JBA trust

Flood and scour related failure incidents at railway assets between 1846 and 2013

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Authors

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Front cover: Malahide Viaduct collapse, 2009
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Purpose

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Executive Summary

Incidence of failures

- This study updates an assessment of railway asset failures due to flooding and scour that was published in 2004 by the Rail Safety and Standards Board in *'Report T112'* covering the period 1846-2003. This update includes incidents between 2003 and 2013.
- Failures of bridges and culverts are prioritised, where failure is defined as "complete or partial collapse of the structure sufficient to cause derailment or closure of the line" Although railway assets are the focus of this study, the collapse of seven road/footbridges in 2009 in Cumbria are also investigated. These are of interest because of the survival, rather than failure, of a railway bridge in the area.
- Seventeen scour failure incidents have been identified in the UK and Ireland. Of these incidents, six relate to railway bridges or viaducts.
- We have found evidence of 138 incidents of failure of rail bridges or culverts related to flooding during the period 1846-2013 in the UK. The annual probability of observing a flood event in which one or more structures fails is estimated to be approximately 41%, or 1 in 2.44 years. This is broadly consistent with the analysis in 2004's *Report T112*.
- Although not the specific focus of this study, it has been found (as for the 2004 RSSB study) that there is more evidence of embankment failures, track damage and landslip in addition to damages resulting from than failures of bridges and culverts due to scour.

Causes of failures

- A quantitative flood and/or rainfall frequency estimate could be carried out for four of the new (2003-2013) incidents identified in this study. Three of the failures happened during relatively minor flood events. One of the bridge failure events was caused by a rare or exceptionally rare flood event.
- A higher number of the reviewed incidents occurred during the winter months (in contrast with the findings of the 2004 RSSB report).
- The failure mechanism of the four incidents was undermining of abutments or piers by scour, resulting in their collapse.
- Associated processes, such as the build up of debris, exacerbated the effects of scour leading to the failure of structures in relatively minor flood events.

Recommendations

- As the current report supports the conclusions drawn in the previous study it further reinforces the recommendations made in the previous report.
- Factors other than high flood flows alone were implicated in three of the four failures that we investigated in detail. This implies that further work should be carried out investigating these factors.
- The higher incidence of embankment and track failures should be investigated.

Dissemination and further updates

- Basic information contained in the flood and scour incident database can be obtained from the JBA Trust website: www.jbatrust.org
- To access further background information please contact the JBA Trust via the "Contact Us" page at www.jbatrust.org.

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Abbreviations

AMAX	Annual Maximum
BIRDIE	Bridge Incident Review Document Investigating Extremeness
CEH	Centre for Ecology and Hydrology
CIRIA	Company providing research and training in the construction industry
EA	Environment Agency
ELR	Engineers Line Reference

FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
FMS	Flow measurement station
FSR	Flood Studies Report
GEV	General Extreme Value Distribution
GL	General Logistic Distribution
NERC	Natural Environment Research Council
NRFA	National River Flows Archive
NRW	Natural Resources Wales
OS NGR	Ordnance Survey National Grid Reference
PR	Percentage Runoff
QMED	Median Annual Flood (with return period 2 years)
SAAR	Standard Average Annual Rainfall (mm)
SEPA	Scottish Environment Protection Agency

1 Introduction

1.1 Summary

In 2004 the Railway Safety & Standards Board (RSSB) published results of an appraisal of the scour risk rating method *Handbook 47*. As part of that project *(Rail Safety & Standards Board Infrastructure Integrity (4) Research Theme: Project Number T112 Scour & Flood Risk at Railway Structures)* a database of historic flood and scour related failure incidents of railway assets was collated.

The project reviewed the priority scoring system and threshold risk rating used by Network Rail to classify structures which may be subject to scour. The aim of the project was to "help work towards eliminating catastrophic accidents by application of existing control measures and new initiatives" (RSSB, 2004).

This report is an update of the work carried out in *Project T112* to include incidents that have occurred in the ten years (2003-2013) since the compilation of the database for the 2004 study.

1.2 Objectives

The objectives of the present study were therefore:

- To update the Railway Assets Scour and Flood Failure Incidents Database to include incidents which have occurred between 2003 and September 2013.
- To carry out detailed incident reports investigating the extremeness of the events causing failure.

This report is published for use as a research and educational resource.

1.3 Scope

To achieve the objectives listed above the following work was carried out:

- A review of the report *Rail Safety & Standards Board Infrastructure Integrity (4) Research Theme: Project Number T112 Scour & Flood Risk at Railway Structures* by JBA Consulting, 2004.
- A brief overview of scour mechanisms and assessment procedures.
- Research to identify and collate information about scour-related failure of structures during the period 2003-2013.
- Identification of additional information to collate for the updated Railway Assets Scour and Flood Failure Incidents Database
- Detailed investigations into identified scour incidents, including rainfall and flood rarity estimates.

2 Review

2.1 Review of the 2004 study 'Flood and Scour Failure of Railway Assets Database for 1846-2003'

2.1.1 Overview of findings

The previous study *RSSB Project Number T112 Scour & Flood Risk at Railway Structures* was undertaken in 2002 and the reporting completed in 2004 on behalf of the Rail Safety and Standards Board (RSSB) as part of a research theme to investigate scour and flood risk at railway structures.

The study compiled a record of incidents between 1846 and 2003. During this period, 131 failure incidents were found in the UK and Ireland, resulting from 65 discrete flood events. Failures tend to be documented more reliably at larger structures due to the extent of disruption and cost. Therefore to increase confidence in the inclusion of most failure events the study aim was to report on the failure of larger structures.

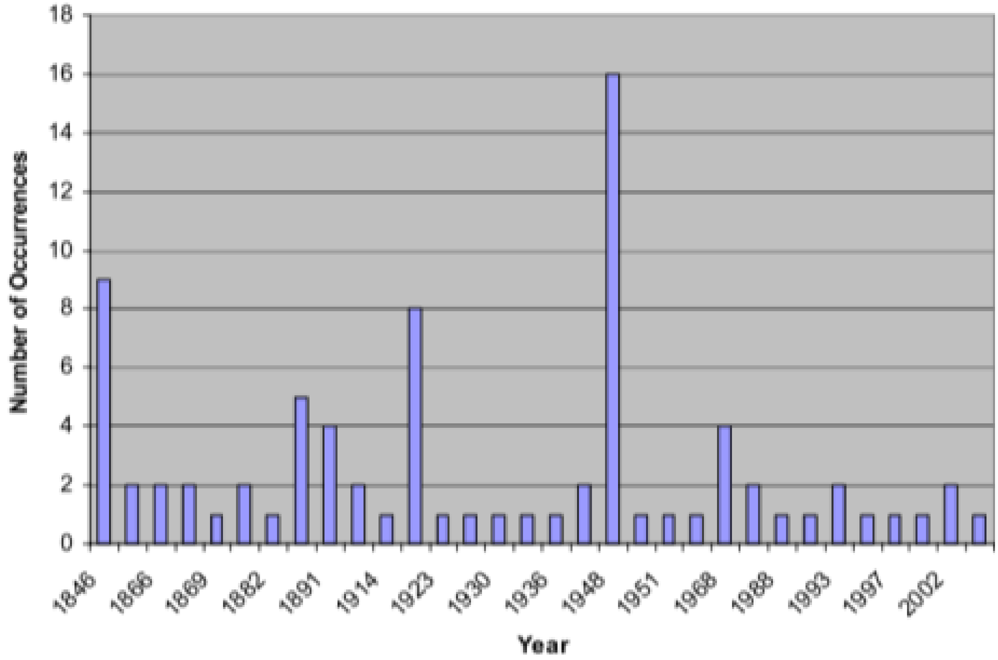

Figure 1: Timeline of bridge scour failures published by RSSB (2004)

Failure was defined as "complete or partial collapse of the structure sufficient to cause derailment or closure of the line" (RSSB, 2004). Figure 1 shows the timeline of incidents found in the study. No significant trend or periodicity was found for the incidents. It was found that failures could occur in any month of the year, but that there were more incidents in summer.

Figure 2 shows the geographical distribution of the failure incidents. It was found that many of the structure failures occurred in groups associated with a common flood event, and are therefore geographically close.

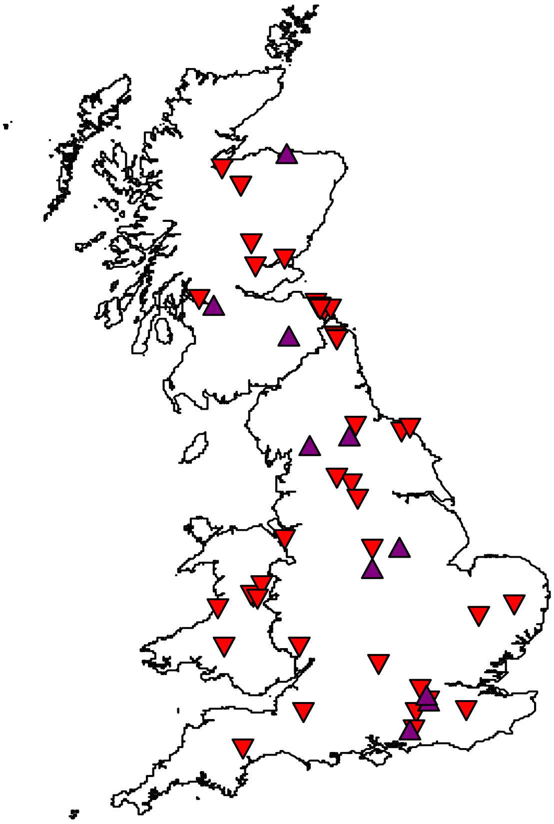

Figure 2: Geographical distribution of incidents (RSSB, 2004)

2.1.2 Data

The failure incident database included the following fields, although information was often not available for all fields:

- Incident date, location, watercourse, structure type
- Description of failure, hydrological classification of failure, contributing factors, consequences of failure (e.g. injuries)
- Bridge details: line/route, name, Engineering Line Reference (ELR), Bridge number, construction and reconstruction details
- Catchment Descriptors and Qmed values
- Photos, pictures and diagrams

2.1.3 Data Sources

The RSSB 2004 database was compiled based on:

- Network Rail Structures Records held at Waterloo, Swindon, Birmingham, York, Manchester, Liverpool Street and Glasgow
- Rail Property/ BRB Residuary Records held at York
- Accident Reports of the Board of Trade held at the Public Records Office, Kew and the National Railway Museum, York.
- Accident Reports of the Railway Inspectorate.
- Ransom, P J G. 'Snow Flood & Tempest – Railways & Natural Disasters'. Ian Allen Publishing, 2001.
- Simmons, J and Biddle, G. 'The Oxford Companion to British Railway History'. Oxford University Press, 1997.
- Holt, L T C. 'Red for Danger. The Classic History of British Railway Disasters'. Sutton, 2001.

- 'British Railway Disasters'. Ian Allen Publishing, 1996. British Hydrological Society.
- Chronology of British Hydrological Events.
- Web searches.

2.2 Scour Process and Assessment Procedure

2.2.1 Introduction

Hydraulic action can lead to the failure of structures such as bridges through several different mechanisms, including the following.

- Scour can undermine shallow foundations or cause destabilisation of deep foundations through erosion of the river bed. This can lead to undermining or tilting of the bridge piers or buttresses.
- Bank erosion and channel migration causing undermining of piers or abutments on the floodplain.
- Lateral forces can cause failure through sliding or overturning whilst uplift can lift bridge decks from their bearings or reduce the compression in arches.
- Debris accumulation, which increases the effective width of a pier, increasing the scour risk as well as constricting the flow, which leads to higher water levels and flow velocities through the structure.

Of these mechanisms it is believed that scour is the most common cause of failure. In the UK there are estimated to have been 15 fatalities due to flood/scour failure of a structure since the 1840s (RSSB, 2004).

In recent years notable failures due to scour include the Glanrhyd railway bridge disaster in 1989 in Wales, which collapsed due to scour of a pier resulting in four fatalities as an approaching train attempted to cross the collapsed bridge and fell into the river.

More recently the Lower Ashenbottom viaduct in Lancashire failed in June 2002 as its central pier partially collapsed due to scour during a flood event; the scour was exacerbated by the presence of debris, exceeding the estimated foundation depth.

In the 2009 Cumbria floods seven road and foot bridges failed due to the combination of scour and hydrodynamic loading. The collapse of the Northside road bridge in Workington led to one fatality.

2.2.2 Scour

Scour is interpreted here as the removal of material from the bed and banks of a channel by the action of water. Guidance on management of scour has been given in a CIRIA report *Manual on Scour at Bridges and Other Hydraulic Structures* by May et al. (2002), which is currently undergoing an update[1]. Scour can cause failure of the foundations of the abutments or piers of bridges. Scour occurs naturally, and is most common in granular alluvial river beds and banks. Materials such as clay and even some kinds of rock are susceptible to scour. Scour may result from natural changes of flow in the channel, as part of longer-term morphological evolution, or as a result of human activity, such as the building of structures in the channel or dredging.

It was found in previous work by JBA Consulting (RSSB, 2004) that bridge failure due to scour was most commonly associated with flood events broadly with return periods of 50 to 500 years. Most of these failures are encompassed in 200 to 250 year return period events, with an average return period of 160 years. High intensity localised rainfall on small catchments appears to have caused a number of incidents in summer and early autumn.

2.2.3 Scour Mechanisms

There are three main scour mechanisms known as natural scour, contraction scour and local scour, which work additively to give total scour as shown in Figure 3.

[1] http://www.ciria.org/Research/Projects_underway2/scour_at_bridges.aspx

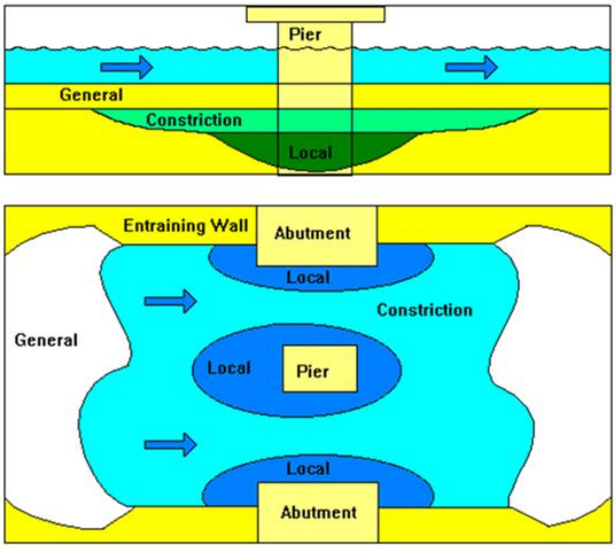

Figure 3: Components of total scour

2.2.4 Natural Scour

Natural scour is the result of long term changes to the river or catchment. Degradation of the channel occurs as the river attempts to find a balance between sediment load and sediment transport capacity to reach an equilibrium condition called regime flow. This can be disturbed by both natural and man-made alterations to the catchment and river such as dredging, changes in catchment drainage or long term morphological changes.

Lateral channel migration, where the entire river channel position changes due to meander progression, or where the deep water channel changes position within the channel banks, may also occur due to these natural or man-made causes. These changes occur slowly over time or in steps during flood events. Braided rivers may also be susceptible to confluence scour, which occurs where two rivers meet as the centreline of the meeting flows is directed towards the channel bed. Bend scour occurs due to flow curvature, which creates secondary spiral currents that increase scour at the outside of river bends.

2.2.5 Contraction Scour

Contraction scour occurs where the narrowing of a river channel (for example due to the presence of bridge piers or abutments) causes increased velocity and shear stress at the bed. Material may be removed from the entire width of the channel. Contraction can also occur where the flow has been forced from the flood banks to flow under a bridge due to approach embankments, where a downstream control has been removed or where the stream flow rate at a site increases for some other reason.

2.2.6 Local Scour

Obstructions to the flow in rivers can increase flow velocities and turbulence locally, which can cause the formation of vortices exerting forces on the river bed, leading to erosion. This causes the river bed to be lowered in the immediate locality of the obstruction.

Formulae can be used to predict the depth of the scour hole caused by different types of structures. In the case of bridge abutments and piers the turbulent structure which occurs is known as the horseshoe vortex, shown in Figure 4. The vortices which are deflected to the downstream side of the pier increase flow velocities and cause scour of the river bed at this location, creating what is known as a ‘scour hole’. Material from the scour hole is deposited downstream, further changing the river bed level. The flow structures are discarded periodically and move downstream, which can cause further erosion of the river bed downstream on either side of the pier (May et al., 2002).

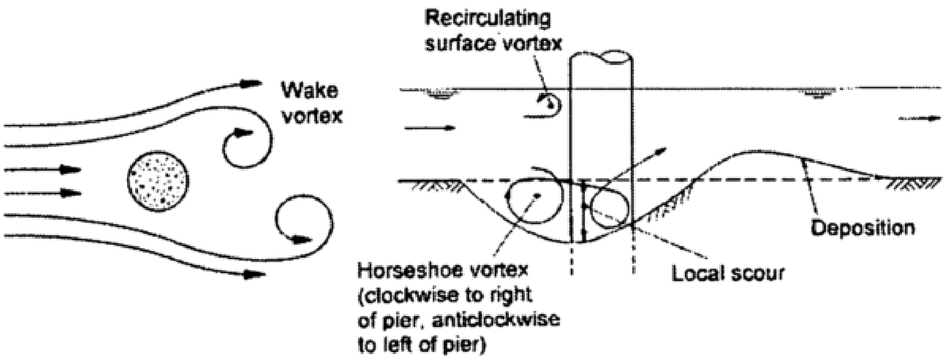

Figure 4: Local scour and turbulence at a circular pier (after May et al., 2002)

Bridge pier is 1.6m wide and 4m long. Direction of flow is from left to right

General or natural scour resulting in exposure of bridge foundations.

Figure 5: Structures showing a developing scour hole (left) and general scour (right), from Environment Agency (2004).

The three different scour mechanisms need to be considered when evaluating the scour conditions in a river. It is important to note that both long term, in the case of natural scour, and short term monitoring is required; the scour hole often re-fills after the flood event.

2.2.7 Factors Affecting Scour

Factors which affect flow are listed in the CIRIA Manual on scour at Bridges and other Hydraulic structures as the following:

- the position and type of structure
- the flow conditions affecting it
- the characteristics of the channel boundary materials in the vicinity of the structure and in the upstream reach

These factors are subject to a high level of uncertainty, and hence scour predictions cannot be made to the same level of accuracy as structural calculations. For example, the flow and sediment conditions affecting the structure may change because of climate or catchment changes during the life of the structure.

2.2.8 Impact of Scour

Scour can cause the undermining of bridge pier and abutment foundations, thereby causing failure of the structure through various mechanisms (Table 1).

Table 1: Hydraulic structure failure mechanisms due to hydraulic action

Primary	Secondary
• Pier settlement due to loss of support to foundation • Pier tilting, or tilting of group of piles • Abutment settlement or tilting • Piers, abutments or footings damaged by hydraulic loading, possibly aggravated by debris accumulation • Piers, abutments or footings damaged by collision, sediment abrasion or impact from boulders • Superstructure or deck sliding off supports due to hydraulic or debris loading or collision • Superstructure or deck damaged by collision of debris or vessel • Scour hole or washout of embankment behind abutment	• Structural damage to superstructure or deck caused by twisting from differential settlement of piers and/or abutments • Superstructure or deck falling off abutment or pier due to adverse tilt of support. increasing gap between supports • Superstructure or deck buckling or riding up over support due lo reduced gap between supports • Superstructure or deck sliding off supports because of tilting of supports • Collapse of railway into embankment scour hole or washout

The collapse of the Malahide Viaduct in the Broadmeadow Estuary, Ireland (shown in Figure 6 and front cover) was a structural failure due to scour. A combination of natural scour and local scour led to the exposure of the pier foundations, which were undermined by hydraulic action resulting in the collapse of the pier when it was loaded by two trains in August 2009 (RAIU, 2010).

Figure 6: Malahide Viaduct Collapse (Railways Archive, 2010)

2.2.9 Assessment Procedure

Network Rail follows a four step process in the management of scour as shown in Figure 7. A risk based approach is used to assign priority ratings to structures depending on the level of assessed risk from scour. This procedure was developed following the 1987 Glanrhyd disaster and was known as *Handbook 47* (British Railways Board, 1989), this was revised in 1992 and is now generally known as *EX2502* (Bettess, 1993).

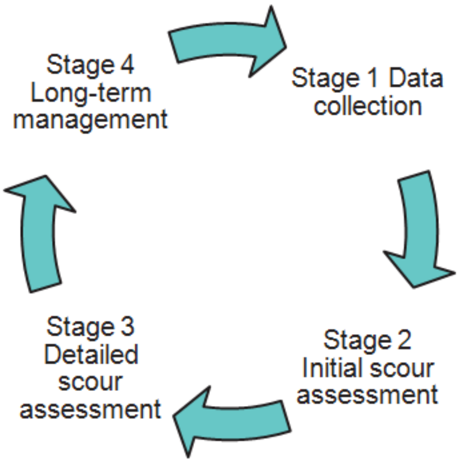

Figure 7. Network Rail scour assessment procedure

More recent studies, such as that carried out by JBA Consulting, *Safe management of railway structures: flooding and scour risk*, have been commissioned by the Rail Safety and Standards Board to review and improve these methods (JBA Consulting, 2004).

The Network Rail standard for management of existing bridges and culverts (RT/CE/S/080) states that "all structures over watercourses, adjacent to flowing or tidal water, or at risk of flooding or susceptible to damage or reduced load carrying capacity as a result of scour or flooding (including overturning, sliding and/or uplift)" should be subject to initial scour assessments at a minimum of once every three years. Any structures which are deemed to be at risk are to be included in the flood warning plan. Unlike previous standards, there is not a recommended assessment procedure such as EX2502.

2.2.10 Stage 1: Data Collection

The first stage of the assessment procedure was to collate all available information on the structure. This includes sources such as previous EX2502 examinations and drawings, coring and underwater surveys and as-built design drawings.

2.2.11 Stage 2: Initial Scour Assessment

The data collected in Stage 1 was used to carry out an initial scour assessment to identify which of the 9000 structures that cross permanent water courses and which of the 20,000 further structures at risk from flooding were in need of a more detailed scour assessment (JBA Consulting, 2004).

2.2.12 Stage 3: Detailed Scour Assessment

The structures identified in Stage 2 were subjected to a detailed scour assessment. This assessment includes further review of the data collected in Stage 1 along with more detailed data collection and a risk assessment.

EX2502

EX2502 (Bettess, 1993) is the risk assessment procedure which has been followed by Network Rail to assess structures at risk of scour and flooding.

A preliminary priority score (PP) is assigned to a structure by summing the contraction scour and local scour discussed in section 2.2.3 to give total scour (TS) and dividing this by the foundation depth (FD). As natural scour is the most difficult to assess it is treated as a separate variable.

$$PP = f(TS/FD) = 15 + \ln(TS/FD)$$

The PP is then modified by several factors which up or down scale it to its final priority rating (PR)

$$PR = f(TS/FD,TR,FM) = 15 + \ln(TS/FD) + TR + FM$$

where river type (TR) describes the changeability of the river course, the natural scour, and FM describes the foundation material.

2.2.13 Stage 4: Long-term Management

Any structure with a priority rating above 16.0 is classified as high risk. Structures which have had scour protection put in place should not automatically be excluded from flood plans as the need for the scour protection indicates that the structure is vulnerable, and should therefore be inspected on a regular basis. The priority rating system is shown in Table 2.

Table 2: Priority rating meanings (JBA Consulting, 2004)

Priority rating	Category	Priority
> 17	1	High
16 - <17	2	High
15 - <16	3	Medium
14 - <15	4	Medium
13 - <14	5	Low
<13	6	Low

2.2.14 Mitigation

Scour mitigation options follow a hierarchy of preferred choices which can be included in the design or in many cases retrofitted to a structure.

Scour reduction measures improve flow conditions at the bridge to reduce the magnitude of scour. This is likely to be the most cost effective measure. Structural measures take into account the increase in hydrodynamic forces due to predicted scour depth. Scour protection measures include erosion resistant surfaces that can be fitted to limit scour depth, and may increase the whole-life cost of the bridge as maintenance of the scour protection will be required.

2.2.15 Scour Reduction

Choosing a stable channel location for the crossing can reduce the risk of natural scour. Building bridges on confluences, bends or alluvial fans should be avoided. Man-made changes such as dredging, removal of hydraulic structures such as weirs and deforestation should be minimised at the location.

Contraction scour can be reduced by minimising the contraction, i.e. increasing the flow area. This can be achieved by ensuring there is sufficient waterway opening, providing flood relief openings and by designing the bridge so that it has a lower approach to roads, which will allow flow to bypass the structure.

The choice of streamlined bridge elements reduces both local scour and debris accumulation which can exacerbate scour. The choice of shape is important. Using circular piers eliminates the problem of changes in approach flow alignment and elliptical piers reduce turbulence in comparison to rectangular piers. Sloping or spill-through abutments can be used instead of vertical wall abutments to reduce scour. Deflectors or sacrificial piles can be used to direct flow away from the structural elements and so reduce scour. For retrofits it is possible to add cut-waters to bridge piers.

Increasing the stability of the river through the use of bed control structures, longitudinal structures which prevent lateral movement of the channel or transverse structures which deflect flow away from the bank are river training methods which can be used to reduce scour.

2.2.16 Structural Measures

Bridges can be designed to withstand the predicted scour depth or can be retrofitted. For example, care should be taken when designing shallow foundation so that they are placed either on non-erodible material or below the expected scour depth. The effective width reduction due to the spread footings should also be taken into account. Similarly, with piled foundations, the pile cap should be placed below the maximum predicted scour depth. If the pile cap is exposed to flow then the impact this has on scour, and the impact of the scour on the foundations should be taken into account. Structural repairs may be carried out to reduce the effect of scour, care should be taken, however, to ensure that this does not significantly increase contraction scour.

2.2.17 Scour Protection

Scour protection consists of the provision of a non-erodible layer to protect the channel. The extent, elevation and detail of the scour protection should be carefully designed to ensure that it does not cause further scour problems. Scour protection measures can be classed as flexible or rigid. Flexible methods include riprap, gabion baskets, articulated concrete blocks and biotechnical solutions. Rigid solutions include grout filled mattresses, concrete aprons and steel sheet piling.

2.2.18 Monitoring

As well as the above measures the effect of scour can be monitored to provide early warning of scour problems. However, for this to be effective, high reliability of the monitoring devices is required. Fixed or portable monitoring equipment can be used, with the advantage of fixed equipment being that it can provide a more timely warning. However, issues such as the need for a power supply mean that this is the more costly option.

2.3 Conclusion

Natural, constriction and local scour erode river channels, putting hydraulic structures at risk of failure by undermining abutment or pier foundations. In many cases this has led to the catastrophic collapse of bridges, viaducts and culverts, causing millions of pounds of damage, numerous casualties and even fatalities.

Scour assessment procedures classify structures as being at low, medium or high risk. High risk structures are included in the flood plan and actions are carried out to ensure their risk is managed effectively.

Scour risk can be managed by carrying out scour reduction measures, structural measures, installing scour protection or scour monitoring. Careful consideration of the changeability of the channel and catchment is required to ensure that scour mitigation measures are employed effectively.

3 Failure Incident Database

3.1 Definitions and scope

The creation of a database of failure incidents of railway assets due to scour and flooding requires definition of the terms so that a boundary can be drawn as to which incidents should be included.

In line with previous work, "failure" has been defined as *"total or partial destruction of a structure that is sufficient to cause line closure"* (RSSB, 2004).

Priority was given to the investigation of failure of railway bridges and culverts.

The failure of retaining walls was also considered, although this was a secondary consideration as it is difficult to obtain information on these failures.

Track failures due to landslips caused by flooding have been listed. However as these are numerous and often not due to scour they are not further investigated in this report.

The failure database focuses on railway assets. Additionally some road and foot bridges have been included in particular from floods in Cumbria in 2009 when six road and foot bridges collapsed but a nearby railway bridge remained intact.

The study was confined to the UK and Ireland.

3.2 Data Sources

JBA staff provided a list of seven failure incidents known to them. Another 13 scour-related bridge failure incidents were identified through the use of web searches. Sources used along with a comment on their usefulness are shown in Table 3.

Table 3: Data sources for identification of incidents

Source	Comment
National Railways Archive	Database of Railway Accidents in the UK and Ireland. Searchable by year, year range, locations, companies involved, causes, results, and relation to a certain development. Links are provided to related published reports such as accident investigation reports. *Verdict: Very useful*
RAIB & RAIU	The railway Accident Investigation Branch and its equivalent in Ireland provide free accident investigation reports. The website is not as easy to search as the national railways archive so it is recommended to find the incidents through this. Provides technical information. *Verdict: Very useful*
BBC News website	News reports on incidents were found to be useful in identifying new incidents and giving qualitative descriptions. Although they did not provide any technical information, they were helpful in pin pointing the dates of the incidents. *Verdict: Useful, good starting point*
New Civil Engineer (NCE)	NCE articles were of similar use to the BBC pages but provided slightly more technical information *Verdict: Useful, good starting point*
Rail News & Railway Magazine	Similar use to BBC News website.
Local government/Council	Provides more qualitative information, often a good source of

websites	photographs.
Published Research Papers	Provide technical information regarding specific incidents. Found to be very useful when available. *Verdict: Very Useful*
Previous reports carried out by JBA Consulting, often for the Environment Agency or the RSSB.	Useful source of technical information, full descriptions of events and in depth review of the mechanism and/or rainfall and flooding events. *Verdict: Very useful*
Scour Assessment Reports (JBA)	Where scour or general assessment reports have been carried out by JBA these are a useful source of information regarding the scour rating and technical details of the structure. *Verdict: Useful*

It is thought that the search has identified most of the major incidents which have taken place over the past 10 years.

There is a large degree of variability between the amount of information available for incidents, some have had detailed technical reports carried out whereas others receive merely a passing comment in a newspaper article.

3.2.1 Data source matrix

Identifying what information should be included in the failure incident database was done in two steps. Firstly, the previous database was used as a starting point. JBA personnel with experience in the sector were then asked to identify the information they thought would be useful for inclusion in the database. The information was categorised as shown in Table 4.

A matrix of specific data sources is shown in Table 4.

Table 4: Information sought

Information category	Details	
Basic Information	Date River Location OS NGR Type of Structure Use	Failure mechanism Description of event Damages Injuries Fatalities Source
Bridge Information	Line/Route Name ELR Number Date of Construction Original	Construction Date of Reconstruction Type of Reconstruction Span Width (m) Foundation Depth
Weather and Rainfall Data	Total Daily rainfall depth (mm) Storm Return period Antecedent conditions EA River level gauge Proximity to watercourse (to identify flooding cause) Drainage data	Whether there has been a recent scour assessment. Whether the location is in the flood risk database. Cost and disruption periods. Comments
Flood and Scour Information	Flow (m3/s) Flow return Period	Scour Rating Peak Water Level

Table 5: Data Sources- technical information

Data Source	Description of source	Accuracy and reliability of source	Owner of source	Comments
Scour, assets, failures				
Railways Archive	Failure reports	Not all incidents included	Railways Archive	
News Reports	Internet searches for news reports	Not all incidents included		Lack of technical information
New Civil Engineer (NCE) magazine	Incidents included as news items	Not all incidents included		Some technical information
Weather and Rainfall Data				
EA/NRW	Rainfall and river flow data	Good	EA/NRW	
Hi-Flows UK	Flood peak data	Good	EA	
NRFA	River flow data	Good	CEH	
Retaining walls				
CIV28	Database of failures, includes impact reason	Not detailed, no river flow/rainfall data included	Network Rail	Earthwork failures only
Railways Archive	Failure reports	Not all incidents included	Railways Archive	

4 Methodology

4.1 Bridge Incident Reviews (BIRDIEs)

Bridge Incident Review Documents Investigating Extremeness, or *BIRDIEs*, are the reporting methodology adopted from previous work for the RSSB, originally developed by Dr Duncan Reed. The BIRDIEs consist of a loose structure which is adapted depending on the available information.

The previous RSSB (2004) study reviewed historic incidents. As the current study investigates more recent events a slightly different approach has been adopted with the focus on two questions:

1. What is the flood and rainfall frequency for the failure event?
2. Have there been greater flooding events in the past which the structure survived?

The second question leads into an investigation into the failure mechanism of the incident, so that the reasons for its current failure can be identified where the structure has survived greater flood events.

The BIRDIE structure and format is shown in Table 6. For example, where available, a historic review of previous flood events has been included in the flood event rarity section to put the event in a larger historic context.

Table 6: Headings included in previous study BIRDIEs (RSSB, 2004)

Sections	Subsections
Header information	[Map from FEH CD-ROM 1999]
Miscellaneous notes	
JBA entry	
Tabular information	Table 1: Notes on subject catchment and possible donor catchments
	Table 2: FEH catchment descriptors
	Table 3: List of gauges potentially operating in year of incident (by RAINMASTER)
Notes from *British Rainfall* yearbook and rainfall archives	Rainfall depths
	Rainfall profile
	Antecedent condition
	Impacts
Other extracts	Books/reports
	Newspapers
	Web sources
	Maps
Rarity assessments	Rainfall rarity
	Flood rarity
Verdict	
Classification	
References	

In addition to these headings a summary page has been included for each BIRDIE which includes the following information:

- Event Description
  - A short, qualitative description of the event
- Incident & Gauge data
  - A map showing gauge and incident location, as well as flood and rainfall frequency estimates obtained for the gauges.
  - List of gauging station data available, including length of record
- Estimate Certainty
  - Comment on the certainty of the estimate, including the gauges and methods used.

4.2 Probability classification system

For consistency with the previous study the same classification system is adopted for expressing the rarity of the hydrological or meteorological events associated with failure incidents. This categorical approach was taken in view of the considerable uncertainty in assessments of event rarity, in particular for the earlier historic events reviewed in RSSB (2004).

The classification scheme is shown in Table 7. These categories were chosen in the original study in the context of rail-bridge flood safety. Due to the uncertainties in the assessments the incidents are often classed as having a return period of greater or less than 100 years.

Table 7: Classification of failure events

Category	Associated flood return period (years)
Not induced by fluvial flood	N/A
Flood-assisted failure, but a relatively minor flood	2, 5, 10, 20
Induced by a relatively rare flood	50, 100
Induced by a rare flood	200, 500
Induced by an exceptionally rare flood	1000, 2000, 5000

4.3 Event probability assessments

4.3.1 Data

For failure incidents where a nearby river gauge was identified, gauged flood data was used to obtain annual maximum (AMAX) peak flow series. Where available the AMAX series were directly obtained from Hi-flows UK, a publicly available database of peak flow data for around 1000 river flow stations around the UK (Environment Agency, 2013).

Where the relevant river gauge was not included in the Hi-flows database, the AMAX series was derived from 15-minute instantaneous flow data provided by the Environment Agency.

4.3.2 Flood Estimation Handbook frequency estimation

For the more recent events reviewed in this update, Flood Estimation Handbook (FEH, Institute of Hydrology, 1999) methods could be applied where relevant rainfall or river measurements could be found. Where 15 minute rainfall data is available the start and end point of the rainfall event are identified through visual examination of the (plotted) data. The total depth and duration of the event can then be calculated. The FEH rainfall Depth-duration method is applied to obtain a rainfall rarity assessment for the catchment. Flow data were analysed using FEH statistical methods based on fitting parametric extreme value distributions.

Flood frequency estimation is subject to uncertainties relating to the quality, geographical distribution and length of gauged records, and also possible changes in climate, river channel or catchment. Therefore it is recognised that the rarity assessment will only ever be as robust as the data and sampling techniques used. Site specific limitations, brought about by representativeness and accuracy of the gauges and their catchments are discussed within the BIRDIEs.

4.3.3 Use of historic data

Bayliss and Reed (2001) discussed use of historical evidence in flood frequency analysis. A rank-based probability analysis can be used to obtain a flood frequency estimate from qualitative historic accounts of flood events such as can be found in newspaper archives. This allows the assessment to be extended beyond river gauge records, which generally tend to start in the 1960/70s. Historic data can be found for flood events as far back as the 1800s. The Gringorten formula is a well known plotting position formula used to calculate the exceedance probability from ranked data (Shaw, Beven, Chappell, & Lamb, 2011). The exceedance probability, P(X) is estimated as

$$P(X) = \frac{r - 0.44}{N + 0.12}$$

where r is the rank position of the data and N is the size of the data period. The formula overcomes the problem that when N is not large, r/N is not a good estimator.

It is important to be aware of the authenticity and relevance of historic sources. For historic data to be useful for a Gringorten analysis it should include information regarding the date of the event, the location (ideally naming the tributary and location) and some information allowing the event to be ranked. This would ideally be the peak flow but may have to extracted from the historic record in less direct ways, for example from comparisons made to other floods in the historic extract.

Ideally it would be possible to extract the river flow from the historic data sets so that this can be linked to the AMAX series for the gauged period. Another option which could be considered for linking the two sets of data would be by looking at gauged rainfall data for the site, as some records date back over the historic period. Obtaining this information, however, was beyond the scope of this project. As it was not therefore possible to obtain detailed flood frequency estimates from the historical data, the historical information was instead simply listed in an estimated ranked order so that the floods which caused bridge failure incidents can be placed in a wider historic context.

The Gringorten formula is approximately quantile-unbiased (i.e. performs well when estimating flood magnitudes of a given frequency) for samples drawn from a Gumbel distribution (NERC, 1975). It relies on the use of a complete, uninterrupted dataset. In practice gauged records are often subject to periods of missing data for various reasons. In this study these datasets are used as the benefit of using a larger historical dataset (rather than excluding any periods containing missing data) outweighs the errors introduced due to missing data points.

Determining the length of the dataset is a great source of uncertainty in plotting position analysis when used on historic datasets. Bayliss and Reed (2001) suggest taking the start date as either a set number of years (~20) before the earliest flood record; as the period between the first and second flood record or as the average number of years between the flood events. The estimated probabilities are sensitive to choice of record length, especially for the largest few events

Ranking of historic data (from previous flood study reports) can be dubious. The ranking is often based on qualitative statements such as “the flood was the greatest in magnitude in living memory” as well as levels given on certain streets which are repeated in several records and statements concerning the recorded rainfall depth for the event. Not all historic data includes any of this information and few contain all three. Further to this it has been found that statements such as the above regarding “floods in living memory” should not be taken as being accurate for greater than approximately 20 years (Bayliss and Reed, 2001).

5 Incidents identified between 2003 and 2013

5.1 Bridge failure incidents identified between 2003 and 2013

Seventeen scour related incidents were identified in the study. These are divided into categories and listed in Table 8. The full list is shown in Table 9.

Table 8: Failure incidents

Failure and asset type	Number of incidences
Railway bridges and viaducts	6
Road and foot bridges	7
Track failures	4

Figure 8 shows a time series of the failures during the period studied. The difference between the number of incidents and number of events is accounted for by the seven Cumbrian bridge failures that occurred during the same event in 2009 (although this was not the only flood event related to a failure incident in 2009).

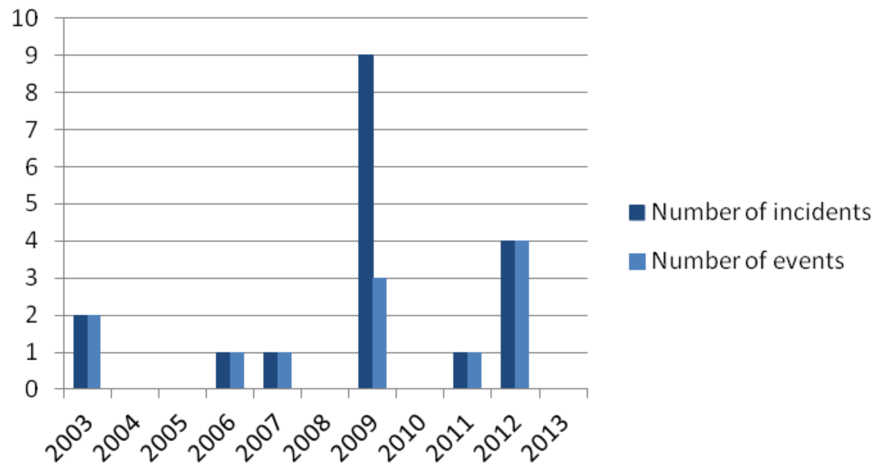

Figure 8: Counts of number of failure incidents by year, and the number of hydro-meteorological events associated with one or more failures.

Table 9 Scour related incidents between 2003 and 2013

Date DD/MM/YYYY	River	Location	Type of Structure	Use
Railway Bridges/Viaducts				
11/09/2003	Rother	Beighton	Brick arch - twin brick piers.	Rail
??/01/2003	Monk's Brook	Chandler's Ford, Hampshire	Brick arch with invert	Rail - goods line
14/11/2009	Crane	Feltham, West London	Bridge	Rail
??/12/2013	Taw	South West- Barnstaple line	Bridge and Track	Rail
01/11/2006	Burn of Winless	Watten	Bridge	Rail
21/8/2009	Broadmeadow	Malahide - Broadmeadow Estuary	Viaduct	Rail
Road/Foot bridges				
21/11/2009	Derwent	Northside Bridge, Workington, Cumbria	Bridge	Road
??/11/2009	Derwent	Northside Foot Bridge	Bridge	Foot
01/11/2009	Derwent	Calva Bridge, Workington, Cumbria (road bridge)	Bridge	Road
21/11/2009	Derwent	Camerton bridge, Workington, Cumbria (foot bridge)	Bridge	disused railway/ footbridge
??/11/2009	Cocker	Lorton Bridge, near Cockermouth	Bridge	Road
??/11/2009	Eamont	suspension footbridge near Dalemain	Bridge	Foot
??/11/2009	Newlands Beck	Newlands Beck bridge, near Keswick	Bridge	Road
Track				
18/07/2007	Multiple	Moruisg/Loch Sgamhain	Track	Rail
28/06/2012	N/A	Tebay	Track	Rail
Nov/Dec 2012	Exe	South West- Cowley bridge Junction	Track	Rail
26/11/2011	N/A	Cornwall, Bodmin and Wenford	Track	Preserved Railway

5.2 Geographical distribution

Figure 9 shows the locations of the scour failure incidents found between 2003 and 2013. It can be seen that the incidents are geographically spread out, except for the road/footbridge failures in Cumbria which occurred during the same event. This is similar to the findings of report T112. The cluster of incidents in Cumbria is not a repeat of any of the clusters found in the previous study.

The Incident in Feltham in 2009 adds to the events found in the previous study clustered around London. The only repeated event is Cowley Bridge Junction in the South West, which is known to flood on a regular basis.

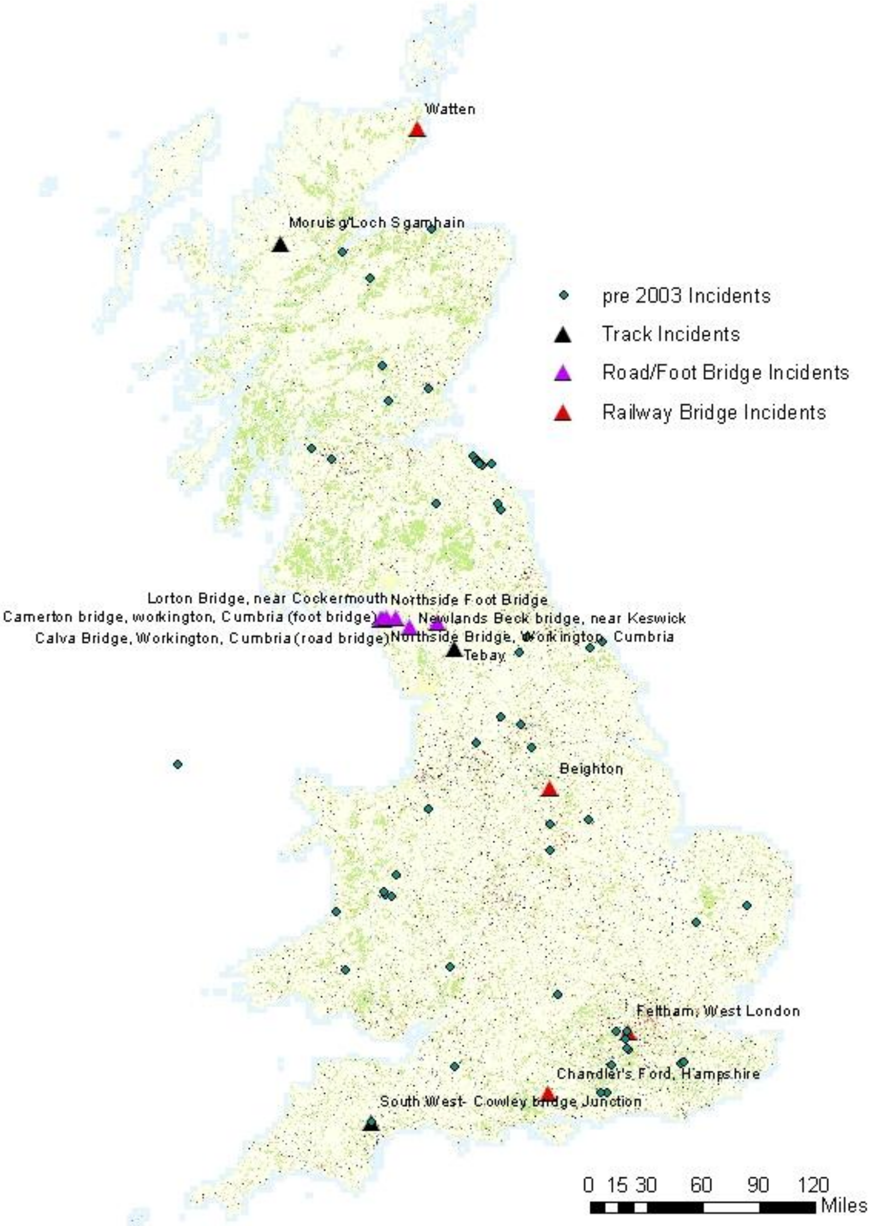

Figure 9: Incident map

5.3 Seasonality

Figure 10 shows that there is a skew of failure events towards the winter months. This is as expected as this is known to be the main flood season. However, it is in contrast to the previous RSSB (2004) study of the longer historical record, which found more scour related failures to occur in the summer months.

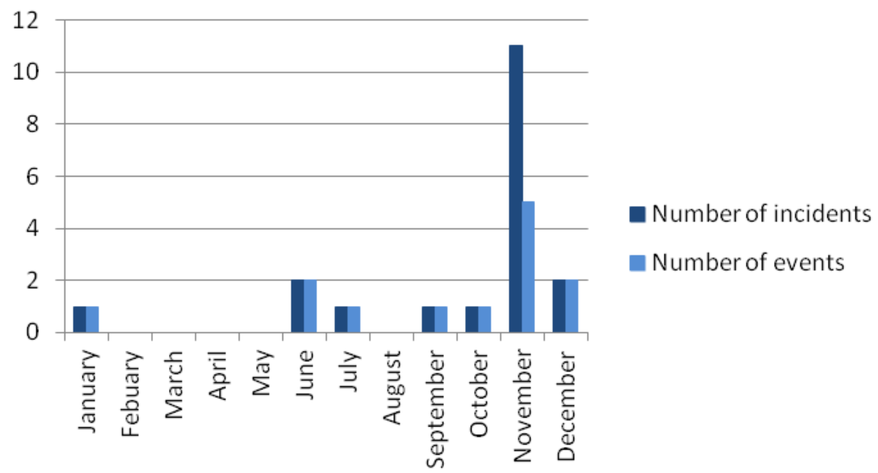

Figure 10: Count of number of failures by month

5.4 Assessments of event rarity (BIRDIEs)

Out of the 17 failure incidents identified, four were found to satisfy the criteria listed below which allowed a BIRDIE to be carried out.

- Structural Failure
- Failure caused by a flood event
- Flow and/or rainfall data available or provided by the national gauging authority

BIRDIEs were not carried out for the other incidents for several reasons:

- Four events related to track failure, which is not prioritised in the study.
- In one case the structure could not be identified from the source (a BBC news item)
- One incident was caused by scour due to tidal action rather than a weather event.
- It was not possible to obtain any flow or rainfall data for one event, although this was requested from the gauging authority.

A BIRDIE assessment was carried out for the 2009 Cumbria event associated with seven Cumbrian road and footbridge failures. This is of interest since the nearby rail bridge did not fail, but the return period assessment is not included in later analysis because of the primary focus of the study on railway bridges.

The frequency estimates and subsequent classification assigned to the failure events for which BIRDIEs were carried out are shown in Table 10.

Table 11 shows a summary of the gauge data used to carry out these estimates.

Table 10: BIRDIE frequency estimates

Date	River	Incident	Return period estimate (years) Flood: FEH	Flood: GG*	Rainfall	Classification
11/09/2003	Rother	Beighton	2-3	2-3	<1 month	Minor flood
14/11/2009	Crane	Feltham, West London	1	1		Minor flood
01/11/2006	Burn of Winless	Watten	15	32	3	Minor Flood
21/11/2009	*Derwent*	*Northside Bridge, Workington Cumbria*	*600†*	*90*		*Exceptionally rare flood.* *Not a rail bridge failure.*

**Gringorten plotting position estimate*

†Derived from a post-event analysis for the Environment Agency (JBA Consulting, Review of November 2009 Flooding in Cumbria (River Derwent Catchment) Event Analysis Report, 2010)

Table 11: Gauging stations

Incident, date	River flow gauging station used for analysis	Flow period of record	Rain gauge	Rainfall period of record
Beighton, 2003	27025 Woodhouse Mill	1960-2009	084532 Woodhouse Mill	2002-2013
Feltham, 2009	39057 Crane at Cranford park	1973-2009		
Watten, 2006	1001 Wick at Tarroul	1995-2013	97002 Thurso at Halkirk	1997-2013
Northside Bridge, 2009	75002 Derwent at Camerton	1960-2010		

Unlike with the findings of the T112 report, it can be seen that the failure events were predominantly caused by minor floods. In the previous 2004 study, only 14% of incidents fell into this category, with 80% being associated with more extreme floods (RSSB, 2004). However the events in Cumbria 2009 were associated with a more extreme flood, despite the survival of the rail bridge.

The T112 study found that the average flood rarity which caused the incidents was approximately 1/160 annual exceedance probability (RSSB, 2004). Inspection of the flood frequencies shown in Table 10 shows that this is not representative of the estimates obtained for the studied incidents.

The results do support the statement given in the previous report that "The very rare floods appear to be so destructive that is hard to imagine any reasonably economic bridge protection measure that would withstand the associated forces, other than to ensure that the bridge/culvert opening is wide enough to accommodate these floods." (RSSB, 2004).

5.5 Failure mechanisms

As for the previous study it is found that the main cause of failure due to scour is the undermining of abutments and piers. The lack of emphasis of the role of debris found in the previous study is still found to be relevant. Further to this refilling of scour holes during flood events, leading to their under judgement in scour assessments is also found to play a role in failures.

The previous study noted that numerous embankment failures due to scour were encountered. This is emulated in the current study.

The scour ratings assigned to the structures on which BIRDIEs were carried out were between 15.6 and 15.8, showing that none of them exceeded the high risk threshold of 16. The RSSB (2004) report investigated the priority rating threshold and concluded that 16.0 was an appropriate score.

5.6 Summary

In the period between 2003 and 2013, we identified 17 scour failure incidents in the UK and Ireland. Of these incidents, six related to railway bridges or viaducts.

Of the four events for which it was possible to carry out a more detailed assessment of rarity, it was found that three were attributed to relatively minor floods. As these floods events have been exceeded in previous events it seems that factors other than a peak flow alone may have contributed to failure of the structures; this could possibly include cumulative effects over time.

It was found that most failure incidents during 2003 - 2013 occurred in the winter months, which is in agreement with this being the main flooding season but in disagreement with the previous 2004 study which found more historic incidents occurred in the summer months.

6 Updated chronology of failure incidents

6.1 Consolidated list of failure incidents from 1846 to 2013

Table 12 is a consolidated list of failure incidents at railway bridges or culverts over watercourses in the UK for the period 1846 to 2013. Also included are two events in the Republic of Ireland.

The list combines data compiled in the RSSB (2004) *Report T112* with the more recent events identified in this update study.

When researching events of this type over such a long historical period there are inevitably some events for which the information in the various historical sources is ambiguous or possibly even mistaken. Whilst care has been taken in the interpretation of sources, it is possible that there could be some errors in the list presented here, particularly in situations where historical accounts are unclear about whether the failure of a structure could be attributed to flooding or scour processes.

The basic facts about the occurrence of many incidents are reasonably well established. However inferences about the rarity of the events, in particular the associated probabilities, are much more uncertain and should be regarded as indicative assessments.

6.2 Frequency of failure incidents

6.2.1 Analysis of RSSB (2004) Report T112

Report T112 estimated that there had been, historically, a 40% chance of at least one structural failure per year, and deemed this risk unacceptable.

This figure was derived from there having been approximately 60 events associated with a structural failure over a period of approximately 150 years. It was also noted that there was no evidence of this risk being reduced over time.

Based on the current re-analysis of the Report T112 data, plus the new information for 2003-2013, we can now update this estimate of failure probability.

6.2.2 Analysis of the 2003 to 2013 update

For the period covered by this update study, there have been five rail crossing failure incidents identified in the UK over 10 years, each from a separate flooding event, suggesting an annual probability of 50% or 1 in 2 years. Therefore although this is a small sample, it would not support a view that the occurrence rate or probability of such incidents is diminishing.

6.2.3 Analysis of the consolidated 1846 to 2013 chronology

Taking the consolidated records for 1846-2013 as a whole, there are 140 incidents thought to be bridge or culvert failures related to flooding over the 167 years since the first recorded incident in 1846. This includes data from UK plus two incidents in Ireland. The precise location of some of the affected structures is not known. Therefore it is not possible to be sure how many unique structures have been affected.

The development of the railways pre-dates the earliest recorded failure event (1846) in our database. In the following analysis we assume that the effective period of record over which our evidence has been sampled is the period from 1840 to 2013. The year 1840 has been adopted because this marks the establishment of HM Railway Inspectorate and just slightly pre-dates the start of the "railway mania" of the 1840s. The effective period of record for our study is therefore assumed to be 173 years.

The following analysis treats the flood incident records as a homogenous sample and therefore takes no account of changes that may have occurred since 1840s and that would affect the probabilistic interpretation. Such changes include:

- increase or decrease in the number of structures on the rail network as a result of new development or of line closures
- changes in asset management and maintenance regimes

- new design standards
- new construction practices
- changes in river catchments that could affect flood hydrology or sediment regimes
- climate change and variability
- changes in practices that affect the recording and documentation of events, including attitudes to risk or newsworthiness and evolving institutional arrangements for data collection.

Annual probability of failure incidents in the UK

We have found evidence of 138 incidents involving failures of rail bridges and culverts related to flooding during the period 1846-2013 in the UK. We have assumed that this is representative of an effective record length of 173 years from 1840 to 2013. The annual probability of a structure failure incident somewhere in the UK is therefore estimated to be approximately 138/173 ≈ 80%, or 1 in 1.25 years.

Some of the historical events were characterised by clusters of multiple structural failures within close proximity. For example in Scotland there have been several occasions when many bridges and culverts were washed out apparently as a result of the same underlying flood event (16 structures in one event in 1915, 16 culverts in Lochaber in 1962, another 8 bridges and culverts washed out in Lochaber in 1969, amongst other events). It is possible that some structures may have failed more than once historically, although we cannot be sure.

Annual probability of flood events associated with failure incidents in the UK

We have identified 68 flood events in which one or more rail bridge or culvert failures occurred. Assuming an effective period of record of 173 years, the annual probability of observing a flood event in which one or more structures fails is therefore estimated to be 67/173 ≈ 39%, or 1 in 2.6 years. This is consistent with the analysis in 2004's *Report T112.*

Probability of a year containing failure incidents in the UK

For the consolidated record up to 2013, there are 47 years during which one or more structure failure incidents were observed somewhere in the UK.

The probability of a year being one in which one or more such events occur is therefore approximately 27%, or 1 in 3.7 years.

Table 12: Consolidated list of railway bridge or culvert failure incidents related to flooding between 1846 and 2013

Number of structures	Day	Month	Year	Watercourse	Approx location(s)	Country	Flood history?	Estimated return period
1		Feb	1846?	River Sheppey	Charlton Viaduct, near Shepton Mallet	England		
1	20	Jan	1846	River Medway "backwater"	Between Tonbridge and Penshurst, Kent	England	Y	
9	29	Sep	1846	Eye Water, Tower Burn, Tyne	Grantshouse, Cockburnspath, East Lothian	Scotland	Y	
2	8	Jul	1847	River Camel	Near Dunmmer Bridge, Bodmin, Cornwall	England		
1	30	Aug	1866	River Esk	Between Grosmont and Whitby, Malton and Whitby Line	England		
1	16	Nov	1866	River Aire	Apperley, West Yorkshire, Midland Railway Leeds to Lancaster Line	England	Y	65
2		Feb	1868	River Severn	Caersws, Central Wales Line	Wales	Y	
1	13	Nov	1869	River Tees	Darlington, County Durham, Merrybent Railway Company	England	Y	13
3 (?)	17	Jul	1880	Afon Wnion	Near Dolgellau, Bala, exact locations unknown	Wales		
1		Mar	1881	Unnamed stream	Ladmanlow, near Buxton, Cromford and High Peak Railway	England		
1			1881	Solway Firth Viaduct	Failure of piers as a result of ice pressure after a history of problems	Scotland		
1		Nov	1882	Nant Burn	Near Taynuilt Station, Callander and Oban Railway	Scotland	Y	

Number of structures	Day	Month	Year	Watercourse	Approx location(s)	Country	Flood history?	Estimated return period
3	14	May	1886	River Teme	Near Bransford (Worcester) and between Ludlow and Craven Arms on the Hereford and Shrewsbury Line	England		
1		Dec	1886	River Thames	Osney, near Oxford	England		
1	26	Dec	1886	Trib of River Rother	Selham, West Sussex, Midhurst Branch of London, Brighton and South Coast Railway	England		
1		Aug	1891	Black Brook	Chorley, Lancashire, Chorley to Blackburn (Cherry Tree Line)	England	Y	
3	21	Sep	1891	Gala Water	Galashields	Scotland	Y	30
1		Aug	1912	River Tas	Between Forncett and Flordon, Norfolk	England		
1		Aug	1912	River Stiffkey	Fakenham, Norfolk	England		
1	15	Jun	1914	Baddengorm Burn	Aviemore to Inverness, near Carrbridge Station, Highland Rlwy	Scotland	Y	1000
16	26	Sep	1915	Findhorn and Spey Valley	Highland Railway	Scotland		
4	8	Jul	1923	Bogbain Burn	Near Carrbridge	Scotland	Y	2000
1	9	Jun	1924	River Erewash	Pye Bridge, Ripley, Erewash Valley Line	England	Y	
3	23	Jul	1930	River Esk	Glaisdale, Esk Valley Line	England	Y	1000
1	4	Sep	1931	River Esk	Glaisdale, Esk Valley Line	England	Y	500
1	21	Jun	1936	Mochdre Brook	Dulais Bridge, near Glandulais, Newtown, Powys	Wales	Y	100

Number of structures	Day	Month	Year	Watercourse	Approx location(s)	Country	Flood history?	Estimated return period
1	7	Sep	1945	Llangollen Canal	Sun Bank Halt, GWR Llangollen Line	Wales		
1	12	Aug	1946	River Blackwater	Railway Bridge at Ballymaquirke, near Kanturk	N. Ireland		
1		Mar	1947	River Wye	Strangford Viaduct, near Fawley, Hereford to Gloucester Line	Wales	Y	100
1	12	Apr	1947	Eastburn Beck	Eastburn Bridge, between Skipton and Keighley, Yorkshire	England		
9	12	Aug	1948	River Eye	Harelawside Bridge, Smiddy Bridge, Mason's Bridge, Free Kirk Bridge, Eyemouth Viaduct and others Between Dunbar and Berwick, East Coast main line	Scotland	Y	500
1	12	Aug	1948	Birns Water	Between Humbie and Gifford, possibly Gilchriston.	Scotland	Y	500
1	12	Aug	1948	Wooler Water	Wooler (Haugh Head), Northumberland	England	Y	200
1	25	Oct	1949	Wooler Water	Wooler (Haugh Head), Northumberland	England	Y	111
1	26	Oct	1949	Lilburn Burn	Near Lilburn Tower, Northumberland	England		
1	19	Nov	1951	Midhurst Stream	Between Cocking and Midhurst, West Sussex	England	Y	100
2		Oct	1954		Exact Location unknown. Culverts collapsed near Coniston, Cumbria	England		
1		Oct	1954	River Derwent	Bridge between Cockermouth and Workington	England		

Number of structures	Day	Month	Year	Watercourse	Approx location(s)	Country	Flood history?	Estimated return period
1	8	Dec	1954	River Tolka	Great Northern main line to Belfast, half a mile from Dublin terminus	Ireland		
1	30	Sep	1960	River Creedy (or Exe)	Cowley Junction	England		
16		Feb	1962		16 culverts washed out near Lochaber, exact locations unknown	Scotland		
1	12	Dec	1964	River Ystwyth	Llanilar, near Aberystwyth, Cambrian Railway	Wales	Y	30
1	12	Dec	1964	River Banwy	Castle Caereinion	Wales	Y	30
1	9	Jul	1968	River Chew	Viaduct near Pensford, Somerset	England		
1	15	Sep	1968	River Wey	Between Farncombe and Godalming,	England	Y	200
1	15	Sep	1968	River Mole	Cobham	England	Y	200
1		Sep	1968	River Kennett	Nuns Wood, between Kennett and Higham, Newmarket	England	Y	200
1		Sep	1968	Trib of R. Waveney	Bridge 317, Norwich Ipswich Main Line, between Diss and Burston	England	Y	200
8	10	Aug	1969		Lochaber, 2 bridges and 6 culverts washed out, exact locations n/a	Scotland		
1	31	Aug	1973	Glen Finnan	Fort William to Mallaig Line, bridge 313/051 Drumsallie	Scotland		
1	27	Dec	1979	Nant Rhyd-y-Car	Culvert near Merthyr Tydfil (exact location unknown)	Wales		
1			1985	River Deben	Whickham Market, East Suffolk Line			

Number of structures	Day	Month	Year	Watercourse	Approx location(s)	Country	Flood history?	Estimated return period
2	19	Oct	1987	R. Towy and R. Dulais	Glanrhyd and Llanwrda, Central Wales Line	Wales	Y	50
1	10	May	1988	Colne Brook	Wraysbury, bridge No. 71, Staines - Windsor Line	England		
1	7	Feb	1989	River Ness	Ness Viaduct near Inverness	Scotland	Y	100
1	2	Jan	1991	Afon Twymyn	Cemmaes Road	Wales		
3	14	Jan	1993	Rivers Tay, Earn and May	Dalguise, Forgandenny, Forteviot (10km SW of Perth)	Scotland	Y	100
1		Jan	1994	River Severn	Cilcewydd, between Welshpool and Newtown	Wales		
1		Oct	1997	Ettrick Water	Heatherlie Bridge near Selkirk (disused line)	Scotland		
1	15	Oct	1998	Trib of R. Leven	Renton (Balloch), near Dunbarton	Scotland		
1	8	Dec	2000	River Exe	Cowley Junction, bridge carrying Barnstaple Branch	England		
1		Oct	2000	River Taw	Weir Marsh Bridge	England		
1	3?	Oct	2002	River Tay		Scotland		
1	14	Jun	2002	River Irwell	Lower Ashenbottom Viaduct, near Rawtenstall, Greater Manchester	England	Y	100
1		Dec	2002	Monks Brook	Between Eastleigh East Junction and Romsey Junction, at Chandlers Ford	England		
1	11	Sep	2003	River Rother	Beighton	England	Y	2

Number of structures	Day	Month	Year	Watercourse	Approx location(s)	Country	Flood history?	Estimated return period
1	1	Nov	2006	Burn of Winless	Watten	Scotland	Y	15
1	21	Aug	2009	Broadmeadow	Malahide - Broadmeadow Estuary	Ireland		
1	14	Nov	2009	River Crane	Feltham, West London	England	Y	1
1		Dec	2012	River Taw	Barnstaple line	England		

Notes

**Road and foot bridges damaged or collapsed (railway bridge survived)*

"Flood History" indicates that an analysis of the rarity of the associated flood event was carried out (referred to as BIRDIEs, see Section 4).
Some BIRDIE studies were unable to find enough information to estimate a flood event return period, in which case the Return Period column is left blank.

7 Recommendations

The present study updates and appears broadly to confirm the findings of the earlier RSSB (2004) historical study. The recommendations from the 2004 work therefore continue to be relevant. These were summarised as follows:

> *"A risk priority score of 15.0 would be appropriate for a 250-year flood event, and in view of the age profile of railway structures, this is highly relevant. The risk assessment method could be improved at little additional cost. Also the collection and recording of information on damage incurred and water levels reached after a flood will be valuable in developing effective management procedures.*
>
> *[Report T112] also recommend[s] that enhancements to the existing EX2502 scour assessment procedure should be considered, if it is to cover the full range of flood-related risks (e.g. build up of debris within the watercourse and impounding of water behind embankments) and all the types of structure maintained by railway operators*."

The occurrences of embankment failure due to scour during the period 2003 to 2013 imply that this issue should be further investigated, especially where track damage has caused derailment of trains. It would be interesting to investigate the balance between frequency of occurrence and impact of the incidents for embankment and structural failures. It may be found that although structural failures have a greater impact in terms of direct costs, the more frequent track damage caused by scour may have a greater impact in terms of the aggregated disruption to services.

8 Dissemination and updates

8.1 Contact for further information

This report and supporting information can be obtained from the JBA Trust website: www.jbatrust.org

The flood and scour incident database and BIRDIE reports are available for research purposes. Please contact the JBA Trust via the JBA Trust website “Contact Us” page to request further details.

8.2 Updates

We would be pleased to hear about any further information sources that could help in improving the historical records for future updates. Please contact us at www.jbatrust.org as above if you have any further information that you would like to tell us about.

9 References

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10 Web based resources

Information	Available at
Online resource of archived railway information including a searchable database of accident and incident reports	www.railwaysarchive.co.uk
RSSB Report: *Infrastructure Integrity (4) Research Theme : Project Number T112 Scour & Flood Risk at Railway Structures (2004)*	Available via http://www.sparkrail.org
HiFlows-UK (flood peak data at river flow gauging stations in the UK)	http://www.environment-agency.gov.uk/hiflows/91727.aspx

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