07 - REVIEW OF HYDROLOGICAL INDICATORS FOR CLIMATE PROOFING OF WATER AND FLOOD PROJECTS

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Abstract

In July 2021 the European Commission (EC) published technical guidance on Climate Proofing of infrastructure projects. The purpose of climate proofing is to have a consistent and robust approach to demonstrating that investments by the EIB and under other EC funding streams are resilient to climate change and consistent with the Paris Agreement and other national or sectoral climate change action plans.

The focus of this paper is on the climate resilience pillar of the climate proofing process. This pillar is concerned with how a project manages all climate hazard risks to an acceptable level through a) inbuilt resilience, b) additional adaptation measures, or c) a clear long term implementation plan for future adaptation measures informed by a monitoring programme.

This paper provides a summary of how readily available hydrological datasets and indicators can be used in the climate proofing process for water, wastewater and flood risk management projects. The paper presents suggestions for pragmatic, relevant and robust evidence for different stages of climate proofing. We present examples of the use of EU datasets from Copernicus and the European Environment Agency, approaches to deriving rainfall uplift factors for UK stormwater design, and a data-poor region in Sub-Saharan Africa. It is important for scoring systems to reflect how hydrological climate hazards actually effect the type of project in question. Not all climate indicators are available for the latest ICCP AR6 shared socio-economic pathways and so decisions on how to interpret older scenarios and projects are often required. The paper also reviews how Ireland's uplift factors in the context of EU guidance.

1. INTRODUCTION TO CLIMATE PROOFING

The legal, policy and moral justification for mitigating and adapting to climate change is well established. A just transition requires a robust evidence base that can be clearly communicated and understood by experts, stakeholders and across society. The focus of this paper is on the selection and use of robust and relevant indicators for hydrological climate hazards to inform evidence based adaptation planning of water and flood projects.

Global context

The international context is clear through the Paris Agreement which includes climate adaptation as well as the more commonly known climate mitigation targets. The 6th Assessment Report (AR6) from the Intergovernmental Panel for Climate Change (IPCC) presents the latest climate science and evidence on impacts, adaptation, vulnerability and mitigation at the global and regional scale.

European context

Climate Proofing is a process that has been established by the European Commission (EC) together with the European Investment Bank (EIB) for setting common standards for EU funded infrastructure investments in the 2021-2027 programming period. In 2021 the EC published technical guidance[1] for climate proofing to meet the following requirements laid down in the legislation for several EU funds, notably InvestEU, Connecting Europe Facility (CEF), European Regional Development Fund (ERDF), Cohesion Fund (CF), and the Just Transition Fund (JTF):

- It is consistent with the **Paris Agreement and EU climate objectives**.
- It follows the **principle 'energy efficiency first'**, which is defined in Article 2(18) of Regulation (EU) 2018/1999.
- It follows the **principle 'do no significant harm'**, which is derived from the EU's approach to sustainable finance and enshrined in Regulation (EU) 2020/852 (Taxonomy Regulation).

The EC technical guidance has two pillars for climate proofing which are then combined into an overall climate proofing document. The first pillar is climate change mitigation, the second which - the focus of this paper - is climate change resilience (or adaptation). For the climate change resilience pillar, EC technical guidance retains the Climate Change Vulnerability and Risk Assessment[2] process as previously established in the 2014-2021 programming period. Figure 1 presents a schematic from the EC technical guidance of the two pillars and stages in the process. Figure 2 outlines what a climate proof project is in practical terms.

The EU Taxonomy is a basis for a transition to transparent sustainable finance across the EU for achieving the EU climate and energy targets for 2030 and delivering the European Green Deal[3]. The Do No Significant Harm (DNSH) principle requires a project or investment to substantially contribute to one of six objectives and to do no significant harm to all the other five objectives. Climate mitigation and climate resilience are two of these objectives. Climate Proofing and Climate Change Vulnerability and Risk Assessment are specifically noted in the delegated acts to the EU Taxonomy Regulations as means of demonstrating and verifying compliance with the DNSH principles.

The use of robust and relevant indicators for hydrological hazards therefore opens up a huge range of funding opportunities for investment in the water and flood sector. Following a recognised process helps with verification that investments are climate proof.

[1] Commission Notice — Technical guidance on the climate proofing of infrastructure in the period 2021-2027 (europa.eu) (Commission Notice (C(2021) 5430) Technical guidance on the climate proofing of infrastructure in the period 2021-2027).
[2] As described in European Commission (2016) Non-paper Guidelines for Project Managers: Making vulnerable investments climate resilient https://climate-adapt.eea.europa.eu/en/metadata/guidances/non-paper-guidelines-for-project-managers-making-vulnerable-investments-climate-resilient and other guidance documents (some of which are no longer available online)
[3] Text of the EU Green Deal: EUR-Lex - 52019DC0640 - EN - EUR-Lex (europa.eu)

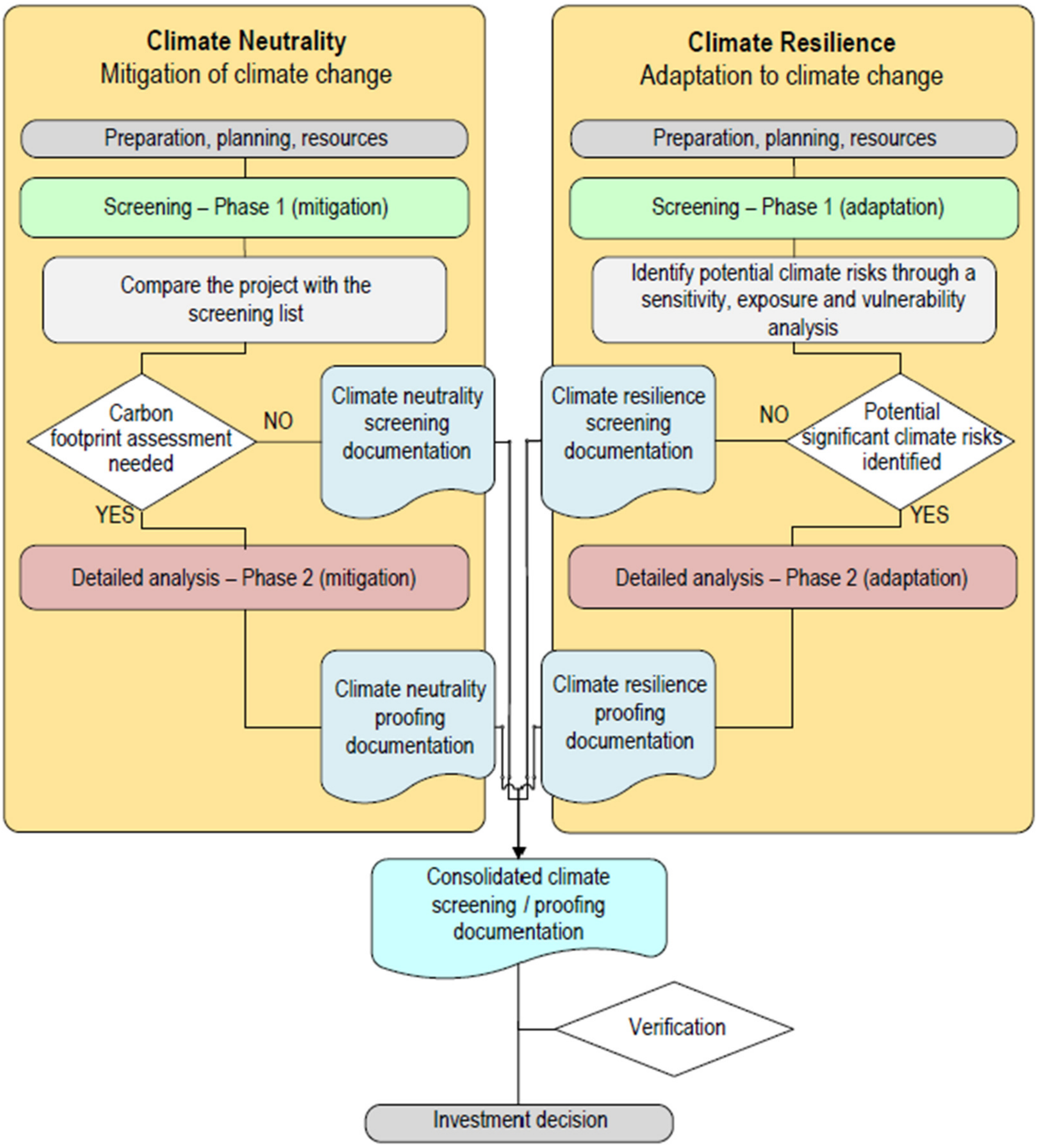

Figure 1. Climate Proofing Pillars from EC Technical Guidance for Climate Proofing of Infrastructure in the Period 2021-2027.

Is consistent with the ability to achieve GHG emission and climate neutrality targets by demonstrating:

- It will not generate significant GHG emissions,
- Has considered GHG emissions from alternative means of achieving project objectives (which must be compliant with EU legislation and policy (e.g. UWWT Directive).

Manages all climate hazard risks to an acceptable level through:

- Inbuilt resilience of the project to climate hazards,
- Additional adaptation measures included within the project investment, or
- A clear long term implementation plan for future adaptation measures informed by a monitoring programme (which may include measures to be implemented as part of the project investment to facilitate future adaptation).

Figure 2. What is a climate proof investment

National context

In Ireland, the Climate and Environmental Assessment of the National Development Plan Review Spending Proposals was a qualitative scoring of investment programmes against seven objectives. To achieve positive score an investment programme needs to meet the following criteria[4]:

+3 climate adaptation score

- The expenditure is likely to directly and **unambiguously** provide some degree of protection from the likely impacts of climate change and aligns with Ireland's National Adaptation Framework.
- An example of a measure likely to receive this ranking is investment in flood risk management or works to prevent or limit coastal erosion.

+1 climate adaptation score

- The expenditure is likely to at least tangentially contribute to improved climate resilience, but increasing resilience is not the direct focus of the measure.
- For example investment in infrastructure that will be specifically future-proofed against the projected geophysical impacts of climate change is likely to lead to a net improvement in Ireland's climate resilience and should therefore receive this ranking.

The distinction between a score of +3 or +1 could potentially be critical for the alignment of an infrastructure programme or investment portfolio when seeking further investment from public or private financers. To be unambiguous and for project assessments more detailed analysis is required. For example, the Climate Change Sectoral Adaptation Plan for Flood Risk Management[5] includes specific actions which relate to climate proofing both existing and proposed flood risk management measures. This paper also contributes towards the progress against a number of objectives and actions in the sectoral adaptation plan. The following objectives and actions require a robust link between climate indicators and climate related hydrological hazards as discussed in this paper:

- OBJECTIVE 2: Adapting flood risk management practice to effectively manage the potential impact of climate change on future flood risk.
  - ACTION 2A: Assessment of appropriate adaptation measures for those existing flood relief schemes, where climate change may in time impact the current standard of protection.
  - ACTION 2B: The Brief for the detailed development of flood relief schemes to include a requirement for a Scheme Adaptation Plan that will set out how climate change has been taken into account during the design and construction, and what adaptation measures might be needed and when into the future.
  - ACTION 2C: Proposals submitted under the Minor Works Programme should take account of the potential impacts of climate change to ensure, where possible, that any measures proposed are adaptable to possible future changes.
  - ACTION 2E: Progress a review of the current and future effectiveness of the protection provided by existing Arterial Drainage Scheme embankments to urban developments.

Of most relevance is the Scheme Climate Change Adaptation Plans (SCCAP) – Guidance Note for new Flood Relief Schemes, which the OPW is currently developing. This takes a scenario-based approach

[4] Climate and Environmental Assessment of the National Development Plan Review https://assets.gov.ie/201734/ce310fd8-a2d7-4f25-83d7-2c835d23c9fa.pdf

[5] OPW (2019) Flood Risk Management Climate Change Sectoral Adaptation - Plan Prepared under the National Adaptation Framework https://www.gov.ie/en/publication/97984b-climate-change-and-sectoral-adaptation-plan/

to analysing how a proposed flood relief scheme can adapt to continue to provide an acceptable level of flood protection. The key difference is that the EC Climate Proofing process is to ensure a proposed infrastructure investment is resilient to all possible climate hazards, whereas the SCCAP is focused on continued provision of flood relief objectives.

The water and water services sectoral adaptation plan[6] does not include such specific actions. Instead, it identifies a number of adaptations to climate change; the following adaptations are those which could be informed by this paper:

- Implementation of monitoring programme and undertaking research to enhance understanding of climate-related changes.
- Integrate climate change into flood risk assessments for planning and flood defence design.
- Improved asset management and upgrade of assets of 'at-risk' infrastructure.
- Review specifications for flood risk assessments and flood defences.
- Improved asset management and planning.

Even without analysing appropriate hydrological indicators, it is clear that this sectoral adaptation plan omits any specific actions to ensure future resilience of water and water services infrastructure investments or maintenance of existing services. There is EC guidance readily available and applicable.

HYDROLOGICAL CLIMATE HAZARDS

For climate proofing all climate hazards need to be screened and investments which are potentially vulnerable require a more detailed risk assessment. Nolan (2015)[7] describes the challenges in deriving projections of hydrological extremes from global and regional climate model outputs. The correct selection and interpretation of hydrological climate indicators is also important because the readily available indicators do not directly correspond to a flood or rainfall extreme event probability. A range of indicators such as projected percentage changes in annual maximum daily precipitation (Rx1day) are described in Leahy, et. al (2021)[8]. Projected change in annual and seasonal mean rainfall, and the projected change in the number of wet days (>20mm rainfall) cannot be used as an indicator of projected change in rainfall extremes. The indicator Very wet days (>30mm rainfall) is also not always sufficient for the extreme rainfall that causes flooding with defined rainfall probabilities.

To simplify the process and link climate indices to climate hazards, recently produced guidance for JASPERS (technical assistance arm of the EIB) for climate proofing of water, wastewater and flood projects. This guidance included a table of which hazards are relevant for these types of project in terms of both infrastructure construction and operation. This not only stated why the hazard is relevant to the project but listed the available climate indices that could inform the climate proofing assessments. An extract of this table for hydrological hazards is presented in Table 1.

[6] DHPLG (2019) Water Quality and Water Services Infrastructure Climate Change Sectoral Adaptation Plan - Prepared under the National Adaptation Framework https://www.gov.ie/en/collection/51df3-sectoral-adaptation-planning/

[7] Nolan, Paul. (2015). Ensemble of regional climate model projections for Ireland. Wexford: Environmental Protection Agency. https://www.epa.ie/publications/research/climate-change/research-159-ensemble-of-regional-climate-model-projections-for-ireland.php

[8] Leahy, P., Gonzalez, L.H., Hickey, K., Kiely, G., Allen, M., Nowbakht, P., Pasik, A., n.d. (2021) ClimAtt: Tools for Climate Change Attribution of Extreme Weather Events. https://www.epa.ie/publications/research/climate-change/research-384-climatt-tools-for-climate-change-attribution-of-extreme-weather-events.php

Table 1. Hydrological climate hazards, related climate indices and possible links to a hazard indicator developed for JASPERS.

Climate hazards	Related climate indices that could inform hazard (national datasets in brackets)	Relevance of hazard to flood projects	Relevance of hazard to water and wastewater projects	Relevance of hazard to interdependencies and operational aspects of all projects
Wet and Dry hazards				
Annual / seasonal / monthly average rainfall	Total precipitation	✓ potential effect on wetland and catchment functioning.	✓ effect on water resources from changes to hydrological regime.	× rainfall patterns do not cause a hazard
Extreme rainfall (frequency and magnitude)	Maximum consecutive five-day precipitation Extreme precipitation total Frequency of extreme precipitation	✓ effect on pluvial flood probability and hazard. Change on drainage system design parameters.	✓ effect on pluvial flood probability and hazard to infrastructure. Effect on drainage system design parameters.	✓ effect on pluvial flood probability and hazard to access roads, power supply and administrative buildings.
River flooding	River flood index using runoff (or Floods Directive Flood Hazard and Risk Maps)	✓ change to flood scheme design parameters.	✓ effect on river flood probability and hazard to infrastructure.	✓ effect on river flood probability and hazard to access roads, power supply and administrative buildings.
Aridity	Aridity days Consecutive dry days	✓ effect of soil moisture conditions on infrastructure stability.	✓ effect on ability to abstract sufficient water to meet demand for irrigation.	×
Drought / Water availability	Duration of meteorological droughts Magnitude of meteorological droughts Duration of soil moisture droughts	×	✓ effect on ability to abstract sufficient water to meet all water supply demands. Effect on receiving water body assimilative capacity for discharge.	✓ Effect on the ability of humans to operate, maintain and manage systems.

From climate metrics to hazard indicators for exposure scoring for extreme rainfall

The vulnerability or screening stage of the climate proofing process is informed by scoring the sensitivity of typical project components to a climate hazard, and exposure of the project location to a climate hazard. A resulting vulnerability score is then derived and any climate hazard with a moderate or higher vulnerability requires a detailed risk assessment and, if necessary, adaptation measures. The present day and future exposure is scored on a *high>medium>low>none* scale. At least one, and often a range of, future emission pathways (e.g. SSP[9]1-2.6, SSP2-4.5 and SSP5-8.5) and timescales (e.g. +30yrs, +50yrs, +100yrs) need to be considered. Some default exposure score definitions are shown in

[9] Shared Socio-Economic Pathway (SSP)

Figure 3; however, the ability to assign a score requires a link between a readily available climate indicator and projection to a specific climate hazard.

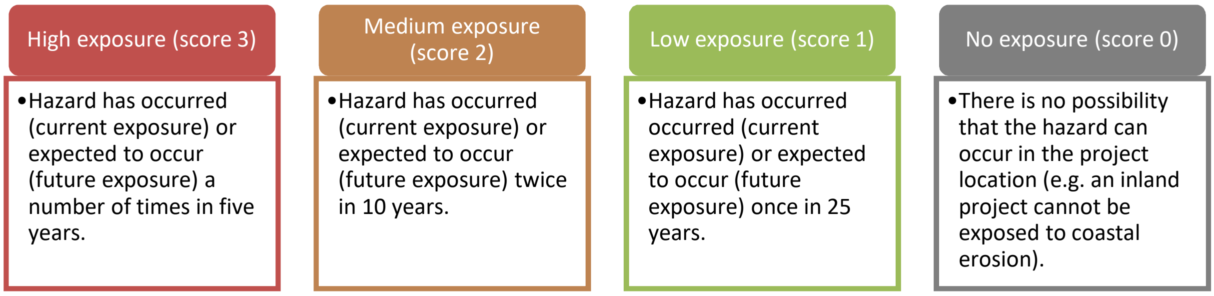

Figure 3. Examples of default exposure scoring (from guidance for JASPERS).

In this paper we explore approaches to linking readily available climate indicators and datasets to indications of how a region, country or asset base is likely to be impacted by future rainfall. Past trends give an indication of how more recent extreme, or high-intensity rainfall events compare with historic records. However, there is not necessarily any link between recent trends and the expected future projections. Annual average and seasonal rainfall changes do not provide sufficient insight into the projected change in extreme rainfall. Other indicators therefore need to be referenced. We can select from international, regional or national datasets. In the case of climate change uplift factors that can be applied to discrete rainfall events, these require historic rainfall statistics to determine the absolute change in the future. Not all climate indicators are available for the latest ICCP AR6 shared socio-economic pathways and so decisions on how to interpret older scenarios and projects are often required. The remainder of this paper provides examples of the application of rainfall estimates in different climate change projections.

Relevant international projections

The IPCC AR6 report (see Figure 4) projections for Ireland show no change (within +/-5%) in the annual daily maximum with 1.5 °C Global Warming Level (GWL) and an increase of more than 10% under a 3.0 °C GWL. The application of this projection requires comparing a Global Warming Level to a climate projection and then to convert the maximum one day precipitation amount to a typical design event probability.

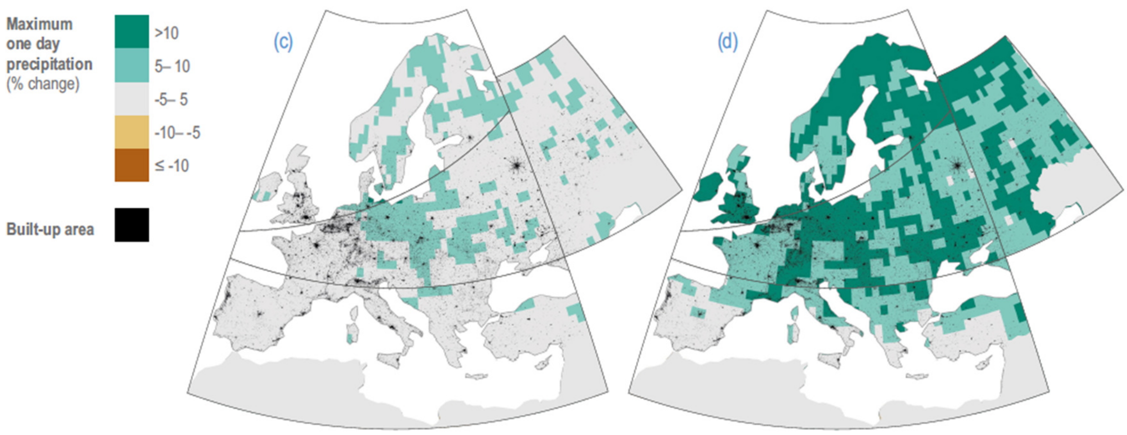

Figure 4. Change in Maximum one day precipitation with 1.5 °C GWL (left) and 3.0 °C GWC (right) (from IPCC AR6 Chapter 13)

Relevant regional projections

The Copernicus Climate Change Data Store contains hydrology-related climate impact indicators from 1970 to 2100 derived from bias adjusted European climate projections. The dataset provides water variables and indicators based on hydrological impact modelling, forced by bias adjusted regional climate simulations from the European Coordinated Regional Climate Downscaling Experiment (EURO-CORDEX). The dataset contains Essential Climate Variable (ECV) data in the form of daily mean river discharge and a set of climate impact indicators (CIIs) for both water quantity and quality.

Relevant European Environment Agency (EEA) indicators for assessing exposure to extreme rainfall[10] are described below. Indicators and projections at the European scale are not yet available for the SSPs and so RCPs[11] can be used for the exposure assessment.

- RCP 2.6 15th percentile in the near future (2041-2060) for the current exposure. This is because the historical data in the EEA indicator is for the period 1986-2005 and so already almost 20 years out of date.
- RCP 2.6 in the far future (2081-2100) for future exposure comparable to SSP 2.0-4.5.
- RCP 4.5 in the far future (2081-2100) for future exposure comparable to SSP 3.0-7.0.
- RCP 8.5 in the far future (2081-2100) is also considered to determine if a more significant long term exposure score should be assigned to manage the range of possible future climate impacts.
- Future exposure is based on the 85th percentile estimates to take a precautionary approach.

One example of the EEA datasets is the **Extreme precipitation total** index which represents the total precipitation on all days with heavy precipitation, defined as precipitation exceeding the 99th percentile of daily precipitation values over the reference period. Therefore, the index accounts for both the frequency and the magnitude of unusual precipitation events identified with respect to baseline conditions. The index is mainly relevant for water-related sectors, agriculture, transport and urban-related applications. It provides information on changes in the overall amount of rain falling during intense precipitation events, which can affect the risk of floods, landslides and erosion.

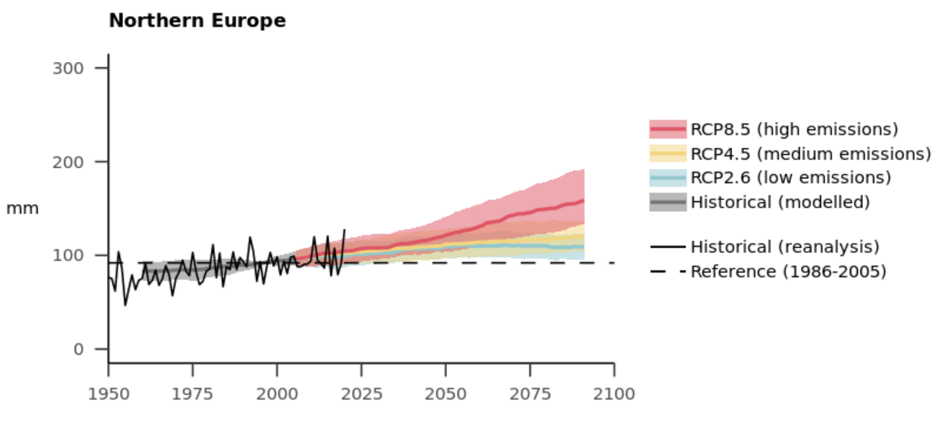

Figure 5. Extreme precipitation total for Northern Europe. (Source: European Environment Agency (EEA))

For JASPERS, we suggested a scoring method for current and future exposure as presented in Figure 6. The key to simple and meaningful scoring is to link the rainfall intensity change to stormwater design standards and the frequency in which these would be exceeded within a given time period. This is

[10] Wet and dry — heavy precipitation and river floods — European Environment Agency (europa.eu)

[11] Representative Concentration Pathway (RPC)

based on a simple absolute indicator which can be obtained from the European climate indicators for the present day and selected future projections at set points in time. The absolute values in the table may need to be adjusted to fit regional rainfall regime and what the region can typically cope with. The recommendation is for an exposure score to be given for:

- Present day conditions.
- 30 years' time for a medium climate change projection (typically within the shorter term all climate projections are within a narrow range and so a mid-point can be selected)
- 70 or 100 years' time for a slow and faster climate change projection (in the medium and long term there is much more significant divergence in climate change impacts across the different future projections).

High exposure (score 3)	Medium exposure (score 2)	Low exposure (score 1)	No exposure (score 0)
• Extreme precipitation total index greater than 150 mm.	• Extreme precipitation total index greater than 100 mm.	• Extreme precipitation total index greater than 50 mm.	• Extreme precipitation total index less than 50 mm.

Figure 6. Example of exposure scoring method for extreme rainfall. If more than one indicator is suitable the highest score from these could be used as the exposure score for extreme rainfall. (Source: climate proofing guidance document for water, wastewater and flood projects produced for JASPERS)

We must remember that in the screening stage we just need to know how exposed the project location is to the hazard. Detailed climate resilience risk assessments should take account of assets such as stormwater management systems and sub-daily duration storms that cause flooding (e.g. to accommodate the 30yr 3-hour storm, or other national requirements for stormwater design standards). Thresholds exist that relate to rainfall exceeding the capacity of drainage systems, above which flooding, damage to infrastructure, pollution from combined sewer overflows and other knock-on effects can occur. In such cases, a different source of climate impact data is appropriate: one that is derived from a convective permitting climate model that operates at spatial and temporal scales that are small enough to represent the atmospheric physics giving rise to convective processes. We expand on this later in the paper.

Irish scenario-based approach

In Ireland a scenario-based approach uses an uplift factor to be applied to present day peak rainfall volume for each probability analysed. The scenarios are widely understood and in use since the Planning Guidelines for Flood Risk Assessment, the Catchment Flood Risk Assessment and Management (CFRAM) studies, and continue to be recommended for Flood Relief Scheme Climate Change Adaptation Plans:

- +20% rainfall total for the Medium Range Future Scenario (MRFS).
- +30% rainfall total for the High End Future Scenario (HEFS).

The extreme coastal level climate change factors for these scenarios are roughly comparable to the IPCC AR6 projections for sea level rise; SSP2-2.5 for the MRFS and SSP5-8.5 for the HEFS. More research may be necessary to validate the rainfall and peak discharge uplift factors to the latest IPCC AR6 climate change projections. It is important to note that the projected 20% increase in heavy rainfall events (Nolan, 2015) is not a 20% increase in rainfall amount for heavy rainfall events.

Two recent rainfall intensity research studies in the UK

Two research studies conducted between 2019 and 2022 detail the use of cutting-edge climate science developed by the UK Met Office in which a Convective-Permitting Model (CPM) was developed for the whole of the UK[12]. The way this research relates to urban flood risk and pollution management is described in a recent paper[13]; the datasets used for this research are summarised below.

Future Drainage (NERC / UKRI) 2019-21

The UK Future Drainage[14] project funded by the Natural Environment Research Council (NERC) and managed under the Climate Resilience Programme has derived updated climate change rainfall uplift factors at a 5km spatial resolution with varying factors by event probability and storm duration. The uplift factors are estimated for 2050 and 2070 for RCP8.5 compared to the baseline of 1990 for precipitation durations of 1-, 3-, 6-, 12-, 24-hours. Three probabilities are provided (2, 30, and 100-year return periods) on a 5km resolution grid. The future changes are available as GIS layers (.shp) and comma-separated values (.csv) format for each 5km grid point in the UK. The duration and probability varying uplifts are demonstrated in Figure 7 for four UK locations.

The benefit of this new dataset is that the rainfall uplifts are derived from a CPM that captures convective processes explicitly. Convection gives rise to highest rainfall intensities and for sub-daily rainfall intensity change; hence, this modelling provides a much more realistic representation of change due to future greenhouse gas emissions than has been possible with coarser, regional climate models (RCMs) in the past. The uplifts (percentage changes in rainfall amounts) can be applied directly to rainfall statistics for any location in the UK on a 5km grid. The Future Drainage projections have been used by the Environment Agency and Scottish Environment Protection Agency in their flood risk guidance, and is being used by Natural Resources Wales and Department of Infrastructure Northern Ireland to update their flood guidance currently.

Figure 8 shows the indicative change in uplift factors compared to factors derived in a previous UKWIR study in 2017[15]. Central and high estimates of change are presented, indicative of a range of uncertainty in the projections. High estimate values can be used in cases where there is high potential vulnerability where greater precaution is desired.

[12] Kendon,E.J. Roberts,N.M.,Fowler,H.J.,Roberts,M.J.,Chan,S.C., Senior,C.A. ,2014. Heavier summer downpours with climate change revealed by weather forecast resolution model. Nature Climate Change 4,570–576.doi:10.1038/nclimate2258.

[13] Dale, M. 2021.Managing the effects of extreme sub-daily rainfall and flash floods–a practitioner's perspective. Philosophical Transactions A of the Royal Society. doi:10.1098/rsta.2019.0550.

[14] Chan, S.C.; Dale, M.; Fowler, H.J.; Kendon, E.J. (2022): Extreme precipitation return level changes at 1, 3, 6, 12, 24 hours for 2050 and 2070, derived from UKCP Local Projections on a 5km grid for the FUTURE-DRAINAGE Project. NERC EDS Centre for Environmental Data Analysis, 31 October 2022. https://dx.doi.org/10.5285/18f83caf9bdf4cb4803484d8dce19eef

[15] Dale,M.,Gill,E.,Potter,R.,Chan,S.C.,2017a. Rainfall Intensity for Sewer Design-Stage2. Technical Report 17/CL/10/17. UKWIR. URL:https://ukwir.org/rainfall-intensity-for-sewerdesign-stage-2-0.

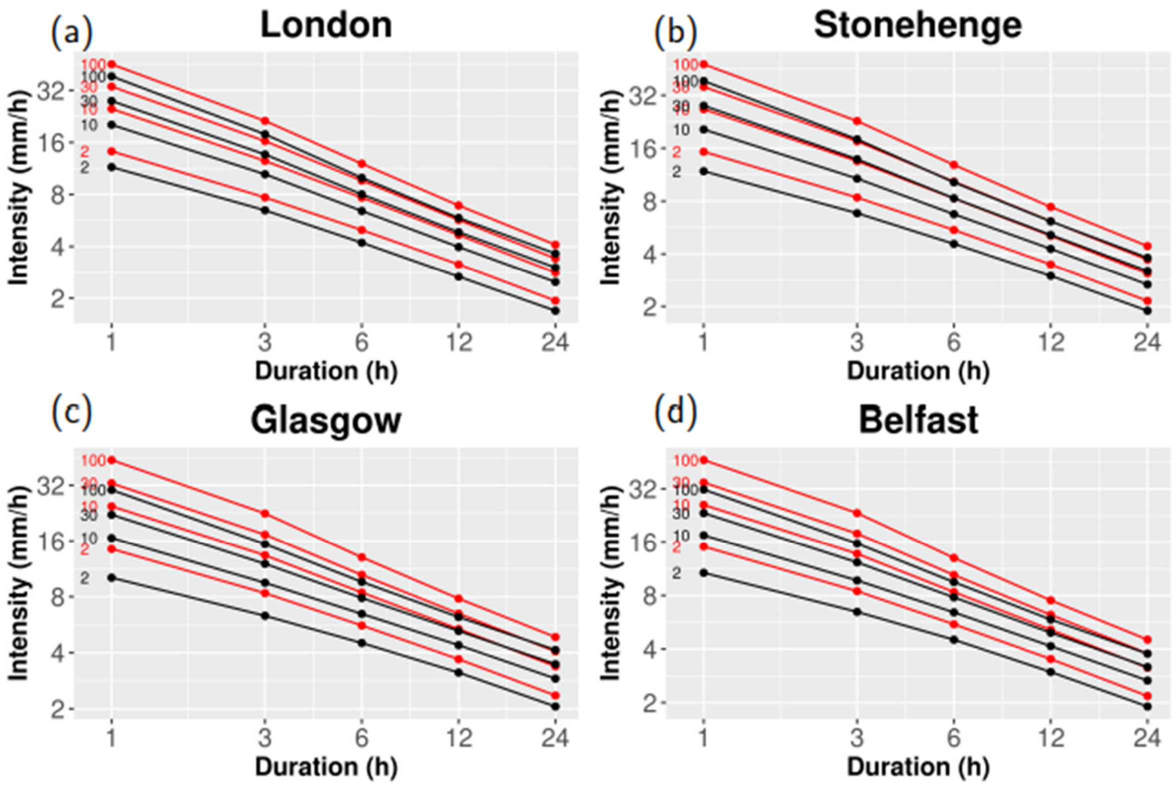

Figure 7. Future changes to rainfall Intensity-Duration-Frequency IDF curves for four locations. Black lines for the present day, red for the 01-ensemble mean (figure 5 from Chan, S.C. et al 2022)

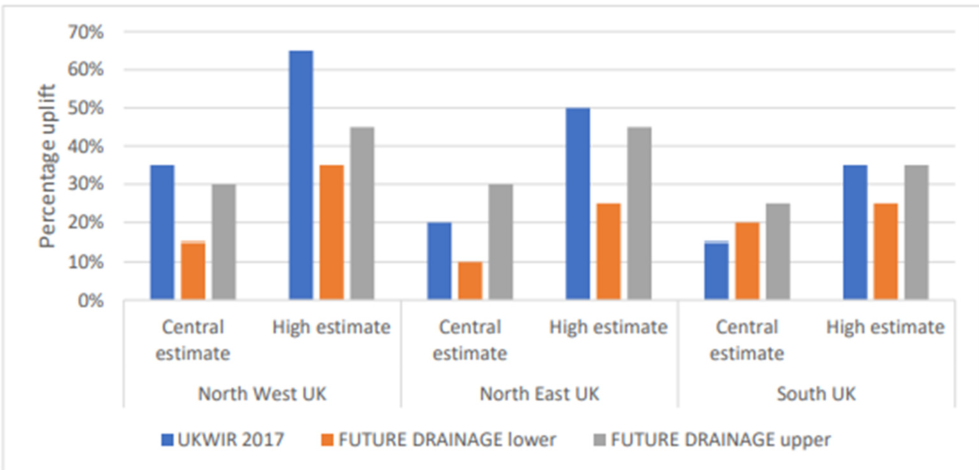

Figure 8. Indicative differences in climate uplift factors from the previous UKWIR 2017 and new Future Drainage Estimates.

UK Water Industry Research (UKWIR) Climate Change Rainfall for use in Sewerage Design 2021-22

There has been increasing water industry attention in the UK on storm overflows and inclusion of the latest projections of future rainfall intensities and patterns. This is so that the operators of urban drainage systems can predict and plan for future flooding and pollution risks. UK Water Industry Research (UKWIR) commission research on behalf of all major UK water companies and, since 2016, Irish Water[16]. The first UKWIR study on climate change impacts on rainfall for urban drainage was

[16] https://ukwir.org/about-water-industry-research

carried out between 2001 and 2004[17] using 50km and 25km climate model projections. The 2017 UKWIR project[10] was the first to use convective-permitting climate model (CPM)[18], and develop time series perturbation tool. The recent 2021-22 project[19] uses 5,500 times more data than 2017; based on the 12-member ensemble of CPM, all land based 2.2km cells.

This data was used to develop a time series perturbation tool that allows historic rainfall to be perturbed to reflect future rainfall conditions, including intensity changes, changes to seasonal rainfall amounts and changes in the number of dry days between rainfall events. The tool was called 'RED-UP' because it uplifts Rainfall Event Data (.red) files used in ICM drainage modelling software. An example of its output is shown in Figure 9. Here the perturbed rainfall time series has some increased intensity events compared to the historic time series, but also reduced total rainfall in the summer season.

We understand that many of the larger UK water companies are using RED-UP to assess the robustness of urban drainage systems to future rainfall projections through ICM modelling.

The UKWIR 2022 study also includes recommendations for design storm profile change, antecedent wetness and Areal Reduction Factor in sewer modelling. All these aspects have implications for flood risk and urban drainage management modelling.

A note on storm profiles

The UKWIR studies found that the standard symmetrical design storm profile (from FSR research published in the 1970s) may no longer be valid, however there was insufficient evidence from climate model analysis to recommend a change to the storm profile. Further research in this area would be worthwhile because the timing of rainfall within a storm can have an influence on how attenuation and routing of runoff and flow in drainage systems impacts capacity of structures.

[17] UKWIR (UK Water Industry Research) (2003) Climate Change and the Hydraulic Design of Sewerage Systems–Volume I: Climate Change Effects on Rainfall; IA–Climate Change and the Production of FSR, FEH and Year 2080 Rainfall Maps. UKWIR, London, UK, Ref.03/CL/10/1.

[18] Kendon,E.J.,Short,C.,Pope,J.,Chan,S.C.,Wilkinson,J.,Tucker,S., Bett,P., Harris,G., Murphy,J. ,2021. Update to UKCP Local (2.2km) projections. Technical Report. United Kingdom Met Office. Exeter, United Kingdom. URL:https://www.metoffice.gov.uk/research/ approach/collaboration/ukcp/guidance-science-reports.

[19] Dale,M., Faulkner, D., Fowler, H.J., Gill, E., Shelton, K., Titterington, J., Villalobos-Herrera, R. 2022. Climate Change Rainfall for use in Sewerage Design - Design Storm Profiles, Antecedent Conditions, RED-UP Tool Update and Seasonality Impacts. Technical Report for UKWIR. Ref. 22/CL/10/19. ISBN 978-1-84057-956-7

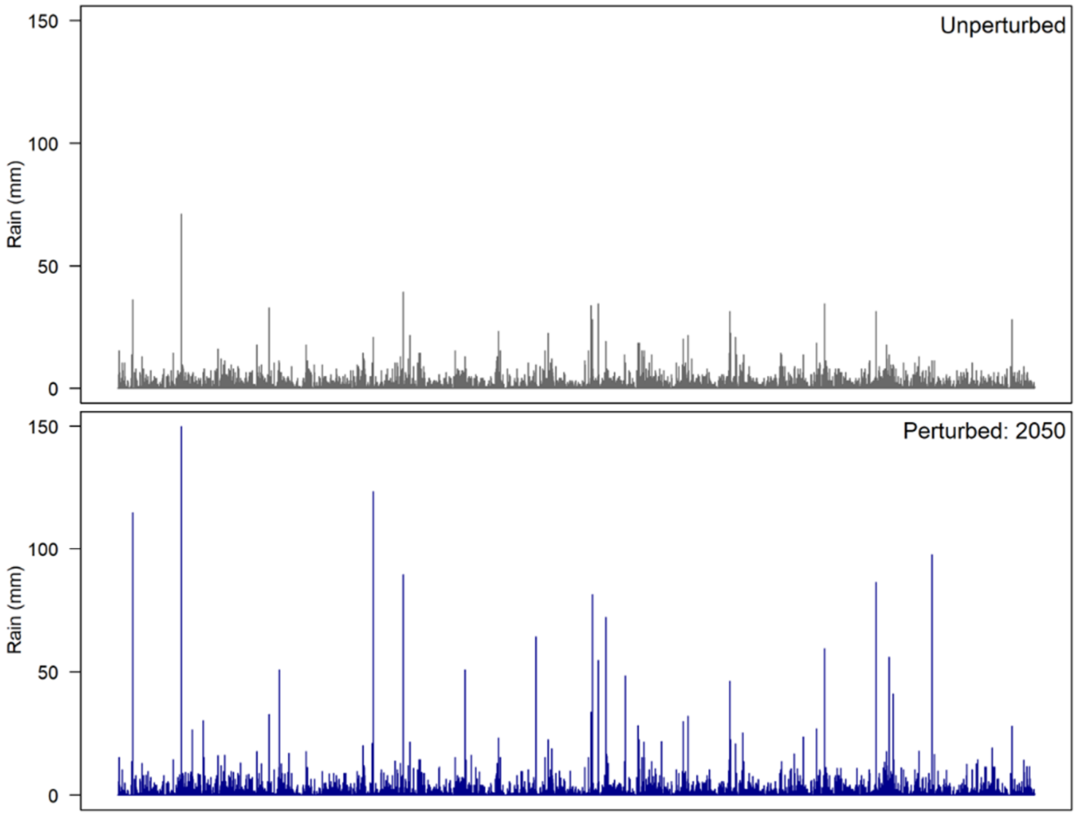

Figure 9. Example of unperturbed and perturbed rainfall. (Source: Dale et al , 2022[19])

Climate change projection information informing future flood risk in Niger, west Africa

In a recent project we have used climate change projection information available in the World Bank's Climate Knowledge Portal[20]. This allows extraction of pertinent datasets of climate change projections for specific countries, such as *days with precipitation greater than 50mm* for future time horizons and different emission scenarios. It also allows an analysis of the variety of projections from different global climate models (GCMs) to be assessed, to examine where there are agreements or discrepancies in the projections.

In a country like Niger, where both flooding and drought conditions present significant threats, we have needed to use variables that highlight future projected changes seasonal precipitation, annual precipitation and short term, daily precipitation. Our work in Niger, funded by the World Bank Group, is assessing future flood risk and proposing flood risk reduction measures that can also benefit water resources, such as how catchment land use can be changed to hold back flood water runoff while benefit agricultural production – i.e. a nature based solution to flood risk management. An example of such a practice is shown in Figure 10.

[20] https://climateknowledgeportal.worldbank.org/

Figure 10.Demi-lunes – an example of a landuse practice to benefit flood risk as well as agricultural production (image source: Meguetaninfos [21])

Concluding remarks

This paper has highlighted some of the possible ways in which climate change indicator and projection datasets can be applied to climate proofing of infrastructure and investment. The indicators and data need to be transposed into meaningful and robust measures of exposure to climate hazards. In the case of extreme rainfall hazards the simple uplifts such as the MRFS and HEFS climate scenarios in Ireland are practical and pragmatic but may potentially not be representative of the latest IPCC Shared-Socio Economic Pathways (SSPs) from AR6 or capture processes that drive local variations in rainfall events and extremes, especially convective rainfall. Given that flooding and extreme rainfall are key risks for Europe[22] it is critical to progress research or adopt existing research in at least the following specific topics:

- Robust and unambiguous means of demonstrating how infrastructure projects and investment portfolios contribute to climate adaptation objectives.
- Changes to concurrent and coincidence of hydrological extreme events.
- Effect of changes to North Atlantic and Northern Hemisphere atmospheric and oceanic circulations on extreme hydrological events. Both in terms of the influence of changes to global circulation patterns (e.g. el Nino), but also in the locking or stalling of the jet stream.
- Revision or validation of the MRFS and HEFS climate scenarios using fine resolution Convective-Permitting Models to Ireland as regional and national scale climate change factors that relate to specific projections (e.g. SSP) and timescale.
- Recent research in the UK using convective-permitting climate modelling by the UK Met Office is highlighting significant differences in the effect of the same projection when using

[21] https://www.meguetaninfos.com/archives/18588

[22] Bednar-Friedl, B., R. Biesbroek, D.N. Schmidt, P. Alexander, K.Y. Børsheim, J. Carnicer, E. Georgopoulou, M. Haasnoot, G. Le Cozannet, P. Lionello, O. Lipka, C. Möllmann, V. Muccione, T. Mustonen, D. Piepenburg, and L. Whitmarsh, 2022: Europe. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1817–1927, doi:10.1017/9781009325844.015.

fine scale CPM and broad scale UKCIP models. The Republic of Ireland could benefit from this UK research through a range of possible approaches.