Resilience of rail infrastructure

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

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Executive summary

The derailment of a passenger train near Carmont on 12 August 2020 was a tragedy for the families and friends of the three people who lost their lives and will have a lasting effect on those injured and involved in responding, as well as the wider railway industry. It has raised questions about the resilience and safe performance of the railway, and how the risk of such an event happening again can be minimised.

Emerging findings from the investigations suggest that a significant contributing factor to the derailment was heavy rainfall washing material onto the track. Therefore, this report commissioned by the Secretary of State for Transport seeks to provide an initial review of the resilience of rail infrastructure, in particular in the context of severe weather. Because of the nature of events that led to the derailment at Carmont, the report focuses on the resilience of earthworks and drainage infrastructure to heavy rainfall.

It is critical to understand fully what went wrong, what is being done now and what more can and should be done. This report in no way pre-empts the outcome of formal independent investigations. It is a look at our current approach, procedures and risk; our immediate and longer-term plans and actions; and initial consideration of next steps.

The challenge

- Britain's railway is one of the safest railways in Europe1. 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 beside our railway were built more than 150 years ago. They were constructed without detailed engineering design and not to modern 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 and while they have served us well, and despite many improvements over the years, they are not as robust as a modern-day equivalent.2 Such structures are complex to manage due to underlying geology, adjacent environments and assets, and local weather patterns. In the short term, rebuilding thousands of miles of earthworks to modern day standards is not practicable either from a funding or deliverability perspective.

The current situation

- Infrastructure improvements are targeted to locations where we have identified the greatest safety risk. We manage the railway to a low level of risk and apply a robust management system to achieve that. Our investment is carefully prioritised to locations assessed as higher risk and using technology to predict and warn of failures.

[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

- We have developed techniques to monitor and manage ageing earthworks assets, which have been high on our risk radar for some time and these techniques are recognised as industry leading by fellow member organisations of the UK Geotechnical Asset Owners Forum.

- Climate change considerations are being embedded in our standards and planning, and the Government's Committee on Climate Change recognises our resilience planning for climate change adaptation is well advanced[3]. 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, and as a result it has become even more important to implement these plans.

What we are doing

- Industry rules for reporting and reacting to heavy rainfall are being clarified and strengthened in September 2020. Supporting more consistent use of real-time rainfall data and application of extreme weather action teleconferences has already been addressed in refreshed company standards.

- We have already implemented recommendations from earlier relevant Rail Accident Investigation Branch (RAIB) reports or have action plans in place. Following two particularly relevant reports from washout incidents at Watford tunnel (2016) and Corby (2019) we are continuing to improve how we manage risk from washouts. We recognise our records of drainage condition and serviceability require further work.

- Investment in earthworks and drainage has nearly doubled from Control Period 4 (CP4: 2009-2014) to Control Period 6 (CP6: 2019-2024) to £1.274bn. Investment in CP6 is 20% higher than Control Period 5 (CP5: 2014-2019). Our investments are ahead of plan for CP6 and we will redirect risk funds to prioritise immediate needs. Proposals for further investments will be developed in conjunction with the recently announced task forces 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 ten years and we have been ramping up deployment: predicting and warning of failures and better weather forecasting to enable 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, enabling over £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 have been established in August 2020. One led by Lord Robert Mair will review our management of earthworks. The other led by Dame Julia Slingo will help us make best use of weather data in our operational arrangements.

- 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.

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[3] 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/

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, the increasingly clear implications of climate change mean that we must and will do more. This is particularly important with respect to how we operate the railway and the wider deployment of technology.
- The report examines in detail: the immediate facts from the Carmont derailment, current asset and operational controls, short term improvements, longer term strategic sustainability, the financial facts, and in section six sets out some next steps.
- Our next report will go into more detail about what can be accelerated and where, particularly the options around extra technology that could sharpen where we focus and improve warnings, and initial consideration of next steps.

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 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 and it is likely to be one of the wettest Augusts ever recorded in Scotland. There had been 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 stone onto the track after the previous train had passed on the same line two and a half hours before.

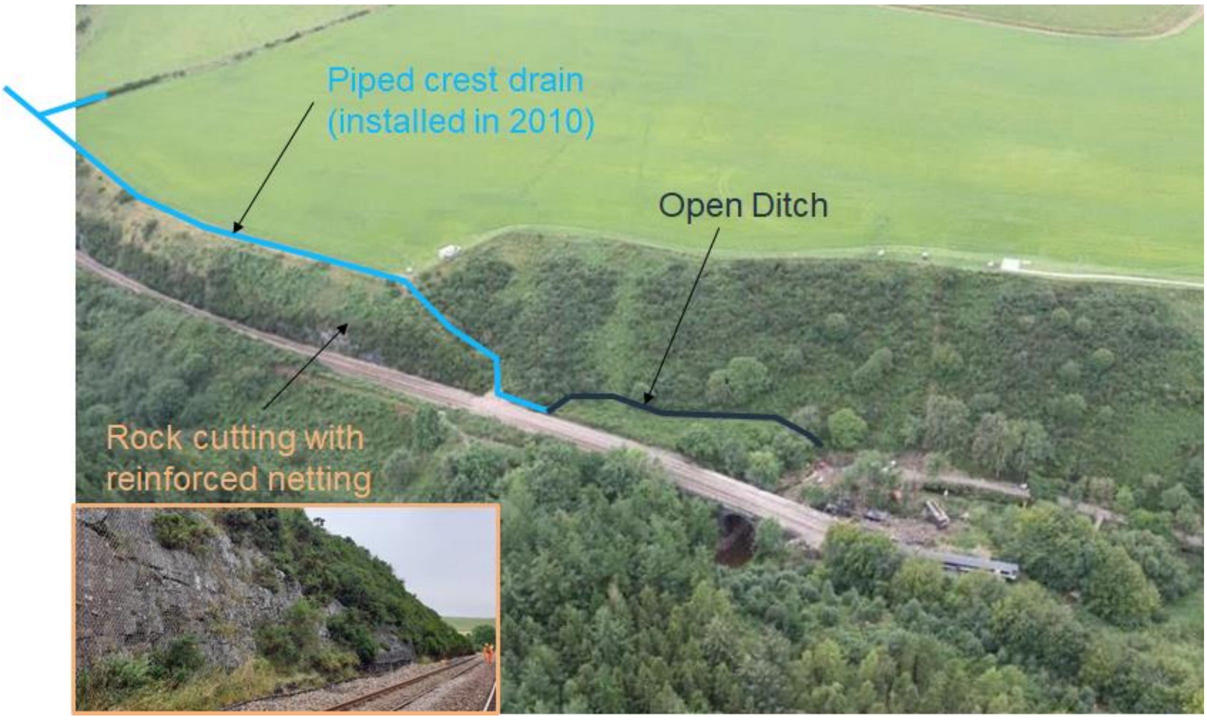


Figure 2. Drainage features in the area of the washout

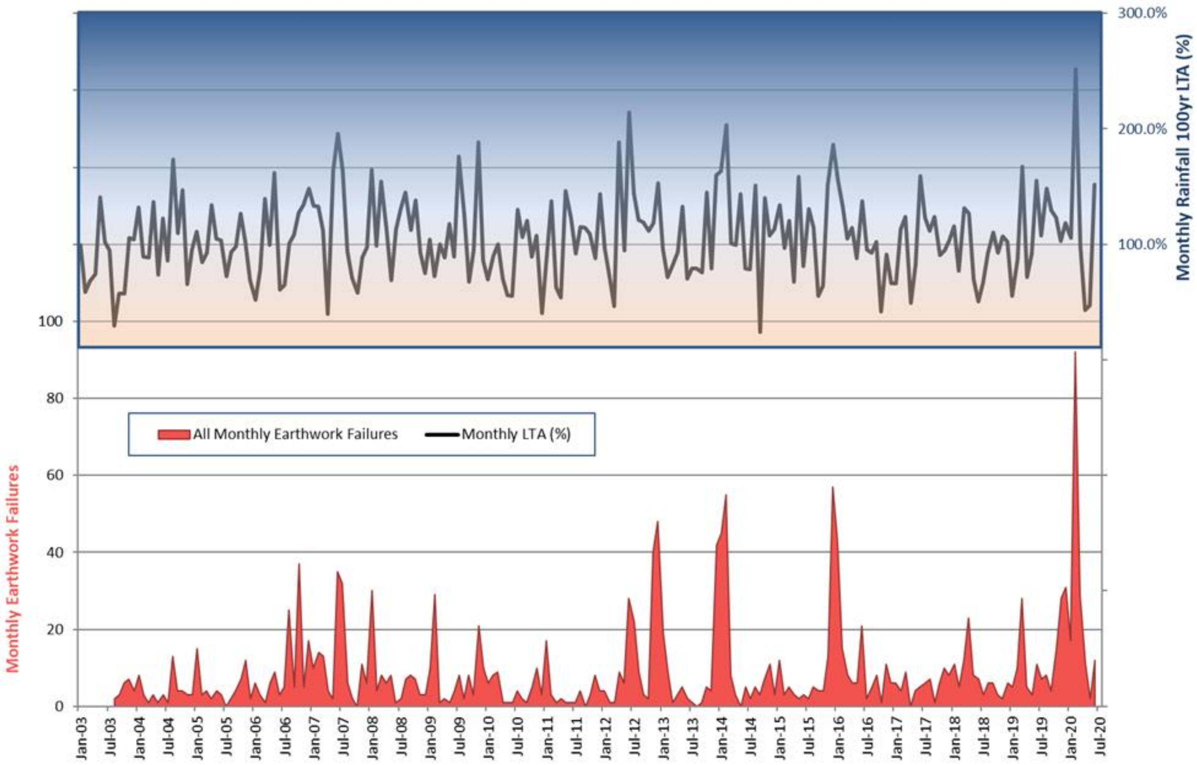
Site investigations indicate the water causing the washout flowed from the adjacent land. It is not yet understood how new drains installed in 2010 and any pre-existing field drains interact. Site investigation currently underway in collaboration with police and the Rail Accident Investigation Branch (RAIB) includes CCTV surveys, ground penetrating radar and LiDAR analysis, and in due course trenches, to understand how the storm water came to wash out the stone.

The drainage installed in 2010 and owned by Network Rail was last inspected in May 2020 with no defects recorded, and investigations will further examine the accuracy of those records. The earthworks were last inspected in June 2020 and scored as having a low to medium likelihood of failure.

Wider context of weather, earthworks failures and the safety record

2020 has seen heavy rainfall which has caused ground slips at many embankments and cuttings across the network. While disruptive, none in 2020 before Carmont have caused derailment. Severity is 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. The chart below demonstrates the correlation between the network-wide monthly earthwork failures from mid-August 2003 to June 2020, and the UK monthly rainfall totals (expressed as Long-Term Averages).



Since the impact of winter 2019/20 on the network we have commissioned a piece of work to improve the way our inspections can identify assets most susceptible to failure.

The assets most relevant to weather resilience in the context of the derailment at 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. Cutting failures carry a higher safety risk but are harder to identify as there are often no early warning signs.

Control Period	Date 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 the Office of Rail and Road (ORR) in our annual return[4]. 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, these failures remain high on our risk radar 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 more recently we have also started to 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 threat. The potential impact of these risks has become clearer in recent years, so we are working hard to understand it 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 are completing our drainage inventory and 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 or catchment. Recognising the importance of water management, we established a new 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

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

available to effectively manage drainage assets and promote a broader and more integrated approach to the management of drainage assets.

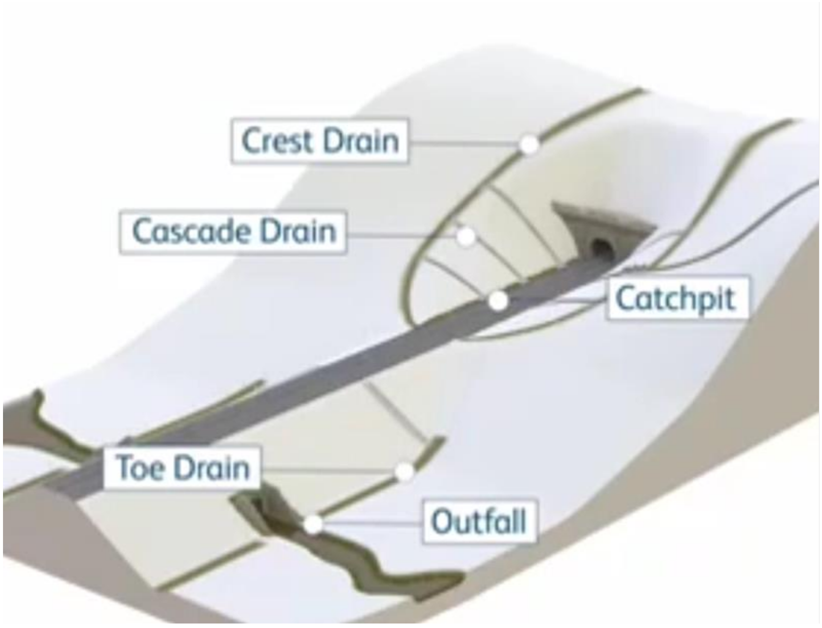


Figure 3: Key drainage features

We mitigate the risk of drainage system failure through a coordinated approach to the management of railway drainage assets. Our control documents describe a co-ordinated approach to managing railway drainage, supporting catchment water management, and 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 the risks from earthworks

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 condition 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). 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).

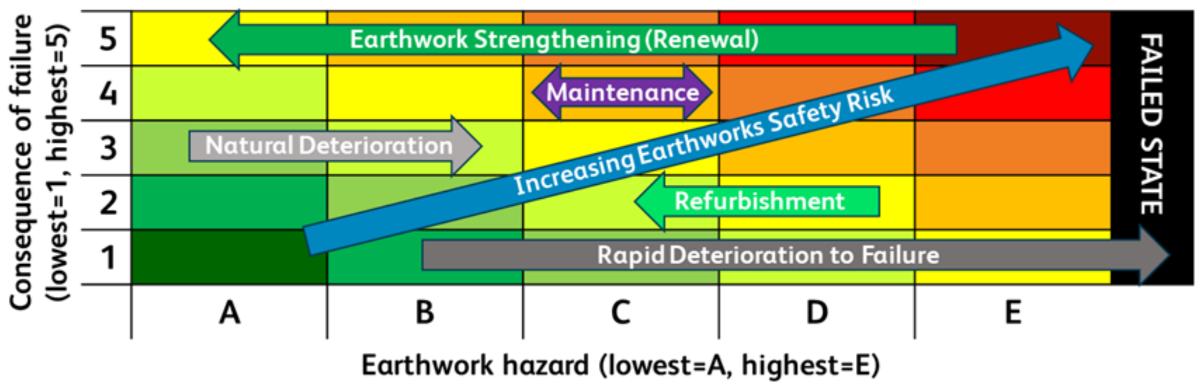


Figure 4: Risk matrix

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.

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.

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). The most recent RAIB report relating to landslips is from Corby (2019, published May 2020) and we are shortly to write to ORR with our action plans to address these areas of recommended improvement.

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*[5]) and due to report later in 2020. 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 we are working with academia to understand further how the changing climate will impact our infrastructure. Unfortunately, it is simply not economically viable to strengthen all sub-standard infrastructure slopes. Putting this into context our current rate of strengthening through renewal and refurbishment is approximately 3.5 % of the asset base in CP6. So, despite continuing improvement, we 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.

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 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, 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.

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. As technology to

[5]RSSB (2018) Devices to Guide Derailed Trains
https://www.sparkrail.org/Lists/Records/DispForm.aspx?ID=25913 viewed 26 August 2020

predict and warn of failures matures, and we deploy it in more places, the risk of such disruption will reduce.

We recognise that speed restrictions can cause disruption to passengers and freight services, and to some degree create additional safety issues if not managed appropriately, e.g. through crowding or frustrated passenger behaviour. We work closely with our train operator and freight colleagues to ensure that train services are managed pro-actively to minimise disruption and delay, and to share timely information to allow passengers and freight users to plan their journeys.

Section 3 – Immediate actions to manage risk and build confidence

The factors contributing to the Carmont derailment are 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 establish additional 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. These include additional control arrangements, checks to earthworks and drainage and opportunities to apply technology.

Our first priority is to establish additional precautionary measures

We have used the established cross-industry group chaired by RSSB and involving the ORR, the Rail Delivery Group, 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 will also be revised to clarify train operating principles during extreme weather conditions, where earthworks are at risk of failure. The review will also provide 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 will be issued in the Weekly Operating Notice and are effective from 5 September 2020.

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;
- from drivers, railway staff or others of an increase in water levels on and near the railway;
- of concerns about risks to specific areas which appear unstable due to heavy rain; and

of 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 due to 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. And 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 act upon 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 are also publishing emergency changes within two of our existing National Operating Procedures and Weather Management Standards to cover the development of route operations control instructions and introducing a new guidance document for route operations controls during periods of adverse and extreme rainfall. The instructions will 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 provide 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 on 25 August 2020, with the new control guidance due to be published in September 2020.

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 deal with the risk of rainfall on earthworks, with pro-active and iterative syndicated assessments of operational management risks to cuttings and embankments, drainage and structures. 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 have identified sites sharing some of the characteristics at Carmont and are currently doing extra inspections

We have identified 584 sites which share some characteristics of 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 also incorporate high risk drainage sites that have already been identified from our asset resilience inventory.

We are using both in-house engineers and specialist contractors to undertake these inspections, 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 since the Carmont derailment have not identified any significant issues requiring emergency intervention. At around 1 % of the sites we have identified defects that have deteriorated and require action sooner than originally planned.

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

We have mobilised teams at a route, regional and national level to ensure that a national picture is represented on the progress of additional earthworks and drainage inspections that have been taking place since 12 August 2020.

An earthworks management task force, led by Lord Robert Mair, has been set up to review our capability to better understand, manage and improve all aspects of earthworks safety. The task force will consider our current skills and competence, look at what can be learned from other organisations and countries, as well as the use and deployment of the latest technology. It will focus on cuttings and embankment construction and the age of our assets.

Reviewing the latest weather forecasting technology to enhance our approach

Additionally, as an interim short-term measure, the national weather team is enhancing our weather services website, which is the forecasting tool used by all operational controls, maintenance delivery, train operators and freight operators. A new tool providing improved alerts for convective storm events is being accelerated and will be trialled over the coming months.

We have implemented a review, as part of a weather advisory task force led by Dame Julia Slingo, of our weather forecasting information in relation to rainfall and thunderstorms. We are exploring the benefits of introducing a 'real-time' weather alert system that can better equip us with understanding the local risk of rainfall to our infrastructure and operations. This will draw on the latest science developments in monitoring, real-time observations, and weather forecasting.

The weather advisory task force will investigate the deployment of readily available spatial resolution rainfall data to a granular level of a 500-metre grid size with images of rainfall rates updated every five minutes. Specialist resources including weather analytics and forecasting will be procured to support the provision of this additional service. The information will bolster our existing decision-making capability in assessing the risk that rainfall has on our infrastructure, using condition-based asset data available from our inspections and records to apply appropriate measures that will protect the safe passage of trains. We are separately exploring how climate change might increase the frequency and severity of heavy rainfall events and storms and will draw this into our future analysis and tools.

Terms of reference for both the earthworks management task force and the weather advisory task force are appended to this report. Both task forces will be closely aligned.

Technology-based solutions already heading towards implementation

Our research and development portfolio involves development and trials 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. We have also recently completed work applying ‘machine learning’ to enhance our earthworks risk hazard scoring, improving targeting of interventions. We have now installed telemetry at more than 200 locations.

Section 4 - long terms plans to improve resilience to climate change

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

Climate change is often viewed as a future problem. However, 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".[6] "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."[7]

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 Scottish Government's high level output specification for CP6 https://www.transport.gov.scot/media/39496/high-level-output-specification-hlos-for-control-period-6-final.pdf specifically mentioned the need for climate change adaptation, and measures to assess the effectiveness of the approach. The Secretary of State, in the England and Wales high level output specification, also 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[8]), our key challenge will be implementing these plans and improving resilience on the ground.

[6] 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
[7] World Weather Attribution (2017) https://www.worldweatherattribution.org/uk-storm-desmond-revisited-december-2017/ viewed on 26 August 2020
[8] 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

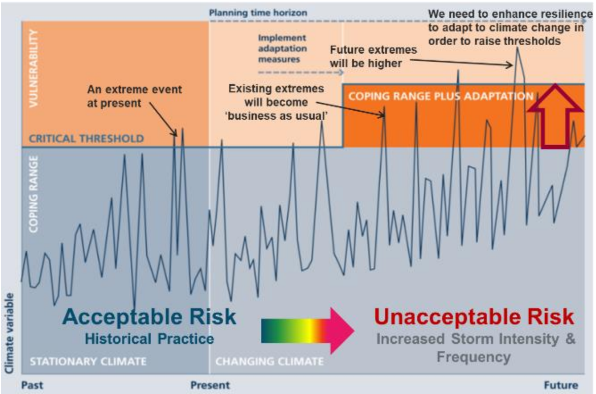


Figure 5: Coping thresholds and the need to manage unacceptable risk

Source: Adapted from Willows, R.I. and Connell, R.K. (Eds) (2003) Climate adaptation: Risk, uncertainty and decision-making, UKCIP Technical Report, UKCIP, Oxford. [9]

Our challenges are shared by other operators of historical infrastructure[10]. Our resurveys are suggesting accelerated deterioration and the Environment Agency (EA) has estimated this increase to be between 30 % and 60 % for their assets[11]. These findings are consistent with the changes we forecast for Control Period 7 (CP7: 2024-2029) but have arisen much sooner than we anticipated.

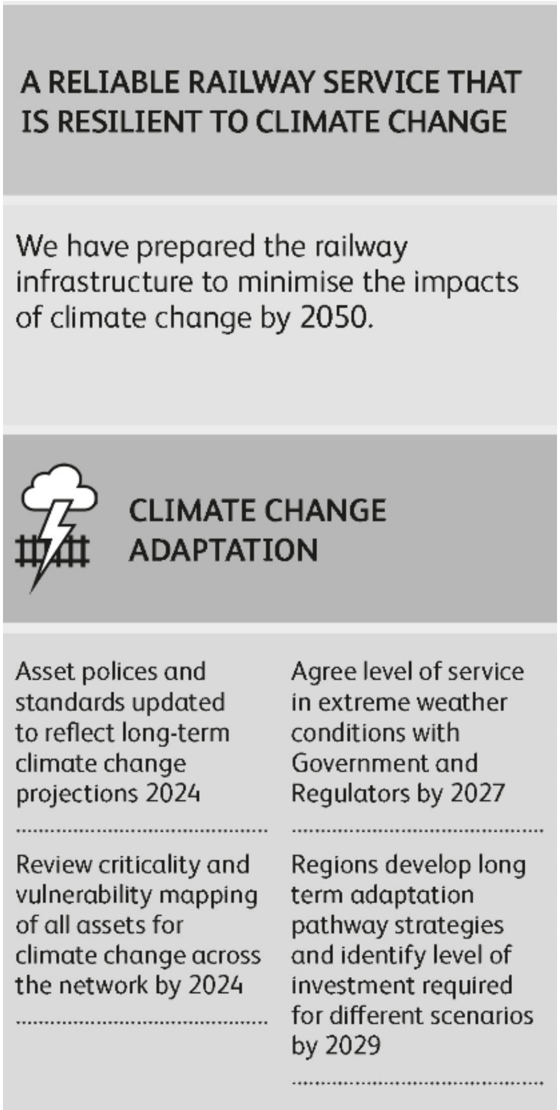
The threat of extreme weather also increases the influence of broader 'catchment-wide' impacts. The complex nature of drainage systems that transfer water from multiple private owners can concentrate risks at or near the railway (for example Figure 6). Past inspection processes have not always been able 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.

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

[9] 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
[10] Examples include Environment Agency (EA), Scottish Environmental Protection Agency (SEPA), Canal & Rivers Trust (C&RT), Scottish Canals, Natural Resources Wales and utility companies.
[11] Jim Barlow, Deputy Director for Asset Performance & Engineering at the Environment Agency in discussion with Tim Kersley on 17 August 2020

Our forthcoming **Environmental Sustainability Strategy** 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). One of the key ambitions is the development of local climate change adaptation strategies and investment plans for each railway corridor that will map out our intentions to be achieved by 2050.

Our previous Weather Resilience and Climate Change Adaptation Strategy (WRCCA[12]) has been in place since 2017, and we are making good progress identifying and managing key risks and areas of vulnerability across the Network Rail regions. Critical to our plans for minimising safety and reliability and performance impacts 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 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 our customers and passengers.



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 (UKCP1813) in risk assessments and designs. Since 2014 we have produced Weather Resilience and Climate Change adaptation plans for each of our routes14. For CP6, these are

[12] Available at: https://safety.networkrail.co.uk/home-2/environment-and-sustainable-development/wrcca/wrcca-strategy-2/
[13] More information available at: https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/index
[14] Available at: https://www.networkrail.co.uk/communities/environment/climate-change-and-weather-resilience/climate-change-adaptation/

being updated to confirm local actions already delivered, funded actions for CP6 and future opportunities and priorities for additional funding. Each of our technical authority asset teams are undertaking 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 to make solutions to manage assets cost-effectively and 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 has recently resulted in 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 Achilles programme investigates deterioration, performance, forecasting and decision support for earthworks across the infrastructure sector[15]. 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.

Our CP6 strategic business planning focussed on addressing priority weather resilience. We are still developing stronger cases for investment to proactively enhance our assets and deliver resilience to future climate change.

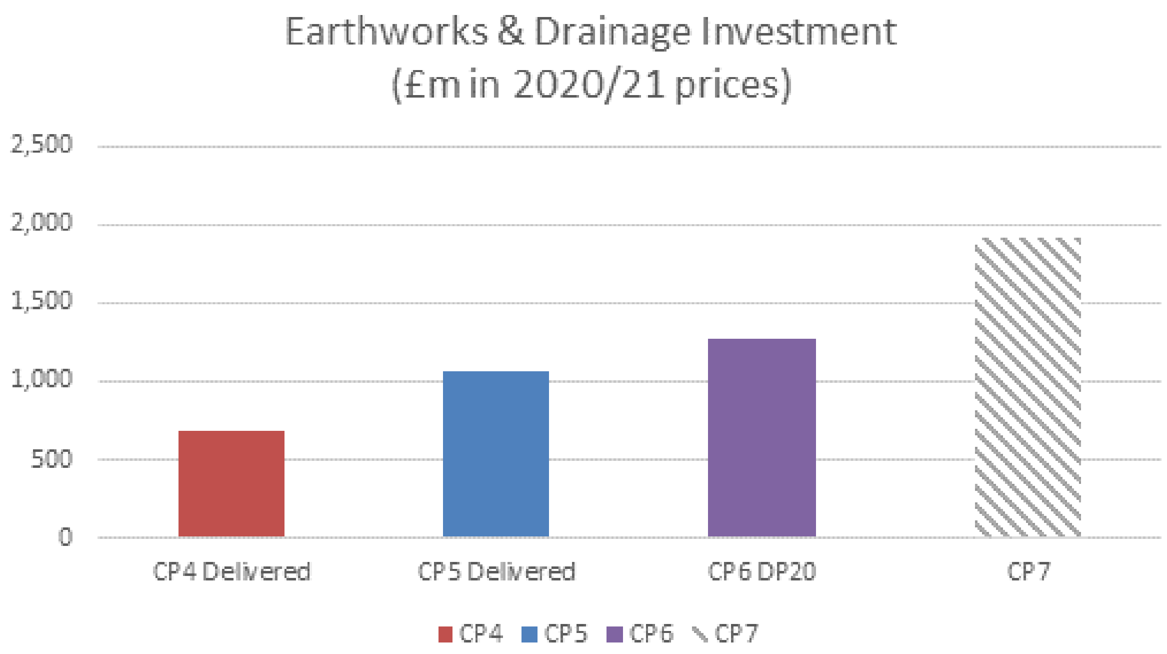
We will continue to work closely with Governments and regulators to make sure our resilience plans are proportionate to the level of service expected from the railway during adverse and extreme weather conditions in the future and that they are funded. We will set out more detail on our climate change resilience work and future action plans in the follow up report.

[15] More information on the ACHILLES Programme: https://www.achilles-grant.org.uk/

Section 5 – Investment and financial planning to improve resilience

Our plans already incorporate significant addition 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 an overall small 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), recognising the increasing challenges. 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 satisfactorily with emerging insights outlined in section 4 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 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 both 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, and the findings of the task forces on weather resilience and geotechnical work will further inform actual requirements. We will provide an update on this in future reports.

Section 6 – Next steps

We are continuing to support the RAIB and the ORR on their Carmont accident investigations while also leading the industry investigation. This can be expected to continue for several months. The learnings from the investigations will be fed into our business planning process in due course.

In the short-term, we continue the work with our meteorological partners to harness real-time, more granular data and incorporate them further into our operational response processes. This will be done in conjunction with operators to bring their specific insights into management during extreme weather and the potential impact on passenger and freight customers.

We are also reviewing the speed of deployment of on-the-shelf geotechnical monitoring technology where there may be an opportunity to accelerate our existing programme. We will work with other agencies, such as Highways England, the Civil Aviation Authority, Transport for London and other infrastructure bodies in Scotland specifically to compare approaches to the issues that emerged from Carmont including work with neighbouring landowners for more system and catchment level consideration of water flow and drainage.

We are reviewing international benchmarks and practices for insights that may be used in Britain. We will also 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.

In the medium-term, the two task forces will bring fresh insights to our approaches to weather resilience and geotechnical asset management. We will also update our research and development agenda to capture future requirements and opportunities.

For longer term planning, we are drawing together these combined learnings to update our asset management strategy for CP7 and beyond. This will be incorporated in our proposal for the CP7 periodic review process. We will work closely with Governments' transport departments and ORR to ensure our proposal reflects and contributes positively to the emerging position adopted by Governments following the recommendations by the National Infrastructure Commission report on resilience establishing clear standards, ensuring systems are tested regularly and that operators take action to deliver resilience both now and in the future. Data will be shared as it becomes available during 2021.

Annex A – Draft remit for earthworks management task force

Earthworks Management Task Force

An external review of Network Rail's capability to manage and understand the implications of earthworks is requested of the Task Force led by Lord Robert Mair. The aim of this review is to equip Network Rail with the expertise and competence in order that it can better manage earthworks in future, particularly taking into account effects of climate change

The rail industry precursor risk model shows earthworks to be our highest risk asset. There have been several different failure modes, rock falls, rotational slips, washouts etc. and we need to recognise the different modes, causes and consequences, and so improve all aspects of earthworks safety.

1) Our controls framework for earthwork assets is described by our engineering standards. The Task Force is to undertake an independent review of this framework. Is it effective for controlling the risks we manage? Does it place realistic demands on our frontline engineers?
2) Do we have the competence framework and resource needed to manage our earthworks and drainage assets? Do we manage drainage and earthworks assets in an integrated and effective way? Or do we need greater coordination between these two engineering functions?
3) Do other organisations manage earthwork risks more effectively and what might we learn from them?
4) Are we aware of the latest technologies and do we deploy them effectively? There are significant numbers of innovative technologies for monitoring, many of which are already being used by NR - are there any recent innovations that can further enhance NR's capabilities?
5) The Task Force will consider both cuttings and embankments. History of embankment construction will be important and the review will consider the work that has occurred on this across Network Rail and in other organisations such as London Underground. The review will include considerations of vegetation change and its link with climate change, with age of both cuttings and embankments likely to be a significant factor.
6) The Task Force will also consider what can be learned from organisations in other countries.

There is a need for this earthworks workstream to interface with experts on climate change and the separate review workstream being led by Dame Julia Slingo. Separately the Task Force's Expert Panel may need advice from a monitoring specialist (INSAR satellite technologies etc). The Expert Panel will also seek advice from other specialists as necessary.

[Timescales to be agreed]

Annex B – Draft remit for weather advisory task force

Weather Advisory Task Force

Purpose:

An external review of Network Rail's capability to manage and understand the implications of rainfall is requested through a Task Force led by Dame Julia Slingo FRS. This aim is to equip Network Rail with the expertise and competence in order that it can better manage rainfall in the future.

Rainfall can affect the railway in many ways, from flooding, washing out ballast, damaging structures (particularly bridges and culverts), washing down debris, to triggering landslips and rockfalls.

Anything that undermines the strength of the railway formation, or that can be an obstacle to trains (and thus creating a risk of derailment) is a risk that must be mitigated.

Network Rail's Safety Management System provides an assurance process for management of the cuttings, embankments, structures and drainage. These have assisted Network Rail to limit the effects of rainfall on the infrastructure. The events at Stonehaven on 12 August 2020 have highlighted that these risks are only mitigated by the SMS, not eliminated.

Aims:

The review is requested to explore the following questions with the objective of shaping the organisation for moving forward, better equipped to understand the risk of rainfall to its infrastructure and operations. It should draw on the latest science developments in monitoring, real-time observations, weather forecasting and climate prediction, to contribute to the following questions:

1. What level of expertise in rainfall should Network Rail employ in order that it can either manage rainfall itself, or so that it can act as an informed client when procuring specialist services?
2. To what extent is Network Rail availing itself of data and research on historical, current and future rainfall and its effects on the operational railway? How should such information be used to:
    a. understand the likely levels of rainfall today, at a location level, that may pose a risk to the operational railway;
    b. understand the potential levels of rain today and up to 10 years ahead, that could fall at a location, in order to estimate the potential damage to infrastructure that such levels could inflict;
    c. ensure that future engineering decisions (such as for drainage specifications) take account of local weather factors, and to identify where existing assets are insufficient; and
    d. track how changing land use and/or river management policies near the railway affect how quickly rain enters and leaves the system.
3. How effectively does Network Rail make use of available forecasting technology to identify where rainfall could create a risk to the railway?
    a. How can it make better use of weather monitoring technology (such as rainfall radar) and state-of-the-art nowcasting to guide decision-making during a high-impact weather event?

   b. How can Network Rail ensure that it manages the risk while keeping the system open to passengers and freight who depend on the system?
4. How extensively has Network Rail explored the potential of real-time weather monitoring technology, particularly with augmenting of different data sources (such as its asset databases), to introduce better means of identifying location specific risks?
   a. How could the EWAT process be improved to take advantage of such processes?
   b. What real-time weather competence and capability would support a national organisation with devolved accountability?
5. How should Network Rail use such weather expertise and competence to provide input into longer term planning or procurement decisions? This could be in earthworks engineering or providing guidance to track and rolling stock design specifications.

When considering the questions, best practice from other industries and sectors will be included where appropriate.

For clarity, the work should focus on Network Rail's ability to deal with current rainfall levels and the associated likely outcomes over the next ten years. It should however consider potential changes in rainfall out to 2050 to ensure infrastructure investments are climate-proofed.

It is understood that the above questions will involve the procurement of specialist resources including weather analytics and forecasting, as well as how best to translate rainfall extremes to high impact hazards (e.g. surface water flooding, river flooding, landslides). A process will be agreed as part of the remit to enable this.

[Timescales to be agreed]