CIREG
Construction Insurance
Risk Engineers Group

The CIREG Guide to Managing Flood Risk During Construction

Managing Rainfall, Inundation & Flood Risk
on Building, Civil Engineering & Infrastructure Projects
during the Development, Design & Construction Phases

This Guidance Document is Published by the Construction Insurance Risk Engineers Group

1st Edition, December 2023

With the support of the

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The CIREG Guide to Managing Flood Risk During Construction document (CIREG MFRC) provides advice on the prevention and mitigation of damage to construction works due to rainfall, inundation and flooding during the development, design and construction phases. Whilst the guidance is intended for all types of building, infrastructure and civil engineering projects, some of the advice may also be equally applicable to other types of construction and projects.

This guidance is endorsed by all CIREG and UK CAR Underwriter member companies and represents industry's intended best practice in the prevention and mitigation of losses due to rainfall, inundation and flooding

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1 Introduction & Scope - Why is it a problem?

Flooding is one of the largest causes of physical loss or damage during the construction phase of buildings, civil engineering, and infrastructure projects.

The damage and disruption caused to partially or substantially completed schemes can be considerable, with significant reinstatement and clean-up costs incurred. Delays occur to time schedules and projects are often completed late and over budget, with consequential loss of revenue and penalties, including DSU policy expenses. The resultant disruption and losses are experienced by all stakeholders including clients, designers, consultants, contractors, insurers and third parties.

Many elements of projects are impacted, including partially constructed assets, temporary works, storage, and laydown areas, stored materials, and construction plant & equipment, including long lead items. The scope of large infrastructure projects tends to be geographically extensive and spreads across numerous sites, resulting in exposure to multiple catchment areas and potential reduced risk separation. High rise and specialist buildings offer a high concentration of values at risk.

Therefore, where flood risks exist, it is essential that these exposures are clearly identified, risk allocation, roles and responsibilities explicitly defined by contract and control and mitigation measures adequately priced for as part of project development and delivery.

As a consequence of climate change, weather patterns are becoming increasing unpredictable and more extreme. Heavy rainfall and flood events continue to make the headlines causing extensive damage and delay to construction projects .as. The change in weather patterns also casts doubt on the reliability of past hydrological data and historical records.

This guide has been compiled by the Construction Insurance Risk Engineers Group (CIREG) and is intended to provide a focus on flood risk exposure, share lessons learnt and deliver a reference protocol to dealing with the issue. Case studies are included to illustrate typical loss scenarios experienced by insurers on many large and diverse projects.

The aim of the guide is to raise awareness of the potential hazards and exposures related to flood and rainfall during the construction phase of projects and prompt suitable risk management activity and to enable the production of a Flood Risk Management Plan.

It is strongly recommended that early engagement with the project broker and project insurers/potential insurers in respect of flood is undertaken and that the flood risk information is provided at the earliest opportunity.

Be aware: Flood mitigation measures are only as effective as the weakest point.

Note: *a separate guide is available covering the issue of damage as a result of water leaking from pipework or equipment within buildings – 'Managing Escape of Water Risk on Construction Sites' published by the Construction Insurance Risk Engineers Group www.cireg.org*

Comments: *Please forward any comments relating to Guide or its use thereof to CIREG@CIREG.ORG*

2 Exposure and Inherent Flood Risk

Project works design and construction factors can affect the inherent exposure and susceptibility of the project site to flooding. During the construction phase the assets can be inherently more vulnerable to damage and this can depend on and vary according to the different stages of the works.

2.1 Temporary and incomplete project works and elements vulnerable to flooding

i. **Excavations, foundations, and fresh-cut earthworks** can become unstable when saturated and are exposed to erosion, wash-out and settlement. Large, deep excavations are often required for elements of infrastructure projects, such as hydro-electric dams, bridges, deep foundations, and station boxes etc. Being at a low level these excavations are vulnerable to flood events as well as any partially completed structures, materials and plant working in the excavation.

> **Case Study 1: Deep Excavation - Water Main Flood**
>
> During construction of an inner-city site, a deep basement area was submerged with a significant inflow of flood water. The water emanated from an old water main, exposed adjacent to the site by a third-party contractor carrying out street works. The main burst during the night – when water pressures were at a maximum – and flowed unabated into the deep excavation. Damage occurred to plant & materials.

ii. **Underground works** have a significant potential for flood water ingress and damage due to the likely pooling effect of water finding its way to the lowest level and points of the site. Pathways can include heavy rainwater percolating at sufficient rate, surface runoff waters directly entering open excavations and/or groundwater infiltration. Access shafts, adits and main tunnel works, as well as TBMs are vulnerable to flood damage. Ground water can penetrate the tunnel wall or storm water enter the open excavation if the top of access shafts is not set well above the anticipated flood level.

> **Case Study 2: TBM Shaft Inundation**
>
> A large shaft – constructed to receive a TBM – was built without any bunding or upstand collar at the surface. Subsequent to the TBM and equipment entering the shaft, heavy rainfall led to stormwater running-off and inundating the shaft and tunnel. Significant clean-up costs were incurred.

iii. **Inundation of pipeline trenches** can channel water over long lengths, wash in materials, destabilise the trench and cause floatation of the pipe. Large areas can be exposed and may be difficult to protect. Consequential damage can occur to the joints with displacement of whole pipelines.

Case Study 3: Pipeline Flotation Damage

A project in the Middle East to install a 300km pipeline was inundated with stormwater falling many kilometres away and flowing to the site via wadis . This resulted in displacement and damage to the pipeline over a 1km long section. The loss could have been mitigated with suitable flood protection measures including minimising the length of pipeline installed but not yet backfilled and the number of open sections.

iv. **Partially completed structures** can be inherently less resilient and require stability calculations for each intermediate stage e.g., dams and cofferdams, water conveyance channels, buried concrete basins and tanks, cut & cover tunnels or station boxes and shafts; tunnel networks can distribute the water widely and extensively.

v. **Temporary works** are often designed and maintained to lower standards than permanent works in terms of safety factors, durability and design life and can be more exposed to flooding risks, e.g., temporary site offices and welfare units, laydown areas, plant, camps, and temporary structures such as cofferdams, berms, retaining walls, propping, and scaffolding.

Case Study 4: Materials Conveyor Failure

A temporary materials conveyor - installed to facilitate the construction of a hydro-electric dam - was undermined following heavy rainfall during a 1 in 10yr storm event. The adjacent river rose significantly and washed away the supporting ground and temporary shallow foundations. The arrangement had been designed using a minimal flood return period of 1 in 5yrs and the Return Period chosen was wholly insufficient for the works exposure period.

vi. **Temporary flood protection measures**, prior to any permanent flood mitigation or defence measures being put in place, if in place at all, are typically designed to lower return periods, standard of protection and quality and are subject to limited or no maintenance.

Case Study 5: HPP Dam – Temporary Cofferdam Failure

A hydro-electric dam project constructed an earth/rock-filled cofferdam and diversion tunnel to facilitate construction of the dam foundations. During prolonged heavy rainfall, the diversion tunnel and cofferdam were overwhelmed. The upstream cofferdam was overtopped, and the downstream cofferdam was washed away. Damage occurred to stored plant as well as the temporary works. The loss could have been prevented with a more robust temporary works design and design criteria for the cofferdam.

vii. **Partially weathertight structures** can allow significant water ingress in to building whilst fit-out works are progressing. Plasterboard, timber floorings, timber frame/panelling and sandwich panel cladding present swelling issues in presence of water and increased susceptibility to mould.

Case Study 6: Fit-out works when the building was not Weathertight

With the building not weathertight and fit-out underway repeated heavy rain events lead to an un-noticed build-up of water across the sunken concrete slab of raised and heavily insulated ward floor on the uppermost level of a hospital. Immediately prior to occupation rising damp and mould was noted across the internal walls. Investigations revealed that internal plasterboard walls had been placed directly onto the screed and soaked-up the collected rainwater. The entire ward had to be stripped-out and re-instated significantly delaying the occupation of the hospital.

viii. **Incomplete pipe connections, manholes, unplugged penetrations and incomplete waterstops and barriers** can re-direct and divert storm water downhill towards lower relative-level surface areas, structures etc. as well as underground structures, plant rooms and storage areas and other areas vulnerable to flood risk and result inconsequential damages and losses.

Case Study 7: Unstopped Flow Paths

During the construction of a metro project, heavy rain occurred when a high percentage of long lead items were installed and under Testing and Commissioning. Significant storm water ingress occurred through unplugged pipe penetrations and incomplete manholes, flooding technical rooms in the lower levels resulting in severe schedule delays and repair and reinstatement costs.

Extensive damages occurred in electrical and electronic equipment as well as in installed architectural finishes.

2.2 Later project elements vulnerable to flooding

i. **Vulnerable materials, equipment and plant are often stored at ground, reduced-floor or basement levels** during the construction phase. Water damaged mechanical and electrical plant and equipment may become non-compliant with quality specifications and warranties making it difficult to repair.

Case Study 8: Stadium flooding

During a summer storm event at a sports stadium under construction, rainwater overwhelmed incomplete drainage arrangements and rapidly flowed down the terracing into the partially fitted-out basement via the stairwells flooding the area to a depth in excess 150mm. Damage occasioned to the flooring, walls, stored materials, and electrical installations. Non-compliant items were replaced, and the project delayed.

Damage to plant and equipment; even large/heavy plant has the potential to float along with water flows causing further damage to assets; 30cm of flowing water can be enough to move a c.1.5 tonne car or plant; reference should be made to flood/depth velocity graphs freely available.

Case Study 9: Vulnerable Materials' Storage

During construction of a sea-front hotel a significant weather event occurred. The resultant storm-surge overtopped the limited sea defences and inundated the site. At the time, the basement area was being used to store expensive fit-out materials and equipment, which were destroyed by the flood waters. There were also significant clean-up costs and delays to the project.

2.3 Indirect consequences of flooding

i. Damage to public utilities and supply to the site
ii. Flooding to local roads and infrastructure effecting access to the site and supply chain
iii. Impact of demand surge for third party specialist contractors and suppliers post flood events e.g., specialist clean-up services, emergency generators, water pumps, de-humidifiers etc.
iv. flooding can trigger low likelihood - high impact events such as landslides, liquefaction, and electrical short circuits etc

Case Study 10: Temporary Road & Bridge – Loss of Site Access

An access road to a remote, 5 year long civil engineering project, which included a single temporary bridge, was overwhelmed by a fast-flowing river following heavy rainfall. The flood event resulted in a loss of materials, various temporary works arrangements and loss of access to the project site. Reinstatement costs and delays were significant. The temporary works had been designed on only a 5yr flood return period. The Return Period chosen was wholly insufficient for the works exposure period.

2.4 Third Party Exposure and Business Interruption

Where flood waters are diverted and/or collected on site there is a risk that the containment systems such as trenches, culverts, attenuation tanks, reservoirs etc. can be overwhelmed. In such instances overtopping of these structures could result in areas occupied by third parties being at increased risk of flood damage where originally there was limited or no flood exposure. Such flood event could lead to physical damage to third party property as well as business interruption and potentially life-threatening events.

2.5 Inherent and Residual Risks

Where sites are exposed to flooding there will always be an element of inherent and residual risk which will remain to a certain degree and extent irrespective of any mitigation measures. The extent of the inherent risk will depend on various factors, such as:

i. **Location of the project** - Site location in close proximity to water sources and courses, especially where this is in a floodplain. Flood plains by their nature will flood at some point and can be considered inevitable events. Even with flood defences there is a residual risk of overtopping or breach failures.

Case Study 11: HPP Powerhouse - Adjacent Watercourse

During construction of a hydro-electric dam, a small stream running adjacent to the powerhouse site, swelled significantly following a period of heavy rain from a 1 in 30-year storm event. Temporary protection measures to the powerhouse – designed for a 1 in 10yr event - were overtopped and partially constructed building works within the excavation were inundated and damaged.

ii. **Nature of the project** - Extensive below ground works, excavations, basements, tunnel networks etc. as water always finds the weak point and low point. Also, some wet works can never be fully protected from water e.g., dredging, rip-rap, river works etc

iii. **Stage of the project** - Periods where physical flood defence systems cannot reasonably be put in place, especially in the early works phases, earthworks, partially completed and temporary structures.

Case Study 12: Road Project – Incomplete Drainage

An 18 km long bypass was being built in a low-lying area along an existing water-course close to the coast. A large culvert was being constructed to divert the existing river, but this was not yet completed when a major storm took place. Damage to the project works occurred along much of the 18 km alignment. Following the loss, additional temporary drainage measures were put in place during the winter season and when severe rainfall was forecast. The project also liaised with local drainage authorities which interfaced with the project.

Where there are significant inherent exposures there will be greater emphasis on risk management and emergency planning to mitigate.

It may even be a case where this is considered a reasonably foreseeable risk and not one that can be transferred to Insurers. Project management should become familiar and be aware of such issues and plan accordingly.

For example:

i. where there is a deliberate strategy of planned flooding to allow the site or portion of the site to flood

ii. where the site is considered too difficult or too expensive to protect

iii. where flood mitigation measures are set to an ineffective level based on an inappropriate return period given anticipated project duration and potential flood water levels.

2.6 Consequences of a Flood Event

The consequences of a flood event to a project depend on two factors: Exposure and Severity.

i. **Exposure***:* A measure of the assets' value at risk of flooding and the costs associated with reinstatement and delays that may be incurred as a result

ii. **Severity:** A measure of potential for flood damage to the exposed assets and the associated delay and costs to the project programme both directly and indirectly such as loss of utilities or access

Property damage loss is directly proportional to the intensity i.e. speed of spread, velocity, depth, and duration of flood water events, combined with the susceptibility of the property to water damage.
Consequences of flood could range from debris removal, contamination, physical damage of permanent and temporary structures, saturation as well as injury and harm.

2.7 Probability and Magnitude of a Flood Event

The chance and scale of a flood occurring are usually based on statistical estimations of flood event frequency and the expected behaviour of future flooding. Typically referred to in terms of return periods or annual exceedance probabilities, these aim to quantify the likelihood and magnitude of flood events. See Appendix 5: Probabilities & Limitations for further information.

The impact of climate change should be considered where past data may not adequately predict Probability and Magnitude of future events.

The consequences and probabilities form the basis of the Flood Risk Assessment which is covered in Section 4 Project Flood Risk Assessment.

3 Flood Hazards Sources of Water and Vulnerabilities

Water is the hazard in this context and all sources of water including the following , should be considered.

Vulnerabilities are the features of the project or individual location that aggravate the impact of water hazards on the project both from the delivery and physical damage perspective.

3.1 Sources of Water

i. Pluvial
    a. Surface water flooding
    b. Overwhelming of surface water and/or foul water sewer drainage systems
    c. Flash floods
    d. Reactivation of desert wadis or channels of creeks that are normally dry
    e. Driving rain
ii. Fluvial
    a. Rivers
    b. Streams and brooks
    c. Canals forming part of a river system
    d. Culverts and channels diverting rivers and streams
iii. Coastal
    a. Storm surge
    b. Tidal
    c. Tsunami and meteo-tsunami
iv. Groundwater
v. Utility water mains burst
vi. Levee, reservoir, dam failure or overflow including Glacial Lake Outburst Flood and consequence of slope failure on bodies of upstream water
vii. snow-melt runoff

Flooding can be a combination of multiple sources driven by the weather i.e., a heavy rainfall storm event causing surface water runoff, saturated ground conditions (if prolonged periods of rainfall), combined with rivers overtopping, drainage networks overflowing from capacity being exceeded or from blockages, and coastal storm surge flooding.

When tidal surges coincide with high fluvial flows this can prevent discharge into the estuary, known as tidal locking.

See Appendix 3: Common types of flooding for more detailed information on common types and sources of flooding.

3.2 Vulnerabilities

i. Location
    a. close proximity to a water source, water course and/or within a flood plain
    b. high groundwater infiltration potential leading to rapid increases of levels due to local geological and hydrological conditions
    c. high rainfall seasonal weather patterns

Case Study 13: Temporary Site Offices – Washed Away

Temporary accommodation and a materials lay-down area were sited on a temporary, prepared area adjacent to a small stream. Following significant rainfall, the stream burst its banks and undermined the prepared area. Materials, equipment and temporary site buildings, and offices which contained expensive computer equipment and critical projects information– were washed away by the flood waters.

ii. **Topography of site and surrounding land** can affect potential flow pathways or routes of floodwater into and within the site such as low-lying areas and sites situated at the bottom of a valley or depressed terrain. Elevation, direction, and degree of sloping land can impact speed of spread, velocity, depth, and duration of flood water. In very wide and relatively flat floodplains, flood levels will normally rise more slowly, have a lower velocity, and be shallower in depth with larger flood extents but relatively smaller differences in depth between different return period events. In small and steep valley areas, the opposite is more likely with fast flowing deep flood waters with smaller extents and larger differences in depth between return period events.

Case Study 14: Road Structure – Low Point Location

The excavation for a structure traversing a road project, was inundated with stormwater. The excavation was located at a low point on the trace and not provided with any temporary flood protection arrangements to deal with the rainwater run-off. Damage occurred to formwork and reinforcement being installed in the excavation.

iii. **Changes in land use, including changes to topography and infrastructure**. Urbanisation, when land is covered in impermeable concrete and tarmac or hard landscaping, can decrease and/or disrupt natural infiltration, drainage, and soakaway times as well as changing flood pathway and flow routes.

iv. **Agricultural areas** can also negatively affect flood processes and increase flood magnitudes. Higher sediment loads due to erosion can be expected in agricultural areas, leading to significant higher clean-up costs after flooding.

v. **Project design changes in both temporary and permanent state** such as:
   a. changes in drainage designs or insufficient drainage capacities
   b. changes to the existing flowing or static watercourses such as damming, re-routing, altering overflow facilities,
   c. changes to flood wall and defence systems.
   d. subsurface activities such as basement, pile / diaphragm wall construction can alter the course of groundwater

   Such design changes can affect the flood risk and may not be predicted by pre-project design flood models.

vi. **Adjacent third party works and activities** may alter the local topography, introduce flood plains and/or create preferential flood water paths which may direct and divert flood water to the project premises. Such design and construction changes and topographic alterations by third parties can affect the flood risk of the project and may not be predicted by pre-project design flood models. Groundworks increases the possibility of utility strikes and can lead to flood events.

Case Study 15: Flooded underground station due to adjacent road construction works

A heavy rain event flooded an underground metro station under construction and in testing and commissioning stage, caused by storm water diverted to the project premises from an adjacent road project under construction. The temporary earth works, and grading of the road project altered the local topography of the catchment area and the natural storm water discharge channels and created new preferential storm water paths and ponding areas which flooded the adjacent underground metro station and led to severe damages and cost and schedule implications.

vii. **Site-based activities during both the temporary and permanent works phases** may conversely alter the local topography, introduce flood plains and/or create preferential flood water paths which may direct and divert flood water to third party areas and premises. Such changes can affect the flood risk to third parties during construction which may not be predicted by pre-project design flood models.

viii. **Driving rain and localised heavy rainstorm events also known as “stormbombs” are of concern in** is a particular issue for buildings under construction or renovation Such events can introduce excessive water into a building overwhelming any temporary protection measures and introducing immediate water damage to the works as well as the longer-term risk of mould and damp. This is of particular concern where there is exposed timber and other hydroscopic material are present.

4 Project Flood Risk Assessment

Flood risk assessment and management needs to be undertaken and carried out throughout the whole life of a project, including both development, design and construction phases and it is most cost efficient and effective during the project development and design phases. The responsibility to manage flood risks is then gradually transferred from Project Owner and Consultant to the Main Contractor as the project progresses to construction stages.

In some parts of the world, Flood Risk Assessments are statutory requirements and are necessary components for regulatory approvals. Unfortunately, these generally consider only the operational flood risk and the permanent works and are mostly silent on the temporary works and the flood risk during construction.

It is acknowledged that the flood risk during construction is likely to be different and more onerous to that affecting the completed assets since the permanent works are typically less vulnerable and respond better to flood risks.

A combined Flood Risk Assessment covering both the construction and operational phases, or a standalone Flood Risk Assessment During Construction should be produced, see Schedule of Deliverables in Section 6.4.

A combined Flood Risk Assessment covering both the construction and operational phases is more efficient since the construction phase flood risk assessment will be the more onerous and incorporate all aspects of the operational phase plan. It should typically consider:

i. Design of permanent works, in respect of materials, location, elevation etc.
ii. Temporary works for flood protection and mitigation and early provision of embankments and other flood risk management infrastructure incorporated in the permanent works.
iii. Elevation or protection of sensitive equipment.
iv. Appropriate sequencing of the permanent works construction
v. Provision for storage of construction materials and equipment.

Demonstration to insurers that flood risk has been considered at the earliest possible opportunity to inform development, design, construction, and operational aspects, and this may result in more favourable terms and conditions offered by prospective project insurers.

4.1 Flood Risk Baseline Report and Hazard Maps

During the project planning and development stage and prior to the Tender stage, the Project Owner should prepare and develop a Flood Risk Baseline Report (FRBR) to serve as the contractual baseline for flood related scenarios and associated risks, see Schedule of Deliverables in Section 6.4.

The FRBR should consider the existing site conditions and topography during the project planning and developments stages and the final configuration of the tendered permanent works. It should be based on the storm event key design parameters and flood return periods stipulated in the contract.

For the Design stage, Construction Stage (including the construction sequence of the works), Testing & Commissioning Stage and Trial Operation Stage before the project hand-over, the Designer should incorporate the FRBR and develop Flood Risk Hazard Maps (FRHMs) for flood related scenarios and associated risks (refer to 6.4 Schedule of Deliverables).

The FRBR and the FRHMs should:

i. Be quantitative,
ii. Incorporate hydrological assessments, probabilistic methods and analysis in flood modelling with probabilities of exceeding baseline and design assumptions,
iii. Implement real-time or almost real-time mechanisms for weather and storm prediction,
iv. Review and consider historical flood data
v. Take into consideration uncertainties in the key modelling design parameters due to climate change, which may lead to sudden and severe storm events/flash floods, exceeding the design assumptions and overwhelming storm water drainage networks. Flash floods should consider potential vulnerability, rapidity, impact from both water and materials and the requirement for emergency actions,
vi. Consider all sources of water and vulnerabilities such as those noted in Section 3,
vii. Incorporate the results of the flood risk assessment during construction,
viii. Be monitored, reviewed, and updated at regular intervals as necessary.

4.2 Construction Phase Flood Risk Assessment

The construction phase flood risk assessment should reflect the construction specific aspects of the site, including, but not limited to the following:

i. Adjacent projects and developments
ii. Topographic changes during the project.
iii. Excavations and earthworks.
iv. Project sequencing and phasing.
v. Locations for welfare, storage areas (plant, machinery, equipment, materials)
vi. Access and egress routes, which may change during the project.

Case Study 16: Submerged Piling Rigs

Several piling rigs were installing foundations for a power plant when heavy rain fell across the site area. All the rigs were submerged and required overhauling before being put back into service. The project had not undertaken a construction phase flood risk assessment and had little focus on flood damage mitigation.

The construction phase flood risk assessment should include, as a minimum the following information:

i. Quantification of the risk of flooding from all relevant sources and for all vulnerabilities.
ii. Locations at risk, with severity and exposure.
iii. Recommended mitigation measures required to manage the risk of flooding and reduce the residual risk to as low as reasonably practicable. These should reflect the nature, risk tolerance and duration of the project within a cost/benefit analysis framework and should be explicitly stated and documented.
iv. Suggested monitoring and review frequency.
v. Any other site or project specific particular considerations related to flood risk during construction.

vi. The Source-Pathway-Receptor model can also be applied to flood risk assessment during construction, as discussed later in this section. Downstream effects of flood pathways including third party impact from debris and pollution etc

It is strongly recommended that the project owner requires, as condition to the contract and employer's requirements, that the contractor(s) submit the construction phase flood risk assessment and implement the recommended mitigation measures.

Competent persons should be engaged in preparing, maintaining, monitoring implementation, and reviewing the construction stage flood risk assessment.

4.3 Preparation of the Construction Phase Flood Risk Assessment

The main contractor is responsible for preparing and updating the construction phase flood risk assessment. Actions arising from the assessment should be detailed within the Flood Management Plan, see Schedule of Deliverables in section 6.4. It is recommended that the construction phase flood risk assessment is periodically and/or as required reviewed to ensure that it remains appropriate/applicable.

This typically may include consideration of:

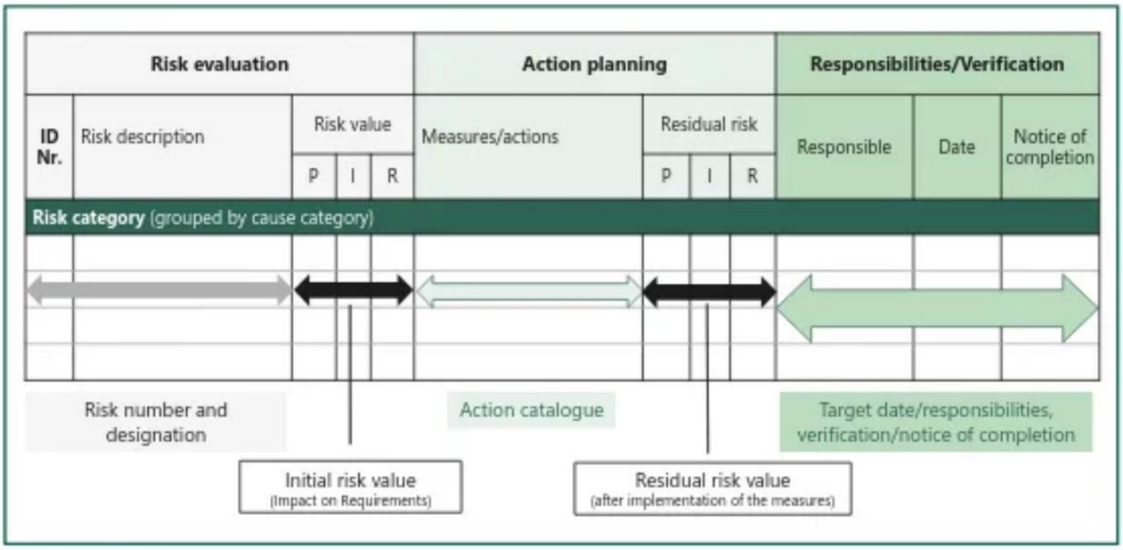
i. Changes to the sequencing of the project.
ii. Changes to the project programme, so works may be undertaken in a different climatic season to that originally envisaged.
iii. Current and future adjacent projects and developments.

4.4 Construction Phase Flood Risk Assessment Process

The construction phase flood risk assessment should consider all the stages of the project execution and all temporary and permanent works, and should be undertaken by the following:

i. Planning/Project Development Stage: Project Owner
ii. Tender Stage: Project Owner
iii. Design Stage: Contractor/Designer/Project Owner, depending on the contractual framework
iv. Construction Stage, including Testing & Commissioning and Trial Operation Stage before project Hand-over: Contractor/Designer

The identified construction phase flood risks for all project execution stages and for both the temporary and permanent works should be documented in a formalized risk register. This can be either a full project risk register or specific flood risk register depending on extent and severity of flood exposure.



Example of formalised risk register (DAUB, Project Risk Management in Underground Construction)

It is recommended that the construction phase flood risk assessment follows the risk management process as per ISO 31010 or similar.

Construction phase flood risk workshops, brainstorming sessions and continuous feedback loop should take place between the key project participants and stakeholders. This may be done with regular meetings and updates of the respective risk register as required.

Potential construction phase flood risks should consider both project internal and external interfaces and factors from third parties and stakeholders during the project execution stages which should be dealt with through effective management and coordination.

Risk factors may typically include but not limited to:

i. Alterations of the local topography
ii. Creation of preferential surface water paths and low points
iii. Diversion of runoff water causing local flood
iv. Changes of the water discharge capacity from the project area. There may be variations in natural and seasonal discharge capacity and condition of water paths such as irrigation and waterway channels which are often regulated by authorities.
v. Blockage of the drainage network
vi. Increase of hard surfaces and reduction of natural infiltration capacity
vii. Increase from dynamic effects (wind-blown, minor wave, etc)
viii. Installation of new water utility pipes

The construction phase flood risk model should also use the 'source – pathway - receptor' approach, which considers:

i. the source or type of flooding and associated probability
ii. the pathway or route flood waters will take to reach the project site area
iii. the susceptibility of the project site (receptor) to flooding

In assessing the flood exposure of the project site area, the following should be considered:

i. Identify the flood hazards i.e., flood source, pathways and other contributing factor that may lead to a flood event occurring.
ii. Quantify the probability and magnitude of potential flood events
iii. Determine and assess factors that affect the consequences of a potential flood event for both property damage and delay and/or interruption of the project
iv. Evaluate level of adequacy of any on site and /or external mitigation measures and what additional measures are necessary to manage the risk and reduce it to ALARP
v. Review assessment and controls as project progresses

The construction phase flood risk assessment should consider the likelihood, extent and impact of debris, pollution and contamination carried in the flowing waters. Where waters are contaminated with silt or sewage, salt water, oil, lubricants, asbestos, etc., there can be significant clean-up costs and durations to consider.

Prolonged exposure can also result in health hazards such as damp and mould.

The construction phase flood risk assessment should be proactive and consider:

i. All possible sources of water as described in section 3
ii. All possible scenarios and combinations of scenarios
iii. Tidal effects and water level fluctuations
iv. Discharge capacity and run off
v. Flood attenuation and storage
vi. Blocked drainage
vii. Local and wider topography
viii. Landscaping and any architectural constraints
ix. Topographic changes which could affect the location of and potential depth of floods – changes could include bunds, drainage channels, cuttings etc
x. Future interfaces and adjacent projects
xi. Potential impact on pollution and contamination
xii. Irregular natural processes and events specifically due to global warming and climate change
xiii. Use of buoyant materials including insulation and void formers in enclosed spaces susceptible to flood

Case Study 17: Floating of Basement floor

Following a storm event water encroached below a recently completed basement floor slab which has been cast on 200mm of foam insulation. The material is extremely buoyant and there was sufficient uplift to rise and damage the slab. The entire floor system was cut-out and re-laid.

The construction phase flood risk assessment should follow a holistic approach as various flood elements interact and/or could occur simultaneously, such as:

i. Surface drainage system and coastal flooding
ii. Surface drainage system and groundwater
iii. External water utility burst and storm
iv. External water utility burst and blocked drainage network

The construction phase flood risk assessment should typically:

i. Assess climate change trends in precipitation and storm duration
ii. Assess and implement the acceptable worst-case scenario (or combinations of scenarios) in determining the maximum flood threshold levels for all project execution stages and for all temporary and permanent works.
iii. Determine the minimum asset level with a risk-based freeboard
iv. Map consequences with different operational response times
v. Identify and evaluate additional and appropriate flood protection measures
vi. Comply with relevant Standards, Codes of Practice and Regulatory Requirements

Case Study 18: Blocked Third Party Drainage – Loss of Stored equipment

In a narrow and steep-sided river valley, the contractor had located an equipment storage area next to a major highway. During a significant storm event a drainage pipe below the highway, which had not been maintained and kept clear of debris became blocked. Consequently, significant quantities of water and silt from a steep gully on the other side of the highway flowed onto and down the road, then into the storage area some 200m away. Significant damage was caused to equipment resulting in a major claim and project delays.

4.5 Water Utility Burst Assessment

The water utility burst assessment and the associated flood risk should be carried out in three stages:

i. Asset Categorisation: Identify and categorise the pressure mains within close proximity to each location. These mains should then be classified by characteristics including type, diameter, and pressure.
ii. Identify Worst Case Failures: Hydraulic calculations should be used to establish potential flow rates and flood volumes for various failure modes for different operational response times (e.g., two-hour and eight-hour operational response times):
    a) Failure Mode 1 – Small Orifice
    b) Failure Mode 2 – Large Orifice
    c) Failure Mode 3 – Rupture (Distribution mains only)
iii. Consequence Mapping: A flood model should be used to determine the overland flow and flood impacts on the project site area. The flood hazard level and flood depths predicted by the model should be assessed. In addition, a worst-case scenario with blocked drainage gullies should be considered.

5 Flood Control – Design, Planning and Selection

Where flood risks exist, it is essential that flood exposure is clearly identified. Risk allocation, roles and responsibilities should be clearly defined by contract, with control and mitigation measures adequately priced-for as part of project development and delivery.

This section determines key activities related to:

i. Planning/Project Development Stage
ii. Tender Stage
iii. Design Stage
iv. Design Considerations (refer Appendix 5)
v. Third Party Influence
vi. On Appointment of Contractor & Detailed Design
vii. Works Sequencing & Planning

For each project stage, the responsible party (i.e., the party in a better position to manage flood risk) should produce the respective deliverables and check-sheets. A detailed Schedule of Deliverables in Section 6.4 outlining the responsibilities of each party as outlined below:

i. Planning/Project Development Stage (Project Owner)
ii. Tender Stage (Project Owner)
iii. Design Stage (Contractor/Designer/Project Owner, depending on the contractual framework)
iv. Construction Stage, including Testing & Commissioning and Trial Operation Stage before project Hand-over (Contractor/Designer).

Digital Flood assessment and modelling tools are common and should be considered for use in the design process.

5.1 Planning/Project Development Stage

The planning and development stage is the most important in the project's life cycle since decisions made at this stage define to a large extent the degree of potential exposure and vulnerability of the project to flood risk, including the construction sequence, activities, and methods.

The project owner and the appointed consultants should carry out comparative risk assessments of the considered project options (and alignments, mainly in case of linear projects) with respect to flood risk. They should demonstrate both qualitatively and quantitatively that the selected project configuration utilising an "As Low As Reasonably Practicable" (ALARP) approach or similar to managing the risk of flooding and/or appropriate and adequate control. Mitigation measures should be incorporated in the design to reduce the inherent flood risks to ALARP and have residual flood risks within the risk tolerance and appetite of the project owner.

The project owner and the appointed consultant should carry out flood risk modelling studies incorporating probabilistic methods and analysis with probabilities of exceeding baseline and design assumptions. In addition, they should take into consideration uncertainties in the key modelling design parameters due to climate change, which may lead to sudden and severe storm events/flash floods, exceeding the design assumptions and overwhelming storm water drainage networks.

The consultant appointed by the project owner should be Competent having suitable and sufficient experience in similar types of projects exposed to flood hazards and similar environmental conditions.

Inadequate and substandard levels of expertise and past experience may directly impact the quality of the design work with regards to flood risk and lead to over or under design by adopting unrealistic or incorrect assumptions. In addition, the appointed consultant should have access to adequate resources to discharge their duties.

5.2 Tender Stage

The Project Owner should include a Flood Risk Baseline Report (FRBR) in the tender documentation to serve as the contractual baseline for flood related scenarios and associated risks as described in Section 4.

All baseline statements contained in the FRBR should be specific and measurable and all the assumptions adopted for its development should be clearly and explicitly stated.

The project owner and the appointed consultant should establish the necessary provisions for risk allocation within the contract documents and explicitly define the roles and responsibilities for flood risk management, control, and mitigation. Established contractual arrangements and provisions should enable adequate pricing of the necessary control and mitigation measures as part of the project development and delivery.

It is strongly recommended that a Clause in the tender documentation requiring the drafting and delivery of a construction-phase Flood Risk Management Plan (FRMP) be inserted into the Contract.

The level of expertise and demonstrated former experience of the Main Contractor in similar types of projects exposed to flood hazards and similar environment conditions can be an important factor and should be considered during the Tender Stage. For example, an inexperienced Project Owner awarding the EPC Contract to a foreign domiciled company who has no former local experience in the Country or Region could be problematic.

5.3 Design Stage

The pre-tender, tender and post-tender Design Stages should include risk identification and mitigation of flood exposures based on available data and project site flood assessment and modelling. The process should consider the temporary state during construction and not just in reference to permanent design solutions. Design stage planning should include early sequencing of site physical flood controls for permanent and temporary systems and drainage. Where a flood risk assessment for the operational phase is planned or has been carried out, this may assist the construction phase assessment process.

The project flood mitigation measures should be considered at the design stage for the whole life of the scheme, including the construction phase and not only on the final built operational phase.

Design considerations such as location of vulnerable equipment or materials, location of the works in relation to flood sources etc. all should be considered as part of the high-level design. Where possible, undesirable features should be avoided, or mitigated.

In assessing the flood risk and corresponding controls, it is important to remember that where sites are exposed to flooding there will always be an element of inherent risk which will remain irrespective of any mitigation measures. The extent of the inherent risk will depend on various factors such as the location, nature, and stage of the project. Where there are significant inherent exposures there will be greater emphasis on risk management and emergency planning to mitigate. See Section 2 under Inherent and Residual Risks.

The flood risk to the project should be included in the project Risk Register that is issued to the contractor as part of tender process.

During the Design Stage, the Designer should develop and produce Flood Risk Hazard Maps (FRHMs) for flood related scenarios and associated risks, incorporating the results of the Flood Risk Baseline Report.

Elements for be considered in the design phase are included in Appendix 5

Case Study 19: Railway Embankment - Insufficient Freeboard

The temporary diversion of a section of railway to facilitate on-alignment upgrading works, was overwhelmed by flood waters. Ballast and embankment works were washed away, and the rail track settled. Sufficient 'freeboard' between the expected flood level and the track had not been allowed for in the temporary works design.

5.4 Third Party Influence

Contact should be made with third parties that control features that are outside of the projects control, this can include river authorities, dam, and reservoir owners etc of whose actions such as river flow modifications (release of water from reservoir for example) can impact the works. Notice of such actions should be received in advance and appropriate steps taken to mitigate impacts

5.4.1 Third party activities/features affecting the project

The project may rely on third party flood defences that are external to the project boundary, or responsibility. These can include flood barriers/walls (fluvial/coastal), upstream water retention storage areas used to manage and store excessive flows (fluvial/pluvial), and storm drains used to manage excessive rainfall surface water. These types of formal flood defence systems, which are specifically designed and maintained to provide a specific return period standard of protection, are often state or municipality controlled.

For these to be considered an effective mitigation feature, confirmation is needed of the return period design rating, that the defences are in good condition, and that they are regularly maintained.

Case Study 20: Off-site Watercourse Capacity – Back-up Loss

A small watercourse, crossing a major road project, was diverted via a box-culvert to facilitate construction of an underpass structure. Following a period of heavy rain (1 in 70yr intensity) the increased discharges from various sources into a river downstream of the project, caused the watercourse to back-up through the culvert (designed for 1 in 100yr events) and overflow onto the slip-road and into the underpass. Post-event review works involved modelling flows and catchment areas of surrounding watercourses, prior to considering remedial works options, including widening the approach to the culvert to increase flows to override other watercourses.

Even if in good condition and well maintained, if the design rating is for example to protect against 50-year flood events, then in the 100-year flood event the defence is likely to exceed the drainage capacity or walls be overtopped and therefore the site would still effectively be at risk to a 100-year flood. There also remains a residual risk of failure and breach and once overtopped or breached, flood defences can act as a barrier slowing the rate of waters subsiding.

The project team should have awareness of third-party works being undertaken, these include works to modify or improve flood defences, third party projects that may exacerbate impact of, but not limited to flood exposure in relation to water runoff, river flow, or flood heights etc. This may influence the project's short-term planning or sequencing, due to detrimental impact on assumptions made during earlier project planning.

5.4.2 Third Party properties/activities affected by the project

Where flood waters are diverted and/or collected on site there is a risk that the containment systems such as temporary trenches, attenuation tanks/ reservoirs, etc. may be overwhelmed.

In such instances overtopping of these structures could result in areas occupied by third parties being at increased risk of flood damage where limited/no original flood exposure was present.

Such flood event could lead to physical damage to third party property as well as business interruption and potentially life-threatening events.

The project team should have awareness of the potential increased flood exposure to third party property due to the project and may need to modify or improve existing or construct new flood defences to protect third parties. This may influence the project's short-term planning or sequencing, due to detrimental impact on assumptions made during earlier project planning.

Case Study 21: Tunnel Aquifer Flood – Loss of Third-Party Water Supply

A relatively shallow tunnel for a hydropower project encountered a zone of fractured rock, resulting in the ingress of significant quantities of water from an overlying aquifer. This caused drawdown of the groundwater level above the tunnel, cutting-off water supplies to a local town.

The project owner had to provide temporary water supplies while extensive chemical grouting of the fractured zone was carried out.

5.5 On Appointment of Contractor & Detailed Design

The appointed Main Contractor should be or have been provided with a project risk register that includes flood risk, a project tender design that identifies key flood exposure and vulnerabilities and a FRBR in order to produce FRHM's during the period of construction. This information will contribute to further development of detailed design, works planning and scheduling, sub-contract and procurement strategy, and emergency planning.

During the detailed design, designers should consider potential sequencing concerns and identify aspects of the design that are vulnerable to flood events. This can include aspects such as specification and choice of materials, and permanent works during temporary stages such as hydrostatic and buoyancy effects on basements and excavations et al.

The selected Main Contractor should therefore update/develop their Flood Risk Management Plan and ensure that it includes design features to mitigate the risks of flood damage, permanent and temporary flood protection systems, and flood monitoring systems together with pre-flood management planning and post flood emergency response.

The FRMP needs to be in place prior to the works commencing and reviewed as the project progresses.

The Main Contractor, or Project Principal where a bespoke delivery organisation is created, shall appoint a Responsible Person for Flood who has the ability and power to influence key design and construction related activity.

The Responsible Person for Flood should undertake a number of functions, including but not limited to:

i. Have oversight of design development
ii. Have oversight of project planning and scheduling
iii. Have oversight of methodology from contractor and supply chain
iv. Ensure appropriate liaison is made with external parties
v. Have power to ensure appropriate choices and mitigation measures are implemented.
vi. Ensure the FRMP is up-to-date, included within the overall project management/delivery plan, details the management of flood risk during the construction period and how the flood risk to the proposed project construction methodology will be mitigated during the various construction phases.
vii. Ensure preparation of Pre-Flood Event Acton List and associated mitigation measures
viii. Track and ensure close-out of flood mitigation deliverables

During works planning and execution, critical path and near critical path works vulnerable to flood risk should be identified, to enable appropriate mitigation measures are implemented in a timely manner. This can assist in minimising flood related delays to project delivery.

Permanent and temporary flood protection systems, where they form part of the scope of works should be sequenced as early as practically possible to enable the project to benefit of the protection they provide.

Subcontract packages which are vulnerable to water , such as earthworks, should include requirements for mitigation features identified during the project design phases. Attendances by main contractor should be clear in respect of who provides what, examples include protection of prepared formation for roads, over-pumping attendances, temporary weather proofing etc.

The FRMP should include provision of temporary bunding or protection, specific sequencing requirements, limitation of works to certain times of the year, provision of dewatering or pumping facilities etc.

During the construction phase (including the construction sequence of the works), Testing & Commissioning phase and Trial Operation Phase before the project hand-over, the Contractor should regularly monitor and update the FRHMs for flood related scenarios and associated risks, developed in the Design phase.

The FRHMs during the construction phase should implement real-time or almost real-time mechanisms for weather and storm prediction, incorporate the results of the Flood Risk Assessment during construction and inform as and when required the FRMP.

Emergency planning and response activities to flood and inundation events should be included within an overarching Flood Emergency Response Plan (FERP), see section 8.

In the event of a potential flood event, the contractor should develop and follow their Pre-Flood Event Action List, (an example is presented in Appendix 2).

5.6 Works Sequencing and Planning

The proposed construction programme and sequence of works should be reviewed as early as possible, and key project risk phases should be identified to enable implementation of mitigation measures at each of the key stages, including flood prone areas, vulnerable materials, or features.

These can include exposures such as incomplete building envelope, incomplete flood defences, unprotected prepared formation, increase in site values, storage including off-site and third-party storage areas/depots, or delivery of equipment or materials to site, exposed site infrastructure such as access roads etc. The project sequence should be modified, where possible, to avoid or minimise vulnerable features. This can include delay or acceleration of certain activities of the project to ensure protection to vulnerable elements is provided.

Works should be planned and executed with due regard to flood exposure. This includes temporary installations such as working platforms, temporary access roads etc, as loss or damage to these can have significant impact in terms of repair and recovery costs as well as on timely delivery of the project, even if the permanent works are not affected.

The use of 4D plans or similar can help identify flood risks and mitigation measures. They can, for example, show that flood water cannot be trapped in sections of linear projects such as roads and tunnels.

Where a project is complex construction sequence “storyboards” should be developed so that all parties become aware of what has to be constructed and when.

The use of Virtual Reality systems to model such exposures is likely to increase and should be considered throughout the lifetime of the project.

Permanent flood defences or mitigation such as raising site topographic levels should be undertaken as early as possible in the programme to minimise duration of flood exposure to the site. Features such as drainage systems, external protection etc. should be installed as early as possible, not only to provide early protection, but also to provide a discharge location of accumulated run off water.

Where this is not possible, and sequencing cannot be modified, temporary measures should be provided.

The programming of works should consider seasonal influences and variations , as well as extended breaks in work including holiday periods.

Wherever possible, the works programme should align the installation of temporary and permanent flood protection works with anticipated regular and extended periods of dry weather with an adequate margin to absorb delays and weather uncertainty.

Nevertheless, flood events can still occur outside of seasonal norms, especially with the growing effects of climate change. Also, in case of accumulated delays that push the execution of the temporary works into the wet season and a such delays should prompt a full review of the both the FRMP and FERP.

Where sufficiently robust physical flood defence systems cannot reasonably be put in place or where temporary systems provide very limited protection, there will be an increased inherent flood exposure. In such situations, appropriate mitigation measures such as sequencing of the works to minimise and limit the consequences of the event and robust emergency planning and response management are essential.

6 Resilience and Mitigation from flood water

Mitigation measures can take a number of different forms; these include scheduling aspects discussed within the previous section, or more managerial and physical aspects as noted below.

These can reduce the impact and likelihood of flood related damage; it should be noted that permanent or operational phase mitigation may have minimal influence over construction phase exposure, depending on phasing and construction sequence.

<u>6.1 Managerial Aspects</u>

The Responsible Person appointed for Flood should undertake project supervision duties throughout construction phase, ensuring:

i. Mitigation actions identified in the FRMP are executed appropriately. Mitigation measures are to be reviewed regularly to ensure they remain appropriate.
ii. Sub-contractors undertake works in accordance with the flood risk management plan during construction
iii. Prestart construction meetings are held with sub-contractors to review of flood aspects and method statements developed explicit for these areas.
iv. Site supervision obligations at Superintendent and Agent level, that can be delegated to positions such as Foreman to include flood mitigation inspection as part of daily and weekly mandated checks in addition to typical activities such as excavation and scaffold inspections are undertaken. This can include, but is not limited to:
    a. regular inspections of drainage channels, culverts, and pipes to ensure these are free from of blockages
    b. Regular review, inspection and maintenance of temporary protection systems and measures with repair and upgrade as needed
    c. Emergency supply of materials and equipment is readily available and in working order, as noted in the emergency plan.

The Responsible Person should ensure that the FRMP is reviewed at a regular and appropriate frequency; this can be as frequent as monthly, but never greater than six months. Any significant changes to the project need to be accommodated, this can include delay, acceleration, works modification etc. The plan is to be updated depending on development or changes during project progress.

Management of Change is an essential part of the planning and delivery cycle. Proposals to amend works that may impact flood mitigation and resilience activities need to be thoroughly reviewed throughout the project life. Consideration should be given to ensuring that the original designers flood protection intentions are not compromised.

Emergency provisions need to be considered including on-call attendances, material supply, back up plant and off-site monitoring etc.

Project Logistics Plans are regularly created to demonstrate proposed site arrangement, material and plant movement and storage requirements and it should take due regard to:

v. The parking/ storage of materials and plant. Consideration should be given to splitting plant fleets to reduce accumulation and loss potential of equipment that may be impacted by flood events.

vi. Storage of Materials. Materials should be stored appropriately, with water vulnerable materials raised off floor levels and in covered areas. The extent of raising should consider potential depth of flood water.

vii. Bulk materials. These should be stockpiled in non-flood vulnerable areas and protected as required. Suitable programme allowances are to be given for drying out and moisture control/ checking. Free issue materials intended for use on the project such as material from excavations, or stock piled from previous projects should be treated with due regard to replacement value. This includes protection from flood or water that can degrade its engineering properties. Stockpiles of cohesive material should be compacted and sealed to prevent degradation by change of moisture content. Granular materials should be protected from wash out, and consequential blockage of drainage or culverts.

viii. Chemicals and other liquids. These should be stored appropriately to avoid potential for contamination in event of flood. This is for environmental protection and to reduce clean-up effort post event

ix. Temporary accesses and haul roads. These should be designed and installed with due regard to potential cut off or influence of potential flood water discharge routing; temporary culverts and conduits should be sized accordingly, taking into account additional flow due to influence of the works

Weather and other water aspects such as river flow or water and flood level indicators need to be monitored appropriately to ensure suitable medium and short notice actions can be implemented.

6.2. Resilience and robustness of materials

Where a structure is to be constructed in a location vulnerable to flood risk, the designers should consider the resilience and robustness of the materials that are to be used. Materials and equipment are typically considered during the planning and development stage so that budgets can be obtained, however they may be changed for less resilient and robust products following a "value engineering" review post-tender to either reduce the overall cost or programme. It is important that the project sponsor, the design team, and insurers are fully aware of any changes to the original specifications to ensure that material and equipment resilience and robustness targets are not compromised.

Following a flood, it is important that a facility can be back in action swiftly, especially if it is part of essential or critical infrastructure. Using resilient and robust materials and equipment during planning and construction is one of the most important principles that underpins overall resilience and robustness.

The contractor must ensure that they are constructing those parts of the structure or facility first that provide adequate protection to the less resilient and robust parts or otherwise provide some form of adequate temporary protection.

Generally concrete foundations will be resilient once the concrete has sufficiently cured but walls of any material may need to be temporarily propped until they have reached the designed strength.

Resilient and robust materials will include the following:-

i. Concrete
ii. Structural Steel
iii. Brick and blockwork once the mortar has cured
iv. Stone, provided the joints are complete.

Less resilient materials such as timber and plasterboard should not be incorporated within a structure until it is adequately protected from flooding and ingress of water which leads to persistent areas of standing water within a building under construction.

Tanking, the use of water-resistant materials and raising of services above anticipated flood levels are considered best practice during construction.

Prior to buildings becoming weathertight, persistent areas of standing water from heavy rain events have led multiple instances of significant damaged and delays, see Section 7

It is generally accepted that all buildings, structures, and facilities with any basements should be founded on either steel piles or reinforced concrete; the ground floor slab should be constructed in concrete and the ground floor columns and walls in either structural steel, reinforced concrete, or masonry.

6.3. Physical Mitigation

Examples of engineered physical flood defence solutions to minimise effect of floodwater include but are not limited to the following:

i. Raising the ground level and/or slab or finished floor levels above the expected maximum flood threshold levels. Raised ground levels should also apply to temporary access/haul roads and laydown areas. The surface should relate to a determined return period level plus climate change effects and freeboard allowance.
ii. Having the ground sloping away from excavations, basement levels and low-level openings during the construction.
iii. Minimising the exposed length of non-back-filled pipelines/trenches. N.B. policy conditions limiting insurable lengths of open trenches may apply and should be taken into consideration
iv. Basements and below ground voids should be protected, where the ground cannot be profiled sufficiently, with upstands to prevent water ingress in event of surface water accumulation. Upstand height should be determined on expected flood levels based on suitably high return period; this is likely to be the design life of the structure.
v. Protecting the site boundary with raised embankments, berms, retaining sheet pile walls, cofferdams and spillways that divert the accumulated waters off the site.
vi. Protecting openings into vertical shafts with flood-resistant upstands in order to comply with local H&S requirements and location flood risk exposure.
vii. Protecting openings into the site buildings to area below ground using temporary/demountable flood defence boards and air brick covers above expected water levels and/or installing temporary drainage channels .
viii. Temporarily sealing of manholes, lift shafts and incomplete pipe and utility connections up to the temporary design flood level using bungs etc.

ix. Early completion and beneficial use of permanent drainage solutions including pumps and associated back-up power systems is preferred over to the use of temporary systems where appropriate.
x. Considering influence of flood during construction stages and including features such as tension piles or counterweights to mitigate effect of buoyancy on below ground structures.
xi. Provision of dewatering equipment to minimise piping or base failure of excavations during high groundwater events.
xii. Extending piling works to provide cut off structures to limit or manage migration of ground water.
xiii. Protecting the site boundary by using temporary/demountable flood barriers and/or installing temporary drainage channels.

Temporary flood defence products should be capable of quick and easy deployment. Passive systems that include automatic raising of flood barriers by using the hydrostatic pressure of flood waters can be deployed.

ANSI/FM 2510, BS 85118 and other internationally certified products are available.

Ensure that, where openings to buildings or external walls are protected, the systems are strong enough to withstand the weight of floodwater, which increases with depth e.g., floodwater one metre deep will exert a force of around half a tonne.

Windows have limited strength and cannot be relied upon to withstand the pressure of floodwater.

Raising temporary welfare units off the ground and installing mesh areas within perimeter hoarding to allow for flood water flows beneath (these need appropriate design to allow for water flow pressures).

Temporary and permanent Engineered drainage design solutions should consider, but not be limited to the following:

i. Designing temporary storm-water drainage systems for the appropriate return period events. In the permanent state Sustainable Drainage Systems are being increasingly used especially in urban areas that mimic natural drainage
ii. Checking drainage systems to ensure adequate hydraulic pressure can be contained within the system in the event of pressurisation from surcharging or attenuation effect from events such as intense rainfall, or manmade flooding such as burst pipe or tanks. This includes connections to attenuation tanks, especially those contained within basements or internal to buildings. Design the drainage to allow both subsurface routing (drainage piping) and overland flow capacity to be used to store and direct the runoff away from key assets, and especially open excavations or underground works, for the duration of the project
iii. Sizing temporary openings or conduits to adequately accommodate intense rainfall or surge discharge (accumulated outflow following periods of rain and run off from surrounding catchments). Accommodation for debris or foreign bodies within the flow should be considered to prevent full or partial blockage

iv. Utilising pumping systems

a) Drainage systems should ideally be gravity based, avoiding as much as possible the use of pumping systems as these are susceptible of machinery breakdown. When there is no other feasible solution than employing pump sumps in the drainage system these should be of adequate capacity for the expected potential flood event, have filtration to prevent clogging and a backup should be available (including backup generator for power supply).
b) Where there are automatic pumps, these should be provided and maintained with motors and their control systems flood-proofed (submersible type) or else located above the maximum flood level (pedestal type).
c) Power supply for essential pumps to manage flood water should be provided on an N+1 arrangement, fuel for temporary generators or pump set should be inspected on a daily basis and replenished accordingly.
d) Pump alarms should be monitored off-site for response to activation or failure and subject to a preventive maintenance schedule and be tested regularly to be sure they will operate properly when needed.
e) Consideration also needs to be made on issues of pumping out of contaminated flood waters, including settlement tanks.

v. Preventing backflow from hydraulic surcharge

a) Non-return valves (NRV) should be installed on drainage connection points into culvert connections and foul and surface water drainage systems to prevent back flow into the site
b) Drainage access covers should be secured to prevent them being pushed open from surcharging water.
c) Back flow is more likely where the external flooding depth outside is above the internal level of the drain entry points
d) Once NRVs are closed to prevent backflow, it effectively disconnects the property from the public sewerage system and systems such as toilets etc. cannot be used until the flooding has subsided and the device re-opens, otherwise the property may be flooded by its own discharges
e) Depending on the type of device, regular maintenance may be needed to ensure effective operation

It should be noted that drainage and pumping systems for surface water are unlikely to be effective from fluvial/sea inundations and extreme rainfall events. These can be overwhelmed as volumes are likely to exceed the design capacity therefore alternative flood mitigation measures should be considered

Regardless of the above, there can be periods where physical flood defence systems cannot reasonably be put in place, especially in the early works phases, and this will be an inherent exposure where greater emphasis on works planning and sequencing, risk management and emergency planning will be required.

6.4 Schedule of Deliverables

These Deliverables are dependent on the nature and exposure of flood to/by the scheme and the extent and detail for each Deliverable may vary.

Clause	Deliverable	Primary Responsibly	Scope and intent
Planning/ project Development Stage	Project Option Flood Risk Assessment	Project Owner / Consultant / Owner's Engineer	Demonstrate that flood risks have been accounted for at an early stage
	Flood Risk Modelling Studies	Project Owner / Consultant / Owner's Engineer	Consider key design parameters in assessing flood risk, including hydrological models, hydrodynamic models, uncertainties, climate change impact
	Consultant's experience, references, team structure	Project Owner	Demonstrate adequate level of expertise, experience and management structure of the Consultant developing the project in relation to flood risk management
	Planning stage Risk Register	Project Owner / Consultant / Owner's Engineer	To verify that Water and Flood Risk Assessments associated with the preferred project option have been formalised in a Risk Register that can be shared with other stakeholders in subsequent Project Stages.
Tender Stage	Flood Risk Baseline Report	Project Owner / Consultant / Owner's Engineer	Serve as the contractual baseline for flood related scenarios and associated risks.
	Contractual arrangements for flood risk management	Project Owner / Consultant / Owner's Engineer	Define risk allocation, roles and responsibilities for flood risk management.
	Tender stage Risk Register	Project Owner / Consultant / Owner's Engineer	To understand how the tender submission assesses the risks arising from water and Flood to the Works and how these will be managed during the Construction Stage.
Design Phase	Flood Assessment - Permanent	Designer / Hydrologist	Identify key flood exposures to the project in operational phase

	Flood Assessment – Construction Phase	Designer / Hydrologist	Identify key project flood exposures, indicating features that are vulnerable to water during construction such as construction in flood plains, flood vulnerable works during wet season , vulnerable materials etc
	Design stage Risk Register	Designer	To verify that Risk Assessment associated with the design have been formalised in Risk Register that can be shared with other stakeholders in subsequent Project Stages
	Flood Risk Hazard Maps	Designer / Hydrologist	Map the assessed flood risk, incorporating the results of the Flood Risk Baseline Report.
	Construction Feasibility	Designer	Consideration of early contractor involvement / or construction sequencing to manage flood exposure
Contractor Appointment Construction Stage	Contractor Competence	Principal / Owner/ Owner's Engineer	Ensure successful contractor has appropriate competence to manage flood risk to the project
	Appointment Responsible Person	Main Contractor	Appoint Responsible Person for overseeing flood risk, exposure, and consequential mitigation actions.
	Flood Risk Management Plan	Main Contractor / Designer / Principal's Engineer	Develop and maintain a Flood Risk Management Plan to demonstrate mitigation of flood exposure to and by the project. See Appendix 1 for a typical structure and example checksheet. **NB** The FRMP needs to be reviewed by Designer and Principal/Owner's Engineer.
	Construction stage Risk Register	Main Contractor / Designer / Principal's Engineer	To confirm how the Contractor intends to manage the Risks arising from water and Flood to the Works during the Construction Stage including risks identified by the Contractor as well as construction related risks brought forward from the Tender and Design Stage Risk Registers

	Sequencing	Main Contractor / Designer / Principal's Engineer	Project Schedule takes due regard of flood by limiting flood exposed works during high-risk seasons or prior to completion of flood defences. NB The sequencing needs to be reviewed by Designer and Principal/Owner's Engineer.
	Sub contract or procurement strategy	Main Contractor	Sub-contractors with flood exposed works have appropriate requirements in sub contracts detailing protection requirements with clear allocation of responsibility between parties.
	Third Party Influence	Main Contractor	Main Contractor in contact with parties that manage assets that can influence project flood exposure. Assess Third party works, and any deleterious effects considered, and assumptions made in initial planning are validated.
	Flood Risk Hazard Maps	Main Contractor	Regularly monitor and update the FRHMs developed at the Design Stage
Mitigation during construction phase	Managerial Aspects	Main Contractor	Inspection Schedule is developed and delegated appropriately
	Logistics Plan	Main Contractor	Logistics Plan developed incorporating aspects e.g. plant fleet parking, storage of chemicals, bulk and normal materials. Temporary access and haul roads are designed with flood considered in respected of drainage and inundation.
	Physical Mitigation	Main Contractor	Review of physical mitigation against recommended measures in respect of heights and features
	Drainage	Main Contractor	Drainage and discharge provision is reviewed against recommended measures in respect of heights and features as noted in this document
Emergency Planning during the construction phase	Development of Emergency Plan	Main Contractor	Emergency Plan is developed with clear allocation of responsibility and provision of pre-emptive and reactive actions. Stock of emergency materials and plant is available for use.

7 Protection of the Construction Envelope from rainstorm

The building envelope should be made watertight before any interior fixes, fit out and finishing works are carried out, especially fixtures, fittings and equipment that are susceptible to water damage.

Where the programme path sequencing requires fit out to commence prior to the completion of the envelope and full water tightness being achieved measures should be implemented to mitigate the risk of any potentially exposed fit out works. This can include the following:

i. Fit out and finishing works are sequenced at a minimum of three floors below the current level of the perimeter cladding installation and agreed watertight level. This should in effect mean the upper floor slabs provide a 'temporary roof' before the building's envelope is complete, the roof topped out and enclosed,
ii. Openings in the perimeter cladding should be kept to the minimum necessary such as openings required for tower cranes, hoists, and mast climbers.
iii. Temporary waterproofing should be planned and installed at incomplete non-watertight facade and roof openings and penetrations. Where necessary a temporary roof system may need to be installed including covers for crane bases.
iv. The perimeter gap between the edge of the floor slab and cladding should be sealed with a weather protection membrane which can also act as protection to any fire barrier material.

There should be regular inspections of all temporary waterproofing and drainage systems with additional inspections prior to and after severe weather events with any defects rectified immediately

Roof and cladding should be thoroughly tested for water tightness, and that it meets design and manufacture specifications during construction and once completed as part of the quality control and sign off procedures. Any low spots on flat roofing causing water to accumulate should be rectified to reduce the risk of failure

Completed roof areas should be free of debris and materials storage as this can damage certain types of roof weather proofing materials

There should be formal documented procedures to ensure all windows, doors and other openings are closed or protected with temporary covers

As part of the severe weather planning there should be formal visual site inspections of weatherproofing elements immediately before any forecast storm events, during such events and after the event to identify areas which may have suffered from water ingress

Interior vertical openings and penetrations can include floor slab penetrations, riser shaft openings, stairwells and lift shafts which can allow water to flow down through the building under construction

To protect against water flows all floor slab service penetrations should be designed to prevent vertical flow of water through the floor plates. This should include the following:

i. Permanent solutions can be sequenced early in the project where feasible, such as pipe collars and caps installed to the slab penetrations and riser upstands at least 100mm high at the riser or penetration openings;
ii. Where this is not feasible, temporary upstands and penetration covers or seals may need to be installed prior to any final finish installations

iii. Temporary enclosures with water tight membranes should be constructed over lift shafts and service risers, especially at the roof or current top slab level

To allow pooled water to be removed from the floors in the event of ingress, allocated risers should have temporary outlets connected to the permanent rainwater system formed within the temporary covers to provide drainage points

7.1 Rainwater drainage system

The project should have a formal permanent drainage management plan which is usually a requirement of planning permission conditions

Permanent rainwater pipes and drainage plus any other drainage measures such as soakaways, retention ponds or tanks, should be installed as early in the construction sequence as possible and connected up to discharge water away from the site with full functionality

Prior to the permanent measures additional temporary equipment may be required to manage the discharge of water from the building during construction, such as temporary rainwater pipes linking up rainwater outlets and any standing water removed by temporary pumps or wet-vacs.

Any rainwater drains should be fixed to allow for large volume storms and maintained throughout the construction period

To avoid blockages, rainwater roof gullies and drainage covers should be inspected and kept clear of any debris or materials

7.2 Materials Storage

The delivery schedule should consider state of building envelope completion and weather exposures. It should attempt to minimise the arrival of susceptible materials and equipment until after the building is weathertight tight.

There should be a formal delivery and storage plan in place which includes ensuring all water susceptible materials are kept dry. Measures should include:

i. Delivery of water susceptible materials i.e., plasterboard, joinery, electrical components, to start after completion of the building envelope or when the structure is sufficiently watertight and that minimal risk of water damage. If this is not possible, then such materials should ideally be stored in externally in watertight containers or if this is not possible. only be stored up to three floors below the agreed watertight level (see comments under Envelope)
ii. Water susceptible materials should be stored at least 100mm off the floor / ground and protected with covers (note any covers used should also be fire retardant (see Section 3)

Where 'just in time' delivery is being used, there should be backup storage plans for water susceptible materials and equipment to ensure materials are protected in the event the stage of project is not ready for safe installation when delivered

7.3 Pipe penetrations sealed on levels

i. In the temporary condition these should be covered using apply base and hot melt roofing felt.
ii. As the permanent pipework is inserted the rubber seal within the fire collar will stop water from tracking past the pipe.

8 Emergency Response to Flood

Emergency response in relation to forecast high rainfall or imminent flood events, as well as post event recovery should be actively planned for.

Emergency planning and response activities to flood and inundation events should be included within an overarching Flood Emergency Response Plan (FERP).

The FERP should include a checklist of the previously identified temporary flood protection activities/packages (including the protection of third-party storage areas where these include project items) required to supplement any existing flood protection measures. A sample Pre-Event Action list is in Appendix 2.

The FERP should identify who is responsible for the delivery of each activity/action – the Responding Person - along with their contact detail and should also identify who is responsible for the tracking, management, and overall delivery of the plan. This is usually the Responsible Person.

The Responsible Person should also ensure the plan can be implemented and actions untaken in a timely manner. They should appoint Emergency Preparedness (EP) leader(s) and identify members of the Emergency Project and Emergency Response Teams (ERT).

It is critical that the FERP includes section on when and how to implement the plan and who is responsible for triggering it.

The FERP should be circulated to the Emergency Response Teams on each shift. Team members should be familiar with their role, responsibilities, and actions in the event of an emergency.

Emergency Response Drills should be regularly undertaken where appropriate, such drills are essential to ensure adequacy of response. Communication is key to the successful delivery of FERP, a failure to act is most often down to a failure to communicate effectively in a timely manner.

8.1 Weather and flood warning systems

Weather and other monitoring systems should be tracked with sufficient frequency to ensure the identified medium- and short-term actions can be implemented.

Weather, nowcasting and other monitoring systems can be provided by Government and commercial services. These can be supplemented by site specific coverage monitoring installations such as upstream river monitoring.

8.2 Preparedness and Communication

Emergency procedures within the FERP should be clearly defined and immediately to hand.

The EP leaders need to be identified and their roles defined. The EP leaders are those tasked with undertaking the implementation of the flood protection protocols as identified in the FERP.

The roles and responsibilities of all other parties including subcontractors must be clearly identified and instructed accordingly.

All personnel should receive the appropriate training prior to and depending upon the likelihood of an event. Contractors should take the time to discuss flood risks and action plans with all personnel and provide regular reminders throughout the relevant storm/flood periods.

The plans should be regularly reviewed and tested to ensure timely action and adequacy of response, this can include desk top reviews and theoretical checks as well as physical activities

An early warning communication plan should be prepared and confirm in detail how and to whom the EP project team communicates weather/flood warnings and alerts. The plan should:

i. Identify event command structure with identified responsible person to lead overall communication and notification planning,
ii. Confirm who monitors events and coordinate execution of the plan when a storm/flood is approaching,
iii. Define what mitigation measures are required to protect the site and when the mitigation activities should commence
iv. Confirm how will they communicate flood conditions and advisories to the rest of the team and trade contractors,
v. Confirm how warnings and alerts will be issued if adverse weather/flooding is imminent,
vi. Confirm which activities can continue and which are to be stopped, e.g., working in below grade confined space.
vii. Confirm who is responsible for the inspection of the mitigation measures to confirm they are in place and robust.

The plan should define and include how much time workers have to secure and protect items before they need to move to a safe place.

The method of communication with all parties should be assessed, standardised, tested and confirmed as robust and workable. It should ensure that all site operatives are aware of the storm/flood warnings, are familiar with what needs to be done and how they will be notified.

It should ensure that the procedures include any impacts on temporary accommodation. For example, it needs to be ensured that the site offices/accommodation blocks and associated utilities are adequately tied down to resist flood water forces, located in a safe place and, if required, available for use as a safe shelter.

8.3 Emergency Checklists

i. Ensure all emergency equipment is available, their locations known, and equipment checked for functionality – such items should include Batteries, Extension cords, Fire extinguishers, Flashlights, First Aid equipment, Flood lights, Generators and Generator fuel, Ladders, Plastic bags, Plastic sheeting, Ropes, Tape, Tarps, Tie down kits and utility knives, flood barriers, etc.
ii. A checklist of protection measures should be used to confirm that vulnerable areas, plant, machinery, temporary works and partially completed works have been inspected and protected.
iii. A review of plant shut down/start up procedures on sites may be required where utilities, fire protection, electrical, boilers, compressors, and gas systems etc are in place.
iv. The actions should include:
    a. Ensuring personnel are trained in proper shut down/start up procedures in accordance with manufacturer's specifications.

b. During testing and commissioning phase, ensure the systems are shut-down in sufficient time to prevent damage and in such a way to minimise effects of the storm/flood event
c. Where necessary ensure a UPS is available and in working condition sufficient to maintain the condition of the plant and backup power supply
d. Ensure contracts exist with at least two diesel fuel suppliers for emergency deliveries.
e. Check for securement of roof equipment.
f. Inspect perimeter conditions and action deficiencies prior to a storm's arrival
g. Identify possible water entry points and determine mitigation procedures.

v. Ensure a reliable access route is maintained sufficient to allow any remaining personnel to be moved to a designated area of safety.

8.4 Alert timings

Alerts should be appropriate to the amount of warning time available. It should be noted that "weather bombs" from thunderstorms are localised hit and miss events and can occur with limited site-specific warnings.

i. Storm/flood conditions expected within 72 hours:
   a. Activate Flood Emergency Response Plan and schedule ERT meeting
   b. Storm/flood conditions expected within 24–48 hours
   c. Notify local fire department and follow Impairment System Guidelines if sprinkler systems, fire pumps, detection systems, fire alarm systems are to be taken out of service.
   d. Conduct full or partial shutdown procedures if needed.
   e. Complete installation of temporary flood protection measures using check sheet.

ii. Storm/flood conditions expected within 24 hours:
   a. As above, if not already actioned
   b. In some areas, nowcasting services offer up to 6 hr warning with probable flood depths. Such systems should be utilised, and the alerts acted upon.

iii. During the storm if volunteers remain on site:
   a. **Note**: During the height of the storm/flood volunteers should remain in a safe area and only be released by the responsible person.
   b. If safe conditions permit, the following activities should be conducted:
      i. Monitor areas for leaks in roofs, windows, walls, and vent openings.
      ii. Mitigate water damage by removing water/repairing protection
      iii. Document items needing repair.
      iv. Monitor critical equipment that has been left operational.

8.5 Post storm activities

i. Recovery and start-up
   a. Assessing facility's overall conditions immediately following the event shall typically include but not limited to:
      i. Physically inspect facility for repairs.
      ii. Inspect area for security vulnerabilities
      iii. Inspect working platforms
      iv. Check integrity of foundations especially temporary works

   v. Check for contamination of feedstock, fuels, and pollutants
   vi. Check condition of stored materials, exposed plant, and machinery
   vii. Where safe to do so, check basements and confined spaces

ii. Notify the management team, brokers, insurers, and relevant civil authorities as required.
iii. Take measures to secure access to the property such as repairing fencing and posting security guards until normal conditions can be restored.
iv. Once conditions are safe inspect, repair and re-connect critical utility lines, remove debris, and begin general start-up activities in pre-agreed plan.
v. Undertake salvage and repair activities. Liaise with loss adjusters and others as necessary.

8.6 Review and feedback

Review the response and implementation of the FERP , obtain detailed feedback from all involved to improve the effectiveness of the plan

9 APPENDIX 1: Flood Risk Management Plan

The Flood Risk Management Plan should be appropriate for the project and the flood risks presented and should be drawn up to capture all the identified flood risks, mitigation measures and emergency / contingency procedures established for the project. It should include, but not limited to the below:

i. roles & responsibilities (See sections 1, 5-8)
   a) Responsible persons
   b) Package managers
   c) ERT personnel
   d) Third parties such as drainage and highway authorities
   e) Specialist contractors working in the ground
ii. lines of communication
   a) These shall be formalised and are likely to be determined by roles and responsibilities above and the project's organisational chart
iii. flood risk assessments (FRA) (See section 4)
   a) FRA prepared at the planning tender stage
   b) Baseline FRA and FRBR prior to construction
   c) FRA and FRHMs during the construction period
iv. flood hazards identified, including (See sections 2 and 3)
   a) water sources,
   b) topography,
   c) vulnerable wet season works, etc.
   d) Existing features such as basements, storage lagoons, third party discharges, swales, and attenuation tanks
v. flood risk registers (See sections 4 and 5)
   a) Vulnerable works (temporary and permanent)
   b) Vulnerable plant
   c) Vulnerable machinery
   d) Vulnerable materials
   e) Off-site materials/machinery
   f) Storage and laydown areas,
vi. design principles, including return periods for temporary protection measures (See sections 2 to 6)
   a) Prepare 4D plans to show that flood water cannot be trapped in sections of linear projects such as roads and tunnels
   b) Where a project is complex prepare construction sequence "storyboards" so that all parties are aware of what has to be constructed and when
vii. weather watches and forecasts, frequency, and source, (See sections 1 -8)
   a) Review historical data if this has not included in the planning FRA
   b) Real time monitoring during construction
viii. practical mitigation measures and arrangements (See section 6)
ix. emergency procedures, including the involvement of the Fire & Rescue Service etc. (See section 8)
x. check sheets (see example below)

FLOOD RISK MANAGEMENT PLAN CHECKSHEET	Yes/No
Roles & responsibilities (Sect. 1, 5-8)	
Are the Responsible persons named and roles identified	
Are the Package managers named and roles identified	
Are the ERT personnel named, and roles identified	
Have Third parties such as drainage and highway authorities been contacted	
Specialist contractors working in the ground	
Lines of communication	
is communication list up to date	
Are the internal contact details up to date	
Are the Specialist contractors details up to date	
Are Third parties contact details up to date	
Flood risk assessments (Sect. 4)	
Was the FRA prepared at the planning tender stage	
Was a FRBR completed prior to construction	
Are FRHMs prepared and regularly reviewed during the construction period	
Are FRA's undertaken and regularly reviewed during the construction period	
Flood hazards identified, (Sect.2-3)	
Are all water sources identified	
Has the existing topography been reviewed	
Are there regular impact assessments for future topographic changes	
Have the seasonal influences been included	
Are existing features included e.g., basements, tanks, lagoons, swales, TP discharge	
Flood risk registers (Sect.4-5)	
Are vulnerable works identified and included	
Is vulnerable plant identified and included	
Is vulnerable machinery identified and included	
Are vulnerable materials identified and included	
Is off-site materials/machinery identified and included	
Design principles, including return periods for temporary protection measures (Sect. 2-6)	
On linear projects (e.g., roads/tunnels) are there 4D plans for flood water confinement	
On complex projects, have construction sequence "storyboards" been developed	
Weather watches and forecasts, frequency, and source, (Sect. 1-8)	
Has a review historical data been undertaken (if this has not included in the planning FRA)	
Is there real time monitoring during construction	
What real time monitoring systems are in use	
Practical mitigation measures and arrangements (See section 6)	
Have mitigation measures been identified	
Has information been provided on how the mitigation measures are to be implemented	
Emergency procedures, including Fire & Rescue Service etc. (Sect. 8)	
Is an up-to-date Emergency Plan in place and available for review	
Is the Emergency Plan regularly updated	
Is there a Pre-Flood Event Acton List	

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10 APPENDIX 2: Pre-Flood Event Acton List (An Example)

Pre-Flood Event Action List	Responsing Person advised (Name)	Action Completed Y/N	Time/date of completion	Corrective Action details where activity not Completed
Enact Emergency Plan and notify all Package Managers				
Notify Civil Authorities in event of possible threat to life/environment				
Suspend activities in confined space and flood-risk areas				
Install/erect temporary flood defence measures				
Ensure roof drainage systems are clear and operational				
Secure and clear downpipes: use rigid downpipes where possible				
Protect basement and other vulnerable low-lying areas				
Seal-up openings/ducts/cable runs with impermeable barriers/bungs				
Ensure flood gates/other flood barriers are operating as designed				
Ensure flood gates are open downstream of site to prevent back-up				
Move or elevate stock/materials/plant/ machinery above flood levels				
Protect/seal vulnerable parts of immovable plant/machinery				
Anchor/weight down buoyant materials/ cylinders to prevent floating				
Raise/tie-down/protect temporary accommodation				
Relocate gas cylinders/flammable liquids/hazardous substances etc.				
Support open trenches and backfill where possible				
Provide sufficient number/ size of pumps to manage volume of water				
Ensure all pumps have sufficient fuel/UPS				
Ensure previously identified sacrificial flood areas are available				
Shut-off electricity except for safety,fire protection and flood pumps				
Check the main gas valve is closed				
Check the valves in piping carrying hazardous materials are closed				

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11 APPENDIX 3: Common types of flooding

1 <u>Fluvial</u>

a) Rivers, streams, and brooks

ii. Flood water from rivers, and smaller watercourses such as streams and brooks are known as fluvial flooding. This occurs when the amount of water exceeds the flow capacity of the channel (or when this is blocked by debris especially at culvert openings and bridges).

iii. River systems drain the rainwater collected from a specific area, known as a catchment, and can be made up of numerous tributaries draining large geographical areas and encompass many independent river basins. Upstream precipitation over large areas and/or by melting snow during spring season can result in downstream flood events sometime later.

iv. Most watercourses have a natural floodplain into which the water overflows into during a flood event.

v. Debris carried in flood waters can result in blockages of watercourses especially at artificial structures such as bridges, restricting the flow and causing more extensive flooding than predicted return periods.

vi. Planned changes to the existing flowing or static watercourses (damming, re-routing, change in overflow facilities etc.) can affect the flood risk and not be predicted by pre-project flood models.

b) Canals

i. Canals can be channelled above the natural ground level. While flooding may occur as a result of a canal being overwhelmed, this tends to be a lower risk as the water levels in these bodies are generally regulated through locks, weirs, sluice gates, pumping and overflow systems. They do not usually have a significant catchment drainage area and therefore are less effected by rainfall events.

ii. Canals that do form part of a river system, should be treated more as a fluvial-type exposure.

c) Culverts and channels diverting rivers and streams

i. Culverts are simple artificial structures completely enclosing sections of a watercourse usually underneath a linear infrastructure such as a road, a railway, a canal or even a building, e.g., to allow a small river or stream to pass under it. These tend to be pipes, concrete box, or masonry structures.

ii. Culverts, and especially those with screens, present a particular increased risk of flooding, especially in times of flash flood extreme rainfall events, when the water flow exceeds the design capacity of the channel, and/or large amounts of debris are carried downstream causing blockages.

iii. Culverts and associated screens in close proximity to the construction site should be specifically assessed in relation to the flood exposure.

2 Pluvial

a. Rainfall-generated flooding with surface water and overland flow.

b. Surface water flooding

A result of extreme rainfall event which exceeds the capacity of natural and engineered drainage and sewer systems (both public and part of the project site works). The falling water quickly runs off land and results in local flooding, especially in lower lying areas. This can be exacerbated from continuous changes in land use patterns such as urbanization and as part of construction, which can decrease/disrupt the natural drainage flow paths when land is covered in impermeable concrete and tarmac which disrupts natural drainage and soakaway times.

c. Back up of the pipework

When surface water and/or foul water sewer drainage system capacity is insufficiently designed and is exceeded by the amount of rainfall or becomes damaged or blocked, this can result in a back-up in the pipework resulting in hydraulic surcharging of water (often polluted) directly into the site or building.

d. Flash floods

These can be the most severe types of rainfall flood events. Caused by extremely high intensity local rainfall over a short period of time on elevated terrain resulting in deep and fast flowing flooding with little warning. Since a large portion of the rain cannot be absorbed by the ground and drainage systems, this results in the rapid onset of deep and fast flowing flooding with little warning along watercourses. Small systems can be turned into high velocity torrents with debris in the flowing waters which can also result in landslides and mudflows causing considerable property damage.

e. Wadis in desert areas or creeks and channels

These can normally be dry for long periods, although can temporarily or seasonally fill and flows reactivated after torrential rainfall events. These can be a spontaneous event (developing in a matter of minutes) with often no consistent pattern behind the occurrence. Areas that do not have a history of flooding are not immune.

3 Coastal

a. Storm surge

Windstorm events that create storm surges and increased wave action and heights especially when these coincide with high tides. Most extreme events are associated with a hurricane or typhoon. An inlet or bay can focus storm winds causing waters to be driven higher with corresponding larger increases in water levels, wind-driven waves, and flooding. These scenarios can also be manifested in large lakes, although they are usually less pronounced.

The severity of coastal flooding is often influenced by the strength, size, speed, and direction of the windstorm and the location's topography and bathymetry. The under-sea land slope will affect the depth of water that can be expected from a storm of a given strength. A shallow-slope ocean bottom usually creates larger storm surge floods.

b. Tidal

Inundation of low-lying areas during exceptionally high tide events, such as at full and new moons. Rivers can also flood during high tides solely due to tidal influence extending upstream.

c. Tsunamis

A series of waves in a water body caused by the displacement of a large volume of water, generally in an ocean or a large lake, as a result of earthquakes, landslides, or volcanic activity. The onset of flooding can be extremely rapid, deep, and fast-flowing extending over a mile into low-lying coastal areas.

4 Groundwater

Water below the surface of the ground and within the permanently saturated zone in soils and permeable rocks or rock fractures.

Groundwater flooding can be produced during excavation and foundation works below ground level resulting in seepage issues or more extensive inundation.

Local geological conditions may present a slope at the interface between the less permeable rocks and the overlying gravel. Groundwater can flow and large basement structures or foundation walls through gravel into clay can act as a barrier to the flow of ground water resulting in a build-up of hydrostatic pressures with the potential for catastrophic failure of these infrastructures.

5 Utility water mains

Flooding as result of burst pipework due to age, poor design or accidental damage from construction works. Operational pipelines under pressure could accidentally burst due to a number of reasons, such as:

i. Asset Deterioration – ageing, corrosion, fatigue
ii. Pressure transients/surge
iii. Ground movement – seismic and natural or man-induced differential settlements
iv. External Loading – excessive imposed loads, impact/strikes from construction plant
v. Design Error – thrust restraint, pressure rating
vi. Poor workmanship – poor bedding/surround, poor jointing

Failure of pressure pipelines conveying liquids can lead to flooding of public areas and pose a risk to the project site area and third-party assets.

The consequences of a pipe burst are dependent on the burst flow rate and subsequent volume based on system behaviour/response time, local topography, drainage provisions and the proximity of pressure pipelines to assets.

6 Levee, reservoir, dams

a. Levee or a dam break or overflow causing a sudden release of rapidly flowing, deep water.
b. Dam failure or levee breeches can be caused by constructional design or defects, lack of maintenance or extreme weather events overcoming the intended design. When unintentional failure occurs, this can result in a sudden release of extremely high volumes

of water and sediment at high velocities creating a flood wave than can be more dangerous and damaging than natural events.

c. In some cases, release of water can be intentional in order to stop more catastrophic failure, to protect other areas or to drain flooded areas. In these cases, the situation is typically monitored over time and warnings provided.

7 Combination Events

a. Flooding is often a combination of multiple sources driven by the weather i.e., a heavy rainfall storm event causing surface water runoff, saturated ground conditions (if prolonged periods rainfall), combined with rivers overtopping or coastal storm surge flooding. When tidal surges coincide with high fluvial flows this can prevent discharge into the estuary, known as tidal locking. These events, while lower probability, can exceed predicated flood extents which only model one source of flooding.
b. Where rainwater and sewer drainage systems flow into rivers and culverts that have already reached capacity, this can significantly reduce the drainage effectiveness and even cause water flow to back up into the site. The distinction between surface water runoff, fluvial and groundwater flooding is rarely clear. During high flows in rivers and culverts water can also back up into rainwater drainage systems causing flooding from a surcharge into the site or building even if there is no direct overland flooding.
c. Estuaries and the tidal extent of rivers are also heavily influenced by the tidal cycle of the sea and flooding can occur. When tidal surges coincide with high fluvial flows preventing discharge into the estuary, known as tidal locking. These events, while lower probability, can exceed predicated flood extents which only model one source of flooding.
d. Rain-on-snow driven floods can cause significant additional volumes of combination pluvial and fluvial events.

8 Flood Duration Cycles

a. These can vary and may be limited to hours, days, weeks or even months with the longer periods occurring especially when grounds are already saturated after periods of persistent rainfall.
b. Fluvial flooding normally lasts a few days until draining back into the river and channels.
c. Tidal flooding can have several cycles matching the local tides until the waters recede.
d. Pluvial flooding durations will usually vary from relatively short periods depending on local drainage although in some cases areas may remain flooded for several days until the water levels can recede.

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12 APPENDIX 4 : Culvert Screens

Experience has shown that in major pluvial/rainfall flash flood type conditions the use of culvert screens can significantly increase the potential for blockage and resultant flooding. Screens usually comprise a steel grille system and are installed on the end of a culvert, normally the inlet, for two main reasons:

i. Trash screens reduce the amount of trash and debris entering the culvert, where it could cause a blockage and restrict the flow. Debris or Trash in this context is solid material transported within a watercourse particularly during flood events. Debris can move intermittently and has potential to cause blockages that impede the free flow of water

ii. Security safety screens prevent unauthorised access to the culvert (particularly children) so as to avoid a risk of death or injury

It is possible for a screen to serve both of these functions, although normally there will be one dominant purpose. If, however, a screen is proposed for security reasons it also needs to be assessed for the flood risk associated with its potential blockage.

It is important to note that the introduction of a screen should be decided on a risk-based approach and best practice guidance discourages the use of any form of screen except in circumstances where the benefits are significant and outweigh the risks. Alternative solutions should be analysed prior to deciding to provide a screen.

All screens, regardless of their primary purpose, will trap and accumulate debris to certain extent which can further restrict the water flow of the culvert. These are more prone to blockages than unscreened culverts, especially in times of flash flood rainfall events when large amounts of debris can be carried downstream.

Design

If a screen is required, an evidence-based methodology should be used to determine the minimum required useable screen area and effectiveness of the design based on available local best practice industry guidance.

Although the structural elements of screen design will generally be straightforward, the layout and size of the screen and associated inlet between the watercourse channel and the culvert is normally more complex in order to encompass various factors i.e.:

i. the volume of debris that is expected to arrive at the location of the screen

ii. the general arrangement of the screen, including location, accessibility, and maintenance

iii. the hydraulic performance of the screen

As a major concern in the design of a screen is the risk of flooding if the screen becomes blocked (partially or completely) with debris, an essential part of the design is therefore an assessment of the consequences of such blockages and what can be done to mitigate the flood risk.

In order to carry out this assessment a hydraulic analysis is required to determine the screen design in relation to efficiency of flow, safety, and the impacts of blockages on the performance of the system. Where necessary the design of the screen should be refined so that it performs efficiently under a range of flow and blockage conditions so the flood risk arising from blockage of the screen is minimised and any safety hazards are understood and managed or mitigated. The hydraulic analysis should include the screen and the structure it 'protects' i.e., the system as a whole.

If the screen blocks, the way in which water flows through or round the structure should be considered as part of the design process, including 100% blockage. If overtopping might occur when a screen becomes blocked and it is impracticable to put in place measures to avoid blockage of the screen, the provision of a safe overtopping flow route should be considered if the overtopping would otherwise result in damage to property and/or infrastructure.

In terms of sizing, there are specific criteria for calculating the effective screen area including the expected debris amounts, blockage scenarios and hydraulic analysis. However, as an approximate guide the effective or useable screen area should be at least three times the minimum cross-sectional area of the culvert being protected. The effective screen area is the element of the screen below the maximum allowable water level and does not include working platforms designed for use by operatives (usually close mesh open tread panels) or any parts of the screen obstructed by supporting structures. The spacing between the bars of a screen should be the widest commensurate with achieving the objectives. It is counterproductive to have a screen that traps debris which would otherwise pass harmlessly through the culvert.

Maintenance and Cleaning

If a culvert or screen is poorly managed with no regular monitoring, inspections, or clearance there is a significant risk that the accumulation of debris will restrict the water flow sufficiently to cause water levels upstream to rise above bank full and flood the local area leading to significant damage to property and infrastructure. Whilst the time taken for a screen to become blocked or the degree of blockage that will occur varies dependent on circumstances, our experience indicates that blockage and resulting flooding can happen over a very short space of time from significant levels of debris carried down the watercourse, including stripping of foliage from the banks, by high levels and high velocity water flows.

Clearing screens and culverts against a significant head of water is usually difficult and can be dangerous for operatives and once the level and velocity of flow reaches a certain point clearing will no longer be possible. Proactive monitoring and structured cleaning procedures of culverts, screens, and the upstream watercourse (including removing or cutting back excess foliage) are therefore crucial and should include escalation protocols for increased inspections and cleaning based on weather conditions, seasons, water levels and flows.

All screens have to be cleaned at intervals and may require a rapid response in a high flow event. Establishing the extent and cost of this maintenance liability, including the practicality of mobilising a maintenance team in a short time period, and securing a commitment to it from the responsible party are essential components of the planning and design process.

It is therefore important that the maintenance and cleaning commitment is accepted by the owner or operator of the screen and this responsibility should be defined and agreed by all interested parties and recorded in an operational plan. This would include:

i. regular cleaning of the screen and safe disposal of accumulated debris

ii. emergency response in the event that the screen becomes blocked with debris during a flood event

iii. maintaining the screen in a safe and effective working condition according to its design

Arrangements for cleaning the screen must be appropriate to the nature and quantity of the debris anticipated at the site. It should be possible for operatives to safely rake a screen under routine and most non-routine conditions. However, during high flow level and velocities, especially if a screen is mostly submerged it is likely that it will not be safe to clear the screen, however the design should afford operatives early and safe access to the screen once water levels subside.

There are three main systems for cleaning screens: manually using suitably hooked rakes; mechanically by specific grab systems or mobile plant (e.g., Hiab lorries, excavators); and mechanically by automated screen-clearing mechanisms. Each method for screen cleaning should be evaluated separately and the design should minimise manual clearing and provide suitable safety arrangements. It is essential that the arrangements for cleaning the screen are appropriate to the nature and quantity of the debris anticipated at the site. The manual method is most common and normally most effective; a mechanical system is generally justifiable only in special circumstances such as emergency clearance and in general has a poor record of routine use on screens protecting culverts on rivers in urban environments.

Cleared screen debris will need to be stored temporarily in a holding area before transferring off-site and this storage area should be remote from the screen itself so there is no possibility of debris migrating back to the screen or watercourse and located to make transfer from screen to storage straightforward for operatives.

Every screen should have an Operational Plan that:

i. sets out the inspection and cleaning frequency

ii. describes emergency response procedures

Monitoring

Water-level monitoring will enable those responsible for maintaining and cleaning of a culvert and screen to assess whether their performance requirements are being met and also act as a means of alerting a potential blockage in a non-routine event i.e., due to a natural rapid build-up of debris or the result of vandalism.

Monitoring may take many forms but can generally be grouped into periodic measurements (e.g., flow gauging, silt depths, structural condition) and real time monitoring (visual and electronic). The frequency of periodic monitoring is normally risk based depending on the risk in terms of likelihood and consequence of blockage of the culvert and the risk of flooding, weather reports and seasonal considerations.

Any monitoring needs to include periodic visual inspections of the culvert and screen and the use of graduated depth gauges. There should also be adequate lighting provision. However, where there is a risk of flooding as a result of screen blockage causing life safety issues and/or significant property damage with subsequent impact to business revenues, the use of water-level monitoring with remote alarms (telemetry) and closed-circuit television (CCTV) to give early indication of a developing problem should be used as an integral part of the scheme.

13 APPENDIX 5: Elements to be considered in the design phase

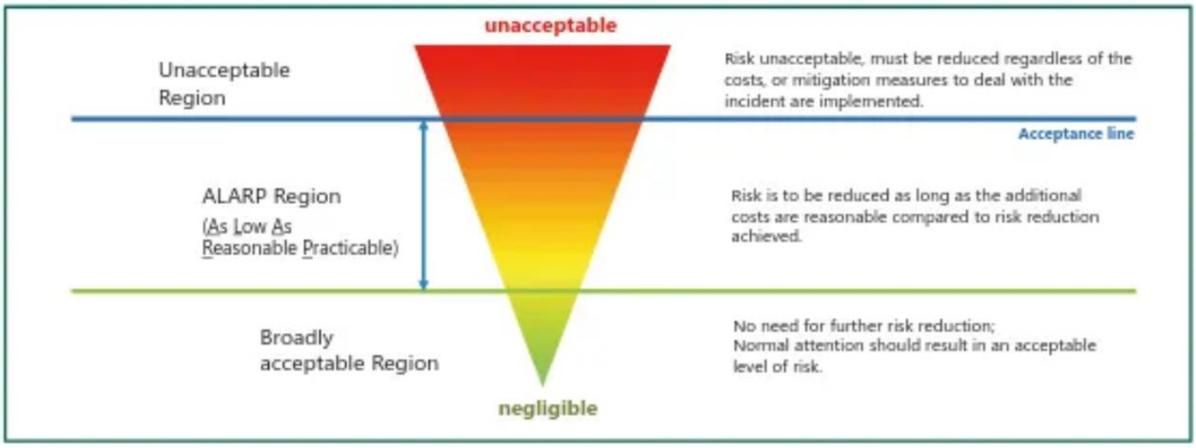
Design Data and Key Modelling Parameters

The following design data and key modelling parameters should be used for the flood risk assessment:

i. Rainfall, runoff and hydrological assessment
    a. Flood return period
    b. Storm duration
    c. Average annual rainfall
    d. Maximum annual rainfall
    e. Maximum daily (24h) rainfall
    f. Maximum hourly rainfall
    g. Discharge and runoff data and simulations
ii. Site area topography
iii. Site area landscape and vegetation
iv. Site area plans in global coordinates
v. Utility information – combined services plans
vi. Surface water drainage model
    a. hydraulic model,
    b. groundwater infiltration parameters
    c. storm profiles
    d. scenarios modelling undertaken (see below as an example, but not limited to):
        i. Surface water assumed to enter the drainage system
        ii. Surface water assumed not to enter the drainage system i.e., 100% blocked gully/inlet scenario, with all rainfall flowing overland and ponding.
vii. Foul sewer drainage model
viii. Coastal water assessment where applicable, considering different flood risk scenarios (see below as an example, but not limited to:
    a. Scenario 1: 100-year return period water level + sea level rise (upper case) + tsunami
    b. Scenario 2: 100-year return period water level + sea level rise (median range)
    c. Scenario 3: 50-year return period water level + sea level rise (lower case)
ix. Ground information
x. Evaporation parameters
xi. Landscape design
    a. Levels
    b. Low point areas
    c. Slopes
    d. Surface of hard- and softscape areas
xii. Groundwater assessment (Note: Groundwater flooding occurs in a range of geological settings. Often caused by the combination of high groundwater levels with intense and/or long periods of rainfall leading to water emerging above the ground surface. This document does not cover flood risk for underground water ingress which does not result from a rainfall/storm water flood event).
xiii. Safety Margin and Freeboard

a. The Project Owner should specify for the assets a minimum acceptable freeboard, which is defined as the height of an asset's threshold (finished floor) level above the maximum predicted flood threshold water level
b. The minimum freeboard should consider both temporary and permanent works and construction sequence
c. As a minimum, the adopted freeboard should take account of:
   i. contingency for uncertainties in modelling data
   ii. dynamic effects such as wind-blown effects and minor wave effects
   iii. Other effects such as climate change, local features or weather/ climate effects, period of exposure,
d. Undertake sensitivity analysis to understand absolute difference between specified return periods – i.e., between 1–20-year, 1-50 year and 1–100-year events.
e. Follow a risk-based approach according to the ALARP principles, as presented in the example table and figure below; note this is typical for the UK however other territories may differ:

Freeboard (over and above determined max flood threshold level) (mm)*	**Acceptability**	**Mitigation**
<0	Unacceptable	Structural measures or relocation should be implemented to increase the asset level to or above the maximum flood threshold level
<100**	ALARP	A combination of structural and non-structural measures is required in order to reduce the residual risk to acceptable. In case implementation of structural measures is not feasible or introduces disproportionate time and cost impact, only non-structural measures will be implemented BUT it must be demonstrated through risk assessment that the residual risk is acceptable and manageable
300 to 100**	ALARP	Structural measures are not required BUT non-structural measures may be required (e.g., inflatable seals underneath the entrance doors, water absorbent tubes, flood boards and barriers, self-inflating roll out systems, etc) in order to reduce the residual risk to acceptable. To be demonstrated through risk assessment
>300 **(for inland) 600** (coastal)	Acceptable	No further measures are required



(*)These values are exemplary. The threshold values should be defined with respect to the project and risk characteristics, e.g., in relation to flood height for return periods of different scales.

(**) All examples of freeboard are indicative only and require project specific review

The risk-based freeboard approach aligns with industry best practice of a minimum 300mm as a generalised figure as typified by the Wastewater Planning Users Group (WaPUG) Code of Practice for the Hydraulic Modelling of Sewers (3rd Edition). This sets guidelines for acceptable verification of peak depth in a hydraulic model between observed and predicted data to be in the range +0.5m to -0.1m, indicating the range of uncertainty that is to be expected.

Flood Return Period and Protections

The aim of flood protection and control measures is to mitigate against reasonably probable or anticipated severe events. These events need to be assessed with due regard to flood levels expected in relation to a determined return period.

For permanent operational / final built assets, typically flood protections should be designed to at least a 100-year return period or 1% Annual Exceedance Probability (AEP) and based on modelled flood return periods plus climate change and freeboard allowances for a margin of error. Typical flood protections may include physical flood defence systems such as barriers or attenuation storage, raised finished floor levels / structural slab levels or new drainage systems (or existing in rehabilitation projects) for conveying or storing rainfall induced runoff. During the construction phase, the permanent protection measures should be installed and operational as early in the construction sequence as possible to provide a comparable level of flood protection expected for the operational phase for as much of the construction phase as is feasible.

Temporary flood protections should preferably achieve the same standard of protection as the permanent design or at least 100-year return period, that is 1% AEP for the duration of the construction works. Nevertheless, projects should be aware that there may be situations where the temporary stage flood protection may be more onerous than the permanent stage, this can be for example works prior to installation of wider area drainage systems, or constraining river cross sections by temporary platforms etc.

It is recognised that depending on the type of flood control system and duration of the project, achieving the permanent standard of protection may not always be feasible or cost effective. Nevertheless, even shorter-term exposures should have protection against flood events.

It should be noted that in relation to return period probability, every year has statistically the same chance of a flood event occurring and even cumulatively there is little difference.

Examples of where temporary systems may not be reasonably designed to higher standards of protection can be in relation to rainwater drainage and attenuation tank systems. Conversely, for fluvial and coastal defences such as the height of raised ground levels, embankments, berms, and cofferdams, can often be designed to achieve the higher standards of protection for relatively little effort i.e., additional height of a temporary cofferdam required between a 20 year and 100-year event protection can be relatively small.

Where the complexity and cost of installing temporary physical flood controls to the same standard or protection as the permanent standards is considered unduly onerous for the construction stage, consideration may be given to adopting a lower standard of protection (or as high a standard of protection that can reasonably be achieved), which should be combined with enhanced flood management planning and emergency response aimed to prevent from loss damages in case of flood event.

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14 APPENDIX 6: Probabilities & Limitations

Probability and Magnitude of a Flood Event

Flood event probabilities quantify the likelihood and magnitude of flood events and are typically referred to in terms of:

i. a probability of occurrence expressed as a percentage known as the Annual Exceedance Probability, or 'AEP'.

ii. a return period to express the average frequency of occurrence expressed in years (e.g., the 100-year flood).

It should be understood that the return period is not the length of time that will elapse between two such events occurring, as it is possible for two very severe events may occur within a very short space of time. For any given year the probability of flooding occurring statistically has an equal chance of occurring i.e., a 100-year flood has an 1% chance (AEP) of happening in each year.

The less probable events will result greater volumes and flows, with corresponding greater damages e.g., a 100–year flood has a lower likelihood but has larger magnitude than a 50–year flood.

The table below provides a comparison of a range of flood event probabilities expressed in the different terminology.

Flood Event Probabilities Comparisons

Annual Exceedance Probability (%)	Return Period (years)
50	2
20	5
10	10
5	20
4	25
3.33	30
2	50
1.33	75
1	100
0.5	200
0.2	500
0.1	1000

Duration of Risk Exposure

The length of time the site is exposed i.e., the duration of the construction contract, will also influence the probability with the longer the period the higher the probability of a flood occurring.

However, the differences for lower probability events (such as 100-year or AEP 1%) over short contract periods are relatively small, although differences increase the higher the event probability and/or for long duration periods e.g.

i. approximate probability of a 100-year (AEP 1%) event over: 1 year is 1%; 2 years is 2%; 5 years is 5%; 10 years is 10%; 30 years is 26%

ii. approximate probability of a 50-year (AEP 2%) event over: 1 year is 2%; 2 years is 4%; 5 years is 10%; 10 years is 18%; 30 years is 45%

iii. approximate probability of a 25-year (AEP 4%) event over: 1 year is 4%; 2 years is 8%; 5 years is 18%; 10 years is 34%; 30 years is 71%

iv. approximate probability of a 20-year (AEP 5%) event over: 1 year is 5%; 2 years is 10%; 5 years is 23%; 10 years is 40%; 30 years is 79%

The formula to calculate the chances over a given time period (period of cover) that a flood will reach or exceed a specific magnitude is:

$$p = 1 - \left(1 - \frac{AEP}{100}\right)^N$$

p = lifetime probability of exceedance

AEP = annual exceedance probability (%)

N = period of contract / insurance cover (years)

Return Period Limitations

Return periods are a statistical estimation only of flood event frequency and the expected behaviour of future flooding. This is affected by the data used in these calculations e.g.

Length of available historical records
The longer the period of record, the better the likelihood of capturing the range of possible events. Estimates of flood return periods beyond the length of available data records are possible, but this relies to a greater extent on mathematical algorithms and therefore a lower confidence level of accuracy. Floods or droughts that occur infrequently may be underrepresented by a limited period of records.

The consistency of the hydrologic conditions within the drainage basin
Basin changes such as land development, water diversions and reservoir construction may alter the hydrologic properties of a drainage basin over time, changing the way a river and land responds to storms. This can result in future flow behaviour that is different from in the past and consequently, flood frequency statistics generated prior to the basin changes would no longer apply. In other words, if you have a 100-year record, but major urbanization took place 20 years ago, then you only have a 20-year homogeneous record for the now urbanized basin.

Also, a common misconception is that a 25-year rainstorm will always produce a 25-year flood. While this may be accurate, as the conditions on the ground greatly affect the runoff generated from a particular storm, the actual flood event may be greater or lesser than the rainstorm event. For example, if the soil is saturated, it is possible that a 25-year rainfall would become runoff so efficiently that it could result in a runoff event larger than the 25-year flood. Likewise, dry ground conditions could mitigate the impact of a large rainstorm and produce a smaller flood.

Climate change impact on estimations

The impact of global warming is causing the frequency of large magnitude events to increase which can make historical data unrepresentative of both current and future flood risks and, therefore, potentially underestimating flood return period calculations. What was considered a 50-year flood a decade ago may well now be only a 30-year flood, making areas previously considered lower risk, or flood defences built to a specific standard of protection, more vulnerable.

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15 APPENDIX 7: Abbreviated Glossary of common terms

Annual exceedance probability (AEP)	AEP (measured as a percentage) is a term used to describe flood size. It is a means of describing how likely a flood is to occur in a given year.
Average recurrence interval (ARI)	ARI (measured in years) is a term used to describe flood size. It is the long-term average number of years between floods of a certain magnitude.
Catchment	The land draining through the main stream, as well as tributary streams
Discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m3 /s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving.
Exposure	A measure of the assets' value at risk of flooding and the costs associated with reinstatement and delays that may be incurred as a result
Flood Risk	Flood risk is the combination of the probability of a flood event (hazard) and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event or in the current case for construction sites (exposure). The measure of risk can be defined as a mathematical function of the probability of occurrence of a specific flood event (hazard) and the adverse consequences (vulnerability, including exposure).
Flood Emergency Response Plan (FERP)	A live document developed and maintained to identify how to co-ordinate and respond to the imminent risk of flooding.
Flood Risk Baseline Report (FRBR)	Initial flood risk assessment based on the storm event key design parameters and flood return periods stipulated in the contract, conducted before the implementation and construction of the project. It considers the existing site conditions and topography and the final configurations of the intended permanent works. It serves as the contractual baseline for flood related scenarios and associated risks.

Flood Risk Hazard Maps (FRHMs)	Engineering maps used for planning related to flood risk and mitigation. They show the results of hydrologic and hydraulic investigations, including areas of potential flooding in different scenarios.
Flood Risk Assessment (FRA)	A comprehensive review of all potential flood events and their impact on/by the project from the perspective of physical damage, disruption, delay, and personal injury
Flood Risk Management Plan (FRMP)	A live document developed and maintained to identify how flood risks are being managed during construction using a risk-based co-ordinated approach.
Freeboard	A factor of safety expressed as the height above the design flood level. Freeboard provides a factor of safety to compensate for uncertainties in the estimation of flood levels across the floodplain, such and wave action, localised hydraulic behaviour and impacts that are specific event related, such as levee and embankment settlement, and other effects such as climate change.
Hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak discharges, flow volumes and the derivation of hydrographs (graphs that show how the discharge or stage/flood level at any particular location varies with time during a flood).
Reliable access	Safe means of egress for site personnel and others during a flood, having regard to the depth and velocity of flood waters, the suitability of the evacuation route, and other relevant factors.
Runoff	The amount of rainfall that ends up as flow in a stream, also known as rainfall excess.
Severity	A measure of the scale of flood and related potential for flood damage to the exposed assets and the associated delay and costs to the project programme both directly and indirectly such as loss of utilities or access
100-year flood	A flood that occurs on average once every 100 years. Also known as a 1% flood. See annual exceedance probability (AEP) and average recurrence interval (ARI).

50-year flood	A flood that occurs on average once every 50 years. Also known as a 2% flood. See annual exceedance probability (AEP) and average recurrence interval (ARI).
20-year flood	A flood that occurs on average once every 20 years. Also known as a 5% flood. See annual exceedance probability (AEP) and average recurrence interval (ARI).

CIREG https://cireg.org would like to thank the following co-authors and their Employers, who generously gave their time and expertise to the compilation of this guidance document:

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CIREG would also like to thank Patrick Bravery and Matthew Herrnegger for their time spent reviewing earlier drafts of the document.