CLIMsystems Extreme Rainfall
Climate Change Projection Solutions

Glossary

IDF – Intensity Duration Frequency

DDF – Depth Duration Frequency

GCM – Global Circulation Model

RCM – Regional Climate Model

RCP – Representative Concentration Pathway

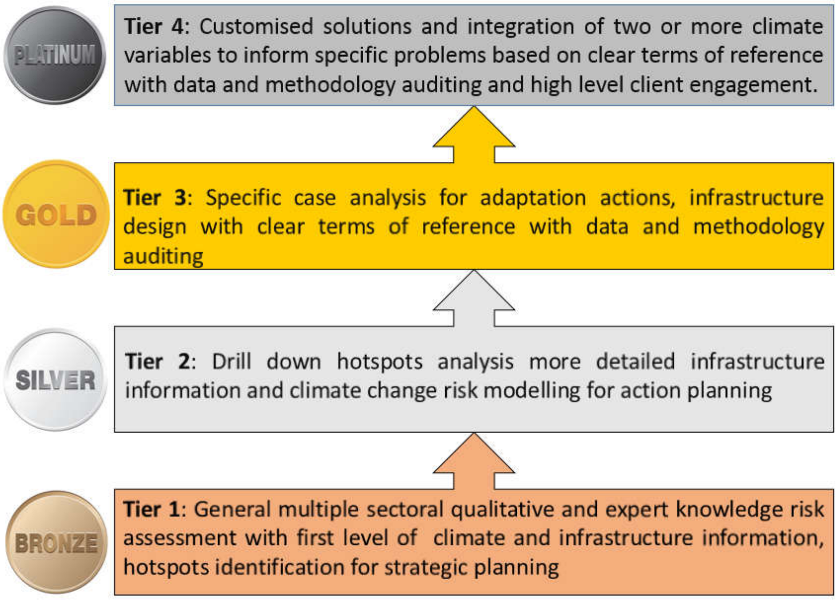
Introduction

Climate change changed precipitation characteristics in trend, variability and extremes, namely, annual total amount, seasonal patterns, and extremes. Changes in different aspects have specific impacts on natural and manmade systems. Table 1 presents a summary from annual to sub-hourly change in precipitation, potential implications, and CLIMsystems' solutions to provide appropriate data for real applications.

CLIMsystems' solutions focus on real application and providing robust climate change data derived from our rich experience providing data and software service to different sectors over the last 15 years.

Climate change impact/risk assessment needs highly specialized experience and knowledge of climate change science, and a thorough understanding of climate change data and its limitations and applicability to specific climate-related problems.

Close and seamless cooperation of a team with experts and specialists in climate data and with sectoral experience can offer a range of integrated and useful information for different sectors. Common understanding of data applications, limitations and caveats, and transparent communication and interpretation of the data is very important in achieving credible outputs.



Tier 4: Customised solutions and integration of two or more climate variables to inform specific problems based on clear terms of reference with data and methodology auditing and high level client engagement.

Tier 3: Specific case analysis for adaptation actions, infrastructure design with clear terms of reference with data and methodology auditing

Tier 2: Drill down hotspots analysis more detailed infrastructure information and climate change risk modelling for action planning

Tier 1: General multiple sectoral qualitative and expert knowledge risk assessment with first level of climate and infrastructure information, hotspots identification for strategic planning

Figure 1: Climate data and analysis often needs to be processed to different levels of robustness depending on the nature of the project i.e. from screening to major infrastructure investment with either a long life cycle or critical lifelines function like a hospital or water/waste treatment facility.

To assist our clients to better understand the implications of data and methods to extreme rainfall events analysis we have put together the following matrix and links to more detailed information. After digesting some or all of this information sometimes a quick call is helpful to further refine your specific methodological requirements. We are available for such consultations using a wide variety of technologies. Send us an email to arrange a call: info@climsystems.com or call +64 27 316 9777.

Further information is available online from one of our Climate Scientists, Dr Chonghua Yin:

https://www.linkedin.com/pulse/brief-introduction-how-apply-idf-information-chonghua-yin

https://www.linkedin.com/pulse/small-note-updating-short-duration-idf-curves-under-climate-yin

https://www.linkedin.com/pulse/do-get-confused-change-factor-method-bias-correction-when-yin

https://www.linkedin.com/pulse/bias-correct-methods-used-statistical-adjustment-gcmrcmsdsm-yin

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Table 1: Climate change related precipitation analysis and their application

Applications	Baseline and total seasonal and monthly changes in slow onset for water resources planning	Extreme changes, changes in return period, IDF, or DDF for water infrastructure design	Extreme changes in short duration (hourly), changes in return period, IDF, or DDF for urban water infrastructure design	Water resources, flooding, inundation modelling	Extreme changes in short duration (hourly), changes in return period, IDF, or DDF for urban water infrastructure design
Precipitation related climate change analysis type	Annual or monthly mean	Daily precipitation extremes	Sub-hourly to multiple day IDF or DDF for storm water system design	Hydrological model input data	Very high resolution RCM precipitation changes for urban water systems
Recommended methodology	Change factor approach (Percentage change per degree, or percentage in different scenarios)	Generalized Extreme Value analysis, multiple distributions fitting testing.	Generalized Extreme Value analysis and IDF curve fitting, multiple distributions fitting testing.	Bias correction statistical downscaled with climate change projection	1-3 km resolution convection permitting RCM simulations
Historical data required	Observation based Monthly historical data	Daily observation time series	Subdaily observation data	Subdaily or daily observations	Sub-hourly precipitation observation
GCM/RCM data required	Multiple GCM and RCM monthly mean ensemble results	Multiple GCM daily precipitation	Multiple GCM/RCM 1 hourly or 3 hourly precipitation output	Multiple sources: subdaily or daily GCM or RCM	RCM sub-hourly data
CLIMsystems tool	SimCLIM monthly pattern scenario generator	SimCLIM GEV tool and in-house tools	Sub-hourly Subdaily extreme event analysis in-house tool	Multiple GCM daily/sub-daily BCSD dataset	WRF specific domain case by case
Potential linkage to other models	WEAP,DSSAT	Related infrastructure design	Related infrastructure design	SWAT, DHI, EWater, HECS,	SWAT, DHI, EWater, HECS, SWMM, other

		models	models	SWMM, Flood Modeller	Related infrastructure design models
Pros/Cons	Quick and easy to generate, but seasonal/monthly average change can't reflect the extremes which is crucial for water resource management	Widely used for engineering design, applying daily GCM/RCM output may under estimate sub-daily changes in extremes, which is important for flooding.	Widely used for engineering design. GCM/RCM sub-daily data reflects changes in higher temporal resolution. Not directly applicable for detailed flood modelling	Can be directly link to hydrological flood modelling and cost-effectively for multiple scenario and multiple time slices.	Can be directly link to hydrological flood modelling and may reflect some detailed change patterns. But it is costly and time consuming, therefor this method is not easy to apply to multiple scenario and time slices experiment

IDF/DDF Projection Methodology

A warming climate might change the extreme precipitation quantiles represented by the DDF or IDF curves, emphasizing the need for updating the DDF or IDF curves used for the design of urban storm water management systems, including sewers, storm water management ponds, street curbs and gutters, catch basins, swales, among a significant variety of other types of infrastructure. Currently, DDF and IDF curves are usually developed using historical observed data with the assumption that the same underlying processes will govern future rainfall patterns and resulting DDF and IDF curves. This assumption is not valid under changing climatic conditions and therefore IDF curves that rely only on historical observations will misrepresent future conditions (Sugahara, *et al.* 2009; Milly *et al.* 2008). Global climate models (GCMs) provide understanding of climate change (i.e., non-stationary conditions) under different future emission scenarios, also known as representative concentration pathways (RCPs), and provide a way to update DDF and IDF curves under a changing climate. The updating procedure is illustrated in Figure 2 below.

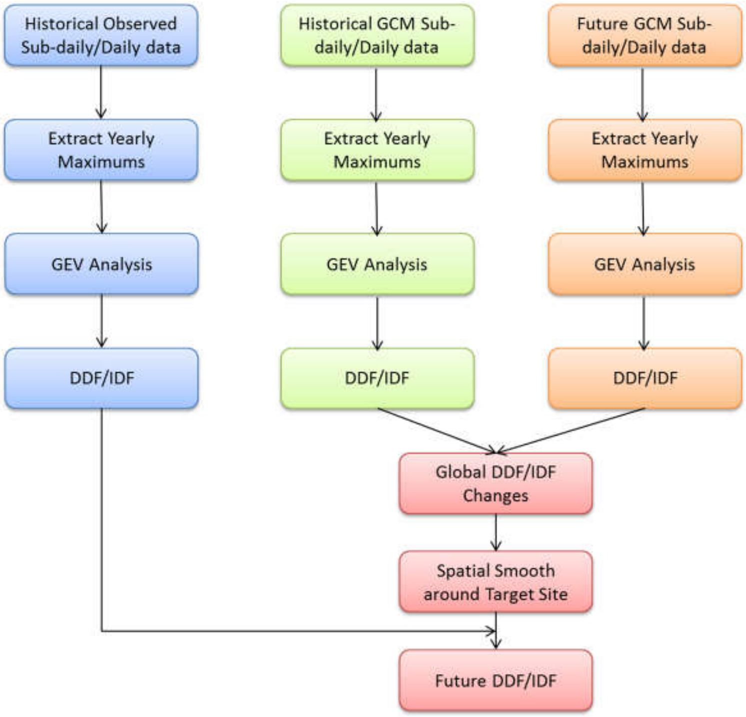

Figure 2 Equidistance Quantile-Matching Method for generating future DDF and IDF curves under Climate Change

Historical DDF and IDF Curve (or table) Development

A fundamental issue in the estimation of quantiles is the need to extrapolate to recurrence intervals significantly larger than the available records. This can be solved using regionalization, a standard practice for improving the estimation of event quantiles at sites with comparatively short records. In this report, the index regional flood frequency analysis method based on L-moments proposed by Hosking (Hosking and Wallis, 2005) is applied to estimate the regional rainfall quantiles at the site.

Step 1: Derive the rainfall intensity time series of the different durations from historical hourly data time series. The durations include: 3, 6, 12, 24, 48, 72, 120, 144 and 168 hours, then select annual maxima series from the rainfall intensity series. Fit the annual maxima series for each duration to a group of probability distribution functions. Three distribution functions were tested, including: Generalized Logistic (GLO), GEV, and Gumbel distribution. *L*-moments method was deployed for distribution parameter estimation.

Step 2: Assess their goodness of fit with the Anderson-Darling test to follow the method used (Vigione, 2008). The Anderson-Darling test measures the extent of the departure, in terms of probabilities, between a simulated hypothetical distribution and the frequency distribution for consideration. If the estimated probability is greater than some defined significance level, the test fails. In this case of the three distributions, the GEV provided the best fit. Therefore the GEV parameters were used for further analysis.

Step 3: Calculate rainfall depths for the range of return periods (including 2, 3, 5, 10, 15, 25, 50, 100, 200 and 300 year) for each storm duration using GEV distribution parameters obtained from **Step** 1. The values consist of the table of depth-duration-frequency (DDF). The intensity-frequency-duration (IDF) table can be computed directly from the DDF table by simply dividing the rainfall depths by duration in hours.

Step 4: Generate the DDF and IDF curves based on the tables of DDF and IDF. A shape-preserving piecewise cubic interpolation is used to produce smooth DDF and IDF curves.

Future DDF and IDF Curve (or table) Development

The impacts of climate change on historical DDF and IDF are evaluated based on climate model data. In order to reduce uncertainty of climate change simulated by GCMs, the outputs of as many as possible of these GCMs are used. According to the Fifth Assessment Report of IPCC (AR5), there are 42 GCM models developed by various research centres around the world. Currently, this analysis adopts only 22 GCMs out of the 42 GCMs because: i) Not all the GCMs generate the two selected RCPs for future climate scenarios (i.e., 4.5 and 8.5); and ii) there are some technical issues related to downloading (such as connection to remote servers or repositories) for some GCM models. The basic procedure is employing an equidistant quantile matching (EQM) method to update the DDF and IDF curves under changing climate conditions.

Step 1: GCM 3 hourly output for each grid cell were analysed using extreme value analysis (EVA) to calculate extreme rainfall amounts for current climate (called the baseline, 1986-2005), and the future periods of interest. For GCM resolution, please refer to the GCM summary table.

Step 2: DDF and IDF change factors for the range of durations (3, 6, 12, 24, 48, and 72, 120, 144 and 168 hours) and return years (2, 3, 5, 10, 15, 25, 50, 100, 200 and 300 year) for each GCM under RCP4.5 and RCP8.5 were calculated by applying a pattern scaling approach (Li and Ye, 2011).

Step 3: Interpolated the global DDF and IDF changes into the same spatial resolutions (0.5^o x 0.5^o) to construct a global database. Furthermore, a super ensemble method was carried out to derive ensemble statistics at different percentiles (e.g., 25th and 75th percentile of the GCM ensemble), with both RCP4.5 and RCP8.5 change factors for all GCMs being applied equally without any weighting.

Step 4: Perturbed the historical estimated precipitation depth/intensity values of each duration and return period using the global DDF and IDF changes surrounding the site of XXXX. The global DDF and IDF changes show high variability around the world. There are also considerable differences among GCM members. To further reduce the impact of natural variabilities, the change factors applied in this work are averaged over the whole study area.

Step 5: DDF and IDF curves for selected future time periods (2020-2030, 2040-2050, 2070-2080, 2090-2100) were calculated using the same smoothing method as the historical ones.

A New Approach for Sub-Hourly Precipitation Climate Perturbation for Robust Water System Design

CLIMsystems has developed equally efficient and scientifically credible approaches for hourly, daily and multiple day extreme rainfall perturbation for application in a variety of water-related projects where future climate-related time series data is critical.

Sub-hourly extreme rainfall events have changed in magnitude more dramatically than daily, even hourly events in our climate changed world. This has put additional pressure on water infrastructure exemplified by increasing incidents of urban water management problems (loss of life and property, sewer system overtopping, infrastructure damage, disruption to services). Urban designers and engineers are developing and applying better testing and engineering solutions, however, because of constraints in modelling and data storage capacity, General Circulation Models (GCM) and Regional Climate Models (RCM) have until now not been adequately applied to provide data for sub-hourly water system modelling and adaptation decision support.

To meet the growing necessity for better and more robust data to support decision making the team at CLIMsystems developed an innovative hybrid approach to perturb 5 to 15 minute (and other temporal resolution) time series data. The approach better reflects the climate change signal projected in GCMs and RCMs, including extremes, variation and total amount of change in precipitation that can be applied either for either a locale or spatially. There are several key factors accommodated in the approach that are important: (1) the method must preserve the extreme precipitation change information in the climate model (perturbed) output, especially the Intensity Duration Frequency (IDF) change characteristics; (2) the changes in non-extreme precipitation Cumulative Distribution Function (CDF) distribution in all quantiles must be retained; and, (3) the changes in annual and monthly precipitation must be retained. The approach devised and applied by CLIMsystems meets these three criteria.

To avoid the problems of single model uncertainty and bias, multiple model ensembles and probability approaches are recommend by the Intergovernmental Panel on Climate Change (IPCC). With the recent and dramatic increase in the availability of GCM and RCM data plus advances in methods of analysis, an ensemble approach has become much more feasible. CLIMsystems holds extensive repositories of CMIP5 GCM and RCM data for the globe and through careful storage and post-processing the time and hence cost of generating scientifically rigorous sub-daily and daily outputs for flood and engineering studies has been dramatically reduced.

This type of modelling and the data and methods required have already been successfully applied in several locations in the USA and Asia. The perturbed data has been used to stress test sewer system performance under various climate change scenarios. Our experience allows us to quickly and efficiently generate useful data for flood modellers, system stress testers and planners looking at reducing climate risk through the design of infrastructure that considers the impacts of intense short duration rainfall.

Table 2: Example of available CORDEX RCM data for North America* (CORDEX-NAM) with daily data

No.	GCM/RCM combination and resolution	No.	GCM/RCM combination and resolution
1	NAM-44-CanESM2-CRCM5	9	NAM-44-HadGEM2-ES-RegCM4
2	NAM-44-MPI-ESM-LR-CRCM5	10	NAM-44-MPI-ESM-LR-RegCM4
3	NAM-44-MPI-ESM-MR-CRCM5	11	NAM-22-CanESM2-CanRCM4
4	NAM-44- CanESM2-CanRCM4	12	NAM-22-GFDL-ESM2M-RegCM4
5	NAM-44-EC-EARTH-HIRAM5	13	NAM-22-HadGEM2-ES-RegCM4
6	NAM-44-CanESM2-RCA4	14	NAM-22-MPI-ESM-LR-RegCM4
7	NAM-44-EC-EARTH-RCA4	15	NAM-22-GFDL-ESM2M-WRF
8	NAM-44-GFDL-ESM2M-RegCM4	16	NAM-22-MPI-ESM-LR-WRF

Table 3: Available CORDEX-NAM hourly data

No.	GCM-RCM combination
1	NAM-22-MPI-ESM-LR-RegCM4
2	NAM-44-CanESM2-CanRCM4
3	NAM-44-MPI-ESM-LR-RegCM4

Table 4: Available CMIP5 GCMs with 3 hourly precipitation data

	GCM	nlat	nlon			GCM	nlat	nlon
1	ACCESS1-0	145	192		12	GISS-E2-H	90	144
2	BCC-CSM1-1	64	128		13	GISS-E2-R	90	144
3	BCC-CSM1-1-M	160	320		14	HadGEM2-ES	145	192
4	CCSM4	192	288		15	INMCM4	120	180
5	CMCC-CM	240	480		16	IPSL-CM5A-LR	96	96
6	CNRM-CM5	128	256		17	IPSL-CM5A-MR	143	144
7	EC-EARTH	160	320		18	MIROC5	128	256
8	FGOALS-g2	60	128		19	MIROC-ESM	64	128
9	GFDL-CM3	90	144		20	MIROC-ESM-CHEM	64	128
10	GFDL-ESM2G	90	144		21	MRI-CGCM3	160	320
11	GFDL-ESM2M	90	144		22	NorESM1-M	96	144

*Other RCM data is available around the world. A complete list of RCM data can be found at: http://documents.climsystems.com/SimCLIM%204.0/CORDEX%20data%20availability%20in%20SimCLIM.pdf

Sample Site 1: Washington DC precipitation IDF changes under RCP 8.5

Discussion points:

- For 3 hourly precipitation data only selected RCPs (RCP45 and RCP85) and time slices (2026-2045, 2081-2100), therefore only RCP85, 2090(2981-2100 data) were visualized
- This analysis only for demonstration or testing purpose, there was no pattern scaling or weighting method applied.
- The existing SimCLIM daily extreme precipitation patterns are obtained from pattern scaling method.
- Visualization and explanation need to be discussed.

Characteristic of extreme precipitation change:

(1) Short duration precipitation depth changes larger than longer duration. For example, 2 year return 3hr precipitation increase 25% in 2090, RCP85, while 168hr precipitation changes about 16%.

(2) The longer return period event changes larger than shorter return period event. For example, 100 year 3 hr precipitation changes about 32%, while 3hr 2 year return event changes 25%.

(3) Regional average shows a clear signal of above characteristics, but for individual grid cell, this may not clear hence the requirement to include a regional analysis.

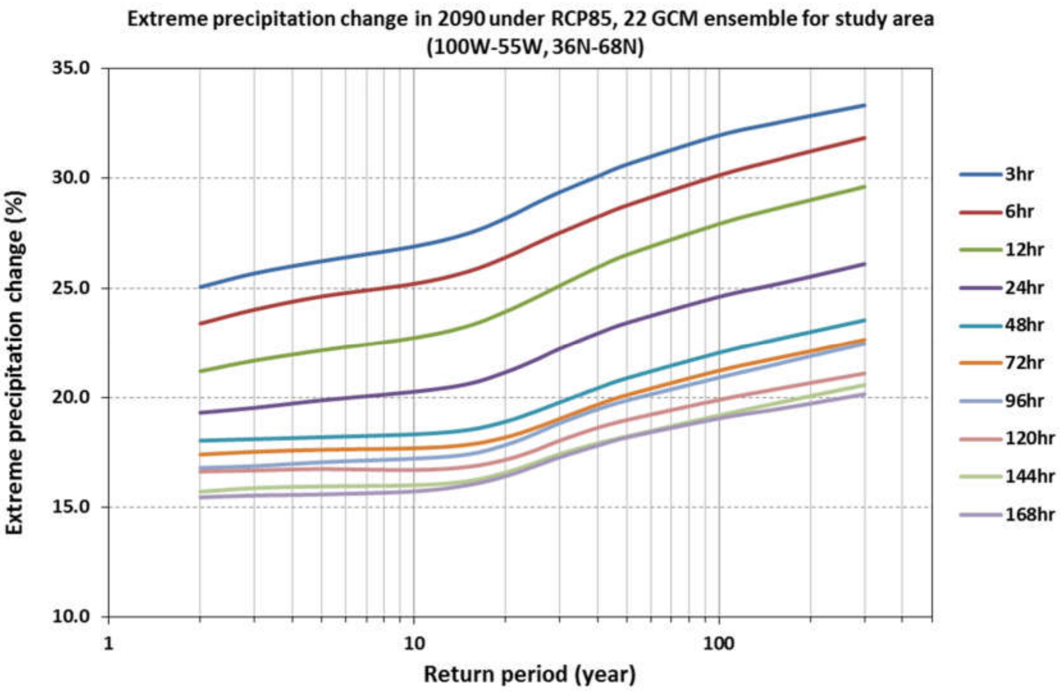
Extreme precipitation change in 2090 under RCP85, 22 GCM ensemble for study area (100W-55W, 36N-68N)

Figure 3: Extreme precipitation changes in 2090 under RCP85, 22 GCM ensemble median, for study area (100W-55W, 36N-68N)

GCM data 22 GCM 3 hourly precipitation output for 1986-2005 (baseline), 2081-2100 period, RCP45 and RCP85.

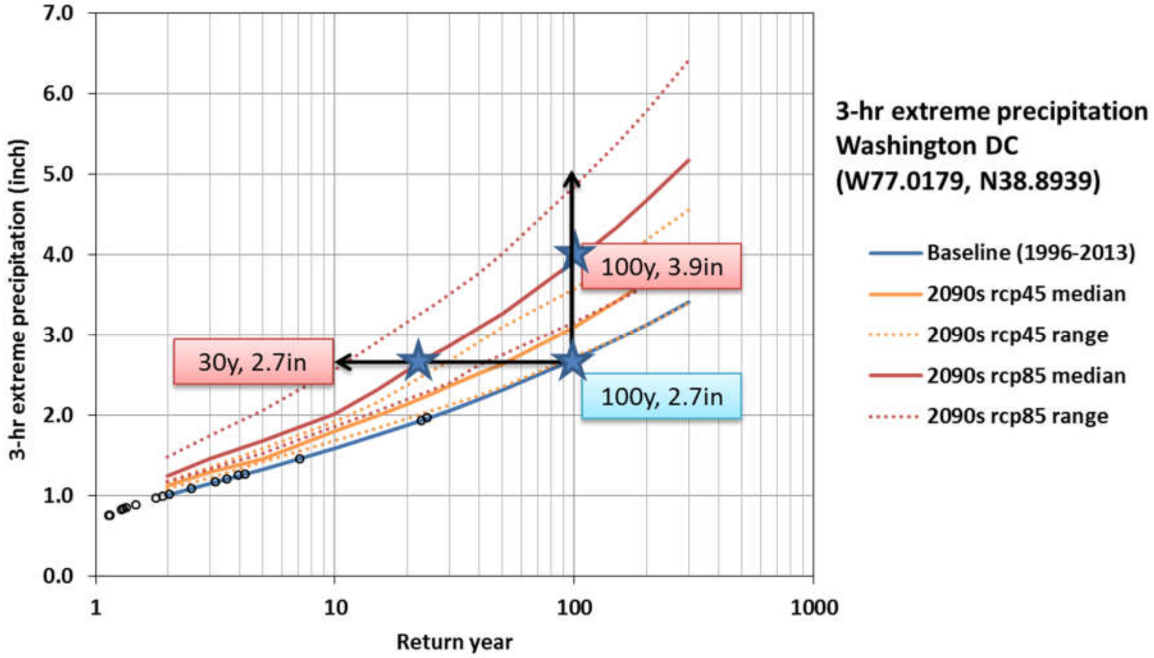

Figure 4: 3 hour extreme precipitation analysis. 100 year return 3 hour precipitation is 2.6 inch during historical period. However in RCP8.5 scenario 2090, it will become 3.9 inch. Or this change can be expressed as: 2.7 inch becomes the 30 year return event.

Sample site 2: 15 minutes precipitation time series data perturbation and depth-duration scaling

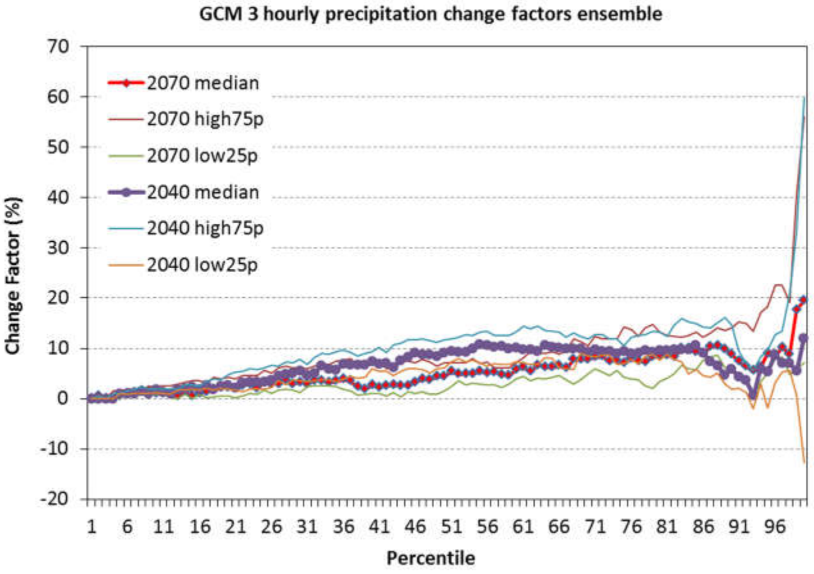

Figure 5: GCM 3 hourly data change factor ensemble result (8 GCMs).

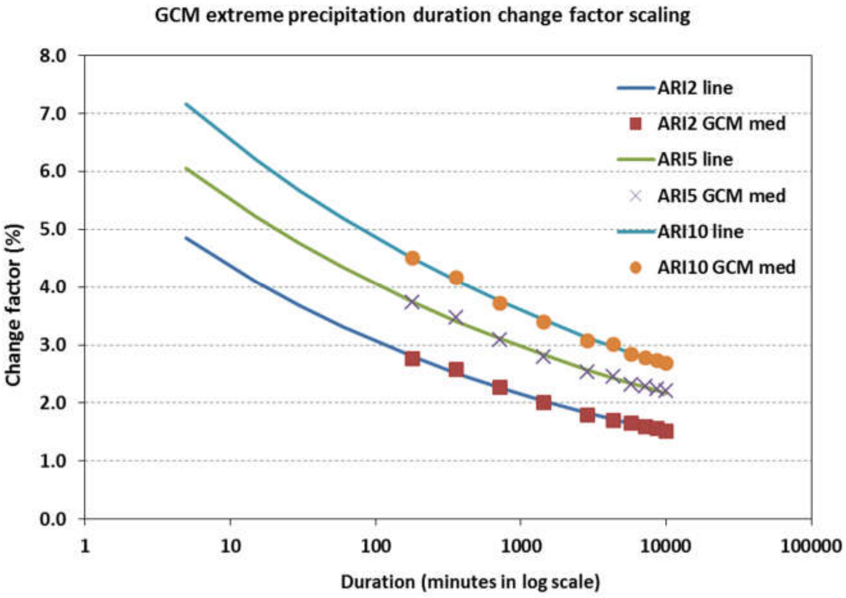

Figure 6: 22 GCM ensemble extreme precipitation change factor scaling example results.

Guidelines for Return Periods

Ideally, the choice of a design return period should be based on an economic evaluation in which the costs of providing the drainage works are compared with the benefits derived. However, comprehensive local flood damage data are normally not available to the degree of precision required for cost-benefit analysis. For this reason, a general policy decision based on such considerations as land use, hazard to public safety and community expectations is more appropriate. Admittedly, for new drainage systems or drainage upgrading in some existing areas, particularly low lying ones or those in congested urban locations, the recommended standards may not be suitable or achievable. A pragmatic approach should be considered. In a case in Hong Kong the return periods recommended in urban drainage situations ranged from 50 to 200 years (Drainage Services Division, 2014). For the City of Dublin, Ireland a 100 year return period is applied for protection of flooding within properties (Greater Dublin Strategic Drainage Study, 2005).

Guidelines for the selection of return period

No.	Type of project or feature	Return period (yr)
1	Urban drainage [low risk] (up to 100 ha)	5 to 10
2	Urban drainage [medium risk] (more than 100 ha)	25 to 50
3	Road drainage	25 to 50
4	Principal spillways (dams)	25 to 100
5	Highway drainage	50 to 100
6	Levees [medium risk]	50 to 100
7	Urban drainage [high risk] (more than 1,000 ha)	50 to 100
8	Flood plain development	100
9	Bridge design (piers)	100 to 500
10	Levees [high risk]	200 to 1000
11	Emergency spillways (dams)	100 to 10,000 (PMP)
12	Freeboard hydrograph [for a class (c) dam]	10,000 (PMP)

Source: Ponce, V.M. Q & A on the return period to be used for design. Sourced 20 May 2016.
http://returnperiod.sdsu.edu/

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