

Good Practice Guide

Cross-Country Pipeline Flood Risk Identification

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Comments, questions, and enquiries about this publication should be directed to:

UK Onshore Pipeline Operators' Association

Ripley Road
Ambergate
Derbyshire
DE56 2FZ

E-mail: secretary@ukopa.co.uk

Website: www.ukopa.co.uk

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ACRONYMS AND ABBREVIATIONS

AGM	Above-Ground Marker
BGS	British Geological Survey
BS	British Standard
CFR	Code of Federal Regulations
CIRIA	Construction Industry Research and Information Association
CP	Cathodic Protection
DEFRA	Department for Environment, Food and Rural Affairs
DEM	Digital Elevation Model
DfI	Department for Infrastructure (Northern Ireland)
EA	Environment Agency
EIA	Environmental Impact Assessment
EM	Electromagnetic
FAWRG	Fault and Risk Assessment Working Group
FRA	Flood Risk Assessment
GIS	Geographic Information System(s)
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPG	Good Practice Guide
GPR	Ground Penetrating Radar
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HSE	Health and Safety Executive
IGEM	Institution of Gas Engineers and Managers
ILI	In-Line Inspection
ISO	International Organization for Standardization
IMU	Inertial Measurement Unit
JNCC	Joint Nature Conservation Committee
LIDAR	Light Detection and Ranging
MAGIC	Multi-Agency Geographic Information for the Countryside
MCZ	Marine Conservation Zone
NaFRA2	National Flood Risk Assessment (version 2)
NIEA	Northern Ireland Environment Agency
NLD	National Landslide Database
NNR	National Nature Reserve
NPPF	National Planning Policy Framework

NRW	Natural Resources Wales
OS	Ordnance Survey
PHMSA	Pipeline and Hazardous Materials Safety Administration
PSR	Pipelines Safety Regulations
ROW	Right-of-Way
SAC	Special Area of Conservation
SEPA	Scottish Environment Protection Agency
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
UKCP18	UK Climate Projections 2018
UKOPA	UK Onshore Pipeline Association
VIV	Vortex-Induced Vibration
WFD	Water Framework Directive

1 INTRODUCTION

1.1 Background

Across the UK, approximately 23,000 km of hydrocarbon pipelines run through both urban and rural areas. These pipelines are usually buried to depths of around one metre, though burial depth can be shallower, and pipelines may become visible at surface water crossings.

Flooding is an increasingly important hazard for pipelines in the UK. Climate change is driving more frequent and intense rainfall events, elevated river flows, and greater pressure on drainage systems. Although buried pipelines are out of sight, they can still be damaged during floods. Fast-moving water can remove soil cover and expose pipeline sections, while saturated ground—particularly on slopes—may trigger landslides or subsidence that affect pipeline stability. Coastal surges and high tides can inundate normally dry ground near shorelines, and fluctuating groundwater levels can in certain instances accelerate pipeline corrosion. Additionally, flooding can restrict access to pipeline infrastructure such as valves or above-ground items.

Once exposed or inadequately buried, pipelines become more vulnerable to bending, fatigue, and impact damage, increasing the likelihood of rupture or leakage. Floodwaters can also spread released hydrocarbons over a large area, increasing environmental impacts. Effective flood risk assessment and mitigation are therefore essential for pipeline operators to maintain safety, protect the environment, and ensure continuity of supply. Proactive management reduces risk to people, the environment, assets, property, and business operations in the event of flooding.

This Good Practice Guide (GPG) has been prepared for the UK Onshore Pipeline Operators' Association (UKOPA) Fault and Risk Assessment Working Group (FARWG). It applies to onshore cross-country hydrocarbon pipelines across England, Wales, Scotland, and Northern Ireland.

The flooding considered includes from surface waters (including canals) and the sea, pluvial flooding from heavy rainfall, groundwater flooding, and emergency discharges from reservoirs managed by water companies.

1.2 Objective

The aim of the GPG is to provide a structured approach for identifying flooding hazards relevant to cross-country hydrocarbon pipelines, and although focussed on buried pipelines, is also considered applicable to above-ground pipelines. The guidance is non-prescriptive and focuses on how an operator may want to attempt to quantify the flood hazard, location-specific vulnerability, and receptor consequence, in order to identify relative differences in risk across a given pipeline extent. This enables operators to identify areas of pipeline that may require further investigation or prioritisation for mitigation.

Figure 1.1 is a flowchart that summarises the GPG approach to identifying flood risk along a pipeline.

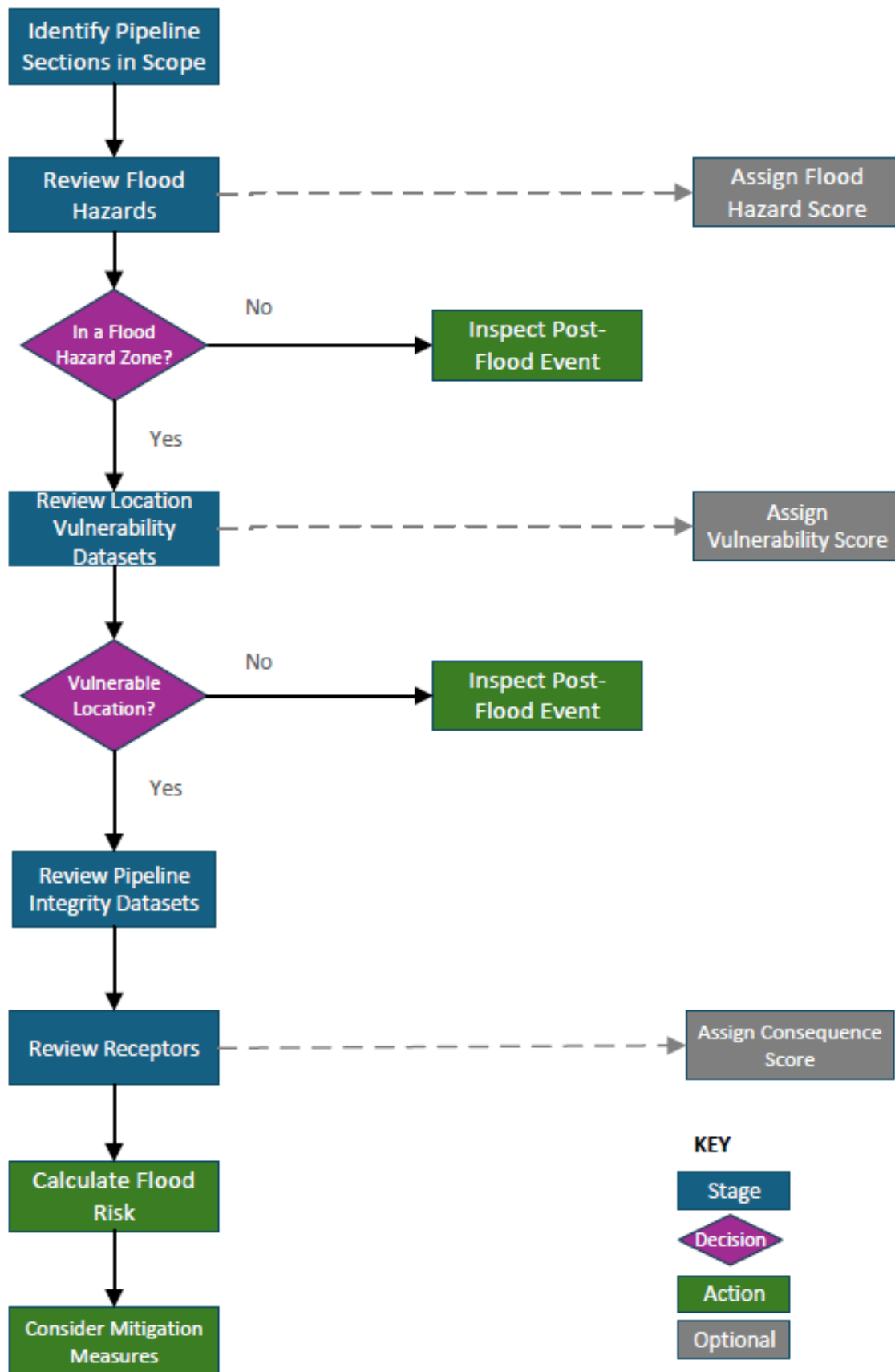


Figure 1.1 – Flowchart of Risk Prioritisation Process

This GPG sets out how to:

- Assess flood-related hazards and location-specific vulnerabilities;
- Consider the potential consequences of a flood-related incident;
- Identify the risk-profile of pipeline assets; and
- Consider potential mitigation actions.

Risk identification involves understanding the likelihood of flooding, the influence of local vulnerabilities such as soil type and slope, the surrounding receptors potentially affected by a release, and available data relating to pipeline integrity.

Identifying Flood Risk: Section 0 discusses how publicly available datasets from the Statutory Authorities can be used to identify where different types of flooding may occur along the pipeline route. These datasets inform the likelihood of a flood-related failure.

Vulnerability of Pipeline from Flooding: Section 0 considers location-specific factors that influence vulnerability, independent of flood probability. Key parameters include soil type, ground slope, and depth of cover. Publicly available resources—such as national soil, superficial geology, and topographic (slope) maps—support this assessment across the UK. Depth-of-cover data is expected to be obtained directly from operators. These factors contribute to the likelihood of a flood-related failure.

Pipeline Integrity: Section 4 describes the operator-held datasets that provide further insight into pipeline vulnerability. These typically include information on construction materials, age, corrosion, wall thickness, bends, remedial or replacement works, slabbing or other engineering controls, inspection frequency, and maintenance actions (completed or outstanding). These integrity datasets also contribute to the likelihood of a flood-related failure.

Consequence of Failure: Section 5 evaluates the potential impacts of a release at the point of failure, considering local population, infrastructure, and environmental receptors. The first step is identifying the hydrocarbon type and release phase (liquid or gas).

For hydrocarbons that are released in the gas phase or volatilise, the primary concern is ignition and the resulting thermal radiation, which may affect people and combustible receptors such as vegetation. For liquid releases, environmental consequences are assessed for designated habitats, agricultural land, surface waters, fishing and aquaculture areas, and groundwater. Consequences may also need to factor in the built environment (for instance damage to highway infrastructure) or where access/inhabitation is restricted following a release.

Detailed assessment of operational and business-continuity impacts are not included in this GPG. However, operators may wish to consider potential costs associated with supply interruption, remediation, pipeline replacement, and loss of revenue. Reputational impacts and possible regulatory fines may also be relevant to the overall consequence assessment.

Flood Risk Prioritisation: Section 6 combines the likelihood and consequence information and enables operators to understand the flood-related risk profile along the length of its pipeline. The completion of the risk prioritisation will help highlight critical “hotspots” that may require further investigation or mitigation.

Identify Mitigation Options: Section 7 provides guidance on typical measures to reduce flood risk, such as enhanced monitoring, physical protection of pipelines, operational controls, and emergency response planning.

1.3 Legislative, Regulatory and Consent Requirements

In the UK, multiple agencies and regulations govern flood risk management. **Error! Reference source not found.** outlines the applicable legislation, regulatory and consent requirements affecting work on watercourses, estuaries and floodplains in the UK. However, users should consult a competent legal authority for definitive advice.

Pipeline operators must also comply with the Health and Safety Executive's (HSE) Pipelines Safety Regulations (PSR) 1996 ¹ which mandate safe design, operation, and maintenance of pipelines – including consideration of external hazards like flooding and ground movement. Industry standards (e.g. IGEM/TD/1 [1] for gas pipelines and BS PD 8010 [2] for pipelines on land) recognise flood and erosion threats and provide design guidance.

¹ <https://www.legislation.gov.uk/uksi/1996/825/contents/made> (Accessed 10/09/2025)

Issue	England	Wales	Scotland	Northern Ireland
Public safety and emergency planning	Civil Contingencies Act 2004			
Health and safety at work	Health and Safety at Work etc Act 1974 Construction (Design and Management) Regulations 2015			Health and Safety at Work (NI) Order 1978 Construction (Design and Management) Regulations (Northern Ireland) 2016
Flooding	Flood and Water Management Act 2010	Flood Risk Management (Scotland) Act 2009	Water Environment (Floods Directive) Regulations (NI) 2009	
Land drainage	Water Resources Act 1991 Land Drainage Acts 1991 and 1994		Drainage (NI) Order 1973 (as amended)	
Work in watercourses		Water Environment (Controlled Activities) (Scotland) Regulations 2005		
Works on, under, or over the seashore lying below the high water mark of ordinary	Coastal Protection Act 1949			
Habitats and protected species	Wildlife and Countryside Act 1981			Wildlife (NI) Order 1985
	Conservation of Habitats and Species Regulations 2010	Conservation (Natural Habitats etc.) Regulations 1994		Conservation (Natural Habitats etc.) Regulations (NI) 1995
Water Framework Directive (WFD)	Water Environment (WFD) (England and Wales) Regulations 2003	Water Environment and Water Services (Scotland) Act 2003 Water Environment (Controlled Activities) Regulations 2005 (as amended)		Water Environment (WFD) Regulations (NI) 2003
Fisheries	Salmon and Freshwater Fisheries Act 1975 Eel (England and Wales) Regulations 2009	Salmon and Freshwater Fisheries (Consolidation) (Scotland) Act 2003 Council Regulation (EC) 1100/2007		Fisheries (amendment) Act (NI) 2001 Eel Fishing Regulations (NI) 2010
Waste	Environmental Permitting Regulations 2010 Waste (England and Wales) Regulations 2011	Waste Management Licensing (Scotland) Regulations 2011		Waste Management Licensing Regulations (NI) 2003
Planning permission	Town and Country Planning Act 1990	Town and Country Planning (Scotland) Act 1997		Planning (NI) Order 1991

Issue	England	Wales	Scotland	Northern Ireland
<i>Permitted or exempted development</i>	Town and Country Planning (General Permitted Development) Order 1995		Town and Country Planning (General Permitted Development) (Scotland) Order 1992	Planning (General Development) Order (NI) 1993
<i>Environmental impact assessment</i>	Town and Country Planning (EIA) Regulations 1999 EIA (Land Drainage Improvement Works) (amendment) Regulations 2006		Town and Country Planning (EIA) (Scotland) Regulations 2011	Drainage (Environmental Impact Assessment) Regulations (NI) 2001
<i>Flood risk assessment</i>	National Planning Policy Framework [3] Technical Advice Note 15 [4]		Scottish Planning Policy [5]	Water Environment (Floods Directive) Regulations (NI) 2009

Table 1-1 - Legislation, Regulatory and Consent Requirements

1.4 Example Pipeline Route

Throughout this guidance an example pipeline route we will be used to help visualise the use of this guidance document, which includes reviewing flood hazards, location-specific vulnerabilities, consequence layers, and ultimately the overall pipeline risk for prioritisation.



2 IDENTIFYING FLOODING HAZARDS

This section outlines the types of flooding and the data sources for evaluating flood hazard along a pipeline route in the UK.

The Statutory Authorities across Wales (NRW), England (EA), Scotland (SEPA), and Northern Ireland (Rivers Agency and Northern Ireland Environment Agency (NIEA)) typically define the following type of flooding;

- Fluvial – flooding from rivers
- Coastal – flooding from estuaries and the coast
- Pluvial - surface water flooding from intense rainfall
- Groundwater – flooding from rising water table
- Impoundment – typically from reservoirs, dams and canals

Using data that provides the probability of different types of flooding, the operator can identify which sections of pipeline are located in zones of increased flooding likelihood. Additionally, to further filter the pipeline sections of focus, the operators may consider quantifying the flooding likelihood of the different types of flooding. For example, this can be achieved through developing an overall flood hazard score, ranging from 0 to 10 which is comprised of individual flood scores for fluvial (0-2), coastal (0-2), pluvial (0-2), groundwater (0-2), and reservoir / dam / canal flooding (0-2). The approach to scoring these different flood possibilities is detailed in the subsections below.

2.1 Flood Events

The Statutory Authorities provide freely available datasets for most of the flooding types. The groundwater flooding dataset from the British Geological Survey (BGS) is, however, only available through paid access. In most instances, the datasets are available in Geographic Information Systems (GIS) format.

2.1.1 Fluvial Flooding

Table 2-1 presents the fluvial flood classification across the UK along with a proposed flood hazard quantification score.

Fluvial Flood Likelihood per Year	Wales	England	Scotland	Northern Ireland	Suggested Flood Hazard Score
Very Low	< 0.1%	< 0.1%	< 0.1%	< 0.1%	0
Low	0.1 - 1%	0.1 - 1%	0.1 – 0.5%	0.1 – 0.5%	0.5
Medium	1 – 3.3%	1 – 3.3%	0.5 – 10%	0.5 – 10%	1
High	> 3.3%	> 3.3%	> 10%	> 10%	2

Table 2-1 - Fluvial Flooding

Water Crossings

In addition to the likelihood of fluvial flooding, the pipeline operator should identify all points where the pipeline crosses a river, stream, ditch, or drain. Even small watercourses (like field ditches or drainage channels) can flood or cause erosion which could affect a pipeline or pipeline support. It is also

recommended that operators identify sections of pipeline that run parallel to and in close proximity (e.g. <50 m) to surface water courses, as lateral riverbank erosion could affect these sections of pipeline.

In terms of flood hazard quantification, it is proposed that a fluvial flood hazard score of 2 be assigned to water crossing points, and a score of 1 for pipeline sections located within 50 m of a watercourse.

2.1.2 Coastal Flooding

Table 2-2 presents the coastal (including estuaries) flood classification across the UK along with a proposed flood hazard quantification score.

Apart from inundation risks, coastal flooding and erosion can undermine pipelines formerly on dry land by shifting coastlines. The pipeline operator should note any pipeline segments within low-lying coastal zones vulnerable to storm surge or sea level rise.

Coastal Flood Likelihood per Year	Wales	England	Scotland	Northern Ireland	Suggested Flood Hazard Score
Very Low	< 0.5%	< 0.5%	< 0.1%	< 0.1%	0
Low	0.5 - 1%	0.5 - 1%	0.1 – 0.5%	0.1 – 0.5%	0.5
Medium	1 – 3.3%	1 – 3.3%	0.5 – 10%	0.5 – 10%	1
High	> 3.3%	> 3.3%	> 10%	> 10%	2

Table 2-2 - Coastal Flooding

2.1.3 Pluvial Flooding

Table 2-3 presents the pluvial flood classification across the UK along with a proposed flood hazard quantification score.

It should be noted flash flooding is related to the speed of onset of the flooding, rather than the type/cause, such as fluvial or pluvial. The pluvial flood datasets maps are explicitly designed to represent flooding from short-duration, high-intensity rainfall events – i.e. the core physical mechanism of flash flooding.

The pluvial flooding dataset considers rainfall event modelling, flow over the terrain and through shallow flow paths, and topographic control (such as valleys, flow convergence, slope breaks).

Features commonly associated with flash flooding include narrow valleys, steep headwater catchments, and rapid runoff concentration.

Pluvial Flood Likelihood per Year	Wales	England	Scotland	Northern Ireland	Suggested Flood Hazard Score
Very Low	< 0.1%	< 0.1%	< 0.1%	< 0.1%	0
Low	0.1 - 1%	0.1 - 1%	0.1 – 0.5%	0.1 - 1%	0.5
Medium	1 – 3.3%	1 – 3.3%	0.5 – 10%	1 – 3.3%	1
High	> 3.3%	> 3.3%	> 10%	> 3.3%	2

Table 2-3 - Pluvial Flooding

2.1.4 Groundwater Flooding

Groundwater flooding data for England, Wales and Scotland can be purchased from the BGS². An equivalent dataset for Northern Ireland has not been identified. The BGS data is a hazard-based dataset that identifies areas susceptible to groundwater emergence but does not include likelihood or consequence information, and therefore does not constitute a risk assessment. It has a spatial resolution of approximately 50 m and is considered suitable for regional or national-scale planning.

Table 2-4 presents the three classes of susceptibility to groundwater flooding within Wales, England and Scotland:

GW Flooding Class	Wales	England	Scotland	Northern Ireland	Suggested Flood Hazard Score
A	Limited potential for groundwater flooding to occur			-	1
B	Potential for groundwater flooding of property situated below ground level			-	1.5
C	Potential for groundwater flooding to occur at surface			-	2
Elsewhere (Onshore)	Not considered to be prone to groundwater flooding			-	0

Table 2-4 - Groundwater Flooding

2.1.5 Reservoir, Dam and Canal Flooding

Reservoirs, dam, and canals are considered together as water impoundments. Flooding from these human-made structures is not estimated in terms of probability such as the flooding types discussed in the subsections above. Rather, flood hazards from water impoundments are location-specific, and are based on whether a pipeline section is located topographically downgradient of a water impoundment, or within the simulated inundation zone where available.

Reservoir and Dam Flooding

Reservoir and dam flooding is considered extremely unlikely and there has been no loss of life in the UK from reservoir or dam flooding since 1925. All large reservoirs and dams must be inspected and supervised by qualified engineers.

² <https://www.bgs.ac.uk/datasets/groundwater-flooding/> Accessed 23/09/2025)

Unlike other flood types, Reservoir and Dam flooding is not presented as a likelihood category; it is typically shown as a worst-case inundation extent.

Table 2-5 presents the proposed flood hazard quantification score. This score is combined with the canal flooding score, where the highest score is taken to represent the hazard posed by reservoirs, dam and canals.

Wales	England	Scotland	Northern Ireland	Suggested Flood Hazard Score
Outside Inundation Zone	Outside Inundation Zones	Outside Inundation Zone	Outside Inundation Zone	0
Within Inundation Zone	Within Wet Day Inundation Zone	Within Inundation Zone	Within Inundation Zone	2
	Within Dry Day Inundation Zone			

Table 2-5 - Reservoir Flooding

Canal Flooding

Canal flooding refers to the uncontrolled release of water from constructed canals due to overtopping, embankment instability, or structural failure (e.g., locks, sluices, aqueducts, culverts). While canals are normally operated under stable and regulated water levels, extreme rainfall or operational faults can result in sudden release of water. This can lead to rapid, high-energy flows capable of eroding soil, undermining pipeline cover, or washing out banks, particularly where canals run on raised embankments above surrounding ground.

Notable UK examples include:

- Llangollen Canal Breach (near Whitchurch, Shropshire – Dec 2025)³: Multi-agency major incident declared, with Canal & River Trust installing temporary dams, refloating boats and beginning a long, multi-million-pound repair project expected to last through most of 2026.
- Bridgewater Canal Embankment Collapse (Dunham Massey – Jan 2025)⁴: Embankment failure after heavy rainfall led to water overtopping into nearby fields and a sewage works, prompting evacuations and a major incident declaration.

As canal flooding is not explicitly modelled in statutory flood datasets, operators should identify canal-related hazards through:

- Assessing whether the pipeline lies downslope of a canal embankment or directly beneath a canal structure. This can be done qualitatively or through overland flow path analysis using topographic data within GIS.
- Reviewing Canal & River Trust datasets for elevated or embanked canal sections⁵ for England and Wales, and Scottish Canals GIS datasets for the Scottish network⁶.

³ <https://canalrivertrust.org.uk/about-us/where-we-work/west-midlands/llangollen-canal-breach> (Accessed 02/01/2026)

⁴ <https://waterways.org.uk/about-us/news/bridgewater-canal-breach> (Accessed 02/01/2026)

⁵ <https://data-canalrivertrust.opendata.arcgis.com/> (Accessed 02/01/2026)

⁶ <https://www.scottishcanals.co.uk/scottish-canals-data-portal> (Accessed 02/01/2026)

- For Northern Ireland, no dedicated canal dataset exists. The Ireland and Northern Ireland Waterways dataset from OpenStreetMap⁷ may be used as a supplementary data source.

Pipeline operators should screen for canal-related flood hazards when:

- The pipeline runs downslope or adjacent to a canal embankment or analysis shows a flow path from canal to pipeline under a potential breach scenario
- The pipeline crosses beneath a canal or associated structures (e.g., siphons, culverts).
- Canal & River Trust or Scottish Canals datasets indicate embanked or elevated canal sections near the pipeline route.

Where these conditions occur, the location should be flagged even if national flood maps show no fluvial, coastal, pluvial or groundwater flood risk. As canal flooding is not provided in probabilistic form by Statutory Authorities, the following qualitative hazard scores in Table 2-6 are recommended. This score is combined with the reservoir and dam flooding score, where the highest score is taken to represent the hazard posed by reservoirs, dam and canals.

Wales	England	Scotland	Northern Ireland	Suggested Flood Hazard Score
No canals located topographically upgradient of pipeline.				0
Canal located topographically upgradient of pipeline and within 500m.				1
Canal located topographically upgradient of pipeline and within 100m.				1.5
Canal intersects pipeline.				2

Table 2-6 - Canal Flooding

2.1.6 Additional Considerations

The available flooding maps help determine the likelihood that flooding could occur, but there are additional factors which also impact the potential risk to buried pipelines.

2.1.6.1 Flood Depth

Shallow inundation (a few centimetres) might just cover the ground, whereas >1–2 metre depth can exert buoyant forces on the pipeline if it's empty or create significant erosion when the water recedes. Deeper floodwaters are likely to be more forceful and carry more debris (e.g. tree branches, rocks, man-made objects). At water crossings, debris can snag on a pipeline if it becomes exposed, adding stress or impacting it. In cold conditions, ice floes in floodwaters can impact exposed or above-ground pipelines.

The collection of this data likely requires location-specific inundation modelling to be commissioned.

Table 2-7 presents suggested escalation factors to be applied to the flood hazard scoring based on the modelled flood depth.

⁷ https://data.humdata.org/dataset/hotosm_irl_waterways (Accessed 02/01/2026)

Flood Depth (m)	Suggested Escalation Factor
< 0.5	1 (no escalation factor)
0.5 - 1	1.1
1 - 2	1.25
>2	1.5

Table 2-7 - Depth of Flooding

2.1.6.2 Surface Water Flow Velocity

Higher velocity surface waters can wash away bed material (vertical scour) or eat into the surface water banks (horizontal scour). The pipeline should have been buried sufficiently deep below the expected scour depth, but long-term changes or extreme events could exceed design assumptions.

For crossings a scour analysis should be considered – e.g. using formulas or a hydraulic model to estimate potential bed erosion depth during a 100-year flood. Also consider the force of water—fast currents or wave action can impose hydrodynamic loads on an exposed span. CIRIA C742 provides guidance on scour at hydraulic structures which can be applicable to buried pipelines [6]. An escalation factor for pipeline crossings may be appropriate based on these results.

2.1.6.3 Climate Change

It is important to factor in projected increases in flood hazard. UK guidance (NPPF and EA) typically requires considering a future scenario (e.g., +20-40% flow for rivers) for infrastructure with long life. Recent data suggests that by the 2050s the UK could see increased rainfall intensity (the number of days with >10 mm rain rising from ~37 to ~40+ per year under a high emissions scenario).

Climate change data related to rainfall and flooding can be sourced from the following;

- UK Climate Projections (UKCP18)⁸ provides data for rainfall intensity, total rainfall, and seasonality across multiple emission scenarios.
- The EA provides climate change flood datasets, including 'Risk of Flooding from Surface Waters – Climate Change 1' and 'Risk of Flooding from Rivers and the Sea – Climate Change 1'⁹ for England. The data follows the High, Medium, Low and Very Low flooding likelihood categories.
- NRW provides 'National Flood Hazard Maps - Climate Change'¹⁰ that consider flooding in Wales through to 2120.
- SEPA provides 'Surface Water & Small Watercourses – Plus Climate Change'¹¹ datasets, while climate change is embedded in its River and Coastal Flood Maps.
- DfI Rivers provides 'Technical Flood Risk Guidance in relation to Allowances for Climate Change in Northern Ireland' which sets out the DfI Rivers approach to Climate Change in Flood Risk Management.

⁸ <https://climatedataportal.metoffice.gov.uk/> (Accessed 19/02/206)

⁹ <https://environment.data.gov.uk/support/announcements/569147407/568197126> (Accessed 19/02/206)

¹⁰ <https://datamap.gov.wales/documents/7106> (Accessed 19/02/206)

¹¹ <https://www2.sepa.org.uk/FloodData/> (Accessed 19/02/206)

As the impacts of climate change relate to the future, and are already considered in some of the above datasets, while not explicitly considered in others, a quantification for the flood hazard posed by climate change is not considered necessary.

However, the operator should consider the impacts of climate change along the pipeline extent, and factor any potential resultant increases in future flood hazard into decision-making and risk management.

2.1.6.4 Historical Flood Data

Review historical flood data to see if any overlap the pipeline route. This can include consulting Environment Agency Historic Flood Maps which provide data from 1946, the Dartmouth Flood Observatory database for flood information post-1980 or the Hydro-GIS UK Historical Flood Database which has some data going back as far as 1860.

Table 2-8 presents the escalation factors for the presence of historical flood events intersecting the pipeline route.

Historical Flooding	Suggested Escalation Factor
None identified.	1 (no escalation factor)
Historical Flooding Identified within 100m of pipeline	1.1

Table 2-8 - Historical Flooding

2.2 Flood Hazard Data Sources

2.2.1 Third-Party Sources

Table 2-9 presents the sources of different flood datasets across the UK and Table 2-10 presents data sources for the flooding escalation factors.

Type of Flooding	Wales	England	Scotland	Northern Ireland
Fluvial	NRW Flood Risk (Accessed 23/09/2025)	EA Long Term Flood Risk (Accessed 23/09/2025)	SEPA Flood Maps (Accessed 23/09/2025)	DfI Flood Maps (Accessed 28/01/2025)
Coastal				
Pluvial				
Groundwater	BGS Groundwater Flooding (Accessed 28/01/2026)			No data identified.
Reservoir	NRW Flood Risk (Accessed 28/01/2025)	EA Reservoir Flooding (Accessed 28/01/2025)	SEPA Reservoir Flood Map (Accessed 28/01/2025)	Reservoir Flooding (Accessed 28/01/2025)
Canal	Canal & River Trust Open Data (Accessed 28/01/2025)	Canal & River Trust Open Data (Accessed 28/01/2025)	Scottish Canals Data Portal (Accessed 28/01/2025)	No data identified. (use LiDAR + NI Flood Maps)

Table 2-9 - Flood Data Sources

Type of Flooding	Wales	England	Scotland	Northern Ireland
Flood Depth	No data identified.	Flood Depth Grid 20m (Accessed 28/01/2025)	SEPA Flood Data (Accessed 28/01/2025)	No data identified.
Surface Water Velocity	National River Flow Archive (Accessed 02/01/2026)	EA Hydrology National River Flow Archive (Accessed 02/01/2026)	SEPA Water Levels National River Flow Archive (Accessed 02/01/2026)	DfI Rivers Agency (Accessed 02/01/2026)
Historical Flooding*	Historic Floodmap (Accessed 23/09/2025)	Recorded Flood Outlines (Accessed 23/09/2025)	None identified.	DfI Flood Maps (Accessed 23/09/2025)

Table 2-10 - Escalation Factor Data Sources

*Historical flash flooding across England, Wales and Scotland is also available from [JBA Trust](#) (Accessed 02/01/2026)

Additional resources of note include;

- Climate and rainfall data – Met Office extreme rainfall statistics, UKCP18 climate projection data for future flood scenario planning¹², and EA long term flood risk¹³.
- Topographic & drainage data – Digital elevation models (LiDAR) to see low spots where water may collect, and drainage networks to spot any interaction (e.g. pipeline following a valley that could channel floodwater).
- Site walkover / local knowledge – landowner or operator knowledge of areas that get marshy or submerged in heavy rains (even if not on official maps). Sometimes farmers can point out “this field always floods” – valuable information not to overlook.

2.2.2 Commissioned Surveys

In the absence of publicly available data or the identification of potentially high-risk pipeline segments there may be a need to consider commissioning site-specific surveys / assessments, and the scope and associated guidance for undertaking these are presented in Table 2-11.

Survey / Assessment	Details	Guidance
Flood Risk Assessment	An FRA must identify flood mechanisms, model potential flood extents and depths, consider climate change allowances, assess vulnerability, and define mitigation measures.	National Planning Policy Framework [3] Technical Advice Note 15 [4] Scottish Planning Policy Water Environment (Floods Directive) Regulations (NI) 2009
Reservoir / Dam Breach Assessment	Models breach hydrographs, flood routing, hazard to life, structural failure modes, and downstream impacts.	EA Risk Assessment for Reservoirs (Risk assessment for reservoirs - GOV.UK , Accessed 29/01/2026) Breach of Defences Guidance [7]

¹² <https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/index> (Accessed 11/09/2025)

¹³ <https://www.gov.uk/check-long-term-flood-risk> (Accessed 11/09/2025)

Surface Water Velocity / Depth	For watercourses without gauging stations, the commissioning of gauging equipment should be considered at each water crossing. This should be considered on a case-by-case basis.	EA River Modelling Technical Standards (River modelling: technical standards and assessment - GOV.UK , Accessed 29/01/2026)
Scour	Evaluates vertical/lateral channel scour, sediment transport, pipeline exposure risk, channel migration and hydraulic loads during floods.	CIRIA C742 [8]

Table 2-11 - Commissioned Surveys

2.3 Example of Identifying Flood Hazards

This initial analysis will provide an indication of which sections of pipeline may be vulnerable to flooding, and this can be quantified by following the flood hazard scores and escalation factors provided above. For some locations there may be a combination of outcomes where there are hazards identified from different types of flooding.

Figure 2.1 presents an illustrative example of a pipeline route, with the yellow point representing a theoretical point of interest along the pipeline in the example. The point intersects:

- Some areas of low and medium likelihood of fluvial flooding represented by the light and dark blue polygons respectively
- The yellow polygon representing an area with 'potential for groundwater flooding to occur at surface'
- The purple polygon represents an area that has experienced historical flooding

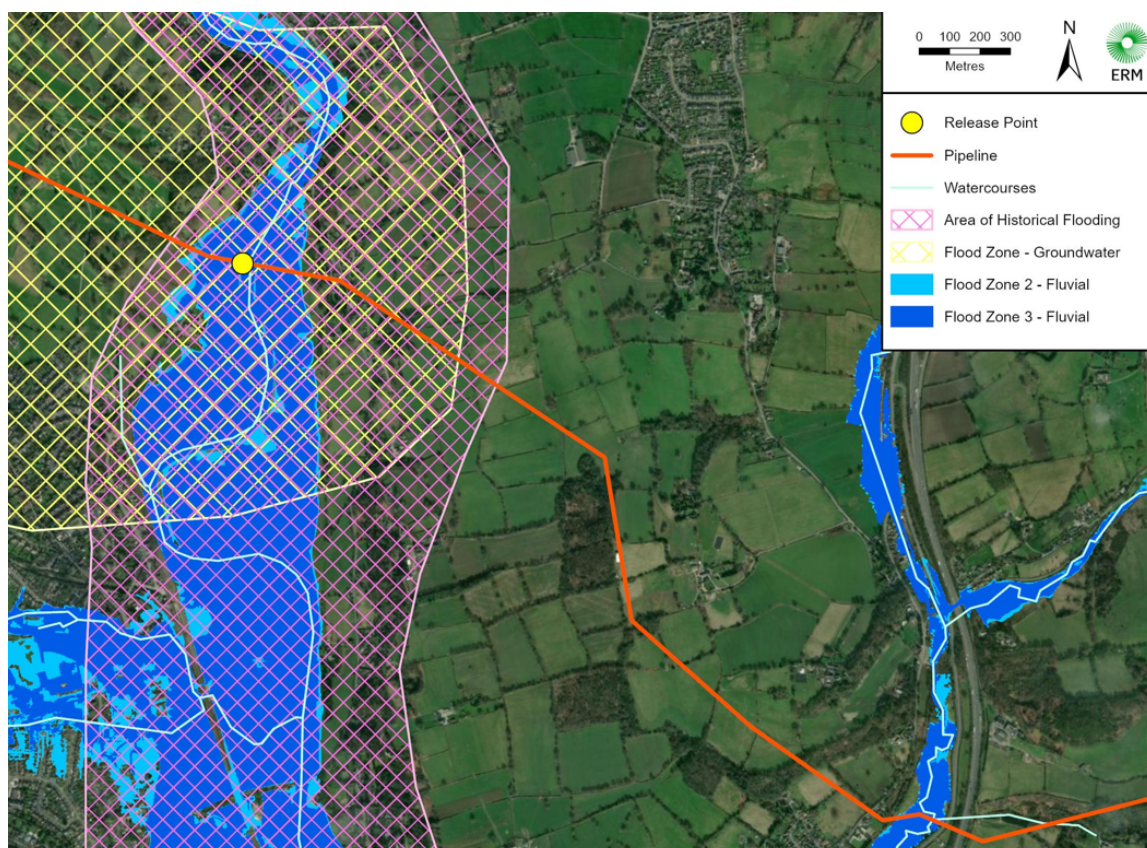


Figure 2.1 – Flood Hazard Mapped on Pipeline Route

An example of flood hazard scoring for the theoretical point of interest above is presented in Table 2-12.

Yellow Point in Figure	Fluvial Hazard Score	Coastal Hazard Score	Pluvial Hazard Score	Groundwater Hazard Score	Reservoir / Dam / Canal Hazard Score	Total Score
Flood Hazard Scores	2	0	0	2	0	4

Table 2-12 - Example Flood Hazard Quantification

Additional considerations;

- Flood Depth
- Surface Water Flow Velocity as water crossing
- Climate Change
- Historical Flooding

The presence of any of these additional elements would enable the flood hazard score to be escalated (e.g. due to the known occurrence of previous floods at the location or analysing flood depth information and identifying the potential for flood depths to exceed 0.5 m across some sections of the pipeline).

Continuing from the example above, the theoretical point of interest along the pipeline also lies within an area that has experienced historical flooding (represented by the purple polygon). As such, referring to Section 2.1.6.4, we can choose to apply an escalation factor of 1.1, which would act to increase our flood hazard score of 4, to 4.4. In this example, this would provide further considerations within the areas that are at low and medium risk of fluvial flooding, and that also have a potential for groundwater flooding, based on whether there is previous recorded evidence of historical flooding or not.

3 VULNERABILITY OF PIPELINE FROM FLOODING

Beyond the probability of flooding, there are location-specific elements which influence the potential for a flooding-related pipeline failure to occur. Three critical location-specific elements include soil type, ground slope, and pipeline depth-of-cover. These influence the pipeline's vulnerability to erosion, scour, landslides, or flotation during floods. This section explains how each factor affects flood risk and quantifies each based on readily available data.

It is necessary to quantify the risk score for these parameters, in order to account for higher risk soil types, steeper slopes, and shallower depth-of-cover. The subsections below explain how risk scores may be applied to these parameters.

3.1 Soil Type

Soil type determines how easily floodwaters can erode supporting ground cover. Loose sands, silts, or peat are highly erodible, whereas clay may resist scour but become weak when saturated. As such it is important to identify the soil type along a pipeline route.

Easily erodible soils: Non-cohesive soils like sand are more vulnerable to being scoured by flowing water. If a pipeline is buried in predominantly sandy soil, a strong flood current might excavate the area around the pipe, whereas the same flow may not impact a clay bank. Peat and soft organic soils are also considered vulnerable to being washed away or decomposing when waterlogged.

In known erodible soils, extra depth of cover or protective armouring (rock or geo-textile mats over the pipe) may be required in flood-prone segments. Exposed pipe should be promptly re-covered.

Coarser granular soils (gravels) are considered less vulnerable to being washed out. Additionally, coarse soils drain quickly, which can result in decreased landslide risk, however, if underlying fine materials are washed out, the gravel above may collapse.

Cohesive soils (clays): Clayey soils are less prone to immediate scour from flood water due to increased cohesion. However, clay soils can weaken significantly when saturated. Heavy or prolonged rain can turn firm clay into a soft, elastic state, reducing its ability to support loads. Saturated clay slopes may fail even without high flow velocities. Clay can also shrink and crack in dry periods, with the cracks subsequently allowing water intrusion and softening during rains.

For pipelines in clayey slopes there should be adequate drainage to prevent water ponding. If analysis shows a slope's factor of safety drops too low when saturated, engineering solutions like terracing, retaining walls, or soil nailing may be required.

Soluble rocks: In certain geologies, longer term concerns from flooding may include the formation of sinkholes over time. Sinkholes are often saucer-shaped hollows that are the result of some kind of collapse or removal of an underlying layer of rocks that used to support the layer of material at the surface. In the UK they occur in karst regions, which is the geomorphological term applied to the landscape that results from the dissolution of soluble rocks. Sinkholes can form due to a number of reasons including heavy rainfall, flooding, changes in water table level, and water leaks / releases from human structures (e.g. drainage pipes, water mains etc). The locations of karst areas are provided by the BGS¹⁴.

The BGS OpenScience database provides information on the following which may be helpful to identify areas of elevated risk associated with soil types:

- **Collapsible Deposits:** Indicates areas underlain by loessic or metastable materials that may collapse rapidly when loaded and then wetted, leading to ground subsidence and potential structural damage¹⁵.

¹⁴ <https://www.bgs.ac.uk/discovering-geology/earth-hazards/sinkholes/> (Accessed 13/04/2026)

¹⁵ <https://www.bgs.ac.uk/datasets/bgs-geosure-collapsible-deposits/> (Accessed 11/02/2026)

- **Compressible Ground:** Identifies soils containing soft, highly compressible materials (e.g., peat, alluvium, soft clays) that may compress under load or groundwater change, causing differential settlement, foundation damage, and service disruption¹⁶.
- **Running Sand:** Highlights areas where loosely packed saturated sands or silts may become fluidised, leading to “running sand” conditions. Hazards include excavation instability, ground loss around pipes, and uneven settlement. Triggered by groundwater pressure, springs, leaking pipes, or vibrations¹⁷.
- **Shrink Swell:** Maps the susceptibility of clay-rich soils to shrink (dry) or swell (wet) with seasonal moisture changes¹⁸.
- **Soluble Rocks:** Identifies areas underlain by karst-forming rocks (limestone, chalk, gypsum, salt) that may dissolve, creating cavities, sinkholes, uneven rockhead, and zones of subsidence. Dissolution features can destabilise buildings and infrastructure if not managed¹⁹.

Pipeline operators should also use available geotechnical data from borehole logs where available (e.g. from the pipeline construction or the BGS Onshore Index), soil surveys, or nearby ground investigations. If such data is old or sparse, consider performing soil sampling at critical locations (like river crossings or steep slopes) to understand grain size distribution, plasticity (for clay), and shear strength. Knowing the soil's erosion resistance can inform whether additional protection is needed.

Additionally, consideration should be given to whether trench backfill material differs from the native soil. Some pipelines are backfilled with imported sand which can be more vulnerable to washout than the native soil during flooding.

Table 3-1 presents suggested soil type vulnerability score.

¹⁶ <https://www.bgs.ac.uk/datasets/bgs-geosure-compressible-ground/> (Accessed 11/02/2026)

¹⁷ <https://www.bgs.ac.uk/datasets/bgs-geosure-running-sand/> (Accessed 11/02/2026)

¹⁸ <https://www.bgs.ac.uk/datasets/bgs-geosure-shrink-swell/> (Accessed 11/02/2026)

¹⁹ <https://www.bgs.ac.uk/datasets/bgs-geosure-soluble-rocks/> (Accessed 11/02/2026)

Hazard Class	Collapsible Deposits	Running Sand	Compressible Deposits	Slope Instability (Landslides)	Soluble Rocks (Dissolution)	Shrink Swell	Suggested Vulnerability Score
A	No known collapsible deposits; low likelihood of collapse.	Running sand not expected under any water-table conditions.	Compressible strata are not thought to occur.	Instability not expected.	Soluble rocks absent or not dissolution-prone.	Ground conditions predominantly non-plastic.	0
B	Deposits with potential to collapse when loaded and saturated are unlikely to be present.	Running sand unlikely; only a concern with rapid water-table rise.	Low compressibility; settlement unlikely for most land uses.	Instability unlikely; neighbouring slopes may need consideration.	Soluble rocks present but with few features; low subsidence potential.	Ground conditions predominantly low plasticity.	0.5
C	Possible collapsible deposits; localised issues may occur.	Running sand may occur; constraints for excavation/water management.	Moderate compressibility; settlement potential requires assessment.	Instability possible; site-specific slope checks recommended.	Soluble rocks with some dissolution features; occasional localised risk.	Ground conditions predominantly medium plasticity.	1
D	Deposits with potential to collapse when loaded and saturated are probably present in places.	Running sand likely; excavation/water changes require controls.	Significant compressibility; variable ground behaviour expected.	Instability probable or historically documented; detailed assessment required.	Soluble rocks with many dissolution features; subsidence possible.	Ground conditions predominantly high plasticity.	2
E	Collapsible deposits present; collapse under load/water almost certain.	Running sand almost certain; major constraints on excavation/water changes.	Highly compressible ground; strong constraint on development.	Instability almost certain; may be active; major constraint.	Soluble rocks with numerous features; investigate for subsidence risk.	Ground conditions predominantly very high plasticity.	3

Table 3-1 - Soil Type

3.2 Ground Slope

Steep slopes along the pipeline are vulnerable to rain-triggered landslides or washouts. When flooding (e.g. pluvial via heavy rain or a watercourse overflowing) saturates a hillside, it can lose stability and slide – potentially resulting in a pipeline failure.

Hillside runoff and erosion: On slopes, heavy rainfall runs downhill and can gouge channels (gully) in the soil. If a pipeline is buried along the slope, runoff can cause erosion of the cover on the uphill side, potentially exposing the pipe. If it's buried across the slope, erosion could undercut it. Steeper slopes and less vegetated slopes are increasingly vulnerable to impacts from flooding.

Where the buried pipelines are below a steep slope, it is recommended that erosion controls are installed, such as re-vegetation to stabilise the slope, diversion of surface water with berms or drains, and slope breakers on the pipeline trench to reduce water flow.

Landslides and slope failures: Saturated soils may lead to slope failure where water percolates into a slope, adding weight and reducing soil shear strength. In the UK, extreme rainfall events have caused localised landslides in upland areas (e.g., in Wales and Scotland). It is considered slope angles greater than, 20–30° are highly vulnerable with experimental studies showing rainfall-induced failure typically occurring on slopes steeper than 30°²⁰; evidence of past landslips such as scarp or bulges on the slope; and weak geology (e.g. mudstone or weathered shale that is more likely to fail when wet). If a pipeline is on or at the foot of a steep slope, flood-induced landslide risk should be assessed. The Department of Environment, Food and Rural Affairs (DEFRA) provide slope angle categories for risk of runoff and soil erosion²¹, although targeted at the transfer of contaminants, may still be considered appropriate for differentiating slope categories for risk quantification.

Topographic data can be used to calculate slope angles, with those exceeding a relevant threshold value potentially requiring slope stability analysis performed by a geotechnical engineer. Techniques include calculating factors of safety with elevated groundwater (using software or charts). If risk is high, mitigation could involve installing drainage (to relieve water pressure), grading the slope to a gentler angle, installing retaining structures or gabions, or even rerouting the pipeline if feasible around the most unstable zone. If high-risk slopes are identified, it can be useful to engage external geotechnical specialists. For example, overlaying the British Geological Survey's National Landslide Database (NLD)²² onto pipeline alignments can highlight specific sections requiring enhanced monitoring. For initial high-level screening, the BGS GeoSure Landslides 5 km Hex-Grid dataset provides a generalised national-scale overview of landslide susceptibility, after which more granular datasets, such as the detailed BGS GeoSure Landslides (1:50,000) layer or full NLD point data, may be required for site-specific assessment.

Soil loosening and subsidence: Even on moderate slopes or flat areas, long-term wetting can cause settlement or subsidence of the pipeline due to soil consolidation or washout of fines. If a pipeline lies in a floodplain with soft alluvial soil, repeated flooding might gradually compact the soil or migrate fines, causing the pipe to settle or sag. This is usually a slow process but should be checked via periodic depth-of-cover surveys or in-line inspections (ILI).

Vibrations and seismicity: Pluvial flooding can trigger slope movement / creep (slow downhill movement of soil). Over years, creep can bend a pipeline. Operators should check for any lateral displacement or bending strain (In-line inspection tools that measure geometry can pick this up). UKOPA/GPG/026 provides guidance on approaches to the verification of features identified by in line inspection (ILI).

Table 3-2 presents the suggested ground slope vulnerability scores.

²⁰ <https://www.frontiersin.org/journals/earth-science/articles/10.3389/feart.2023.1291592/full> (Accessed 08/01/2026)

²¹

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/901821/CS_Runoff_and_Soil_Erosion_CS11_v1.00_.pdf (Accessed 08/01/2026)

²² <https://www.bgs.ac.uk/datasets/national-landslide-database/> (Accessed 08/01/2026)

Ground Slope	Suggested Vulnerability Score
0°	0
0 - 10°	1
10 - 20°	3
>20°	4

Table 3-2 - Ground Slope

3.3 Depth of Cover

Depth of cover refers to the thickness of soil above the pipeline. UKOPA/GPG/001 Edition 2, as well as industry codes IGEM/TD/1 Edition 6 and PD 8010 specify that the depth of cover should be a minimum of 1.1 m in rural and suburban areas and should be 1.2 m below roads (measured from the true clean bottom of the adjacent drainage ditches) and 1.2 m below the bottom of watercourses, canals and rivers (measured from the lowest anticipated true clean bed level) and 1.4 m below railways. A cover <1 m is considered shallow and high-risk in flood zones as water can strip away soil and potentially float the pipe if empty.

Depth-of-cover can reduce over time, as such the data must be collected by the operator themselves with appropriate surveys to ensure coverage along the pipeline route but to also keep the dataset up-to-date over time. Depth-of-cover can be measured using probing rods, GPS surveys, or through the use of smart pigs.

Depth-of-cover data can be overlain onto flood probability maps to identify segments with low depth-of-cover lying within elevated flood probability areas.

A buried pipeline can float out of the ground if the buoyant force of floodwater in the soil exceeds the pipe's weight (plus the weight of soil over it). This is more likely for empty or low-pressure pipelines (a liquid-filled pipeline has extra weight). During flooding, the water table rises to the surface; if the pipe is light and shallow, it can heave upwards, especially if the soil above is eroded or loosened.

In practice, many flood-related pipeline incidents involve shallow cover. For example, in the USA, a pipeline spill on the Yellowstone River (2011) happened due to extreme flooding scouring the riverbed and exposing the pipeline, along with stresses brought about by vortex-induced vibration, and additional loading from the build-up of debris. UK operators have taken note of such incidents and now generally design new river crossings with sufficient cover (sometimes >5 metres below riverbed for major rivers) or use horizontal directional drilling to place pipelines well below the river. Existing pipelines, however, require evaluation – some older crossings might not meet today's standards for cover depth. Table 3-3 presents the suggested vulnerability scores for depth-of-cover.

Depth-of-Cover (m)	Suggested Vulnerability Score
>1.5	0
1.25 – 1.5	1
1.1 – 1.25	1.5
1 – 1.1	2
<1	3

Table 3-3 - Depth-of-Cover

3.4 Data Sources

3.4.1 Third-Party Sources

There are third-party data sources for soil type and ground slope, however, depth-of-cover is a pipeline-specific dataset that must be collected by the operators. Table 3-4 provides data sources for the location-specific parameters.

Parameter	Wales	England	Scotland	Northern Ireland
Soil Type	BGS GeoSure - British Geological Survey (Accessed 29/01/2026)			
Ground Slope	View map DataMapWales (Accessed 29/01/2026)	Open Data Environment Agency Geomatics Hub (Accessed 29/01/2026)	Scottish LiDAR Remote Sensing datasets Scottish Government (Accessed 29/01/2026)	Dataset - Open Data NI (Accessed 29/01/2026)
Depth-of-Cover	Operator is expected to have this data.			

Table 3-4 - Location Vulnerability Parameters

3.4.2 Commissioned Surveys and Investigations

In the absence of publicly available third-party data, there may be a need to commission site-specific surveys or investigations to improve understanding of the location-specific parameters, and options with associated guidance are provided below.

Trial pits / boreholes

Trial pits expose the soil layers, where samples can be taken and sent for laboratory analysis for the identification of soil type, soil horizons, superficial geology, chemistry, moisture content, strength / compaction. Additionally, the presence and depth to groundwater can be identified if it occurs within the depth of the trial pit.

Boreholes typically allow for greater depths of investigation and can include the bedrock geology as well as the superficial and soil layers. Soil samples can be taken, as well as groundwater samples if encountered. Additionally, the presence and depth to groundwater can be identified if it occurs within the depth of the borehole.

Relevant standards and guidance for trial pitting and boreholes is listed below.

- BS 5930:2015 + A1:2020 - Code of Practice for Ground Investigations [9]
- BS EN ISO 14688 (Soil Identification & Classification) [10]
- Environment Agency Standard Rules Permit SR2015 No.36 - Trial pits & boreholes in floodplains [11]

Topographic analysis

Although topography data is widely available at horizontal resolutions of up to 1 – 2 metres, with some areas having resolutions as high as 25 cm. However, for areas where publicly available topographic data is not available, or a higher resolution is required, there are several providers that can be consulted to acquire the data at a cost. Data available for purchase can be 'off the shelf' but can also include bespoke commissioned aircraft / drone surveys that can run along the pipeline route, capturing not only topographic data, but also using remote sensing technology to capture additional datasets such as soil moisture and vegetation cover as required.

Where steep slopes of concern are identified, the critical shear stress of soils can be tested to measure the amount of force the soil can resist before it fails or slides. This resistance is a function of inter-grain friction, cohesion, and water content.

Relevant standards and guidance include;

- BS 1377 (Parts 7 & 8) – Shear Strength Tests [12]
- BS EN ISO 17892 – Geotechnical Investigation and Testing [13]

Depth-of-Cover

It is expected that operators collect and store depth-of-cover data, and that it is updated over time. Approaches for collecting depth-of-cover data are presented in Table 3-5.

Data Collection Method	Description	Pros	Cons
<i>GPS / GNSS Survey</i>	Measures ground elevation directly along the pipeline route.	Accurate, fast, non-intrusive	Requires good satellite visibility; does not measure pipe depth directly.
<i>Total Station Survey</i>	Uses optical surveying to map surface levels.	Very precise in obstructed areas (trees, buildings).	Slow; labour-intensive.
<i>Trial Pit / Excavation</i>	Dig down to expose the pipe and measure cover directly.	Most accurate method.	Costly, disruptive, requires permits.
<i>Exposed Crossings (e.g., erosion sites)</i>	Measures depth where pipeline is already visible.	Direct and accurate.	Only possible where the pipe is already exposed.
<i>Ground Penetrating Radar (GPR)</i>	Sends radar waves into the ground to detect pipeline depth.	Non-intrusive; works well in dry, sandy soils.	Poor performance in clays or wet soils.
<i>Electromagnetic (EM) Locator</i>	Follows an induced signal on the pipe to estimate location and depth.	Easy to use; common for utilities.	Depth accuracy varies; interference possible.
<i>Magnetometer Survey</i>	Detects magnetic field disturbance from steel pipelines.	Works when EM signals cannot be applied.	Lower depth accuracy; affected by nearby metal.
<i>LiDAR (Airborne Laser Scanning)</i>	Measures high-resolution ground elevation; DoC = surface minus pipe elevation.	Fast over long distances.	Only surface measured; relies on accurate pipe elevation data.
<i>Drone Photogrammetry</i>	Creates 3D surface models from aerial imagery.	Quick and low-cost.	Provides only surface elevation.
<i>In-line Inspection (ILI) with IMU</i>	Internal "pig" measures the pipe's vertical profile.	Very accurate continuous profile.	Pipeline must be piggable; expensive.
<i>ILI + GPS Above-Ground Markers (AGMs).</i>	Combines IMU tracking with GPS markers for high positional accuracy.	High-resolution mapping of pipe depth.	Requires coordination of field crews.
<i>GIS Integration of Multiple Data Sources</i>	Combines LiDAR, surveys, ILI, and as-built drawings to calculate DoC.	Best overall accuracy; continuously updated.	Quality depends on underlying datasets.

Table 3-5 - Depth-of-Cover Data Collection Methods

Relevant standards and guidance include;

- UKOPA GPG/001 – Managing Pipelines with Reduced Depth of Cover
- HSE Guidance on Pipeline Depth (PSR 1996 supporting guidance)

3.5 Example Output

Error! Reference source not found. and Figure 3.1 present soil type and ground slope data for the example pipeline route. Table 3-6 presents the vulnerability scores based on the soil type and ground slope at the point of interest, along with a depth-of-cover score assigned for water crossings.

Parameter	Measurement	Vulnerability Score
Soil Type	Clay	2
Ground Slope	Water Crossing	4
Depth-of-Cover	1 – 1.25 m	1.5
Total Vulnerability Score	7.5	

Table 3-6 - Example Location-Specific Vulnerability Quantification

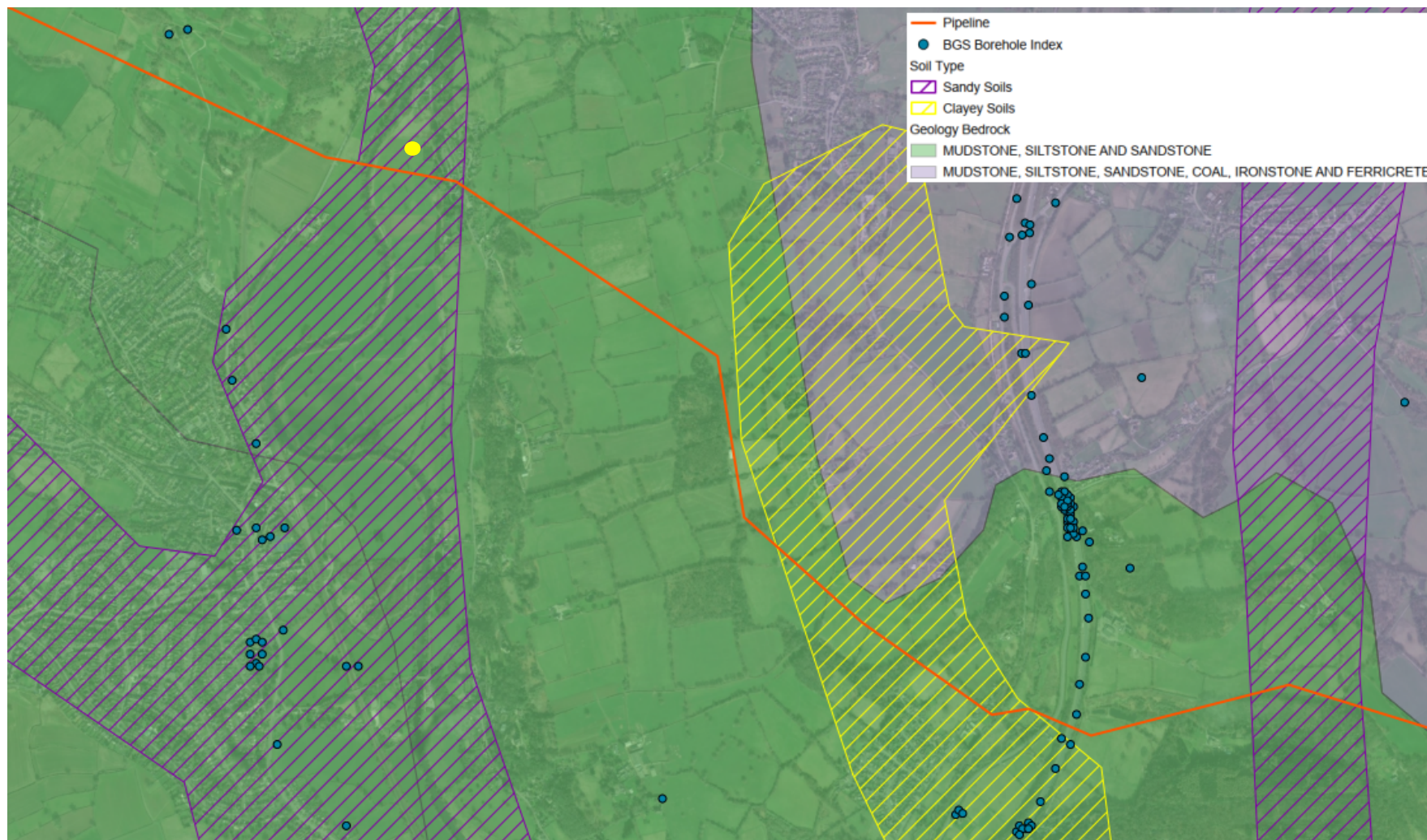


Figure 3.1 – Soil Type on Pipeline Route

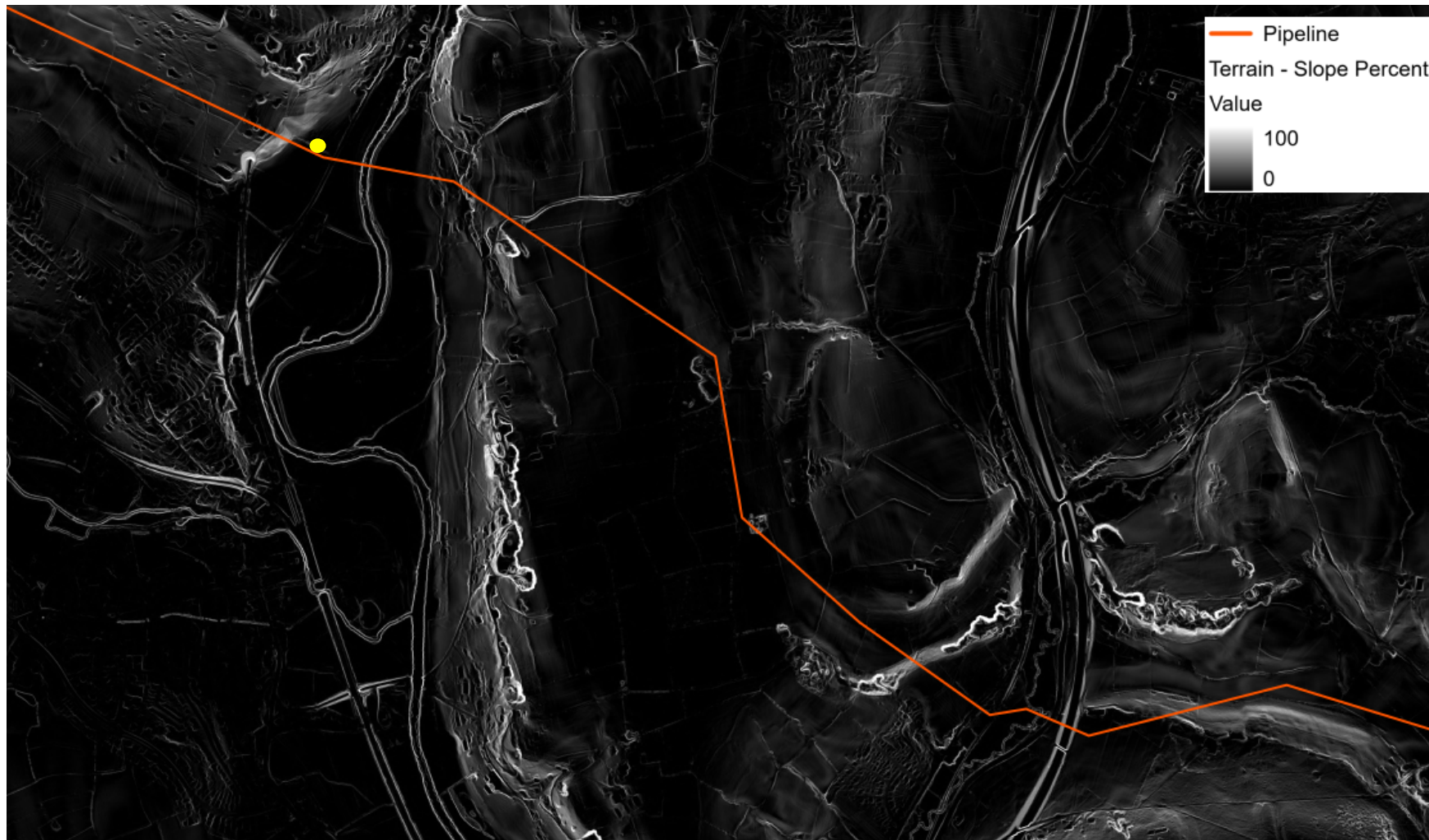


Figure 3.2 – Ground Slope on Pipeline Route

4 PIPELINE INTEGRITY

4.1 Pipeline Integrity Factors

Beyond the flooding probability (and flood hazard score) and location-specific vulnerability (vulnerability score), there are characteristics of the pipeline itself that influence the risk of failure in the event of a flood, which are summarised below;

- Wall thickness / Corrosion rates: Thinner walls are considered more prone to failure.
- Construction material: Steel vs plastic/composite, where steel has increased vulnerability to corrosion, while plastic/composite would be more vulnerable to buoyancy issues and less resistant to impact damage.
- Inspection accessibility: Segments that cannot be accessed for inspections could be more prone to having undetected anomalies or undetected signs of increased failure risk.
- Slabbing areas / engineering controls: Areas of slabbing/engineering controls are less vulnerable than areas that do not benefit from these measures. However, it should be noted washout due to flooding may result in an increased amount of stress on the pipeline.
- Anomalies: Presence of anomalies presents a higher risk of failure than segments where anomalies are not detected.
- Pipeline bend & valve locations: Pipe bend and valve locations are considered more vulnerable to failure than straight sections during a flood event.

Where integrity weaknesses are identified along the pipeline (that will either reduce the strength of the pipeline, or be exacerbated in the event of flooding), that intersect areas of elevated flood hazard, then a higher level of vulnerability should be assigned by the operator.

4.2 Flooding Hazards to Buried Pipelines

Buried pipelines that experience flood events may be exposed to a number of damage mechanisms, which are defined in the UKOPA GPG - Hydrotechnical Hazard Integrity Management [14] and summarised below:

Loss of pipeline support - Scouring can cause a buried pipeline to become exposed. Further erosion under the exposed pipeline removes support from that section. A pipeline is unlikely to have been designed as unsupported. Any unsupported length of pipe should be assessed to ensure it does not exceed the maximum allowable unsupported length. Overcrossings can lose their supports due to scour (or impact) undermining the support structure or an increase in water level can move a pipeline off its supports resulting in an excessive unsupported length.

Buoyancy - Flooding could cause a pipeline without buoyancy control to float following exposure.

Hydrodynamic loads – Once exposed, forces can be imposed on a pipeline by moving water including river or sea currents, and/or wave loading. Debris caught on the pipeline can increase the effective surface area exposed to flow, thereby increasing the magnitude of hydrodynamic forces.

Impact loads – Once exposed, debris transported within water flow downstream can impact the pipeline. Larger debris can be transported during periods of higher flow such as during flooding conditions. Debris impact can damage coating or introduce geometric anomalies into a pipeline.

Soil Saturation – Clayey soils weaken when saturated, turning soft and reducing load support. Saturated slopes may fail, while dry periods can lead to cracks that allow subsequent water intrusion during periods of rainfall.

Corrosion – Pipeline sections originally designed for burial may lack an adequate coating or experience coating damage if exposed. Exposed pipeline steel at areas of coating damage is vulnerable to

corrosion. Horizontal channel scour or coastal erosion could cause cathodic protection components to be compromised.

Fatigue – May result from progressive structural weakening and potential failure caused by cyclic loading. A free spanning pipeline can experience fatigue damage due to vortex induced vibration (VIV), caused by vortex shedding. VIV can be split into two hydrodynamic force components:

- Cross-flow where pipeline movement is perpendicular to flow induced by lift forces.
- In-line where pipeline movement is parallel to flow induced by drag loads.

If the resulting oscillations occur at or near the natural frequency of the pipeline span, failure can occur rapidly. DNV-RP-F105 gives further guidance on the assessment of free spanning pipelines subjected to combined wave and current loading [15].

Third party damage – Once exposed during a flood event, a pipeline may be more vulnerable to damage. Potential sources of third-party damage include the public or emergency response activities.

There is no explicit data set or guidance to enable detailed integration of these risks into the overall failure frequency, however, pipeline operators should be aware of these failure mechanisms and consider potential areas of vulnerability along the pipeline route and escalate the hazard rating of those pipeline sections accordingly.

4.2.1 Failure Examples

Table 4-1 below presents real-life examples of pipeline failures under the mechanisms discussed above.

Incident	Failure Mechanism	Description
<i>San Jacinto River, Texas, 1994</i>	Soil Erosion / Scour	Record floods scoured out riverbeds and new channels, removing cover from multiple pipelines. Eight pipelines ruptured and 29 were undermined when the river changed course and exposed them, spilling ~1.47 million gallons of petroleum into the floodwaters. The event resulted in subsequent fires in flooded neighbourhoods and prompted a re-evaluation of pipeline design in floodplains. The spill response costs were in excess of \$7 million and estimated property damage losses were about \$16 million ²³ .
<i>Pembina Red Deer River (near Sundre, Alberta), 2008</i>	Soil Erosion / Scour (riverbed erosion + channel movement undermining crossing)	High river flows/channel movement undermined a crude oil pipeline at the Red Deer River crossing, leaving a segment effectively unsupported/suspended; external stress then caused the release. Volumes reported as ~75–125 bbl by the operator and up to ~200 bbl (≈32,000 L) by regulators ²⁴ .
<i>Exxon Silvertip (Yellowstone River, Laurel, Montana), 2011</i>	Soil Erosion / Scour / Washout (flooding + debris loading/external force at river crossing)	During prolonged high runoff/flooding, the river crossing failed; the PHMSA investigation describes washout/external force damage with debris caught on the line increasing stress until severance. Reported release ~1,500 barrels into the Yellowstone River ²⁵ .
<i>Bacton Gas Terminal, Norfolk, 2013</i>	Coastal Erosion via Storm Surge	Coastal flooding washed away 10 metres of cliff protecting the Bacton gas pipelines, leaving only ~15 m of land between the North Sea and critical gas pipes. Several pipeline sections were nearly exposed as the soil cover and cliff-face was removed by wave-action, although preventative action was taken prior to a failure ²⁶ .
<i>Bridger “Poplar” Pipeline, Yellowstone River (near Glendive, Montana), 2015</i>	Soil Erosion / Scour (riverbed scour/exposure at crossing; winter ice conditions complicated response)	Poplar Pipeline discharged ≥30,000 gallons of Bakken crude oil into the Yellowstone River upstream of Glendive; trustee documentation describes winter ice/snow conditions and downstream sheen observations. Separate reporting on enforcement/penalty notes the crossing failed after being exposed due to river scour ²⁷ .

²³ <https://www.nts.gov/safety/safety-studies/Pages/SIR9604.aspx> (Accessed 12/09/2025)

²⁴ <https://www.cbc.ca/news/canada/calgary/heavy-river-flows-caused-oil-leak-into-poplar-alberta-lake-regulator-1.845850> (Accessed 30/04/2026)

²⁵ https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/docs/ExxonMobil_HL_MT_10-2012.pdf (Accessed 30/04/2026)

²⁶ <https://www.energyvoice.com/oilandgas/north-sea/204251/erosion-threatens-uk-gas-terminal-with-collapse-into-north-sea/> (Accessed 12/09/2025)

²⁷ <https://www.ktvq.com/news/montana-news/pipeline-companies-agree-to-pay-12-5-million-civil-penalty-for-oil-spills-in-montana-and-north-dakota> (Accessed 30/04/2026)

Incident	Failure Mechanism	Description
<i>Maidstone, Saskatchewan, Canada, 2016</i>	Ground Movement / Landslide	Weeks of heavy rain saturated clay shale slopes, causing ground movement (landslide) that buckled and cracked the buried pipeline. The sudden one-time slope failure pulled apart the pipeline beneath a riverbank ²⁸ .
<i>Amherst, South Dakota, 2017</i>	Design Issues	The Keystone crude oil pipeline ruptured in a waterlogged area, spilling approximately 5,000 barrels of crude oil. Investigators found that concrete weight anchors, installed to prevent floatation in high water-table soils, had damaged the pipe's coating and wall over time. This weight-induced damage led to a sudden failure in November 2017. The incident highlighted how flood-prevention measures (like pipeline weights) can backfire if not engineered properly ²⁹ .

Table 4-1 - Example Buried Pipeline Flood Incidents

²⁸ <https://www.sasktoday.ca/southeast/local-news/the-dirt-did-it-4099824> (Accessed 12/09/2025)

²⁹ <https://www.npr.org/sections/thetwo-way/2017/11/29/567267101/keystone-spill-likely-caused-by-construction-damage-investigators-say> (Accessed 12/09/2025)

5 CONSEQUENCE OF FAILURE

If a pipeline does fail due to flooding, the consequences can be severe. Pipeline operators should evaluate the potential impacts that could result from a failure at each flood-prone location. Consequence evaluation in this context considers who and what would be affected by an unintended release of pipeline contents, given the presence of floodwaters or flood-induced conditions.

At this stage it is important to consider the contents of the pipeline, which are split into two groups. The two groups are;

- Natural gas and hydrocarbons which volatilise upon release due to their boiling points being below ambient temperature (e.g. butane and propane, typically in the C1-C4 range); and
- and hydrocarbons that remain in liquid form (e.g. kerosene and diesel, typically in the C5+ range).

For hydrocarbons that volatilise upon release, the main concern is subsequent ignition and generation of thermal radiation which poses a risk to people and the environment. The consequence to people is considered via datasets that identify where people are likely to be present or concentrated, such as residential and public buildings (e.g. houses, schools, places of worship, hospitals, and urban environments), and may also include businesses such as stores, restaurants, recreation sites. For liquid releases, the environmental surroundings are sensitive to impacts including designated and protected areas, habitats and agricultural land, alongside receptors such as surface waters, areas where fishing and aquaculture are undertaken. Similarly, groundwater is vulnerable to impact from liquid releases.

5.1 Public Safety and Socio-Economic Impacts

The risk to people in the vicinity of a flood-related pipeline failure is paramount. For natural gas and liquid under pressure pipelines, a rupture in flood conditions could lead to gas release and subsequent fire or explosion (if ignited) with thermal radiation affecting nearby individuals. In the case of liquid pipelines (oil or refined products), the immediate safety hazard might be lower (no explosion risk unless the product is flammable and an ignition source is present), but there is still risk of fires or toxic exposure from volatile components. Additionally, floodwaters can spread hazardous substances over a wider area – for example, fuel from a ruptured pipeline could contaminate floodwaters that come into contact with residents or rescue personnel at significant distances from the break site. When assessing consequences, operators should note the presence of any nearby population centres, houses, businesses, or critical infrastructure (like roads, schools, hospitals) that could be impacted by a release. Highly populated or sensitive sites (e.g. schools, hospitals) near the pipeline will elevate the societal risk consequences.

When assessing public safety and socio-economic consequences along a pipeline route, receptor sensitivity may be evaluated using the HSE Land Use Planning (LUP) Methodology. The HSE LUP Methodology classifies developments by occupancy, vulnerability, and land use type, and provides a structured, qualitative means of reflecting societal exposure within consequence assessment.

The HSE LUP Methodology does not define any numerical receptor sensitivity scoring system and does not explicitly quantify the likelihood or severity of harm. Instead, it assigns developments to broad sensitivity categories. In the absence of further quantification within the guidance, these high-level categories represent the only formal basis available for differentiating societal consequence within a non QRA framework. As such, the approach provides a simple but inherently blunt tool for incorporating societal concerns into an otherwise individual risk-based assessment.

Used in this way, the LUP framework helps ensure that consequence scoring reflects not only proximity to the pipeline, but also the nature of surrounding receptors, allowing higher consequence scores to be assigned where populations, critical activities, or essential infrastructure could be significantly affected. Some pragmatic adaptation of the guidance may therefore be appropriate when applying it to pipeline risk screening and prioritisation.

The following receptor groupings are typically considered:

- Houses and populated areas: Residential areas and other populated developments are treated as high sensitivity receptors, as people may be exposed to thermal radiation, overpressure, or toxic effects following a loss of containment event. Under HSE LUP guidance, such locations fall within the highest sensitivity categories.
- Transport routes: Roads, railways, and other transport corridors can contribute to socio economic consequences through disruption to movement, access, and emergency response. These are generally considered lower sensitivity than residential receptors under HSE LUP, but remain relevant where network disruption could be significant.
- Businesses and workplaces: Commercial and industrial facilities typically represent medium sensitivity receptors due to potential impacts on workers and business continuity. Sensitivity may increase for sites with high occupancy or critical operational functions.

These receptors may be affected by both gaseous and liquid phase hydrocarbon releases.

For certain pipeline systems — particularly natural gas pipelines — fully quantitative risk assessment (QRA) models are readily available and can be used to predict physical consequences (e.g. thermal radiation, overpressure, and individual or societal risk contours) explicitly. A QRA approach allows consequences and risk to be quantified in probabilistic terms and provides a more refined representation of harm and societal risk.

By contrast, the HSE Land Use Planning Methodology does not constitute a quantitative consequence model. Its use in this context is intended as a pragmatic, conservative screening approach to introduce societal considerations where a full QRA is disproportionate, unavailable, or outside the scope of the assessment. The resulting consequence scores should therefore be interpreted as indicative rather than predictive, and suitable for prioritisation and comparison rather than absolute risk quantification.

5.2 Environmental and Water Impacts

Flood-related pipeline failures can have major environmental consequences. A rupture of an oil pipeline can release large volumes of product into floodwaters that then disperse into the surrounding environment, contaminating soil, surface waters, and potentially groundwater over a broad area. Environmentally sensitive areas along the pipeline route – such as protected habitats, nature reserves, watercourses supporting fisheries, groundwater source protection zones or agricultural land – should be identified as receptors at risk. Even a gas pipeline failure can have environmental impacts: for instance, fires from ignited gas may damage vegetation or habitats. In flood scenarios, spilled liquids may be carried far from the failure point, so any downstream aquatic habitats or water supply intakes could be at risk and should be considered in consequence analysis.

The receptors considered under potential environmental impacts are summarised in Table 5-1, along with whether they are considered to be at risk from a liquid or gaseous release. The table also highlights publicly available data sources, which are generally available in GIS format, and which may be used to help assess sensitivity along the pipeline route.

5.3 Business and Supply Implications

If a pipeline segment is taken offline by a failure, there could be significant downstream effects on customers (e.g. fuel shortages or gas supply interruptions to consumers or industrial facilities). Operators might internally estimate the impact of an outage in terms of cost, lost throughput, and contractual or economic ramifications. Reputational damage and potential regulatory fines following an incident are further considerations. These factors can be included in a separate business risk or consequence evaluation, but they are not explicitly accounted for in the technical risk scoring of this GPG (which is focused on health, safety, and environmental impacts). However, operators should be aware of these broader impacts when prioritizing mitigations (for instance, a pipeline supplying a critical power station might be prioritized due to the high economic/societal cost of failure-induced downtime, even if the immediate safety risk is low).

Receptor Type	Receptors	Liquid vs Gaseous Vulnerability	Data Source
Internationally Designated Sites	SPA SAC Ramsar	Liquid and Gaseous	MAGIC (Accessed 29/01/2026) Advisor to Government on Nature Conservation JNCC (Accessed 29/01/2026) Scotlands environment map (Accessed 29/01/2026) NRW Interactive Map Viewer (Accessed 29/01/2026)
Nationally Designated Sites	SSSI NNR MCZ	Liquid and Gaseous	See Internationally Designated Sites
Other Designated Land	Local Wildlife Trusts Ancient Woodland Country Parks	Liquid and Gaseous	See Internationally Designated Sites
Priority Habitats	Designated Habitats	Liquid and Gaseous	See Internationally Designated Sites
Agricultural Land	Agricultural Land	Liquid and Gaseous	OS Mapping Google Earth MAGIC (Accessed 29/01/2026)
Aquaculture and Fishing	Aquaculture and Fishing	Liquid only	Home - Angling Trust (Accessed 29/01/2026)
Surface Water	Surface Water	Liquid only	MAGIC (Accessed 29/01/2026) SEPA Flood Risk Mapping EA Flood Risk Mapping
Groundwater	Groundwater	Liquid only	BGS Accessed 29/01/2026) MAGIC (Accessed 29/01/2026) NRW Interactive Map Viewer (Accessed 29/01/2026)

Table 5-1 - Environmental Receptors

5.4 Example Output

Figure 5.1 presents receptors identified in the vicinity of the point of interest along our hypothetical pipeline route, with associated consequence scores. The example assumes the pipeline contains a hydrocarbon that remains liquid on release.

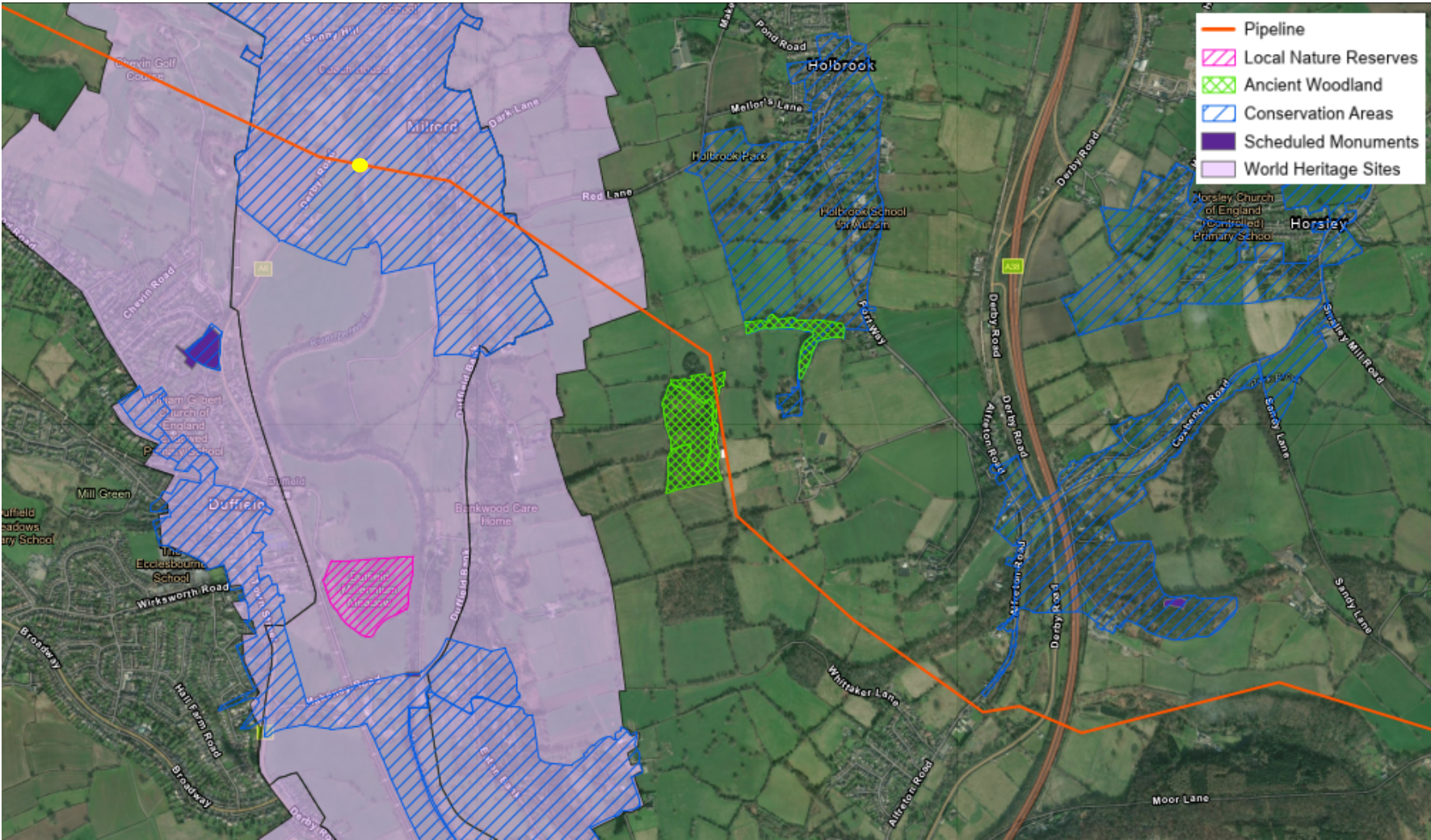


Figure 5.1 – Receptor Consequence on Pipeline Route

Based on the presence and location of surrounding receptors, an example of consequence scoring is provided in Table 5-2.

	Distance from Receptor						
RECEPTORS	Within	<50m	50-100	100-250m	250-500m	500 - 1,000m	1 - 5km
People, Built Environment and Transport							
People and Population Centres	10	8	7	6	4	2	1
Built Environment Areas	8	5	2	0	0	0	0
Transport	8		5	4	0	0	0
Environmental Receptors							
International/National Protected Areas	10	6	5	3	0	0	0
Local Protected Areas	8	3	2	1	0	0	0
Agricultural Land	10	8	7	6	4	0	0
Water Environment							
Surface Waters	10		8	6	4	2	0
Groundwater	10	0	0	0	0	0	0

Table 5-2 - Receptor Consequence Score

Using the consequence scoring in **Error! Reference source not found.**, the results for our example point of interest are summarised in Table 5-3, where the consequence scores are summed for each of the receptor groupings (each out of 10), giving a maximum consequence score of 30.

The consequence score is presented geographically in Figure 5.2. In our example the quantified consequence score for our point of interest is 26 out of 30.

Receptor Type	Distance	Consequence Score
People, Built Environment and Transport: 6		
Population Centres	Within 250m	6
Built Environment & Transport	Within 250m	0
Environmental Receptors: 10		
Internationally Designated World Heritage Site	Intersection	10
Local Protected Area	Intersection	8
Agricultural Land	Intersection	10
Water Environment: 10		
Surface Water	Intersection	10
Aquaculture and Fishing	Not identified.	0
Groundwater	No intersection	0
Total Consequence Scores	26	

Table 5-3 - Example Receptor Consequence Score on Pipeline Route

It is worth noting that for a pipeline containing gaseous phase hydrocarbon upon release it is unlikely that a release will pose a significant risk to the water environment, and would not be considered in the consequence score. In the example above the Total Consequence Score would be 16 (excluding the consequence score contribution of 10 for the water environment). It may be appropriate to review thermal radiation contours to consider the impact from ignition of a gaseous release.



Figure 5.2 – Example Pipeline Consequence Output

6 RISK ANALYSIS

6.1 Risk Calculation

With both the likelihood of a flood-related failure (derived from flood hazard, escalation factors, vulnerability and pipeline integrity indicators) and the consequences of such a failure quantified for each location, the next step is to calculate flood-related pipeline risk.

For the purposes of this Good Practice Guide, UKOPA recommends the use of a semi-quantitative scoring approach, as defined in Sections 2 to 5 of this document. This approach provides a consistent, transparent and repeatable method for comparing relative flood risk across a pipeline network and identifying locations that may warrant prioritisation, further investigation or mitigation.

Under this recommended approach:

- Flood hazard scores are assigned based on statutory flood datasets (e.g. fluvial, coastal, pluvial, groundwater, reservoir/canal), with escalation factors applied where appropriate (e.g. flood depth, historical flooding).
- Location-specific vulnerability scores are assigned based on soil type, ground slope and depth-of-cover.
- Consequence scores are assigned based on the proximity and sensitivity of population, environmental and water receptors.

These components are then combined to generate a composite flood risk score for each assessed pipeline segment.

6.1.1 Example Risk Score Formulation

To maintain consistency with the worked examples presented in this GPG, the following formulation is provided as an illustrative example:

Flood Risk Score = ((Flood Hazard Score × Escalation Factors) + Vulnerability Score) × Consequence Score

This formulation reflects two key principles of good practice:

- Flood hazard and vulnerability together influence the likelihood of failure.
- Consequence severity acts as a multiplier, ensuring that locations with sensitive receptors are appropriately prioritised even where likelihood is moderate.

Escalation factors (e.g. for flood depth or historical flooding) should be applied directly to the flood hazard score before combination with vulnerability.

Using the example pipeline location presented in Sections 2 to 5:

- Flood Hazard Score (after escalation): **4.4** (4×1.1)
- Vulnerability Score: **7.5**
- Consequence Score: **26**

The resulting risk score is:

Flood Risk Score = $(4.4 + 7.5) \times 26 = 309.4$

This value represents a relative flood risk index, intended for comparison against other locations on the same pipeline or network, rather than an absolute measure of failure probability.

To support consistent interpretation, operators are advised to define network-specific risk bands. As indicative guidance only, the following ranges may be considered:

Flood Risk Score	Indicative Risk Category	Typical Response
< 100	Low	Manage through routine inspection and monitoring
100 – 300	Medium	Prioritise for enhanced monitoring or further assessment
> 300	High	Consider mitigation, detailed engineering assessment, or intervention

These thresholds are illustrative and should be calibrated by each operator based on pipeline characteristics, operating context, regulatory expectations and risk tolerance.

Qualitative risk matrices (e.g. Low / Medium / High likelihood versus consequence) may be useful as a high-level communication or screening tool, particularly during early assessment stages or for stakeholder engagement. However, due to their limited resolution, they are not recommended as the primary method for flood-risk evaluation under this GPG.

The semi-quantitative approach set out in this document provides greater discrimination between locations, better supports prioritisation, and aligns more closely with integrity-management decision-making.

6.2 Risk Prioritisation

The flood risk scores calculated in Section 6.1 provide a relative, semi-quantitative basis for prioritising pipeline segments according to their exposure to flood-related failure, taking account of hazard likelihood, location-specific vulnerability, pipeline integrity considerations, and consequence severity.

The primary purpose of risk prioritisation within this Good Practice Guide is not to estimate absolute failure probability, but to enable operators to:

- Identify flood-risk “hotspots” along the pipeline network;
- Rank locations consistently and transparently;
- Direct resources toward locations where further investigation, enhanced monitoring, or mitigation is most likely to be required.

Flood risk scores should therefore be used to produce a ranked list or mapped output of pipeline segments, with higher scores indicating higher relative flood risk.

6.2.1 Risk Categories and Use of Thresholds

To support consistent interpretation of results, operators are advised to define risk categories or bands against the calculated flood risk scores. These categories provide a practical link between risk assessment outputs and decision-making.

As indicative guidance only, operators may consider defining thresholds broadly along the following lines:

- Low flood risk – locations with low combined hazard, vulnerability and consequence scores, typically manageable through routine inspection and monitoring.
- Medium flood risk – locations with either elevated likelihood or elevated consequence, where enhanced surveillance, targeted inspections, or further assessment may be appropriate.
- High flood risk – locations with high combined likelihood and consequence, where mitigation, engineering assessment, or operational controls should be actively considered.

The numerical boundaries between these categories should be calibrated by the operator to reflect pipeline type, operating conditions, regulatory expectations, historical performance, and overall risk tolerance. The thresholds may differ between operators or between different pipeline systems within the same organisation.

6.2.2 Linking Risk Scores to Action

Risk prioritisation should be explicitly tied to defined management responses. Examples include:

- Triggering site-specific inspections following flood events;
- Commissioning detailed assessments (e.g. hydraulic modelling, scour analysis, geotechnical review);
- Prioritising mitigation measures such as increased depth-of-cover, bank protection, slope stabilisation, or enhanced protection at crossings;
- Informing emergency-response planning for flood-prone locations.

The prioritisation process should ensure that locations where both likelihood and consequence are elevated are addressed first, while lower-risk locations continue to be managed under routine integrity programmes.

6.2.3 Screening and Scope Considerations

Where appropriate, operators may screen out pipeline segments where flood hazard has been assessed as negligible or absent, focusing prioritisation efforts on locations where flooding is a credible threat. Operational vulnerability or consequence information may still be relevant for other integrity threats, but should not be escalated within the flood-risk prioritisation process unless flood interactions are present.

6.2.4 Review and Update of Risk Rankings

Flood risk prioritisation should not be treated as a one-off exercise. Operators are advised to review and update flood risk rankings periodically, or when new information becomes available, including:

- Updated flood datasets or revised climate-change projections;
- Observed changes in river behaviour, erosion or ground conditions;
- Recorded flood events affecting the pipeline route;
- Changes in land use or receptor sensitivity near the pipeline;
- Results of inspections, surveys, or mitigation works.

Regular review ensures that the prioritisation remains reflective of current conditions and continues to support proactive integrity management.

6.2.5 Relationship to Decision-Making and ALARP

The outcome of risk prioritisation should support proportionate, risk-based decision-making consistent with the ALARP principle. Higher-ranked locations are those where risk reduction measures are more likely to be necessary or reasonably practicable, while lower-ranked locations may be managed through monitoring and periodic reassessment.

In this way, the flood risk prioritisation process provides a clear and auditable link between hazard identification, risk assessment, and mitigation planning, supporting both regulatory engagement and internal integrity-management objectives.



Figure 6.1 – Example Pipeline Risk Output

7 MITIGATION MEASURES

7.1 Inspection and Maintenance Programmes for Flood Risk

After identifying and prioritizing high-risk areas, the final step is to implement measures to mitigate (reduce) the risk of flood-related pipeline failure. Mitigation strategies typically fall into several categories: enhanced monitoring and inspections, engineering modifications or protections for the pipeline, and operational or procedural changes (including emergency preparedness). This section provides guidance and examples of mitigation options. Operators should choose measures appropriate to the severity of risk, site conditions, and operational constraints, often employing a combination of strategies for robust risk management.

The applicable design framework for hydrocarbon pipelines in the UK consists of a combination of European harmonised standards and UK-specific detailed design codes.

At a high level, pipeline systems are governed by standards which define overarching functional and safety requirements, and these are:

- BS EN 14161³⁰ – Petroleum and natural gas industries: Pipeline transportation systems, and
- BS EN 1594³¹ – Gas supply systems: Pipelines for maximum operating pressure over 16 bar.

However, these standards are not intended to provide detailed, prescriptive design rules. In particular, BS EN 1594 is a functional specification rather than a detailed design code.

For detailed technical design, assessment and verification of onshore pipelines in the UK, the principal codes of practice are:

- BS PD 8010-1 – Pipeline systems: Steel pipelines on land – Code of practice, and
- IGEM/TD/1 – Steel pipelines for high-pressure gas transmission (for gas pipelines).

These documents set out the detailed engineering requirements for route selection, wall thickness, design factors, external loads, geotechnical and hydrotechnical hazards, construction, testing, and integrity management, and are widely recognised by industry and the HSE as representing established UK good practice.

Accordingly, flood-risk mitigation, inspection, and engineering measures described in this GPG should be read as complementary to — and implemented consistently with — the requirements of PD 8010-1 and, where applicable, IGEM/TD/1.

Engineering controls and analysis alone are not enough – an effective inspection and maintenance programme is vital to manage flood risk throughout a pipeline's operating life. This ensures that emerging threats (like newly eroded sections or changing environmental conditions) are detected and addressed before they result in failure.

Below, we detail what a robust programme could include for pipelines in flood-prone areas, including inspection frequency, techniques, and upkeep practices as established by industry standards and best practices. Some examples include:

- UK pipeline operators often have dozens of flood hotspots on their networks – e.g., river crossings, low-lying segments – flagged for enhanced monitoring.
- Critical pipeline water crossings are typically inspected at least annually in fair weather, and after every major flood event.

³⁰ <https://standardsdevelopment.bsigroup.com/projects/2021-01179> (Accessed 11/09/2025)

³¹ <https://knowledge.bsigroup.com/products/gas-infrastructure-pipelines-for-maximum-operating-pressure-over-16-bar-functional-requirements-1> (Accessed 11/09/2025)

- Undertaking routine in-line inspections (e.g. via smart pigs) to detect corrosion, deformation or strain in the pipeline

7.1.1 Routine Right-of-Way Surveillance and Inspections

Regular surveillance of the pipeline right-of-way (ROW) is a frontline defence against flood damage. Even when no flooding is occurring, scheduled patrols can reveal vulnerabilities before the next flood hits. Industry practice includes:

Ground patrols (line walking): Trained pipeline technicians or patrolmen walk (or drive) the pipeline route at set intervals. In the UK, high-pressure pipelines are often patrolled every 2 weeks by vehicle or aerial means to detect potential third-party interference. For flood / erosion risk areas a focused walked inspection at least once a year for each water crossing or flood-prone segment is recommended. During these patrols, the inspector looks for signs of erosion, such as exposed pipe, settlement troughs, new gullies, or bank erosion near river crossings. They also check pipeline markers, riverbank protection measures, and drainage along the ROW.

Aerial surveillance: Many operators use aerial patrols (helicopter, small plane, or increasingly drones / UAVs) to cover long distances quickly. While aerial patrols primarily look for third-party activities, they are also useful directly after a flood event when ground access might be limited. Drones equipped with high-resolution cameras can fly along a flooded pipeline route to spot exposures or washouts in real time. Post-flood drone surveys have become part of best practice, as they can cover inaccessible areas and produce detailed imagery of eroded sections. Routine inspections can be overlain with imagery to identify differences – particularly useful after a flood event to help analyse requirement for intervention.

Special inspections after extreme weather: An inspection programme should mandate inspections promptly following significant flood events. If heavy rains or regional floods have occurred, operators should dispatch teams (ground or drone) as soon as it's safe to do so, to check all known high-risk locations. For example, if a pipeline crosses the River Severn and the Severn bursts its banks in a storm, the crossing should be inspected as soon as waters recede. Many operators adopt a rule like “any 1-in-50 year or greater flood in the area, triggers an inspection of affected pipeline segments.” As mentioned earlier, risk-based plans ensure that a pipeline crossing a flood-prone river is patrolled and checked after every flood event.

Coverage and documentation: Each routine patrol (whether scheduled or event-driven) should be documented in maintenance records, noting observations and any anomalies. Observations might be classified (e.g., no issues, minor erosion, significant exposure, etc.). Over time, trends can be identified – for instance, “this corner of the riverbank has eroded 2 m since last year” – prompting proactive maintenance before the next flood season.

Notably, UKOPA GPG/017 on-Line Walking Surveys standardizes how operators perform and record these ROW inspections, ensuring consistency. It's good practice to integrate flood-specific checks into these general survey routines.

Any actions required as part of the inspection should also be recorded and implementation tracked.

7.2 In-Line Inspection and Geotechnical Monitoring

While ROW patrols catch external, visible issues, in-line inspection (ILI) tools and geotechnical monitors catch hidden or subtle problems inside the pipe or underground:

In-Line Inspection (ILI): These are the “smart pig” tools sent through the pipeline to scan for metal loss, deformation, and other integrity issues. Although ILI primarily detects corrosion or mechanical damage, it is highly relevant to flood risk.

- **Deformation:** If a flood event or landslide has bent or strained the pipe, modern ILI tools (calliper or inertial measurement pigs) can detect a change in shape or alignment. For example, a slight buckle or wrinkle in the pipe caused by ground movement can be identified.

- **Metal loss:** Flooding can strip coating and increase external corrosion at exposed sections. ILI can identify new corrosion patches for repair.

Many UK operators run ILI every 5–15 years on major pipelines. For segments subject to geotechnical threats, they might use a geometry pig more frequently, or immediately after a known landslide incident. If pipeline pigging is not an option (older, no launcher/receiver), direct assessment using excavations or external tools (like ultrasonic probes) should be considered.

Depth of cover surveys: This is a specialised inspection to measure how much cover remains above the pipeline. This can be done with probing rods or electromagnetic tools calibrated to the pipe depth. Doing this at river crossings or suspected erosion areas every few years will show if cover is diminishing over time. Some operators complete in-line inspections with an Inertial Measurement Unit (IMU) that can estimate cover or at least detect if a pipe is above ground (some high-end pigs can detect an “air” signal vs. soil).

Strain gauges and fibre optics: In high-risk areas (like unstable slopes), an advanced practice is installing strain sensors on the pipeline or fibre-optic sensing cable alongside it to monitor strain continuously. This is not yet industry-wide standard, but is increasingly adopted for landslide-prone locations. These sensors can alert operators if the pipe starts to bend or tension increases (which might happen if soil support is eroding or the pipe is being pulled by shifting ground). If an alarm triggers (e.g., fibre optic detects strain beyond threshold during a flood), engineers can respond immediately.

Groundwater and pore pressure monitoring: In some cases, operators might embed piezometers or use nearby boreholes to monitor groundwater levels around the pipeline, particularly on slopes. If an instrument shows water pressure building in a slope after heavy rain, it could prompt a precautionary reduction in pressure or increased monitoring of that pipeline segment.

In summary, ILI finds what patrols can't see – internal damage or pipe movement. Combined with external surveillance, it provides a comprehensive picture of pipeline health after floods.

7.3 Maintenance and Mitigation Activities

The goal of the inspections are to identify issues, while the goal of maintenance is to address them. An industry-standard maintenance programme addresses flood-related vulnerabilities promptly. Key elements include:

Erosion repairs and backfilling: If patrols or inspections discover an exposed pipeline section or significantly eroded cover, the immediate action is to secure that area. Pipelines should not be left exposed due to risk of external damage and stress from an unsupported span. UK operators treat these as high priority: for instance, after Storm Desmond, pipeline companies mobilised crews to quickly sandbag and backfill exposed pipeline sections. The guidance is to backfill and re-cover exposed pipes as soon as practicable after a flood. Temporary measures (foam trench breakers, sandbags, plastic sheeting to prevent further washout) might be used until permanent restoration is achieved. If riverbanks are washed out, operators often place riprap (rock fill) to rebuild support for the pipeline.

Slope stabilization and drainage maintenance: For slopes along the ROW, maintenance includes keeping drainage ditches clear, cleaning out culverts, and ensuring any installed slope protection is intact. If minor slides or slumps are noted, these should be remediated during fair weather (e.g., regrade the slope, compact and re-vegetate). It's cheaper and safer to address a slip in its early stages, before it develops further. Measures such as trench breakers or French drains in the pipeline trench on slopes should be inspected and maintained in order to prevent water from running along the pipe and eroding hillsides.

River crossing maintenance: Inspect and maintain riverbed armouring or weights. Many pipeline crossings have protective works – like concrete mats, gabion baskets, or sheet piling. Floods can dislodge or undermine these. After floods, submerged crossings should be inspected. If any exposure or free span is detected under water, remedial work should be scheduled (such as placing additional rock armour or grout bags). Additionally, if a river channel has migrated significantly toward a pipeline

that runs near a bank, its bank should be stabilised (perhaps working with the EA and local authorities, who often have programmes for riverbank protection).

Cathodic protection (CP) checks: After flooding, verify the CP system (which protects against corrosion) is still functioning correctly. Floods can damage CP test posts or wiring, and if a pipeline coating was damaged or scraped by debris, the CP current demand might increase. A quick CP survey will confirm adequate protection is maintained. This is important because an exposed pipe without coating in wet soil can corrode rapidly.

Frequency of maintenance tasks: Many flood mitigation maintenance tasks are done annually (often post-winter). For example, pre-winter inspections and maintenance to ensure everything is ready for the wet season: clear drains, reinforce any thin spots of cover, etc. Then post-winter repairs if needed. Additionally, a comprehensive 5-yearly review of flood risk sites can be scheduled to incorporate new data, as over time the probability and intensity of flood risk will vary.

The programme should also integrate with the company's overall integrity management system – meaning flood risk sites are part of the risk register, and any mitigation actions taken (or needed) are documented and tracked. Operators should adopt a proactive approach: implement mitigation at sites before an incident occurs.

7.4 Documentation, Training, and Continuous Improvement

Industry standards like BS EN 14161 place importance on learning and improving. In context of flood risk:

Maintain records of flood incidents and near-misses: Every time a flood affects a pipeline or even comes close, log it. Record the date, extent, any damage observed, and repairs made. Over decades, this builds institutional knowledge. UKOPA's Pipeline Fault Database collects such data industry-wide, but each operator should have their own records too. Analyse these for trends (e.g., "Segment at River X has required repairs 3 times in 10 years" – maybe a permanent reroute or deeper burial is justified).

Training staff: Ensure that pipeline patrol personnel and integrity engineers are trained to recognize flood hazards. The person walking the line should know, for example, how to identify early signs of scouring or tension cracks on a slope. Also, during flood emergencies, all relevant staff (including control centre personnel) should know the protocol for heightened monitoring or shutdowns if needed.

Continual improvement and review: After major flooding events (whether locally or learning from international incidents), review the procedures. For instance, the 2021 floods in Europe might prompt UK operators to revisit the extreme flood contingencies.

The bottom line is that a robust inspection & maintenance programme for flood risk is preventative and responsive. It prevents problems by keeping the pipeline protected (through regular upkeep and improvements) and is ready to respond quickly when nature throws a severe event at you. By following these practices – routine checks, leveraging advanced inspection tech, rapid repair of erosion, and adaptation over time – pipeline operators can dramatically reduce the likelihood of flood-induced failures.

7.5 Engineering Measures

Flood risk management should be tailored to the local ground conditions. A pipeline section crossing a marshy, low-lying field on a gentle slope might need a focus on keeping it weighted down and covered (to prevent floatation), whereas another section crossing over a hillside needs measures to keep the slope from sliding. The following sections outline how operators should maintain and inspect pipelines to identify flood-related issues early and keep protections in place.

7.5.1 Soil Type

Erodible soils (Sand, Silt, Peat) are easily scoured by flowing water, potentially resulting in a loss of support as soil washes away.

Mitigation measures may include the use of deeper burial, laying protective rock armour over pipeline in flood zones, maintaining vegetation to reduce surface erosion, and monitoring for any signs of trench exposure after floods.

Cohesive soil (Clay) resists initial scour, but saturates and softens, which can lead to slope failures or heavy settlement when wet.

Mitigation measures may include improving drainage (e.g., trench breakers, surface water diversions) to avoid longer term saturation. On slopes, terracing or retaining structures could be considered. Additionally, the pipeline should be inspected for strain after large storms (via ILI or strain gauges), and for settlement.

7.5.2 Ground Slope

Steep slopes can generate surface runoff, leading to gullying and erosion of pipeline cover. Intense rainfall may also trigger slope failures or landslides, potentially resulting in pipeline damage or rupture. In such locations, it may be appropriate to undertake geotechnical slope-stability assessment. Where required, mitigation measures may include improved drainage, re-grading to reduce slope angles, retaining structures, or ground anchors.

Vegetation can increase slope stability by binding soil and reducing surface erosion, and where utilised should be maintained, as loss of established vegetation may reduce slope stability. However, vegetation selection and management should be carefully considered to ensure root systems do not adversely affect pipeline integrity. In particular, indiscriminate or excessive removal of mature vegetation may locally reduce stability in some ground conditions, and vegetation management should therefore be based on site-specific geotechnical judgement rather than routine clearance. Guidance on the use of vegetation for slope stabilisation is provided in CIRIA C708³² and C810³³ guidance.

7.5.3 Depth-of-Cover

If surveys find a shallow cover, operators might re-bury the pipeline deeper or add physical protections. UK operators often apply concrete weight coating or slabs on pipes in floodplains – this not only adds weight (preventing uplift) but also serves as an erosion barrier.

Shallow depth of cover (<1 m) creates a higher risk of exposure – floodwaters can quickly erode thin cover. For existing pipelines, operators may add cover (sandbags, gravel) or install concrete mats over the pipeline. For new pipelines the design objective should be to exceed minimum cover in floodplains (aiming for >1.5 m or greater than the scour depth). Concrete coating or screw anchors may be used in areas with high water table to counteract buoyancy. It is recommended that shallow-cover sections be inspected after every major flood event.

If located in a floodplain, operators should confirm that even deeply buried pipelines have adequate weight coating.

7.6 Detailed Assessments

For more complex or high-risk situations, operators may undertake dedicated analysis or modelling:

Hydraulic modelling: Using tools like HEC-RAS or Flood Modeller to simulate flood behaviour can yield detailed velocity and depth information at pipeline crossings or along corridors. For example, a 2D flood model of a river reach could show how water flows around a pipeline crossing embankment and where the highest scour risk is. If internal expertise is unavailable, pipeline operators often collaborate with flood modelling experts or use data from infrastructure project FRAs (Flood Risk Assessments) in the area.

³² https://www.ciria.org/CIRIA/CIRIA/Item_Detail.aspx?iProductCode=C708&Category=BOOK (Accessed 13/04/2026)

³³ https://www.ciria.org/ci/iCore/Store/StoreLayouts/Item_Detail.aspx?iProductCode=C810&Category=BOOK (Accessed 13/04/2026)

GIS risk mapping: Building a GIS layer that combines flood hazard (probability, depth) with pipeline attributes (elevation of pipe, cover depth, etc.) is very useful. Some operators develop a flood risk scoring system in GIS: for each pipeline segment, calculate a score based on flood zone, distance to water, soil erodibility, etc. This can be done by weighting factors – for example, a segment in a flood zone with sandy soil and <1 m cover gets a high composite score. GIS analysis can also include upstream catchment data: e.g., identify pipeline points that lie downstream of large catchments (meaning high flow potential).

Site inspections for flood risk: In addition to desktop analysis, field inspections of vulnerable sites help refine the assessment. A walkover of a river crossing might reveal, for instance, active bank erosion or debris blockages that aren't evident on maps. Many pipeline operators incorporate flood risk checks into routine patrols – e.g., checking if riverbank markers are still in place or if any exposure is starting to show.

Examples of best practice: One UK pipeline operator (via UKOPA) implemented a Rapid Geohazard Assessment System that integrates flood risk layers in their pipeline GIS³⁴. This system flagged pipeline sections by crossing data from the British Geological Survey (for landslide risks) with floodplain maps, allowing engineers to quickly see where a pipeline is simultaneously in a flood-prone and landslide-prone zone. Such combined analyses are valuable since flood and ground stability hazards often interact.

In practice, this system was developed to support routine integrity management by allowing pipeline engineers to visualise geohazard exposure in a single GIS environment, rather than reviewing multiple datasets separately. The British Geological Survey supplied national-scale landslide and soluble-rock hazard layers, enhanced with records from the National Landslide Database and karst features, which were then spatially truncated to pipeline buffer zones to highlight only the sections where ground conditions could influence pipeline stability. The output consisted of continuous hazard-potential layers that enabled rapid hotspot identification along approximately 18,000 km of high-pressure pipeline network, supporting targeted inspections, prioritised surveillance, and more informed discussions with the safety regulator on how ground-movement risk was being managed.

7.7 Operational Preparedness and Emergency Response

Flood risk mitigation is not only about physical changes – it also involves operational planning and preparedness.

Operators should update or augment their Emergency Response Plans to account for flood scenarios. This includes ensuring that pipeline isolation and shutdown procedures consider flood conditions (for example, the potential need to shut valves if a line is exposed or a leak is suspected during a flood). It also means planning for access difficulties – flooding can wash out roads or make areas only reachable by boat or helicopter. Pre-identify alternative access routes to critical valves or segments, and stage emergency materials (e.g. spill response equipment) in strategic locations that are less likely to be isolated by floodwaters. Coordinate with local authorities for flood emergency response integration, since a pipeline incident might occur amidst a broader flooding disaster.

In some cases, operators might choose to temporarily adjust operating conditions when extreme flood conditions are anticipated. For instance, if a severe flood is forecast in a region, an operator could pre-emptively reduce pipeline pressure or flow rates as a precaution, especially for pipelines carrying highly hazardous liquids through sensitive areas. Reducing pressure lowers the stress on the pipe, and reducing flow can minimize the amount of product released if a failure occurs. Any such actions should be guided by operational feasibility and safety considerations.

After floodwaters recede, have a plan for systematically inspecting and testing the pipeline before resuming normal operations. This might involve patrols to find any exposed or damaged pipeline sections, performing integrity verification (like pressure testing or smart pigging) on segments that were inundated, and repairing any damage to coatings or supports. Also, be aware of third-party activities in

³⁴ https://nora.nerc.ac.uk/id/eprint/7355/1/Lyon_Pipeline_Assessment_Paper.pdf (Accessed 25/02/2026)

the aftermath of floods (as mentioned earlier). Coordination with other utilities and local authorities can ensure that any reconstruction work in the area does not inadvertently damage the pipeline (for example, heavy equipment building or repairing flood defences should be made aware of pipeline locations and depth).

The selection of mitigations should be risk-based and site-specific. For high-risk locations, multiple layers of defence (monitoring + physical protection + emergency planning) may be appropriate. Lower-risk sites might be managed with surveillance and periodic reviews only. It is generally most effective to implement a mix of short-term measures (e.g. frequent inspections or temporary sandbagging of an exposed site) and long-term measures (e.g. pipeline rerouting or installation of permanent scour protection) to ensure both immediate safety and enduring risk reduction. Operators should also balance the need for protection with environmental concerns and regulatory compliance – often working with natural processes (like using vegetative stabilization) can provide sustainable protection without adverse ecological effects.

Lastly, all mitigation actions and their outcomes should be documented. This enables learning and sharing of experience across the industry. UKOPA members regularly update and publish Good Practice Guides such as this one; as new mitigation techniques are proven, they should be adopted proactively without waiting for formal revisions to guidance.

8 CONCLUSION

Flooding presents a complex and multi-faceted threat to the integrity of cross-country pipelines. However, through the structured approach set out in this Good Practice Guide — encompassing flood-hazard identification, location-specific vulnerability assessment, consequence evaluation, risk calculation, and prioritisation — pipeline operators can systematically understand, manage, and reduce flood-related risks across their networks.

This GPG is intended to support operators in identifying relative differences in flood-related risk, highlighting pipeline segments where further investigation, enhanced monitoring, or mitigation may be warranted. It does not seek to define absolute risk tolerability criteria or prescribe mandatory mitigation measures. Rather, it provides a transparent and repeatable framework to identify flood risk, which may inform integrity management decision-making and support proportionate, risk-based responses.

Where risk reduction measures are being considered, operators should evaluate their suitability and necessity in accordance with the ALARP (As Low As Reasonably Practicable) principle. Decisions on whether additional mitigation is required, and the extent of that mitigation, should be informed by engineering judgement and, where appropriate, supported by cost–benefit analysis consistent with UKOPA GPG/025 – Application of Cost Benefit Analysis to Demonstrate ALARP.

By integrating the outputs of this guidance into existing integrity management systems and by applying ALARP-based decision-making to mitigation selection, operators can enhance the resilience of their pipeline assets to flooding, while ensuring that risk reduction measures remain proportionate and justified.

Effective flood-risk management not only reduces the likelihood of pipeline failure, but also helps protect public safety, minimise environmental harm, and maintain secure and reliable energy supply in the face of increasingly extreme weather events. Continued vigilance, the incorporation of new data and techniques, and collaboration across the industry through UKOPA will remain essential to addressing evolving flood risks and sustaining safe pipeline operations across the UK.

9 REFERENCES

A list of references, data sources, and standards relevant to flood risk management for pipelines is provided below. This includes UK legislation, regulatory resources (e.g. flood mapping portals), industry standards, technical studies, and example datasets mentioned in the guide. Operators should consult these resources for more detailed information and apply the most current data and techniques in their assessments.

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- [4] Planning Policy Wales, “Technical Advice Note 15: Development, flooding and coastal erosion,” December 2021.
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- [6] A. Kitchen, M. Roca, A. Kirby and M. Escarameia, Manual on scour at bridges and other hydraulic structures - supplementary guide (SP171) - ISBN: 978-0-86017-939-9, 2021.
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