Effects of Climate Change on Sewer System Performance

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Introduction

Although there is still considerable uncertainty over the magnitude of future climate change, it is generally accepted that future rainfall patterns in the UK are likely to be significantly different from the present day (Kerr et al, 1999, Futter and Lang, 2001). Changes in climate will differ from one part of the UK to another and climate will be less predictable year on year. Winters are likely to become wetter overall and although summers are predicted to become drier, the less frequent rain events are likely to be much more severe, with greater rainfall intensity.

Since rainfall is the primary input to sewerage systems it follows that increased flooding and increased spills from combined sewer overflows can be expected. Increases in mean sea level will affect tide locked outfalls and decreases in summer river base flows will worsen impacts from continuous and intermittent discharges. Increased base flows due to increased infiltration may also impact on sewage treatment works operation.

Over the past two and a half years a team from HR Wallingford, the Meteorological Office, MWH and Imperial College have been evaluating the potential effects of climate change on the performance or sewerage systems, under a research project for UK Water Industry Research Ltd (UKWIR Project CL10). This project aimed to:

- quantify the effects of climate change on likely future rainfall patterns in the UK,
- provide guidance for engineers on suitable design rainfall events that allow for the effects of climate change,
- develop a stochastic tool for generating synthetic rainfall time series incorporating climate change effects
- determine the impact of climate change on the performance of selected sewerage systems
- estimate the increased impact on sewer base flows and treatment costs, and
- scale up the results to assess the overall impact of climate change for UK water industry.

Rainfall Analysis

Climate predictions were undertaken by the Meteorological Office's Hadley Centre and were based on the UKCIP 1998 scenarios. The medium high emissions scenario was chosen as a conservative estimate but recognising that any of the four emissions scenarios was equally likely. Future rainfall amounts for the year 2080, for varying return period and duration, were predicted and compared with present day rainfall. The results were expressed as simple ratios and represented as scaling contours on maps of the British Isles. In all, 49 such maps were produced by HR Wallingford, based on the Hadley Centre's climate modelling (Dale, Gallani and Hollis, 2002). These maps allow current design rainfall to be rescaled so that an engineer can predict the likely future effects of climate change on sewerage system performance. Examples of the maps are given in figure 1. The maps show that the greatest changes are in South East England and in Scotland, but that the patterns of change are quite different for different rainfall events.

A stochastic rainfall generator tool was built by Imperial College (Onof et al, 2002 a & b) to generate 100 year five minute time series suitable for use in sewer network modelling. The series were used to analyse CSO spill frequency and volume and assess receiving water impacts. The time series were also used to predict changes in infiltration and treatment works flow.

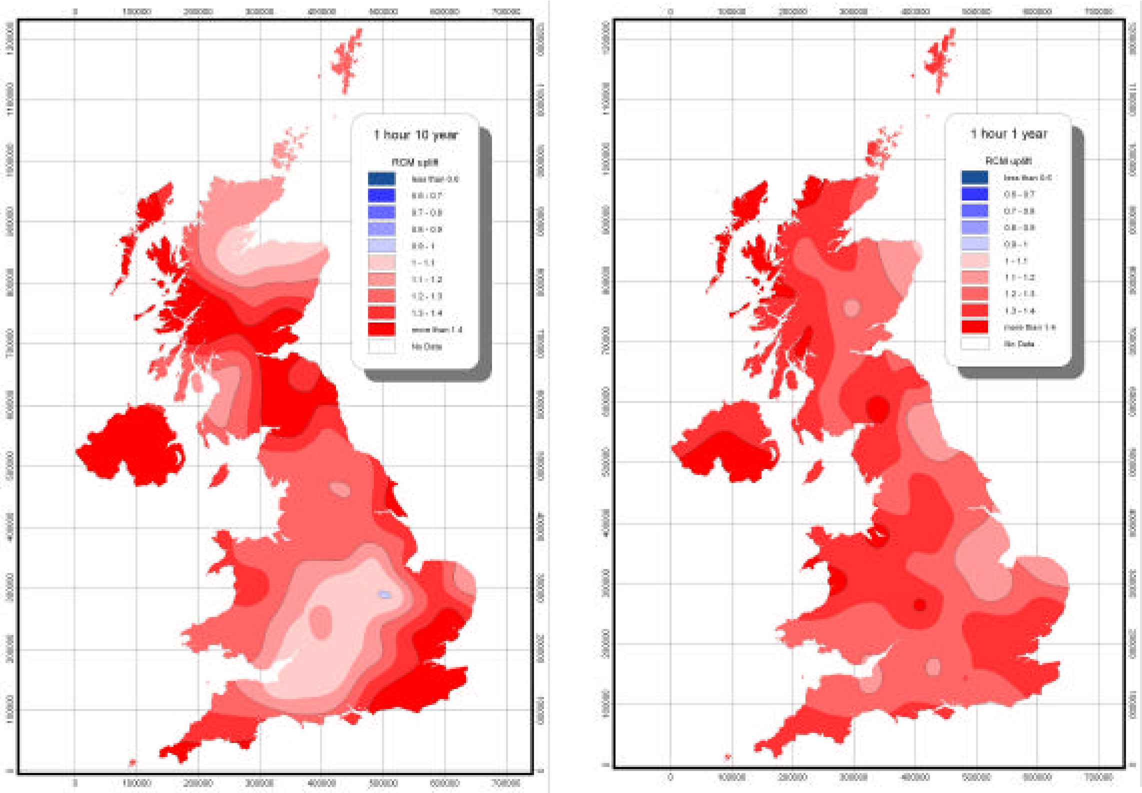

Figure 1. Ratio of 2080/present day 1 Hour Rainfall for 10 year and 1 year Return Periods

Note that there are no values less than 1 on these particular graphs.

Sewer System Performance Analysis

To analyse the impact of climate change, five drainage areas were chosen to represent a variety of drainage types, topography and size. Three were inland and two coastal. Four climate regions were chosen to represent the range of climate conditions across the UK. Climate regions were combined in different ways with the catchments. For example, for the flooding analysis all four regions were tested with each of the five catchments, making 20 combinations. This allowed the effect of catchment characteristics to be separated from climate effects in the analysis. For flooding analysis the 10 year and 30 year return period design storms were used with the duration and season chosen to give the worse case for each catchment (Balmforth, 2002).

For the coastal impact analysis, only the two coastal catchments were used. A representative 10 year time series record was selected from the 100 year synthetic series generated for each climate location. This was used to generate annual and bathing season CSO spill frequencies and volume.

A similar analysis was undertaken on the three inland catchments to generate annual spill frequency and volume from the CSOs. In addition a representative 2 year rainfall series was selected and used in a full UPM analysis on one of the inland catchments using Fundamental Intermittent Standards (FIS) to analyse river impact. The impact analysis was repeated, with the river base flow reduced by 20% to demonstrate this separate effect of climate change.

Finally the effects of climate change on sewer dry weather flow was analysed using regression models from treatment works flow gauges in two different catchments (one urban and a second urban/rural). The present day and future 10 year records were then used to simulate dry weather performance and estimate its effect on treatment works flows.

Flooding

Figure 2. shows the typical effects of climate change on sewer flooding. The graphs show that the proportional increase in flooding is significantly in excess of the proportional increase in rainfall in most cases. Although catchment and sewer network characteristics have some influence on the results, by far the most important parameter affecting flooding is the change in rainfall. For the Elmdon region, where climate change is minimal, only minor increases in flooding are predicted. For the greatest change, using the Greenwich climate, percentage change in flooding can be expected to be up to 150% greater than present day values.

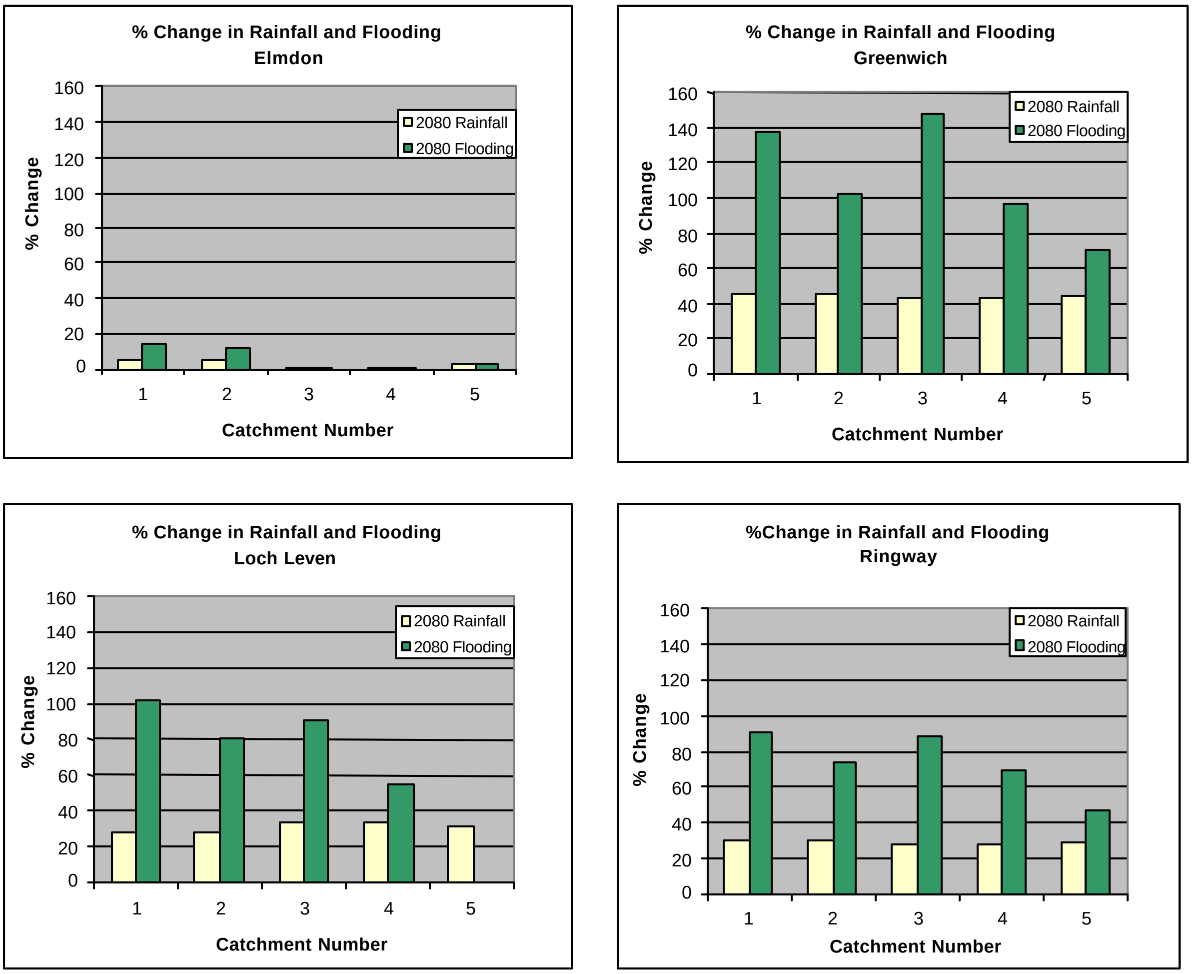

Figure 2. % Change in Rainfall and Flooding between 2080 and Present day 10 year Design Events.

For each of the catchments and each of the climates, storage solutions were developed to achieve a 30 year level of protection of all significant flooding. As expected the larger the increase in rainfall, the larger the storage volume required to deliver a solution, and a good correlation with rainfall was achieved, as shown in figure 3.

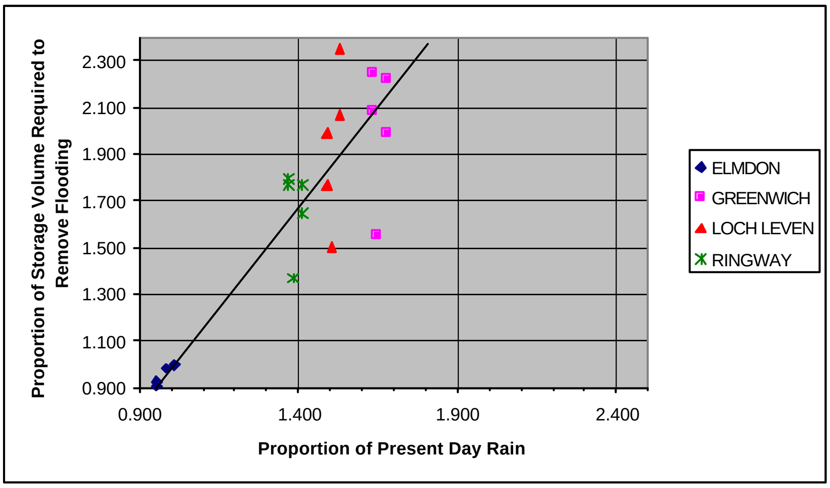

Figure 3. Correlation Between Storage Volume and Rainfall (2080/FSR)

A regression analysis yielded the correlation equation:

Proportional increase in storage = 1.75 x proportional increase in rainfall – 0.75………...(1)

Coastal CSOs

Figure 4 shows the increase in spill volume and frequency for coastal CSOs in the two coastal catchments. Two sets of results are given, for the annual series to test shell fish waters compliance, and for the bathing season to test bathing waters compliance.

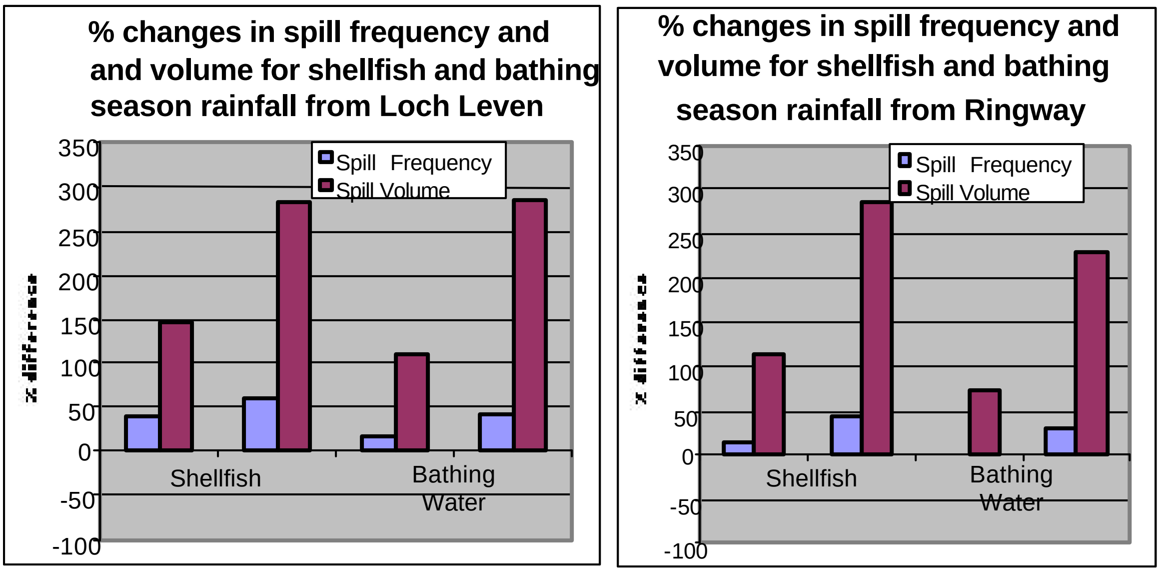

Figure 4. Increases in Spill Frequency and Volume for Coastal CSOs

Storage solutions were developed to meet current shellfish and bathing waters spill frequency standards for present day and 2080 rainfall series. The results of these are shown in figure 5.

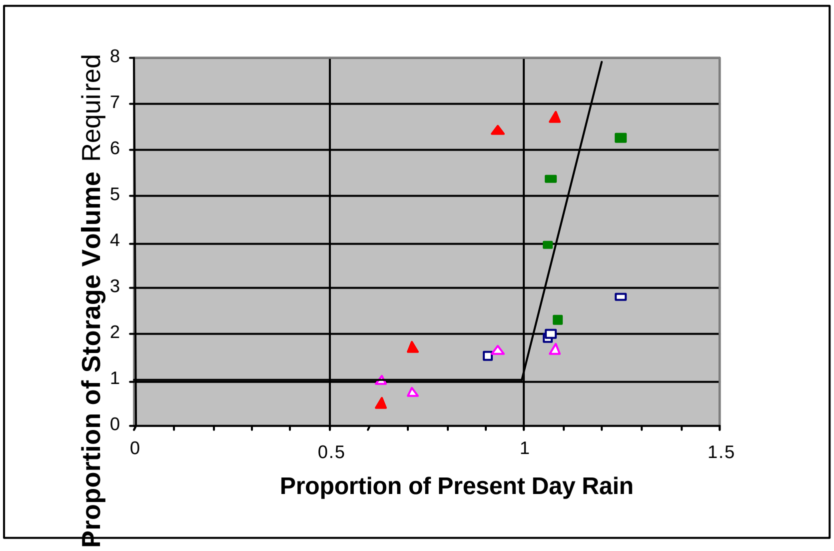

Figure 5. Correlation between Storage Volume Requirements and Rainfall for meeting Coastal CSO Discharge Standards

Figure 5 shows the storage provision to meet the 10 spills per annum for shellfish waters and 3 spills per bathing season for bathing waters. For increasing rainfall, the required storage is proportionally very much greater than the proportional increase in rainfall. For example a 20% increase in rainfall generates an increase of around 7 fold in storage requirement. The scatter is because catchment and sewer network characteristics have some influence on CSO discharge. A regression analysis for increasing rainfall yielded the correlation equation:

$$Proportional\ of\ Storage\ Volume\ Required = 35 \times Proportion\ of\ Present\ Day\ Rain - 34 \ldots\ldots(2)$$

The results show that significant investment would be needed to meet spill frequency standards for both shellfish and bathing waters. It may therefore be more sustainable in the longer term to move to an impact assessment approach to coastal CSO discharges.

Inland CSOs

A similar analysis of inland CSOs again showed that using CSO spill frequency as a surrogate for receiving water impact tends to over assess the consequential effects of climate change. To understand the potential impact more fully a full UPM impact assessment approach was used with one of the inland catchments. A representative 2 year rainfall time series was selected for the analysis. Fundamental Intermittent Standards (FIS) were used for the assessment. Figure 6 shows the results of the assessment. Also on figure 6 are the results of a similar assessment but with the river base flow reduced by 20% to allow for the potential of climate change on this factor.

The results show that changes in rainfall due to climate change have a commensurate effect on future storage requirements. However, by analysing the actual impact, the disproportionate effect of trying to manage spill frequency is avoided. Storage requirements lie within a manageable range similar to present day volumes. Of greater significance is the potential effect of climate change on river base flow. Here a 20% reduction in river base flow, leading to a reduction in assimilative capacity, accounts for increases in storage requirements from 25% to 100%.

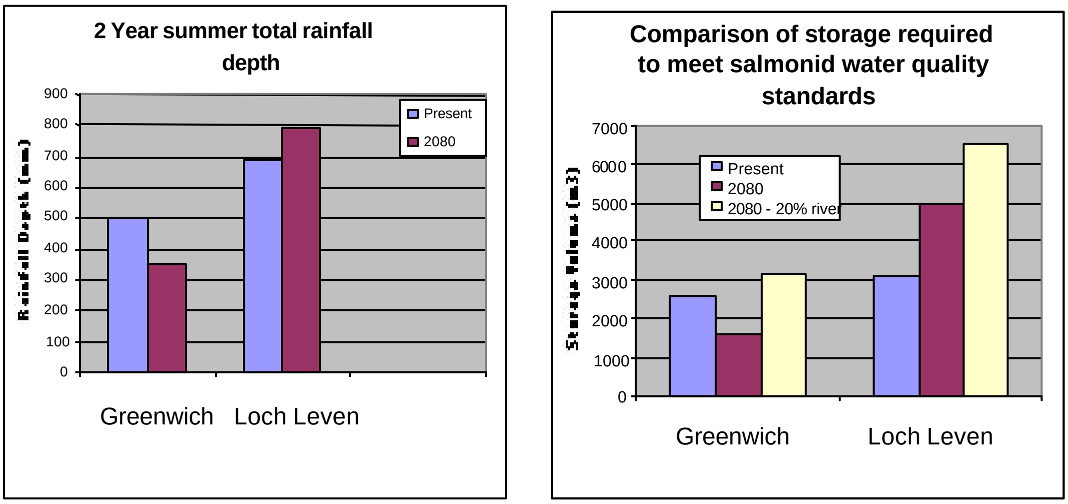

Figure 6. Results of the FIS Analysis for One Inland Catchment

Base Flow and WWTW Costs

To determine the likely effect of climate change on infiltration flow a regression model was developed for two catchments where long term WWTW inlet works records were available (Poole, 2002). The regression models were then run with 10 years of simulated rainfall for present day and 2080 scenarios. The effect on total “dry weather” flow entering the treatment works is summarised in figure 7 below.

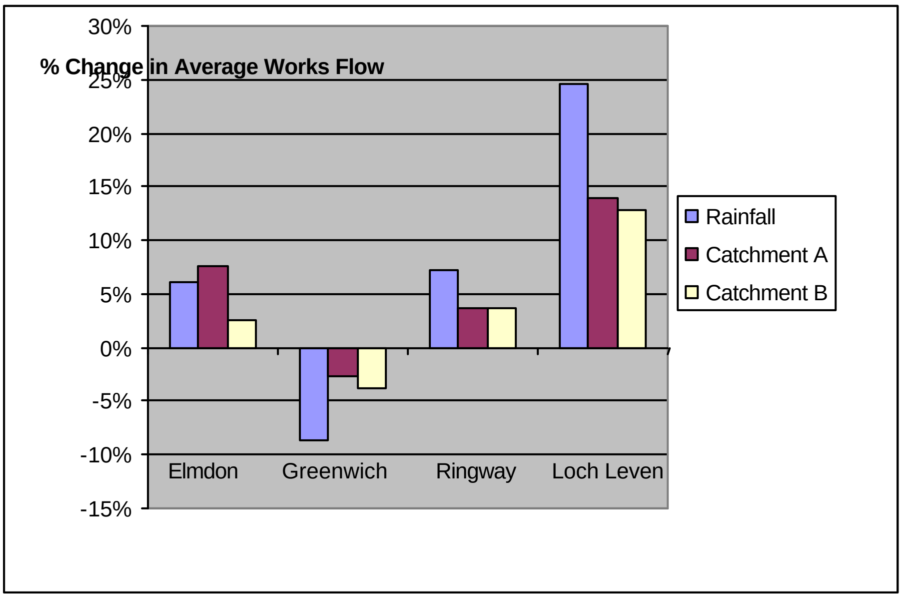

Figure 7. Summary of Effects of Climate Change on WWTW Inflows

There is some variation between the different climate regions with the closest correlation being with annual average rainfall. However, the overall conclusion is that the annual flow delivered to wastewater treatment works in dry weather is not likely to be significantly affected by climate change. The proportion of additional flow was found to be far less than the proportion of additional rainfall, with the largest difference being recorded as 14% for the Loch Leven climate.

Scaling Up

Having determined the likely effects of change on the test catchments, the research team were then faced with the challenge of scaling up the impacts to UK values. Various approaches were attempted. At first it was thought that the most promising approach would be to scale up on the basis of length of sewer or population. However it proved impossible to find any meaningful trend between the observed effects and these parameters. It was finally decided that the most reliable method for scaling results up to area wide values was on the basis of proportional increase and climate region. The four climate regions were overlaid on the respective sewerage undertakers areas and an average value for scale up was determined, based on the regression equations 1 and 2 above. The scale up accounted for population distribution, which was found only to be significant for Thames Water's area.

Towards the end of the project the UKCIP 2002 climate modelling results became available. Using an approximate method of scaling based on the 10 year 6 hour rainfall, a new set of scaling factors was produced for each sewerage undertaker's area. These factors showed changes of between –15% and +11% compared with the earlier model, though this averaging process masked a greater degree of local and seasonal variation between the two climate models.

Conclusions

The results of the study have major implications for the UK Water Industry. The study has produced:

- rainfall maps that enable engineers to determine design rainfall events that allow for the effects of climate change.

- a stochastic rainfall generator that can produce time series rainfall data for future climates, suitable for sewer network modelling.

The research has also shown that:

- for many areas of the UK, climate change may result in an increase in rainfall depths in excess of 1.4 x current values with a subsequent doubling of flood frequency and volume.

- as a result of this increase in rainfall, storage volumes to prevent internal property flooding may need to be increased by more than two fold.

- climate location has a much greater influence on flooding performance than drainage area type or size.

- increases in storage volume to meet spill frequency standards for coastal CSOs for the 2080 scenario are substantial with up to a 6 fold increase for shellfish waters and a 7 fold increase for bathing waters.

- water quality analysis indicates minimal impact on receiving waters in the south (assuming no change in river base flow) with the likelihood of impacts increasing to the north.

- the effect of climate change in reducing river base flows is likely to have a significant additional detrimental effect on river quality requiring additional provision of around 25 - 100% storage volume for a 20% reduction in river flow for example.

- changes to the infiltration from groundwater into sewers are closely related to the change in average annual rainfall. The results show that the effects due to climate change are minimal and the resulting impact on WWTW inflows small.

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