Resilience of rail infrastructure

Update report to the Secretary of State for Transport following the derailment at Carmont, near Stonehaven

Andrew Haines
Chief executive
March 2021

Table of Contents

Executive summary

The tragic derailment of a passenger train at Carmont on 12 August 2020 raised questions about the resilience and safe performance of the railway in a changing climate. Emerging findings from the investigations indicate that the train derailed at Carmont after colliding with drainage material washed out from land beside the railway. A significant contributing factor was heavy rainfall that morning.

Formal investigations into the Carmont accident are still in progress. The Rail Accident Investigation Branch (RAIB), a Police Scotland/British Transport Police (BTP) and Office of Rail and Road (ORR) investigation, and the rail industry's own formal investigation are still gathering and analysing evidence. Interim findings from the industry investigation were distributed in confidence to relevant managers in November to share early learning. It is critical to understand fully what went wrong, the risk controls in place now and what more can and should be done. This report in no way pre-empts the outcome of formal independent investigations.

This report commissioned by the Secretary of State for Transport describes the way railway earthworks, drainage systems and weather risks are managed, and how the risk of such an event happening again can be minimised.

Three significant pieces of work since the Carmont accident have provided further insight to how the risks can be managed most effectively. This report provides an outline of the findings from two independent task forces commissioned by Network Rail and a further fast-tracked internal project to identify immediate opportunities for how railway operations are managed.

The challenge

- Britain's railway remains one of the safest railways in Europe[1]. However, with increasingly frequent severe weather conditions due to climate change, maintaining this high level of safety performance remains a constant challenge. This is particularly true for managing earthworks – the sloped ground beside the track – and drainage infrastructure.
- Most earthworks and drainage beside our railway were built more than 150 years ago. They were constructed without detailed engineering design and not to current standards at a time when the risks associated with earthworks were not scientifically understood. Consequently, cuttings and embankments (defined in section 1) were constructed with steep and unreinforced slopes. Commonly, drainage systems were not built with the original earthworks and the drainage that was installed was not designed to cope with floods. While they have served us well, and despite many improvements over the years, they are not as robust as a modern-day equivalent[2]. Earthworks structures are complex to manage due to underlying geology, adjacent environments and assets, local weather patterns and a propensity for very localised failure. Rebuilding thousands of miles of earthworks and drainage systems to modern-day standards is not practicable, either from a funding or deliverability perspective.

[1] RSSB (2020) Annual Health and Safety Report 2019/20. https://www.rssb.co.uk/Standards-and-Safety/Improving-Safety-Health--Wellbeing/Monitoring-safety/Safety-Performance-Reports
[2] Network Rail (2018) Earthworks Technical Strategy. https://www.networkrail.co.uk/wp-content/uploads/2018/07/Earthworks-Technical-Strategy.pdf viewed 26 August 2020

The current situation

- Infrastructure improvements are targeted to locations where we have identified the greatest risk. We manage the railway to a low level of risk and apply a robust management system to achieve that. Our investment is prioritised to locations assessed as higher risk and using technology to predict and warn of failures.
- We have developed techniques to monitor and manage ageing earthworks assets, which have been prioritised on our risk register for some time; these techniques are recognised as industry leading by fellow member organisations of the UK Geotechnical Asset Owners Forum.
- Climate change considerations are at the heart of our Environmental Sustainability Strategy published in September 2020[3] and the Government's Committee on Climate Change has recognised our resilience planning for climate change adaptation is well advanced[4]. But it is clear from the impact of severe weather events experienced in recent years that this is an area that is accelerating faster than our assumptions. As a result, it has become even more important to adapt our plans. Every route has now updated and published such plans.

What we are doing

- Industry rules for reporting and reacting to heavy rainfall were clarified and strengthened in September 2020 and published in the industry's Rule Book in December 2020. The industry acted more quickly than normal to put these measures in place but recognises the changes do have a performance impact. More effective and tailored action developed in the weather advisory task force will provide more sustainable long-term mitigation. Network Rail standards have been changed to support more consistent use of real-time rainfall data and application of extreme weather action teleconferences.
- We have implemented recommendations from earlier relevant RAIB reports. Following two particularly relevant reports from washout incidents at Watford tunnel (2016) and Corby (2019) we are continuing to further improve how we manage risk from washouts. We recognise our records of drainage assets and serviceability require further work; that work remains in progress.
- Investment in earthworks and drainage continues to increase and has nearly doubled from Control Period 4 (CP4: 2009-2014) to Control Period 6 (CP6: 2019-2024) to £1.274bn. Proposals for further investments will be developed in the light of the two task force reports and are expected to need to rise again for Control Period 7 (CP7: 2024-2029).
- Technology has played an increasingly important role over the last 10 years and we have been ramping up deployment. This is helping us to better predict and warn of failures. Better weather forecasting enables local decisions for imminent weather events. Our overall investment in research and development (R&D) has more than doubled from CP5 to CP6, brought together under a single integrated portfolio and enabling more than

[3] Environmental Sustainability Strategy. https://www.networkrail.co.uk/wp-content/uploads/2020/09/NR-Environmental-Strategy-FINAL-web.pdf
[4] Committee on Climate Change (2019) Progress in preparing for climate change 2019 Report to Parliament. https://www.theccc.org.uk/publication/progress-in-preparing-for-climate-change-2019-progress-report-to-parliament/

£30m to be invested at pace in projects specific to earthworks, drainage and resilience. Data analytics are also useful tools to manage a large and complex asset base and the relationship with real-time data.

- Two task forces led by distinguished independent experts were established in August 2020 and have each reported in February 2021. One led by Lord Robert Mair reviewed our management of earthworks, and particularly how we understand and manage water that interacts with those earthworks. The other, led by Dame Julia Slingo, has identified and trialled opportunities to make best use of weather data in our operational arrangements. The findings are summarised in section four and links to the full reports are in section seven.
- The two strands of our work can be characterised as steadily rising investment in earthworks and drainage assets, and transformational change in how we operate the network and deploy technology.

Conclusion

- Britain’s railway is one of the safest in Europe and that safety record is underpinned by the resilience of our assets and the rigour of our management system. However, climate change happening faster than our assumptions means that we must and will do more. This is particularly important to how we operate the railway and the wider deployment of technology.
- This report examines in detail: the immediate facts from the Carmont derailment, current asset and operational controls, short term improvements, what the task forces have told us, our published Environmental Sustainability Strategy, the financial facts, and in section seven sets out how we will use the task force expertise to continue to develop earthworks, water and weather risk management.

Section 1 – Context

The Carmont derailment, 12 August 2020

On the morning of 12 August, train 1T08 Aberdeen to Glasgow Queen Street derailed just north-east of Carmont, Aberdeenshire, fatally injuring the driver of the train, the train's conductor, and one passenger.

After departing Stonehaven, the train was continuing on its southbound journey when it was stopped by an emergency radio message from the signaller at Carmont, who had received a report of a landslip obstructing the line. Following a period of around two and a half hours waiting for an operations manager to arrive and secure the points, the train was returning to Stonehaven to allow onward travel for the passengers on board. It had reached close to the 75mph line speed.

At around 09:38, the train rounded a left-hand curve and struck a pile of washed-out gravel and other stone covering the line. The front part of the train was derailed by the washed-out material. After striking a bridge parapet, the whole train derailed.

Figure 1. Aerial photograph of derailment site

That morning there had been thunderstorms with associated heavy rain across north eastern Scotland. Weather records indicate that over 50mm of rain fell in the Carmont area between 05:00 and 09:00. Heavy rainfall from convection storms disrupted railways and other transport modes over a wide area of eastern Scotland. This followed a month of greater than average daily rainfall. August brought some challenging weather in Scotland with major landslips on the road infrastructure (e.g. the A83 'Rest and be Thankful' and A68 at Fala) and a breach of the Union Canal at Polmont which also led to significant damage to the Edinburgh to Glasgow main railway line.

The land beside the railway at the initial derailment point rises steeply upwards. On the morning of 12 August, water flowing from higher land beside the railway washed gravel and other stone onto the track after the previous train had passed on the same line two and a half hours before.

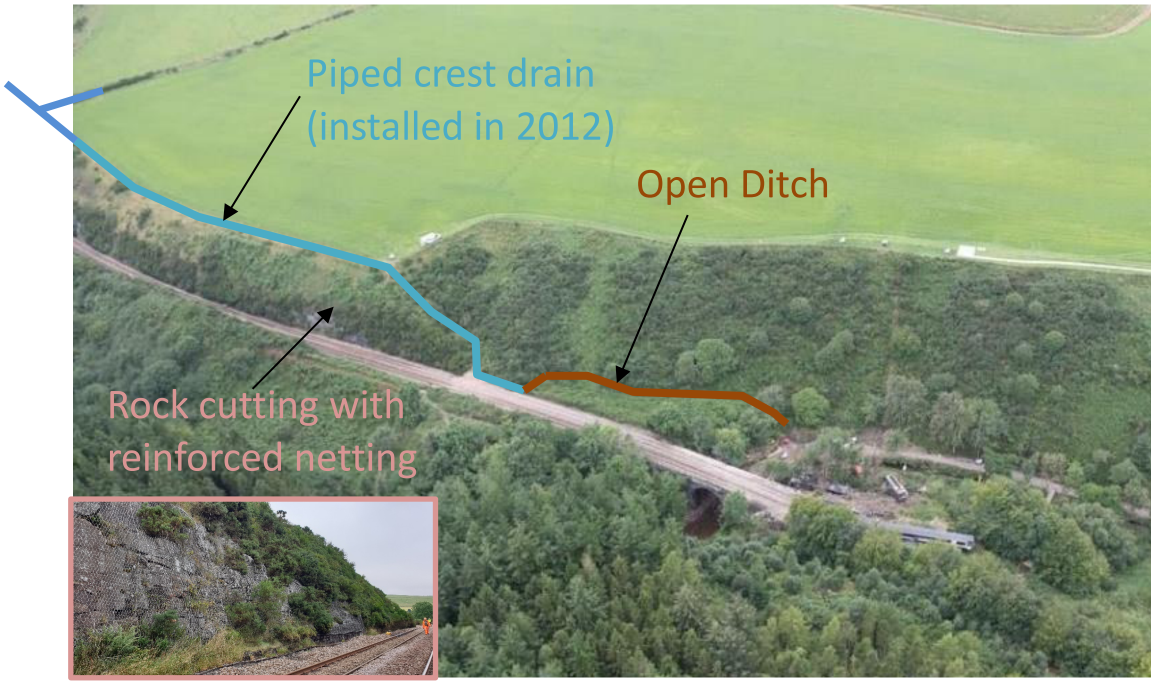


Figure 2. Drainage features in the area of the washout

Site investigations indicate the water causing the washout flowed from the adjacent land. New drains installed in 2012 included single-size gravel backfill above a perforated plastic pipe. Site investigation alongside the police, ORR and RAIB investigations are helping us to understand how the storm water came to wash out the gravel.

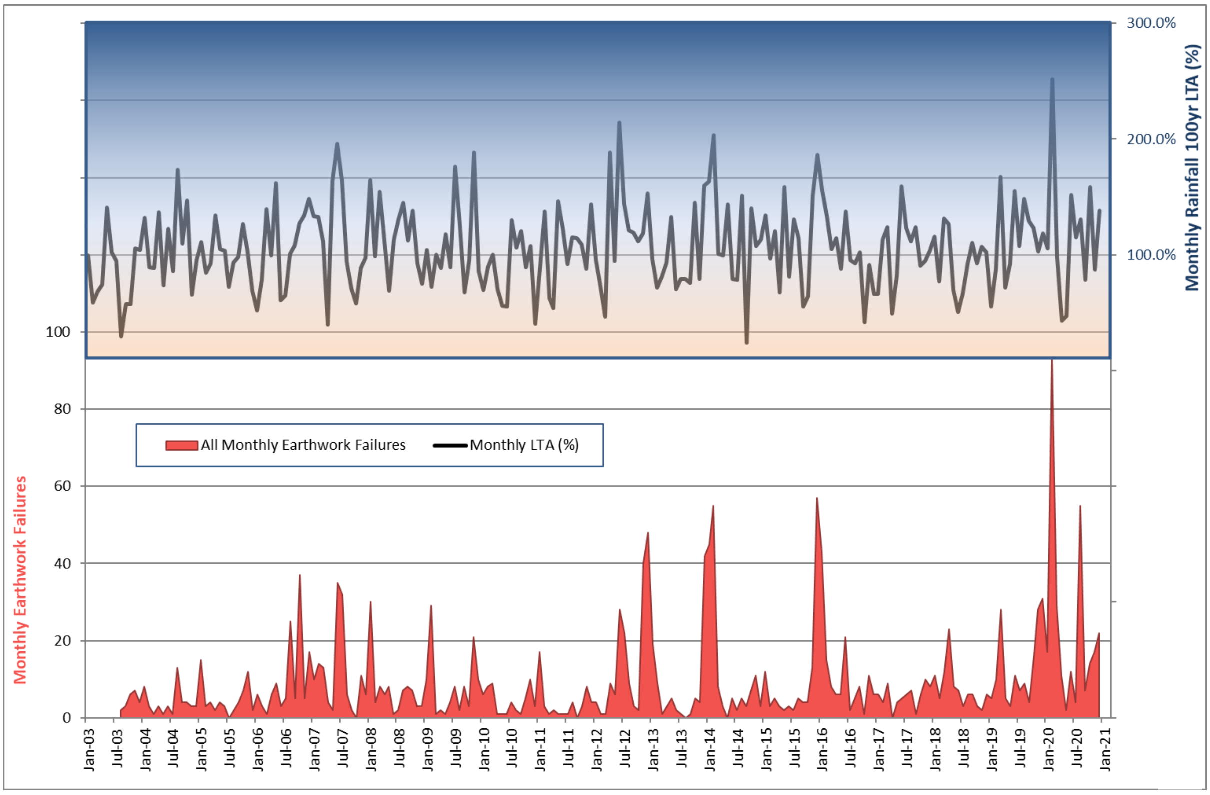
The track-level drainage, and part of that installed in 2012 (for which there were incomplete records), was inspected in May 2020 with no defects recorded. The earthworks were last inspected in June 2020 and scored as having a low to medium likelihood of failure.

The reinstated site has a different design of drainage to manage water from the land above the railway. Enhanced soil slope stability and a combination of pipe, open concrete channel and containment replace the previous piped and gravel-filled trench.

Wider context of weather, earthworks failures and the safety record

2020 saw periods of heavy rainfall which caused ground slips at many embankments and cuttings across the network. While disruptive, none in 2020 other than Carmont caused derailment. The consequences from earthworks movement are influenced by a number of factors including local topography, proximity to structures and train speed.

The autumn and winter of 2019/20 brought challenging weather across large parts of the network. This resulted in 250 earthworks failures in 2019/20, with a significant proportion occurring in February 2020, associated with it being an exceptional month for rainfall. Similarly, across Great Britain, August 2020 saw 130 % of the long-term average August rainfall and 55 earthwork failures, the equal third highest number since our records began. The chart below demonstrates the correlation between the network-wide monthly earthwork failures from mid-August 2003 to January 2021, and the UK monthly rainfall totals (expressed as Long-Term Averages).



After the impact of winter 2019/20 on the network we started to improve the way our inspections can identify assets most susceptible to failure. That is now being further supplemented by analysis from the earthworks task force (see section four).

The assets most relevant to weather resilience in the context of the derailment near Stonehaven are drainage and earthworks.

Earthworks comprise cuttings and embankments. A **cutting** is an excavation that allows railway lines to pass at an acceptable level and gradient through the surrounding ground. An **embankment** is a construction composed entirely of soil or rock fill – usually excavated from cuttings – that allows railway lines to pass at an acceptable level and gradient over low-lying ground, or ground that is susceptible to flooding. **Drainage** includes all components designed to collect surface and groundwater which runs towards, falls onto or issues from the railway and deliver it to a suitable outfall. A drainage system is defined as drainage components which convey water from multiple points of inflow to a single outfall.

The table below shows the quantity of earthwork failures since good record keeping began. Embankment failures are shown as a sub-set as these are primarily performance-related issues where signs of failure often first show up as misalignment of the track with economic impacts and disrupting passenger journeys. Cutting failures carry a higher safety risk but are harder to identify as there are often no early warning signs.

Control Period	Data Range	All Earthwork Failures	Embankment Failures	Earthwork attributable derailments
CP3	2004/05 – 08/09	477	156 (33 %)	8
CP4	2009/10 – 13/14	528	122 (23 %)	8
CP5	2014/15 – 18/19	488	137 (28 %)	2
CP6	2019/20 FY	250	62 (25 %)	0

Section 2 – Management of earthworks and drainage in the operational railway

Managing a diverse asset base and emerging threats

Our assets have a lifecycle and the risk from them failing varies through that lifecycle – they respond to the environment, which varies over time; they interact with other assets; and they deteriorate over time. We manage the risk of them failing by building and maintaining an inventory, monitoring condition and targeting maintenance, renewal and improvement works.

Earthwork failures across the network are reported to ORR in our annual return[5]. The number of train derailments from earthwork failures has been steadily reducing and prior to Control Period 6 (CP6: 2019-2024) there was a generally improving trend in potentially high consequence earthwork failures. However, the trend of earthworks failures has worsened since the start of CP6: 250 reportable earthwork failures, including 16 of potentially high consequence were recorded across the network in 2019/2020. This adverse trend continued into 2020/2021. The number of failures remains high on our risk register and above where we would like to be for this asset group.

Our earthwork asset management activities, funding and operational responses primarily focus on the threat of landslip from our own infrastructure. But recently we more often consider threats beyond our boundary fence from steep sided natural terrain which exists alongside hundreds of miles of the railway. Changing weather patterns are already increasing the likelihood of landslip events from such areas and will continue to do so. To address this, we have been working in conjunction with the British Geological Survey and engaging with Transport Scotland to learn from previous comparable trunk road studies how we can best manage this risk. The potential impact of these risks has become clearer in recent years but we are working hard to understand it even better. We have already undertaken some initial computer modelling and are now progressing our plans for more detailed assessments.

Most of our infrastructure slopes are in excess of 150 years old and are not comparable to the levels of capability and resistance that are provided by modern engineered slopes. The rapid failure of cutting slopes is difficult to predict, particularly when failures are triggered by intensive local rainfall. These weather events can be difficult for meteorologists to forecast accurately with a high confidence.

Drainage plays a vital role in weather resilience

The stability and resilience of earthworks is in most cases critically dependent on the control of water. We manage water through drainage systems that collect surface and groundwater running towards, falling onto or issuing from the railway, delivering water to a suitable outfall. As we have seen more extreme rainfall, the capability of our drainage has been brought to the fore, and we recognise that we have further work to do in improving our water management.

We still have to complete our drainage inventory, capturing structural and serviceability condition of all drainage assets. Most of our existing drainage pipes are in the form of just a few imperial sizes, selected historically either for economy or availability and not for their calculated capacity to handle water from a predicted amount of rainfall, a defined catchment or to control in-situ soil pore water pressures. Recognising the importance of water management, we established a new

[5] Available at https://www.networkrail.co.uk/who-we-are/publications-and-resources/regulatory-and-licensing/annual-return/

senior engineering leadership role for drainage in 2015. A primary focus of this role has been to drive developments in the quality of information and tools available to effectively manage drainage assets and promote a broader and more integrated approach to water management throughout the railway infrastructure.

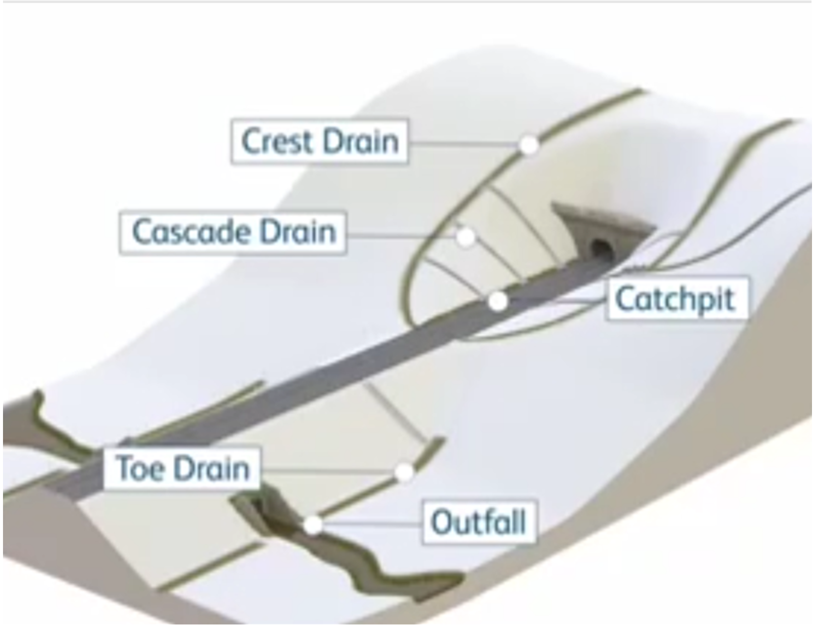


Figure 3: Key drainage features

We mitigate the risk of drainage system failure through a coordinated approach to the management of railway drainage assets (see Figure 3). Our control documents describe procedures for identifying risks, prioritising actions and maintaining effective drainage.

Risk assessment and prioritisation is documented by each Network Rail geographical route, addressing increased risk associated with adverse and extreme weather, with the requirements incorporated into each route's plans. Routes use a drainage decision support tool and data collected from drainage inspections, surveys and assessments. A drainage condition score is key to understanding the status of the system and what mitigating actions need to be taken. Drainage assets are required to be inspected at least every five years.

Our approaches to managing earthworks and drainage risks

We have an extensive inventory of earthworks gathered over the last 20 years; it comprises over 191,000 distinct earthwork assets. We use a range of techniques to monitor their condition and performance over time, including a cyclical programme of inspections. The inventory is maintained with data for changing conditions and to reflect work done to the assets. We use machine learning techniques to optimise our predictive algorithms to focus activities on assets that are more likely to fail.

Risk is categorised (using algorithms for consistency) as a combination of the condition of earthworks and the consequence of failure. The condition (or hazard category) ranges from A (lowest likelihood of failure or best condition) to E (highest likelihood of failure or worst condition) (see Figure 4). The distribution of assets enables prioritisation, with most assets in condition A (c98,000), with reducing quantities B (c46,000), C (c38,000), D (c8,000) and E (c1,000).

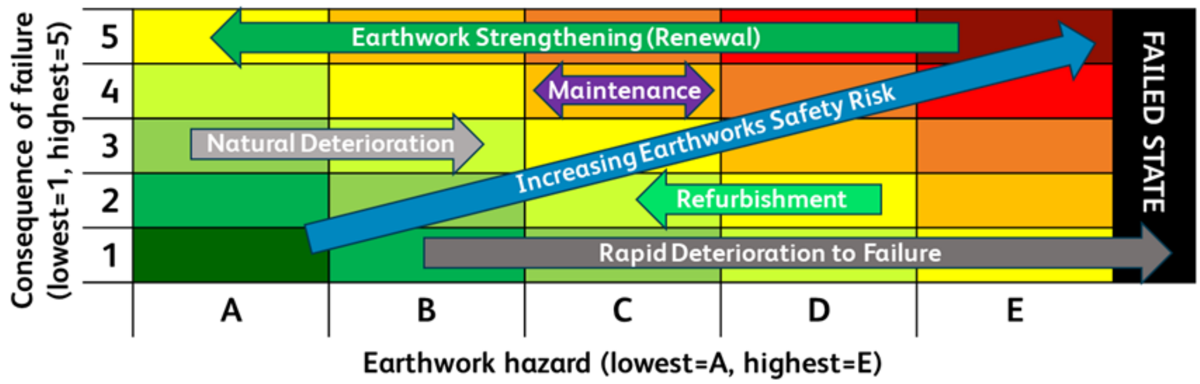


Figure 4: Risk matrix

The risk matrix forms the building block of our policy, which targets available resources towards the most susceptible assets in the locations of highest safety consequence. The consequence of failure ranges from 1 (lowest) to 5 (highest) and includes variables such as line speed, frequency of train services and proximity to tunnels, bridges and other infrastructure features. The highest scoring risk category is E5.

Inspection frequencies for earthworks, ranging from annual inspections to ten-yearly, are determined by their condition score. Other processes increasingly being deployed to support and improve observations by our engineers include aerial survey using helicopters and more recently drones, train-borne survey, and remote monitoring on sites assessed as high risk, where devices continuously feed-back data on changes. Remote monitoring has been installed at the Carmont site as part of reinstatement work.

Risk categories provide a framework for our specialist engineers to evaluate actions to manage the likelihood of failure (such as improving the drainage), and actions to mitigate the consequence of failure (such as installing failure detection equipment). Thousands of individual evaluations are undertaken each year and the actions are prioritised to manage the greatest safety risks, using decision support tools, within funding constraints and planned for cost-efficient delivery.

Priorities and decisions are made regionally in accordance with company standards and guided by national policies. Risk management is routinely reviewed through an assurance process carried out by central teams. Design and execution of works is undertaken in accordance with international, British and Network Rail company standards which embed legislative requirements and best practice.

Our asset management maturity in the areas of earthworks and drainage has advanced significantly over the last decade. Specialist earthworks and drainage teams are now established in every route and in our Technical Authority. But opportunities to do more have been addressed in the task force work recently reported.

ORR and RAIB recommendations from reports going back several years have progressively been closed with action plans implemented to address findings in earthwork management. There are open recommendations not yet fully implemented for drainage improvement (for example completing the drainage inventory).

One action from RAIB's 2017 report into the Watford tunnel washout and derailment is to consider ways to mitigate a derailment by keeping the train close to the line of the track. This is being addressed in research managed by Rail Safety and Standards Board (RSSB) (project T1143 – *Devices to Guide Derailed Trains*[6]) which is due to conclude in spring 2021. The work is reviewing international best practice in train design and criteria for where extra rails could be fitted in the track ('check rails').

We recognise the importance of embracing technology and how the changing climate will impact our infrastructure. We also have helpful insight from the recent task force reports. Unfortunately, it is simply not economically viable to strengthen all earthwork slopes constructed before modern-day standards. Putting this into context, our current rate of strengthening through renewal and refurbishment is approximately 3.5 % of the asset base in CP6. Reactive work to fix recent failures adds more pressure to available funding. So, despite continuing improvement, we have to expect there will still be earthwork failures as a result of challenging weather. What we can and will do is continue to evolve our application of technology and refine our operational procedures to manage their safety impact and protect our passengers, colleagues and members of the public.

Our investment plans target areas that have the highest risk of failure and consequence, based on data which will often include intelligence from sub-surface ground monitoring we have installed. Our renewals portfolio will prevent many failures and will be accelerated where monitoring is showing assets that are actively failing and require more urgent strengthening to prevent collapse. However, high rainfall will continue to present challenges as it triggers a high proportion of rapid cutting slope failures with little or no indication of visible distress prior to failure: some 70 % of the failures so far in CP6 were not at locations allocated for investment in the next ten years.

Our procedures to manage trains where there is heightened safety risk from weather events

Our standards, developed with our meteorologists, establish plans for each route that identify vulnerable assets, identify risk-based trigger thresholds for action and recommended actions such as speed restrictions. We have a small team of weather specialists who work with our weather forecast provider to support the operational railway with forecasts and incorporate engineering standards to help improve our operational response to weather resilience. The current weather forecast management approach uses extreme weather action teleconferences (EWATs) to advise our routes of forthcoming heavy rainfall and thunderstorms and analyse historical weather events and delays to improve our response.

When action is triggered, EWATs bring together route control, asset managers, maintenance, operations, and train and freight operators to amend timetables and make critical decisions to reduce safety risk. Our weather forecasting service provides a five-day outlook of weather conditions at a national and local level to provide alerts of adverse or extreme events. These forecasts are updated daily and communicated to operations control centres and to our EWATs to improve our response.

[6]RSSB (2018) Devices to Guide Derailed Trains. https://www.sparkrail.org/Lists/Records/DispForm.aspx?ID=25913

When two or more routes may be affected by an impending weather event, a national EWAT is invoked led by our national operations centre (NOC) and attended by the Department for Transport (DfT). An equivalent system operates in Scotland's Railway with Transport Scotland. Route teams inform the national team and information is distributed across the industry. Plans and processes are reviewed based on learning points from events.

There will be occasions when additional speed restrictions will be required on particular lines if heavy rainfall is judged to present a heightened risk to earthwork stability. Technology to predict and warn of failures has the scope to reduce disruption. Similarly, as described in section four of this report, the sandpit trial of localised and dynamic weather event forecasting enables those controls to be tailored to where the risks require.

Blanket speed restrictions cause disruption to passengers and freight services, and to some degree create additional safety issues, e.g. through crowding or frustrated passenger behaviour, if not managed appropriately. We work closely with the train and freight operators so that train services are managed to minimise disruption and delay, and to share timely information to allow passengers and freight users to plan their journeys. Precautionary and locally-tailored speed restrictions implemented using Global System for Mobile Communications - Railway (GSM-R) broadcasts will reduce the adverse impact from June 2021.

Section 3 – Immediate actions to manage risk and build confidence

The factors contributing to the Carmont derailment were complex. Until we fully understand the event and its causes, and do everything we can to reduce the risk of similar incidents, our first priority has been to take extra precautionary measures to safeguard passengers and trains.

These additional precautions sit on top of our current asset management processes and how we manage operations where there is a heightened safety risk to the infrastructure.

Additional precautionary measures

We used the established cross-industry group chaired by RSSB with ORR, the Rail Delivery Group (RDG), representatives of train and freight operating companies, and ASLEF and RMT trades unions, to review communication processes and provide a consistent network-wide response to extreme rainfall-related events by drivers, railway staff, signallers and control centres.

The group identified the need to strengthen industry rules providing instructions on train operation during extreme weather in the event of reports of water build-up and /or damage to structures above or below the railway. Our operating instructions were revised to clarify train operating principles during extreme weather conditions, where earthworks are at risk of failure. The review provided improved guidance using a 'high-medium-low' risk alert status aligned with weather forecasts and infrastructure risk registers to determine the appropriate response to implement during adverse and extreme weather.

The rule changes were effective from 5 September 2020, formally changed in the industry's Rule Book in December 2020 and will be further clarified in June 2021.

Additional precautions for operating trains

An emergency instruction was issued to signallers on 18 August 2020 as a reminder of our operational procedures for reporting and managing services during heavy rainfall events which cause water levels to rise on or near the railway, or where there is a potential for infrastructure damage. The instruction clarifies actions for signallers to report to route control centres when they receive reports:

- of significant weather events;

or reports from drivers, railway staff or others of:

- an increase in water levels on and near the railway;
- concerns about risks to specific areas which appear unstable due to heavy rain;
- subsidence,
- water flowing from an earthwork that has the potential to cause a landslip,
- damage to a structure or bridge above or below the railway that could result in a landslip due to heavy rainfall, or the cumulative effect of rain,
- where flood water is moving and likely to cause ballast to become unstable, and
- where there has been a washout.

It requires:

- that all trains are stopped until the infrastructure is inspected by a competent engineer; and
- to report all conditions to the operations control centre and then to follow instructions given or take any action required by their Signal Box Special Instructions.

There are additional rules covering circumstances where signallers have not received reports of asset damage from staff on track, but route controls are aware that our thresholds for defined extreme rainfall have been exceeded in a given area.

To coincide with these changes, we also published emergency changes to two of our National Operating Procedures and Weather Management Standards to cover the development of route operations control instructions. And we introduced a new guidance document for route operations controls during periods of adverse and extreme rainfall. The instructions allow route operations controls to determine rainfall thresholds and the operating restrictions to the train service based on local conditions and knowledge. The changes also provided an update to the EWAT on whether additional operating restrictions are required due to rainfall forecasts and severe weather events. The emergency changes to our existing standards and procedures were published by September 2020.

Following a trial, the Convective rainfall Alert Tool (CAT) is in use on North West & Central region. It gives a 'nowcast' of rainfall at a more granular level (500m intervals), issuing audible and visual alerts in the control room when locally set thresholds are reached. Work is underway to roll out the tool nationally and develop it further to enhance prediction for frontal rain systems as well as convection rainfall.

In December, we trialled use of the GSM-R communications system (which is fitted across the network and to every train) to implement local operational controls identified using the CAT. Train drivers can be instructed on the move to adapt their driving, such as at a slower permitted speed, to localized weather-related risks. The trial proved the concept works; and after some further development and wider industry engagement will be nationally implemented in June 2021. Replacing the interim controls developed since the Carmont accident is important to reduce the current performance impact.

Additional precautions for managing earthworks

We issued an emergency instruction on 18 August on our management of earthworks during adverse and extreme weather that adds to our existing procedure to either reduce train speeds or withdraw services until we have completed safety checks on the infrastructure. These instructions align with the new operations guidance to route operations controls. The change introduces a structured approach to assessing and managing the risk of rainfall on earthworks. The difference with this enhanced, more precautionary approach is that more attention is focused from an earlier stage to understand and evaluate the threat from weather.

These enhanced procedures are documented in local integrated weather management plans. Risks will be assessed based on emerging weather conditions with mitigating actions reviewed to confirm that they are appropriate to protect the safety of passengers and railway staff and to deploy additional controls when necessary.

We identified sites sharing some of the characteristics at Carmont and did extra inspections

We identified 584 sites which share some characteristics with the Carmont location, constructed from soil cuttings with track drainage, including any local features that are considered a risk, using our existing lists of adverse and extreme weather sites. Our inspections incorporated high risk drainage sites already identified from our asset resilience inventory.

Using in-house engineers and specialist contractors, the inspections were supplemented by aerial surveys, with checks for significant defects (for example blocked crest drains which can affect the stability of slopes). We completed these on 28 August. The 584 specialist inspections did not identify any significant issues requiring emergency intervention. At around 1 % of the sites, we identified defects that had deteriorated and required action sooner than originally planned.

We have experienced a few other landslips on the network in the past few months, including rapid cutting failures where trains have collided with washed out material. Defects such as blocked drainage are significant causal factors in these incidents and are the types of defect we look for in preventive inspection. However, slopes can fail with little indication of distress prior to failure if a sufficiently high volume of water falls locally.

Improved weather forecasting capability

As an interim, short-term measure, the national weather team enhanced our weather services website, which is the forecasting tool used by all operational controls, maintenance delivery, train operators and freight operators. Additional guidance was developed and provided to each route to interpret the forecasts and structure decisions about operational restrictions.

Technology-based solutions already heading towards implementation

Our research and development portfolio involves the development and trial of new earthwork monitoring systems, including surface ‘tilt meter’ technology to warn of sudden earthwork movement.

Through research and development, we will continue to adopt new remote monitoring and remote sensing technologies, and algorithmic interpretation of data. Our processes increasingly exploit technology including aerial derived laser survey (using helicopters and drones), train-borne survey, and asset monitoring using telemetry. This is improving our insight on the changing state of our assets and can provide early warning alerts. The scope for drones to help more widely is dependent on our application for approval to use them ‘beyond the visual line of sight’.

We have recently completed work applying ‘machine learning’ to enhance our earthworks risk hazard scoring, improving targeting of interventions and have installed telemetry at more than 200 locations. Future opportunities for sharing best practice with other earthwork asset owners such as the Highways Agency and Environment Agency were noted in Lord Mair’s task force report.

Section 4 – Independent reviews of current practice

Independent task forces

In August 2020, Network Rail appointed two eminent experts to review current earthworks management and weather advisory arrangements in the company. The earthworks task force was brought together under the leadership of Lord Robert Mair and that for weather by Dame Julia Slingo. Each was asked to review the current risk control framework, compare practice with other sectors and countries and to explore how effectively Network Rail has harnessed technology and scientific advance.

Earthworks and drainage systems

In a comprehensive review of earthwork performance, current asset management arrangements and comparisons with the best practice in other sectors and abroad, Lord Mair places great focus on water management in the earthworks report. An overriding message from this task force is that soil pore water pressure is a key parameter in determining earthwork stability. Changes in pore water pressure are linked to the availability and ability of water to flow into the soil profile, while strong surface flows can also cause soil erosion and flooding in their own right. Lord Mair proposes Network Rail should improve its knowledge of pore water pressure distribution in earthwork slopes. This will greatly assist understanding of slope behaviour, particularly in response to adverse weather and climate change.

There is thorough coverage of historic railway earthwork construction and the continuing difficulty with the stability of slopes in high plasticity (i.e. prone to changing shape) clay soils that are over-steep by modern standards. Lord Mair noted that many of the 2019/20 failures occurred in slopes which had not been identified as vulnerable and most of the failures were observed first by the train drivers. Earthwork examination and risk evaluation processes should be improved. The aim should be to improve the earthwork failure prediction rate, especially for rapid cutting slope failures, a feature of which there is often little or no indication of visible distress prior to failure. Earthwork assets beside high-consequence features such as tunnel portals merit additional focus to drainage and slope stability.

He concludes that effective control of water and proper understanding and maintenance of drainage assets is fundamentally important for the safe operation of the rail network. Surface and sub-surface water management is probably the single most important factor in determining if where and when an earthwork failure will occur. The report advocates a holistic approach to water management, considering catchment to outfall and integrating all drainage systems to manage earthworks stability and track quality. Understanding the size, shape and location of all natural catchments draining towards the railway is necessary to determine the expected water flow rates and required drainage design. Arrangements for identifying all localised water concentration features at the top of cutting crests and the likelihood of failure from washout or earthflow should be fundamentally reviewed.

On technology, Lord Mair notes Network Rail's recent positive advances in developing and deploying tilt meters to provide advance warning of slope movement. These wireless sensor systems are capable of detecting and sending alarms when movement occurs, as well as data on the performance and condition of an earthwork slope, and possible precursors to failure. But there is considerable scope to deploy them more widely, together with monitoring pore water pressure.

Drawing insight from work in Japan, Hong Kong and Canada, the report also references instrumented flexible barriers as suitable measures for detecting and partially containing slope movement.

The report commends wider aerial inspection, using combinations of photography and LIDAR analysis rather than the limited benefit brought by site, ground-level inspection alone.

There is an important connection between earthwork and vegetation management. Reflecting the Varley[7] review of vegetation management, Lord Mair advocates treating vegetation on slopes as an asset, influencing pore water pressure, and with roots aiding slope stability, but being managed to limit any adverse impact of leaves, fallen branches, etc, on railway infrastructure.

Noting the changing climate, with more intense rainfall and higher frequencies of extreme rainfall being likely, the report predicts an increase in washout and earthflow slope failures, particularly in cuttings. Intense rainfall associated with localised storms that are particularly prevalent in the summer risks shallow slope failures and washouts on cut slopes. That localisation makes the prediction of precisely where they may occur almost impossible. But advances in monitoring technologies and surveillance techniques, together with improved data and further forensic analysis of past failures, can help identify which geologies and geometries are especially vulnerable.

The report observes the difference between those dedicated teams inspecting and condition-scoring earthwork assets with the comparative work on drainage assets where it is one task of many for 'off-track' maintenance teams. It concludes there is a need for greater specialism in drainage engineering and a more integrated approach to managing earthworks, drainage and vegetation assets, taking account of changing weather patterns.

Weather advisory task force

Given earthwork management is intricately linked to water management, a vital control is to understand and accurately predict rainfall. Dame Julia Slingo led the weather advisory task force, bringing together a number of experts in meteorology and weather forecasting, to explore current practice and available advances in predicting where and when extreme rainfall could threaten earthwork stability. In recent years, there has been considerable progress in weather/climate science and its applications, including new analyses of past rainfall, improvements in observing systems, significant advances in early warning systems, local-scale nowcasting and forecasting, and the emergence of innovative digital technologies for gathering, combining and sharing information.

Dame Julia describes the evidence demonstrating our changing climate with increased temperatures as meaning warmer air carries more moisture, and in turn that heavy rainfall extremes are intensifying with that warming. Local increases in rainfall intensity are related to convection and intensified local flash flooding.

Network Rail's current weather forecast service has served Network Rail well but is limited by its capacity to access, absorb and process the very large data volumes now available for more detailed analysis and forecasting. The company standards informing operational decisions based

[7] Valuing nature – a railway for people and wildlife. The Network Rail vegetation management review. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/955344/valuing-nature_a-railway-for-people-and-wildlife-the-network-rail-vegetation-management-review-document.pdf

on the existing forecasts are not sufficiently sensitive to local conditions. An internal fast-track project in September 2020 led Network Rail to act swiftly to improve its preparedness for adverse and extreme rainfall events and their potential impacts on earthworks through the development of a Convective Alert Tool. A revised operational decision tree for these events has been implemented, based on thresholds separated into extreme convective intensity and heavy rainfall accumulation.

Advances in global data capture and predicting probable weather patterns from past events, together with much more tailored, local kilometre-scale forecasting, enable much more accurate and locally relevant forecasts. The differences between forecasts at 10km and 1km accuracy, for rainfall intensity and location, are profound. Network Rail currently has access to a global forecast which, although world-class, can only be produced at a resolution of 10km because of the cost of processing such a vast amount of data. But kilometre-scale forecasts are immensely valuable for assessing the locations of maximum risk from intense rainfall, such as line convection and thunderstorms.

Weather is inherently chaotic which means there is no single, deterministic forecast; instead, an ensemble of forecasts is always produced operationally. It is essential that Network Rail gains access to ensemble forecasting capabilities. We currently receive advice from a single deterministic forecast, which although of high quality, may misplace or fail to capture some extreme events.

Severe convective storms represent major risks to Network Rail's infrastructure and improved nowcasting capabilities are urgently needed to manage their risks and reduce operational delays. Emerging data technologies may revolutionise the management of these risks. The report concludes that although Network Rail understands the importance of weather to its operations, it currently does not have the capabilities and resources to keep abreast of the latest scientific and technological advances.

Responding to that broad conclusion, we ran a three-week 'sandbox' trial in real time in December 2020 to engage the routes and regions in assessing its potential value. The aim of the trial was to jointly explore next generation forecast capabilities and expertise across the whole 'awareness – preparedness – response – recover' cycle to improve decision making. The trial was conducted during a period of disturbed weather and a number of impactful events occurred which demonstrated the value of delivering a route-based service.

During the trial, on 5 December, an active system brought very localised weather hazards including snow, flood and an earthwork failure in eastern Scotland as well as flooding in Kent. The route-based forecasts did a remarkable job in correctly identifying areas affected that required local risk control while the rest of the network remained unaffected and not requiring either speed restrictions or other response action. The sandpit trial has demonstrated the potential value of dynamic, site-specific forecasting for optimising the management of the network during adverse weather. That is now in use in North West and Central region and being rolled out to all other parts of the network in the next few months.

The weather advisory task force report concludes that the weather forecasting service must be more dynamic, enabling swift adoption of new technology to keep up with the state of the art. The massive data and required computational power point to more partnership working and Dame Julia advocates an integrated transport centre providing a forecast service across different transport modes.

Section 5 - Long term plans to improve resilience to climate change

Adverse weather linked to climate change is accelerating deterioration of earthworks and increasing demand on drainage

Climate change is often viewed as a future problem. But as Dame Julia Slingo's report underlines, it is already causing more frequent and more severe extreme weather events and we are experiencing its impacts. The weather over the past two years shows clear trends towards an increased frequency of extreme drier periods followed by prolonged and extreme wet weather. Very hot summers such as 2018 are "30 times more likely than would be expected from natural factors alone".[8] "Extreme regional rainfall such as Storm Desmond in 2015 has a return period of about five years (20 % chance in any given year) and is at present roughly 60 % more likely due to human-caused climate change."[9]

These factors increase deterioration of our earthworks and put pressure on drainage systems, increasing the likelihood of critical coping thresholds being exceeded, prompting increased levels of intervention (as illustrated in Figure 5). Adverse weather can also impact other assets, with accelerated scour increasing risk at bridges over rivers for example. Some assets can be replaced more quickly/easily with current technology (e.g. track/signalling), but others, such as earthworks, cannot be future-proofed quickly. These assets require progressively rising investment accompanied by transformational change in how we manage the network and deploy technology. 'Good' management of climate change risk involves improved on-the-ground resilience which will come at significant cost and will take many years to achieve.

The high-level output specifications for both England/Wales and Scotland for CP6 referred to the importance of weather resilience and taking into account the impacts of climate change.

Whilst our planning for climate change adaptation is well advanced (as recognised by the Committee on Climate Change in their 2019 Progress Report[10]), our key challenge will be implementing these plans and improving resilience on the ground.

[8] Madge G (2019) Study examines drivers of 218 UK summer heatwave. https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2019/drivers-for-2018-uk-summer-heatwave viewed 26 August 2020
[9] World Weather Attribution (2017) https://www.worldweatherattribution.org/uk-storm-desmond-revisited-december-2017/ viewed on 26 August 2020
[10] Committee on Climate Change (2019) Progress in preparing for climate change 2019 Report to Parliament. https://www.theccc.org.uk/publication/progress-in-preparing-for-climate-change-2019-progress-report-to-parliament/ viewed 26 August 2020

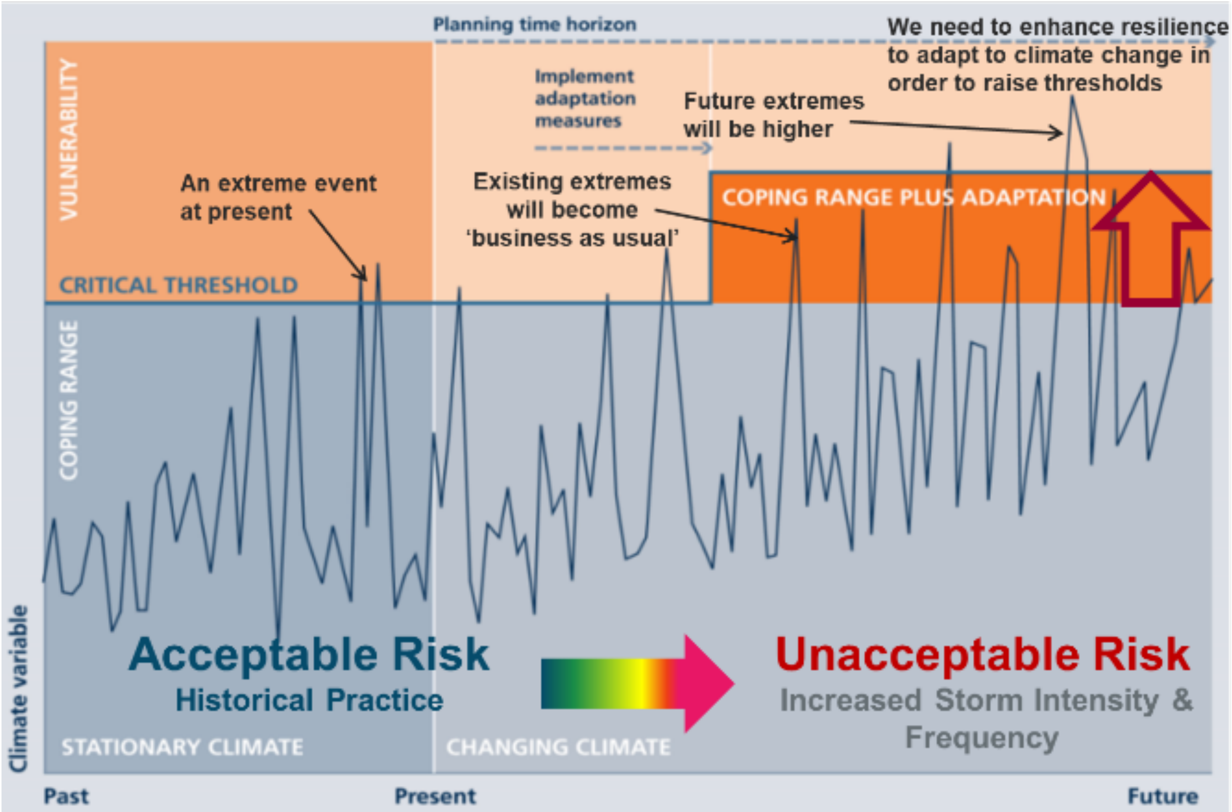


Figure 5: Coping thresholds and the need to manage unacceptable risk

Source: Adapted from Willows, R.I. and Connell, R.K. (Eds) (2003) Climate adaptation: Risk, uncertainty and decision-making, UKCIP Technical Report, UKCIP, Oxford. [11]

Our challenges are shared by other operators of historical infrastructure[12]. Our resurveys are suggesting accelerated deterioration and the Environment Agency (EA) has estimated this increase to be between 30 % and 60 % for their assets[13]. These findings are consistent with the changes we forecast for Control Period 7 (CP7: 2024-2029) but have arisen much sooner than we anticipated.

The threat of extreme weather also increases the influence of broader 'catchment-wide' impacts. The complex nature of drainage systems that transfer water from multiple private owners can concentrate risks at or near the railway (for example Figure 6). Past inspection processes have not always been able to pick up vulnerabilities associated with these diffuse sources, or how others are changing these. We must now focus more on these interdependencies to redress risks from the changing climate. We already work with other infrastructure operators to share experiences and learning to help validate our own judgements and work together to better understand deterioration, performance and forecasting improvements.

[11] UK Climate Impacts Programme (2003) Climate adaptation: Risk, uncertainty and decision-making. https://www.ukcip.org.uk/wp-content/PDFs/UKCIP-Risk-framework.pdf viewed on 26 August 2020
[12] Examples include Environment Agency (EA), Scottish Environmental Protection Agency (SEPA), Canal & Rivers Trust (C&RT), Scottish Canals, Natural Resources Wales and utility companies.
[13] Jim Barlow, Deputy Director for Asset Performance & Engineering at the Environment Agency in discussion with Tim Kersley on 17 August 2020

Figure 6: Interdependencies: The Union canal embankment collapse washed away the railway between Edinburgh and Glasgow (12 August 2020)

In September 2020 we launched our **Environmental Sustainability Strategy** which outlines our ambitions for Climate Change Adaptation and a roadmap to 2050 which looks to embed long-term, forward-looking adaptation into the core of what we do (see Figure 7). We are continuing to refine local climate change adaptation strategies and investment plans for each railway corridor that will map out our intentions to be achieved by 2050.

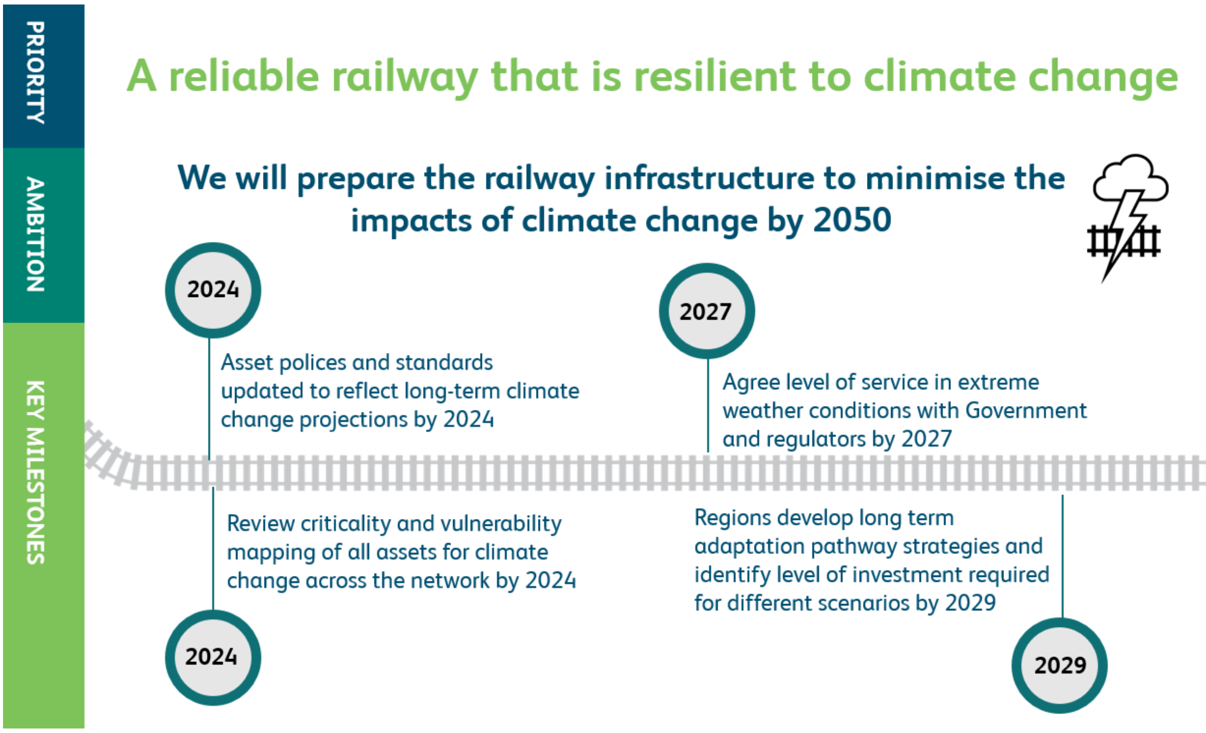


Figure 7: Summary of Climate Change Adaptation Roadmap in Environmental Sustainability Strategy

Our previous Weather Resilience and Climate Change Adaptation Strategy (WRCCA[14]) had been in place since 2017, with good progress identifying and managing key risks and areas of vulnerability across the Network Rail regions. Critical to our plans for minimising impacts on safety, reliability and performance caused by climate change is embedding resilience into the way that we design, build, operate, maintain and replace our railway assets. Our principle for replacing assets in the future will

[14] Available at: https://safety.networkrail.co.uk/home-2/environment-and-sustainable-development/wrcca/wrcca-strategy-2/

be ‘replace like with better’ rather than ‘replace like for like’. This change will mean we will continually improve the network, making it more resilient for passengers and freight customers.

Our regions are preparing for climate change

We continue to work on improved guidance, tools and research to support the integration of climate change within business-as-usual activities, including embedding the latest climate change projections (UKCP1815) in risk assessments and designs. We have published updated Weather Resilience and Climate Change Adaptation plans for each of our routes[16]. They describe local actions already delivered, funded actions for CP6 and future opportunities and priorities for additional funding. Each of our Technical Authority asset teams has undertaken a climate change risk assessment to understand the direct and indirect impacts of weather and climate change on the asset performance, safety and functionality. This includes consideration of the extent to which current asset, technical, operational, research and procurement policies, procedures, specifications and strategies need to be changed to control weather and climate change risk. Action plans will look at how management of the asset needs to change in the short, medium and long term in order to improve safety and reliability performance in light of future climate change.

We are applying technology to help manage the impacts of climate change

We are investing heavily in research and innovation for solutions to manage assets and risk cost-effectively; we are ahead of planned progress in making this happen. This investment includes better monitoring, condition assessment, modelling and decision support for earthworks and drainage assets.

We continue to improve near term through our intelligent infrastructure programme, to join up data, including weather data, through decision support tools. We are improving longer term through our research and development portfolio to prove new remote monitoring and sensing technologies and develop algorithms to interpret data. Our review of the research portfolio led to prioritising a £3m project to further improve the performance of earthworks, focusing primarily on assets that pose the greatest likelihood of derailment. The priorities in these programmes are adjusted as we learn from events.

Our innovation programme is complemented and underpinned by our participation in research led by world-leading universities. The ACHILLIES programme investigates deterioration, performance, forecasting and decision support for earthworks across the infrastructure sector[17]. We are working to include consideration of climate change and future weather conditions in our studies to improve our knowledge of how our assets will perform in the future.

Managing water as a system – from rainfall to outfall

We co-operate with governments, regulators, rail and other transport and wider infrastructure sectors including train designers, manufacturers, passenger and freight train operators, and river authorities to share knowledge, collaborate on research and improve adaptation action and co-ordination. Such collaboration is essential to manage water as a system from rainfall to outfall.

[15] More information available at: https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/index
[16] Available at: https://safety.networkrail.co.uk/home-2/environment-and-sustainable-development/wrcca/wrcca-strategy-2/
[17] More information on the ACHILLES programme: https://www.achilles-grant.org.uk/

Section 6 – Investment and financial planning to improve resilience

Our plans already incorporate significant additional investment and we have been accelerating work on earthworks and drainage

We are investing increasing amounts in works to manage weather resilience on the ground and to improve our ability to manage it better in future. In total for CP6 we will invest £1.274bn to maintain and renew earthworks and drainage, supporting improvement in resilience to weather. This is a real term increase of 20% on Control Period 5 (CP5: 2014-2019) and nearly doubling that in Control Period 4 (CP4: 2009-2014). For CP6 we also identified in 2018 the potential to use £185m of our risk fund as further needs emerged, including responses to extreme weather events.

Also included within our plans is £33m to increase remote monitoring and sensing, improved weather services monitoring and diagnostics for earthworks and drainage, together with £31m on research and development specific to earthworks, drainage and resilience. Much of this activity is in collaboration with other operators to broaden access to knowledge and insights and forms part of a prioritised research and development portfolio that balances investment spanning all our challenges. This is progressing well with emerging insights outlined in section four of this report.

So far in CP6 we are ahead of programme in terms of volume of work completed and expenditure. Reprioritisation of activities by our regions has added £210m more to base plans as the need to respond to weather-related events has been greater than we forecast, and this has resulted in additional operational expenditure. We are continuing to review our investments in this area for CP6 and we will elaborate further on this in future reports.

Preparing for future investments

As part of readying our plans for future cycles we anticipate investing around £80m in CP6 to design and develop projects to be able to deliver quickly from the start of CP7. This will include deployment of monitoring and additional risk assessment.

Further outputs from both our research and development programme and our support to cross sector learning will build a clearer understanding of the risk and need, location and form of future interventions required. We know that we will want to continue to deploy improved monitoring and sensing technologies to better guide our interventions. Research is helping us more accurately quantify rates of change and we produce updated, improved analysis annually to improve confidence in our forecasts. The most recent insights from research and our own analysis indicates that, for some types of earthworks, the future design of interventions must evolve to be effective against future weather conditions, and if rates of change accelerate we must treat more locations. To accommodate these changes, future funding needs will potentially grow further than our previous models suggested, although we have yet to fully confirm the scale of impact.

Before the Carmont derailment, our conventional modelling identified a need to grow investment for earthworks and drainage in CP7 by c.£300-500m beyond CP6 levels. We will complete further work on rates of change to forecast accurately the medium- and longer-term need.

The findings of the two task forces will further inform actual requirements. We will continue to work closely with Governments and regulators to make sure our investment is proportionate to the risks and level of service expected from the railway during adverse and extreme weather conditions in the future, and that they are funded.

Section 7 – Next steps

We are continuing to support RAIB and Police Scotland/British Transport Police/ORR on their Carmont accident investigations while also leading the industry formal investigation. Reports are expected during the summer of 2021. The learnings from the investigations and any recommendations will be used to improve any identified areas of weakness.

Network Rail has established a Weather Risk Management Steering Group to oversee activity across the various initiatives described in this report from the two task forces and other in-house work since the Carmont accident.

The weather advisory task force work has led to close working between Network Rail and the Met Office with world-leading tools being developed even before the final report was published. Deploying those tools across the network remains our immediate priority.

We have commissioned two developments from our weather forecast provider for alerts and warnings about the amount of rainfall linked to convective and frontal rainfall systems. The convective alert tool has been trialled and planning is now underway for deployment in regional controls. This will take place throughout 2021. We are considering how we can improve our approach and response to frontal weather using existing forecasting capabilities ahead of future system overhauls as we improvement recommendations from Dame Julia Slingo's work.

After trials over the winter, we are working with the Met Office to see how we can collaborate on developing and using the 'Decider' tool which identifies higher-risk rainfall events from the 30 weather patterns that predominate in the UK. These are combined with forecasting and now-casting at 1km resolution to identify where the railway is at risk from high levels of rainfall.

In June 2021, the changes to the industry's Rule Book will further clarify the way we and train operators manage weather-related operational risk and use GSM-R to enable less disruptive, localised precautionary speed restrictions in all parts of the country. This will be used initially for convective weather alerts.

The Met Office relationship is supporting work arising from the earthworks task force to better understand the rainfall events that led to earthworks failures or washouts. This extends beyond 'how much rain will fall?' and to 'where will the rain land, and where will it end up?'. This is important in understanding surface flows, likely flooding sites, where river erosion could be a risk and how saturated the ground is. This science is relatively immature but the emerging relationship with the Met Office means that Network Rail will have access to the latest research and thinking for it to improve its analysis further.

Lord Mair made in excess of 50 recommendations in his report. We intend first to deliver the full scope of the geotechnical and drainage solutions already planned within the Intelligent Infrastructure programme. We have analysed the rest of the recommendations to identify those which have the greatest scope for reducing risk and by the degree of investment required to implement each.

Lord Mair is clear the biggest opportunity for a step change in earthwork risk management will be provided through strengthening our water management capabilities. The outputs from the impact / effort assessment identify drainage initiatives to be high scoring opportunities. These are also therefore priority recommendations to progress. A common thread in the recommendations made by each of the task forces addresses people issues such as culture, competence and organisational design. Again, aspects we know we can and will implement.

Some of the other proposals will require deeper consideration and hard decisions about what lies within the scope of acting so far as is reasonably practicable. These will inform discussions with funders and ORR as we refine our plans for CP7 and beyond.

We have retained the services of the task force report authors to act as mentors to the organisation as we develop our skills and capability in both weather and earthworks management. These world-renowned specialists will provide links to a wider group of peers who will provide guidance and challenge in the complex sciences around hydrology, meteorology and earthwork management.

We continue to work closely with RSSB on their current research into derailment containment measures, particularly as it considers rolling stock design opportunities and additional targeted track improvements. Once the research reports, we will consider with train operators how best to use the findings in risk mitigation on the operational railway.

Annex A – Task force reports

Earthworks Management Task Force

The earthworks management task force report can be found at: www.networkrail.co.uk/stonehaven

Weather Advisory Task Force

The weather advisory task force report can be found at: www.networkrail.co.uk/stonehaven