CLIMATE CHANGE AND THE SCOTTISH ROADS NETWORK: UKCP09 UPDATE ON THE PROJECTED CHANGES TO CLIMATIC VARIABLES THAT AFFECT THE DESIGN, MANAGEMENT AND OPERATION OF THE ROAD NETWORK

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Abstract

The Scottish Executive (2005) published its “Scottish Road Network Climate Change Study” report which covered the possible impacts on the road network arising from predicted climate change and recommended adaptation actions. Since then new climate change projections have been released for the UK in the form of the UKCP09 Projections. This paper presents an updated view on how those climatic variables of key importance to the Scottish roads network are now projected to change during the 21st century. The work was undertaken for Transport Scotland as part of their Scottish Road Network Climate Change Study and was delivered during 2011.

1. INTRODUCTION

In 2009 the new UKCP09 climate change scenarios were released (Jenkins et al, 2010). These scenarios are designed to provide improved and more detailed descriptions of the likely climate that the UK will experience throughout the 21st century. As such they supersede the UKCIP02 projections. There was a need therefore to revise the current “Scottish Roads Network – Climate Change Study”, including its recommendations of adaptive strategies to minimise future impacts to the management of the Scottish roads, in light of this improved climate change understanding. This enables refined targeting of those issues that are likely to be of most importance in the future.

The provision of the UKCP09 projections was in a different format than earlier studies. Much more information regarding uncertainty was provided in the form of probability functions and access to much of the data is via a sophisticated Internet User Interface permitting impacts to be assessed at the local scale through to the regional and national scales. Some of the variables of particular importance and considered in the earlier study needed to be derived from basic raw output supplied by the User Interface.

2. APPROACH AND METHODS

This was an innovative and technically challenging project as much of the study was based on the numerical analysis of site specific UKCP09 model output. The work required close collaboration with the Transport Scotland team and the Jacobs Highways team to determine the exact variables required and appreciate the Client’s expectations. Combining the above and taking into consideration the time and budget limitations, the following approach was developed.

The UKCP09 projections for the more general variables such as mean annual/seasonal temperature or precipitation are downloadable as pre-prepared images from the UKCP09 website. However, many of the climatic variables of importance to this study have not been the subject of these pre-prepared graphics, therefore bespoke analyses of climate change time-series generated by the UKCP09 Weather Generator were undertaken. The Weather Generator tool creates synthetic time series of weather variables at 5 km resolution, which are consistent with the climate projections. It cannot provide regionally varying time-series.

The variables of particular interest to the design, management and operation of the Scottish road network and that could derived from the Weather Generator output are listed in Table 1. Other climatic variables of importance to the network include extreme wind speed, fog and snow but the UKCP09 projections do not provide guidance or data on these.

Variable	**Definition**
Frost days	Average annual number of days with min temperature below 0°C
Freeze Thaw	Average annual number of days when temperature fluctuates above 2°C and below -1°C
Winter duration	Road managers currently work to a winter period defined as 1 October to 15 May
Hot days	Average annual number of days with max temperature above i) 25°C and ii) 30°C
10-year rainfall	The extreme daily rainfall depth that has a return period of 1 in 10 years. (Equivalent to an annual occurrence probability of 0.1)
2-year rainfall	The extreme daily rainfall depth that has a return period of 1 in 2 years. (Equivalent to an annual occurrence probability of 0.5)
Soil moisture deficit	Average annual pattern of the development and replenishment of soil moisture deficit for a grass vegetation cover
Groundwater recharge	Average annual pattern of recharge periods. Determined as the period when the soil moisture deficit has been replenished above field capacity of the soil.

Table 1 - The climatic variables derived from the UKCP09 weather generator

Three locations (Glasgow, Aviemore and Dundee) were selected as being broadly representative of the climatic and geographic range across Scotland. For each site the Weather Generator was run for the future time horizon of interest. The generator output for each requested run comprises: 100 separate time-series simulations of 30 years of daily climatic data. (Each of the 100-year series is a plausible time series though each will be slightly different). This large amount of simulated data is provided both for the future time period requested and also for the baseline 1961-1990 period. For the three target sites a total of 18 sets of this data (6 for each location) were exported from the Weather Generator. Table 2 summaries the datasets used.

Location	Emission scenario		
	Low	Medium	High
Glasgow	2020s & 2080s	2020s & 2080s	2020s & 2080s
Aviemore	2020s & 2080s	2020s & 2080s	2020s & 2080s
Dundee	2020s & 2080s	2020s & 2080s	2020s & 2080s

Table 2 – Weather Generator datasets used in the analysis (note each future dataset also comes with its own baseline 1961-1990 data set)

Each of the 18 datasets has the equivalent of 3,000 years of daily data. This simulated data can be analysed as if it were actual observed data, but each of the 2 x 100 runs were kept separate. The results of the runs were plotted on frequency graphs and the spread of the graph used to indicate the uncertainty of the analysis. From this percentile estimates of the projected change could be calculated. For example the 50 percentile estimate is the median value of the 100 runs, whilst the 10 percentile would be the tenth value if all the results of the runs were ranked in ascending order. For a fuller description of how the probabilistic analysis was undertaken for each of the variables refer to Jacobs (2011).

Where possible observed data was also analysed to check the reliability of the baseline data produced by the Weather Generator. Greater confidence in the performance of the Weather Generator is gained if it can simulate the current climate accurately. Where this does not occur, the findings and conclusions need to be treated with caution. Therefore climate data for Paisley was obtained as a surrogate for Glasgow and the variables of interest calculated from this record for comparison. Similarly both the 10-year and 2-year extreme rainfall estimates for each of the 3 target sites were obtained from the Flood Estimation Handbook software and compared to those values derived from the Weather Generator.

3. PRESENTATION OF RESULTS

The projected changes to the various climate variables have been tabulated in the following sections in two ways:

1. Provision of the baseline and future 10%, 50% and 90%-tile values. This permits the magnitude of the particular climatic variable to be assessed in the appropriate units of measurement.

2. Provision of the projected change in the climatic variable compared to the baseline. This permits the magnitude of the change of the variable to be assessed. This is derived from multiple runs of the weather generator. The predicted changes can be used to create a probabilistic distribution of the change in that variable.

Although there will be reasonable consistency between these two sets of tables it is possible for slight "apparent" differences to occur. This is a function of the slightly different basis of the calculations and should not be interpreted as inconsistencies.

The tables presenting results from the weather generator analysis should be read in the context of figure 1

How to interpret the results tables:

Emission scenario	Glasgow
High 2080s	**+3.8** [+2.5 to +5.6]

Change in Annual Mean temperature compared to the 1961-1990 baseline period (in °C)

The main number represents the mid point of the probability range. There is a 50% chance the average temperature will be more than 3.8 °C hotter and a 50% chance that it will not have increased quite so much.

The figures in brackets show the range within which the actual change is likely to be. In this case, the projections suggest that it is unlikely the increase in summer average temperature will be less than 2.5 °C or greater than 5.6 °C. (These correspond to the 10 and 90 percentile values).

Figure 1 - How to interpret the results tables

4. RESULTS

4.1 Annual mean temperature

Emission scenario	Glasgow	Aviemore	Dundee
High 2080s	**+3.8** [+2.5 to +5.6]	**+3.5** [+2.2 to +5.2]	**+3.4** [+2.2 to +5.1]
Medium 2080s	**+3.1** [+2.0 to +4.6]	**+2.9** [+1.8 to +4.3]	**+2.8** [+1.7 to +4.3]
Low 2080s	**+2.5** [+1.5 to +3.8]	**+2.4** [+1.4 to +3.7]	**+2.4** [+1.4 to +3.6]

Table 3 - Change in annual mean temperature compared to the 1961-1990 baseline period for different emission scenarios (in °C).

4.2 Frost days

Emission scenario	Glasgow	Aviemore	Dundee
High 2080s	**-33** [-24 to -39]	**-74** [-46 to -101]	**-42** [-26 to -54]
Medium 2080s	**-31** [-19 to -38]	**-67** [-44 to -92]	**-38** [-19 to -49]
Low 2080s	**-30** [-23 to -37]	**-55** [-29 to -77]	**-30** [-20 to -40]

Table 4 - Reduction in the number of days per year of frost by the 2080s compared to the 1961-1990 baseline period for different emission scenarios (in days).

4.3 Freeze -Thaw

Site	Observed	Baseline 1961-1990			2080s Medium		
		10%	**50%**	90%	10%	**50%**	90%
Glasgow	38.1	35	**38**	70	3	**13**	25
Aviemore	(na)	98	**108**	206	35	**77**	117
Dundee	(na)	44	**51**	95	10	**22**	51

Table 5 - Number of freeze-thaw days per year derived from the UKCP09 Weather Generator for the baseline and 2080s periods.

4.4 Winter Duration

Figures 2 a) – c) indicate how the present allocated winter period (1 October to 15 May) is likely to reduce at each of the three example sites. For the 2080s medium scenario the predictions suggest a 45-day reduction to the winter period for both Glasgow and Aviemore. However for Dundee, the decrease is predicted to be a larger at 65 days.

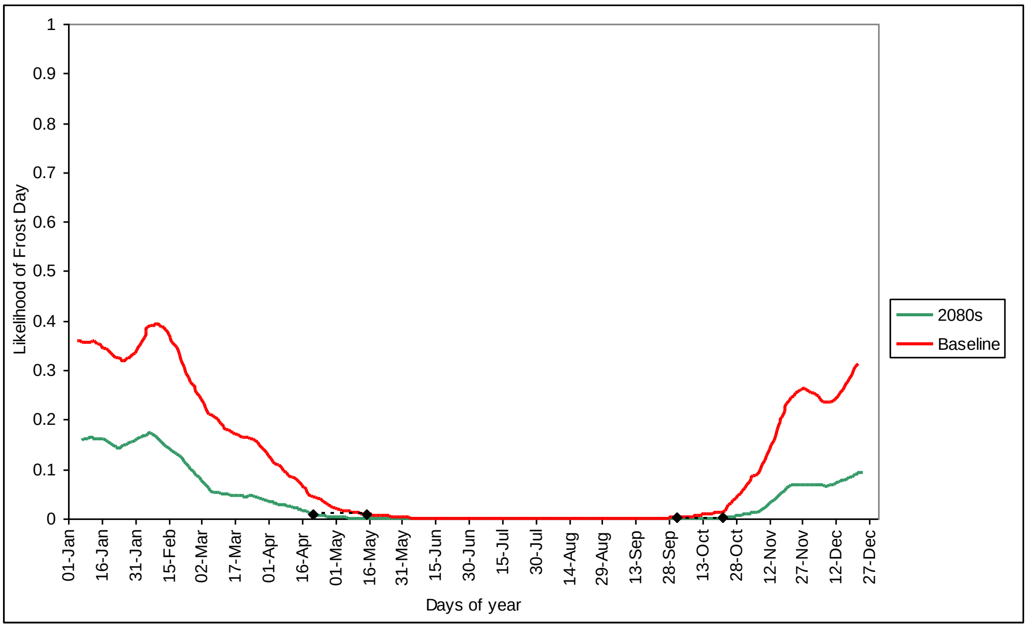

Figure 2 a) - Glasgow: projected change in the winter duration, 2080s medium emission scenario (change indicated by black dotted line).

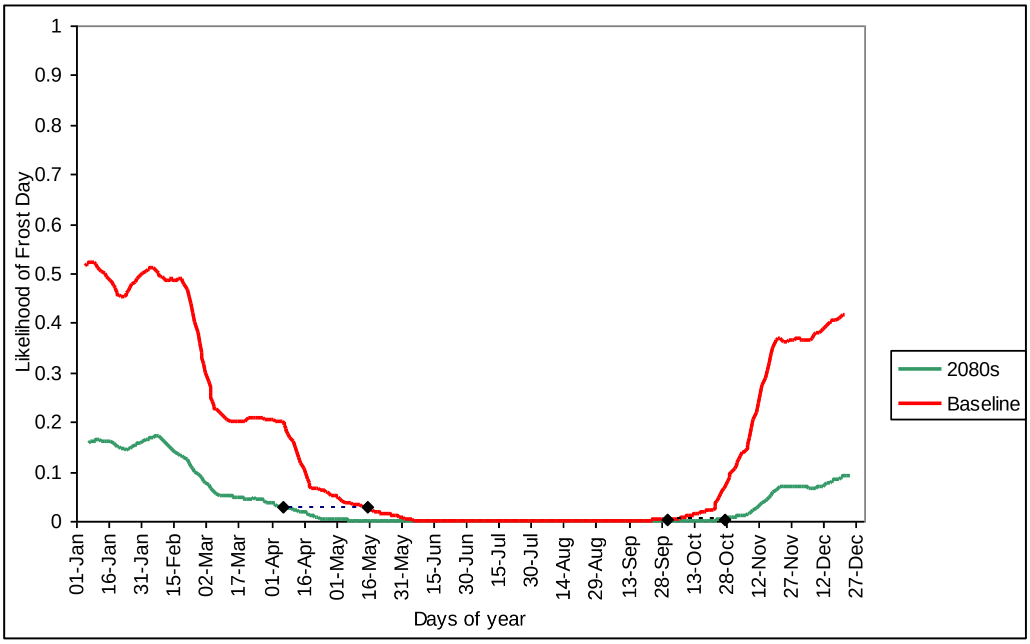

Figure 2 b) - Dundee: projected change in the winter duration, 2080s medium emission scenario (change indicated by black dotted line).

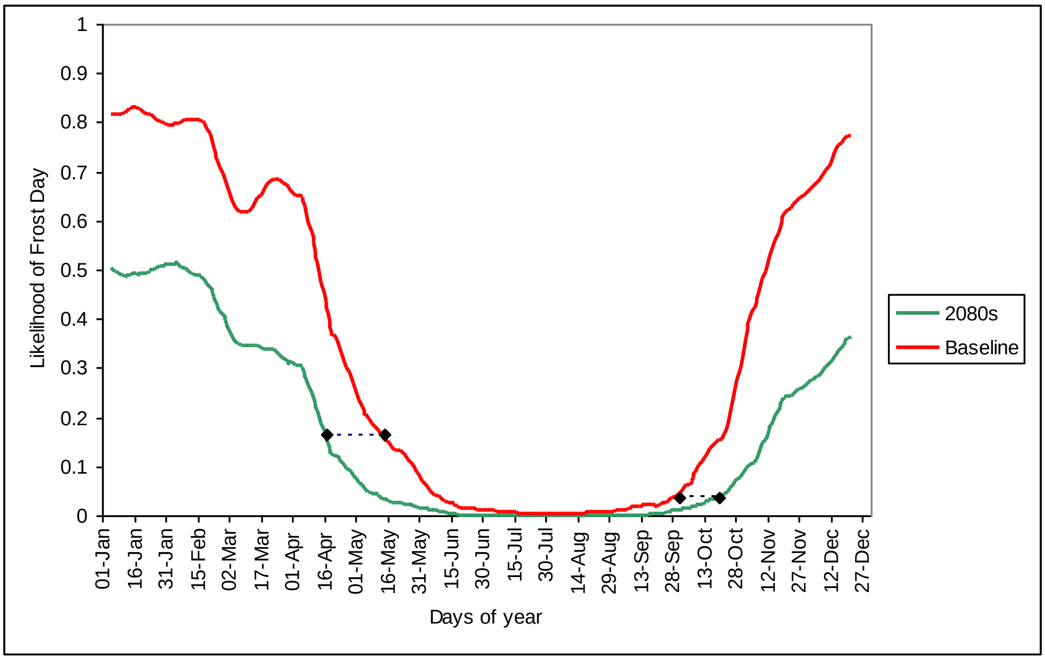

Figure 2 c) - Aviemore: projected change in the winter duration, 2080s medium emission scenario (change indicated by black dotted line).

4.5 Hot days

Site	Observed	Baseline 1961-1990			2080s Medium		
		10%	**50%**	90%	10%	**50%**	90%
Glasgow	4.5	0.9	**1.2**	1.5	6.2	**16.8**	38.9
Aviemore	(na)	0.0	**0.1**	0.2	1.5	**4.1**	20.8
Dundee	(na)	0.4	**0.6**	0.8	3.7	**14.4**	34.9

Table 6 - Number of days per year with maximum temperature greater than 25 °C derived from the UKCP09 Weather Generator for the baseline and 2080s periods.

Emission scenario	Glasgow	Aviemore	Dundee
High 2080s	**+20** [+8 to +60]	**+8** [+2 to +23]	**+24** [+6 to +56]
Medium 2080s	**+15** [+5 to +38]	**+4** [+1 to +21]	**+14** [+3 to +34]
Low 2080s	**+9** [+3 to +25]	**+3** [+0 to +10]	**+10** [+2 to +25]

Table 7 - Increase in the number of days per year with maximum temperature greater than 25 °C by the 2080s compared to the 1961-1990 baseline period for different emission scenarios (in days)

4.6 Annual Precipitation

Emission scenario	Glasgow	Aviemore	Dundee
High 2080s	**+0.6** [- 11.4 to +14.6]	**-1.2** [-6.4 to +3.8]	**+2.7** [-4.1 to +10.6]
Medium 2080s	**-0.4** [-9.0 to +9.3]	**-0.9** [-5.6 to +3.8]	**+1.4** [-4.9 to +8.5]
Low 2080s	**+0.5** [-7.6 to +9.5]	**+0.6** [-3.5 to +5.0]	**+2.6** [-2.2 to +8.0]

Table 8 - Change in annual mean precipitation compared to the 1961-1990 baseline period for different emission scenarios (in %).

Little change to average annual totals by the end of the century is predicted. This however masks the marked projected seasonal changes which suggest reasonably uniform winter increases of 10 to 20% and summer decreases of 20 to 30% across the majority of Scotland.

4.7 Extreme Storm Rainfall Depths

Tables 9 to 12 present the percentage changes likely to the 10-year and 2-year daily rainfall depths for the 2020s and 2080s time horizons for the different scenarios. Some regional difference is predicted with similar changes suggested for both Glasgow and Dundee whilst Aviemore is projected to be less affected. The range of the uncertainty is particularly large for this variable and the implications of this need to be recognised when adaptation measures are being considered.

Emission scenario	Glasgow	Aviemore	Dundee
High 2080s	**+36%** [+4% to +72%]	**+22%** [-1% to +75%]	**+39%** [+7% to +72%]
Medium 2080s	**+29%** [+2% to +61%]	**+20%** [-8% to +55%]	**+31%** [+1% to +70%]
Low 2080s	**+16%** [-3% to +47%]	**+13%** [-8% to +50%]	**+17%** [-5% to +55%]

Table 9 - Projected percentage change from the baseline condition to the 10-year return period daily rainfall depths for the 2080s for the range of emission scenarios at the three example sites across Scotland.

Emission scenario	Glasgow	Aviemore	Dundee
High 2080s	**+28%** [+12% to +49%]	**+16%** [+1% to +30%]	**+26%** [+11% to +44%]
Medium 2080s	**+21%** [+9% to +38%]	**+12%** [-2% to +23%]	**+19%** [+4% to +11%]
Low 2080s	**+11%** [-3% to +22%]	**+10%** [-7% to +24%]	**+15%** [+0% to +32%]

Table 10 – Projected percentage change from the baseline condition to the 2-year return period daily rainfall depths for the 2080s for the range of emission scenarios at the three example sites across Scotland.

Emission scenario	Glasgow	Aviemore	Dundee
High 2020s	**+15%** [-10% to +47%]	**+12%** [-6% to +44%]	**+19%** [-9% to +45%]
Medium 2020s	**+14%** [-5% to +38%]	**+9%** [-7% to +39%]	**+16%** [-18% to +44%]
Low 2020s	**+10%** [-10% to +47%]	**+11%** [-11% to +50%]	**+13%** [-12% to +50%]

Table 11 - Projected percentage change from the baseline condition to the 10-year return period daily rainfall depths for the 2020s for the range of emission scenarios at the three example sites across Scotland.

Emission scenario	Glasgow	Aviemore	Dundee
High 2020s	**+10%** [-2% to +13%]	**+8%** [-6% to +26%]	**+7%** [-5% to +26%]
Medium 2020s	**+8%** [-4% to +21%]	**+4%** [-5% to +20%]	**+5%** [-7% to +21%]
Low 2020s	**+9%** [-2% to +23%]	**+3%** [-10% to +21%]	**+5%** [-5% to +20%]

Table 12 – Projected percentage change from the baseline condition to the 2-year return period daily rainfall depths for the 2020s for the range of emission scenarios at the three example sites across Scotland.

Further analysis was undertaken to estimate the change in the frequency of the 2-year and the 10-year one day rainfall. The scenario used for this exercise was the 2080s medium emission scenario. The results are presented in Figures 3 for Glasgow, and similar results were also found for Dundee and Aviemore (though not presented). The return period on the x axis is drawn in logarithmic scale. The baseline (1961-1990) 10-year one day design rainfall magnitude is likely to be as frequent as a 5-year event by the 2080s. The baseline 2-year one day rainfall event is also likely to be more frequent, becoming approximately a 1.3 year event.

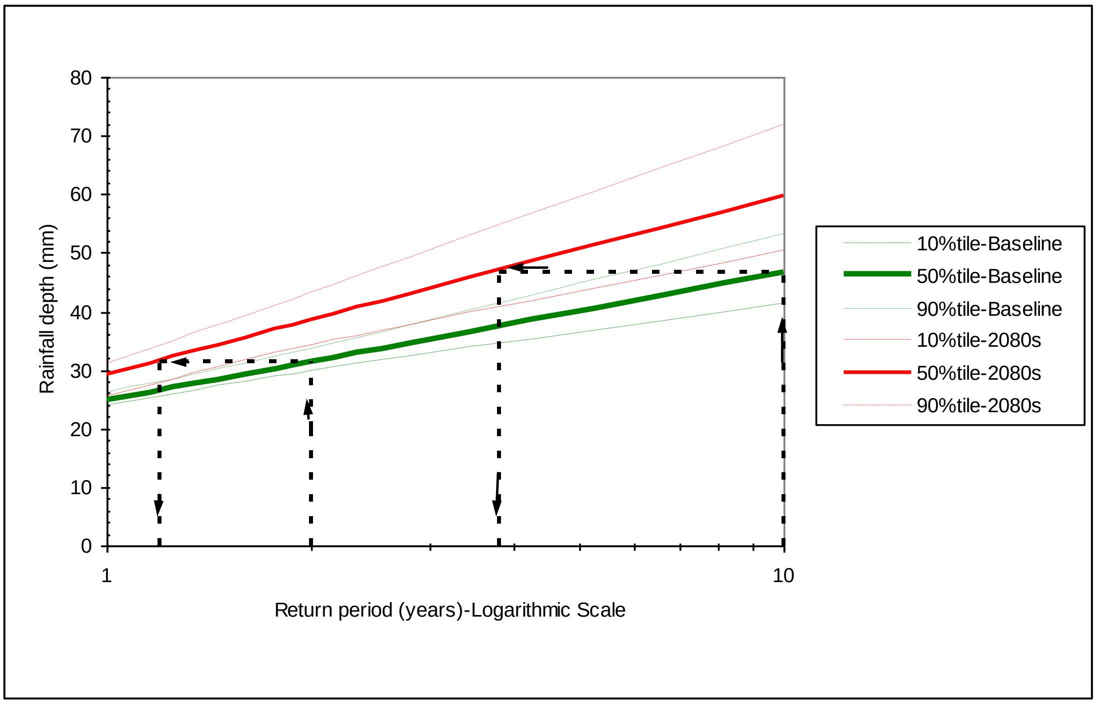

Figure 3 - Glasgow: reappraisal of the frequency of the baseline 10-year and 2-year 1-day rainfall depths by the 2080s (based on the medium emission scenario).

4.8 Soil moisture deficit

Only the 2080s medium emission scenario has been assessed for the Glasgow area (Figure 4).

The maximum magnitude of the soil moisture deficit does increase in the future, but not as much as might be expected based on the projected summer decreases in precipitation and summer increases in potential evaporation. This is because plant transpiration is constrained during particularly dry periods when roots cannot access soil water and as a result, deficits cannot increase at the same rate.

The average duration of the deficit is predicted to change by little in the future. At this site the findings refute the speculation that deficits will in the future last significantly longer into the autumn and early winter period; and hence mitigate the likely increase to flood flows as a result of increased autumn and winter rainfall.

The similar average durations of soil moisture deficit also suggest that on average significant groundwater recharge will occur during the same months as it does now. However with the winters projected to be wetter in the future, it is anticipated that a higher amount of recharge (on average) will occur in the future leading to higher winter and spring groundwater levels.

The averaging used to produce these projections masks significant inter-annual variability. In the future as for now, there will continue to be large inter-annual soil moisture temporal variations. The climate change models do not resolve localised convective storms. Such storms have been linked to landslides in Scotland and it is therefore premature to investigate how climate change may affect this particular landslide process.

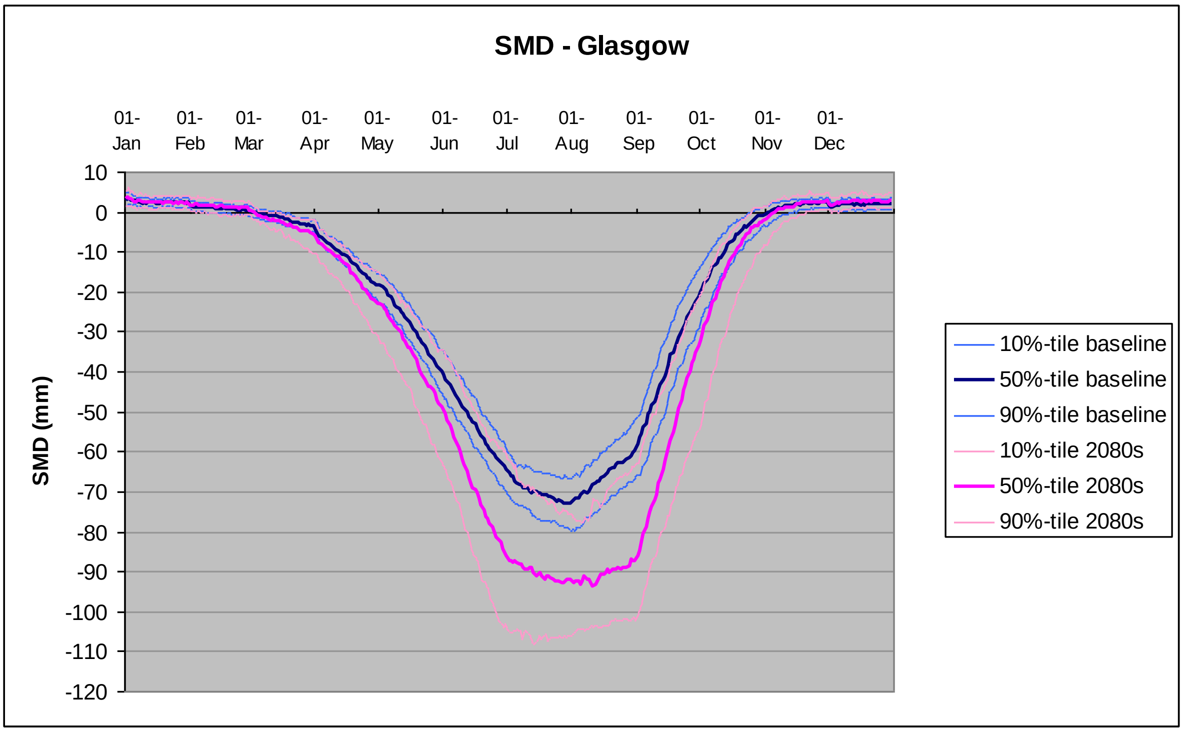

Figure 4 - Glasgow baseline and projected 2080s soil moisture deficit (medium emissions).

5. Discussion and conclusions

The UK Climate Projections provide projections of climate change for the UK, that give greater spatial and temporal detail, and more information on uncertainty than previous UK climate scenarios.

Of the climatic variables assessed the projected increases to storm event rainfall were identified as being the most important factor affecting the design and operation of the road network.

The implementation of new road schemes, which have been completed recently or are ongoing, will have considered and made to some extent allowance for the effects of climate change in their design. It is therefore the older existing trunk road network that remains the most vulnerable to the effects of increased storm intensity rainfall and its associated flooding. In the absence of robust adaptation measures, it is predicted that the historic incidence of flooding across the network will increase in frequency and severity.

Assuming that the changes to the 10-year daily rainfall event can be used as a surrogate for how natural watercourse design flows are likely to change, the following observation is made:

By the 2080s peak river flood flows with rarities between 10-years to 100-years are predicted to increase by 15% to 40% compared to the current situation. This suggests that the current 100-year river flood would become the approximately the 40-year event by the end of the century.

Assuming that the changes to the 2-year daily rainfall event can be used as a surrogate for adjusting short duration low return period surface water flood events (typically used in surface water drainage situations), the following observation is made:

By the 2080s a 1-year storm of 15 to 60 minutes would become on average a 2 +/- 0.6-year storm when assessed on the present day rainfall depth-duration-frequency relationships. (Similarly by the 2020s the storm would become a 1.4 +/- 0.2-year storm).

The range of uncertainty associated with the above predictions should however be recognised. For example some model runs for the 2080s suggested almost no change whilst others as high as 75% increases.

There are a number of further issues worth highlighting with regards to future adaptation activities. These are discussed below.

The probabilistic nature of the UKCP09 projections provides better definition of the uncertainties behind climate change projections and this report provides a fuller understanding of the envelope of uncertainty than could be achieved before. Although the uncertainties may be awkward to manage this is a more informative and honest way of presenting the data. It is necessary for those considering adaptation measures, to consider how to balance the probabilistic nature of the projections together with the associated risks and consequences to the issue that is being managed. Ideally an agreed approach should be developed to guide decision makers on how to address the envelope of uncertainty that accompanies the projections. A unified approach across all sectors of the Scottish Government would be advantageous so that a consistent framework exists for decision making.

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