The Metropolitan Glasgow Strategic Drainage Partnership

# Climate Change Technical Guidance

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## Contents

## 1.0 Introduction

The purpose of this paper is to describe a preferred approach for managing and planning for climate change impacts on drainage in Glasgow within projects undertaken by the Metropolitan Glasgow Strategic Drainage Partnership (MGSDP) in a consistent manner.

This paper has been developed to provide guidance on the suitable climate change quantities to use and the source of these quantities for practitioners involved in undertaking modelling assessments and planning works for the MGSDP. It is considered that these approaches are consistent with those required for Flood Risk Management and River Basin Management plans.

## 1.1 Overview of Climate Change Impacts on Drainage Infrastructure

Climate change is an accepted phenomenon and the Scottish and UK Governments both recognise the need to act to reduce the harmful effects of climate change.

Climate change is projected to have a range of impacts on drainage infrastructure. Water UK (2008) summarised those impacts as;

- Assets on the coast or in flood plains will be at increased risk from flooding, storm damage, coastal erosion and rises in sea levels.
- Existing sewerage systems were not designed to take climate change into account. This means that more intense rainfall is likely to exceed the capacity of parts of the network and cause local flooding.
- Pipe systems for both drinking water supply and sewerage will be more prone to cracking as climate changes lead to greater soil movement as a consequence of wetting and drying cycles.
- Lower river flows will reduce the dilution of wastewater effluent. Additional treatment may be required to meet higher standards, which are likely to be achievable only by using energy-intensive processes, with all that means for greenhouse gas emissions.
- Colour and odour problems will result from higher temperatures and more intense rainfall events.

Further to this, Defra, in their Supplementary Note to Operating Authorities (Defra, 2006), has shown that peak river flows may increase in magnitude and frequency in the future. Where rivers flow through urban areas, as is the case in Glasgow, increases in fluvial flow peaks due to climate change may impact local drainage conditions and urban flood risk.

Climate change research is an ongoing process and every new study increases the knowledge base of what parameters may be affected and by how much. However, in order to develop an approach to quantifying the potential impact of climate change then a source of data on which base the projected revised parameters has to be selected. The most recent research data available is from the UKCP09 Study and the central probability estimate (50% probability level) from the Medium Emissions Scenario has been selected as the baseline to develop any parameters changes applied unless specifically stated otherwise.

Two exceptions to this approach have been documented in the guidance that follows. It is recognised that the climate models that UKCP09 are based on have particular limitations with respect to predicting changes to convective rainfall. Consequently, it is accepted that UKCP09 does not quantify changes in convective, localised and intense rainfall events. In order to ensure these effects are sufficiently quantified, guidance on design storm uplifts as developed by Defra in 2006 have been used in place of UKCP09 data. Secondly, research carried out after publication of UKCP09 suggests that Scotland's observed tidal record now lies close to the 95% probability of the UKCP09 High Emission Scenario. In the situation of modelling tide locking of drainage outlets in Glasgow, and taking into consideration of the latest published research, the 50% probability High emissions scenario data should be used in place of the 50% probability Medium scenario to test sensitivity of sea level rise projections from this dataset as this is regarded as a more realistic representation of current sea level in Scotland.

## 1.2 Adaptation Approaches

The two accepted methods of dealing with climate change are to reduce greenhouse gas emissions – ***mitigation*** of the impact – and to adapt our society, economy and environment to cope with inevitable climate change impacts – ***adaptation***. Scottish Government policy is focused primarily on adaptation and how to manage the impacts of climate change on drainage in a sustainable and effective way. However, solutions to managing the future climate impacts should also consider greenhouse gas emissions (principally carbon dioxide) and how these can be reduced within solutions proposed – tackling the problem from both ends.

Two adaptation approaches were described in the Defra 2006 guidance. A limited review of available information from Scottish Government and SEPA published material does not explicitly make reference to these forms of adaptation. Scottish adaptation policy is described within Scotland's Climate Change Adaptation Framework, published 08/12/2009 (details in references section at the end of this note). The two Defra adaptation approaches in the Defra 2006 guidance are summarised as follows:

***Managed Adaptive*** – A managed approach allows for adaptation in the future, and is wholly appropriate in the majority of cases where ongoing responsibility can be assigned to tracking the change in risk, and managing this through multiple 'phased' interventions. This approach provides flexibility to manage future uncertainties associated with climate change, during the whole life of a flood risk management system. To consider a precautionary approach only, could lead to greater levels of investment at fewer locations. A managed approach is therefore important to ensure best value for money from public and/or private investment, offering the potential for maximum customer benefits over time within inevitable financial constraints (e.g. across Glasgow or Scotland as a whole).

***Precautionary*** – For some circumstances, future adaptation may be technically infeasible or too complex to administer over the long term (e.g. the design life of a flood risk management solution). Hence, this approach, resulting primarily in one-off interventions such as in the design capacity of a major culvert or in the span of a road bridge across a flood plain, may be the only feasible option.

Before these adaptation options can be employed, however, the potential quantities of likely change in key climate variables need to be understood. The proposed approach to manage climate change impacts on the variables of rainfall, sea level and temperature is to use information from both UKCP09 and the Defra 2006 guidance (the latter for peak rainfall change) to obtain quantities of possible change in these different variables. Because these projected amounts of climate change are subject to considerable uncertainty, the quantitative estimates should, wherever possible, be incorporated through the managed adaptive approach (described above). The reasons for this are as follows:

- i managed adaptive approaches are much less costly – you can adapt to a lower quantity of change over a short term and review at pre-set, periodic time intervals;
- ii managed adaptive approaches enable risk to be monitored and managed at periodic intervals within the design life of a development, e.g. 5-yearly;
- iii managed adaptive approaches are usually more sustainable over the long term, facilitating opportunities for environmental enhancement, societal benefits and cost savings that cannot be achieved through precautionary approach solutions.
- iv managed approaches won't close the door on innovative advances over time and allow for flexibility to cope with future climate change projections that may differ from those available to us today.

## 2.0 Technical Guidance for Users

### 2.1 Climate change variables & impact

This technical guidance section provides information for those requiring climate change parameters for use in modelling or other planning activities undertaken as part of MGSDP. The note provides guidance in the following variables impact areas that will influence the overall drainage strategy for Glasgow:

| Variable | Impact Area | Information Source (see Section 2 for detail) |
|---|---|---|
| Rainfall depth for design storms (future uplift) | Flooding / flood risk management | Defra 2006 guidance |
| Sea level rise | Tide locking of outfalls leading to increases in flood risk and/or impact on overflow performance | UKCP09 |
| Peak river flows | Flooding of urban areas within flood plain; inhibiting drainage outflows into urban watercourses during periods of high fluvial flow | Defra 2006 guidance (N.B. New Regionalised Flood Flow estimates are currently being developed by SEPA – though no agreed data are available yet for design purposes – details in Section 2.2.3) |
| Time series rainfall for pollution modelling | Reduced summer flows in receiving watercourses and change in the frequency and volume of combined sewer overflow discharges. | UKCP09 / Weather Generator |
| Temperature (pollution modelling) | Water quality | UKCP09 |

### 2.2 Appropriate source of climate change quantity estimates

#### 2.2.1 Rainfall depth for design storms (future uplift)

For design storms used for urban drainage modelling, the recommended sensitivity allowances are those provided in the Defra 2006 guidance. The relevant part of this table is reproduced below in Table 2.1.

Table 2.1 – Defra 2006 Design Rainfall Uplift Ranges

**Table 2: Indicative Sensitivity Ranges**

| *Parameter* | *1990-2025* | *2025-2055* | *2055-2085* | *2085-2115* |
|---|---|---|---|---|
| Peak rainfall intensity (preferably for small catchments) | +5% | **+10%** | +20% | +30% |

Users should remember that the values are <u>sensitivity ranges</u> that are designed to test whether systems are sensitive to these quantities of change – **they are not absolute predictions of change** These should be used in modelling and calculations as follows below:

i for managed adaptive approach solutions (described in the Strategic Overview section of this note), the values of +5% to +30% can be used for the time horizons for which they apply. For example, if a SuD scheme has a design life of 100 years, but has been designed to be capable of enlargement (i.e. sufficient land has been secured to enable this), it could be designed with a 5% increase in peak flow up to a review period of, say, 10 years (such a decision would be likely made on the basis of whole life cost or cost benefit analysis). At the end of this review period, the design of the scheme could be revisited to take into account the latest guidance based on up to date climate modelling science and, if necessary, the scheme adapted to manage increased design storm depths for the same, or a different, level of service as the original design.

ii for precautionary approach solutions (described in the Strategic Overview section of this note), the recommended allowance for climate change uplift on design storms would need to use the appropriate figure from Table 2 of the Defra 2006 guidance depending on the design life of the solution.

Guidance on the application of managed adaptive and precautionary approaches are provided in Section 3 of this note.

Recommended design storm uplifts for surface water flooding analyses in urban areas makes use of the values in the Defra 2006 guidance rather than using information from UKCP09 and the Weather Generator. The reasons for this are twofold:

i the Weather Generator and UKCP09 do not provide explicit resolution of convective rainfall cells that are largely responsible for surface water flood events in urban areas (more information on this topic is given within the box in Figure 2.1 below);

ii the Defra 2006 guidance has not been superseded by more recent guidance (based on UKCP09 or research subsequent to 2006) and therefore provides the most up-to-date UK Government position on climate change allowances for flood risk management purposes. (This may not be the case for the sea level rise – see Section 2.2).

**Figure 2.1 - The issue of convective rainfall for future climate flood risk in urban areas**

The main type of rainfall resulting in urban surface water flooding events is convective – a type of rainfall caused by the vertical movement of an ascending mass of air that is warmer than its environment. Convective rainfall is generally of higher intensity than other rainfall types. Collier & Hand (2002) identified 50 extreme rainfall events in a UK-wide survey of the 20th century, of which 30 were convective storms; they also note that they all occur in the summer months (June, July & August). UKCP09 does not quantify changes in convective, localised and intense rainfall events. The general message of drier, hotter summers coming from UKCP09 relates predominantly to the frequency of large scale (frontal) rainfall events that occur at a spatial scale that climate models can simulate quite realistically. While an allowance for convection is made within the Hadley Centre Regional Climate Models, sub-grid scale processes, such as individual convective rainfall events, are not simulated and hence the drier summer general message may mask any increased risk from this highly damaging rainfall type (Dale, 2005). For this reason a recent study for Defra[1] identified the uncertainty in quantitative estimates of future convective rainfall events as the most important limitation of UKCP09 output for flood risk management in the UK, particularly in urban environments and small fluvial catchments in which convective rainfall dominates the flood response.

[1] Alternative approaches for the use of UKCP09 in Flood and Coastal Erosion Risk Management, FL0110, study undertaken for Defra by Halcrow Group Ltd., May 2010

### 2.2.2 Sea Level Rise

Sea level rise allowances are also provided in the Defra 2006 guidance, as reproduced below in Table 2.2. These provide allowances that are in the form of exponential increases in sea level over time. The allowances for net sea level rise for Scotland from this guidance are between 2.5 and 13mm per year, depending on the time horizon.

Table 2.2 – Defra 2006 Regional Sea Level Rise Ranges

**Table 1: Regional net sea level rise allowances**

| *Administrative or Devolved Region* | *Assumed Vertical Land Movement (mm/yr)* | *Net Sea-Level Rise (mm/yr)* | | | | *Previous allowances* |
|---|---|---|---|---|---|---|
| | | *1990-2025* | *2025-2055* | *2055-2085* | *2085-2115* | |
| East of England, East Midlands, London, SE England (south of Flamborough Head) | -0.8 | 4.0 | 8.5 | 12.0 | 15.0 | 6mm/yr* constant |
| South West and Wales | -0.5 | 3.5 | 8.0 | 11.5 | 14.5 | 5 mm/yr* constant |
| NW England, NE England, Scotland (north of Flamborough Head) | +0.8 | 2.5 | 7.0 | 10.0 | 13.0 | 4 mm/yr* constant |

*Updated figures now reflect an exponential curve, and replaces the previous straight line graph representations.

However, the Defra 2006 guidance allowances are based on research prior to 2006. SEPA's current position[2] is that UKCIP09 projections should be applied for future levels. The relevant allowances for Glasgow and the Clyde estuary are available from the UKCP09 user interface, for different emission scenarios and different probability distributions. As an indication, the projected increases in relative sea level rise (accounting for land movements) can be shown in the image below, taken from the UKCP09 Marine Report. This indicates that estimates of change for Glasgow (similar to that of Belfast in the image below) will be between approximately 5 and 60cm, depending on the emission scenario and the probability percentile used. The exact values are available in the UKCP09 datasets.

**Post UKCP09 Research**

Recent published research (Rennie and Hansom, 2010) suggests that Scotland's observed tidal record now lies close to the 95% projection of the UKCP09 High Emission Scenario and isostatic uplift now contributes little towards mitigating the effect of relative sea level rise on the Scottish coast[3]. If the observed recent patterns in sea level rise are maintained, Rennie and Hanson assert that this

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[2] Information provided by SEPA on 1/3/2011. SEPA indicate that output will become available from an on-going project: now re-named Coastal flood boundary conditions for UK mainland and islands. Project SC060064 as part of the DEFRA Flood and coastal erosion flood risk management research and development programme. It is essentially a replacement for POL 112 method and associated technical guidance for sea level calculation around UK coastline considering new and updated datasets. The finalised reports are now available on the Environment Agency web-site but the finalised dataset for Scotland has not yet been released.

[3] The Rennie and Hansom paper indicates that "A widely held belief persists that rising land levels since the latter part of the last glaciation will help safeguard much of the Scottish coast from the impact of global sea level rise. Although the landforms of much of Scotland's coast reflect long-term land uplift, recent investigations show that uplift rates are now modest and are less than rising sea levels."

finding has significant implications for strategic planning, flood risk management and sustainable development on Scotland's coast, and particularly on low-lying coastal zones around the major cities.

Having a range of possible values, rather than single sea level rise allowances, presents practitioners with a choice of which values to use for modelling and design purposes. The probabilistic output from UKCP09 provides an indication of likelihood of possible change quantities and can be applied within a risk based framework. In broad terms, this would mean that if the consequence (or impact) of the sea level rise is very high, then practitioners would be wisest to apply the most precautionary estimates of sea level rise (high emissions scenario and low probability estimates). If the impact is more moderate, a medium emissions / central probability estimate might be appropriate.

In the situation of modelling tide locking of drainage outlets in Glasgow, and taking into consideration of the findings of Rennie and Hansom described above, the High emissions scenario data for the 50% probability level (central estimate) should be used in place of the Medium scenario to test sensitivity of sea level rise projections from this dataset as this is regarded as a more realistic representation of current sea level in Scotland.

In flooding investigations, the principal driver is rainfall; applying uplifts on design storms as discussed in Section 2.1 makes allowances for climate change. To also model a sea level rise estimate that is higher than the Central Estimate would result in a rarer situation – a lower joint probability. Hence, the central probability estimate (50%) from UKCP09 data is appropriate for this case. The UKCP09 change estimates for three time horizons for Glasgow are presented in Table 2.3. These have been extracted from the on-line UKCP09 database. The grid box selected from UKCP09 is 12594, as shown in Annex 3.

It would also be advisable to run simulations using a higher estimate as a sensitivity analysis: for example, $95^{th}$ percentile limit with Medium emissions scenario. The results of the sensitivity analysis should be noted and, if necessary, any increased risk would need to be managed appropriately.

Table 2.3 - UKCP09 sea level rise projections change for Glasgow High Emissions

| **UKCP09 sea level rise projections (m) change from 1990 for UKCP09 Grid Box 12594 (Glasgow)** | | |
|---|---|---|
| **Date** | **Probability level** | |
| | **50th percentile** | **95th percentile** |
| 2020 | 0.07 | 0.13 |
| 2050 | 0.17 | 0.31 |
| 2100 | 0.39 | 0.72 |

### 2.2.3 Peak River Flows

Peak river flows will have an impact on urban drainage, either through direct flooding of urban areas adjacent to rivers if defences are overtopped, or due to high river water levels preventing outflow of surface water drainage and/or combined sewer overflow outfalls.

The recommended sensitivity allowances are those provided in the Defra 2006 guidance. The relevant part of this table is reproduced below in Table 2.4.

Table 2.4 – Defra 2006 indicative sensitivity ranges for peak river flow due to climate change

**Table 2: Indicative Sensitivity Ranges**

| ***Parameter*** | ***1990-2025*** | ***2025-2055*** | ***2055-2085*** | ***2085-2115*** |
|---|---|---|---|---|
| Peak rainfall intensity (preferably for small catchments) | *+5%* | **+10%** | *+20%* | *+30%* |
| Peak river flow volume (preferably for larger catchments) | +10% | **+20%** | | |
| Offshore wind speed | *+5%* | | **+10%** | *+10%* |
| Extreme wave height | *+5%* | | **+10%** | *+10%* |

**Updating Defra 2006 allowances for Scotland**

SEPA are currently participating in a project with CEH to update the peak flow information provided by Defra in the 2006 report. The revised approach will follow the methodology that has been used and approved by the EA and DEFRA, but is now being adapted and applied to Scottish catchments to fulfil one of the requirements of the FRM Act. This work is nearing completion, with an expected delivery date of 31st March 2011.

Until information from this project is completed and guidance in its use is available, the use of the Defra 2006 indicative sensitivity ranges for peak river flow will be applied. As for peak rainfall estimates, users should remember that the values are sensitivity ranges that are designed to test whether systems are sensitive to these quantities of change – **they are not absolute predictions of change.**

In applying the values in Table 2.4 for design or planning purposes, users are recommended to apply a rainfall allowance in the way described in Section 2.2.1 and to apply peak flow increases of between 0 and 20% in the receiving river(s) to assess sensitivity to these peak flow increases on flood risk. If, for example, the increase in peak flow of 20% has no impact on the discharge capacity of the drainage system (there is no additional backing up of surface water), the system can be regarded as insensitive to climate change impact on the receiving river. If flood risk is increased due to the discharge capacity of the drainage system being influenced by the increases in peak flow, a suitable allowance for peak flow increase due to climate change should be applied. However, as the design rainfall event applied to the urban area may not result in a fluvial flow peak of the same return period (the two environments are likely to respond differently to the same rainfall), users should be aware that applying a peak rainfall uplift of, say, 20% and a peak flow uplift of, say 20%, in the receiving river would be regarded as a precautionary estimate of flood risk.

### 2.2.4 Time series rainfall for pollution modelling

In this case time series rainfall data are needed to simulate future flows and water quality in receiving watercourses resulting from discharges of final effluent and combined sewer overflows. The area of concern is low flow periods in receiving watercourses as the pollutant impact is highest when river flows are lowest and dilution is reduced. Hence, time series rainfall is required for use in hydrological models to provide an indication of seasonal change in recipient watercourse catchment flow regimes in the future. For this purpose, we would recommend that the rainfall data available from the UKCP09 Weather Generator would be appropriate. While the Weather Generator may not provide estimates of future convective rainfall intensity (for the reasons given in Figure 2.1 above), the data are indicative of projected trends in seasonal rainfall affecting flow regimes in receiving river catchments. With the general trend of drier, hotter summers and wetter winters in Scotland being reflected in the Weather Generator time series data, we would expect the impact of low flows (both in terms of severity and temporal extent) to be greater in the future: i.e. longer periods of low flow through summer months and into the autumn and lower low flows (e.g. lower Q95 values) than in the current climate flow regime.

The issue of ‘first flush’ pollutants from summer convective rainfall events will be identified with the use of the ‘future climate’ rainfall, time series. While the predicted changes in the timing of such events (i.e. frequency and inter-event dry periods) is not something predicted by climate models currently, the use of the same rainfall series within the hydrological models to generate watercourse flows will simulate the impact of the projected lower baseflows in summer.

### 2.2.5 Temperature (pollution modelling)

Future temperature estimates for Glasgow can be estimated on a seasonal basis from UKCP09 output. For an indication of future daily temperature patterns, daily time series data from the Weather Generator can be extracted. As for sea level rise, there is a range of temperature predictions, depending on emission scenario used and which part of the probability distribution data are extracted from. Figure 2.3 below (Figure 9 in the UKCP09 Briefing Report) indicates that temperature rise is projected to be approximately 1 to 5 degrees for western Scotland in the 2080s under the Medium emissions scenario, both in the summer and winter seasons. It should be remembered that these are seasonal average temperature change; ‘hottest day’ changes are likely to be higher than these average estimates.

For assessing impact of temperature increase on water quality it would be advisable to first assess what temperature *thresholds* exist that impact on water quality. Such thresholds can then be assessed against the future projections to assess sensitivity to change. For example, if a threshold mean summer (June, July & August) water temperature rise of 5 degrees was identified (i.e. 5 degrees of warming on average over a season would be needed to have an impact on water quality) then the relative likelihood of such a change could be assessed. If a mean summer water temperature change of 5 degrees is found to be relatively rare (i.e. a 5% probability of occurrence under a Medium emissions scenario) an appropriate way to manage that impact would be needed. If it were found that the threshold was lower, say 2 degrees, the likelihood of that change would be significantly higher and managing that impact would need to take this increased likelihood into account.

Time horizons will also affect risk management decisions. An indication of projections of change for the 2080s is shown below – changes in temperature for shorter time horizons will be less. Users of the UKCP09 data would need to be careful to use data for the appropriate time horizon.

Tabulated in Table 2.5 are projections of mean summer air temperature change (at 1.5m elevation) in degrees centigrade for the UKCP09 grid box 764 (the Clyde). The rows highlighted in yellow show the projected mean annual air temperature changes for different time horizons in the 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile probability levels. For the purposes of this analysis, we would recommend the use of the central probability estimate (50% probability level).

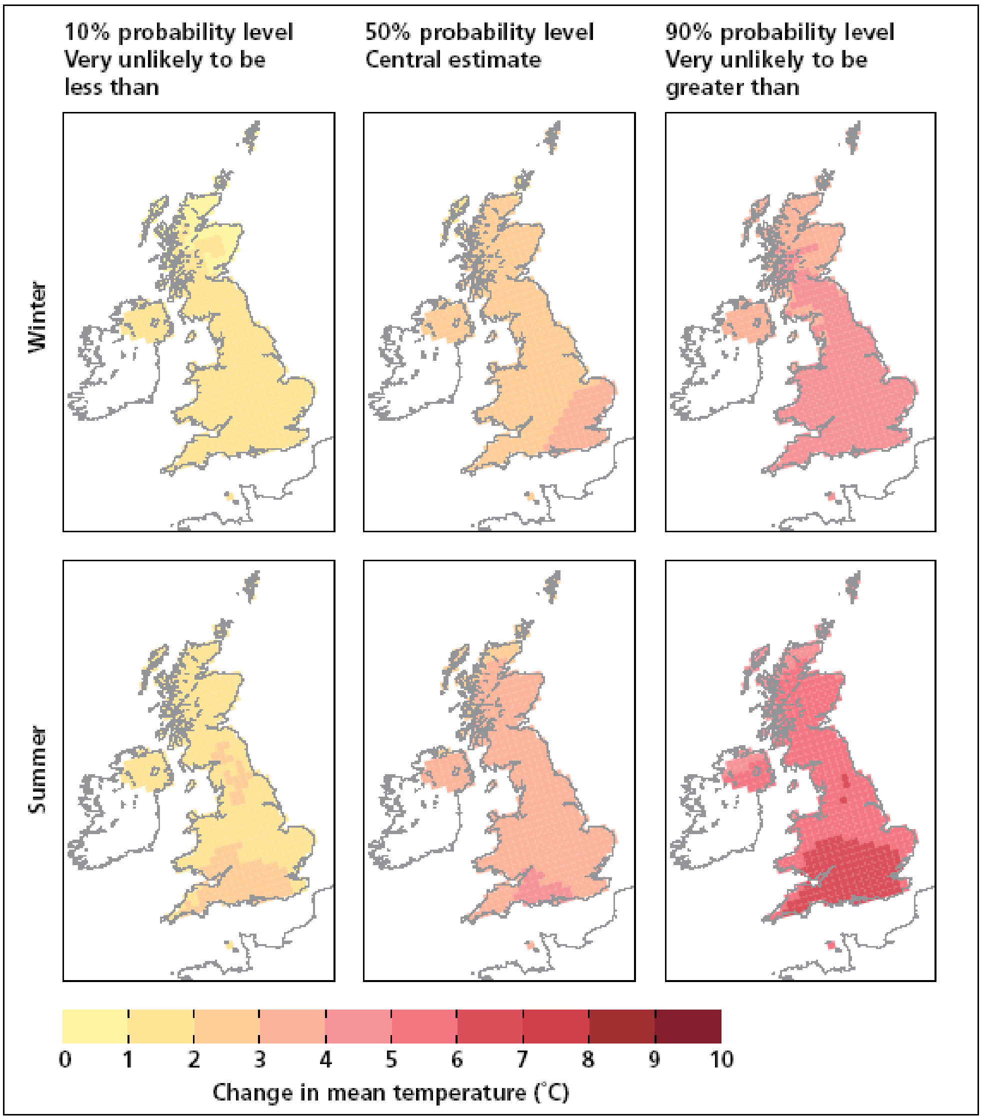
To convert the mean summer air temperatures to water temperature we would recommend applying a factor of 0.8 to the air temperature projections to derive estimated water temperature change. This is consistent with findings in literature (Morrill et al, 2001 and Web & Walling, 1992).

Figure extracted from UKCP09 Briefing Report – indicating 10, 50 and 90% probability levels of changes to the average daily mean temperature (ºC) of the winter (upper) and summer (lower) by the 2080s, under the Medium emissions scenario.

| Additional UKCP09 information 22 | cumulative distribution function | Mean air temperature at 1.5m for 2010_2039 (degC) | Mean air temperature at 1.5m for 2020_2049 (degC) | Mean air temperature at 1.5m for 2030_2059 (degC) | Mean air temperature at 1.5m for 2040_2069 (degC) | Mean air temperature at 1.5m for 2050_2079 (degC) | Mean air temperature at 1.5m for 2060_2089 (degC) | Mean air temperature at 1.5m for 2070_2099 (degC) |
|---|---|---|---|---|---|---|---|---|
| Data section | 5 | 0.344 | 0.483 | 0.617 | 0.855 | 1.02 | 1.279 | 1.49 |
| Data section | 50 | 1.468 | 1.833 | 2.14 | 2.481 | 2.8 | 3.173 | 3.616 |
| Data section | 95 | 2.755 | 3.404 | 3.961 | 4.509 | 5.076 | 5.668 | 6.392 |

Table 2.5 – Projected change in mean summer (June, July, August) air temperature for the Clyde (UKCP09 grid box 764) for the Medium emission scenario. (Supporting UKCP09 data associated with this data are included in Annex 4). To convert to estimates of change in water temperature these values should be multiplied by a factor of 0.8.

Figure 2.3 – Estimate for Temperature Change from UKCP09



## 3.0 Guidance on Suggested Approaches

The following three examples illustrate two managed adaptive approach examples and one precautionary approach example. These are aimed to provide additional practical guidance for engineers or planners incorporating climate change allowance in designs and flood risk management solutions.

**A1. Managed adaptive approach – Management of surface water in urban area:**

- Use 10% increase in design storm uplift (applicable for time horizon 2025 – 2055) to estimate flood extents / overland flow of excess storm water through modelling
- Examine solutions to manage overland flow and improve below ground conveyance of storm water where possible
- Build into the solution a requirement for review of the climate change impact on a periodic basis (e.g. 10 year).
- Incorporate flexibility in any design solutions (e.g. the potential in the future to raise kerbs to route surface water, having designated sacrificial flood areas – e.g. parks, sports grounds – for potential future, unplanned increases).

**A2. Managed adaptive approach – SuDS scheme for new development:**

- Use 5% increase in design storm uplift (applicable for time horizon present day - 2025) on standard return period estimates of rainfall for modelling
- Design SuDS scheme to manage the storm water for usual return periods (e.g. 1 in 30 year) with 5% climate change uplift allowance.
- Incorporate flexibility in the design solutions (e.g. French drains with additional land set aside at edge for widening the drain in the future, additional land purchased for future surface storage area).
- Review the climate change allowance and design at set periodic intervals – e.g.every 10 years.

**B1. Precautionary Approach – necessary upgrade of below ground trunk sewer main:**

- One opportunity to incorporate a climate change allowance in the design. If feasible, using the 30% uplift on design storm would be appropriate for a design life to the end of the century.
- After examining the costs & feasibility of the above, examine any opportunities to employ a hybrid managed adaptive / precautionary approach – for example, allow for 20% uplift to design storm for sizing new trunk sewer, and increase the ability to manage and store the excess flood water in more sustainable above-ground solutions, such as routing surface water in highways or various source control measures like rain water harvesting, soakaways etc.

Engineers and planners using this note are also referred to the two appendices to this document. These give further information about the managed adaptive approach to flood risk management (Annex 1) and guidance on flood management in the Glasgow City Council Climate Change Strategy & Action Plan (Annex 2).

## 4.0 References

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# Annex A

**Illustration of managed adaptive approach**

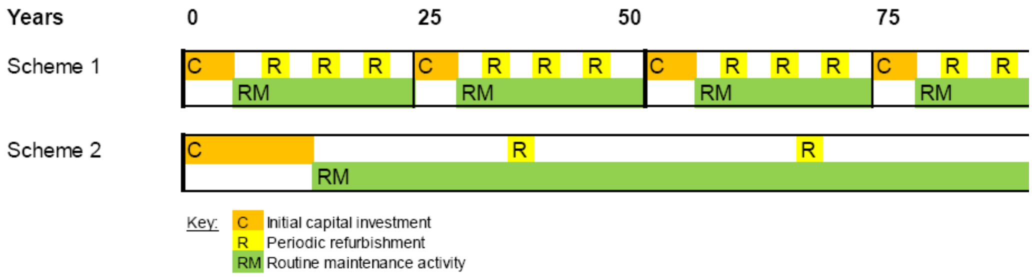
**extracted from: FUTURE FUNDING FOR FLOOD AND COASTAL EROSION RISK MANAGEMENT IN ENGLAND Draft Technical Guidance Issued for consultation by Defra, November 2010**

## Section E: Duration of benefits, and costs and benefits for the current investment

The previous set of household outcome measures did not take into account the expected useful life of defence assets being constructed, nor the duration of benefits being delivered. This has meant that schemes that provide protection for a short period of time have had the same access to funding as schemes that deliver similar benefits to households but for a much longer period of time.

To overcome this, the proposed system takes into account the duration of benefits being delivered by the investment seeking approval at this stage. Any future full replacement of assets (beyond maintenance and refurbishment) that may be required to maintain levels of protection would be ignored, as otherwise national budgets would be paying now for benefits that rely on future investment and approvals, and would end up paying for those benefits twice. It would also be unfair to expect local contributors to pay now for their share of future investment that may not be required for several decades.

The diagram below illustrates this using two schemes over a 100-year time period (the period often used for project appraisal). One involves a single, large, initial investment, and the other a series of smaller investments every 25 years, to maintain levels of protection over time. In both cases, the initial investment is supported by ongoing routine maintenance (RM) and refurbishments (R) which are necessary for the initial investment to reach its design life.




| *Scheme* | *Costs over appraisal period* | *Benefits over appraisal period* | *Appraisal period* | *Whole Life Costs for initial investment* | *Whole Life Benefits for current investment* | *Duration of benefits* |
|---|---|---|---|---|---|---|
| Scheme 1 | £5m | £80m | 100 years | £2m | £30m | 25 years |
| Scheme 2 | £5m | £80m | 100 years | £5m | £80m | 100 years |

For the purposes of the illustration, both schemes are assumed to have the same overall costs and benefits identified over the whole appraisal period; each based on a 100 year outlook. Whilst Scheme 1 will need less initial investment, levels of protection and benefits over the full 100 year period rely on additional investment (asset replacement) in years 25, 50 and 75. Therefore the funding approved at this stage for Scheme 1, and the whole-life costs and benefits recognised, should be those anticipated for the next 25 years, i.e. up to the point at which further investment is required. For Scheme 2, where a single investment is expected to deliver benefits for the full appraisal period, the whole-life costs and benefits will be as in the full appraisal, and the duration of those benefits will be 100 years. In both cases, the whole-life costs of the current investment should include all project development costs, plus any anticipated maintenance and refurbishment costs expected up to the point of the next major investment (defined as a full replacement of the initial asset), i.e. during the next 25 years for Scheme 1.

***Managed adaptive approaches to climate change adaptation***

A 'managed adaptive' scheme, involving a series of decision points through time, each potentially leading to investments to adapt a system to climate change, may be similar in character to Scheme 1 in the above example. However, at each decision point, the relevant period over which benefits and costs should be considered when determining an OM score is the whole life of the investment being considered, which is not necessarily the same as the time to the next adaptation decision.

For example, a defence constructed now with the option to raise its height in year 25 as a response to climate change, may have a design (economic, or whole) life of 50 years with ongoing maintenance. The relevant duration of benefits under this example would be 50, not 25 years. Any decision in or around year 25 would need to be made on the basis of the additional outcomes, costs and benefits expected at that stage in comparison with continuing with the defence at its original height.

# Annex B –

## Extract from Glasgow City Council Climate Change Strategy & Action Plan 2010 – 2015 (Published online in 2010)

# Water

### Objective

*To reduce water consumption in Glasgow City Council's premises and in the wider community, while improving water quality.*

*To improve flood prevention infrastructures, while encouraging people to be prepared for this risk.*

*To comply with the Flood Risk Management (Scotland) Act 2009.*

### Water and Climate Change

Water shortage is expected to become a growing problem in the future, for different reasons.

First, the distribution of precipitation in space and time is very uneven, leading to temporal variability in water resources worldwide (Oki et al, 2006). If all the freshwater on the planet were divided equally among the global population, there would be 5,000 to 6,000 m3 of water available for everyone, every year (Vorosmarty 2000).

Second, the rate of evaporation varies significantly, depending on temperature and relative humidity; this impacts the amount of water available to replenish groundwater supplies. The combination of shorter duration but more intense rainfall with increased evapotranspiration and increased irrigation is expected to lead to groundwater depletion (Konikow and Kendy 2005).

### Our Current Position

Water is a fundamental part of this Strategy as its quality and availability are likely to be affected by Climate Change through regular wetter winters and longer drier summers.

The Council is focusing on two different areas likely to be affected by changing climate patterns:

- Water efficiency and infrastructure
- Reducing the overall flood risk within the City

### Water Efficiency and Infrastructure

Even though no water shortages have yet been identified in Scotland, at a global level water is becoming a scarce resource in certain places, making its preservation everywhere all the more critical.

Water issues are also closely linked to other areas in this strategy. For instance, the provision and removal of water requires a significant amount of energy, it represents on average 2% of the overall energy consumption in the UK.

In City Plan 2, water supply infrastructure is now addressed separately from flood alleviation and sewerage. In terms of water infrastructure, the City Council aims to promote comprehensive coverage of all areas of Glasgow by a network, sufficient to meet the current and planned requirements of the City.

Reduction of Water consumption by the City Council, businesses and residents will help reduce the city's energy consumption and therefore its carbon footprint. Based on data from the Energy Efficiency Unit (EEU), in 2008/09, Glasgow City Council's services total water consumption equates to approximately 3.014 million litres per day.

Glasgow City Council acknowledges the need to minimise water use and increase water efficiency internally. To date, a series of actions have been undertaken and identified, they include:

- Meter rightsizing – meters are being downsized to realise financial savings
- Audits are underway in all sites and have identified opportunities for urinal controls, tap restrictors, etc
- Maintenance to be carried out on existing water controls
- Benchmarking to be carried out by Glasgow City's Water Supplier on site performance
- Investigating the opportunities for water harvesting and reuse

## Flood Alleviation

Glasgow City Council is working with key partners to reduce the impact of flooding. The responsibilities regarding flooding are varied, and at present a number of agencies have responsibility for dealing with its aspects in Glasgow. The Council is responsible for the drainage of public highways, reduction in overall flood risk, maintenance of watercourses, maintenance of flood prevention schemes and dealing with flooding caused by extreme rainfall, tidal and river flooding.

The complexity of flooding events within an urban environment requires a partnership approach. The development of Surface Water Management Plans for urban areas to reduce the impact of flooding is underway in Glasgow and is being carried out through the **Metropolitan Glasgow Strategic Drainage Plan**.

Glasgow City Council, Scottish Water, Scottish Government, SEPA and South Lanarkshire Council have been working together to tackle the issues of drainage and sewerage in the metropolitan Glasgow area since 2002, when the East End of the City suffered major flooding.

The work undertaken by the MGSDP has already led to informed and innovative decisions which ensure that the MGSDP plays its part in the success of the Clyde Gateway and the Commonwealth Games in Glasgow in 2014. This includes improved surface water management to prevent the waste water system from being overwhelmed by diverting into 'green corridors', flood plains or storage areas until a storm passes.

## Sustainable Urban Drainage Systems

The objectives of the Metropolitan Glasgow Strategic Drainage Plan (MGSDP) are: flood risk reduction, river water quality improvement, enabling economic growth, habitat improvements and integrated investment planning. Sustainable solutions for the management of surface water form an integral component of the MGSDP strategy and, as such, GCC has prepared Surface Water Management Plans (SWMPs) for a number of key development areas within the City, the first stage being the development of an Integrated Water Plan (IWP) in the Clyde Gateway Initiative area in the East End.

The development of IWPs, which include Sustainable Urban Drainage Systems (SUDS) techniques, allows development to proceed in areas where the combined sewerage and watercourse system is already at capacity serving as a drainage 'blueprint'. This ultimately promotes sustainable economic growth in the City.

In addition to providing a drainage solution for an area, by linking to other environmental strategies, the SWMPs will also present an opportunity for well designed schemes to provide additional environmental benefits for that area, these include:

- Wildlife and ecological benefits (e.g. through opportunities to reopen covered watercourses)
- Protection and enhancement of existing environmental designations
- Landscape improvement
- Improved public access (i.e. cycling, walking)
- Provision of greenspace and waterspace for local amenity benefit

## Our Future Plans

The City Council will progress actions across a number of fronts to achieve the objectives of this key theme, including:

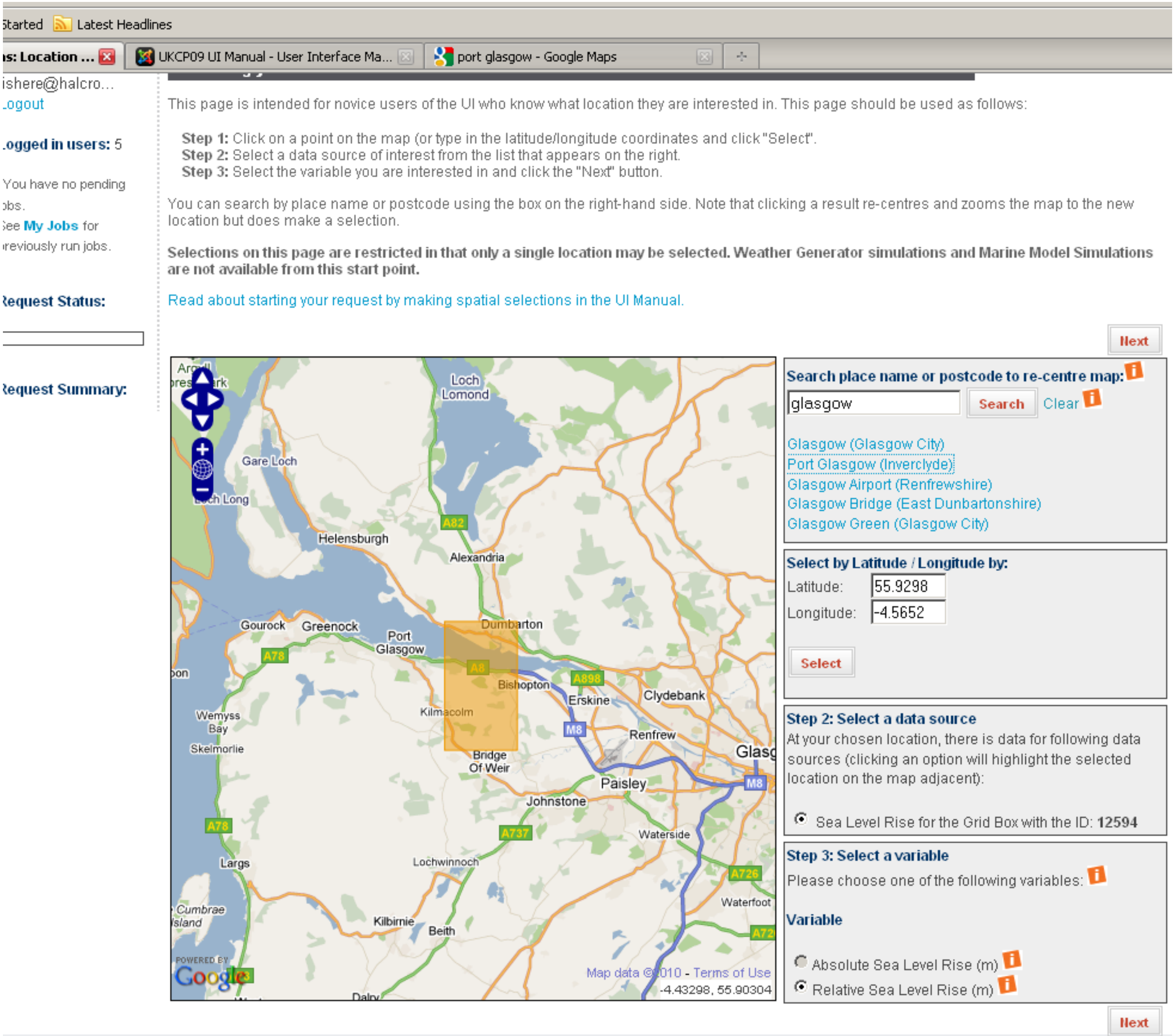
- Carry out audits on water consumption in Council properties and implement recommendations to reduce consumption
- Develop further Integrated Water Plans across the City
- Promote the linkage between drainage solutions and habitat improvements
- Complete the White Cart Water Flood Prevention Scheme
- Continue to work with our partners on the River Clyde Flood Strategy Commission to identify and develop an acceptable solution which will provide protection from inundation by the River Clyde in Glasgow
- Develop (preliminary) flood risk assessments for the City
- Develop flood risk and hazard maps for the city

## Key Theme 7: Water

| No. | Action | Mitigation/ Adaption | Crosscutting | GCC Role | Lead Service | Relevant Service/ Partner | Timescale |
|---|---|---|---|---|---|---|---|
| 7.1 | Establish a Climate Change Water Officers Group:<br>• Co-ordinate design advice on water efficiency, quality and conservation for new developments and retrofits<br>• Raise awareness of water efficiency to all relevant GCC staff<br>• Produce a management plan to set baselines and targets<br>• Highlight water conservation issues | Both | Education | Both | DRS | LES | January 2011 |
| 7.2 | Implement Surface Water Management Strategy:<br>• Development of Surface Water Management Plans for all drainage catchments of Metropolitan Glasgow<br>• Reduction of surface water run-off to drainage systems<br>• Creation of an effective drainage infrastructure across Glasgow<br>• Identify areas vulnerable to flooding during extreme events<br>• Identify suitable sites for SUDS | Adaptation | Cultural and Natural Heritage<br>Planning and Built Environment | Direct | DRS | | Ongoing |
| 7.3 | Carry out audits on water consumption in GCC properties and implement recommendations to reduce consumption | Mitigation | Energy | Direct | DRS | | Ongoing |
| 7.4 | Complete the White Cart Water Flood Prevention Scheme | Adaptation | Cultural and Natural Heritage<br>Planning and Built Environment | Direct | DRS | | Summer 2011 |
| 7.5 | Continue to work with our partners on the River Clyde Flood Strategy Commission to identify and develop flood protection measures | Adaptation | | Direct | LES | DRS | Ongoing |
| 7.6 | Establish a Water Efficiency Award Scheme for GCC Services | Both | Education<br>Behaviour Change | Direct | DRS | LES | March 2011 |
| 7.7 | Promote grey water recycling and rainwater harvesting | Both | Planning and Built Environment | Both | DRS | | Ongoing |
| 7.8 | Development of preliminary flood risk assessment of the City | Adaptation | Cultural and Natural Heritage<br>Planning and Built Environment | Both | DRS | LES | December 2011 |
| 7.9 | Development of flood risk and hazard maps for the City | Adaptation | Cultural and Natural Heritage<br>Planning and Built Environment | Both | DRS | LES | December 2013 |

# Annex C

## Image showing grid cell selected for Glasgow from UKCP09 (12594)


Latest Headlines
UKCP09 UI Manual - User Interface Ma...
port glasgow - Google Maps
Logged in users: 5
You have no pending jobs.
See My Jobs for previously run jobs.
Request Status:
Request Summary:
This page is intended for novice users of the UI who know what location they are interested in. This page should be used as follows:
Step 1: Click on a point on the map (or type in the latitude/longitude coordinates and click "Select".
Step 2: Select a data source of interest from the list that appears on the right.
Step 3: Select the variable you are interested in and click the "Next" button.
You can search by place name or postcode using the box on the right-hand side. Note that clicking a result re-centres and zooms the map to the new location but does make a selection.
Selections on this page are restricted in that only a single location may be selected. Weather Generator simulations and Marine Model Simulations are not available from this start point.
Read about starting your request by making spatial selections in the UI Manual.
Next
Search place name or postcode to re-centre map:
glasgow
Search
Clear
Glasgow (Glasgow City)
Port Glasgow (Inverclyde)
Glasgow Airport (Renfrewshire)
Glasgow Bridge (East Dunbartonshire)
Glasgow Green (Glasgow City)
Select by Latitude / Longitude by:
Latitude: 55.9298
Longitude: -4.5652
Select
Step 2: Select a data source
At your chosen location, there is data for following data sources (clicking an option will highlight the selected location on the map adjacent):
Sea Level Rise for the Grid Box with the ID: 12594
Step 3: Select a variable
Please choose one of the following variables:
Variable
Absolute Sea Level Rise (m)
Relative Sea Level Rise (m)
Next
Loch Lomond
Gare Loch
Helensburgh
Alexandria
Dumbarton
Gourock
Greenock
Port Glasgow
Bishopton
Erskine
Clydebank
Kilmacolm
Renfrew
Wemyss Bay
Skelmorlie
Bridge Of Weir
Paisley
Johnstone
Waterside
Largs
Lochwinnoch
Kilbirnie
Beith
Waterfoot
Cumbrae Island
Map data ©2010 - Terms of Use
-4.43298, 55.90304

# Annex D

## UKCP09 supporting data associated with Table 2.4 (mean summer temperature change projections under Medium emissions scenario)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Number of header lines; UKCP09 CSV sub-format code | 109 | 1001 | | | | | |
| Name of data creator | MOHC; NCL; UEA; UKCIP; BADC | | | | | | |
| Institute of data creator | Met Office Hadley Centre; Newcastle University; University of East Anglia; Proudman Oceanographic Laboratory; UK Climate Impacts Programme; British Atmospheric Data Centre | | | | | | |
| Model name | UKCP09 Models | | | | | | |
| Project name | UKCP09 | | | | | | |
| File number; Total number of files | 1 | 1 | | | | | |
| Starting date of data (YYYY MM DD); File creation date (` | 999 999 999 | 2011 1 18 | | | | | |
| Interval between coordinate variable values (zero if not us | 0 | | | | | | |
| Name of coordinate variable (with units) | cumulative distribution function | | | | | | |
| Number of primary variables defined | 7 | | | | | | |
| Scale factors for each primary variable | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Missing values for each primary variable | -999.999 | -999.999 | -999.999 | -999.999 | -999.999 | -999.999 | -999.999 |
| Name of primary variable (with units) 1 | Mean air temperature at 1.5m for 2010_2039 (degC) | | | | | | |
| Name of primary variable (with units) 2 | Mean air temperature at 1.5m for 2020_2049 (degC) | | | | | | |
| Name of primary variable (with units) 3 | Mean air temperature at 1.5m for 2030_2059 (degC) | | | | | | |
| Name of primary variable (with units) 4 | Mean air temperature at 1.5m for 2040_2069 (degC) | | | | | | |
| Name of primary variable (with units) 5 | Mean air temperature at 1.5m for 2050_2079 (degC) | | | | | | |
| Name of primary variable (with units) 6 | Mean air temperature at 1.5m for 2060_2089 (degC) | | | | | | |
| Name of primary variable (with units) 7 | Mean air temperature at 1.5m for 2070_2099 (degC) | | | | | | |
| Number of lines defining UKCP09 Request Paremeters | 66 | | | | | | |
| Information about UKCP09 Request and Variables 1 | ==== Special Comments follow ==== | | | | | | |
| Information about UKCP09 Request and Variables 2 | === UKCP09 Request Parameters = Start === | | | | | | |
| Information about UKCP09 Request and Variables 3 | Dataset = prob_land | | | | | | |
| Information about UKCP09 Request and Variables 4 | ChangeOnly = True | | | | | | |
| Information about UKCP09 Request and Variables 5 | Variables = temp_dmean_tmean_abs | | | | | | |
| Information about UKCP09 Request and Variables 6 | EmissionsScenarios = a1b | | | | | | |
| Information about UKCP09 Request and Variables 7 | TimeSlices = ... | 2070-2099 | | | | | |
| Information about UKCP09 Request and Variables 8 | MeaningPeriod = jja | | | | | | |
| Information about UKCP09 Request and Variables 9 | LocationType = grid_box_25km | | | | | | |
| Information about UKCP09 Request and Variables 10 | Location = 764 | | | | | | |
| Information about UKCP09 Request and Variables 11 | ProbabilityDataType = cdf | | | | | | |
| Information about UKCP09 Request and Variables 12 | DataOutputFormat = csv | | | | | | |
| Information about UKCP09 Request and Variables 13 | === UKCP09 Request Parameters = End === | | | | | | |
| Information about UKCP09 Request and Variables 14 | === Additional Variable Attributes defined in the source file === | | | | | | |
| Information about UKCP09 Request and Variables 15 | == Variable attributes from source (NetCDF) file follow == | | | | | | |
| Information about UKCP09 Request and Variables 16 | Variable cdf_temp_dmean_tmean_abs_for_2010_2039: Mean air temperature at 1.5m for 2010_2039 (degC) | | | | | | |
| Information about UKCP09 Request and Variables 17 | base_units = K | | | | | | |
| Information about UKCP09 Request and Variables 18 | long_name = Mean air temperature at 1.5m for 2010_2039 | | | | | | |
| Information about UKCP09 Request and Variables 19 | grid_mapping = rotated_pole | | | | | | |
| Information about UKCP09 Request and Variables 20 | coordinates = lon lat | | | | | | |
| Information about UKCP09 Request and Variables 21 | cell_methods = time: mean within days time: mean within years time: mean over years | | | | | | |
| Information about UKCP09 Request and Variables 22 | units = degC | | | | | | |
| Information about UKCP09 Request and Variables 23 | Variable cdf_temp_dmean_tmean_abs_for_2020_2049: Mean air temperature at 1.5m for 2020_2049 (degC) | | | | | | |
| Information about UKCP09 Request and Variables 24 | base_units = K | | | | | | |
| Information about UKCP09 Request and Variables 25 | long_name = Mean air temperature at 1.5m for 2020_2049 | | | | | | |
| Information about UKCP09 Request and Variables 26 | grid_mapping = rotated_pole | | | | | | |
| Information about UKCP09 Request and Variables 27 | coordinates = lon lat | | | | | | |
| Information about UKCP09 Request and Variables 28 | cell_methods = time: mean within days time: mean within years time: mean over years | | | | | | |
| Information about UKCP09 Request and Variables 29 | units = degC | | | | | | |
| Information about UKCP09 Request and Variables 30 | Variable cdf_temp_dmean_tmean_abs_for_2030_2059: Mean air temperature at 1.5m for 2030_2059 (degC) | | | | | | |
| Information about UKCP09 Request and Variables 31 | base_units = K | | | | | | |
| Information about UKCP09 Request and Variables 32 | long_name = Mean air temperature at 1.5m for 2030_2059 | | | | | | |
| Information about UKCP09 Request and Variables 33 | grid_mapping = rotated_pole | | | | | | |
| Information about UKCP09 Request and Variables 34 | coordinates = lon lat | | | | | | |
| Information about UKCP09 Request and Variables 35 | cell_methods = time: mean within days time: mean within years time: mean over years | | | | | | |
| Information about UKCP09 Request and Variables 36 | units = degC | | | | | | |
| Information about UKCP09 Request and Variables 37 | Variable cdf_temp_dmean_tmean_abs_for_2040_2069: Mean air temperature at 1.5m for 2040_2069 (degC) | | | | | | |
| Information about UKCP09 Request and Variables 38 | base_units = K | | | | | | |
| Information about UKCP09 Request and Variables 39 | long_name = Mean air temperature at 1.5m for 2040_2069 | | | | | | |
| Information about UKCP09 Request and Variables 40 | grid_mapping = rotated_pole | | | | | | |
| Information about UKCP09 Request and Variables 41 | coordinates = lon lat | | | | | | |
| Information about UKCP09 Request and Variables 42 | cell_methods = time: mean within days time: mean within years time: mean over years | | | | | | |
| Information about UKCP09 Request and Variables 43 | units = degC | | | | | | |
| Information about UKCP09 Request and Variables 44 | Variable cdf_temp_dmean_tmean_abs_for_2050_2079: Mean air temperature at 1.5m for 2050_2079 (degC) | | | | | | |
| Information about UKCP09 Request and Variables 45 | base_units = K | | | | | | |
| Information about UKCP09 Request and Variables 46 | long_name = Mean air temperature at 1.5m for 2050_2079 | | | | | | |
| Information about UKCP09 Request and Variables 47 | grid_mapping = rotated_pole | | | | | | |
| Information about UKCP09 Request and Variables 48 | coordinates = lon lat | | | | | | |
| Information about UKCP09 Request and Variables 49 | cell_methods = time: mean within days time: mean within years time: mean over years | | | | | | |
| Information about UKCP09 Request and Variables 50 | units = degC | | | | | | |
| Information about UKCP09 Request and Variables 51 | Variable cdf_temp_dmean_tmean_abs_for_2060_2089: Mean air temperature at 1.5m for 2060_2089 (degC) | | | | | | |
| Information about UKCP09 Request and Variables 52 | base_units = K | | | | | | |
| Information about UKCP09 Request and Variables 53 | long_name = Mean air temperature at 1.5m for 2060_2089 | | | | | | |
| Information about UKCP09 Request and Variables 54 | grid_mapping = rotated_pole | | | | | | |
| Information about UKCP09 Request and Variables 55 | coordinates = lon lat | | | | | | |
| Information about UKCP09 Request and Variables 56 | cell_methods = time: mean within days time: mean within years time: mean over years | | | | | | |
| Information about UKCP09 Request and Variables 57 | units = degC | | | | | | |
| Information about UKCP09 Request and Variables 58 | Variable cdf_temp_dmean_tmean_abs_for_2070_2099: Mean air temperature at 1.5m for 2070_2099 (degC) | | | | | | |
| Information about UKCP09 Request and Variables 59 | base_units = K | | | | | | |
| Information about UKCP09 Request and Variables 60 | long_name = Mean air temperature at 1.5m for 2070_2099 | | | | | | |
| Information about UKCP09 Request and Variables 61 | grid_mapping = rotated_pole | | | | | | |
| Information about UKCP09 Request and Variables 62 | coordinates = lon lat | | | | | | |
| Information about UKCP09 Request and Variables 63 | cell_methods = time: mean within days time: mean within years time: mean over years | | | | | | |
| Information about UKCP09 Request and Variables 64 | units = degC | | | | | | |
| Information about UKCP09 Request and Variables 65 | == Variable attributes from source (NetCDF) file end == | | | | | | |
| Information about UKCP09 Request and Variables 66 | ==== Special Comments end ==== | | | | | | |

| | |
|---|---|
| Number of lines of additional UKCP09 information | 22 |
| Additional UKCP09 information 1 | Format_Details = This CSV format header is based on the NASA Ames data exchange format. |
| Additional UKCP09 information 2 | The UKCP09 format specification document is available at: |
| Additional UKCP09 information 3 | http://ukclimateprojections-ui.defra.gov.uk/ui/docs/formats/ukcp09_file_format_spec.pdf |
| Additional UKCP09 information 4 | Dataset = UK probabilistic projections of climate change over land |
| Additional UKCP09 information 5 | History = File generated on 2011-01-18 15:44:50 by UKCP09 User Interface (v1.0) |
| Additional UKCP09 information 6 | Licence_Details = All products generated by the UKCP09 User Interface are licensed under the Terms and Conditions at: |
| Additional UKCP09 information 7 | http://ukclimateprojections.defra.gov.uk/content/view/992 |
| Additional UKCP09 information 8 | The licence granted to the Licensee operates as a permission only and does not imply any obligation |
| Additional UKCP09 information 9 | or liability or a warranties or representations in relation to the accuracy of the Data |
| Additional UKCP09 information 10 | on the part of the Department and organisations responsible for producing UKCP09. |
| Additional UKCP09 information 11 | The Licensee acknowledges that the Department has made the Data available on the basis that they reflect |
| Additional UKCP09 information 12 | current scientific understanding and that the Licensee is aware of the uncertainty described in the accompanying reports |
| Additional UKCP09 information 13 | available on the UKCIP and Defra websites. |
| Additional UKCP09 information 14 | Location_Details = The grids and spatial averages used in UKCP09 are documented at: |
| Additional UKCP09 information 15 | http://ukclimateprojections-ui.defra.gov.uk/ui/docs/grids |
| Additional UKCP09 information 16 | The actual locations of grid box IDs are available on the grids pages. |
| Additional UKCP09 information 17 | References = Murphy; J.M.; B. B. B. Booth; M. Collins; G. R. Harris; D. M. H. Sexton and M. J. Webb; 2007: |
| Additional UKCP09 information 18 | A methodology for probabilistic predictions of regional climate change from perturbed physics ensembles. |
| Additional UKCP09 information 19 | Phil. Trans. R. Soc. A; 365; 1993-2028. |
| Additional UKCP09 information 20 | Source = Probabilistic climate prediction based on family of Met Office Hadley Centre climate models HadCM3 |
| Additional UKCP09 information 21 | HadRM3 and HadSM3; plus climate models from other climate centres contributing to IPCC AR4 and CFMIP. |

| Additional UKCP09 information 22 | cumulative distribution function | Mean air temperature at 1.5m for 2010_2039 (degC) | Mean air temperature at 1.5m for 2020_2049 (degC) | Mean air temperature at 1.5m for 2030_2059 (degC) | Mean air temperature at 1.5m for 2040_2069 (degC) | Mean air temperature at 1.5m for 2050_2079 (degC) | Mean air temperature at 1.5m for 2060_2089 (degC) | Mean air temperature at 1.5m for 2070_2099 (degC) |
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| Data section | 0.25 | -0.461 | -0.478 | -0.44 | -0.224 | -0.131 | 0.096 | 0.142 |
| Data section | 0.5 | -0.295 | -0.279 | -0.223 | -0.006 | 0.099 | 0.329 | 0.41 |
| Data section | 0.75 | -0.193 | -0.157 | -0.089 | 0.13 | 0.243 | 0.479 | 0.582 |
| Data section | 1 | -0.12 | -0.07 | 0.007 | 0.227 | 0.348 | 0.584 | 0.704 |
| Data section | 2 | 0.066 | 0.149 | 0.246 | 0.471 | 0.606 | 0.85 | 1.003 |
| Data section | 3 | 0.184 | 0.29 | 0.402 | 0.633 | 0.78 | 1.03 | 1.209 |
| Data section | 4 | 0.272 | 0.396 | 0.521 | 0.755 | 0.912 | 1.167 | 1.364 |
| Data section | 5 | 0.344 | 0.483 | 0.617 | 0.855 | 1.02 | 1.279 | 1.49 |
| Data section | 6 | 0.405 | 0.556 | 0.698 | 0.94 | 1.111 | 1.376 | 1.599 |
| Data section | 7 | 0.459 | 0.62 | 0.769 | 1.015 | 1.192 | 1.46 | 1.694 |
| Data section | 8 | 0.506 | 0.676 | 0.833 | 1.081 | 1.265 | 1.536 | 1.78 |
| Data section | 9 | 0.55 | 0.728 | 0.891 | 1.142 | 1.331 | 1.606 | 1.858 |
| Data section | 10 | 0.589 | 0.776 | 0.944 | 1.199 | 1.392 | 1.67 | 1.93 |
| Data section | 11 | 0.627 | 0.82 | 0.994 | 1.251 | 1.449 | 1.73 | 1.998 |
| Data section | 12 | 0.661 | 0.862 | 1.041 | 1.301 | 1.503 | 1.787 | 2.062 |
| Data section | 13 | 0.694 | 0.902 | 1.085 | 1.347 | 1.554 | 1.841 | 2.122 |
| Data section | 14 | 0.725 | 0.939 | 1.127 | 1.391 | 1.602 | 1.892 | 2.18 |
| Data section | 15 | 0.755 | 0.974 | 1.167 | 1.434 | 1.648 | 1.94 | 2.235 |
| Data section | 16 | 0.783 | 1.008 | 1.205 | 1.474 | 1.692 | 1.987 | 2.287 |
| Data section | 17 | 0.81 | 1.041 | 1.241 | 1.513 | 1.735 | 2.033 | 2.339 |
| Data section | 18 | 0.836 | 1.073 | 1.277 | 1.551 | 1.776 | 2.077 | 2.388 |
| Data section | 19 | 0.862 | 1.103 | 1.311 | 1.588 | 1.816 | 2.119 | 2.435 |
| Data section | 20 | 0.887 | 1.132 | 1.345 | 1.623 | 1.855 | 2.16 | 2.482 |
| Data section | 21 | 0.91 | 1.161 | 1.377 | 1.658 | 1.893 | 2.201 | 2.527 |
| Data section | 22 | 0.934 | 1.189 | 1.408 | 1.692 | 1.93 | 2.24 | 2.571 |
| Data section | 23 | 0.956 | 1.216 | 1.439 | 1.724 | 1.966 | 2.278 | 2.614 |
| Data section | 24 | 0.978 | 1.243 | 1.469 | 1.757 | 2.001 | 2.316 | 2.656 |
| Data section | 25 | 1 | 1.269 | 1.499 | 1.788 | 2.036 | 2.353 | 2.698 |
| Data section | 26 | 1.021 | 1.295 | 1.528 | 1.819 | 2.07 | 2.389 | 2.738 |
| Data section | 27 | 1.042 | 1.32 | 1.556 | 1.849 | 2.103 | 2.425 | 2.779 |
| Data section | 28 | 1.063 | 1.344 | 1.584 | 1.88 | 2.136 | 2.46 | 2.818 |
| Data section | 29 | 1.083 | 1.369 | 1.611 | 1.909 | 2.169 | 2.495 | 2.857 |
| Data section | 30 | 1.103 | 1.392 | 1.639 | 1.938 | 2.201 | 2.529 | 2.896 |
| Data section | 31 | 1.122 | 1.416 | 1.665 | 1.967 | 2.233 | 2.563 | 2.934 |
| Data section | 32 | 1.142 | 1.439 | 1.692 | 1.995 | 2.264 | 2.597 | 2.971 |
| Data section | 33 | 1.161 | 1.462 | 1.718 | 2.024 | 2.295 | 2.63 | 3.008 |
| Data section | 34 | 1.18 | 1.485 | 1.744 | 2.051 | 2.326 | 2.663 | 3.045 |
| Data section | 35 | 1.198 | 1.508 | 1.769 | 2.079 | 2.356 | 2.696 | 3.082 |
| Data section | 36 | 1.217 | 1.53 | 1.795 | 2.107 | 2.386 | 2.728 | 3.118 |
| Data section | 37 | 1.235 | 1.552 | 1.82 | 2.134 | 2.416 | 2.76 | 3.154 |
| Data section | 38 | 1.254 | 1.574 | 1.845 | 2.161 | 2.446 | 2.792 | 3.19 |
| Data section | 39 | 1.272 | 1.596 | 1.87 | 2.188 | 2.476 | 2.824 | 3.226 |
| Data section | 40 | 1.29 | 1.618 | 1.895 | 2.215 | 2.506 | 2.856 | 3.262 |
| Data section | 41 | 1.308 | 1.64 | 1.92 | 2.241 | 2.535 | 2.888 | 3.297 |
| Data section | 42 | 1.326 | 1.662 | 1.944 | 2.268 | 2.565 | 2.92 | 3.333 |
| Data section | 43 | 1.344 | 1.683 | 1.969 | 2.295 | 2.594 | 2.951 | 3.368 |
| Data section | 44 | 1.362 | 1.705 | 1.993 | 2.321 | 2.623 | 2.983 | 3.403 |
| Data section | 45 | 1.379 | 1.726 | 2.018 | 2.348 | 2.653 | 3.014 | 3.439 |
| Data section | 46 | 1.397 | 1.747 | 2.042 | 2.374 | 2.682 | 3.046 | 3.474 |
| Data section | 47 | 1.415 | 1.769 | 2.067 | 2.401 | 2.711 | 3.077 | 3.51 |
| Data section | 48 | 1.432 | 1.79 | 2.091 | 2.427 | 2.741 | 3.109 | 3.545 |

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|---|---|---|---|---|---|---|---|---|
| Data section | 47 | 1.415 | 1.769 | 2.067 | 2.401 | 2.711 | 3.077 | 3.51 |
| Data section | 48 | 1.432 | 1.79 | 2.091 | 2.427 | 2.741 | 3.109 | 3.545 |
| Data section | 49 | 1.45 | 1.812 | 2.115 | 2.454 | 2.77 | 3.141 | 3.58 |
| Data section | 50 | 1.468 | 1.833 | 2.14 | 2.481 | 2.8 | 3.173 | 3.616 |
| Data section | 51 | 1.486 | 1.855 | 2.165 | 2.507 | 2.829 | 3.205 | 3.652 |
| Data section | 52 | 1.504 | 1.876 | 2.189 | 2.534 | 2.859 | 3.237 | 3.688 |
| Data section | 53 | 1.521 | 1.898 | 2.214 | 2.561 | 2.889 | 3.269 | 3.724 |
| Data section | 54 | 1.539 | 1.92 | 2.239 | 2.588 | 2.919 | 3.302 | 3.76 |
| Data section | 55 | 1.558 | 1.942 | 2.264 | 2.616 | 2.949 | 3.334 | 3.797 |
| Data section | 56 | 1.576 | 1.964 | 2.289 | 2.643 | 2.98 | 3.367 | 3.833 |
| Data section | 57 | 1.594 | 1.986 | 2.314 | 2.671 | 3.01 | 3.4 | 3.871 |
| Data section | 58 | 1.612 | 2.008 | 2.34 | 2.699 | 3.041 | 3.434 | 3.908 |
| Data section | 59 | 1.631 | 2.03 | 2.366 | 2.727 | 3.073 | 3.467 | 3.946 |
| Data section | 60 | 1.65 | 2.053 | 2.392 | 2.755 | 3.104 | 3.501 | 3.984 |
| Data section | 61 | 1.668 | 2.076 | 2.418 | 2.784 | 3.136 | 3.536 | 4.022 |
| Data section | 62 | 1.687 | 2.099 | 2.444 | 2.813 | 3.168 | 3.571 | 4.061 |
| Data section | 63 | 1.707 | 2.122 | 2.471 | 2.842 | 3.201 | 3.606 | 4.101 |
| Data section | 64 | 1.726 | 2.146 | 2.498 | 2.872 | 3.234 | 3.642 | 4.141 |
| Data section | 65 | 1.746 | 2.17 | 2.526 | 2.902 | 3.267 | 3.678 | 4.182 |
| Data section | 66 | 1.766 | 2.194 | 2.554 | 2.933 | 3.302 | 3.716 | 4.223 |
| Data section | 67 | 1.786 | 2.219 | 2.582 | 2.964 | 3.336 | 3.753 | 4.265 |
| Data section | 68 | 1.807 | 2.244 | 2.611 | 2.995 | 3.371 | 3.791 | 4.308 |
| Data section | 69 | 1.828 | 2.269 | 2.64 | 3.028 | 3.407 | 3.83 | 4.351 |
| Data section | 70 | 1.849 | 2.295 | 2.67 | 3.061 | 3.444 | 3.87 | 4.396 |
| Data section | 71 | 1.87 | 2.322 | 2.7 | 3.094 | 3.481 | 3.911 | 4.441 |
| Data section | 72 | 1.893 | 2.348 | 2.731 | 3.128 | 3.52 | 3.952 | 4.487 |
| Data section | 73 | 1.915 | 2.376 | 2.763 | 3.163 | 3.558 | 3.995 | 4.535 |
| Data section | 74 | 1.938 | 2.404 | 2.795 | 3.199 | 3.598 | 4.038 | 4.583 |
| Data section | 75 | 1.962 | 2.433 | 2.828 | 3.236 | 3.64 | 4.083 | 4.633 |
| Data section | 76 | 1.986 | 2.462 | 2.862 | 3.273 | 3.682 | 4.13 | 4.684 |
| Data section | 77 | 2.011 | 2.492 | 2.898 | 3.312 | 3.725 | 4.177 | 4.737 |
| Data section | 78 | 2.036 | 2.524 | 2.933 | 3.353 | 3.77 | 4.226 | 4.792 |
| Data section | 79 | 2.063 | 2.556 | 2.971 | 3.394 | 3.817 | 4.277 | 4.849 |
| Data section | 80 | 2.09 | 2.589 | 3.009 | 3.437 | 3.865 | 4.329 | 4.907 |
| Data section | 81 | 2.118 | 2.624 | 3.049 | 3.481 | 3.914 | 4.384 | 4.968 |
| Data section | 82 | 2.148 | 2.659 | 3.091 | 3.528 | 3.966 | 4.441 | 5.031 |
| Data section | 83 | 2.178 | 2.697 | 3.134 | 3.576 | 4.021 | 4.501 | 5.097 |
| Data section | 84 | 2.21 | 2.736 | 3.179 | 3.627 | 4.078 | 4.563 | 5.167 |
| Data section | 85 | 2.244 | 2.777 | 3.227 | 3.68 | 4.138 | 4.629 | 5.24 |
| Data section | 86 | 2.279 | 2.82 | 3.277 | 3.736 | 4.201 | 4.698 | 5.317 |
| Data section | 87 | 2.316 | 2.865 | 3.33 | 3.796 | 4.268 | 4.772 | 5.399 |
| Data section | 88 | 2.355 | 2.913 | 3.386 | 3.859 | 4.339 | 4.851 | 5.486 |
| Data section | 89 | 2.398 | 2.965 | 3.447 | 3.927 | 4.416 | 4.935 | 5.58 |
| Data section | 90 | 2.443 | 3.021 | 3.512 | 4 | 4.499 | 5.027 | 5.682 |
| Data section | 91 | 2.492 | 3.081 | 3.583 | 4.081 | 4.59 | 5.127 | 5.793 |
| Data section | 92 | 2.546 | 3.148 | 3.66 | 4.169 | 4.69 | 5.238 | 5.916 |
| Data section | 93 | 2.607 | 3.222 | 3.748 | 4.267 | 4.802 | 5.362 | 6.053 |
| Data section | 94 | 2.675 | 3.306 | 3.846 | 4.379 | 4.928 | 5.504 | 6.21 |
| Data section | 95 | 2.755 | 3.404 | 3.961 | 4.509 | 5.076 | 5.668 | 6.392 |
| Data section | 96 | 2.85 | 3.521 | 4.099 | 4.666 | 5.254 | 5.866 | 6.611 |
| Data section | 97 | 2.971 | 3.671 | 4.275 | 4.866 | 5.48 | 6.116 | 6.889 |
| Data section | 98 | 3.137 | 3.878 | 4.524 | 5.155 | 5.81 | 6.482 | 7.296 |
| Data section | 99 | 3.398 | 4.196 | 4.894 | 5.573 | 6.276 | 6.99 | 7.85 |
| Data section | 99.25 | 3.508 | 4.336 | 5.067 | 5.782 | 6.525 | 7.279 | 8.176 |
| Data section | 99.5 | 3.667 | 4.54 | 5.319 | 6.086 | 6.881 | 7.687 | 8.621 |
| Data section | 99.75 | 3.929 | 4.869 | 5.72 | 6.561 | 7.43 | 8.308 | 9.225 |
| Data section | 99.9 | 4.239 | 5.253 | 6.176 | 7.09 | 8.026 | 8.961 | 9.733 |