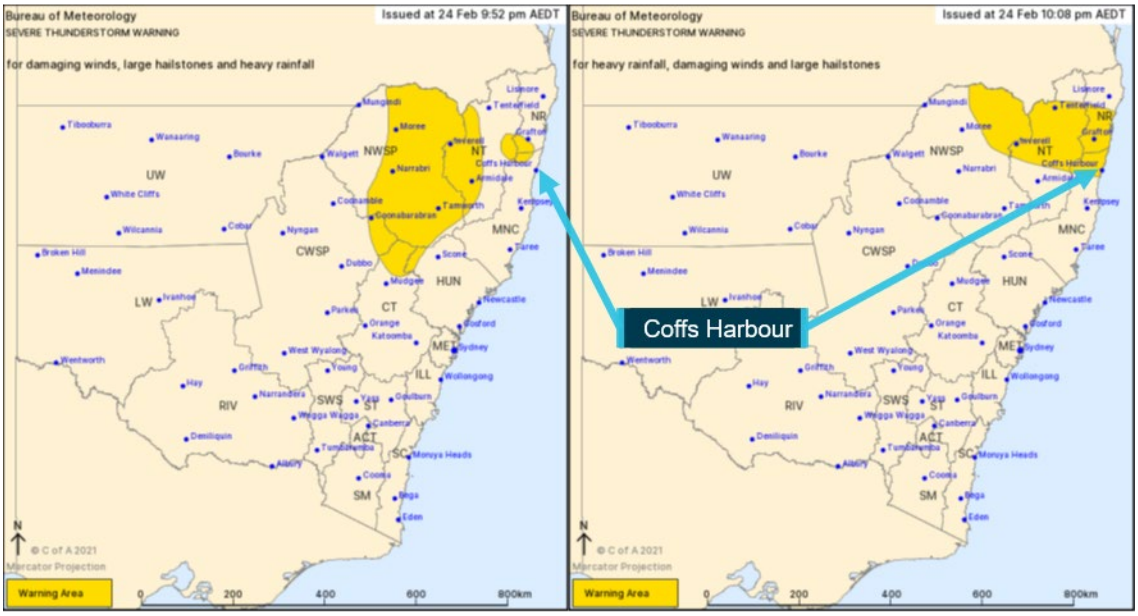
> Severe thunderstorms are likely to produce damaging winds, large hailstones and heavy rainfall that may lead to flash flooding[20] over the next several hours in the North West Slopes and Plains and parts of the Hunter, Central Tablelands, Central West Slopes and Plains and Northern Tablelands districts. Locations which may be affected include Armidale, Tamworth, Gunnedah, Moree, Narrabri and Coonabarabran.

[20] Flash flooding: flooding occurring within about six hours of rain, usually the result of intense local rain and characterised by rapid rises in water-levels.

> Severe thunderstorms are likely to produce heavy rainfall that may lead to flash flooding over the next several hours in parts of the Northern Rivers, Mid North Coast and Northern Tablelands districts. Locations which may be affected include Coutts Crossing, Nymboida and Glenreagh.

This warning was identified by the EWN as relevant and EWN communicated the alert to ARTC at 2159. The warning stated that heavy rainfall may lead to flash flooding and listed Glenreagh as an area that may be affected. The initial warning was communicated by the EWN to ARTC as an amber alert within 7 minutes of the BoM issuing the warning. The BoM threat map as depicted in the warning did not appear to show that the rail line would be affected by the weather event (Figure 11).

Figure 11: BoM severe thunderstorm warning 2152 and 2208 24 February 2021



The threat map for the severe thunderstorm warning issued at 2152 is shown on the left with the warning issued at 2208 on the right. In the later, the threat map warning area changed with the warning area now stretching to the coastline.
Source: Bureau of Meteorology, annotated by OTSI

The EWN advised that they reviewed each alert generated by the BoM and communicated those assessed as genuine alerts to ARTC. If the BoM issued more than one warning for the same weather event, the warnings would only be communicated to ARTC if there was an escalation of the event or significant time had passed between the warnings.

The BoM issued three further severe thunderstorm warnings prior to the derailment (Table 3). The subsequent warnings were not assessed as an escalation by the EWN, and ARTC received no further warnings.

The second alert issued by the BoM at 2208 provided similar information to the first alert however the threat map showed the warning area over a larger portion of the north coast and could impact the rail line (Figure 11). The warning escalated the threat to 'Severe thunderstorms are likely to produce intense[21] rainfall that may lead to dangerous and life-threatening flash flooding'.

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[21] The Bureau of Meteorology classified intense rainfall as rainfall over a period between 30 minutes and 6 hours which exceeds the 2 per cent Annual Exceedance Probability (AEP) depth. Heavy rainfall was classified as rainfall over a period between 30 minutes and 6 hours which exceeds the 10 per cent AEP depth.

Table 3: Severe weather warnings

Date	Time	Warning Description	Comments
24 February 2021	2152	Severe thunderstorms are likely to produce heavy rainfall that may lead to flash flooding over the next several hours in parts of the Northern Rivers, Mid North Coast and Northern Tablelands districts.	Amber alert issued to ARTC at 2159.
	2208	Severe thunderstorms are likely to produce intense rainfall that may lead to dangerous and life-threatening flash flooding, damaging winds and large hailstones in the warning area over the next several hours.	No alert issued by EWN. Escalation of threat level by BoM. Change of threat map area.
25 February 2021	0114	Severe thunderstorms are likely to produce heavy rainfall that may lead to flash flooding over the next several hours in parts of the Northern Rivers, Mid North Coast and Northern Tablelands districts.	No alert issued by EWN.
	0132	Severe thunderstorms are likely to produce heavy rainfall that may lead to flash flooding over the next several hours in parts of the Northern Rivers, Mid North Coast and Northern Tablelands districts.	No alert issued by EWN.

Prior to the derailment, the BoM issued two flood warnings for the Orara River at Glenreagh. The first warning was issued at 0003 on 25 February with minor flooding occurring at Glenreagh and flooding predicted to reach 5.8 m by 0200. The second warning was issued at 0034 with minor flooding occurring and flooding predicted to reach 7.4 m by 0200. Following the derailment, there were eight other flood warnings issued for the Orara River at Glenreagh and Coutts Creek (33 km north-west of the derailment site) between 0200 and 2045.

Weather observations

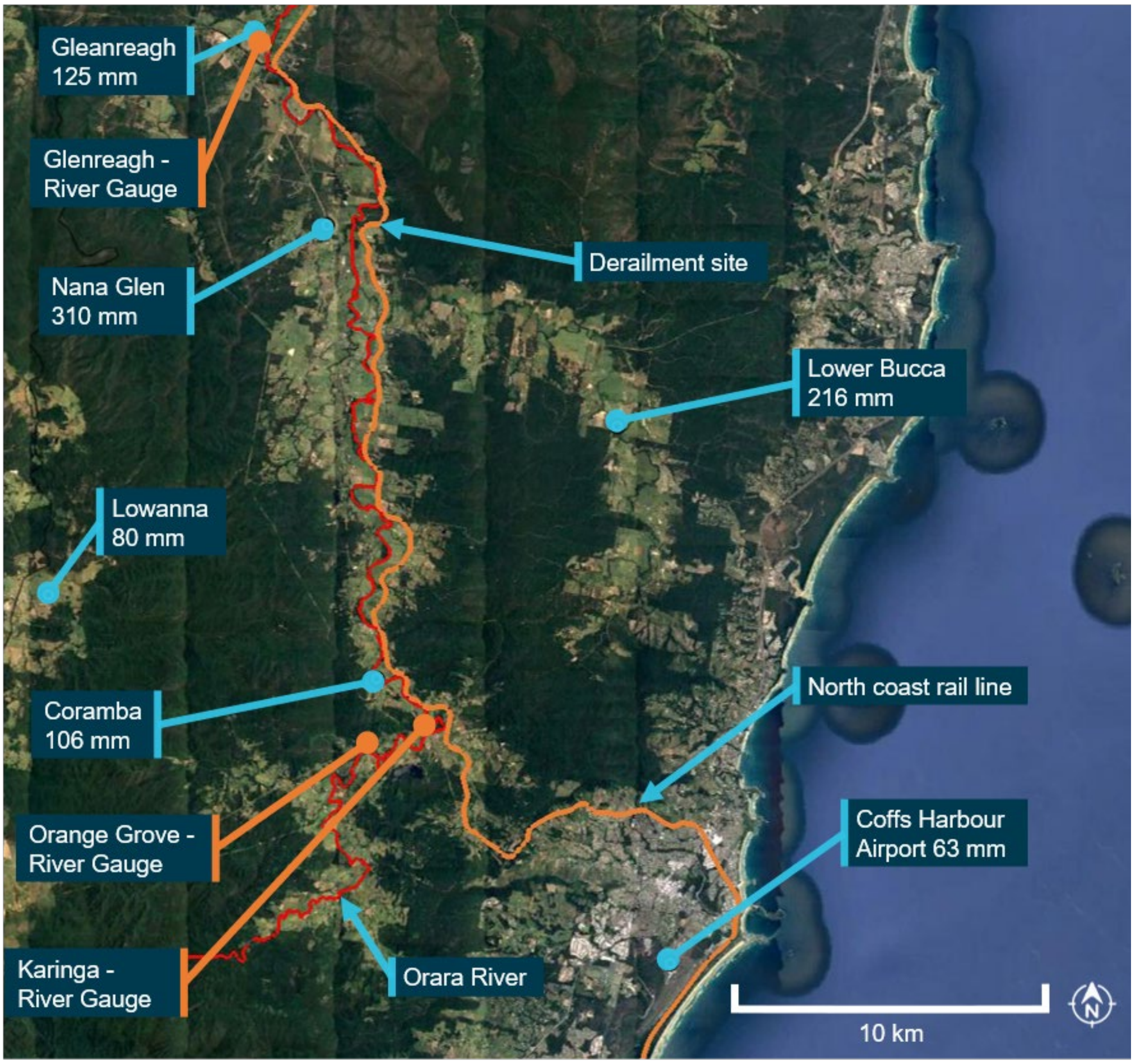
Rainfall

The BoM weather station at Nana Glen[22] recorded 310 mm of rain to 0900 on 25 February 2021. This was the highest recorded rainfall for this station. This station provided readings on a 24-hour period but it was likely that the 310 mm fell over a much shorter duration.

Weather stations surrounding the area recorded between 80 mm and 216 mm while Coffs Harbour recorded 63 mm in 24 hours (Figure 12).

[22] Recorded at the Nana Glen (Cowling Close, Station ID 059139) weather station which was located 1.59 km west of the derailment site on the opposite side of the Orara River.

Figure 12: Record rainfall at 0900 on 25 February 2021 and river height monitoring locations



The figure shows the north coast rail line in orange with the recorded rainfall for weather stations around the derailment site. The Orara River is shown in red with the locations for the river gauges at Glenreagh, Orange Grove and Karinga marked in orange.
Source: Google Earth, annotated by OTSI

River heights

Between 0000 and 2000 on 24 February 2021 the Orara River at Glenreagh[23] rose from 1.83 m to 2.75 m, the height then rapidly rose to 8.59 m by 0130 on 25 February 2021. Rises in river height were also recorded at Orange Grove and Karangi[24] in the same period (Table 4 and Figure 12). The Orara River at Glenreagh peaked at 10.59 m after the derailment at 0930 on 25 February before beginning to recede. The river height would likely have peaked earlier at Nana Glen as the gauge at Glenreagh was approximately 8.8 km further downstream.

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[23] Glenreagh Bridge river monitoring equipment (BoM Id: 559066) was 6.48 km north west of the derailment site.

[24] River height gauges at Orange Grove (BoM Id: 559018) was 17.05 km south-south west from the derailment site and Karangi (BoM Id: 559023) was 16.56 km south of the derailment site (Figure 12).

Table 4: Orara River heights 24 - 25 February

Date	Time	Glenreagh	Orange Grove	Karinga
24 February 2021	0000	1.83 m	2.46 m	1.43 m
	2000	2.75 m	2.47 m	1.46 m
	2100	2.96 m	2.64 m	1.54 m
	2200	3.55 m	3.04 m	1.68 m
	2300	5.30 m	3.57 m	1.88 m
25 February 2021	0000	6.98 m	3.79 m	2.13 m
	0100	8.15 m	3.81 m	2.29 m
	0130	8.59 m	3.97 m	2.35 m
	0200	8.94 m	3.86 m	2.39 m

Source: Bureau of Meteorology

There was no river height monitoring for the Bucca Bucca Creek which joined the Orara River about 2 km south-west of the derailment site. Lower Bucca recorded 216 mm of rain which would have very likely contributed to the rapid rise in the river height at Glenreagh (Figure 12).

Radar

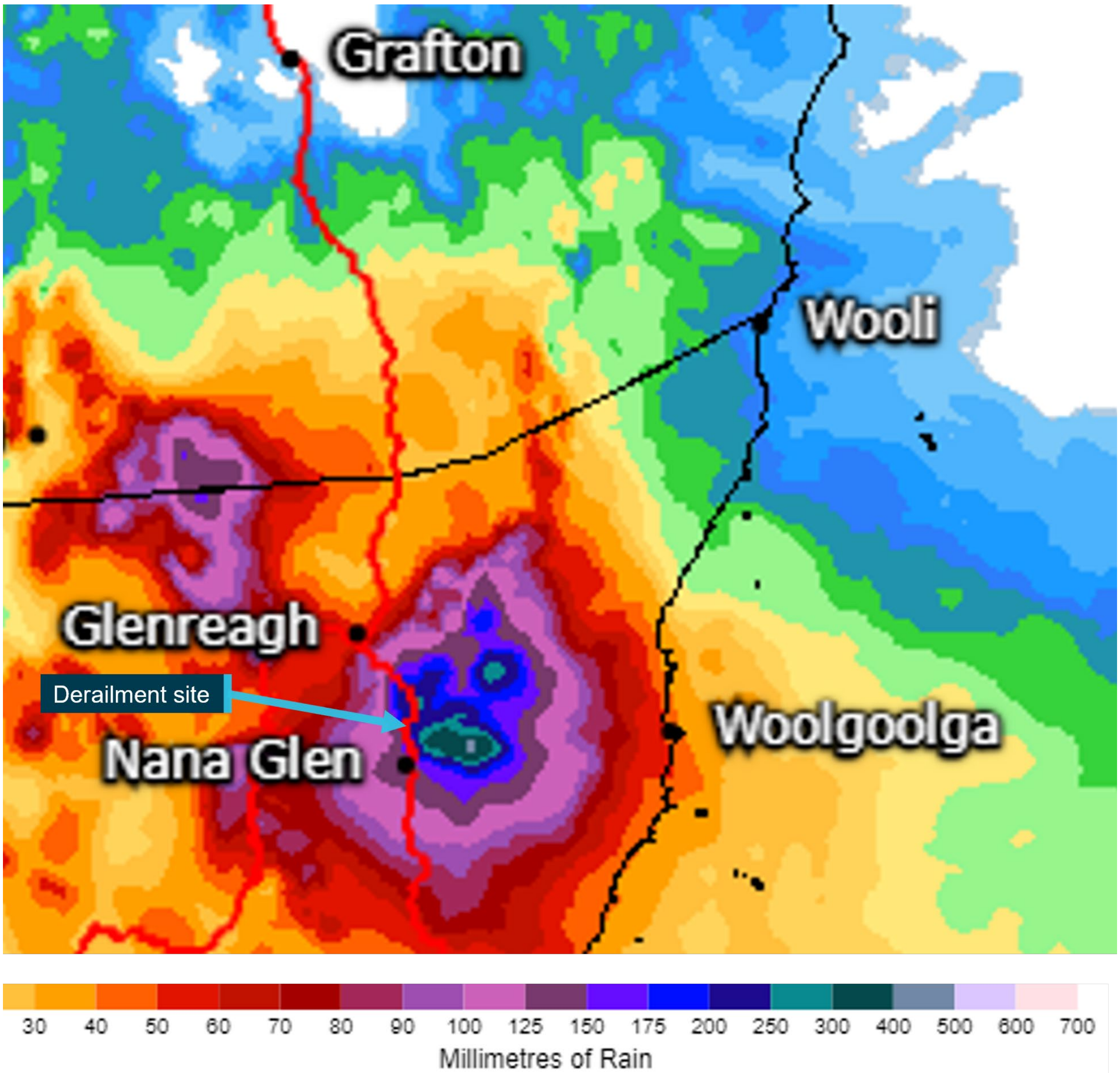
The BoM Grafton weather radar[25] was the primary weather radar for the North-East of NSW, with a southern range to Kempsey. It was located at the NSW Agriculture Research Station, Grafton, about 57 km north of the occurrence site.

The Grafton weather radar indicated consistent light to moderate precipitation (up to 35 mm/h) in the Nana Glen region, from 1710 on 24 February. The rainfall intensity increased in the area from about 2030, up to 50 mm/h, then up to 80 mm/h at 0050 on 25 February. A rain band of heavy intensity remained in the area and was present at the time of the derailment.

Simulations undertaken by the EWN for the rainfall accumulations based on the Grafton radar in the 6-hours to 0115 on 25 February, suggested rainfall of between 200-300 mm may have fallen near the derailment site (Figure 13). Rainfall exceeding 300 mm may have fallen further east which was likely outside the catchment for Cowans Creek.

25 The BoM Weather Watch radars were effective for the detection of rain. These radars could be used by forecasters to interpret the patterns and intensity of the radar images, to provide warnings of major weather events such as severe thunderstorms and areas of heavy rainfall. The radar images showed the location of rain in relation to local features such as the coastline, with different colours used to depict rainfall intensity.

Figure 13: 6-hour rainfall accumulations to 0115 on 25 February 2021



Simulated radar rainfall accumulations shown with the colours depicting the accumulated rainfall depth on the map with the scale at the bottom. The approximate location of the derailment site is depicted.
Source: EWN, modified and annotated by OTSI

Climate conditions

In the months leading up to the event, the BoM declared a La Niña[26] weather pattern (Climate Drivers Update - 29 September 2020). In December 2020, the BoM predicted (Climate Drivers Update – 22 December 2020) that there would be above average rainfall January to March for most of the eastern third of Australia, which included the TAR corridor.

The effects of the La Niña as noted in the Australian Institute for Disaster Resilience (AIDR) *Major Incidents Report 2020-2021* were that:

> The 2020–21 La Niña increased the likelihood of rain bearing weather patterns over eastern Australia and it reduced evaporation due to increased cloudiness and reduced temperatures. These conditions

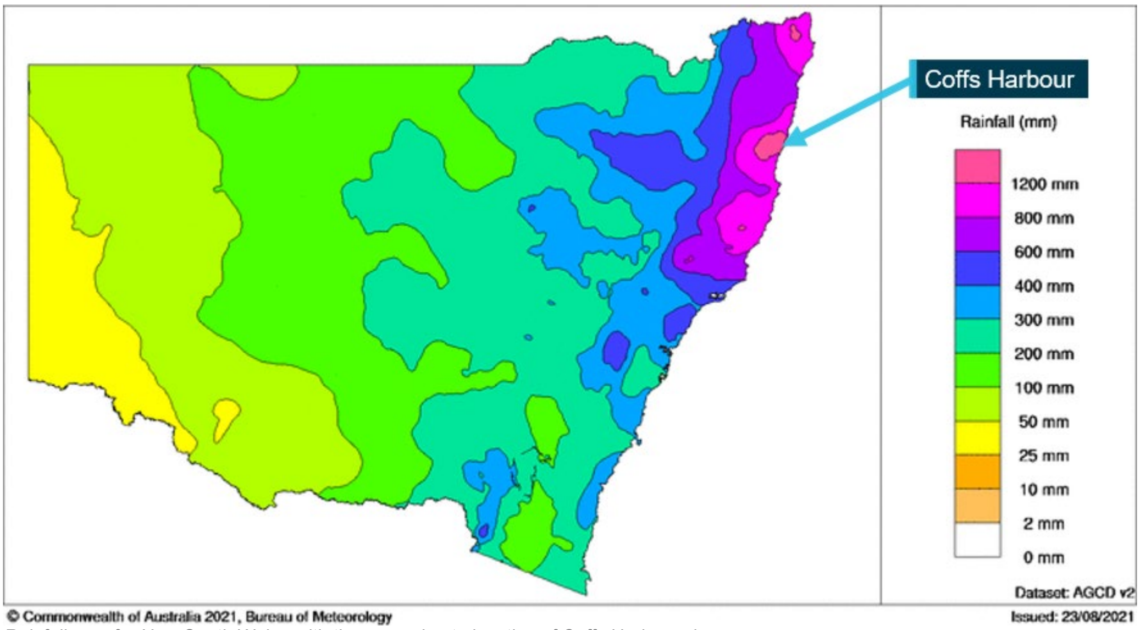
[26] La Niña events increase the chances of above-average rainfall for northern and eastern Australia during spring and summer. The La Niña is influenced by the trade winds and water temperatures of the Pacific Ocean and are of the El Niño Southern Oscillation (ENSO). ENSO is the oscillation between El Niño and La Niña conditions. While La Niña will typically result in above average rainfall the El Niño with typically result in below average rainfall.

resulted in an increase in soil moisture during the spring and summer, meaning any heavy rainfall on the wet catchments saw less water soaked up by the ground and a tendency for rivers to respond more quickly and reach higher levels compared to dry catchments.[27]

Actual rainfall preceding months

Between 1 December 2020 and 28 February 2021 large sections of the north coast of NSW recorded rainfall between 600 mm and 1400 mm (Figure 14). In the same period the weather station at Nana Glen recorded a total of 1530.8 mm, with 581.6 mm in December, 358.2 mm in January and 591 mm in February. Large sections of the north coast recorded rainfall either very much above average or highest on record between December to February (Figure 15).

Figure 14: New South Wales total rainfall (mm) 1 December 2020 to 28 February 2021



Rainfall map for New South Wales with the approximate location of Coffs Harbour shown.
Source: Bureau of Meteorology, annotated by OTSI

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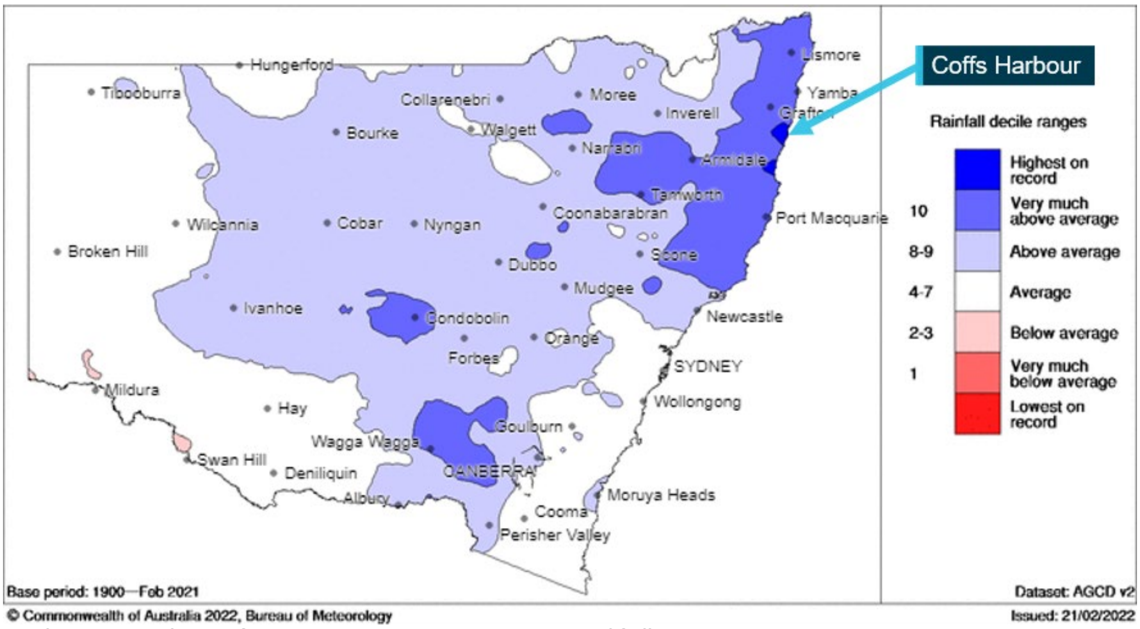
[27] Australian Institute for Disaster Resilience (2021), Major Incidents Report 2020–21

Figure 15: New South Wales rainfall decile ranges 1 December 2020 to 28 February 2021



Rainfall decile map for New South Wales with the approximate location of Coffs Harbour shown.
Source: Bureau of Meteorology, annotated by OTSI

Climate change

The *North Coast Climate change snapshot* predicted that in both the near future (2020 to 2039) and far future (2060 to 2079) that the NSW North Coast was likely to experience:

- increases in maximum temperature and number of hot days above 35°C
- decreased rainfall in winter but increased rainfall in autumn and spring
- summer rainfall was projected to decrease in the near future but increase in the far future.[28]

The existing TAR rail corridor was designed prior to considerations of climate change and in some areas the infrastructure did not meet modern standards.

In relation to rainfall, it was noted in the *State of the Climate 2020* report that:

> Observations show that there has been an increase in the intensity of heavy rainfall events in Australia. The intensity of short-duration (hourly) extreme rainfall events has increased by around 10 per cent or more in some regions and in recent decades, with larger increases typically observed in the north of the country. Short-duration extreme rainfall events are often associated with flash flooding, and so these changes in intensity bring increased risk to communities.
>
> …
>
> As the climate warms, heavy rainfall events are expected to continue to become more intense. A warmer atmosphere can hold more water vapour than a cooler atmosphere, and this relationship alone can increase moisture in the atmosphere by 7 per cent per degree of global warming. This can cause an increased likelihood of heavy rainfall events. Increased atmospheric moisture can also provide more energy for some processes that generate extreme rainfall events, which further increases the likelihood of heavy rainfall due to global warming.[29]

The impact of more intense rainfall on existing infrastructure will likely be significant. Particularly in areas where the design of drainage systems does not meet modern standards or where the rail

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28 NSW Office of Environment and Heritage (2014), North Coast Climate change snapshot

29 Bureau of Meteorology and CSIRO (2020), State of the Climate 2020

corridor is in close proximity to rivers and creeks. However, the influence of these changes may not be felt immediately.

Network control

Network Control Centre

The train control function for the DIRN within NSW was performed by the Australian Rail Track Corporation (ARTC) Network Control Centre South (NCCS) located at Junee, NSW.

The NCCS controlled the interstate operations on the DIRN between Acacia Ridge to Telarah, Macarthur to Melbourne, and Cootamundra to Broken Hill (Figure 9). The NCCS also controlled the Sydney Metropolitan Freight network.

The incident occurred within jurisdiction of the NCCS Coast B Board (known as the North Coast B Board), from Kempsey Signal 30-1 at 503.863 km to Acacia Ridge (Queensland) AR 1 Signal at 971.136 km. This section was a single line and method of train control was Rail Vehicle Detection (RVD).[30]

The NCCS was managed by the Service Delivery Manager (SDM), who reported to the General Manager Operations.

The Train Transit Manager (TTM), who reported to the SDM, was responsible for management of the transit of trains across the interstate network, in accordance with customer access contracts. The TTM role provided supervision of the NCCS, including the Network Controller (NCO) roles.

The role of the NCO was to oversee the day-to-day operational control of safeworking systems, including:

- guide plans and manage the movement of trains over the ARTC network
- control and recording of train performance
- movement of trains and track vehicles over prescribed sections of ARTC's railway network in accordance with ARTC Safe Working Rules and Procedures.

The Hunter Valley corridor was managed by the Network Control Centre North (NCCN) located at Broadmeadow, NSW. The NCCN was responsible for monitoring and responding to extreme weather events for the Hunter Valley corridor. The control centre operated in a similar manner although had some different titles due to the nature of the coal network operations.

Train Transit Manager

The TTM on duty, at the time of the occurrence, had over 17 years of experience in that role. They were trained and certified as competent.

The TTM was rostered on the night shift, from 2200 on 24 February to 0600 the following morning. They reported that they were fit for duty and did not recall feeling fatigued.

The TTM recalled at interview that they were aware that the north coast region was flooding but could not exactly recall how they were aware other than information from previous shifts. They stated that weather information was available by accessing weather radar data via the BoM website but that they relied on the EWN alerting system in operation in the NCCS.

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30 Rail Vehicle Detection (RVD): the portions of line where the system of safeworking relies on track circuiting or axle counters.

The TTM reported that the computer displaying Bureau of Meteorology (BoM) weather radar images, in the foyer area of the NCCS, was generally for local area information and interest, and was not a designated weather information source.

The TTM stated that their role involved active monitoring and problem resolution within the NCCS, with minimal time in the separate TTM office, where their computer was located. In the event that an EWN amber alert was issued, it was transmitted to them via email. However, they would need to be at their computer to receive it. The NCOs would receive an amber alert email to their workstations if it was emailed to them by the TTM, but these may not be read. The TTM could not recall if an amber alert was issued or current at the time of the occurrence.

The TTM reported that on the night shift, they may convene a meeting at midnight with the NCOs, dependant on what was happening. The process was not documented and consisted of verbal discussion and briefing on relevant issues, such as weather and/or upcoming work/possessions. The TTM could not recall if a meeting was conducted with the NCOs during the occurrence shift.

Train Transit Manager roster

In the 14-day period prior to and including the occurrence shift, the TTM worked 13 shifts, with a single rostered calendar day free from any duty.

The TTM's worked roster for that period contained two shift changes that were backwards rotating, with a minimum period away from duty of eight hours, between shifts (Table 5).

Table 5: Actual duty times for TTM for 14-day period (local times)

Date	Duty start	Duty end	Duty time	Time free (of duty) before next shift
11 February 2021	0600	1400	8 hours	16 hours
12 February 2021	0600	1400	8 hours	16 hours
13 February 2021	0600	1400	8 hours	16 hours
14 February 2021	0600	1400	8 hours	32 hours
15 February 2021	2200	0600	8 hours	16 hours
16 February 2021	2200	0600	8 hours	8 hours
17 February 2021	1400	2200	8 hours	8 hours
18 February 2021	0600	1400	8 hours	16 hours
19 February 2021	0600	1400	8 hours	56 hours
20 February 2021	Rostered off			
21 February 2021	2200	0600	8 hours	8 hours
22 February 2021	1400	2200	8 hours	24 hours
23 February 2021	2200	0600	8 hours	16 hours
24 February 2021	2200	0600	8 hours	

Network Controller

The NCO on duty on the North Coast B Board, at the time of the occurrence, had over 24 years of experience in NCO roles and had worked at ARTC's NCCS since its commencement in 2004. They were trained and certified competent.

The NCO was rostered on the night shift, from 2300 on 24 February to 0700 the following morning. They reported that they were fit for duty.

On sign on, the NCO was assigned the North Coast B Board for the duration of the shift. At the time of the occurrence, the NCO had been on duty for about 2.5 hours. They reported that their plans were already in place and were in the execution phase. They stated that they did not feel fatigued.

The NCO reported that up until the derailment, the shift was uneventful, with normal traffic and workload patterns. The NCO recalled that there were no active weather warnings for the area, that they were aware of, in the period prior to the occurrence.

The NCO reported that weather information was available in the NCCS via a computer displaying the Bureau of Meteorology (BoM) weather radar images. The NCOs were also able to access the BoM weather radar images at their workstations. In addition, the Train Transit Manager (TTM) received weather alerts via email, which they would then verbally communicate to the relevant NCOs.

The NCO reported that 'stand-up meetings' were conducted around the period each NCO shift started. The TTM would brief the NCOs on several items, including any network issues and weather alerts. The NCO could not recall if a meeting was conducted at the commencement of the involved shift but considered that it would have occurred.

While the NCO later reported that they had received a briefing from the Train Transit Manager, ARTC had no record of any briefings completed on 24 or 25 February 2021.

The NCO recalled that their first communications with the involved train crew was a radio call from the driver reporting the derailment and location. The NCO reported that after checking on the welfare of the crew, the emergency response commenced. During the response, heavy rain in the area continued delaying the arrival of personnel to the derailment site.

The NCO reported feeling surprised when the derailment was reported, as the XPT had traversed the same section of track about 30 minutes earlier, without incident or report of a CAN, such as water near the rail head.

Network Controller roster

In the 14-day period prior to and including the occurrence shift, the NCO worked 11 shifts. In the seven-day period, from 11-18 February 2021 inclusive, the NCO worked 68 hours. The operator's guidelines were for a maximum of 60 hours worked in seven days.

The NCO's worked roster contained several shift changes that were backwards rotating, with a minimum period away from duty of eight hours, between shifts (Table 6).

Table 6: Actual duty times for NCO for 14-day period (local times)

Date	Duty start	Duty end	Duty time	Time free (of duty) before next shift
11 February 2021	Rostered off			
12 February 2021	0800	1600	8 hours	15 hours
13 February 2021	0700	1500	8 hours	12 hours
14 February 2021	0300	1500	12 hours	12 hours
15 February 2021	0300	1500	12 hours	32 hours
16 February 2021	2300	0700	8 hours	8 hours
17 February 2021	1500	2300	8 hours	16 hours
18 February 2021	1500	0300	12 hours	58 hours
19 February 2021	Rostered off			
20 February 2021	Rostered off			

21 February 2021	1500	2300	8 hours	8 hours
22 February 2021	0700	1500	8 hours	32 hours
23 February 2021	2300	0700	8 hours	16 hours
24 February 2021	2300	0700	8 hours	

Network Control Centre South fatigue management

The operator's *WHS-WI-423 Fatigue Work Instruction*[31] outlined their processes to manage risks associated with fatigue. It applied to all ARTC employees, including those employed in the NCCS. A Fatigue Monitoring System was not in operation at the NCCS.

Section 2.2 *Schedule work hours* documented 'hours of work guidelines' including:

- Maximum hours in 7 days 60 hours
- Maximum hours in 14 days 108 hours
- Maximum hours in 28 days 192 hours
- Forward rotation of shifts Day -> Afternoon / Night -> Night.

The document stated that 'forward rotation of shift means a pattern of shifts that rotate from day to afternoon to night'.

The documented stated that 'should work be required outside of these guidelines, the likely level of additional risk(s) involved will be assessed and appropriate risk control measures identified'. The method/process for assessing additional risks and identifying appropriate risk control measures was not defined, nor what control measures should be applied.

ARTC reported that where the shift cycles did not conform with the guidelines in WHS-HI-423, the 'NCCS ensures the minimum specified time between shifts (8hrs) is applied and confirms at the start of every shift, as part of the sign on process, that each Network Controller is fit for work and not suffering the effects of fatigue'.

Track standards

Flooding

ARTC's Code of Practice *Section 10 Flooding*[32] detailed how flooding was to be managed. The standard was divided into three sections including design and ratings, construction and maintenance, and inspection and assessments.

Design and ratings

The design of waterways[33] and drainage systems was to be in accordance with Australian Standard AS 5100,[34] Waterways Design Manual, Australian Rainfall and Runoff and Australian standards as applicable. ARTC advised that the applicable standards were AS 7637 and RTS 3433 for new railways on greenfield sites.[35]

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[31] Australian Rail Track Corporation (2018), WHS-WI-423 Fatigue, Work Instruction, V4.1, 14 March 2018

[32] Australian Rail Track Corporation (2011), Code of Practice, Flooding, Section 10, V2.2, 8 November 2011

[33] Waterway: A channel or stream. In relation to hydraulic structures, the area available for water to pass through or under a structure.

[34] Australian Standard AS 5100:2017, Bridge Design – Parts 1 to 9

[35] Rail Industry Safety Standards Board (2013), AS 7367:2013, Railway Structures, and Australian Rail Track Corporation (2013), RTS 3433, Track Drainage – Design and Construction, Issue A, Revision 1, 6 June 2013

These standards did not apply to existing infrastructure and there was no requirement to assess existing drainage systems against these standards. Additionally, this standard did not define the design flood events (flood immunity)[36] or the floodwater level relative to the track for a flood event.

Construction and Maintenance

This detailed the requirements for cleaning waterways and that care must be taken when performing maintenance to avoid undermining embankments or retaining structures.

Inspections and assessments

A register of special locations was to be established and maintained for sections of track that had been prone to flooding and flood damage.

Scheduled inspections were required, with patrol inspection performed weekly and general inspection performed annually. The persons conducting the patrol inspection were to keep a look out for scouring, blockage or partial blockages of waterways and indications of flood damage such as overtopping[37] and culvert or drain damage. The general inspection required additional inspection for scouring around culverts and structures, erosion to waterways and blockages or loss of slope for track drains and waterways.

Unscheduled inspections were required at flooding special locations or in response to suspected defects found during a patrol inspection, automatic rainfall monitoring or reported heavy rain and flooding. These inspections were required to check the integrity of the waterway and drainage systems and monitor the flood conditions until the risk had passed.

At the time of the derailment in 2021, there were no flooding special locations registers for NSW. The Corridor Manager (CM) reported that due to the flood prone nature of the TAR corridor they considered the entire corridor as a flooding special location.

Structures

Code of Practice *Section 9 – Structures*[38] was applicable to the design of new railways, road and rail bridges, culverts, and other significant structures on greenfield sites.

In relation to bridges and culverts, the design requirements for waterway infrastructure were dependant on the discharge of water through the structure. Major undertrack structures with discharges greater than 50 m^3/sec were to be designed to 1% Annual Exceedance Probability (AEP),[39] structures with discharge less than this were considered minor and were designed to 2% AEP or 50 Annual Recurrence Interval (ARI).[40]

New bridges were required to be designed to have a flood immunity and serviceability limit of 100 ARI or 1% AEP as required by AS 5100.[41] ARTC reported that most existing bridges were built for 100 ARI flood events, although there was no requirement to confirm their flood immunity or serviceability limit.

Replacements of existing culverts was not addressed as part of the standard and there was no requirement to assess an existing structure against this standard.

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36 Flood Immunity: A measure of the protection provided to infrastructure for a certain flood event (i.e. a bridge that is considered to be immune to a 100-year ARI flood is predicted to not be overtopped during this event).

37 Overtopping: The rising of water over the top of a structure.

38 Australian Rail Track Corporation (2019), Code of Practice, Structures, Section 9, V3.7, 31 January 2019

39 Annual Exceedance probability (AEP): the probability of a rainfall event being equalled or exceeded within a year.

40 Average Recurrence Interval (ARI): the average time period between occurrences equalling or exceeding a given value.

41 Australian Standard AS 5100:2017, Bridge Design – Parts 1 to 9

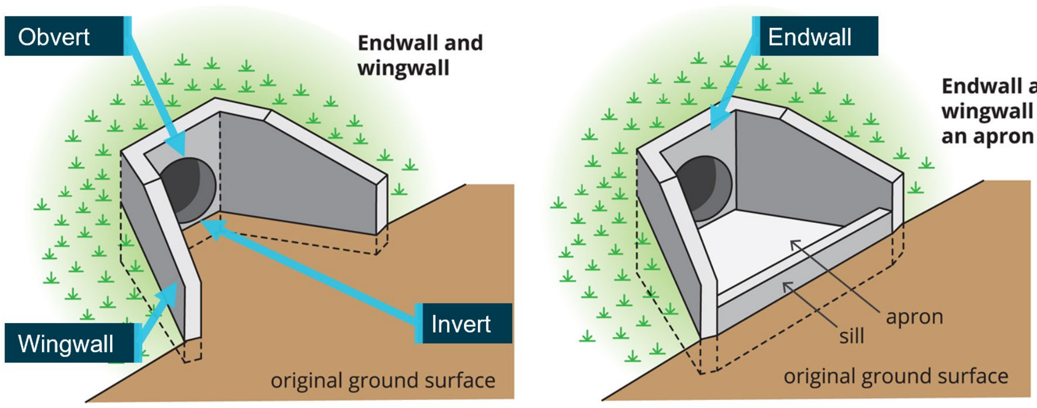
Structures – culverts

The maintenance requirements for culverts were detailed in *Structures Inspection ETE-09-01.*[42] Culverts less than 500 mm were maintained and inspected by the civil maintenance team with larger culverts required to be inspected by qualified structural inspectors.

Culverts required a visual inspection every two years, with an inspection latitude of 10 per cent (±73 days). The purpose of the inspections was to assess the physical condition of the structure and that the structure was safe for operational purposes (continued safe use).

The inspection criteria included checking the culvert for subsidence, cracking, blockage and deformation or broken / separated joints. The inlets and outlets were also checked for cracking of the headwalls and wingwalls, scouring under the apron and heaving of the floor (Figure 16). Defects were defined based on the size or type of defect with a corresponding defect category. Depending on the defect size, the response ranged from monitoring to immediately stopping trains. Culverts that were blocked by more than 20 per cent were required to be reported, while less than 20 per cent could be monitored.

Figure 16: Culvert endwall structure



Source: Australian Rainfall and Runnoff, modified and annotated OTSI.

Technical Maintenance Plan

The maintenance requirements for ARTC's infrastructure were detailed within their *Civil Technical Maintenance Plan ETE-00-03.*[43] This document detailed what items required inspection and the frequency of the inspection. The maintenance inspection requirements for structures were defined with the Code of Practice *Section 9 – Structures* and *Structures Inspection ETE-09-01* as above.

Track patrols were conducted weekly from a road rail vehicle along the corridor. The inspection scope was a general visual inspection and included but was not limited to inspection of the rail, sleepers, ballast, track geometry, earthworks, structures, drainage, signage, and level crossings.

While track patrols were conducted regularly, the inspections were limited to the detection of large or obvious defects on or near to the rail line.

More detailed general inspections were carried out annually, with those relevant to the occurrence below:

42 Australian Rail Track Corporation (2019), Structures Inspection, ETE-09-01, V2.6, 20 August 2019

43 Australian Rail Track Corporation (2021), Civil Technical Maintenance Plan, ETE-00-03, V4.3, 27 October 2021

- Earthworks – Inspection of embankments, cuttings, and geotechnical sites. Inspections included checking for slippage, slumping or heaving, scouring and erosion of track and embankments.
- Flooding – inspection of waterways, surface drains (cess, top and toe), cess drainage pipes less than 500 mm.

Maintenance records

The maintenance records provided showed that the section of track had been inspected in accordance with ARTC's TMP requirements with the most recent relevant inspections detailed at Table 7.

Review of the recent inspections against rainfall at Nana Glen and river height at Glenreagh on the day of the inspection and in the week prior, did not identify any periods of heavy rainfall that would have led to flooding at Nana Glen. During the most recent inspections, it was likely that there were no obvious signs of water accumulating at the culvert at 643.849 km.

Table 7: Recent maintenance inspections

Date	Task	Track kilometrage
21/09/2018	Visual Inspection of Large Culvert	643.849 km
25/11/2019	Visual Inspection of Small Culvert	643.481 km
25/11/2019	Visual Inspection of Small Culvert	644.015 km
27/02/2020	General Inspection of Earthworks - Geotechnical Sites	486.827 km to 739.620 km
05/05/2020	General Inspection of Earthworks - Embankments and Cuttings	486.827 km to 739.620 km
05/05/2020	Drainage - General Inspection	486.827 km to 739.620 km
24/06/2020	General Inspection of Waterways and Drainage Systems	486.827 km to 739.620 km
19/08/2020	General Inspection of Ballast	486.827 km to 739.620 km
30/08/2020	Visual Inspection of Large Culvert	643.849 km
19/01/2021	Detailed Inspection of Track Geometry - Recording Car	486.827 km to 739.620 km
11/02/2021	Front of train inspection	486.827 km to 739.620 km
16/02/2021 and 17/02/2021	Track Patrol	486.827 km to 739.620 km
23/02/2021 and 24/02/2021	Track Patrol	486.827 km to 739.620 km

Track drainage

Derailment site

The track at Nana Glen was in place when ARTC took over the management of the rail corridor in 2004. While details for the locations of culverts was recorded in their asset maintenance system, ARTC did not have any detailed design specifications or drawings for the culverts.

In the immediate vicinity of the derailment site at 643.800 km there were two culverts passing through the embankment with: a large culvert at 643.849 km and a small culvert at 644.015 km. The embankment at the site had a maximum height of between 5-10 m high. There was also a small culvert at 643.481 km that was not within the embankment but any flows that bypassed the culvert would have flowed towards the large culvert at 643.849 km.

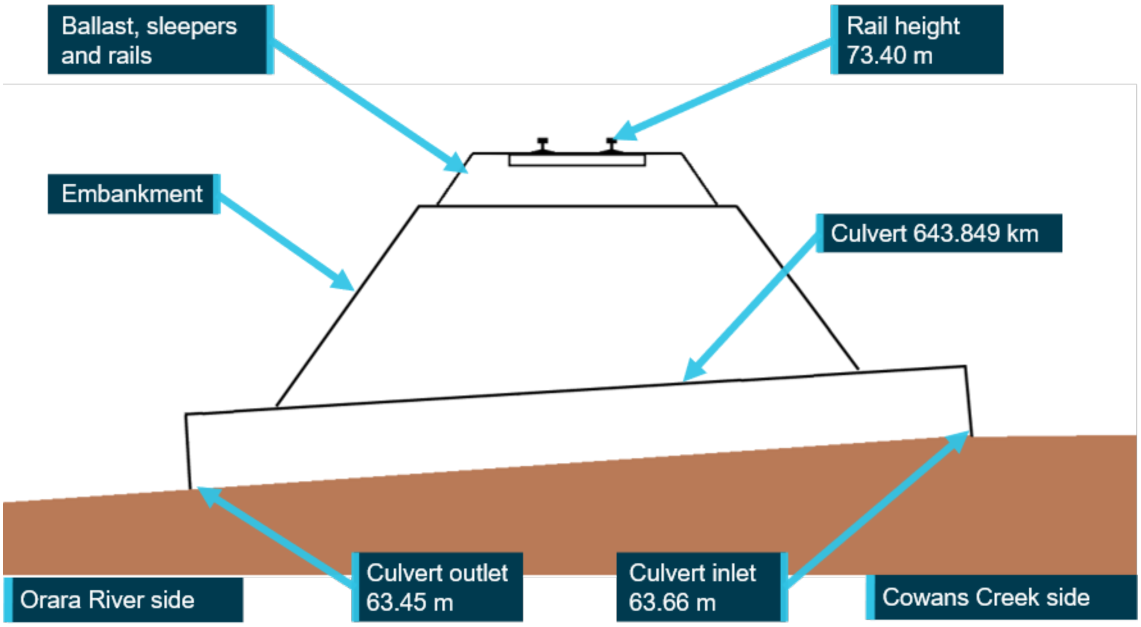
The culvert at 643.849 km was a steel reinforced concrete pipe and was 24 m long with a nominal diameter of 2 m (2020 mm x 1970 mm). The inlet elevation to the invert [44] was 63.66 m and the outlet invert was at 63.45 m (Figure 17).[45] The culvert invert was nominally 9.8 m below the top of the rail, which was at an elevation of 73.398 m. The inlet and outlet of the culvert had concrete headwalls and wingwalls (Figure 18 and Figure 19). The slope of the culvert was approximately 1.7 in 200 (1.7 m in 200 m). There were no records for when this culvert was installed.

For further details relating to culverts see *Appendix C – Culvert concepts*.

The culvert at 643.849 km was inspected on 30 August 2020 and on 21 September 2018.

Photographs taken on 28 February and 1 March 2021 showed that some debris had collected around the inlet and some small branches were near the inlet. These photographs showed that the culvert about the water line was not blocked. Some of the debris would likely have moved as the water levels receded.

Figure 17: Track drainage



Drawing depicting a cross section of the embankment at the derailment site through the culvert at 643.849 km. The elevations for the culvert inverts and rail heights are also noted. Not to scale. The elevations were in reference to the Australian Height Datum.
Source: OTSI

[44] Invert refers to lowest interior level or floor of a culvert, trench or tunnel. The obvert refers to the highest interior level or ceiling.
[45] Elevations referenced to the Australian Datum Height (ADH).

Figure 18: Culvert inlet

The inlet of the culvert at 643.849 km is shown with the headwall and wingwalls. Debris was present near the inlet with some small branches laying across the channel as well as collected above the culvert.
Source: ARTC, modified and annotated by OTSI

Figure 19: Culvert outlet

The outlet of the culvert at 643.849 km is shown with the headwall and wingwalls. The culvert was visibly clear above the waterline and the branches visible at the inlet could be seen.
Source: ARTC, modified and annotated by OTSI

The large culvert at 643.849 km permitted Cowans Creek to flow through the embankment towards the Orara River. Cowans Creek ran in a northerly direction and was fed by runoff water coming from the south-east and flows coming off the steep escarpment which rises to approximately 300 m above the derailment site (Figure 20). The approximate catchment[46] size for Cowans Creek required to discharge through the culvert at 643.849 km was approximately 400-450 ha or 4-4.5 km^2.

There were two other smaller culverts located on either side of the derailment site (643.481 km and 644.015 km) that allowed water to flow towards the Orara River. These culverts were not fed from Cowans Creek.

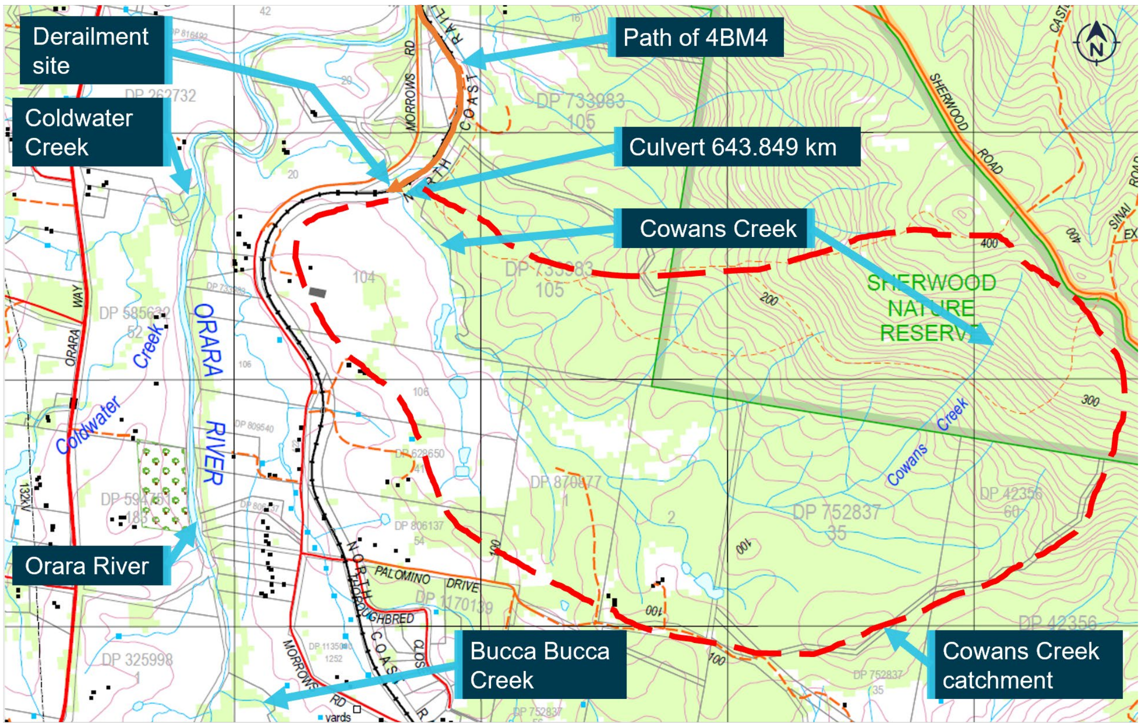
The working plan noted that the embankment in the vicinity of the derailment had previously been washed away. It contained several handwritten notes marked as from April 1962:

- 643.68 to 643.71 km - scour 8-feet [2.43 m] deep
- 643.71 to 643.84 km - embankment completely washed away 14-feet [4.26 m] deep
- 643.84 to 643.91 km - scour 10-feet [3.04 m] deep.

The working plan also contained a record dated from 1938 that suggested the embankment at 643.600 km had been totally washed away. It was not clear what was the exact date of this or the source of the information.

Public records suggested that a railway embankment at Nana Glen had been washed away during the 1950 floods, however, the location was not noted.[47]

Figure 20: Topographical map and Cowans Creek



The grid is 1 km and contour lines are in 10 m increments. The approximate catchment area is highlighted in the red dashed line and was approximately 400-450 ha or 4-4.5km^2. The path of 4BM4 is also marked in orange showing the approach to the derailment site.
Source: NSW Sixmaps, modified and annotated by OTSI

46 Catchment: the land area draining to a point of interest, such as a water storage or monitoring site on a watercourse.
47 GHD Pty Ltd for Coffs Harbour City Council (2012), Final Report Orara River Flood Study, Section 1-10, p 21.

There were several rivers and creeks that joined the Orara River near Nana Glen including the Bucca Bucca Creek approximately 2 km south-west of the derailment site, and the Coldwater Creek approximately 800 m from the derailment site (Figure 20). A flood study undertaken for the Coffs Harbour Council for the Orara River noted:

> The Orara River and Bucca [Bucca] Creek confluence downstream of the village of Nana Glen, and receive inflows from a number of significant tributaries, as follows:
>
> - Urumbillum River, Mirum Creek and Fridays Creek, discharging to the Orara River in Upper Orara;
> - Wongiwomble Creek discharging to the Orara River near Karangi;
> - Nana [Creek] and Coldwater Creek discharging to the Orara River near Nana Glen; and
> - Kings [Creek] and Finberg Creek discharging to Bucca [Bucca] Creek upstream of Nana Glen.[48]

It was likely that these creeks contributed to the rapid rise in Orara River height recorded at Glenreagh on 24-25 February 2021.

Culvert assessment study

In 1995, the then infrastructure manager SRA commissioned the *North Coast Line Culvert Assessment.*[49] This assessment was for culverts between Nana Glen (640.000 km) to Glenreagh (651.600 km) and Gurranang (727.900 km) to Lawrence Road (734.100 km).

The assessment consisted of developing a system to analyse the culvert capacity and assess the risk of failures, and to develop a prioritisation method for remedial works.

A total of 52 culverts were assessed as part of the study with the results summarised as:

- 15 of 52 culverts listed with capacities less than once in 20 year event [20 ARI]
- washout or ash apparent in 5 of the 15 culverts and occurs with embankments heights between 2 to 10 metres
- 34 of 54 culverts have capacity greater than 50 years
- 4 culverts needed immediate attention.

The risk of overtopping was assessed as flooding exceeding the nominated freeboard[50] height under the designed rainfall conditions. The total freeboard height utilised for the assessment was 0.8 m below the top of the rail. The embankments were assessed for overtopping and ranked from those most likely to suffer from overtopping to the least likely due to the culvert capacity. The culvert nearest to the derailment site (643.800 km) at 643.849 km was ranked as 14th with the culvert at 643.481 km ranked 18th.

The culvert at 643.849 km was assessed at risk of overtopping the embankment for events of between 1 in 10 and 1 in 20 ARI. Evidence of ash[51] and previous washaways were also found at that location.

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48 GHD Pty Ltd for Coffs Harbour City Council (2012), Final Report Orara River Flood Study, Section 1-10.

49 Paterson Consultants Pty Limited (1995), North Coast Line Culvert Assessment, Nana Glen to Glenreagh, Gurranang to Lawrence Road.

50 Freeboard: The difference in height between the calculated water surface elevation and the top, obvert, crest of a structure or the floor level of a building, and provided for the purpose of ensuring a safety margin above the calculated design water elevation.

51 Waste ash from locomotive boilers was historically used as fill material to repair embankments.

There were no records available for what actions, if any, were taken by SRA at the time of the study to address the issues. ARTC had records of the report and the information was recorded in their geotechnical sites database.

Geotechnical database

ARTC geotechnical database for Coramba (634.290 km) to Glenreagh (654.160 km), contained summary notes for the geotechnical sites along the corridor. In this section there were 121 geotechnical sites.

The geotechnical site where the derailment occurred was between 643.400 and 644.050 km. The site was described as:

> Freestanding embankment. RH->LH [right-hand to left-hand]. Part of the embankment widened on the Downside during LX [level crossing] widening. Ash visible at 643.600 km and road base visible under track from 634.7 km to 634.75 km (was probably emergency fill).
>
> Small culvert at 643.481 km, large culvert at 643.849 km and small culvert at 644.015 km.
>
> Sag point in vertical curve ~643.8 km, with track grade rising for ~800 m City and Country sides.
>
> The waterway area is too small. Hydrological study shows culverts at 643.481 km and 643.849 km are under capacity. Refer to report by Paterson Consultants June 1995.

Additional observations for this site were recorded as:

> 29/09/2005 - This problem is primarily to do with hydrology and no significant geotechnical problem was observed.
>
> 10/05/2016 - No change to site conditions. TP [Track Patrol] report no problems. Hydrology problem. Increase waterway.

There was a geotechnical risk ranking against those observations and the status was listed as inactive. There were no other records available from ARTC for this site. The hard copy records from the previous infrastructure maintainer were missing for this specific geotechnical site.

The database contained references to at least seven culverts identified as undersize through this section. These included those assessed as part of the culvert assessment study as well as others identified as having problems during rainfall and flooding of the Orara River.

ARTC were unable detail how these flood risks were assessed or provide copies of risk assessments associated with the identified risks.

ARTC weather monitoring

Weather monitoring and response

East-west corridor

ARTC's extreme weather monitoring procedure (OPP-01-05)[52] was originally developed for the east-west corridor[53] in 2014. The procedure detailed the roles and responsibilities for the various network control and corridor personnel. The procedure required an Extreme Weather Group (EWG) made up of appropriately qualified ARTC staff to make decisions in relation to forecast extreme weather events[54] for amber, red and black forecasts (Table 8). The EWG consisted of

[52] Australian Rail Track Corporation (2014), Monitoring and Responding to Extreme Weather Events in the East-West Corridor, OPP-01-05, V1.0, 29 May 2014

[53] East-west corridor for the purpose of the procedure was between Cootamundra, NSW and Kalgoorlie, Western Australia.

[54] Extreme weather event: any event including but not limited to floods, electrical storms, and damaging winds which demonstrate potential to impact on the ARTC rail network or the organisation's operations.

representatives with sufficient seniority and expertise to formulate the organisation's response. This group could assess and consider if the alert needed to be elevated to a red or black alert or downgraded to an amber or red alert.

A risk matrix was developed as part of the procedure which broke down weather events into rainfall, flooding and wind. The risk rankings were colour coded from green, amber, red and black alerts to denote the level of perceived risk (Table 8). The description for each level escalated from no threats to severe network disruptions or damage. The risk matrix detailed the severity of the weather for the corresponding alert level (Table 9).

Table 8: ARTC warning levels

Colour	Risk level	Description
• Green	• Low risk	• No threats
• Amber	• Medium risk	• Heightened alert
• Red	• High risk	• Potential for network disruptions
• Black	• Extreme risk	• Severe network disruptions or damage

Table 9: ARTC extreme weather alert levels risk matrix

Colour and risk level	Rainfall	Flooding	Wind
• Green • Low risk	• Rain intensity below 25mm/hr	• No warnings present	• No warning present. • Average wind speed below 40km/h.
• Amber • Medium risk	• Heavy Rain – (Intensity from 25 to 50mm/h)	• Heavy Rain reported in the region. • BoM Flood Alert, Watch or Advice issued • Field reports of water accumulating adjacent to the track	• BoM 'Strong Wind' warning. • Average wind speed from 40 to 62km/h.
• Red • High risk	• BoM 'Severe Weather Warning' in the region • Violent Rain – (Intensity above 50mm/h) • Recorded regional rainfalls in the ranges prescribed under the Code RED column in Table 2[1]	• Minor flooding reported in the region. • Flash flood or generalised Flood warning by BoM. • Field reports of water 0.3m below top of formation	• BoM 'Gale Force Wind' warning. • Average wind speed from 63 to 87 km/h.
• Black • Extreme risk	• BoM Severe Thunderstorms Warning' or 'Cyclone Warning' • Recorded regional rainfalls in the ranges prescribed under the Code BLACK column in Table 2[1]	• Major flooding reported in the region. • BoM warning of Moderate or Major flooding in the region. • Stream Flow Detector alert received. • Field reports of water at or above the top of formation	• BoM 'Storm Force Wind' or 'Hurricane' warning. • Average wind speed above 87km/h.

[1] Table 2 refers to regional rainfall depth and durations determined by ARTC for each section of their corridors. The durations of 1 hour, 6 hours, 24 hours and 72 hours were recorded with the corresponding ARI rainfall depths for that section of track.
Source: Australian Rail Track Corporation (2014), Monitoring and Responding to Extreme Weather Events in the East-West Corridor, OPP-01-05, V1.0, 29 May 2014

The BoM provided rainfall data that could be used to assess rainfall Intensity, Frequency and Duration (IFD)[55] for an area. The IFD information, in conjunction with the Australian Rainfall and Runoff (ARR) 1987 guideline, was utilised to determine the design rainfall Average Recurrence Interval (ARI) for the ARTC east-west rail corridor.

The east-west corridor was broken into six different geographical areas[56] and an ARI rainfall depth for the durations of 1 hour, 6 hours, 24 hours and 72 hours were developed. ARTC advised that the thresholds of 20 ARI and 50 ARI for the red and black levels was to account for culverts that could be susceptible to rainfall events that exceed those limits. The intent was that should rainfall exceed a 20 ARI a red alert would be generated and if the 50 ARI was exceeded a black alert would be generated.

Stream flow monitoring gauges were also fitted to some culverts and configured to generate a black alert if flow was detected.

The procedure contained responses for rainfall / flooding, and wind that were colour coded and detailed the actions to be taken by the responsible party. Weather events classified as black were the most extreme risk, requiring all operations in the affected area to cease.

The procedure detailed the mechanism for communicating alerts and warnings to the nominated recipients as:

- Green – Email
- Amber – Email
- Red – Email and text message (SMS message)
- Black – Email and text message (SMS message).

Additional updates were also available to ARTC personnel for amber, red and black alerts if they wished to contact the EWN.

Defined Interstate Rail Network and Hunter Valley

In August 2017, ARTC expanded their extreme weather monitoring procedure to include their entire rail network with the procedure re-named OPE-PR-014.[57] Between 2017 and 2019 the extreme weather monitoring procedure was revised on three occasions. The version current at the time of the derailment was last updated in June 2019.[58] The risk matrix, threat level and mechanism for communicating forecasts, alerts and warnings was unchanged from the original procedure with most changes being clarification of roles or titles.

The EWG role was changed from the original procedure (OPP-01-05) from reviewing amber forecasts to one that was only required to review and assess forecast red and black alerts for rainfall / flooding as well as black alerts for wind. The purpose of the group, which was unchanged according to the revised procedure, was to determine the ARTC's response to forecast extreme weather events.

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[55] Intensity-Frequency-Duration (IFD): rainfall intensity (mm/h) or design rainfall depths (mm) are based on statistical analysis of historical rainfall events with a corresponding probability of the rainfall event occurring. The IFDs are used for designing infrastructure such as culverts, storm water drains and flood mitigation but can also be used to assess the severity of observed rainfall.

[56] The east-west corridor for the purpose of the procedure was Cootamundra to Broken Hill (NSW), Broken Hill to Peterborough (South Australia), Peterborough to Pimba, Pimba to Oodlea, Oodlea to Rawlinna (Western Australia), and Rawlinna to Kalgoorlie.

[57] Australian Rail Track Corporation (2017), Monitoring and Responding to Extreme Weather Events, OPE-PR-014, V3.0, 15 August 2017

[58] Australian Rail Track Corporation (2019), Monitoring and Responding to Extreme Weather Events, OPE-PR-014, V3.4, June 2019

The revised procedure (OPE-PR-014) divided the network into the Defined Interstate Rail Network (DIRN) and the Hunter Valley (HV) network. The roles and responsibilities were updated to reflect the differences in network control personnel for these two networks. The DIRN was divided into four corridors and the HV was listed as a standalone corridor. Each of the corridors was further divided into a total of 50 different geographic areas with a corresponding ARI threshold for each of five sections. The corridors consisted of the following sections:

- Kalgoorlie to Cootamundra (KFC) – 6 geographic areas
- Melbourne to Crystal Brook (MAC) – 10 geographic areas
- North Corridor (Sydney to Brisbane) – 9 geographic areas
- South Corridor (Melbourne to Sydney) – 10 geographic areas
- Hunter Valley – 15 geographic areas.

Refer to *Appendix B – ARTC and EWN rainfall monitoring areas* for further details.

Under the revised procedure, responses to rainfall / flooding and wind were listed separately for the DIRN and HV but had similar responses for both networks for those alerts. The full details of the response required by ARTC personnel to the different alerts is contained in *Appendix A – OPE-PR-014 response tables*.

In response to the amber alert issued by the EWN at 2159 on 24 February, the TTM was required under the procedure (OPE-PR-014) to 'advise operators and other network users[59] of the current alert level' and to 'ensure operators are advised'. The process of advising operators and network users required the TTM to send an email to a distribution list that would advise both internal users (NCOs, asset management and support functions personnel) and externals users (rolling stock operators and customer management centre) of the alert and its level.

As per the ARTC procedure, the Corridor Manager (CM), Service Delivery Manager (SDM) and Area Manager (AM) were also required to respond to amber alerts as outlined below and as per Table 14 the:

- Corridor Manager was required to consider more frequent track inspections including inspection of culverts and water levels, and to make arrangements, if needed, to enable inspections after downpours or reports of high water.
- Service Delivery Manager was required to advise customers of potential network disruptions due to an extreme weather event.
- Area Manager was required to provide local input, collect information from maintenance crew, develop a local response plan and hold toolbox meetings as required.

At the time of the alert, the CM, SDM and AM were not working but had on-call personnel available who would have also received the alerts.

At interview the CM reported that they were woken by a message for the amber alert, but as on-call personnel were available, they did not feel that it warranted further action by them. The CM advised that in any event, as it was an amber alert, they would typically wait for further alerts before responding as it was only a forecast alert. If further alerts were received detailing how much rain had fallen then that would have been the trigger for them to respond.

The CM reported that if it was a red alert or larger weather events were forecast, they would have considered mobilising personnel to inspect the network or position personnel at locations of known risk.

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59 Train crew were not considered as 'network users' as part of the process of the TTM advising network users and operators.

On the night of 24-25 February there were no track patrols or inspections prior to the derailment.

Rainfall thresholds

The ARI for the North Corridor between Border Tunnel (876.5 km) and Woodville Junction (595 km) is shown in Table 10. The ARI was for the overall corridor section rather than a specific location within the section.

Table 10: Border Tunnel to Woodville Junction ARI

Duration	20-50 ARI - Red alert		50-100 ARI - Black alert	
	Min (mm)	Max (mm)	Min (mm)	Max (mm)
1 hour	68	79	79	88
6 hour	121	140	140	154
24 hour	204	238	238	264
72 hour	313	377	377	426

In 2016, the BoM provided a new data set for the assessment of design rainfall IFD.[60] This replaced the 1987 dataset that was used by ARTC to determine the ARI thresholds for their procedure (OPE-PR-014). The actual ARI for the derailment site was higher than the thresholds specified for the Border Tunnel to Woodville Junction section. The design rainfall depths for Nana Glen are shown in Table 11 with the ARI and corresponding AEP.

Table 11: Nana Glen IFD design rainfall ARI and AEP

Duration	Infrequent			Rare	
	20 ARI	50 ARI	100 ARI	200 ARI	500 ARI
	5% AEP (mm)	2% AEP (mm)	1% AEP (mm)	0.5% AEP (mm)	0.2% AEP (mm)
1 hour	75.8	91.4	104	116	133
6 hour	156	194	225	251	289
24 hour	290	352	401	446	513
72 hour	436	520	584	649	735

Source: Bureau of Meteorology – Design Rainfall Data System, Lat -30.103, Long 153.017
http://www.bom.gov.au/water/designRainfalls/revised-ifd/

Weather monitoring service

At the commencement of the original weather monitoring service, ARTC engaged the EWN through a purchase order with standard terms and conditions. In April 2017 and prior to ARTC formally expanding their extreme weather monitoring procedure, they requested a quote from the EWN to include weather monitoring for the north-south and Hunter Valley (HV) corridors. The EWN provided the quote based on the service they were already providing for the east-west corridor with the inclusion of the new network areas. The quote was accepted in May 2017 and formalised the services the EWN were providing into a consultancy service agreement (CSA) contract (CA-SA-05445-00).

Monitoring of ARI rainfall depths required the EWN to identify weather stations within 50 km of the east-west and HV corridors, and 25 km of the north-south that would be used. Most stations were from the BoM and those were configured within the EWN monitoring software to trigger at the ARI thresholds. ARTC had also installed some remote weather monitoring stations with most along the

60 Bureau of Meteorology Design Rainfall Data System (2016) Australian Rainfall and Runoff - 2016 Design rainfalls

east-west corridor to provide additional coverage. At the time of the occurrence, the nearest working ARTC weather station was at Roto, NSW, approximately 786 km from the derailment site.

The EWN had configured the weather stations for the east-west corridor as part of the weather monitoring for ARTC's original procedure (OPP-01-05) and there were no changes to those stations. However, they needed to identify and configure the additional weather stations required for the expansion of the weather monitoring procedure (OPE-PR-014) to include the north-south and HV corridors and the revised 2017 contract. To allow the EWN to complete this work they required the following information from ARTC:

- location of the rail corridor
- appropriate corridor boundary (25 km and 50 km either side of the corridor)
- threat matrix and rainfall depths for the sections
- distribution list detailing who was to receive the alerts.

In May 2017, ARTC provided this information to the EWN. The EWN later advised ARTC that the new weather monitoring services would commence on 10 June 2017. The EWN commenced the weather monitoring for the DIRN and HV before ARTC's revised weather monitoring procedure (OPE-PR-014) had been completed. It was completed in August 2017.

While not detailed within ARTC's procedure, ARTC had requested EWN to provide a phone call service for all red and black alerts. The phone call was to consist of an automated message to the relevant network control centre to advise of a red or black alert.

When the inclusion of phone call notifications for red and black alerts was requested in November 2018, ARTC discovered that EWN had not implemented weather monitoring for the entire HV corridor. Instead, weather monitoring had only been set up in 2017 for Woodville Junction and Telarah.

Following this discovery, the EWN provided a new proposal that included weather monitoring for the entire HV corridor. The CSA was amended on 18 December 2018 to reflect this change. The EWN advised ARTC that forecasting for the entire HV corridor was set up and would commence on 2 January 2019.

The CSA was amended on three occasions (in December 2018, September 2019 and June 2020) to either extend the term of the contract or add additional culvert flow monitoring equipment along the east-west corridor.

In 2020, ARTC requested a revised service proposal from EWN which was accepted and became CA-SA-06312-00.[61] At the time of the occurrence, the services EWN provided under the CSA included:

- Rainfall alerts – Colour coded (red and black) alerts utilising BoM and ARTC rainfall data to trigger when ARI thresholds were exceeded. Alerts to trigger for durations of 30 minutes, 1 hour, 6 hours and 24 hours.
- Culvert (flow monitor) alerts – Colour coded alert generated if flow was registered in the culvert (amber), height reached the top of the culvert (red) or bottom of the sleepers (black). There were 36 culverts fitted with flow monitoring equipment along the east-west corridor.
- Weather and bushfire alerts – There were six different alerts that the EWN provided that included:
  - Bushfire Watch & Act

[61] Australian Rail Track Corporation (2020), Consultancy Services Agreement, CA-SA-06312-00, Early Weather Warning Alerts, 21 August 2020.

  - Bushfire emergency warnings
  - Severe thunderstorm warning only if destructive winds in the headline
  - Severe weather warnings if destructive winds and/or heavy rain in the headline
  - Tropical cyclone watches and warnings
  - Tsunami warnings.
- Daily brief and three-day forecast – Forecast for the DIRN and HV compiled by a qualified meteorologist for rainfall, temperature, wind and fire bans. The forecast was required to be sent by 0900 each morning.

The weather and bushfire alerts were required to be communicated to ARTC within 6-8 minutes of the BoM issuing an alert. The EWN issued an amber alert at 2159 on 24 February. It was communicated within seven minutes and there were no other alerts communicated to ARTC.

ARTC weather monitoring equipment

Automatic Rainfall Monitoring

ARTC had an engineering standard *Automatic Rainfall Monitoring*[62] that was applicable to NSW only. This standard detailed the requirements for determining the need for automatic rainfall monitoring (ARM) through to installation and commissioning. The standard was divided in to four stages including:

- Initial assessment – Determine if a particular site or general areas were at increased risk of rainfall and identify areas where existing risk controls (track patrol, speed restriction) would not be effective.
- Investigation – Geotechnical and hydrological studies to assess the rainfall conditions and risk at the site. Additional requirement to assess the risk characteristics including traffic density and type, stopping distance as well as system characteristics (train control and response times).
- Detailed design – Review all information and develop the detailed design including thresholds and alert levels to be communicated to network control.
- Purchasing, installation and commissioning – Approval to purchase and install once detailed design was complete. Commissioning and testing of equipment and alerts to network control.

The standard also contained a specific note that reassessment must be conducted at intervals of two years or less due to the likelihood of changing conditions over time.

Remote weather monitoring

In the week prior to the derailment, a remote weather monitoring station[63] had been installed at Nana Glen at 639.500 km. This station was approximately 3.7 km from the derailment site (643.800 km) but was not operating and commissioned at the time. A remote weather station had also been installed at Craven (290.724 km) on the TAR corridor and while working had not been commissioned. The station at Craven was approximately 250 km from Nana Glen. A further 12 remote weather stations were planned to be installed along the TAR corridor at:

- Oakhampton 198.613 km
- Dungog 245.747 km
- Mt George 342.141 km

62 Australian Rail Track Corporation (2010), Automatic Rainfall Monitoring, ETD-10-01, V1.1, 18 June 2010
63 The remote weather monitoring stations that were being installed were the Davis, Vantage Pro 2 system.

- Wauchope 454.740 km
- Kempsey 503.634 km
- Koolkhan 706.321 km
- Camira Creek 756.439 km
- Wiangaree 846.210 km
- Loadstone 864.210 km
- Glenapp 888.550 km
- Tamrookum 905.430 km
- Greenbank 955.259 km.

At interview the CM indicated that the original intent of installing remote weather monitoring stations was to monitor temperature for track stability during hot weather. This was first considered in 2014, however, did not progress at the time. Further information provided by ARTC suggested that the locations for the 14 remote weather stations were selected in 2018/2019. Once installed and commissioned, the data from the weather stations was available to the EWN for their weather monitoring service.

Risk register

In March 2020, the installation of remote weather monitoring stations was listed as a proposed control within ARTC's risk register which detailed the risk of *Inclement weather (including flooding).* The proposed treatment date for implementation of that control was listed as 30 June 2020.

Approximately two months after the derailment, the risk register was revised on 26 April 2021 with the risk re-named *Infrastructure loss or degradation due to a weather event*. A new treatment date of 30 June 2021 was listed for the installation of remote weather monitoring equipment as this work had not been yet completed. The description of the control was:

> Placing remote weather stations at critical points where there is no information at the BoM. The information is web based and log-ins will be supplied to the EWN group to enhance their service.

The other controls listed within the risk register included ARTC's weather monitoring procedure (OPE-PR-014) and the EWN service.

There were no stream flow detectors along the TAR corridor at the time of the occurrence and they were not considered within the risk register.

Network rules and procedures

Condition affecting the network

Network rule *ANGE 206 Reporting and Responding to a Condition Affecting the Network (CAN)*[64] detailed the requirements for reporting and responding to unsafe conditions affecting or potentially affecting the network. The requirements for reporting were:

> Conditions that can or do affect the safety of rail operations in the ARTC NSW Network *must* be reported promptly to the Network Control Officer responsible for the affected portions of track.
>
> The Network Control Officer must record the information on the Train Control Graph or where used in the Train Register Book.

[64] Australian Rail Track Corporation (2020), ANGE 206 Reporting and Responding to a Condition Affecting the Network (CAN), V3.2, 23 February 2020

If necessary, the competent worker[65] reporting the CAN was required to prevent rail traffic approaching the area by applying track protection. The NCO was required to communicate the CAN to other NCOs as well as operators' representatives. As necessary, the NCO was also required to:

- arrange to warn rail traffic crews of rail traffic approaching the affected portions of track
- arrange to prevent rail traffic from approaching the affected portions of track, and apply blocking facilities
- arrange for the 1500V supply to be isolated in accordance with Rule ANGE 228 Unplanned removal of 1500V supply
- ask Maintenance Representatives to investigate.

Within rail vehicle detection (RVD) areas, a written CAN was required to warn rail traffic when the CAN related to the following conditions:

- CAN block working is introduced
- faulty or potentially faulty level crossings have been reported
- level crossing warning equipment has been deactivated
- rail traffic must be restrained where blocking facilities cannot be applied
- speed restrictions during hot weather have been reported
- temporary speed restrictions have been reported and no signs erected.

If possible, the NCO was to arrange for a competent worker to give a CAN form to the rail traffic crew prior to entering the affected portion of track. Where it was not possible, the NCO was to dictate the contents of the CAN to the rail traffic crew. Where a CAN did not relate to the above conditions, the NCO was permitted to give spoken (verbal) CAN warnings to rail traffic crews.

Rail traffic crew were required to acknowledge and comply with CAN warnings.

The NCO was required to continue warning rail traffic crew until the CAN no longer existed or the crew were warned by other means (such as signage). If maintenance representatives were asked to attend and investigate, the CAN was only able to be removed once the track had been certified as safe for rail traffic.

Responsibility of rail traffic crew

Rail traffic operating through the ARTC controlled network were required to comply with ARTC network rules and procedures. The responsibilities for rail traffic crew operating on ARTC's network was prescribed in *ANGE 232 Responsibilities of Rail Traffic Crews (Train Crews and Track Vehicle Crews)*.[66] Train crews were responsible for the safe operation of rail traffic and the safety of other crew and passengers. Train crew were also required to be qualified to operate the rail traffic and in the systems of safeworking for the area. This rule was applicable to both Pacific National and NSW Trains.

In addition to this, NSW Trains had their own procedure *NTTWP 100 Responsibility of Train Crew*[67] detailing the responsibilities of their train crew (drivers, guards and passenger service supervisors). The responsibilities of the train driver included, but were not limited to:

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[65] Competent worker: a worker certified as competent to carry out the relevant task.

[66] Australian Rail Track Corporation (2017), ANGE 232 Responsibilities of Rail Traffic Crews (Train Crews and Track Vehicle Crews), V3.1, 22 October 2017

[67] NSW Trains (2019), NTTWP 100 Responsibility of Train Crew, 24 October 2019

- immediately inform Network Control Officers or any other relevant employees of any incident, problem or defect relating to trains, signalling, track or overhead wiring, or any other problem affecting or likely to affect train services.
- operate the train in accordance with the requirements contained in the Professional Driving Guide[68]
- be alert for and obey all fixed signal indications, Railway Track Signals and handsignals
- if visibility is affected, slow the train to maintain safety
- keep the train under control so that it can be stopped by applying the automatic air brake, if required
- apply appropriate train management techniques for customer comfort…

The Rail Industry Safety and Standards Board (RISSB) network rule *ANRP 2027 Responsibilities of Rail Traffic Crews*[69] provided additional details for rail traffic vigilance. Rail traffic crews must:

- observe the track in the direction of travel, and
- be prepared to stop or reduce rail traffic speed if required, and
- reduce rail traffic speed if it is considered that the conditions prevent safe operation at normal speed, and
- pay particular attention when:
  - visibility is impaired for any reason, or
  - when approaching:
    - a crossing or passing location, or
    - signals, indicators and signs or
    - level crossings…

This rule was not mandatory for rail infrastructure managers but provided industry recommended best practice.

Australian and international rules – wet weather and flooding

Heavy rainfall and flooding have led to washaways and derailments across Australia and overseas (see *Similar occurrences*). In response to previous flooding, washaways and derailments, Queensland Rail (QR) and Aurizon both released safety alerts or guidance in 2016 which were similar in their wording. The Aurizon safety alert stated:[70]

> Train Traffic Crew must immediately STOP and report to the Network Control Officer:
>
> - water on the formation and near the ballast
> - any potential track or formation deficiencies
> - if the track formation and / or supporting ballast cannot be seen
> - any signs of washouts or scouring on the side of the ballast or formation…

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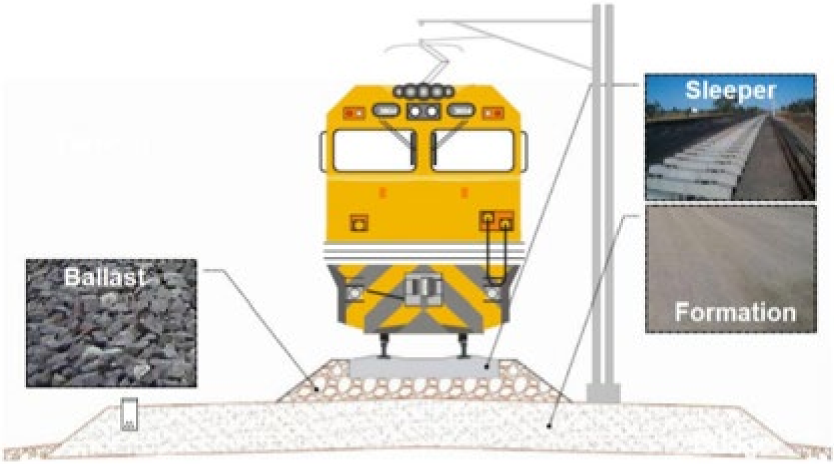
[68] The Professional Driver Guide provided further information for the safe operation of trains including, defensive driving and driving principals, risk associated with the route, signal and distractions.

[69] Rail Industry Safety and Standards Board (2014), ANRP 2027 Responsibilities of Rail Traffic Crews, V1.2, 10 June 2014

[70] ATSB Transport Safety Report, Rail Occurrence Investigation RO-2018-007, Collision with floodwater involving freight train 6792 Little Banyan Creek, Queensland, on 7 March 2018. Report issued 30 June 2020. Available at www.atsb.gov.au

The diagram shown in Figure 21 was included in the safety alert to assist with identifying the sleepers, ballast and formation.

Figure 21: ATSB investigation RO-2018-007 - Except from Aurizon safety alert showing difference between ballast and formation



Source: Aurizon

In 2017, Aurizon issued a guide for *Operations of rail traffic in adverse weather*. The guide was to assist train crews operating in adverse weather. In relation to wet weather and where visibility was affected it stated:[71]

> When it is necessary to operate rail traffic during fog, heavy rain, unexpected storms and similar circumstances where there is reduced visibility, RTC [rail traffic crew] are to take appropriate steps to protect their safety, the safety of the rail traffic and the track infrastructure by driving to the conditions. RTC should assess the situation and regulate the speed of the rail traffic in accordance with the conditions, and advise the NCO and LRC [live run coordinator] of their intended action, i.e. they are proceeding at reduced speed because of low visibility.
>
> If operation of rail traffic in heavy rain is required, the Rail Infrastructure Manager (RIM) will normally monitor any flood indicator alarms and/or water levels and to take whatever action is necessary to ensure safe rail traffic operations (e.g. speed restrictions, track closures etc.). RTC operating rail traffic on the affected line(s) are to adhere to any instructions received and take whatever other action is necessary to ensure their own safety and the safety of the rail traffic they are operating.
>
> Occasionally, RTC will encounter storms, flash flooding or similar events where advice is not received from the RIM. In these situations, RTC are to observe any water adjacent to the rail infrastructure. Where the water level is such that the sleepers and the supporting ballast is not visible, or there is signs of washouts or scouring on the side of the ballast and/or in the formation (Refer Figure 1, 2 & 3)[72] the RTC is required to stop the rail traffic and advise the NCO and LRC.

Some of the information and procedures from QR and Aurizon have evolved following incidents or in response to previous safety issues identified through ATSB investigations.

Internationally, the Rail Safety and Standards Board (RSSB) provides network rules and standards for the United Kingdom (UK). The rules for managing and operating in floodwaters were detailed in *GERT8000-M3 Rule Book, Managing incidents, floods and snow.*[73] This rule provided clear details for what drivers needed to report in relation to flooding. Train drivers were also

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[71] Ibid.

[72] These figures included Figure 21 and other images of section of track affected by flooding.

[73] Rail Safety and Standards Board (2020), GERT8000-M3 Rule Book, Managing incidents, floods and snow, Issue 3.1, 5 December 2020

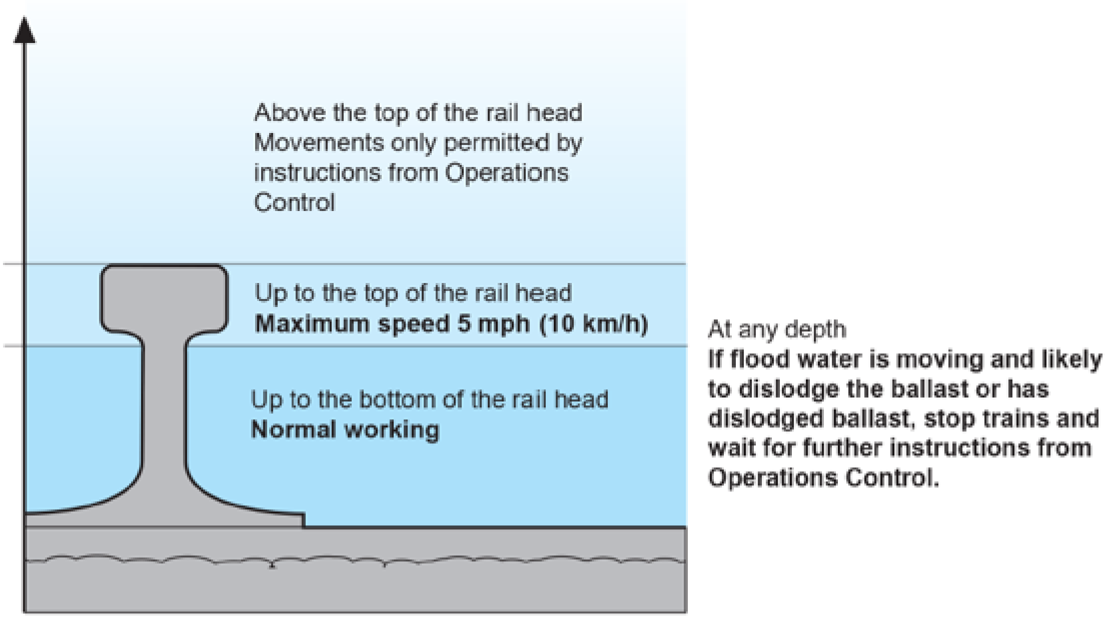
required to stop their train if necessary, to provide that information. Drivers were required to report if they believed floodwater:

- is up to the bottom of the rail head
- is up to the top of the rail head
- is above the top of the rail head
- is moving and likely to dislodge the ballast
- has dislodged the ballast.

To assist with the driver's assessment, a diagram was provided detailing the location of floodwaters in reference to the rail and corresponding response (Figure 22). Trains were permitted to operate under normal working if the water was below the bottom of the rail head provided the water was not moving or had not dislodged or was unlikely to dislodge ballast. If floodwater was up to the top of the rail head, operations were restricted to a maximum speed of 10 km/h. Where water was above the top of the rail or was moving and likely to dislodge ballast or has dislodged ballast trains were to stop.

The driver was also required to ensure that if a train had been stabled or passed through floodwater above the bottom of the axle box that network control was advised. The signaller was provided with similar instructions detailing their response to reports of flooding.

Figure 22: Excerpt from GERT8000-M3 Rule Book, Managing incidents, floods and snow



Source: Rail Safety and Standards Board, United Kingdom

Regulatory oversight

Office of the National Rail Safety Regulator

The Office of the National Rail Safety Regulator (ONRSR) was the regulatory agency for rail in Australia. It was not a government agency, but an independent body corporate established under the Rail Safety National Law Act 2012. Its functions were to regulate the rail transport industry in Australia through its rail safety accreditation regime and the Rail Safety National Law (RSNL). ONRSR set requirements for rail safety management systems (SMS), conducted compliance activities including audits and inspections, and enforced the RSNL.

ONRSR advised that they utilised a risk-based approach to regulation as detailed in The ONRSR Way.[74] The regulatory information they collected for the industry and specific operators was utilised to determine their audit and inspection schedule. This was also utilised to set their national priorities. ONRSR advised that some risks associated with extreme weather were considered in their Track Conditions national priority for 2016 and 2017.

ONRSR had undertaken numerous audits and inspections of ARTC to assess the compliance of their safety management system with the RSNL. Between 2016 and the derailment, ONRSR had undertaken nine audits and 64 inspections across ARTC operations. In that period, they issued three improvement notices and 87 non-conformances to ARTC. One of the non-conformances related to maintenance and recording of defects for drainage systems. That non-conformance was issued in 2018 and closed in 2019. None of the other notices related to risk management of infrastructure risks or design and maintenance of flood mitigation.

Similar occurrences

There have been multiple occurrences with trains derailing during extreme wet weather due to flooding or encountering floodwaters across Australian and overseas. These occurrences provide learning opportunities for organisations to reduce the likelihood and/or consequences of similar occurrences.

ARTC occurrences

Between 2009 and 2014 the ATSB investigated three derailments due to flooding along the ARTC managed east-west corridor. These were:

- Derailment of train 5PS6 near Golden Ridge, Western Australia (RO-2009-003)
- Derailment of train 7SP3, Roto, New South Wales (RO-2012-002)
- Derailment of freight train 3MP9, East of Malbooma, South Australia (RO-2014-006).

In each of these investigations it was found that the heavy rainfall likely exceeded the design of the drainage culvert leading to overtopping of the track and the ballast washing away. The trains then derailed when they passed over the section of track. Each of these trains was a freight train and only the crew of 5PS6 suffered minor injuries.

There were several safety issues and recommendations associated with these investigations that broadly related to the management of weather monitoring, track drainage and flooding, and lack of a flooding special locations register. To address these issues ARTC engaged the services of the EWN for weather monitoring and introduced the extreme weather monitoring procedure (OPP-01-05) initially along the east-west corridor. They also undertook flooding studies along the east-west corridor to assess the risk of flooding and installed culvert flow monitoring equipment at high-risk locations.

In relation to not having a register to record flooding special locations (RO-2014-006), ARTC advised that they were upgrading their electronic asset management system to optimise inspection and maintenance activities including recording of special locations.

National occurrences

ATSB Investigation (RO-2011-019)

On 27 December 2011, freight train 7AD1 derailed at the Edith River bridge near Katherine in the Northern Territory. A section of the embankment had been washed away by flooding that exceeded the 100 ARI flooding that the bridge had been designed for. It was found that the rail

[74] The ONRSR Way, available at: www.onrsr.com.au/operator-essentials/the-onrsr-way

infrastructure manager did not have a system in place to monitor the river height at the bridge although information was readily available. It was also found that there were deficiencies in the procedures and training for the responses to severe weather events and the warning system in place was ineffective.

ATSB Investigation (RO-2015-028)

On 27 December 2015, a severe thunderstorm led to heavy rainfall near Julia Creek on the Mount Isa rail line in Queensland. The network control officer (NCO) was aware of the storms and had received reports from train crew and arranged a track patrol. The crew of freight train 9T92 were travelling towards Julia Creek when they observed a section of track that had been previously flooded but the water had receded. They then encountered another section that had been flooded, however, the flooding had scoured the ballast and compromised the integrity of the track. It was too late for the driver to stop once they sighted the washout and the train derailed. The lead locomotive rolled as it derailed and all 26 wagons containing acid also derailed.

It was found that reporting procedures implemented by Queensland Rail and Aurizon provided insufficient guidance to the NCO or rail traffic crew to identify and respond to potential hazards from a wet weather event.

Both Queensland Rail and Aurizon issued safety alerts to improve the effectiveness of their existing network rules and procedures.

ATSB Investigation (RO-2018-007)

On 7 March 2018, freight train 6792 encountered floodwaters at the Little Banyan Creek rail bridge in Queensland. A condition affecting the network (CAN) had been declared due to a wet weather event. The crew of freight train 6792 were required to operate at a controlled speed[75] due to the CAN for a significant part of their journey. While travelling at 50 km/h the train rounded a curve and encountered floodwaters at Little Banyan Creek that was under 0.6 m of flowing floodwater.

It was found that while there was weather monitoring equipment at the creek it had been out of service. Additionally, while there was a closed-circuit television camera (CCTV) to monitor the water levels, the illuminator to enable effective operations at night was also out of service. The network personnel were not aware that the weather monitoring equipment and illuminator were out of service and were expecting an alert and did not actively search for information.

It was also found Queensland Rail had no restrictions on the distance or time that controlled speed could be used as a risk control during CANs. The effectiveness of the control had the significant potential to deteriorate over extended periods due to workload, vigilance, fatigue and risk perception. Additionally, Aurizon's procedures and guidance for two-driver operations during CANs did not facilitate effective sharing of duties.

Following the occurrence, Queensland Rail improved the processes and procedures for ensuring the reliability of weather monitoring systems and awareness of network control personnel of faults. Aurizon also undertook a review of its procedure for the management of workload for two-driver operations during CANs.

[75] Controlled speed: a speed that allows rail traffic to stop short of an obstruction within half the distance of clear line that is visible ahead.

International

Rail Accident Investigation Branch investigation (Report 02/2022)

On 12 August 2020, a high-speed passenger train[76] derailed near Carmont, United Kingdom. Prior to the derailment, there had been significant storms causing extensive flooding and landslips. There were four landslips within close proximity to the derailment site that were known to network control prior to the derailment. While known, there was no clear requirement to operate at a reduced speed. The passenger train was authorised to operate at normal speed and derailed at 117 km/h after passing over a section of track that was covered by gravel.

The gravel had been washed onto the track from a drain near the rail line. The lead power car derailed and then stuck a bridge parapet a short distance ahead of the washout. This caused the power car to veer off the bridge, and down an embankment. All passenger carriages derailed and jack-knifed with some coming to rest on the side or roof. The fourth carriage remained upright but came to rest on top of the first carriage.

There were two train crew (train driver and conductor) and seven passengers on board at the time of the derailment. Both train crew and one passenger were fatally injured in the derailment. All other passengers were injured. Due to Covid-19 restrictions there were less passengers on-board and it was estimated that there would normally have been between 25-50 passengers.

The immediate cause was that the drain had not been installed in accordance with the design leading to the gravel surrounding the drain washing out and onto the rail line, the train then passed over the gravel and derailed.

There were several findings relating to the way that the rail infrastructure manager responded to and managed the risk of extreme rainfall, some of these were:

- They have not addressed weaknesses in the way that it mitigated the consequences of extreme rainfall events. The underlying reasons for this were:
  - They had not recognised that their existing measures did not fully address the risk of extreme rainfall events.
  - Their assurance processes did not identify the areas of weakness in the implementation of their extreme weather processes or that the controllers lacked the resources and skills necessary to manage complex weather events.
  - They had not clearly identified weaknesses in their operational mitigation measures to manage the risk of earthworks and drainage failures.
- While they were aware of the risk, they had not completed the implementation of additional control measures following previous extreme weather events.

There were 20 recommendations associated with the investigation for the improvement of rail safety. The recommendations were aimed at managing extreme weather events, civil engineering construction, assurances for railway control, train design, and applying learnings from previous events.

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[76] The high-speed train was a Class 43 diesel-electric locomotive passenger train which was the design the XPT passenger train was based on.

Safety analysis

Overtopping and washaway

The embankment at the derailment site had been identified as at risk of overtopping during rainfall events of 10-20 Annual Recurrence Interval (ARI) due to the capacity of the culvert at 643.849 km as part of the 1995 culvert assessment study.[77] The 24-hour rainfall recorded by the BoM of 310 mm on 25 February 2021 at Nana Glen, corresponded with an overall rainfall event between 20-50 ARI (5% and 2% AEP) for that location (Table 11). The actual rainfall was over a shorter duration with varying intensity across the broader area.

The simulation of the rainfall accumulations from the Grafton radar suggested that in 6-hours leading up to the derailment, rainfall of between 200-300 mm may have fallen near the derailment site (Figure 13). The 6-hour rainfall event may have been between 100-200 ARI (1% and 0.5% AEP) and possibly exceeded a 500 ARI (0.2% AEP) for that location (Table 11). The actual duration and intensity of the rainfall could not be determined, although, exceeded ARTC's threshold for black alerts and their infrastructure standards.

The location of the culvert at 643.849 km nearest to the derailment site would likely have been affected by rises in the Orara River with water flowing up Cowans Creek and into the field on the southern side of the embankment. During periods of no or light rainfall in the Cowans Creek catchment, the effect of the Orara River would have been minimal, however, if heavy rain occurred the effect could have been significant as outlined below.

The culvert outlet invert was at an elevation of 63.45 m while the banks of the Orara River were at approximately 60-61 m. Rises in the river level above 5 m would likely have filled the entirety of the culvert as the inlet obvert was at an elevation of about 65.66 m.

Culverts can accommodate increases in headwater; [78] however, the headwater cannot be increased indefinitely without overtopping occurring. The level of rail infrastructure damage depends on the height of the headwater and velocity of water flowing across the track structure.[79] The height of the tailwater[80] also influences the damage on the downstream side of the embankment. Where there is a large difference in height, the velocity of the water flowing down the structure can be high and erosive.[81] Scouring of the embankment as well as the culvert outlet can occur under these conditions.

On the night of the occurrence, the culvert at 643.849 km did not have sufficient capacity to discharge the runoff water from Cowans Creek to the Orara River. Between the time of NT31 passing around 0110 and train 4BM4 arriving at Nana Glen at 0137, floodwater began to overtop the embankment (Figure 23).

Once the water began to overtop the embankment, its velocity increased and began to scour the ballast around 643.800 km on the downstream side. The scouring continued progressively getting wider with the ballast, as well as some of the subgrade material washing away (Figure 24). The

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77 Paterson Consultants Pty Limited (1995), North Coast Line Culvert Assessment, Nana Glen to Glenreagh, Gurranang to Lawrence Road.

78 Headwater: the water on the upstream side of a hydraulic structure, in this case a culvert.

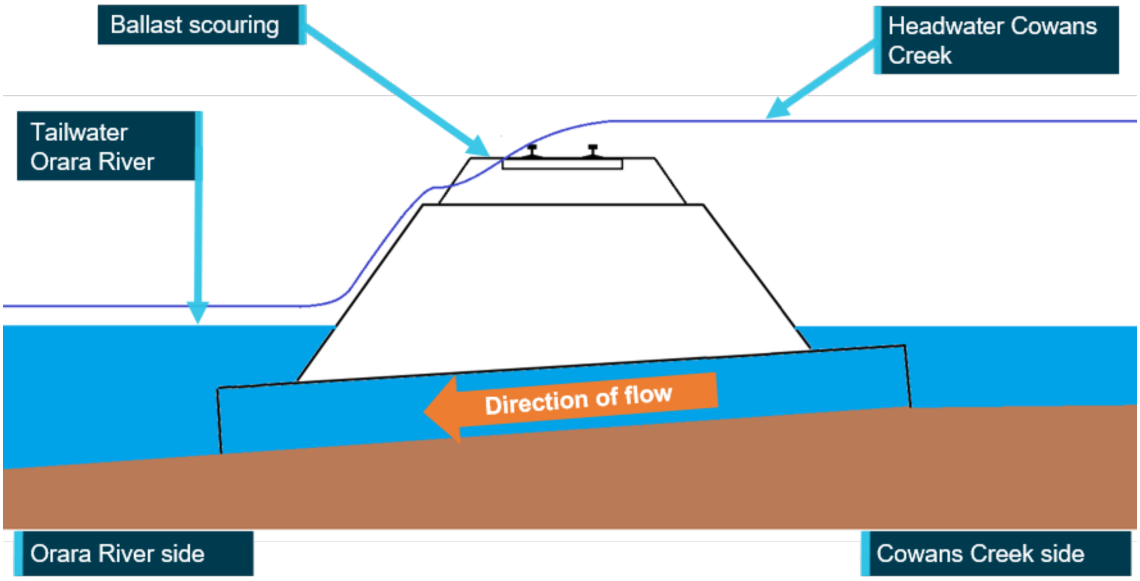
79 Tsubaki R, et al (2016), Development of fragility curves for railway embankment and ballast scour due to overtopping flood flow

80 Tailwater: the water downstream of a hydraulic structure. Tailwater includes oceans, rivers, creeks, lakes and basins, and can either be considered as steady state or varying over time.

81 Austroads (2018), Guide to Road Design Part 5B: Drainage – Open Channels, Culverts and Floodways, edition 1.1, August 2018.

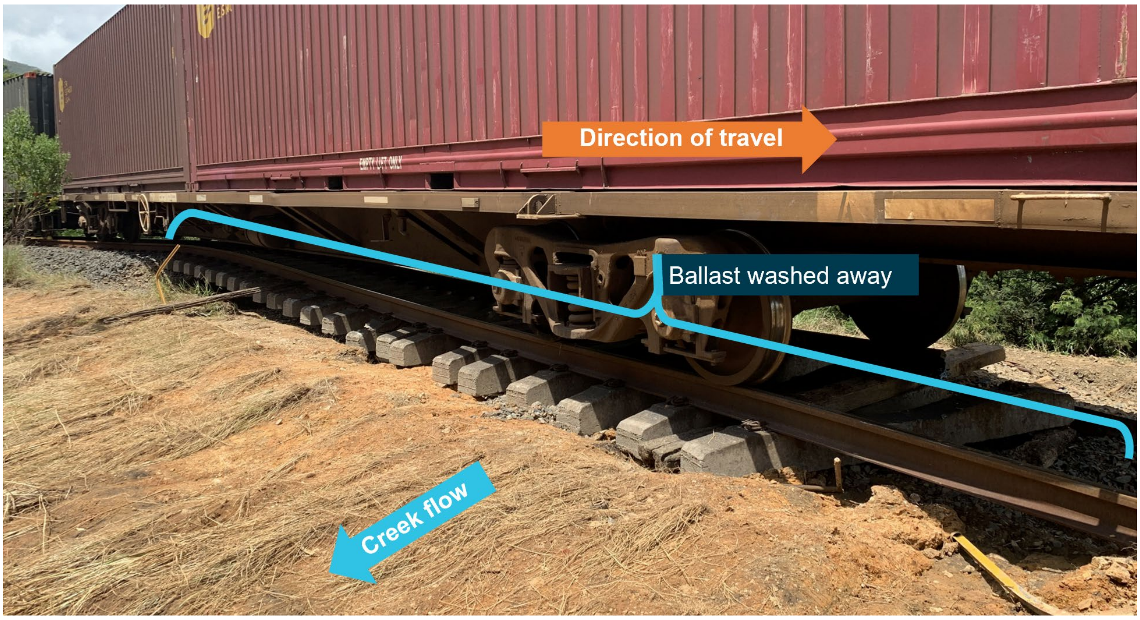
scouring of the ballast and embankment continued for some time after the derailment until the headwater level receded below the top of the embankment.

Figure 23: Overtopping and washaway



The diagram (not to scale) depicts the overtopping of the embankment and process of ballast scouring. Initially the ballast on the downstream side would have washed away before all ballast was displaced. The headwater from Cowans Creek is depicted as a blue line while the possible tailwater and floodwater level from the Orara River is shown as solid blue.
Source: OTSI

Figure 24: Ballast washed away



The image shows an area of the embankment where the ballast had washed away with the sleepers resting on the subgrade material. The vegetation can be seen to be lying flat due to the flow of water over the embankment.
Source: ARTC, annotated by OTSI

The rainfall recorded for Nana Glen by the BoM was on the opposite side of the Orara River, approximately 1.5 km from the derailment. Based on the Grafton weather radar, it was probable that similar rainfall fell within the Cowans Creek catchment on the night of the derailment. The Orara River height at Glenreagh was recorded as rising rapidly from 2.75 m at 2000 on 24 February and reached 6.98 m by midnight. By 0100 on 25 February the height was recorded as 8.15 m, this rose to 8.59 m by 0130 (Table 4). The rainfall alone, would almost certainly have resulted in the overtopping of the embankment. However, the severity was probably increased due to the combination of both the rainfall and rises in the Orara River.

Derailment

At interview driver A reported observing water in and around the rail corridor after passing through Glenreagh. The track speed in the Up direction for freight services was 70 km/h in this section. The train speed was maintained between 65-68 km/h until around 646.010 km. The speed decreased to 63 km/h and then down to 56 km/h at 644.110 km. The train was powering through the section and throttle was maintained between notch 1 and 5. On approach to the derailment site, the speed was increasing and was in throttle notch 5. The conditions at the time were dark, it was raining and the headlights on 4BM4 were on. The track curvature would have provided limited sighting distance for the section of track ahead. The driver reported that there was no indication of a track issue and on exiting a right-hand bend the locomotive suddenly dipped as they passed over the washaway.

The front of train (FOT) footage showed two areas that were washed away as 4BM4 was approaching (Figure 5). As the train passed the washaway, the lead locomotive dipped around 300 mm as there was no ballast to support the weight of the loaded train. The locomotive continued and bounced out of the washaway before coming to a stop. With the continued scouring of the ballast the two areas washed away and joined to become one after the derailment.

The third locomotive and first 10 wagons derailed at the washaway with some wagons and containers entering the floodwater. The trailing portion of the train came to a stop due to the loss of the brake pipe air.

Driver A reported thinking at the time that it was safe to proceed given they had just passed two other trains that had been through the area and not been advised of any issues. Driver D recalled contacting 4BM4 as part of the roll-by inspection on passing at Kungala. Driver A believed they would have spoken to them but could not remember. There had been no communication with the passing trains in relation to the weather or track condition, and they had not received or reported a CAN. At the time Driver A felt the conditions they had observed prior to the derailment did not warrant a CAN.

Driver B recalled that they did not see any floodwater but on approach to Nana Glen were looking out for the distant signal. The water that was observed by driver A was primarily on the left-hand side and would probably have been harder to see from a seated position for the second driver.

It is probable that if actions were taken to slow the train when it first encountered the water building up near the rail head, the train could have either stopped or at least slowed prior to encountering the washaway. If the train had not been able to stop, the train may still have derailed but the severity would have been significantly reduced.

Guidance for extreme weather and flooding

Under ARTC network rule ANGE 206, network users were required to report conditions affecting the network (CAN). Train crew were required to report ‘Conditions that can or do affect the safety of rail operation’ to network control. On the night, the network users and train crews had not received advice about the extent of the weather event or the amber alert.

The drivers of 3MB4, NT31 and 4BM4 were found to all have different interpretations of what ‘conditions can or do affect the safety of rail operations’ meant, especially when operating in extreme wet weather and flooding. While only driver A observed floodwater on approach to Nana

Glen, each of the drivers had a different understanding of when trains were required to either stop or report floodwater in the rail corridor (Table 12).

Table 12: Drivers' observations and understanding wet weather and flooding

Driver	Observation	Understanding
4BM4 - A	Visibility affected by extremely heavy rain. Water building up in the rail corridor and began to build up near the rail head about 1-1.5 km before the derailment.	Trains could continue providing water was not over the top of the rail.
4BM4 - B	Visibility affected extremely heavy rain and condensation on the window. Did not see floodwater.	Trains could continue providing water was no more than 100 mm above the rail head or they had not been advised by network control to stop. Reported concern if water was more than 100 mm above rail was due to the traction motors.
NT31 - C	Visibility affected extremely heavy rain. Did not see floodwater.	Would report floodwater if seen in the corridor and would be concerned if water was seen near the rail.
3MB4 - D	Visibility affected extremely heavy rain. Did not see floodwater.	Trains could continue providing the water was below the rail head as once the water was above this level it could get thrown up into the traction motors. Would report to network control if water was running over the track or if seen on the ballast approaching the rail.

The drivers were unable to detail how they had formed their understanding of the rule or indicate where it was documented. The CAN network rule was broad and open to interpretation by rail traffic crews as to what was to be reported to network control. None of the drivers considered the conditions on the night warranted a CAN and they did not report a CAN. Given the drivers' of NT31 and 3MB4 understanding of what and when to report to network control, if they had sighted floodwater on passing through Nana Glen, they may not have reported the conditions to the NCO prior to 4BM4 arriving.

The absence of guidance to train crew on how to respond to extreme wet weather and flooding increased the risk of adverse events. Had the drivers of 3MB4, NT31, 4BM4 (or any other train) reported the extreme rain prior to the occurrence, it would have provided an opportunity for the NCO to become aware of the increased risk of flooding and to have implemented possible actions. In addition, clear guidance for when trains must stop or slow if floodwaters are encountered in the corridor would likely reduce the severity of the derailment. Without clear guidance, what conditions were to be reported was open to the interpretation of each driver and rail operator.

ARTC did have some details within their original weather monitoring procedure (OPP-01-05) relating to high water. The TTM was to advise train crew of the following for amber alerts:

> High rainfall is expected in the 'XXX to YYY' region. Network users are reminded to drive to the conditions and report unusually high water levels adjacent to the track.

If a red alert was issued, the TTM was required to advise train crew of the following:

> Very high rainfall and rapid stream rises is forecasted in the 'XXX to YYY' region. Network users are required to drive at speed that will enable to stop within ½ the distance that can be seen and report unusually high water levels adjacent to the track.

Train crew were also required to report unusually high water adjacent to the track, bridges and culverts. When the procedure (OPE-PR-014) was expanded in 2017, the requirements to warn rail traffic for amber alerts were removed. The details for what was reportable by train crews, as well as requirements for a reduction in speed were removed altogether.

As the rail infrastructure manager (RIM), ARTC had not defined the requirements or communicated what was reportable on their network for flooding events. ARTC had not provided any information or guidance to rail traffic crews operating in extreme wet weather or how to respond to flooding.

A review of some other rail operators and RIMs indicated that they have issued guidance material and safety alerts for operating in extreme weather and for reporting floodwater in the corridor. This material contained clear criteria to assist train crew operating in extreme wet weather and for reporting floodwater in the corridor, on the formation or covering the ballast, sleepers or rail.

Rail traffic crews were responsible for the safe operation of trains through ARTC's network in accordance ANGE 232. This rule did not require rail traffic crew to reduce their speed if visibility was affected unlike RISSB ANRP 2027 or NSW Trains NTTWP 100. It was a requirement of these rules (ANRP 2027 and NTTWP 100) that if visibility was affected, trains were to slow to maintain safety, reflecting industry best practice. ANRP 2027 also contained specific requirements for rail traffic crew to pay particular attention when approaching a level crossing.

Trains NT31 and 3MB4 were the last two services that travelled through Nana Glen prior to train 4BM4 derailing. Both drivers reported that they experienced extremely heavy rain between Coramba and Glenreagh that affected their visibility. With their visibility severely affected by the weather, the drivers would have had a reduced opportunity to sight signals, potential obstructions or safely traverse the level crossings between Coramba and Glenreagh. The drivers relied on their knowledge of the route and location of signals to continue without reducing their speed.

The Pacific National (PN) train drivers were qualified to a Certificate IV in Train Driving and had undergone training in *TLIF4410 Respond to abnormal situations and emergencies when operating rail traffic*. The training material for this module provided general information but tended to suggest that network control would advise of abnormal situations. Weather was detailed as a potential abnormal situation with no further information for how train crew were to respond. PN had not provided their train crew with guidance for how to respond to extreme wet weather or flooding. There were no explicit requirements to reduce speed if visibility was affected or any details for what constituted a reportable condition in relation to weather or flooding.

Extreme weather monitoring procedure and response

Detection and communication of alerts

Weather forecasts and alerts issued by the EWN were communicated to ARTC personnel through several different methods. The daily forecast was typically sent between 0800 and 0900 by email. Receiving the forecast would be predictable and easily adapted to daily routines. The daily TAR corridor forecast issued by the EWN on the morning of 24 February was distributed to the network users and operators (internal and external stakeholders) by the dayshift Train Transit Manager (TTM) at 0922. The email from the TTM contained the note to 'please pay extra attention to the area Northern NSW'. At 1114 the same TTM resent the forecast to network users and operators with the same note.

The mechanism (email) for advising those who were required to take action in response to an amber alert, would not have ensured that such personnel would have always been made aware in a timely manner. Weather alerts could be sent at any time and amber alerts were only required to be sent via email. These alerts required action but could be missed, in particular by network control personnel after hours.

While not a requirement of ARTC's weather monitoring procedure, some personnel were configured to receive text messages to their phone for amber alerts from the EWN. On the night, the amber alert issued at 2159 was communicated by both email and text message. The text message went to numerous infrastructure maintenance personnel including the Corridor Manager (CM) and Area Manager (AM). The Service Delivery Manager (SDM) also received the message, however the CM, AM and SDM were not working at the time but on-call personnel were available. The TTM and Network Control Officer (NCO) were not configured to receive text messages and did not receive the alert to their phone.

Network controllers were not on the email distribution list to receive weather alerts or forecasts from the EWN. The NCOs would only have received weather alerts if they were detected and communicated by the TTM. If the TTM did not detect an alert, or did not detect it in a timely manner, then neither the alert nor potential risk to the network would be known by the NCO.

The TTM could not recall if they had seen the amber alert issued by the EWN at 2159 before or after the derailment but did confirm that the alert was not communicated to operators and network users as required.

Both Pacific National (PN) and NSW Trains confirmed they had not received any severe weather alerts from ARTC in the days prior to the occurrence. Reviewing the alerts issued by the EWN in the 72 hours prior to the derailment, there should have been at least three occasions where PN and NSW Trains were advised.

If the weather alerts had been communicated to the network users by the TTM, this would not necessarily have ensured that the train crew operating in the area would have received the alert. Neither PN nor NSW Trains had a process to actively communicate weather alerts to their crew once they were in-service. Both relied on ARTC to advise when it was unsafe to operate trains, their train crew to report conditions affecting the network (CAN), or to be advised by the NCO of a CAN.

The nature of train control is that in most instances, the controller is operating remotely from the trains under their control. Unless the control personnel actively searched for weather information or received alerts, they would have been unaware of the risk to the network.

On the night there were no other alerts communicated to ARTC by EWN for the evolving weather event along the north coast (Table 3).

The crews of trains 4BM4, NT31 and 3MB4 had not been advised of the weather event or received any information from the NCO prior to the derailment. While these crews experienced extremely heavy rain this was not reported to the NCO, reducing the controller's awareness of the local conditions.

Red and black alerts issued by the EWN were more likely than amber alerts to be detected in a timely manner by ARTC personnel. Some personnel would receive text messages to their phone and the network control centre would receive an automated voice message to communicate the red and black alerts.

Response to rainfall and flooding - amber and red alerts

The responses to rainfall and flooding (amber and red) alerts were divided between the Defined Interstate Rail Network (DIRN) and Hunter Valley (HV) network, with the DIRN then divided into two corridors, east-west and north-south. The full details for each network are in *Appendix A – OPE-PR-014 response tables*. The design of ARTC's colour coding in the tables was to classify the perceived risk to the network. Colour coded alerts could be for forecast weather, BoM weather warnings or if rainfall exceeded an ARI threshold.

Weather forecasts were based on the best judgement and assessment of the EWN meteorologist using the information available to them. These may or may not have been accurate when compared to actual weather conditions which could be vastly different to forecasts. The forecast on the morning for the TAR corridor was coded as green with two sections north of Grafton coded amber (Figure 10). The actual weather event on 24-25 February far exceeded the forecast conditions from the BoM and EWN.

Under procedure (OPE-PR-014), the ARTC's Extreme Weather Group (EWG) was only required to meet and determine the response to red or black forecasts. Any standalone weather alerts were the responsibility of individuals to respond to without the requirement of the EWG. There was no EWG on 24 February nor was it required based on the forecast.

ARTC's procedure did not distinguish between the responses to forecast and actual extreme weather events. The procedural response to a weather alert for a forecast event (amber, red or black) was the same as to an alert generated by actual rainfall exceeding the ARI threshold. So, for decisions based on a forecast, there was time to review and consider other factors as the threat was not imminent. In contrast, if the red or black alert was triggered for actual rainfall exceeding the ARI threshold, the threat to the network would likely be more immediate and require a more rapid response.

The EWN would generate a red or black alert if rainfall exceeded an ARI threshold, however detection of this also relied on sufficient weather monitoring equipment in the area. While an alert would be generated, the location of the weather station, proximity to the rail line, topography of the area, track drainage features, as well as ground saturation, would all have influenced the level of potential risk to the network. These risks were not addressed as part of the procedure or responses for amber and red alerts. If a black alert was issued all operations were to cease in the area, once stopped, the immediate risk to people and trains in the area would likely be mitigated.

Without sufficient weather monitoring equipment to monitor the actual conditions, the process relied on reports from train crew, maintenance personnel or the results of track inspections to identify and mitigate any operating risks related to localised weather conditions.

In response to an amber alert the only action required by the TTM was to communicate the alerts to network users. There was no requirement for ARTC to advise train crew operating through an affected area of amber alerts for rainfall and flooding. For this occurrence, the TTM should have advised the network users by email, but there was no direct notification to the train crew by ARTC.

If a red alert was issued by the EWN, the TTM was required to 'Ensure communication to trains and network users through the affected area'. In practice, the NCO for the affected area was required to communicate this to train crew. However, before the NCO could advise train crew, the alert would first have needed to be detected and communicated to them by the TTM. The subsequent communication to train crew may or may not be in the form of a condition affecting the network (CAN). There was no further information detailing how this information was to be communicated to train crew or what level of information was required. And, in any event the TTM did not advise the NCO of the alert in this incident.

ARTC advised they also utilised information from train crew reporting a CAN or reports of flooding to inform their response. However, what was reportable as a CAN was open to interpretation by train crew. On the night, there were no reports in relation to the extremely heavy rain in the area from the train crew. (See *Guidance for extreme weather and flooding* for further analysis relating to train crew reporting weather and flooding).

For red alerts, the TTM was also required to consider trains that should be held or moved to 'safe' locations. The procedure did not detail how a location would be assessed as 'safe' or require the considerations and assessment to be documented.

The responses for both the DIRN and HV network as defined in procedure OPE-PR-014 were similar, with some differences based on the different role descriptions or network control organisational structure. One difference of note between the DIRN and HV, was that in response to an amber alert, the HV TTM was required to actively search for weather information from the

BoM and State Emergency Service (SES). This was not a requirement for the DIRN and the TTM advised at interview that they solely relied on alerts from the EWN. ARTC were unable to explain why there were differences in the procedure between the two networks.

For amber and red alerts, the Corridor Managers (CM) were required to consider several actions including higher frequency inspection and inspection of culverts. While they were to be considered, there was no requirement to act or to document what had been considered. Track patrols were to be considered for both amber and red alerts but were not mandatory. The CM advised that they would not have commenced track patrols for an initial amber alert but would have waited for other alerts or reports of rainfall. If a red alert was triggered by rainfall exceeding a threshold then they would have considered track patrols. The time to initiate a track patrol would have varied depending on the location of the alert and availability of on-call personnel. There were no procedures to assist the CM to determine whether trains were required to slow or stop until the track was inspected.

At interview the CM detailed how they would position personnel across their network in preparation for larger events. These would typically be for red or black events that had been forecast. The purpose of this was to undertake inspections or monitor the performance of areas of known weather related risk. This relied on ARTC having already identified areas that were susceptible to flooding and on the local knowledge of maintenance personnel as there was no documented flooding special locations register. Such reliance would not have been a reliable process to manage the risk or ensure areas at increased risk of flooding were monitored.

For amber alerts, the Area Manager was required to collect information from maintenance crews and develop a local response plan. If a red alert was issued, they were required to implement that plan. On the night there were no inspections of the TAR corridor by infrastructure personnel in response to the amber alert.

ARTC's procedure made specific reference to consider 'more frequent and/or targeted track inspections with focus on known *'high risk'* areas'. It was not clear how these known 'high risk' areas were determined or assessed as ARTC did not have a flooding special locations register for the TAR corridor or NSW rail network as required by its safety management system (SMS). See *Flooding special locations* on page 66 for further analysis on flood risk.

Both ARTC and the CM advised that some of their personnel used weather information from sources other than the EWN. These included the BoM, ARTC weather stations and social media groups. While these proactive steps could assist with developing a broader understanding for some, they were not part of a documented process or ARTC's SMS, and as such were inconsistent in application and response. There were several alerts issued and publicly available from the BoM and SES prior to the derailment. If ARTC personnel were monitoring those, they were either not detected or not actioned. At interview the TTM advised that they solely relied on the alerts from the EWN and they were not required to actively search for information.

The evidence supports that the response to amber alerts in practice was to wait for additional alerts or information before acting. In locations where there was sufficient weather monitoring equipment (weather stations/stream flow detected) to report on actual conditions, this may have appropriately managed the medium risk of an amber alert. However, without this equipment or active monitoring of the actual conditions, weather events that exceeded the medium risk of amber could have gone undetected. While responses to red alerts were intended to be more proactive, they did not require specific action to manage the higher risk to the network.

Response to wind alerts

The risk posed by wind was different to the risk of rainfall / flooding. The risk to rolling stock from these risks is largely dependent on the train type (passenger, freight – single or double stacked, road-rail vehicles and track machines). Where there was an active wind alert (amber, red or black) ARTC's procedures required train crew operating through the area to be advised of the alert. This requirement differed from amber rainfall events which did not need to be reported to the crew.

EWG meetings were only required for black wind alerts. The response for the Hunter Valley (HV) (Table 17 - *Appendix A – OPE-PR-014 response tables)* noted EWG meetings as a requirement for both red and black alerts which was incorrect. When the procedure was revised, the removal of EWG meetings for red alerts was not updated in the procedure.

ARTC and EWN weather monitoring service

Weather alerts prior to derailment

The EWN issued the daily forecast for the TAR corridor on the morning of 24 February, this detailed a low chance of severe thunderstorms (10-30 per cent) for the area between Coffs Harbour and Grafton. The actual event far exceeded the forecast for this area.

The weather alerts were issued to ARTC personnel based on the BoM forecasting districts applicable to the corridor section. Alerts for the TAR corridor consisted of:

- NSW districts – 1. Northern Rivers, 2. Mid North Coast, 3. Hunter
- Qld district – 15. Southeast Coast.

The alert issued by the BoM at 2152 was applicable to NSW districts 1 and 2. The threat map showed the warning area away from the rail corridor (Figure 11). The second alert issued by the BoM at 2208 was also applicable to those two districts. The second threat map showed a large section of the corridor could be impacted. The EWN advised that they issued the alerts based on the districts affected rather than on the threat map area. If subsequent alerts were issued by the BoM but with the same description then it would not have been communicated to ARTC. The intent of this was to reduce unnecessary alerts being communicated which could potentially de-sensitise the receivers.

The EWN utilised an alert generator (software program) to assist with generating and distributing weather alerts to their clients. Most severe thunderstorm warnings issued by the BoM were set to a threat level of amber by the EWN. The EWN advised this was based on the title description and some key terms or phrases used within the BoM alert. If the subject of the alert referenced giant hail, destructive winds or tornado, the alert would automatically have been set to a threat level of red.

The title of both alerts issued by the BoM at 2152 and 2208 referred to heavy rainfall, damaging winds and large hailstones. While the key words did not change, the phrasing of the rainfall intensity within the body of the alert did. The first alert referred to 'heavy rainfall that may lead to flash flooding' while the second alert referred to 'intense rainfall that may lead to dangerous and life-threatening flash flooding'. The BoM advised that the change in phrasing was based on their definitions for rainfall:

- Heavy Rainfall - Rainfall over a period between 30 minutes and 6 hours which exceeds the 10% AEP [Annual Exceedance Probability] depth.
- Intense Rainfall - Rainfall over a period between 30 minutes and 6 hours which exceeds the 2% AEP depth.

At the time of the derailment, the EWN's alert generator was not configured to detect the changes in rainfall intensity or references to life-threatening flash flooding used by the BoM. The escalation was not detected at the time and there were no further alerts sent to ARTC on the night. The EWN advised that the BoM had not communicated the change in wording of their alerts or their use of the term life-threatening flash flooding. The EWN reported they were aware of the change which occurred about 18 months before the derailment. The EWN advised they had not seen many examples of where the terms had been used prior to the derailment, so had not changed their program.

The second alert from the BoM referred to rainfall that exceeds the 2% AEP over a duration of 30 minutes to 6 hours. When compared to ARTC's risk matrix this corresponded to rainfall that may have exceeded the minimum threshold for black alerts 50 ARI (2% AEP).

Once alerts were communicated by the EWN, it was up to ARTC personnel to assess if areas of the rail corridor could be affected and what actions were required. The alert issued at 2152 by the BoM stated flash flooding may occur at Glenreagh. The Orara River ran in close proximity to the rail line at both Glenreagh and Nana Glen. The BoM subsequently issued flood warnings for the Orara River but ARTC was not aware of them.

The BoM weather station at Nana Glen that recorded the 310 mm of rain was not being monitored by the EWN. This station reported on a 24-hourly basis, and the 310 mm of rain was reported about 7.5 hours after the derailment. The EWN advised that on the night of the derailment the rainfall gauge at Boyles Bridge[82] that they monitored was offline between approximately 2100 until 0600. If the gauge had been working, it may have triggered a rainfall threshold based on the weather radar.

Service agreement

ARTC had engaged the services of the EWN for weather monitoring of the east-west corridor of the DIRN around 2013. Weather monitoring criteria used by EWN was defined in ARTC's original extreme weather monitoring procedure (OPP-01-05).

In 2017, ARTC introduced an expanded procedure (OPE-PR-014) to include the DIRN north-south and HV corridors. Prior to finalisation of that procedure, ARTC requested a proposal from the EWN to extend the weather monitoring services they were already providing for the east-west corridor to the north-south and HV corridors. The requested EWN proposal was accepted by ARTC. The ARTC understood the requirements of its expanded procedure (OPE-PR-014) would be applied to the east-west, north-south and HV corridors under the new service agreement. At the commencement of the new service agreement, ARTC provided information to the EWN that was needed to configure the additional network areas (north-south and HV) to meet ARTC's specifications for weather monitoring under OPE-PR-014.

In 2018, ARTC identified that weather monitoring for the HV corridor was not being performed for the entirety of the corridor as expected under the contract with EWN. To address this, EWN provided a new proposal which was accepted by ARTC and the service agreement (CA-SA-05445-00) was amended to include the missing areas. During the process of resolving the issue, ARTC again provided the information requested by the EWN to configure the additional network areas. On 20 December 2018, the EWN advised that weather forecasting for the HV corridor was scheduled to commence on 2 January 2019. In this same correspondence they advised that the alerts were operational.

Contract CA-SA-05445-00 expired in March 2020. In July 2020, ARTC requested a further proposal from the EWN based on delivery of their existing service. That proposal formed the basis of a new contract (CA-SA-06312-00) and was awarded in August 2020, 6 months prior to the derailment at Nana Glen. This contract included provision of forecasting and rainfall monitoring, as well as culvert flow and weather alerts for the entire ARTC network.

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[82] The Boyles Bridge (Corindi River) rainfall gauge was owned by Coffs Harbour City Council and was located 12.22 km north east of the derailment site. The gauge reported hourly rainfall data which when working was available on the Bureau of Meteorology's website.

It was found that while forecasting commenced in 2019 for the HV corridor, alerts for rainfall exceeding the ARI thresholds had not been set up by the EWN at that time. The alerts referred to by the EWN as being operational (at commencement on 2 January 2019) were weather alerts based on the BoM districts rather than the rainfall monitoring that was defined in the new contract and expected by ARTC.

While ARTC had provided the information required by the EWN including the ARI thresholds, rail corridor boundary and distribution list needed to set up for these types of alerts. It was not clear why the set up for monitoring of rainfall depths for the HV corridor had not been completed by the EWN in January 2019. This issue had not been identified by ARTC at the time or during the subsequent contract replacement in July 2020.

ARTC's extreme weather monitoring procedure (OPE-PR-014) required rainfall durations of 1 hour, 6 hours, 24 hours, and 72 hours to be monitored. These values were reflected in the 2017 contract (CASA-05445-00) between ARTC and the EWN. The duration of 30 minutes was also included although no values were noted within ARTC's procedure. When that contract was replaced in 2020, the duration of 72 hours was not included in the contract by EWN and this was not detected by ARTC.

At the time of the derailment, the EWN were monitoring rainfall durations of 1 hour and 6 hours but not 24 hours as required by the procedure and contract. The EWN advised that when they initially commenced monitoring for ARTC the longer durations were being monitored but that it stopped after verbal feedback from ARTC that it may not have been useful, although they could not confirm when. EWN reported that they found the longer durations would generally trigger the ARI threshold after a rainfall event when the immediate risk of flooding was perceived to have passed. Post incident, ARTC confirmed that they expected the rainfall durations to be monitored in accordance with their procedure.

From 2017 to 2020, the EWN provided several proposals (quotes) in response to requests or changes of requirements from ARTC. Each of these proposals contained similar references to the EWN providing a 'tailored solution' to meet ARTC's requirements, without further detailing how that was delivered. On each occasion that ARTC asked for a proposal, it was provided with the same service details becoming the service contracts (CA-SA-05445-00 or CA-SA-06312-00). There may have been further discussions and reviews as to what the 'tailored solution' consisted of when the EWN were initially engaged for the east-west corridor. However, it was not done in sufficient detail for the expanded service for ARTC to understand if the 'tailored solution' met its new procedure requirements.

There were several differences between the services the EWN were providing, what was in the service agreement and in the ARTC's extreme weather monitoring procedure (OPE-PR-014). ARTC had not undertaken any audits or inspections of EWN and these differences were not known to ARTC.

Risk matrix and rainfall thresholds

ARTC advised that the risk matrix (Table 9) from their weather monitoring procedure was the basis of EWN's colour coding of rain / flooding and wind alerts. This risk matrix detailed the criteria for the alerts with a corresponding colour code for the perceived level of risk.

Records of the risk matrices used by the EWN were requested. Two different versions of the risk matrices were used internally at EWN and by different people. While both documents broadly aligned, there were some minor differences relating to the probability of severe thunderstorms used for the purpose of forecasting. When the two versions were compared against ARTC's risk matrix (Table 9), they did not directly align to ARTC procedure (OPE-PR-014, version 3.4) or the original procedure (OPP-01-05) for the east-west corridor.

ARTC's procedures had divided the network into 50 different geographic areas with corresponding rainfall depth thresholds assigned to each area. The DIRN consisted of 35 geographic areas and the HV corridor consisted of 15. The information for the rainfall depths for each area on the ARTC's network had been provided to the EWN by ARTC. The EWN had configured the east-west corridor areas within their weather monitoring software however the new corridor sections (north-south and HV geographical areas) had not been added when ARTC expanded their procedure (OPE-PR-014) in 2017.

The EWN provided to OTSI the thresholds they used for monitoring rainfall depths for ARTC on the east-west and north-south corridors. Although the EWN were provided with the specifications for the 35 geographic areas for the DIRN, they had combined different areas based on the latitude and longitude and were only monitoring 15 areas for rainfall depth (see *Appendix B – ARTC and EWN rainfall monitoring areas*). The rainfall thresholds used by the EWN for the DIRN did not directly align to the thresholds specified by ARTC. In some areas the EWN thresholds were the same or lower than what ARTC had identified, while higher in other areas. Specifically, along the TAR corridor between Port Macquarie and Coffs Harbour, the EWN thresholds were higher when compared with ARTC's procedures for red and black alerts:

- Red alert
  - 1 hour – 5-10 mm higher
  - 6 hour – 18-27 mm higher
- Black alert
  - 1 hour – 7-10 mm higher
  - 6 hour – 18-35 mm higher.

Alerts in these areas would not have been triggered until rainfall had exceeded the higher EWN threshold. The differences were more significant for the 6-hour durations for red and black alerts. This increased the amount of flooding that could go undetected and so increased the likelihood that the integrity of the network would have been affected.

Although rainfall depth monitoring was detailed in the service agreement for both the north-south and HV corridors, it was found that rainfall depth monitoring for the HV corridor had not been configured within the EWN's monitoring software. The 15 geographic areas for the HV corridor would not receive red or black alerts when rainfall exceeded the ARI threshold specified within ARTC's procedure. These 15 areas would still have received weather alerts if issued by the BoM but not when rainfall exceeded design thresholds specified by ARTC.

It was also found that the EWN were only monitoring the durations of 1 and 6 hours for the DIRN. The longer durations of 24 hours and 72 hours were not being monitored as per ARTC's procedure (OPE-PR-014) or as expected by ARTC.

The EWN also had two different versions of the ARI rainfall depths for the ARTC network. The second version included the durations of 24 hours and 72 hours, but this was not in use. There were no document control details for either version of the risk matrices or the ARI rainfall depths. It was not clear how changes were managed by the EWN.

Flood warnings

The ARTC risk matrix (Table 9) detailed flood warnings issued by the BoM:

- Amber - BoM Flood Alert, Watch or Advice issued
- Red - Flash flood or generalised flood warning by BoM
- Black - BoM warning of Moderate or Major flooding in the region.

While detailed in the risk matrix, the EWN did not issue flood warnings to ARTC as standalone alerts as this was not in the service agreement. The EWN advised that flood watches and specific flood warnings were communicated to ARTC as part of the daily forecast.

ARTC advised that they thought, given BoM flood warnings were included in the risk matrix, that they would have received flood warnings from the EWN as they were occurring. The two flood warnings issued by the BoM at 0003 and 0034 on 25 February for the Orara River, were not communicated to ARTC by the EWN, nor were they required to be under the service agreement.

Remote weather monitoring equipment

At the time of the derailment, ARTC were installing remote weather monitoring stations along the TAR corridor. In total, 14 locations were identified for weather station installation. Two stations had been installed at the time of the derailment, with one at Craven and one at Nana Glen. Neither weather station had been commissioned.

Although ARTC had a standard for determining the need for automatic rainfall monitoring (ARM) it was not used to assess or determine where weather monitoring was required prior to the derailment in 2021. This standard also required ARTC to reassess the need for ARMs as well as the effectiveness of existing stations at least every two years. While the original intent in 2014 was to install weather monitoring equipment along the TAR corridor to monitor temperature, there had been no assessment since that time of the need for rainfall monitoring in accordance with the ARM standard.

ARTC advised that the placement of weather monitoring equipment was intended to provide sufficient coverage of their network. The weather information would then be available to the EWN for monitoring as well as to trigger alerts if rainfall exceeded the ARI threshold for that location. The CM recalled that there had been some discussions and meetings to determine the locations but was unable to provide any documentation. They advised that some consideration was given to monitoring the extremities of their network, and to provide some coverage between the provisioning centres.[83] The final locations for the installation of the 14 weather stations along the TAR corridor were selected using local knowledge and in areas that had access to a power supply.

Although ARTC had installed a weather station at Nana Glen, there was no specific evidence to support why this location had been chosen over others. It is possible that if this station had been operating and configured to alert the EWN, the derailment may have been prevented, or at least the consequences reduced.

While weather monitoring stations were listed as a proposed control within ARTC's risk registers, the actual effectiveness of the proposed control was likely reduced, as the locations were not selected through a risk-based approach. There was no formal or documented assessment to determine areas of increased risk or susceptibility to extreme weather and flooding. The risk register referred to installing remote weather monitoring equipment at 'critical points where there is no information from the BoM', however, ARTC were unable to detail how critical points were assessed.

The EWN had identified existing weather monitoring equipment within 50 km (25 km each side) of the TAR corridor to monitor rainfall. These stations were primarily owned by the BoM and other government agencies and so were not placed for the purpose of detecting weather events that could impact the rail corridor. These stations did however provide an indication of rainfall in an area that could potentially flow towards the corridor. Not all BoM weather stations reported rainfall

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83 Along the Telarah to Acacia Ridge (TAR) corridor there were provisioning centres (infrastructure maintenance depots) at Taree, Coffs Harbour and Casino.

for frequencies less than 24 hours, which reduced the available data for assessment of shorter periods. Rainfall could have exceeded the 1 and 6 hour ARI for an area but would not have been detected by the EWN or ARTC, if the assessment area relied solely on BoM weather stations.

The lack of additional weather data in the form of weather monitoring stations at locations assessed as critical along the corridor, reduced the effectiveness of ARTC's weather monitoring procedure to detect extreme rainfall events that exceeded rainfall design limits. The existing BoM stations utilised by the EWN provided limited assurance that rainfall, which could affect the integrity of the rain line, would be detected. None of the weather stations that the EWN monitored recorded rainfall at levels that would have triggered a red or black alert on the night of the occurrence.

Available corridor information at the time that could have highlighted identified risks with hydrology, including flooding and embankments susceptible to overtopping, was not used to inform the locations for installation of weather stations.

ARTC did not have an engineering standard or defined process to assess how or where weather monitoring was required across their network. The risk of rainfall was covered within their ARM procedure, but it did not address the risks associated with heat or wind. There was also no standard or defined process to determine where stream flow detectors were required or would be beneficial as an input to assessing the risk of flooding in the rail corridor.

Flood risk and cross drainage systems

Flooding risk

The Telarah to Acacia Ridge (TAR) corridor crossed many rivers and creeks that were prone to flooding. Some of these rivers and creeks were monitored by the BoM but most were not. Bridges over the larger rivers were reported as typically being designed for 100 ARI flooding. These bridges were less likely to experience flooding when compared to cross drainage[84] structures along the corridor.

Where there was river monitoring equipment (river gauges) the BoM and State Emergency Service (SES) could issue flood warnings for those specific rivers and creeks. More generalised flood warnings issued for other rivers and creeks were based on forecast or observed rainfall. While ARTC did not receive BoM flood warnings from the EWN as expected, they had not assessed the TAR corridor for areas that would be affected by those warnings.

Consequently, rises in river levels that could have affected the integrity of ARTC's infrastructure may not have been reliably detected by ARTC. Additionally, areas of increased risk had not been assessed. Therefore, ARTC's awareness of flooding that could have affected the integrity of network infrastructure relied on ARTC personnel to detect flooding through visual inspections or reports from train crew.

Extreme weather risk register

ARTC had a risk register for *Extreme weather events* that was applicable for the Defined Interstate Rail Network (DIRN). The risk was described as flooding causing damage, washaways and delays, as well as delays due to signal failures. The consequences of this risk were derailment, damage to track and train delays. The causes of these risks were extreme weather (including flooding) and unknown hydrology, and the preventative controls for both causes were:

- Inspection

[84] Cross drainage: a system of pipes or culverts which conveys storm flows transversely across or under a railway.

- Hydrology reports
- Inspect and restore drainage where inadequate - at risk areas from last known occurrence
- Risk assess areas likely to be washed out where inadequate or no flood openings
- Advice issued to drivers when extreme weather conditions known
- Investigation of early warning devices now that could be used because of upgraded data availability
- Risk assessment/hydrological surveys conducted for all replacement structures and when incidents are reported
- Flood mitigation strategies reviewed or developed as a result of major flooding on a local basis and when required.

While the risk register included a control to inspect and restore drainage where inadequate and undertaking risk assessments for areas likely to be washed out, ARTC did not provide evidence of this being applied along the TAR corridor. It is possible there were some assessments historically to address these risks but evidence of these was not provided.

ARTC advised that they had undertaken some detailed flood assessments at locations with repeated flooding events to determine if additional risk measures were required. Evidence was provided for several studies undertaken for the east-west corridor. The outcome of those studies was the identification of high-risk locations and installation of 30 sets of stream flow monitoring equipment. Similar studies had not been undertaken along the TAR corridor.

Flooding special locations

It was a requirement of ARTC's Code of Practice *Section 10 Flooding*, that a register of flooding special locations was established and maintained. While ARTC were aware that the TAR corridor was prone to flooding, they had not established or maintained a flooding special locations register. The Corridor Manager (CM) advised that they treated the entire TAR corridor as a flooding special location, however there was no register to document specific areas prone to flooding or damage.

ARTC had reduced visibility of areas affected by flooding as they had not systematically assessed and documented areas with a history of flooding. If a track patrol or unscheduled inspection was triggered by a defined event (rainfall or stream flow), areas of increased risk may not consistently have been inspected. ARTC was reliant on the memory and local knowledge of their maintenance personnel for areas at increased risk of flooding. This approach could have been inconsistent and or compromised by loss of knowledge with the movement of personnel and fallibility of memory.

A flooding special locations register would have been less effective for areas that had not experienced a flash flood event. However, a register of locations where flash flood events had occurred could have highlighted potential areas to monitor for flooding in the future. Recording of flash flooding events could also have provided an opportunity to assess the effectiveness of weather monitoring equipment and any responses for that area.

Drainage systems

There were a significant number of smaller creeks and rivers that needed to pass under the rail line through culverts along the TAR corridor. Of these, numerous culverts were identified as being at increased risk of overtopping the embankment or having issues with hydrology. Some were identified through the culvert assessment study[85] as far back as 1995 and others were noted in ARTC's geotechnical database.

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[85] Paterson Consultants Pty Limited (1995), North Coast Line Culvert Assessment, Nana Glen to Glenreagh, Gurranang to Lawrence Road.

The culvert assessment study was completed nine years prior to the rail corridor being leased to ARTC, and evidence could not be found to explain what if anything had been done in response to the study prior to ARTC being granted the lease. While ARTC had a copy of the study and had recorded information in their geotechnical database, they were unable to provide any records that accounted for how the risk of overtopping and washaway was assessed, addressed, or mitigated in the intervening period. ARTC advised that they inspected all culverts in accordance with their Technical Maintenance Plan (TMP) and in line with their safety management system (SMS). Review of ARTC's asset management system confirmed that the culverts had been inspected, however there was no requirement within their TMP to assess and confirm that the infrastructure was fit for purpose. ARTC were unable to provide any records detailing an assessment of embankment overtopping risk due to culvert capacity or an assessment of hydrology risks along the TAR corridor.

ARTC personnel reported that they treated most existing culverts as having an ARI of less than 20, however, there was no specific requirement to assess the actual capacity. While it was expected that red alerts would be triggered if rainfall exceeded a 20 ARI threshold, alerts would only be generated if there was weather monitoring equipment in the vicinity. However, based on the defined response for a red alert, culverts with capacities of less than 20 ARI may still not have been inspected and flooding could have gone undetected.

While acknowledging the significant number of culverts along the TAR corridor, ARTC had not undertaken assessments to determine locations at most risk of rainfall and flooding events that would exceed culvert design. This reduced the effectiveness of their response to flooding as well as limited the visibility of areas requiring future investment.

Occurrence culvert

The culvert at 643.849 km was known to be at increased risk of overtopping the embankment and washaways since 1995.[86] However, prior to the derailment ARTC did not have any detailed design documents for the culvert and had not undertaken any risk assessments to manage the identified risk.

In 2018, ARTC commissioned a study to assist in determining when it might be safe to re-open their network following a closure from a black alert for the north-south and east-west corridors.[87] To determine this, the study identified the catchments with the longest time of concentration (Tc)[88] for each section of track. The peak discharge for a 100 ARI event was then estimated using the Australian Rainfall and Runoff 1987 data set. A comparison was also performed using the Regional Flood Frequency Estimation (RFFE) Model[89] to validate the estimated the peak discharge.

The culvert at 643.849 km was assessed as being the culvert with the longest Tc for the section of track between 595 km to 877 km. The estimated discharge from the study for the culvert at 643.849 km are shown in Table 13. The upper and lower confidence limits are also shown indicating the potential peak discharges.

86 Paterson Consultants Pty Limited (1995), North Coast Line Culvert Assessment, Nana Glen to Glenreagh, Gurranang to Lawrence Road.

87 Kellogg Brown & Root Pty Ltd (2018), ARTC Track Closure Timing Assessment - North South and East West Rail, BEW854-TD-WE-REP-0001, Rev. A, 5 July 2018

88 Time of concentration: the time for rainfall that falls at the furthest point in a catchment to flow as runoff to the outlet, in this case the culvert.

89 The Regional Flood Frequency Estimation Model allowed for the estimation of peak discharges for ungauged catchments. The model had a number of limitations and could not be utilised for all catchment types or areas.

Table 13: Culvert 643.849 km peak flow discharge estimates

Australian Rainfall and Runoff 1987	Regional Flood Frequency Estimation		
100 ARI Discharge (m^3/s)	100 ARI Discharge (m^3/s)	Lower Confidence Limit (5%) (m^3/s)	Upper Confidence Limit (95%) (m^3/s)
57.6	79.7	27.6	230

Source: Kellogg Brown & Root Pty Ltd (2018), ARTC Track Closure Timing Assessment - North South and East West Rail, BEW854-TD-WE-REP-0001, Rev. A, 5 July 2018

The RFFE model was used to estimate the peak flows for Cowans Creek based on the revised Australian Rainfall and Runoff data 2016.[90] The peak flow discharge estimates for six different rainfall events over a duration of six hours are shown in Table 14.

Table 14: Regions Flood Frequency Estimates – Cowans Creek – 643.849 km

ARI	AEP (%)	Discharge (m^3/s) [1]	Lower Confidence Limit (5%) (m^3/s)	Upper Confidence Limit (95%) (m^3/s)
1.44	50	6.80	2.98	15.5
5	20	15.2	6.95	33.6
10	10	23.5	10.3	54.2
20	5	33.7	13.9	82.6
50	2	51.0	19.1	136
100	1	67.5	23.4	195

[1] Catchment size of $4km^2$ was utilised for the estimates
Source: Australian Rainfall and Runoff – Regional Flood Frequency Estimation Model.
Available at: https://rffe.arr-software.org/

The estimated peak flow discharges during 50 ARI (2% AEP) and 100 ARI (1% AEP) events (Table 14) as well as those from the 2018 study (Table 13) all exceeded 50 m^3/s. As per ARTC's structures standard, major undertrack drainage structures equalling or exceeding 50m^3/s where required to be designed for 100 ARI (1% AEP) flood events. However, this standard was not applied by ARTC to existing structures, nor was it mandatory to apply if replacing existing structures. ARTC advised that when replacing existing structures, they would be assessed on a case-by-case basis using professional judgement and known risk of flooding.

Had the culvert been designed to either a 50 ARI or 100 ARI flood event, overtopping would probably still have occurred, although it probably would have been less severe.

Following the occurrence, no action was taken to increase the capacity of the culvert at 643.849 km. Although a known risk, ARTC did not undertake any risk assessments associated with the culvert capacity before re-opening the TAR corridor. Post derailment, ARTC commissioned a hydrological study for the area, but it was not finalised as of this final report. To manage the risk until the hydrology study was completed, the area between Coramba and Kungala (640 km to 659 km) was added to their flooding special locations register developed after the derailment. The intent was to prevent rail traffic entering the entire area when rainfall exceeded the rainfall thresholds for that area until it was assessed as safe.

90 Bureau of Meteorology Design Rainfall Data System (2016) Australian Rainfall and Runoff - 2016 Design rainfalls

Network Control Centre South fatigue management

In the 14-day period prior to and including the occurrence shift, both the TTM and NCO worked several shifts that were not in accordance with the operator's fatigue Work Instruction. These shifts were backwards rotating with a minimum of eight hours between some shifts.

There was no evidence available that their work outside of ARTC's fatigue guidelines was assessed for the likely level of additional risk involved, or appropriate risk control measures identified, or applied.

While rostering of the TTM and NCO did not contribute to the occurrence, ARTC's network control rostering practices increased the likelihood of persons experiencing fatigue at levels demonstrated to adversely affect safe performance.

Most people need at least 7-8 hours of sleep each day to achieve maximum alertness and performance, with research showing that less than 6 hours sleep can increase risk of fatigue.[91,92] Research has also shown that sleep of less than 5 hours in the previous 24 hours is inconsistent with a safe system of work.[93] The rostered time free of duty between shifts, of 8 hours, provided a period of sleep opportunity of less than 8 hours, in consideration of travel time, meals and other domestic requirements.

In addition, there was a safety improvement opportunity for defining the risk assessment process, when work was required outside of the ARTC's fatigue management guidelines, and for ensuring that identified controls were applied and documented.

91 Thomas MJW and Ferguson SA (2010), Prior sleep, prior wake, and crew performance during normal flight operations, Aviation, Space, and Environmental Medicine, vol. 81, pp. 665–670.

92 Williamson A, et al (2011), The link between fatigue and safety, Accident Analysis and Prevention, vol. 43, pp. 498–515.

93 Dawson D and McCulloch K (2005), Managing fatigue: It's about sleep, Sleep Medicine Reviews, vol. 9, pp. 365–380.

Findings

ATSB investigation report findings focus on safety factors (that is, events and conditions that increase risk). Safety factors include 'contributing factors' and 'other factors that increased risk' (that is, factors that did not meet the definition of a contributing factor for this occurrence but were still considered important to include in the report for the purpose of increasing awareness and enhancing safety). In addition 'other findings' may be included to provide important information about topics other than safety factors.

Safety issues are highlighted in bold to emphasise their importance. A safety issue is a safety factor that (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operating environment at a specific point in time.

These findings should not be read as apportioning blame or liability to any particular organisation or individual.

From the evidence available, the following findings are made with respect to the derailment of freight train 4BM4 at Nana Glen, New South Wales on 25 February 2021.

Contributing factors

- The network users were not aware of the extent of the severe weather event and had not been advised of the amber alert issued prior to the derailment.
- The culvert located at 643.849 km did not have sufficient capacity to discharge the runoff from the rain event on the night of 24-25 February 2021. Floodwater built up on the southern side of the embankment before overtopping the track and washing away the ballast at 643.800 km.
- The driver of 4BM4 observed water in and around the rail corridor after passing Glenreagh and continued close to track speed (between 60-70 km/h) towards Nana Glen. Water was observed encroaching the rail line and on exiting a right-hand bend, train 4BM4 derailed at a washaway at 643.800 km.
- **Although ARTC had procedures in place for monitoring and responding to extreme weather events, the process had significant limitations including:**
  - **The mechanism (email) for alerting operational personnel required to take action in response to amber alerts did not ensure that alerts were always identified or actioned in a timely manner.**
  - **The actions specified for amber and red alerts were insufficient to respond to escalating rainfall and flooding events, both forecast and actual.** (Safety issue)

Other factors that increased risk

- Neither driver of two previous trains through the section reported a condition affecting the network, relating to the poor weather conditions in the vicinity of Nana Glen, to the network controller. Additionally, although visibility was severely affected, as reported by the drivers, they did not slow the train which reduced their opportunity to sight signals, potential obstructions and safely traverse level crossings.
- **Neither ARTC or PN provided guidance for train crew to respond to extreme wet weather events or floodwater in the rail corridor. There was no guidance for when trains should stop or report if there was water on the track formation, covering the ballast, sleepers or the rail.** (Safety issue)

- The culvert at 643.849 km and numerous other culverts along the Mid North Coast had been identified as far back as 1995, as inadequate and susceptible to overtopping which increased the risk of the track structure washing away at those locations.
- **ARTC could not reliably determine the risk of flooding along the Telarah to Acacia Ridge corridor or the risks associated with inadequate capacity cross drainage systems.** (Safety issue)
- **ARTC had not undertaken formal assessments to determine the need for or the locations of remote weather monitoring stations to detect extreme weather events that could affect the integrity of its rail infrastructure.** (Safety issue)
- **The weather alerts issued by the EWN did not reliably reflect the data and frequency of ARTC's extreme weather monitoring procedure or the service agreement. This and the services ARTC believed were included in the service agreement likely impacted the expectations of ARTC users who relied on these warnings to inform their response.** (Safety issue)
- The rostering practices for ARTC's network control leading up to the occurrence, increased the likelihood of persons experiencing fatigue at levels that have been demonstrated to adversely affect safe performance.

Safety issues and actions

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues. The ATSB expects relevant organisations will address all safety issues an investigation identifies.

Depending on the level of risk of a safety issue, the extent of corrective action taken by the relevant organisation(s), or the desirability of directing a broad safety message to the rail industry, the ATSB may issue a formal safety recommendation or safety advisory notice as part of the final report.

All of the directly involved parties were provided with a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

The initial public version of these safety issues and actions are provided separately on the ATSB website, to facilitate monitoring by interested parties. Where relevant, the safety issues and actions will be updated on the ATSB website as further information about safety action comes to hand.

Guidance for extreme wet weather and flooding

Safety issue description

Neither ARTC or PN provided guidance for train crew to respond to extreme wet weather events or floodwater in the rail corridor. There was no guidance for when trains should stop or report if there was water on the track formation, covering the ballast, sleepers or the rail.

Issue number:	RO-2021-004-SI-01
Issue owner:	Australian Rail Track Corporation (ARTC) and Pacific National (PN)
Transport function:	Rail: Rollingstock Rail: Infrastructure
Current issue status:	Open – Safety action pending.

Response by Australian Rail Track Corporation (ARTC)

ARTC advised it has discussed with Pacific National (PN) investigating improvements to the process covering actions to be taken by train drivers and network controllers, when flood water is observed in the rail corridor, e.g. at what point should a train report, slow or stop. Once completed, ARTC will decide whether to roll out the revised process to all rail operators.

Response by Pacific National (PN)

PN advised that what constitutes a reportable condition in a particular scenario may depend on various factors, and that there may be some difficulty with prescribing what is appropriate in each and every adverse or abnormal scenario (wet weather being just one type of potential condition). Pacific National however supported discussion between Rail Operators and the Network Operator with regards to the development of guidance material to support the CAN network rule. Pacific National indicated that it would be appropriate for the Network Operator to lead such discussions given their overall responsibility for managing the movement of trains by multiple rail operators over the Network in accordance with safeworking procedures, including collating and disseminating timely information (via such methods as warnings and alerts regarding particular conditions) to users of the Network.

ATSB comment

The ATSB welcomes and acknowledges the intention by ARTC and PN to develop improvements to the process covering the actions to be taken by train drivers and network controllers. However, as proposed safety action and a timeline were not provided, the ATSB remains concerned with the resolution of this safety issue. Accordingly, the ATSB issues the following safety recommendations to support both ARTC's and PN’s proposed safety action.

Safety Recommendation to Australian Rail Track Corporation (ARTC)

The ATSB makes a formal safety recommendation, either during or at the end of an investigation, based on the level of risk associated with a safety issue and the extent of corrective action already undertaken. Rather than being prescriptive about the form of corrective action to be taken, the recommendation focuses on the safety issue of concern. It is a matter for the responsible organisation to assess the costs and benefits of any particular method of addressing a safety issue.

Recommendation number:	RO-2021-004-SR-20
Action organisation:	Australian Rail Track Corporation (ARTC)
Recommendation status:	Released

The Australian Transport Safety Bureau recommends that Australian Rail Track Corporation develops guidance for train crew to respond to and report extreme wet weather events or floodwater in the rail corridor.

Safety Recommendation to Pacific National (PN)

The ATSB makes a formal safety recommendation, either during or at the end of an investigation, based on the level of risk associated with a safety issue and the extent of corrective action already undertaken. Rather than being prescriptive about the form of corrective action to be taken, the recommendation focuses on the safety issue of concern. It is a matter for the responsible organisation to assess the costs and benefits of any particular method of addressing a safety issue.

Recommendation number:	RO-2021-004-SR-19
Action organisation:	Pacific National (PN)
Recommendation status:	Released

The Australian Transport Safety Bureau recommends that Pacific National develops guidance for train crew to respond to and report extreme wet weather events or floodwater in the rail corridor.

ARTC Remote weather monitoring equipment/needs

Safety issue description

ARTC had not undertaken formal assessments to determine the need for or the locations of remote weather monitoring stations to detect extreme weather events that could affect the integrity of its rail infrastructure.

Issue number:	RO-2021-004-SI-03
Issue owner:	Australian Rail Track Corporation (ARTC)
Transport function:	Rail: Infrastructure

Current issue status:	Open – Safety action pending.

Proactive safety action taken by Australian Rail Track Corporation (ARTC)

Action number:	RO-2021-004-PSA-68
Action organisation:	Australian Rail Track Corporation (ARTC)
Action status:	Monitor

ARTC advised that following the occurrence they installed an additional 20 remote weather monitoring stations along the Telarah to Acacia Ridge corridor in addition to the 15 that were being installed at the time of the derailment. The additional weather stations provide a benefit both for flooding alerts but also increased ARTC knowledge around the risk of flooding.

In response to the draft report ARTC advised of the additional proactive safety actions in progress or planned as outlined below.

- ARTC engaged a consultant to undertake a hydrology review of the ARTC network. The hydrology review is being informed by the results of analysis by separate consultant on the effects of climate change focussing on the Brisbane to Albury corridor.
- The hydrology review will identify the theoretical hydraulic capacity of all of ARTC culverts along the length of its network. This will determine what the culverts are capable of handling and following risk analysis to prioritise the locations for installation of monitors and consideration to upgrade to a greater hydraulic capacity. The first package of this work has been completed. It covered approximately one third of ARTC's network and was based on risk and findings from the analysis of climate change assessment report. The hydrology study for the Nana Glen section will be completed in July 2023, with all hydrology investigation works to be completed by December 2023.
- Planned installation of an additional 50 weather monitoring stations across the network over the next two years, with current plans to install approximately 500 stream flow monitors at higher risk locations.
- ARTC and ONRSR have agreed to a three-stage approach aimed at assessing and improving ARTC's ability to manage increased risks associated with climate change and extreme weather events. The first stage involves an independent assessment of ARTC's maturity in dealing with these risks, while the second stage involves the development of an extreme weather and climate change strategy. The third and final stage entails the design and implementation of an improvement project. The project is a Self-Assessment to assess ARTC's maturity and will evaluate various aspects of ARTC's systems, processes, infrastructure, and people, including expertise and training. Specifically, the Self-Assessment will cover five key areas: risk management, safety governance, asset management, incident management, and regulatory compliance.

ATSB comment

The ATSB acknowledges that some proactive safety action has been completed and anticipates that once all safety actions have been completed the safety issue should be addressed. ATSB will monitor progress on the implementation of ARTC safety actions.

ARTC and EWN weather monitoring procedure and service agreement

Safety issue description

The weather alerts issued by the EWN did not reliably reflect the data and frequency of ARTC's extreme weather monitoring procedure or the service agreement. This and the services ARTC believed were included in the service agreement likely impacted the expectations of ARTC users who relied on these warnings to inform their response.

Issue number:	RO-2021-004-SI-04
Issue owner:	Australian Rail Track Corporation (ARTC) and Early Warning Network (EWN)
Transport function:	Rail: Infrastructure
Current issue status:	Closed-Adequately addressed
Issue status justification:	The ATSB is satisfied that the safety actions taken by both ARTC and EWN addresses the safety issue.

Proactive safety action taken by Australian Rail Track Corporation (ARTC)

Action number:	RO-2021-004-PSA-69
Action organisation:	Australian Rail Track Corporation (ARTC)
Action status:	Closed

In August 2022, ARTC advised that they had undertaken a review of their contract with the EWN to address inconsistencies between ARTC's extreme weather monitoring procedure and contract.

Additionally, they clarified their requirements in relation to flood warnings with the EWN. Monitoring of rainfall depths for the Hunter Valley corridor had also been rectified and commenced.

In response to the draft report ARTC advised of the additional proactive safety actions:

- Appointed a new weather provider that offered a mobile device application that provides lightning and fire alerts specific to a particular location and is expected to deliver a marked improvement in the early warning of severe weather systems.
- The weather provider uses a geographic information system (GIS), so ARTC can geolocate sections of track and achieve more granular reporting.
- ARTC is also using a number of data points to inform decision making e.g., BoM, ARTC monitoring sites, reports from maintainers and drivers.
- The new provider service agreement acknowledges the safety-criticality of the information being provided and the contract has been prepared in line with the requirements of the ARTC procedure OPE-PR-014. This procedure has also been reviewed to ensure it is in line with expectations around how ARTC manages extreme weather events.
- The locations of flooding special locations have been communicated to the service provider with amber alerts to be generated if rainfall exceeds ARTC's thresholds within 20 km of the special location.
- Monitoring of BoM flood warnings (moderate and major) for bridges that cross major rivers/floodplains have also been included in the contract. ARTC are in the process of identifying the locations that require monitoring.
- ARTC will be undertaking regular reviews of the service being provided with an expectation that it is upgraded as required.

- ARTC also advised that their longer-term plan is to have a better understanding of their assets and to improve their knowledge bank to better understand and deal with the many inputs relating to weather and its impact on their network.

ATSB comment

The ATSB notes that ARTC have taken action to ensure that the weather monitoring service is aligned to their extreme weather monitoring procedure and have also introduced more proactive monitoring to manage the risk of flooding at special locations. The action taken by ARTC addresses the safety issue.

Proactive safety action taken by Early Warning Network (EWN)

Action number:	RO-2021-004-PSA-90
Action organisation:	Early Warning Network (EWN)
Action status:	Closed

In response to the draft report the EWN advised that they had performed the following safety actions:

- Monitoring of rainfall depth for the Hunter Valley corridor had been setup and was being performed.
- Rebuilt their entire rainfall alert system, added all ARTC owned gauges and ARTC special locations for amber alerts.
- Developed a Radar Derived Rainfall (RDR) alerts system. Where there was weather radar coverage the system would allow for rainfall accumulations to be derived for a particular area rather than relying on land-based weather monitoring equipment. The EWN reported that based on the rainfall on the night of the occurrence that if the RDR alert system was operating, a red alert would have been issued at 2230 and a black alert at 2245 for rainfall exceeding the 6-hour ARI rainfall threshold.

ATSB comment

The ATSB notes that EWN have taken action to revise their weather monitoring system and services, which addresses the safety issue.

ARTC Extreme Weather Monitoring and Response (Amber and Red Alert)

Safety issue description

Although ARTC had procedures in place for monitoring and responding to extreme weather events, the process had significant limitations including:

- The mechanism (email) for alerting operational personnel required to take action in response to amber alerts did not ensure that alerts were always identified or actioned in a timely manner.
- The actions specified for amber and red alerts were insufficient to respond to escalating rainfall and flooding events, both forecast and actual.

Issue number:	RO-2021-004-SI-06
Issue owner:	Australian Rail Track Corporation (ARTC)
Transport function:	Rail: Infrastructure
Current issue status:	Open – Safety action pending.

Proactive safety action taken by Australian Rail Track Corporation (ARTC)

Action number:	RO-2021-004-PSA-72
Action organisation:	Australian Rail Track Corporation (ARTC)
Action status:	Monitor

In response to the draft report ARTC advised the following proactive safety actions were underway:

- ARTC instigated a 7 Day look ahead weather forecast provided weekly by the BoM which is shared with ARTC's customers.
- ARTC advised that they are undertaking a formal review of their extreme weather monitoring procedure.
- ARTC initiated a project to develop a risk model to support real-time decision-making on operational responses to extreme wet weather events. The first stage of this project is to understand ARTC’s current operational responses to extreme wet weather events, and to assess the strengths, weaknesses and opportunities for improvement, having regard to contemporary wet weather incidents and current industry practice.

  Later project stages will involve the development of a risk model, along with the proposal of strategies to leverage the risk model to better inform ARTC’s management of extreme wet weather events. ARTC engaged a consultant to undertake this work and the first stage of the work is well advanced.
- In December 2022, ARTC released a safety bulletin which increased the rainfall and flooding alerts by one category (i.e., red alerts treated as black alerts) as a preventative measure based on the cumulated conditions impacting on the network e.g., saturated catchments, La Niña weather pattern etc.
- ARTC are investigating the potential of sending weather alerts directly to the customers.
- ARTC are also increasing network control resources to provide additional controls for data management which would assist in the dissemination of alerts between Network Controllers and Rail Operators.

ATSB comment

The ATSB acknowledges that some proactive safety action has commenced and will monitor progress of their implementation.

ARTC flood risk and inadequate drainage systems

Safety issue description

ARTC could not reliably determine the risk of flooding along the Telarah to Acacia Ridge corridor or the risks associated with inadequate capacity cross drainage systems.

Issue number:	RO-2021-004-SI-07
Issue owner:	Australian Rail Track Corporation (ARTC)
Transport function:	Rail: Infrastructure
Current issue status:	Open – Safety action pending.

Proactive safety action taken by Australian Rail Track Corporation (ARTC)

Action number:	RO-2021-004-PSA-71

Action organisation:	Australian Rail Track Corporation (ARTC)
Action status:	Monitor

In response to the draft report ARTC advised the following proactive safety action has been completed or is on-going:

- ARTC advised that they have developed and implemented a work instruction for flooding and special locations management. The work instruction has been communicated to all field staff to assist with monitoring of special locations.

  Additionally, ARTC advised that they have developed an enterprise-wide special locations register (that is to capture infrastructure such as non-standard culverts) which is maintained through their asset management system.
- The locations of flooding special locations have been included in the weather monitoring contract to provide warning when rainfall is occurring near a flooding special location.
- Planning the installation of additional weather monitoring stations or stream flow monitors at some special locations (see RO-2021-004-SI-03), as well as reviewing the use of closed-circuit television cameras at a few special locations.
- Finally, as detailed in response to safety issue RO-2021-004-SI-03 a consultant has been engaged to undertake a hydrology review of the ARTC network which will assist in determining the risk of flooding.

ATSB comment

The ATSB acknowledges that some proactive safety actions have been completed and anticipates that once all safety actions have been completed then the safety issue will be addressed. ATSB will monitor progress of their implementation.

Safety action not associated with an identified safety issue

Whether or not the ATSB identifies safety issues in the course of an investigation, relevant organisations may proactively initiate safety action in order to reduce their safety risk. The ATSB has been advised of the following proactive safety action in response to this occurrence.

Additional safety action by Early Warning Network (EWN)

The Early Warning Network advised that following the occurrence, they revised their alert generator (software program) for generating and distributing weather alerts to include the phrase 'life threatening flash flooding'. Weather alerts issued by the Bureau of Meteorology that included this phrase would automatically be identified as a red alert and communicated to the EWN's customers including ARTC.

General details

Occurrence details

Date and time:	25 February 2021 – AEDT	
Occurrence class:	Accident	
Occurrence categories:	Derailment	
Location:	Nana Glen, New South Wales	
	Latitude: 30° 6.198' S	Longitude: 153° 1.027' E

Train details

Track operator:	Australian Rail Track Corporation	
Train operator:	Pacific National	
Train number:	4BM4	
Type of operation:	Freight - Intermodal	
Consist:	Three locomotives and 37 wagons (2422 t and 1459 m)	
Departure:	Brisbane, Queensland	
Destination:	Melbourne, Victoria	
Persons on board:	Crew – 2	Passengers – Nil
Injuries:	Crew – 1	Passengers – Nil
Damage:	Damage to three locomotives and nine wagons were damage beyond repair.	

Glossary

AEP	Annual Exceedance Probability: The probability that a given rainfall total accumulated over a given duration will be exceeded in any one year. AEP is usually expressed as a percentage, and common references include 1% AEP and 2% AEP. Source: RISSB AS 7637:2013.
ADH	Australian Height Datum
AIDR	Australian Institute for Disaster Resilience
AM	Area Manager
ARI	Average Recurrence Interval: The average or expected value of the periods between exceedances of a given rainfall total accumulated over a given duration. It is implicit in this definition that the periods between exceedances are generally random. ARI is generally expressed as years, and common references include 1 in 2-year ARI, 1 in 10-year ARI, 1 in 50-year ARI, and 1 in 100-year ARI. Source: RISSB AS 7637:2013.
ARM	Automatic Rainfall Monitoring
ARR	Australian Rainfall and Runoff is a national guideline document, data and software suite that can be used for the estimation of design flood characteristics in Australia.
ARTC	Australian Rail Track Corporation
BFT	Brisbane Freight Terminal
BoM	Bureau of Meteorology
CRIA	Country Rail infrastructure Authority
CM	Corridor Manager
Culvert	The term culvert is normally applied in engineering practice to any large underground pipe especially where used in relatively short lengths to convey streams or floodwater under an embankment or structure.
DIRN	Defined Interstate Rail Network
CCTV	Closed-circuit television
ECL	East Coast Lows
EWG	Extreme Weather Group
EWN	Early Warning Network
FOT	Front of train footage
ha	Hectare (ha) – a surface measurement, a common unit of measure for land in the metric system. 1 ha equals 10,000 square meters or 1 km^2
Heavy rainfall	Rainfall over a period between 30 minutes and 6 hours which exceeds the 10% AEP depth (BoM).
HV	Hunter Valley
Intense rainfall	Rainfall over a period between 30 minutes and 6 hours which exceeds the 2% AEP depth (BoM).
IPS	Integrated Planning Services, Pacific National

Low visibility	Any condition that does not allow Competent Workers to view the distance required to work safely (RISSB). Visibility restricted by fog, mist, rain, dust, snow, low light or other similar cause (ARTC glossary).
km	kilometre, a unit of measure equal to 1,000 m
NC	Network Control
NCCN	Network Control Centre North, located at Broadmeadow in New South Wales
NCCS	Network Control Centre South, located at Junee in New South Wales
NCO	Network Control Officer
NSW	New South Wales
ONRSR	The Office of the National Rail Safety Regulator. Administered and enforced compliance with the Rail Safety National Law and Regulations.
PN	Pacific National
QR	Queensland Rail
RAIB	Rail Accident Investigation Branch, United Kingdom
RFFE	Regional Flood Frequency Estimation Model
RIC	Rail Infrastructure Corporation
RIM	Rail infrastructure manager
RISSB	Rail Industry Safety and Standards Board. Responsible for the provision of standards, codes of practice, guidelines, rules, safety data and analysis for the Australian rail industry.
RRV	Road rail vehicle
RSSB	Rail Safety and Standards Board, United Kingdom
RTO	Rail transport operator. Encompassed both rail infrastructure managers (track, signalling etc.) and rolling stock operators (locomotives, wagons etc.).
SDM	Service Delivery Manager
SES	State Emergency Services
SMS	Safety management system. A systematic approach to organisational safety encompassing safety policy and objectives, risk management, safety assurance, safety promotion, third party interfaces, internal investigation and SMS implementation.
SRA	State Rail Authority
t	tonnes, a unit of mass equal to 1000 kilograms
Tc	Time of concentration refers to the time for rainfall that falls at the furthest point in a catchment to flow as runoff to the outlet, in this case the culvert.
TfNSW	Transport for NSW
TTM	Train Transit Manager
UK	United Kingdom

Sources and submissions

Sources of information

The sources of information during the investigation included the:

- train crew of 4BM4 and previous trains 3MB4 and NT31
- network controller, train transit manager and corridor manager
- Australian Rail Track Corporation
- Bureau of Meteorology
- Early Warning Network
- Fire and Rescue NSW
- NSW Trains
- Office of the National Rail Safety Regulator
- Pacific National
- Rail Industry Safety Standards Board.

References

Australian Dangerous Goods Code (2020), Australian Code for the Transport of Dangerous Goods by Road & Rail, Edition 7.7.

Australian Institute for Disaster Resilience (2021), Major Incidents Report 2020–21. Accessed at: https://knowledge.aidr.org.au/resources/major-incidents-report/

Australian Rail Track Corporation (2010), Automatic Rainfall Monitoring, ETD-10-01, V1.1, 18 June 2010.

Australian Rail Track Corporation (2011), Code of Practice, Flooding, Section 10, V2.2, 8 November 2011.

Australian Rail Track Corporation (2013), RTS 3433, Track Drainage – Design and Construction, Issue A, Revision 1, 6 June 2013.

Australian Rail Track Corporation (2014), Monitoring and Responding to Extreme Weather Events in the East-West Corridor, OPP-01-05, V1.0, 29 May 2014.

Australian Rail Track Corporation (2017), Monitoring and Responding to Extreme Weather Events, OPE-PR-014, V3.0, 15 August 2017.

Australian Rail Track Corporation (2018), WHS-WI-423 Fatigue, Work Instruction, V4.1, 14 March 2018.

Australian Rail Track Corporation (2019), Code of Practice, Structures, Section 9, V3.7, 31 January 2019.

Australian Rail Track Corporation (2019), Structures Inspection, ETE-09-01, V2.6, 20 August 2019.

Australian Rail Track Corporation (2019), Monitoring and Responding to Extreme Weather Events, OPE-PR-014, V3.4, June 2019.

Australian Rail Track Corporation (2020), ANGE 206 Reporting and Responding to a Condition Affecting the Network (CAN), V3.2, 23 February 2020.

Australian Rail Track Corporation (2021), Civil Technical Maintenance Plan, ETE-00-03, V4.3, 27 October 2021.

Austroads (2018), Guide to Road Design Part 5B: Drainage – Open Channels, Culverts and Floodways, edition 1.1, August 2018.

Australian Standard AS 5100:2017, Bridge Design – Parts 1 to 9.

Bureau of Meteorology and CSIRO (2020), State of the Climate 2020. Accessed at: http://www.bom.gov.au/state-of-the-climate/documents/State-of-the-Climate-2020.pdf

Dawson D and McCulloch K (2005), Managing fatigue: It's about sleep, Sleep Medicine Reviews, vol. 9, pp. 365–380.

Federal Highway Administration (2012), Hydraulic Design Series Number 5, FHWA-HIF-12-026 HDS 5, U.S. Department of Transportation.

GHD Pty Ltd for Coffs Harbour City Council (2012), Final Report Orara River Flood Study, Section 1-10. Accessed at: https://www.coffsharbour.nsw.gov.au/Environment/Flooding/Flood-risk-management-plans-and-studies/Upper-Orara

Keller R and Weeks W (2019), Flood Hydraulics, Book 6, Chapter 3 Hydraulic Structures in Australian Rainfall and Runoff - A Guide to Flood Estimation, Commonwealth of Australia. Accessed at: https://arr.ga.gov.au/arr-guideline

Kellogg Brown & Root Pty Ltd (2018), ARTC Track Closure Timing Assessment - North South and East West Rail, BEW854-TD-WE-REP-0001, Rev. A, 5 July 2018

NSW Office of Environment and Heritage (2014), North Coast Climate change snapshot. Accessed at: https://www.climatechange.environment.nsw.gov.au/north-coast

NSW Trains (2019), NTTWP 100 Responsibility of Train Crew, 24 October 2019

Paterson Consultants Pty Limited (1995), North Coast Line Culvert Assessment, Nana Glen to Glenreagh, Gurranang to Lawrence Road.

Rail Industry Safety and Standards Board (2013), AS 7367:2013, Railway Structures

Rail Industry Safety and Standards Board (2014), ANRP 2027 Responsibilities of Rail Traffic Crews, V1.2, 10 June 2014

Rail Safety and Standards Board (2020), GERT8000-M3 Rule Book, Managing incidents, floods and snow, Issue 3.1, 5 December 2020

Thomas MJW and Ferguson SA (2010), Prior sleep, prior wake, and crew performance during normal flight operations, Aviation, Space, and Environmental Medicine, vol. 81, pp. 665–670.

Tsubaki R, Bricker J, Ichhii K, and Kawahara Y (2016), Development of fragility curves for railway embankment and ballast scour due to overtopping flood flow, National Hazards and Earth Systems Science, 16, 2455–2472, 2016.

Williamson A, Lombardi DA, Folkard S, Stutts J, Courtney TK & Connor JL (2011), The link between fatigue and safety, Accident Analysis and Prevention, vol. 43, pp. 498–515.

Submissions

Under section 26 of the *Transport Safety Investigation Act 2003*, the ATSB may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. That section allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to the following directly involved parties:

- train crew of 4BM4 and previous trains 3MB4 and NT31
- network controller, train transit manager and corridor manager
- Australian Rail Track Corporation
- Early Warning Network
- NSW Trains
- Office of the National Rail Safety Regulator
- Pacific National.

Submissions were received from:

- Australian Rail Track Corporation
- Early Warning Network
- Office of the National Rail Safety Regulator
- Pacific National.

The submissions were reviewed and, where considered appropriate, the text of the report was amended accordingly.

Appendices

Appendix A – OPE-PR-014 response tables

Table 15: Response to Rainfall / Flooding alerts – ARTC Defined Interstate Rail Network

Colour	Train Transit Manager	Corridor Manager	Service Delivery Manager	Area Managers
Green	• Check daily updates	• No Action	• No Action	• Check daily updates
Amber	• Monitor alerts and warnings • Advise operators and other network users of the current alert level. • Ensure operators are advised.	• Monitor alerts and warnings • Consider higher frequency inspections of track section • Consider inspecting culvert condition and water levels during inspections • Make arrangement to enable inspections if needed following downpour events or reports of high water • Track and Civil Infrastructure Maintainers informed of potential extreme weather event	• Monitor alerts and warnings • Advise customers of potential network interruptions due to extreme weather event	• Monitor alerts and warnings • Provide local input where required • Collect reports from maintenance crews and other sources and inform Network Control, the Service Delivery Manager and the Corridor Manager of any new information • Develop a local response plan • Hold local toolbox meeting as required
Red	• Monitor alerts and warnings • Issue a weather reminder to operators and other network users. • Consider trains to be held at/moved to 'safe' locations • Ensure communication to trains and network users through the	• Monitor alerts and warnings • Participate in daily meeting of the EWG and provide input. • Consideration given to more frequent and/or targeted track inspections with focus on • known 'high risk' areas. • Consideration given to the deployment of staff into/out of	• Monitor alerts and warnings. • Convene a daily meeting of the EWG and consider elevating to BLACK or downgrading to AMBER. • Plan and execute an extreme weather network plan if required. • Advise customers of network interruptions due to extreme weather event	• Monitor alerts and warnings • Provide local input where required • Collect reports from maintenance crews and other sources and inform Network Control, the Service Delivery Manager and the Corridor Manager of any new information • Hold local toolbox meeting as required • Implement local response plan

	affected area and report any new information to the Service Delivery Manager.	critical areas depending on their specific roles.	• Consider additional resourcing of Network Control	
Black	• Monitor alerts and warnings • Cease all operations in the affected area immediately and close the affected sections to all traffic. NOTE: Once track has been closed, inspection (to determine integrity of track) and re-opening can only be carried out upon obtaining the approval of the EWG.	• Monitor alerts and warnings • Participate in update meetings of the EWG and provide input. • Track section or structure may be closed to traffic if deemed necessary until track integrity is confirmed. NOTE: Once track has been closed, inspection (to determine integrity of track) and re-opening can only be carried out upon obtaining the approval of the EWG.	• Monitor alerts and warnings. • Convene a daily meeting of the EWG and consider elevating to BLACK or downgrading to AMBER. • Plan and execute an extreme weather network plan if required. • Advise customers of network interruptions due to extreme weather event • Consider additional resourcing of Network Control NOTE: Once track has been closed, inspection (to determine integrity of track) and re-opening can only be carried out upon obtaining the approval of the EWG.	• Monitor alerts and warnings • Provide local input where required • Collect reports from maintenance crews and other sources and inform Network Control, the Service Delivery Manager and the Corridor Manager of any new information • Hold local toolbox meeting as required

Table 16: Response to Rainfall / Flooding alerts – ARTC Hunter Valley Network

Colour	Train Transit Manager	Maintenance Manager	Manager Operations Services	Area Managers
Green	• Monitor SES and BoM sites to check for daily warnings	• No Action	• No Action	• No Action
Amber	• Monitor current SES and BoM warnings. • Advise Service Delivery Manager as required. • Request the OPO [Operations Performance Officers] to advise operators and other network users of the current alert level via Network Notifications. • Ensure operators are advised. • Provide regular updates to Network Controllers via shift stand-ups.	• Monitor warnings from OPOs. • Consider higher frequency inspections of track section • Consider inspecting culvert condition and water levels during inspections • Make arrangement to enable inspections if needed following downpour events or reports of high water • Track and Civil Infrastructure Maintainers informed of potential extreme weather event	• Monitor warnings from OPOs.	• Monitor warnings from OPOs • Provide local input where required • Collect reports from maintenance crews and other sources and contact the TTM and Manager Maintenance / Manager Central and North West of any new information • Develop a local response plan • Hold local toolbox meeting as required
Red	• Monitor warnings • Advise Service Delivery Manager as required. • Request the OPO to issue a weather warning reminder to operators and other network users. • Consider trains to be held at/moved to 'safe' locations	• Monitor warnings • Participate in daily meeting of the EWG and provide input. • Consideration given to more frequent and/or targeted track inspections with focus on known 'high risk' areas. • Consideration given to the deployment of staff into/out of	• Monitor warnings. • Convene a daily meeting of the EWG and consider elevating to BLACK or downgrading to • AMBER. • Plan and execute an extreme weather network plan if required. • Advise customers (via OPOs) of network interruptions due to extreme weather event	• Monitor warnings • Provide local input where required • Collect reports from maintenance crews and other sources and contact the TTM and Manager Maintenance / Manager Central and North West of any new information • Hold local toolbox meeting as required • Implement local response plan

	• Ensure communication to trains and network users through the affected area and report any new information to the Service Delivery Manager. • Facilitate EWG via VCS. • Provide regular updates to Network Controllers via shift stand-ups or more frequently as required.	critical areas depending on their specific roles.	• Consider additional resourcing of Network Control	
Black	• Monitor warnings • Advise Service Delivery Manager • Cease all operations in the affected area immediately and close the affected sections to all traffic. • Facilitate EWG via VCS • Conduct stand-up post EWG to advise Network Controllers of current status NOTE: Once track has been closed, inspection (to determine integrity of track) and re-opening can only be carried out upon obtaining the approval of the EWG.	• Monitor warnings • Participate in update meetings of the EWG and provide input. • Track section or structure may be closed to traffic if deemed necessary until track integrity is confirmed. NOTE: Once track has been closed, inspection (to determine integrity of track) and re-opening can only be carried out upon obtaining the approval of the EWG.	• Monitor warnings • Convene update meetings of the EWG and consider downgrading to RED • Prepare plans for reopening of the network. • Update customers regularly (via OPOs) re: plans for reopening of the network NOTE: Once track has been closed, inspection (to determine integrity of track) and re-opening can only be carried out upon obtaining the approval of the EWG.	• Monitor warnings • Provide local input where required • Collect reports from maintenance crews and other sources and contact the TTM and Manager Maintenance / Manager Central and North West of any new information • Hold local toolbox meeting as required

Table 17: Response to Wind Alerts - ARTC Defined Interstate Rail Network

Colour	Train Transit Manager	Corridor Manager	Service Delivery Manager	Area Managers
Green	• Check daily updates	• No Action	• No Action	• Check daily updates
Amber	• Monitor alerts and warnings • Advise train crew and other network users of the current alert level. • Collect field reports from train crews and other sources and inform the Service Delivery Manager of any new information.	• Monitor alerts and warnings	• Monitor alerts and warnings	• Monitor alerts and warnings • Collect reports from maintenance crews and other sources and inform Network Control, the Service Delivery Manager and the Corridor Manager of any new information
Red	• Issue a weather reminder to operators and other network users. • Ensure communication with train crews and other network users who report encountering gale force winds that pose a risk to operations and report any new information to the Service Delivery Manager. • Consider holding track machines and road rail vehicles at a safe location if weather	• Monitor alerts and warnings • Inform track maintainers and other contractors of potential for extreme weather in affected areas. • Consider cancelling/modifying any work programmed in the affected area. • Consider need for 'on track' travel and make alternative arrangements if conditions are expected to deteriorate further.	• Monitor alerts and warnings • Advise customers and Area Managers of possible delays due to extreme weather event, and to monitor and advice on the situation locally.	• Monitor alerts and warnings • Secure provisioning centre environs and equipment against potential impacts of damaging winds. • Consider cancelling/modifying any work programmed in the affected area. • Collect reports from maintenance crews and other sources and inform Network Control, the Service Delivery Manager and the Corridor Manager of any new information • Hold local toolbox meeting as required.

	conditions are expected to deteriorate further.			
Black	• Hold track machines and road rail vehicles at a safe location until winds abate. • Issue a weather reminder to train crews and other network users. • Ensure communication with train crews and other network users who report encountering storm force winds that pose a risk to operations and report any new information to the EWG.	• Monitor alerts and warnings • Participate in update meetings of the EWG and provide input • Consider cancelling/modifying any work programmed in the affected area. • Cancel planned operations requiring travel 'on track'.	• Monitor alerts and warnings • Convene update meetings of the EWG and consider downgrading to RED. • Advise customers of network interruptions due to extreme weather event.	• Monitor alerts and warnings • Hold local toolbox meeting as required. • If in affected area, consider closing Provisioning Centre. • Cancel work programmed in the affected area. • Collect reports from maintenance crews and other sources and inform Network Control, the Service Delivery Manager and the Corridor Manager of any new information

Table 18: Response to Wind Alerts - ARTC Hunter Valley Network

Colour	Train Transit Manager	Maintenance Manager	Manager Operations Services	Area Managers
Green	• Check daily BoM updates	• No Action	• No Action	• Check daily updates
Amber	• Monitor BoM, EWN Alerts and warnings • Advise Service Delivery Manager • Instruct the OPO [Operations Performance Officers] to advise operators and other network users of the current alert level via network notifications • Collect field reports from train crews and other sources and inform the Service Delivery Manager of any new information • Provide regular updates to Network Controllers via shift stand-ups	• Monitor warnings from OPOs	• Monitor warnings from OPOs	• Monitor warnings from OPOs • Collect reports from maintenance crews and other sources and inform the TTM and Maintenance Manager of any new information.
Red	• Request the OPO to issue a weather warning reminder to operators and other network users. • Advise Service Delivery Manager • Ensure communication with train crews and	• Monitor warnings • Inform track maintainers and other contractors of potential for extreme weather in affected areas.	• Monitor warnings • Advise of possible delays due to extreme weather event via OPO notices, and to monitor and advise relevant members of EWG on the situation locally.	• Monitor warnings. • Secure provisioning centre environs and equipment against potential impacts of damaging winds. • Consider cancelling/modifying any work programmed in the affected area.

	other network users who report encountering gale force winds that pose a risk to operations and report any new information to the Service Delivery Manager. • Consider holding track machines and road rail vehicles at a safe location if weather conditions are expected to deteriorate further. • Facilitate EWG via VCS • Provide regular updates to Network Controllers via shift stand-ups or more frequently as required.	• Consider cancelling/modifying any work programmed in the affected area. • Consider need for 'on track' travel and make alternative arrangements if conditions are expected to deteriorate further.		• Collect reports from maintenance crews and other sources and inform the TTM, the Manager Maintenance / Manager • Central and North West of any new information. • Hold local toolbox meeting as required.
Black	• Hold track machines and road rail vehicles at a safe location until winds abate. • Advise Service Delivery Manager • Request the OPO to issue a weather warning reminder to operators and other network users. • Ensure communication with train crews and	• Monitor warnings • Participate in update meetings of the EWG and provide input • Consider cancelling/modifying any work programmed in the affected area. • Cancel planned operations requiring travel 'on track'.	• Monitor warnings • Convene update meetings of the EWG and consider downgrading to RED. • Advise customers of network interruptions due to extreme weather event.	• Monitor warnings • Hold local toolbox meeting as required. • If in affected area, consider closing Provisioning Centre. • Cancel work programmed in the affected area. • Collect reports from maintenance crews and other sources and inform the TTM, the Manager Maintenance / Manager Central and North West of any new information.

[redacted]	other network users who report encountering storm force winds that pose a risk to operations and report any new information to the EWG. • Facilitate EWG via VCS • Conduct stand-up post EWG to advise Network Controllers of current status.			

Appendix B – ARTC and EWN rainfall monitoring areas

The table below details the rail corridors as defined with ARTC's extreme weather monitoring procedure (OPE-PR-014) with the corresponding geographic area. These were defined within ARTC's procedure including rail kilometrage for each section. The new corridors added when the weather monitoring was expanded in 2017 also had a designated corridor identification number.

In total, ARTC hade divided their network into 50 different areas with a corresponding ARI threshold for each section for the durations of 1 hour, 6 hours, 24 hours and 72 hours.

The EWN were monitoring ARTC's network as 15 geographical areas rather that the 50 areas defined by ARTC. The 15 geographic areas were further defined with the latitude and longitude for the corridor section rather than rail kilometrage. The ARI thresholds for the 15 areas were defined for the durations of 1 hour and 6 hours.

The table below shows the boundaries of the corridors as defined by ARTC with the corresponding area the EWN were monitoring. Some sections being monitored by the EWN as one area, consisted of up to five different sections as defined by ARTC. In some sections there was an overlap to the adjoining area with different ARI thresholds. There was no rainfall monitoring for the Hunter Valley corridor as required by ARTC.

Table 19: Comparison ARTC and EWN network geographic areas for rainfall monitoring

ARTC - rail corridor	ARTC – geographic areas	ARTC ID	EWN – geographic areas
Kalgoorlie to Cootamundra (KFC)	Cootamundra to Broken Hill		Broken Hill to Parkes
	Broken Hill to Peterborough		Crystal Brook to Broken Hill
	Peterborough to Pimba (including Whyalla Line)		Pimba to Crystal Brook
	Pimba to Ooldea		Cook to Pimba
	Ooldea to Rawlinna		Kalgoorlie to Cook
	Rawlinna to Kalgoorlie		
Melbourne to Crystal Brook (MAC)	Crystal Brook to Bolivar		Possible coverage - Crystal Brook to Broken Hill or Bolivar to Horsham
	Bolivar to Belair (including the Outer Harbor line)		Bolivar to Horsham
	Belair to Callington		
	Callington to Keith		
	Keith to Horsham		
	Horsham to Ararat		Horsham to Melbourne
	Ararat to Hamilton		
	Hamilton to Portland		Portland branch
	Ararat to Geelong		Horsham to Melbourne
	Geelong to Melbourne (including Melbourne Metro)		
North Corridor -	North Coast Single Line (Border Tunnel - Brisbane)	26	SE QLD and Northern Rivers

Sydney to Brisbane	North Coast Single Line (Border Tunnel - Brisbane)	27	
	North Coast Single Line (Telarah - Border Tunnel) - Woodville Junction	28	Taree to Hunter
	North Coast Single Line (Telarah - Border Tunnel) - Woodville Junction	29	
	North Coast Single Line (Telarah - Border Tunnel) - Woodville Junction	30	Port Macquarie region
	North Coast Single Line (Telarah - Border Tunnel) - Woodville Junction	31	
	North Coast Single Line (Telarah - Border Tunnel) - Woodville Junction	32	Coffs Harbour to Kempsey
	North Coast Single Line (Telarah - Border Tunnel) - Woodville Junction	33	
	North Coast Single Line (Telarah - Border Tunnel) - Woodville Junction	34	SE QLD and Northern Rivers
South Corridor - Melbourne to Sydney	Macarthur - VIC Border	16	Sydney Illawarra Southern Tableland
	Macarthur - VIC Border	17	
	Macarthur - VIC Border	18	
	Macarthur - VIC Border	19	
	Macarthur - VIC Border	20	
	Macarthur - VIC Border	21	Riverina and Victoria
	Melbourne (Spencer Street) - NSW Border	22	
	Melbourne (Spencer Street) - NSW Border	23	
	Melbourne (Spencer Street) - NSW Border	24	
	Melbourne (Spencer Street) - NSW Border	25	
Hunter Valley	Main North Down (ARTC Boundary - Muswellbrook)	1	Taree to Hunter
	Main North Single Line (Muswellbrook - Werris Ck)	2	No coverage for Hunter Valley corridor
	Gulgong- Muswellbrook	3	
	Gulgong- Muswellbrook	4	
	Merrygoen - Gulgong	5.1	
	Gulgong- Muswellbrook	5.2	
	Merrygoen - Werris Creek	6	
	Merrygoen - Werris Creek	7	
	Merrygoen - Werris Creek	8	
	Narromine - Merrygoen	9.1	
	Parkes - Narromine	9.2	
	Narromine - Merrygoen	10	
	Narromine - Merrygoen	11	

	Werris Creek - North Star	12	
	Werris Creek - North Star	13	
	Werris Creek - North Star	14	
	Werris Creek - North Star	15	

Appendix C – Culvert concepts

Culverts

Culverts are a hydraulic structure used to convey water under an embankment or other similar earthen structure. The shape of a culvert can be circular, square, arch and can be made of different materials. Culverts are usually laid on a slope to facilitate the flow of water and reduce sedimentation within the culvert.

Control method

Culverts will always be operating in one of two conditions, either inlet or outlet control. The control point can change during operation and can be difficult to predict. A culvert flowing full through its length will always be in outlet control, while a culvert flowing part full can be either inlet or outlet control.

When in inlet control the discharge only depends on the elevation of the headwater above the entrance (invert), and the inlet size and geometry. The length, slope and roughness of the pipe wall do not affect the discharge of the culvert. The discharge velocities can be high when operating under inlet control.

Culverts operating in outlet control are affected by all factors upstream of the outlet. These include the headwater elevation, entrance geometry, and the barrel size, length and slope. Tailwater is also a factor if it is above the elevation of the pipe outlet. With high tailwater, the outlet velocity can be low and high headwater can be an issue.[94,95] High tailwater alone is capable of making a culvert operate under outlet control, when it would otherwise be under inlet control.[96]

With the rise in the Orara River the culvert would probably have been operating in outlet control. Once the tailwater passes above the height of the outlet, any change in the height of the tailwater (Orara River) would be reflected on the upstream headwater at one-to-one ratio.

Inlet and outlet structures

For culvert inlet and outlet structures, headwalls (endwalls) and wingwalls of reinforced concrete are usually needed to provide embankment stability and protection against erosion. Culverts with wingwalls should be designed with an apron extending between the walls. The actual configuration of the wingwalls will vary according to the direction of flow and so protection against scour is maximised through inclusion of the apron.[97]

- Headwall (endwall) – The endwall structure alone acts to support the end of the culvert and as a retaining wall for the embankment.
- Wingwall – Wingwall directs the water into the pipe and helps to transition the culvert flow smoothly into the downstream channel and protects the endwall so that it may continue to function in its original capacity.

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94 Keller R and Weeks W (2019), Flood Hydraulics, Book 6, Chapter 3 Hydraulic Structures in Australian Rainfall and Runoff - A Guide to Flood Estimation, Commonwealth of Australia.

95 Austroads (2018), Guide to Road Design Part 5B: Drainage – Open Channels, Culverts and Floodways, edition 1.1, August 2018.

96 Federal Highway Administration (2012), Hydraulic Design Series Number 5, FHWA-HIF-12-026 HDS 5, U.S. Department of Transportation.

97 Department of Transport and Main Roads (2019), Manual Road Drainage, Chapter 9 Culvert Design. Queensland Government

Blockages

Culverts can be susceptible to blockages which can impact flood levels, change erosions and deposition patterns in channels, and physical damage to the structure.

The factors that can influence blockages include the location of the catchment and availability and type of debris. Leaves and branches can cause blockages very quickly. In larger culverts, rubble or debris can cause an issue. Blockages involving floating debris may arrive or build up as a floating raft that rises with the floodwater and is only deposited over the inlet. Sometimes mud, silt or other natural detritus can build up over time.[98]

[98] Rigby T and Weeks W (2019), Flood Hydraulics, Book 6, Chapter 6 Blockage of Hydraulic Structures in Australian Rainfall and Runoff - A Guide to Flood Estimation, Commonwealth of Australia.

Australian Transport Safety Bureau

About the ATSB

The ATSB is an independent Commonwealth Government statutory agency. It is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers.

The ATSB's purpose is to improve the safety of, and public confidence in, aviation, rail and marine transport through:

- independent investigation of transport accidents and other safety occurrences
- safety data recording, analysis and research
- fostering safety awareness, knowledge and action.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia, as well as participating in overseas investigations involving Australian-registered aircraft and ships. It prioritises investigations that have the potential to deliver the greatest public benefit through improvements to transport safety.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, international agreements.

Rail safety investigations in New South Wales

Most transport safety investigations into rail accidents and incidents in New South Wales (NSW) and Victoria are conducted in accordance with the Collaboration Agreement for Rail Safety Investigations and Other Matters between the Commonwealth Government of Australia, the State Government of NSW and the State Government of Victoria. Under the Collaboration Agreement, rail safety investigations are conducted and resourced in NSW by the Office of Transport Safety Investigations (OTSI) and in Victoria by the Chief Investigator, Transport Safety (CITS), on behalf of the ATSB, under the provisions of the *Transport Safety Investigation Act 2003*.

The Office of Transport Safety Investigations (OTSI) is an independent statutory body which contributes to improvements in the safety of bus, ferry and rail passenger and rail freight services in NSW by investigating safety incidents and accidents, identifying system-wide safety issues and sharing lessons with transport operators, regulators and other key stakeholders. Visit www.otsi.nsw.gov.au for more information.

Purpose of safety investigations

The objective of a safety investigation is to enhance transport safety. This is done through:

- identifying safety issues and facilitating safety action to address those issues
- providing information about occurrences and their associated safety factors to facilitate learning within the transport industry.

It is not a function of the ATSB to apportion blame or provide a means for determining liability. At the same time, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner. The ATSB does not investigate for the purpose of taking administrative, regulatory or criminal action.

Terminology

An explanation of terminology used in ATSB investigation reports is available on the ATSB website. This includes terms such as occurrence, contributing factor, other factor that increased risk, and safety issue.