

Good Practice Guide

Hydrotechnical Hazard Integrity Management

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1 INTRODUCTION

Pipelines are long, linear assets that interact with the surrounding natural environment including coming into close proximity to bodies of water or crossing them. This interaction between water and pipeline assets needs effective management to ensure that pipeline integrity is maintained from the risk of credible hazards. Reducing the probability of pipeline failure at these areas of interaction results in reduced risk to people, environment, assets and property and business operations/reputation. Pipeline standards for construction address crossings of watercourses, but the conditions considered at the design stage are subject to change over time. Changes related to the impact of water over time can result in changes to pipeline crossing design conditions and result in pipeline sections crossing watercourses which were not designed to do so.

For this Good Practice Guide (GPG), a hydrotechnical hazard involves water related threats with the potential to impact pipeline integrity.

This hydrotechnical hazard integrity management GPG aims to provide an overview on the principles involved in developing a hydrotechnical hazard integrity management system including a background to hydrotechnical hazards, risk assessment of identified hazards, and mitigation measures.

1.1 Scope

This guidance is applicable to the integrity management of UK onshore pipelines at risk from hydrotechnical hazards at watercourse crossings or in close proximity to watercourses. The guidance in this document is applicable to pipelines operated by the UKOPA member companies. These pipelines can be categorised as:

- Natural gas transmission and distribution pipelines.
- Petrochemical liquids and gas pipelines.
- Oil and refined liquid hydrocarbon pipelines.

For gas pipelines the guidance is generally applicable to pipelines with maximum operating pressures above 7 bar, however the principles of the document can equally be applied to gas pipelines operating at lower pressures.

This GPG outlines guidance on the background, identification, evaluation, risk assessment, and mitigation of hydrotechnical hazards. It is predominantly aimed at operational pipelines.

1.2 Legislative, Regulatory and Consent Requirements

Table 1 shows applicable legislation, regulatory and consent requirements affecting work in watercourses, estuaries and floodplains in the UK. Table 2 identifies the relevant statutory authorities. They are not intended to be comprehensive, and users should consult a competent legal authority for definitive advice.

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			Water Environment (Controlled Activities) (Scotland) Regulations 2005
Work in watercourses				
Works on, under, or over the seashore lying below the high water mark of ordinary spring tides	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

Issue	England	Wales	Scotland	Northern Ireland
<i>Planning permission</i>	Town and Country Planning Act 1990		Town and Country Planning (Scotland) Act 1997	Planning (NI) Order 1991
<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 [1]		Technical Advice Note 15 [2]	Scottish Planning Policy [3]

Table 1: Legislation, Regulatory and Consent Requirements

Issue	England	Wales	Scotland	Northern Ireland
<i>Flooding</i>	Environment Agency, Local Authority	Natural Resources Wales, Local Authority	Scottish Environment Protection Agency	Rivers Agency
<i>Work in watercourses</i>	Environment Agency, Natural Resources Wales, lead local flood authority, Internal Drainage Boards			
<i>Canals</i>	Canal & River Trust		Scottish Canals	Waterways Ireland
<i>Statutory nature conservation organisation</i>	Natural England	Natural Resources Wales	Scottish Natural Heritage	Northern Ireland Environment Agency
<i>Marine licence¹</i>	Marine Management Organisation	Marine Consent Unit	Marine Scotland	Northern Ireland Environment Agency
<i>Planning permission</i>	Local authorities			

Table 2: Statutory Authorities

¹ Required for construction, deposit or removal of any substance or object, and dredging in and around the sea

1.3 Glossary

The following are intended to familiarise the reader with the terminology in this GPG:

Canal	Artificial bodies of inland water built for navigation.
Catchment	Area of land that drains to a river, drainage system or other body of water.
Dredging	The mechanised removal of material from beneath the water from one area to another. Dredging is regulated but is allowable under certain circumstances with no formal authorisation [4, 5].
Erosion	Process of particle removal by the action of moving fluids over a larger area.
Floodplain	Flat land adjacent to a river or stream which experiences periodic flooding by the river or stream.
Hydrotechnical Hazard	Situation involving the interaction of a pipeline and water with the potential to negatively affect pipeline integrity.
Inland waters	Includes areas of water not categorised as sea. Examples are canals, tidal and non-tidal rivers, lakes, lochs and some estuarial waters (an arm of sea that extends inland to meet the mouth of a river) [6].
Internal Drainage Board	Responsible for land drainage, water level management and flood risk management works on ordinary watercourses in areas of special drainage known as drainage districts.
Main River	Applicable to England and Wales. River marked on the official main river maps held by the Environment Agency and Natural Resources Wales. A main river is generally a larger river or stream but can be a smaller watercourse. The Environment Agency or Natural Resources Wales carries out maintenance, improvement or construction work on main rivers to manage flood risk [7].
Ordinary Watercourse	Applicable to England and Wales. River, stream, ditch, drain, cut, dyke, sluice, sewer (other than a public sewer) and passage through which water flows, but which is not designated a 'main river'. Local authorities, district councils and internal drainage boards carry out flood risk management work on ordinary watercourses [7].
Overcrossing	An exposed pipeline crossing a water feature or other obstacle above ground level. It may be self-supporting or use other civil structures for support.
Scour	Localised erosion as a result of hydraulic action.

2 HYDROTECHNICAL HAZARDS

Pipelines are designed, constructed, and operated to function safely in dynamic natural environments. Rivers are not fixed features and change shape over time. Erosion can cause rivers to shift course, as well as widen and deepen their channels. Similarly, a coastline is everchanging with various processes at work altering the shape of the sea and land interface. These changes can happen slowly over time (years) or rapidly as a result of both natural events such as heavy rain and landslides, or human interaction with the landscape such as changes in land use.

Floods may be a significant hazard and can occur rapidly, but flood waters will recede with time. However, the consequences of river and coastal erosion may be permanent.

The general principles governing design of pipeline watercourse crossings require identification of plausible risks that could impact pipeline integrity with appropriate mitigation implemented. These risks may have changed since the pipeline was originally designed and constructed.

Ongoing integrity management activities should include watercourse surveys to allow identification of changes to the pipeline and river including the riverbed and riverbank. This information can be used to assess any change in risk to pipeline integrity.

Hydrotechnical hazards are situations involving the interaction of a pipeline and watercourse with the potential to negatively affect pipeline integrity. These hazards will develop when the shape of a river changes causing a pipeline to be outside of its design conditions. Erosion of the riverbed and/or riverbank can result in changes in riverbed elevation and/or lateral movement of the river channel exposing pipelines to increased risk of damage. Channel migration can put a pipeline, which was previously not at risk from the watercourse, at risk due to the new river position. Coastal erosion results in a change in the coastline and can lead to a pipeline becoming exposed or undermined.

Flooding is when water levels surpass its normal containment and inundate normally dry land. Coastal flooding is when sea water inundates land, often due to extreme weather or high tides. River flooding occurs when heavy rainfall causes rivers or canals to overflow their banks. Groundwater flooding is when the ground becomes saturated, leading to water rising above the surface. Flash floods develop rapidly in low-lying areas due to intense rain or poor water absorption by the ground or drainage systems. Surface water flooding occurs when heavy rain cannot drain away, often due to blocked drains or urban surfaces, with risks evolving due to changing land use and development. Reservoir flooding, though rare, can cause fast moving water to flow in large quantities if a reservoir fails. Reservoirs are required to have emergency drawdown plans which may involve the release of large volumes of water for several days causing significant scouring of surrounding land [8]. Burst water mains can also result in localised flooding.

Desktop assessment of watercourse crossings can be done as a screening tool but as channel conditions are individual to a watercourse, a site-specific assessment by a competent professional should be considered for any major watercourse crossing.

2.1 River Hydrotechnical Hazard Overview

Scour is the removal of sediment or engineered materials from a riverbed or riverbank. The effects of scour are most notable at areas of flow constriction, obstructions or other local disturbances where flow is redirected. This GPG does not detail the broader environmental processes, including climate change and land use change, that can influence river and coastal morphology.

River hydrotechnical hazards can be categorised as follows:

1. **Vertical channel scour** – Riverbed scour at a pipeline crossing can reduce depth of cover, ultimately exposing a pipeline. Further scour can undermine a pipeline creating an undesigned span.
2. **Horizontal channel scour** – Riverbank scour results in lateral movement of the channel. This movement is often evident on the outside of a meander where flow is greatest. Horizontal channel scour at a pipeline crossing can result in the pipeline being exposed (especially the overbend on the approach to the crossing), and it can cause a pipeline running alongside the watercourse to become exposed.
3. **Channel relocation** – Certain watercourses can experience the rapid abandonment of their channel and the formation of a new channel, referred to as avulsion. This process can occur during floods when the river breaches its banks and creates a new, more direct path to a lower elevation. The new channel may be temporary or permanent but can significantly increase the risk if it results in a new pipeline watercourse crossing in an area not designed as a watercourse crossing.

2.2 Coastal Hydrotechnical Hazard Overview

Coastal erosion is the removal of land over time by the sea. Certain coastlines are more susceptible to the effects of erosion. A change in coastline configuration due to erosion can cause a pipeline to become exposed or undermined resulting in loss of support. The ground around a pipeline may be affected by flooding, or a pipeline originally located in dry land may become located in open water, either temporarily or permanently.

Coastal flooding is when normally dry land is submerged under sea water. This can be caused by high tides and extreme weather events.

2.3 Damage Mechanisms

A pipeline subjected to the hydrotechnical hazards may be at risk from a range of damage mechanisms. An overview of these damage mechanisms is shown below:

1. **Loss of pipeline support:**
 - a. Scouring can cause a buried pipeline to become exposed. Further erosion under the exposed pipeline forms a free span which is an unsupported section of pipe. A pipeline is unlikely to have been designed to be unsupported. Any unsupported length should be assessed to ensure it does not exceed the maximum allowable unsupported length.
 - b. Overcrossings can lose their supports due to scour undermining the support structure or an increase in water level can move a pipeline off its supports resulting in an excessive unsupported length.
 - c. A pipeline affected by flooding could result in a pipeline designed without buoyancy control to float.
2. **Hydrodynamic loads** – Forces 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.
3. **Impact loads** – Debris transported downstream can impact any pipeline exposed to flow. 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.

4. **Fatigue** – 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:
 - a. Cross-flow where pipeline movement is perpendicular to flow induced by lift forces.
 - b. 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 [9].

5. **Third party damage** – An exposed pipeline has an increased likelihood of damage. Potential sources of third party damage include the public, vessels, anchors, and dredging equipment.
6. **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 are vulnerable to corrosion. Horizontal channel scour or coastal erosion could cause cathodic protection components to be compromised.

Areas of pipeline containing reduced wall thickness or defects must be considered for the effect of interaction with any relevant damage mechanisms.

3 RISK MANAGEMENT

Initially hydrotechnical hazards may be managed on a reactive basis. Hazards may be identified from routine integrity management activities such as line walks, aerial surveillance, and third party communications. The aim should be to move from reactive management to proactive management of hydrotechnical hazards through the structured implementation of a hydrotechnical integrity management process incorporating provisions for appropriate resources, hazard identification and risk assessment, monitoring, limits to prompt mitigation, and emergency response.

3.1 Emergency Response

Emergency response aims to limit the consequences of hazards when they occur. Emergency response arrangements must comply with statutory requirements, incorporate risk-specific measures, and provide for clear coordination between pipeline operators and relevant stakeholders.

Responsibilities for the pipeline operator include:

- Notifying Local Authorities of Major Accident Hazard Pipelines and provide relevant pipeline information to support emergency planning.
- Ensure emergency procedures address identified credible hydrotechnical hazards, including arrangements for:
 - Triggering emergency response.
 - Communication plans detailing who to contact, what to communicate, and how.
 - Mobilisation of personnel and assets.
 - Ongoing management and recovery actions.

Local Authorities have a responsibility to prepare emergency response plans using pipeline operator-supplied information and to collaborate with operators to integrate credible hydrotechnical hazards into broader emergency response frameworks. Further references specific to emergency response plans and testing include UKOPA/GPG/010 [10], UKOPA/GPG/011 [11], and UKOPA/GPG/012 [12].

Emergency arrangements should address emergency planning distances (see UKOPA/GPG/016 [13] for further guidance), access to identified areas at risk from hydrotechnical hazards, communication and resource allocation strategies for varying incident scales.

This GPG provides support for emergency response planning through guidance on hazard identification and evaluation, consequence analysis, risk assessment, and mitigation.

3.2 Stakeholder Engagement

Beyond normal landowner liaison, any works involving access to a watercourse require stakeholder engagement to ensure the required approvals. Any works undertaken by others in close proximity or upstream of a crossing have the potential to impact on a pipeline crossing in the future due to changes in the watercourse flow conditions.

Each nation within the UK has its own systems for managing watercourses and the environment. The following list highlights potential stakeholders but is not intended to be comprehensive:

Canal & River Trust	Navigation authority in charge of many of canals and rivers in England and Wales [6].
Environment Agency	Statutory powers related to main rivers in England.
Internal Drainage Boards	Statutory powers related to ordinary watercourses in England and Wales.
Landowners	Landowner liaison will be required for access to undertake pipeline works. Specific areas of concern may warrant additional cooperation with a landowner to facilitate planned and emergency works.
Local Authorities	Statutory powers related to ordinary watercourses in England and Wales.
Natural Resources Wales	Statutory powers related to main rivers in Wales.
Navigation Authorities	Responsible for management and maintenance of inland waterways including locks, bridges, dredging, clearing debris and flood management.
Northern Ireland Environment Agency	Responsible for arterial drainage and flood protection.
Riparian owner	Owner of land or property with a watercourse (such as a river, stream or ditch) [14].
Risk management authority	Local authority (unitary, county or district council), Internal Drainage Board or the Environment Agency [14].
Rivers Agency	The statutory drainage and flood defence authority for Northern Ireland.
Scottish Canals	Navigation authority in charge of many of canals and rivers in Scotland [6].
Scottish Environment Protection Agency	Principal environmental regulator and strategic flood risk management authority in Scotland.
Waterways Ireland	Responsible for canals and waterways in Northern Ireland.
Other asset owners	Examples are owners of structures that a pipeline uses to cross a watercourse such as bridges, or an asset located in close proximity to a pipeline which may be affected by the same hydrotechnical hazard or any mitigation measures.

3.3 Hydrotechnical Hazard Integrity Management Process

The management of hydrotechnical hazards within this GPG is based on identifying and assessing pipeline sections that face a credible integrity risk. This supports the development and implementation of a hydrotechnical integrity management process with a clearly defined scope and proportionate resource allocation. The scope should define what type of watercourse and coastal zone sites are to be assessed. Watercourse and coastal zone sites may include, but are not limited to, rivers, ditches, water bodies with temporary flow, canals, marshes, wetlands, fen, bogs, floodplains, specified proximity to coastline. The scope can be reviewed as the hydrotechnical integrity management process and understanding develops.

Defined watercourse and coastal zone sites will need defined operational limits for hazard identification and evaluation. A site may need one or more defined operational limits. Operational limits may be site specific or applicable to a defined watercourse or coastal zone site. Potential operational limits are:

- Depth of cover.
- River depth.
- Distance from pipeline to watercourse or coastline.
- Span length.
- Probability of damage.
- Probability of failure.

The arrangements of the hydrotechnical integrity management process are intended to identify and manage the risk posed by hydrotechnical hazards on pipeline integrity. Important arrangements include hazard identification, hazard evaluation, consequence analysis, risk assessment, mitigation, and performance review. This process should be risk based and can use the 'Plan, Do, Check, Act' model described in HSG65 Managing for Health and Safety [15]. An example representation of a potential hydrotechnical integrity management process is shown in Figure 1. This process should be subject to periodic audit to ensure it is implemented and achieving its intended aim, is reviewed as needed to incorporate changes to assets, hazards, new technology and understanding. There should be a continuous cycle of improvement.



Figure 1: Visual Representation of Hydrotechnical Integrity Management Process

3.4 Initial Hazard Identification

Hazard identification requires developing a register of pipeline sections at risk from hydrotechnical hazards. All pipeline sections at risk should be identified. This register can be generated by overlaying pipeline and hydrology network mapping to determine actual watercourse crossings or where a pipeline comes into close proximity to watercourses or other bodies of water based on the defined scope of the hydrotechnical integrity management process. Overlaying a pipeline network and coastal mapping allows identification of pipeline sections potentially at risk from coastal erosion. Geographic Information Systems (GIS) are a useful tool to store, analyse and visualise geospatial data.

The register should enable each identified pipeline section at risk from hydrotechnical hazards to be uniquely identified and the relevant information associated with that pipeline crossing and hydrotechnical hazard to be stored alongside. This may be the actual information, or a reference to locate the relevant information.

Available datasets for assessing hydrotechnical hazards are outlined in Appendix B.

Other data sources during the hazard identification (and further stages) to consider are:

- Design documentation.
- As-built documentation.
- Strip maps.
- Special crossing drawings.
- River crossing surveys.
- Line walking surveys.

- Inline inspection (ILI).
- Vantage surveys.
- Aerial surveillance.
- Light Detection and Ranging (LiDAR) surveys.
- Satellite imagery.
- Operator experience.
- River crossing and other hydrotechnical hazard mitigation works.
- Historical imagery.

Initial hazard identification is likely to be based on current river and coastal configurations. This may be further revised to consider historical data to forecast future river and coastal configurations potentially impacting pipeline sections not currently at risk from hydrotechnical hazards.

Review of design and as-built documentation may identify non-documented or inappropriate design and/or construction for the current conditions at a hydrotechnical hazard which will require evaluation.

The output of the initial hazard identification should inform proactive hazard identification.

3.5 Proactive Hazard Identification

Proactive hazard identification builds upon the initial hazard identification stage to pinpoint pipeline sections which have the potential to be impacted by hydrotechnical hazards.

Available datasets for assessing hydrotechnical hazards are outlined in Appendix B.

Further data to analyse includes:

- Flood risk mapping.
- Coastal erosion mapping.
- Sea level rise projections [16].
- River surveys – Often pipeline river crossing surveys focus on the actual pipeline location. The intent of a river survey is to understand the wider environmental circumstances by expanding the scope to include the river area which has the potential to impact on the pipeline crossing (or possible pipeline crossing) in the future. This may include:
 - Topography.
 - Hydrology.
 - Ecology (notably protected and invasive species).
 - River features (bends, signs of erosion, bank collapse, channel instability, upstream structures that can affect flow or lateral movement of river at pipeline crossing, downstream structures that can affect water levels or lateral movement of river at pipeline crossing, potential debris, existing river engineering schemes).
 - Evidence of scour on other structures.
 - Riverbed and riverbank material.

- Depth of cover (or height of structure for overcrossings). UKOPA/GPG/001 [17] outlines the management of pipelines with reduced depth of cover. While watercourse crossings are not within scope of UKOPA/GPG/001, the principles can still be applied to smaller watercourse crossings.
- Historical data including:
 - Weather events.
 - Rainfall.
 - River flow.

3.6 Hazard Evaluation

Hazard evaluation involves analysing the pipeline sections at risk from hydrotechnical hazards to determine the impact on pipeline integrity. Initially this may be done at a high level to screen out pipeline sections where the hydrotechnical hazard does not pose a significant risk to pipeline integrity with the aim of prioritising resources to pipeline sections at higher risk. This will require the application of the defined operational limits to the identified pipeline sections.

Desktop analysis should be performed to identify sites requiring specific surveys. This will involve analysis of the data sources used in the hazard identification stage plus other data consideration may include:

- Hydrological data.
- Historical mapping.

See Appendix B for further information.

Site surveys may be conducted to gather data to feed into the hazard evaluation. The site survey scope will depend on the nature of the hydrotechnical hazard. Useful data gathered may include:

- Location data – Confirmation of pipeline location data including any overbends on approach to the crossing.
- Depth of cover – Consideration should be given to taking readings beyond the identified pipeline section to understand the extent of any changes in depth of cover [17].
- Topographic survey – Include the river channel position and cross-section profile.
- Watercourse survey – Geometrical and descriptive data used to model rivers.
- Bathymetric surveys – Form of hydrographic survey used to map underwater topography.

The Survey Association provide overview guides [18] aimed at those commissioning particular surveys including watercourse surveys [19], topographical surveys [20], hydrographic surveys [21], satellite imagery surveys [22]. UKOPA/GPG/039 [23] outlines the use of remotely operated aerial vehicles which can be employed to perform surveys.

Engineering assessment may be required to evaluate an identified hazard. Design documentation should be referred to prior to a new engineering assessment as the case under evaluation may already be documented. Table 3 gives an overview of potential engineering assessments that may be considered in hazard evaluation. The engineering assessments described are not intended to be exhaustive and relevant engineering judgement should be exercised.

Assessment	Overview	Further Guidance
<i>Static and dynamic stress assessment</i>	Calculation of static stresses due to bending under lateral loads in extreme storm or flood. Static loading on a span is produced by a combination of the self-weight of the pipeline and hydrodynamic forces on the pipeline and any trapped debris.	[24]
<i>Span assessment</i>	To understand the dynamic response of a pipeline subject to hydrodynamic loads with the aim of limiting excessive loading and VIV that could lead to fatigue damage and pipeline failure.	[9, 25]
<i>Buoyancy assessment</i>	Compare the submerged weight with the buoyancy, applying an appropriate safety factor to avoid flotation.	[26]
<i>Impact damage</i>	This can be to establish operational limits for potential damage such as debris impact or to assess damage introduced by impact to demonstrate pipeline integrity or identify remedial actions. This should include any coating damage. The likely type, size and mass of debris could be informed by site investigation.	[27]
<i>On-Bottom Stability</i>	Conducted to ensure an unburied pipeline remains stable on the seabed and does not move due to environmental forces. The objective is to prevent lateral displacement, vertical movement, or excessive stresses on the pipeline, which could lead to damage or failure.	[28]
<i>Flow modelling</i>	To establish current flow velocity at pipeline crossings with unavailable measured data. This may be a simple approach using data from an available upstream or downstream gauging station modified for the specifics of the crossing location, comparison with available data from a similar catchment area, or use of an applicable empirical method. Can be used to ascertain likely locations, rates and patterns of future river channel change.	[29]
<i>Scour assessment</i>	Used to predict extent and rate of vertical and horizontal channel scour.	[30, 31, 32, 33]
<i>Hydrotechnical analysis</i>	Used to increase the understanding of a hydrotechnical hazard and pipeline condition to inform the risk assessment. Can be used to model potential mitigations to assess their effect on pipeline integrity. The hydrotechnical analysis will incorporate work from other assessments to predict performance during potential future scenarios.	[34]

Table 3: Engineering Assessments

3.7 Consequence Analysis

The purpose of consequence analysis is to quantify the effects of a hazard being realised. The analysis should be cognisant of the impact on the population, property, environment, and business operations. This includes disruption to other buried assets. Watercourses are environmentally sensitive with the ability to transport pipeline inventory away from the source of a pipeline failure which could significantly increase the area affected by a product loss event. Compared with work on much of a buried onshore pipeline, surveys and physical works to assess or mitigate hazards at watercourse crossings can require more planning and resources. This may initially lead to assigning a simplified high consequence to all watercourse crossings until the hydrotechnical integrity management process is implement and further refined.

3.8 Risk Assessment

Risk assessment is an evaluation of the probability of a credible hazard occurring and the resulting consequences. Risk assessment of pipeline section at risk of hydrotechnical hazards allows the ranking of hydrotechnical hazard locations to prioritise resources and target mitigation.

3.9 Mitigation

The complexity of any mitigation measure should be informed by the assessed risk. Mitigation can range from specific monitoring through to pipeline diversion or abandonment and depending on the situation, can be applied to the pipeline (e.g. concrete mattresses), the waterbody (e.g. bank restoration), or both. Access to complete mitigation works may not be possible at certain locations until water levels recede, for example after flooding. Mitigation may consist of a blend of approaches to address short and long-term risk management objectives. For example, monitoring, engineering works, and emergency response arrangements can be combined to address both the probability and consequence of failure.

The current approach taken by the environmental regulators to river engineering works emphasises environmentally sympathetic green measures and solutions that do not canalise rivers over more conventional hard engineering solutions such as piling. A green measure could be a bank repair using exclusively natural materials such as willow spiling. Mitigation may involve green measures and conventional engineering, or a solution somewhere between. Early engagement with stakeholders, notably the environmental regulators and riparian owners, will allow the relevant considerations to be planned into a project. Mitigation involving the waterbody should sympathetically manage the waterbody and protect pipeline integrity.

A plan to address erosion within a watercourse may require approval from the relevant regulator. Some activities may be exempt from needing consent, depending on the specific details of the work. Projects should consider the time needed to apply for, process, and receive approval for consent.

Consideration should be given to incorporating geomorphologist and ecologist advice in the design of mitigation projects where appropriate.

Potential mitigations include:

1. Monitoring could include publicly available data related to weather events (rainfall, storm, flood) and river flow, specially installed equipment such as gauges (strain, water level, water flow, water velocity) or equally spaced marker posts stepped back from an eroding riverbank monitored through other surveys. Monitoring type and frequency depends on the risk and there should be defined limits to initiate prepared actions.
2. Inspections encompass aerial surveys, line walking [35], depth of cover surveys [17], ILI [36], scour surveys and vantage points surveys. Inspections may be specified for potential problem areas or relevant data may be collected during other inspections. One example is ILI covering the entire pipeline length but can be used to collect pipeline alignment and condition data. Photographs from surveys should be time and date stamped, and endeavours made to use the same location for follow up photographs to facilitate comparison. Inspection type and frequency depends on the risk and there should be specific limits to initiate prepared actions. Inspections triggered by and after extreme events is recommended.
3. Engineering assessments (as outlined in Section 3.6) can be reviewed to integrate up-to-date monitoring and inspection data. The results should feed into the risk assessment to inform on appropriate mitigation measures.
4. Maintenance activities generally do not require an engineering design. It may be activities to maintain water flow such as ditch clearing or reinstating marker posts. Ditch cleaning undertaken by third parties may require supervision to prevent pipeline damage.
5. Engineering solutions include any physical works applied to the pipeline, pipeline supports or waterbody. Examples include:

- a. Scour mitigation can involve scour reduction, pipeline protection or scour protection.
 - i. Scour reduction improves flow conditions at the crossing to reduce the effects of scour. This includes river management such as meander restoration and bank regrading.
 - ii. Pipeline protection aims to protect the pipeline from the effects of scour. An example is riprap installation over an exposed pipeline.
 - iii. Scour protection limits the effects of scour by installing more erosion resistant materials than the natural riverbed or bank such as sheet piles, gabions, or willow spiling.
 - b. Impact protection could be used to reduce the risk of pipeline damage from third party damage. Examples could be damage from ditch clearing or dredging works.
 - c. Strengthening or upgrading overcrossing supports or structures to reduce the risk of failure due to hydrodynamic and/or impact forces. This may include enhancing support structures, anchoring, or reinforcing abutments to resist scour, debris impact, or high flow conditions.
 - d. Pipeline lowering to increase the depth of cover and so mitigate watercourse interaction.
 - e. Relocating an overbend from a migrating watercourse.
 - f. Relay crossing with potential solutions including horizontal directional drilling, aerial crossing, or rerouting the pipeline.
 - g. Inventory control can reduce the consequences of a pipeline failure at a watercourse crossing. An example is installing isolation valves at accessible points on both sides of the watercourse.
6. Emergency response arrangements (see Section 3.1) may be an appropriate interim mitigation. These may include boom deployment plans, pipeline isolation procedures, or other response actions designed to limit the impact of a potential failure until permanent mitigation can be implemented.
 7. Pipeline mothballing, decommissioning or abandonment may be an appropriate response in cases where mitigation costs preclude continued pipeline operation temporarily or permanently. See UKOPA/GPG/038 for guidance [37].

Further sources of information are shown in Table 4:

Publisher	Title	Overview	Reference
<i>Scottish Environment Protection Agency</i>	Sustainable Riverbank Protection Reducing Riverbank Erosion	Describes methods to protect eroding riverbanks without increasing erosion risks to other banks downstream while improving bankside habitat.	[38]
<i>HR Wallingford</i>	Green approaches in river engineering	River engineering approaches promoting conservation and restoration of the natural character of rivers.	[39]
<i>Construction Industry Research and Information Association</i>	Manual on scour at bridges and other hydraulic structures	Document for the design, construction, operation and maintenance of structures in the water environment that may be subject to scour of erodible beds or banks.	[32]
<i>River Restoration Centre</i>	Manual of River Restoration Techniques	Guidance to identify potential restoration techniques for use in river restoration and sustainable river management.	[40]

Table 4: Further Hydrotechnical and Mitigation Guidance

3.10 Performance Review

The hydrotechnical hazard integrity management process should be reviewed for effectiveness and identify areas of improvement. The hazard register should be maintained to ensure it is up to date. As operator experience and wider industry learning develops, the hydrotechnical hazard integrity management process should be refined as appropriate.

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APPENDIX A EXAMPLE HYDROTECHNICAL HAZARDS

A.1 Vertical and Horizontal Scour

Figure A-1 shows an extract from a combined depth of cover survey, bathymetry survey, and aerial imagery of pipeline exposure at river crossing. The black arrow on the aerial imagery/bathymetry plan view indicates the direction of river flow, the pipeline is red with the exposure marked in pink, riverbank erosion is represented with pink hatching on the right side of the river, the south riverbank. The longitudinal profile has been aligned with the plan view for ease of reading the captured information with the pipeline exposure coloured red. The riverbank erosion has occurred on the steeper south riverbank.

Figure A-2 shows photographs taken from points P3 and P4. These locations are marked on the aerial imagery of Figure A-1 in blue circles (the arrows show the direction of the photograph). Note the collapsed gabion in the foreground seen from position P4 demonstrating that mitigation had been employed in the past.

Figure A-3 shows the variation in flow rate from the National River Flow Archive from the gauging station approximately 3 km downstream of the pipeline exposure. The plot shows that the average flow rate between 2020 and 2022 was approximately 20 m³/s. The maximum flow rate in 2020 and 2021 was approximately 250 m³/s. The maximum flow rate in 2023 was approximately 540 m³/s. These significant variations are to be considered when evaluating a potential hydrotechnical hazard and any mitigation.

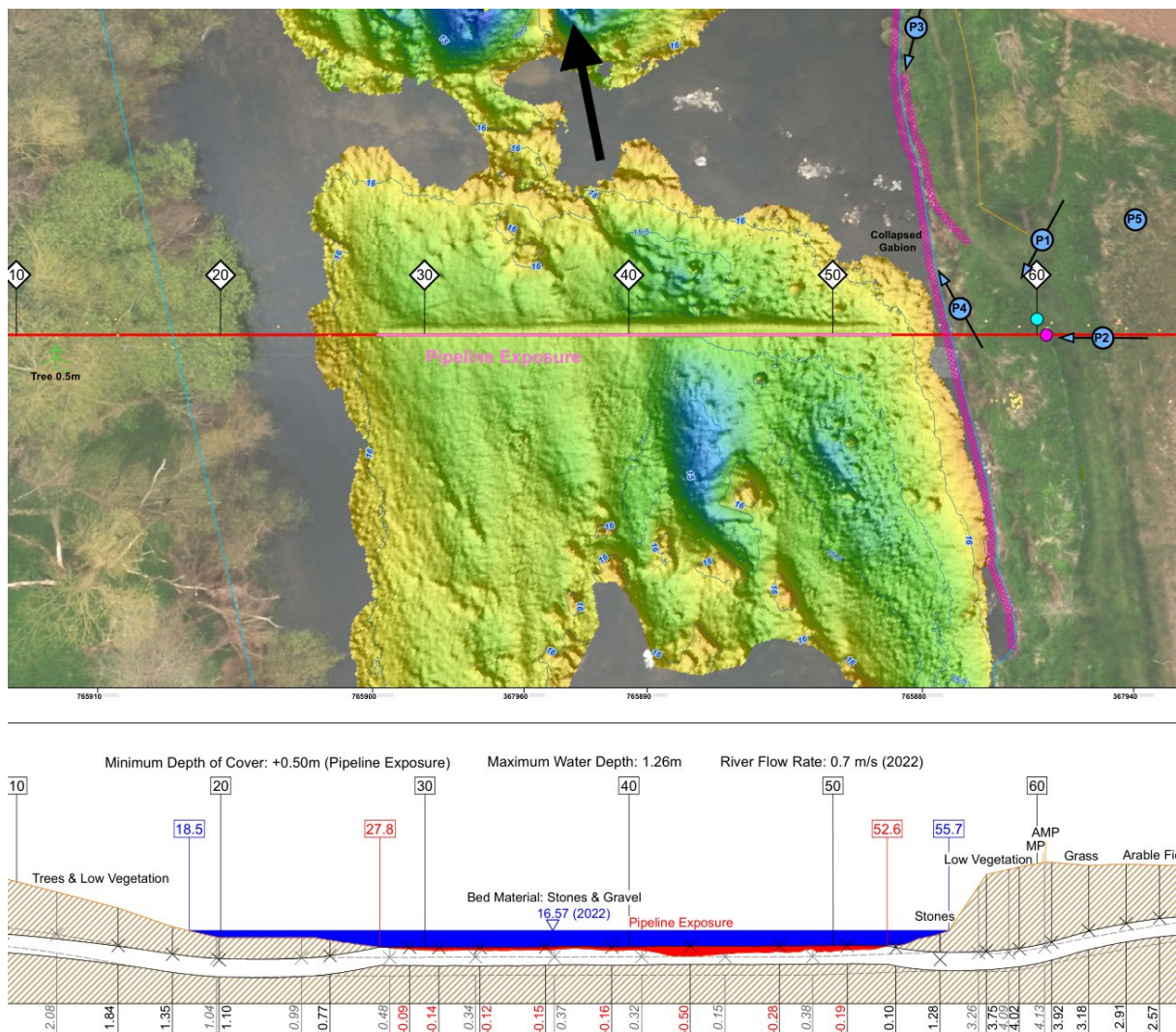


Figure A-1: Combined Depth of Cover Survey, Bathymetry Survey, and Aerial Imagery of Pipeline Exposure



Figure A-2: Left from P3 - View of Erosion on Right (South) Bank Looking North-West (Upstream)
Right From P4 - View of Erosion on Right (South) Bank Looking South-East (Downstream)

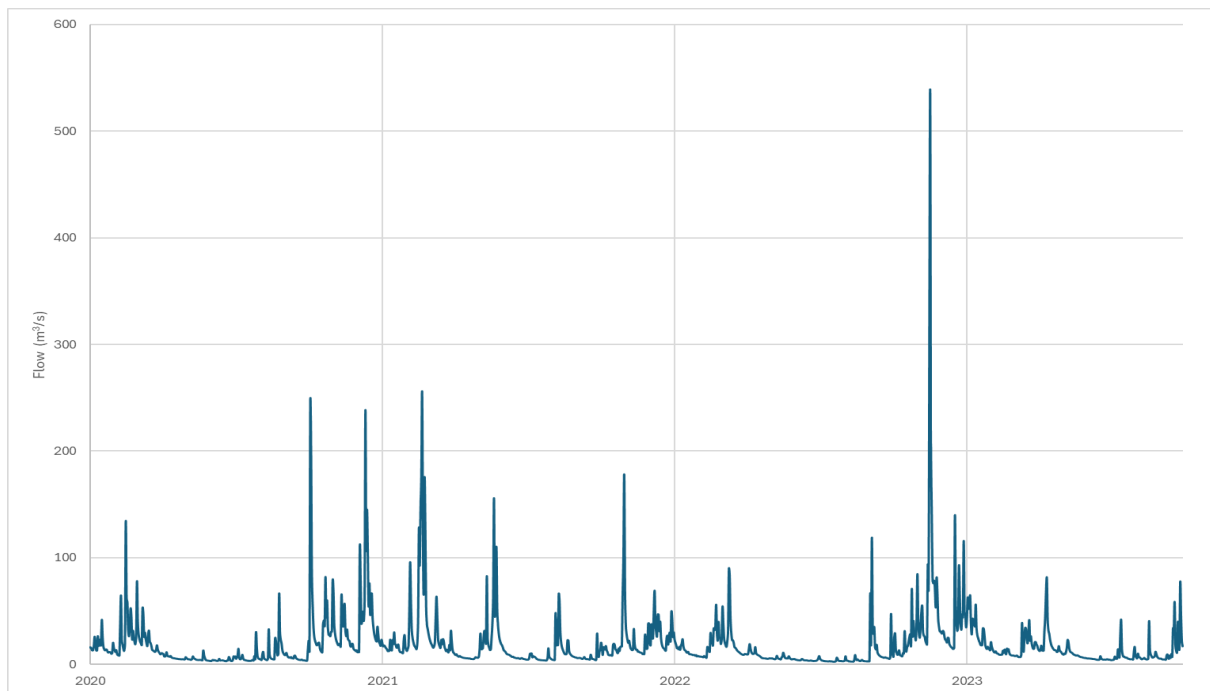


Figure A-3: Plot of Flow Rate against Time

Figure A-4 shows a completed riverbank remediation project to mitigate against horizontal channel scour before the pipeline was exposed. Note the pipeline marker post indicating the pipeline location in the top left of the photograph. Approximately 1.7 m of additional lateral protection was installed using environmentally sympathetic green measures to increase the distance from the pipeline to the edge of the bank to 2 m. This mitigated the risk of the pipeline being undermined by continued bank erosion. Wooden stakes were used to secure coir matting allowing soil to be backfilled. Eventually vegetation will establish stabilising the soil.



Figure A-4: Riverbank Restoration Using Environmentally Sympathetic Green Measures

Figure A-5 shows two pipelines exposed due to washout of soil during flooding. Remedial action involved reinstatement of soil, and improved drainage to redirect run-off away from the pipelines.



Figure A-5: Washout of Soil During Flooding

Figure A-6 shows the outcome of a two stage project involving multiple mitigation measures. The project involved reinforcing a stream bank to prevent vertical channel scour that was exposing a pipeline. Initially, gabion baskets filled with rock were installed to strengthen the banks. The intent was to implement a porous, stable solution that prevented washout. The stream profile could not accommodate increased backfill, so the pipeline was protected using a high-density polyethylene protection (HDPE) board over the backfill to further mitigate washout and provide a clearly visible indicator if cover was reduced. A concrete canvas overlay gave added protection. However, this solution increased water velocity, leading to downstream erosion issues.

Figure A-6 shows the solution implemented to address these issues. The concrete canvas was removed and backfill was excavated down to the HDPE board. A Reno mattress (a flexible, rock-filled mesh structure) was installed in the streambed to increase turbulence and reduce the water velocity. Large boulders were also placed in the channel to further dissipate energy and slow water movement. The gabion-reinforced banks remain in place, ensuring stability while allowing natural vegetation to establish. This revised solution has proven effective in maintaining pipeline integrity, reducing scour, and maintaining water flow.



Figure A-6: Multiple Mitigation Measure

Figure A-7 shows two different exposed free spans which developed after horizontal channel scour. The left picture shows a pipeline free span perpendicular to the river. The right picture shows a pipeline free span parallel with the river.

Figure A-8 shows an exposed pipeline because of vertical channel scour.



Figure A-7: Free Spanning Pipelines Due to Horizontal Channel Scour



Figure A-8: Pipeline exposure due to vertical channel erosion

Figure A-9, Figure A-10, and Figure A-11 show the identification, assessment, and remediation of a pipeline span. Figure A-9 shows the exposed pipeline below the marker post to the left of the tyre. Note that the area affected is the outside of the meander, caused by an upstream fallen tree which redirected water flow onto the bank, creating a concentrated current directly above the pipeline crossing. This accelerated horizontal channel scour at the base of the bank lead to exposure of the pipeline.

Figure A-10 shows the temporary coffer dam installed around the exposed pipeline to control water flow around the exposure and ensure safe working conditions while facilitating inspection.

Figure A-11 shows the installation of the mitigation measures. A barrier using rock bags was built around the pipeline and pre-bagged backfill added. The base of the bank was reprofiled to adjust its slope and reinforced using rock bags as an outer layer to dissipate hydraulic energy. Above this, smaller flexible rock bags were placed and the area behind backfilled with gravel. Soil was secured in place with hessian matting. Willows and shrub were planted to naturally bind the soil and promote long-term

stabilisation. All protective measures were designed to be permeable and have rough surfaces which helps encourage algae and plant growth.



Figure A-9: Exposure to Due Upstream Fallen Tree



Figure A-10: Temporary Cofferd Dam Installation



Figure A-11: In Progress Bank Reinforcement with Rock Bags and Backfill

A.2 Loss of Pipeline Support

Figure A-12 shows the loss of a pipeline support after storm events resulted in increased river flow and mobilisation of debris. Stress analysis was used to feed into the risk assessment to demonstrate continued operations for a defined timeframe until mitigation actions were able to be implemented once the river returned to normal flow conditions.



Figure A-12: Loss of Pipeline Support at Overcrossing

Figure A-13 show two examples of loss of pipeline support which has led to the pipeline floating.



Figure A-13: Pipeline Buoyancy

APPENDIX B DATASETS AND ONLINE RESOURCES

There are various datasets and online resources available under the Open Government Licence and others requiring paid for access. Table B-1 shows some available datasets which may assist in hazard identification and evaluation. It is not intended to be an exhaustive list.

Dataset	Publisher	Overview	Reference
<i>National Coastal Erosion Risk Mapping</i>	Environment Agency	Dataset showing erosion extents with lengths of coast defined which have consistent cliff behaviour and defence characteristics. The data provides upper and lower estimates of erosion risk. The data does not estimate the absolute location of the future coastline. Geologically complex areas are general excluded due to uncertainties forecasting erosion at these sites.	[40]
<i>GeoCoast</i>	BGS	GeoCoast Open consists of historic data, images, regional statistics and coastal domains for erosion and morphology. GeoCoast Premium contains the underlying data of the GeoCoast Open dataset. Its aim is to inform and support coastal management and provide sufficient data to assess a range of coastal hazards.	[41, 42]
<i>Google Earth</i>	Google	Satellite imagery used to portray the Earth. The desktop application encompasses historical imagery allowing investigation into changes in river courses and coastlines.	[43]
<i>GeoScour</i>	BGS	GeoScour Open and Premium provide an overview of catchment and riverine characteristics for assessing river scour.	[44, 45]
<i>Long term flood risk</i>	Government	Mapping displaying long term flood risk	[46, 47, 48, 49]
<i>Coastal erosion risk</i>	Government	Estimated land at risk from coastal erosion at different time periods in the future.	[50, 51, 52, 53]
<i>Flood Map for Planning</i>	Environment Agency	Indicates the flood risk to areas of land when the presence of flood defences are ignored	[54, 55]
<i>Hydrological Open Data</i>	Environment Agency	Hydrological data including river flow, river level, groundwater and rainfall from stations across England.	[56]
<i>Official record of river flow data for the UK</i>	National River Flow Archive	Archive of hydrometric data from gauging station networks including daily and peak river flows.	[57]
<i>Digital river network of Great Britain (1:50,000)</i>	Environmental Information Data Centre	Dataset comprises river centrelines. It consists of four components: rivers, canals, surface pipes, and miscellaneous channels (including estuary and lake centrelines and some underground channels).	[58]
<i>OS Open Rivers (1:15,000 to 1:30,000)</i>	Ordnance Survey	High-level view of watercourses in Great Britain including freshwater rivers, tidal estuaries and canals.	[59]
<i>Coastal Design Sea Levels</i>	Environment Agency	Coastal Design/Extreme Sea Levels data and supporting information providing design / extreme sea level and typical surge information around the coastline of the UK as of 2018	[60]
<i>Main River Map</i>	Environment Agency and Natural Resources Wales	Dataset that defines statutory watercourses in England and Wales designated as main rivers	[61, 62]

Table B-1: Datasets and Online Resources