The Potential Impact of Climate Change Upon Sewerage

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Abstract

This paper outlines the potential threats upon sewerage systems arising from any increase in extreme rainfall events. The paper then describes the methodology and outcome of research undertaken by the Met Office on behalf of Severn Trent Water as the preliminary stage of an extensive project investigating changes in short period rainfall as a result of increasing greenhouse gases. Results and conclusions are presented, together with a discussion regarding their relevance to sewerage design philosophy and criteria.

Introduction

The potential problems arising from the impacts of climate change as a result of global warming is a topic of increasing interest and concern to many. It is widely accepted that the global climate is changing, and the focus has now changed from "if" climate change will occur to "when".

One particular area of concern for the wastewater planner relates to the hypothesis that global warming may lead to an increase in the frequency and intensity of the short-duration extreme rainfall events which can give rise to sewer flooding. To date, there has been very little quantitative research into the long term effects of climate change on the magnitude and frequency of such storm events. However, concern has been raised within Severn Trent Water that, should this hypothesis prove to be correct, one would find that the increased rainfall would create a consequential increase in urban run-off which could not be accommodated in the storm sewer systems leading to wide-scale flooding. Thus, the following question was posed:

"Can the Company's nineteenth century infrastructure
cope with twenty-first century storm events?"

Severn Trent Water covers a landlocked area of some 8000 square miles of central England, serving eight million customers from the Humber estuary to the Bristol Channel and from mid Wales to the East Midlands. For some time, Severn Trent Water has recognised the potential threats to be addressed by water companies arising from climate change and, as such, the Company has played a lead role in the instigation of research into climate change research in the United Kingdom.

The Severn Trent sewerage network comprises more than 52,000 km of pipework. It is therefore clear that any change in the climate, giving rise to increased levels of precipitation, would have a significant impact upon the Company, in terms of storm sewerage. The existing network has been designed to current accepted standards; standards which may or may not meet the demands of any future climate change. Furthermore, Severn Trent, like other UK water companies, has a major ongoing capital works programme, of which investment in sewerage is a significant factor. Any new or replacement sewers will also be designed to current standards. Therefore, it is vital to the industry that the potential for any increases in rainfall is investigated and quantified as a matter of some urgency in order to ensure that appropriate standards are adopted for future sewers.

Sewerage Design Philosophy

A detailed analysis and discussion of the design of sewerage systems, and how that might change in the future, is outside the aegis of this report. It is important, however, to consider the overall philosophy which underpins the design procedure.

It is suggested that water and sewerage undertakers have three options available to them with regard to sewerage design philosophy in relation to potential climate change impacts; viz,

- View the climate as having constant boundary conditions
- Let historic statistics define the risks
- Allow the new climate to define the risks.

Under the first of the three approaches, one would simply apply an arbitrary absolute upper limit to future anticipated climate scenarios and, consequently, the impacts that would result from those changes. Clearly, in adopting such an approach, the undertaker runs the risk of setting the boundary conditions either too high or too low. Too high a limit would generate substantial over design and unnecessary additional expenditure. On the other hand, too low an estimate would result in under-investment and a lack of adequate infrastructure to accommodate the impacts of climate change.

The more traditional approach has been to undertake an examination of historic data and to adopt design standards accordingly. That is, to examine rainfall records to find the worst storms recorded in the previous, say, twenty or fifty years, and to set design standards accordingly. Whilst this approach may have some merit in situations where one is confident that the future rainfall patterns and intensities will be of a similar nature to those of the past, such an approach is clearly flawed where one believes that changes in the climate are likely, if not certain.

Thus, when considering sewerage design, one is left with only one option; that is to gain a detailed understanding of anticipated changes in the climate when compared to the current, to quantify those changes in terms of increased levels of precipitation, and to design new assets accordingly.

It is suggested, therefore, that when considering sewerage investment in the future, in order to adequately safeguard their positions as providers of adequate sewerage services, undertakers must develop strategies for adapting to long-term changes in climate. To this end, undertakers must have a detailed appreciation of the anticipated future climate for the area in order to quantify the potential threat to systems as a result of climate change.

Climate Change

The Natural Greenhouse Effect and the Enhanced Greenhouse Effect

The natural greenhouse effect has operated on earth for billions of years: without it, the earth's surface would be some 33°C cooler than it is, so would not be habitable. The temperature of the earth's surface is determined by a balance between incoming energy from the sun (in the form of visible radiation, sunlight) and that being constantly emitted from the earth's surface (invisible, infrared radiation). The incoming sunlight can pass through the clear atmosphere almost unchanged, but the infrared radiation emitted from the earth's surface is partly absorbed by some gases (primarily water vapour and carbon dioxide) in the atmosphere. Part of this absorbed energy is then re-emitted downwards, warming the earth's surface and lower atmosphere. We need the natural greenhouse effect, but as greenhouse gas concentrations increase and substantially exceed their natural levels, further warming will take place. This extra warming due to the enhanced greenhouse effect could significantly change climate with far-reaching effects on man's activities.

Evidence for increased emissions and recent climate change

Concentrations of carbon dioxide and methane (another important greenhouse gas) have risen substantially over the past 200 years. Pre-industrial carbon dioxide concentration was around 270 parts per million (ppm). Today it is about one third higher at more than 360ppm. Concentrations of methane have more than doubled over the last 200 years.

The global average surface temperature has increased by around 0.6°C over the last century. There is some uncertainty in this figure because we do not know how much natural climate variability would have caused global temperatures to change in the absence of global warming. The four warmest years globally since reliable global records began in 1860 have been, in decreasing order, 1998, 1997, 1995 and 1990. However, care must be taken in the interpretation of this statistic, as natural climate variability means warm years tend to be found in clusters. Figure 1 illustrates this recent rise in global temperatures.

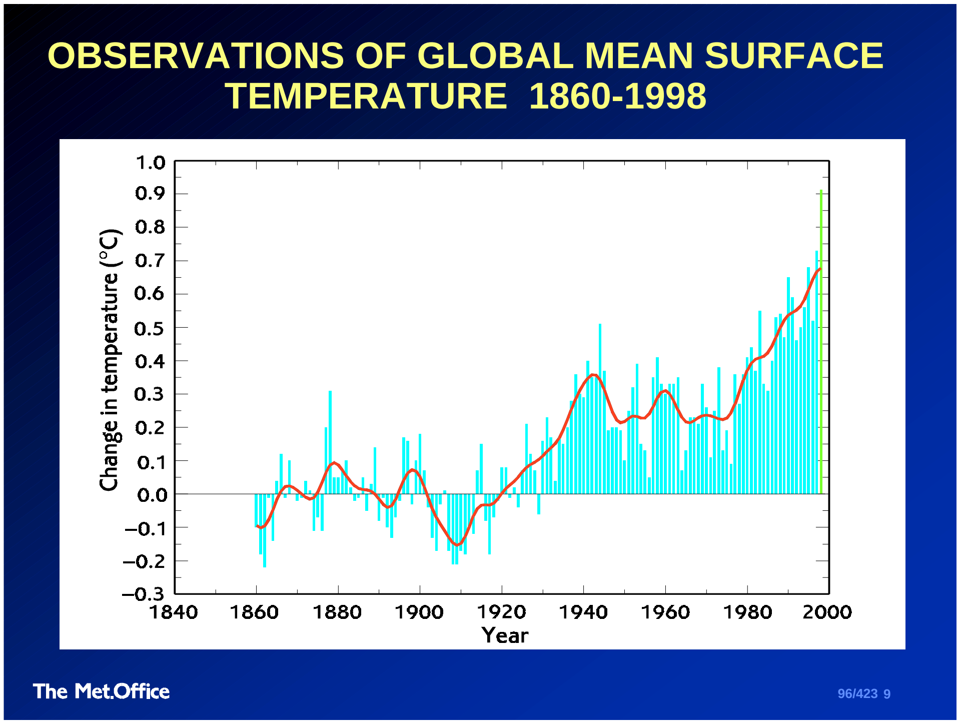

Figure 1: Global average surface temperature measured from 1860 to the present day

Modelling the climate

The Hadley Centre for Climate Prediction and Research at the Met. Office is at the forefront of research and development into modelling the earth's climate to form climate scenarios for the next century.

Before predictions of the future climate can be made, a computer model of the complete climate system must be built, and this must be able to adequately simulate today's climate. All the main components of the climate system are represented. First, the atmosphere: the way it circulates and the processes that happen in it, such as the formation of clouds, the passage of solar and terrestrial radiation through it, and its interaction with the surface. Secondly, the ocean: its exchange of heat, moisture and momentum with the atmosphere and its circulation, which transports large amounts of heat and salt. Thirdly, the land must be represented because it affects the flow of air over it and it is important in the hydrological cycle. In addition the cryosphere (ice on land and sea) is included in the Hadley Centre model. These components of the climate system interact and produce feedbacks. It is vital, therefore, to represent as many physical processes as possible in the model so the important climate feedbacks can be captured. When the model has been tested by providing a simulation of today's climate which is compared to observations, the greenhouse gas concentrations can be made to increase in time as the model is integrated forwards and climate scenarios for the next century and beyond are produced.

One source of uncertainty is the emissions scenario: we can only estimate how much governments will legislate to cut down on greenhouse gas emissions, for example. The estimates of future climate mentioned in this report are taken from a model run that assumes a 'business as usual' emissions scenario i.e. carbon dioxide concentrations increasing at 1% per year. The natural variability of the earth's climate system will also be superimposed on any estimates of future climate.

The Hadley Centre's Global Climate Model (GCM) has a resolution of about 250km over Europe. This means there are just a handful of model gridboxes covering the UK. The coarse resolution means it is difficult to draw conclusions about climate change on a regional scale from the global model predictions. To overcome this problem regional climate models (RCMs) have been assembled to model the climate over a limited area of the globe at higher resolution. Currently, the Hadley Centre has one RCM over Europe and one over the Indian sub-continent. These models have a resolution of about 50km so are much better at representing the effects of coasts, mountains and other smaller-scale features.

Future climate scenarios

Global average temperatures are predicted to rise by about 3°C over the next century. Over the same period, sea levels are predicted to rise by an average of about half a metre. However, this is not a uniform change: some areas will see larger increases than others. The largest contributor to sea level rise is thermal expansion, although the melting of glaciers and the Greenland ice sheet are also important.

By 2050, under a business-as-usual emissions scenario, the UK will be around 2°C warmer, with the south-east warming more than the north-west. According to the Hadley Centre regional climate model, UK rainfall is expected to increase in winter. In summer a decrease is predicted for the south-east and an increase in the north-west of the UK. These changes in seasonal average rainfall mask any underlying trends in the probability distribution of days with different rainfall amounts. However, climate models can also be used to look at the changes in the probability of days with rainfall exceeding a certain threshold (e.g. 20mm). The Hadley Centre's regional climate model results have been used for this purpose in the Met. Office's project for Severn Trent Water.

Initial Studies

Having recognised the potential threats to the sewerage network arising from climate change, in 1997 Severn Trent Water commissioned the Institute of Hydrology (IoH) to undertake a brief assessment of climate change issues in the Severn Trent region.

This study acted as a precursor of the work which is currently being undertaken by the Met Office. As such, a detailed discussion of the work and the results arising from it is not appropriate here. However, one key result from the IoH study is discussed briefly below.

The IoH employed a spatial analogue technique to make an assessment of future climate in the Nottingham area which, despite being fraught with difficulties, did yield some interesting results. The method involves the use of an alternative region as an analogue for the future climate of the study region. In this case, the IoH selected a region in London as an analogue for Nottingham, having a long-term average temperature of 1.5°C higher. A comparison of the growth curves for the two regions showed significant differences in the nature of short-duration (1 hour) extreme rainfall at the two sites. The conclusion drawn from the comparison of the curves was that if the rainfall regime was to be transferred to Nottingham in the next century, and assuming that the difference in rainfall regime between the two regions reflects the differences in mean temperature, then current return periods could be expected to halve. That is, troublesome rainfall would occur twice as often!

It was armed with such a conclusion that Severn Trent Water decided further investigation into climate change impacts within its region was warranted and so approached the Met Office with a view to commissioning a longer term and more detailed study.

Met. Office Project

Project Aims and Objectives

The aim of the project is to undertake research over a three year period for Severn Trent Water to look into changes in short period rainfall as a result of increasing greenhouse gases.

Global warming is expected to lead to an increase in rainfall because the amount of water vapour which the atmosphere can hold doubles for every 10°C increase in temperature. Superimposed on this are the effects of associated changes in the general circulation of the atmosphere.

In the vicinity of the British Isles, a likely increased frequency of westerly winds will lead to wetter winters in northern and western districts, particularly the west of Scotland. In summer, anticyclonic conditions may be more common in the south of Britain, possibly leading to decreases in total rainfall in south-east England. However, a more continental weather regime may be associated with more severe convective storms - hence the concern about an increase in the flooding of storm sewers.

Severn Trent Water requires information on small spatial scales for short timescales and extreme (rare) rainfall events. This combination of criteria has represented a challenge to the climate models because of their relatively coarse spatial and temporal resolution and because of the dependence of extreme events on local scale features.

Methodology

The project is split into 3 logical work stages. Stage 1 provided the groundwork; stage 2, currently underway, contains the main bulk of research to answer the questions asked, whilst stage 3 includes further research to provide more information on the climate predictions. Each stage is explained in more detail below.

Stage 1

Stage 1 of the project focussed on four main strands of research, listed here.

- A literature review of research into the effects of climate change on rainfall was carried out. This ensured that both the Met Office and Severn Trent benefited from existing knowledge of the subject and enabled the researchers to draw on techniques that are established and accepted in the scientific community. However, although many previous studies point to an increase in heavy precipitation driven by global warming (e.g. Gregory and Mitchell, 1995; Henessey et al, 1997), no modelling studies have focussed specifically on the Severn Trent Water region and the shortest period rainfall events.
- In any investigation into climate change it is clearly important to know what variations have occurred in the past. The observed record of extreme rainfall in England (in the form of annual maxima of hourly rainfall) was examined for any trend.
- The Hadley Centre climate model’s ability to simulate the current climate and precipitation characteristics of the Severn Trent region was assessed. Although the ultimate aim of the project is to consider changes to extreme short duration rainfalls in the future, it is necessary to first consider how well the global and regional climate models simulate the current climate of the Severn Trent region. A good simulation gives us confidence in the predictions for the future climate.
- Relationships between daily and sub-daily extreme rainfalls were sought using observed rainfall data. The climate models output rainfall data every 3, 6 or 24 hours; whereas Severn Trent Water requires information on rainfall occurring inside an hour. Consequently there is a requirement for techniques that will allow statistics for short durations (one hour, say) to be derived from statistics for longer durations (3, 6 or 24 hours).

Stage 2

Stage 2 is concerned with looking at the climate scenarios for the future produced by the Hadley Centre climate models, and in particular using the information gathered during stage 1 to assess what this means for the Severn Trent Water region. First the changes in the seasonal average rainfall over the Severn Trent region in the 2020s, 2050s and 2080s will be studied. Then the changes in the probability distribution of rainfall and the associated return period amounts for extreme rainfalls will be examined. Work in stage 1 has formed the basis to how the changes in short period (hourly) rainfall can be inferred from the changes in daily, 6 hourly and 3 hourly rainfall taken from the climate models. Careful consideration will be given to all steps involved in the transformation from current climate, long-period, large area rainfall to future, short-period, small area rainfall. Extensive analysis will then be performed to determine some error bounds in the climate predictions arising from uncertainties in the greenhouse gas emissions scenario, for example.

Stage 3

A further Stage 3 is proposed. This will look at predictions of hourly rainfall directly from the climate models. For this, the models would have to be re-run, but return periods for hourly rainfall could be output directly. The new data would equip us with complementary information to that obtained in Stage 2 of the project and could be used in conjunction with it to provide an overall assessment of likely changes in return period amounts as a result of increasing greenhouse gases.

Preliminary Results

Stage 1

In looking for the existence of trends in the observational record, relatively large amounts of annual maxima of hourly rainfall data collected by May and Hitch (1989) were exploited. Composite records for 20 sites in lowland England were created for the 50 year period 1948-1997. The record for Kew extends back to 1886 and two other stations started in 1922. This information showed that there have been no significant changes in the annual maxima of hourly rainfall in the period of the historical record.

When the simulations of today's climate by the Hadley Centre models were compared to observations, the results were very encouraging. Over the entire range of rainfall events, the regional climate model is very impressive at simulating daily, 6 hourly and 3 hourly variability. It especially performs well in spring and autumn at the daily timescale, when the rainfall is averaged over the Severn Trent region as a whole. This suggests the dominance of large scale processes that the regional model resolution can capture. At the 3 and 6 hourly timescales, and considering rainfall at specific grid boxes, the regional model still performs well. However there is less skill in capturing the most extreme events but this is partly due to the issue of comparing areal (from the model) and point (observed) rainfalls. Rainfall amounts for different return periods are well simulated for all durations for 2, 5 and 10 year return periods but there is some underestimation (which varies geographically) for the 1 in 20 year rainfall. The global model has, as expected, less skill in simulating the probabilities of extreme events when compared to the regional model. The coarser resolution means that the precipitation is bound to be less intense for a particular event. However, on the whole the shape of the distribution is captured, and the fit for less intense events is quite good. The average seasonal rainfall from the regional and global models was compared to the observed climatology over the UK. The regional model can simulate the observed rainfall pattern well, but the coarser resolution of the global model means that it can only capture the broad trend of wet north-west to drier south-east. Figure 2 shows the probability distribution of daily rainfall over the Severn Trent region for Spring and Summer. Probability is measured logarithmically on the vertical axis with 100% at the top.

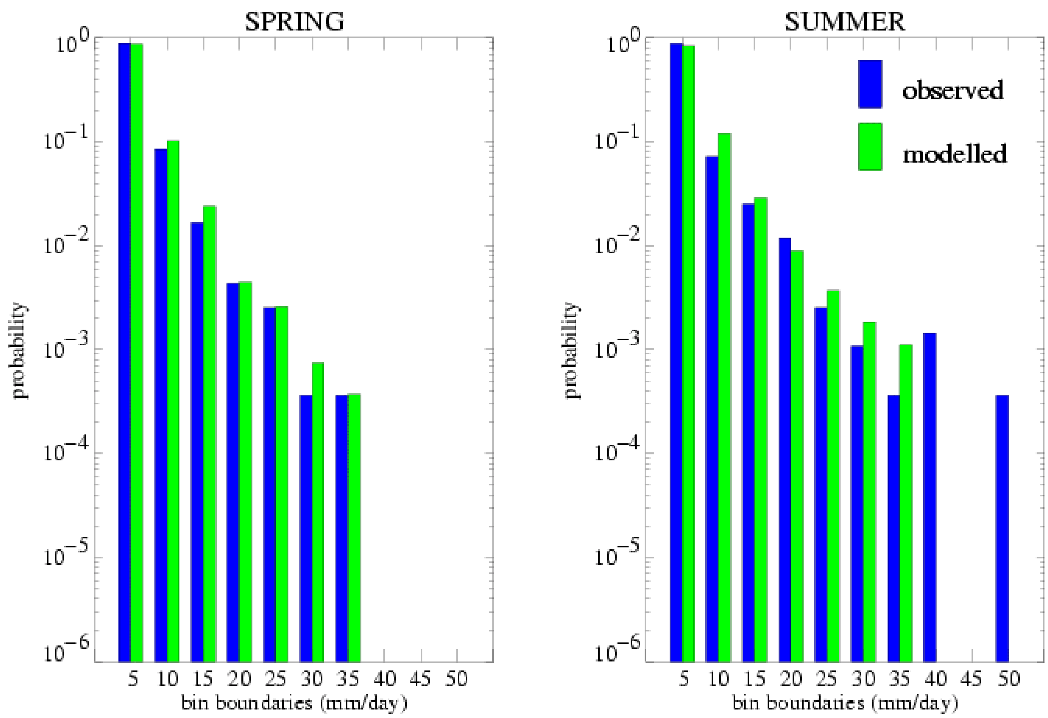

Figure 2: Probability of daily rainfall in the Severn Trent region for (a) March-April-May and (b) June-July-August. A comparison between observations and regional model data.

The horizontal axis measures the rainfall intensity from low on the left hand side (where events have a high probability) to very intense or extreme events on the right (rare events). The observed data is shown by the darker bars and the modelled distribution by the lighter. Spring is very well modelled but there is some underprediction of the most extreme events in Summer.

The research carried out to look for relationships between rainfalls of different durations indicates that it may be possible to use simple linear relationships to transform either series of extremes or return period amounts between different durations. Figure 3 shows an example of one such relationship.

The 24 hour and 6 hour rainfall events for each site have been ranked in decreasing size, and have been plotted against each other i.e. highest 6 hour rainfall against highest 24 hour rainfall etc. Note that these rainfalls may not have occurred in the same day or even year. The results for four main sites in the Severn Trent region are shown, along with the station average which has a slightly steeper gradient than the individual sites.

Some of the graphs show a lot of noise or scatter, particularly the plots of 24 hour rainfall against 1 hour rainfall (not shown). It is likely that regional variations do exist but it has proved difficult to pick out consistent differences between the sites. In contrast, the graphs of 6 hour rainfall against 3 hour rainfall show a very similar relationship for all four sites.

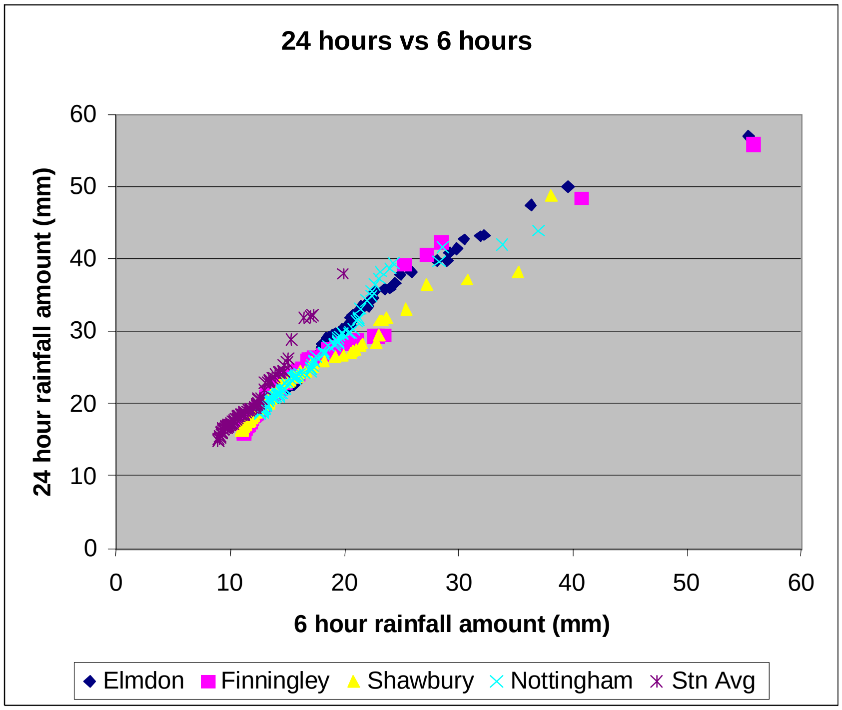

Figure 3: The relationship between the most intense rainfalls in 24 and 6 hours for a number of sites in the Severn Trent Water region. The average of the four stations is also shown.

Stage 2

As described in above, rainfall in the UK is expected to increase in the winter. Preliminary results from stage 2 of the project point towards an increase not only in the average precipitation but also in the frequency of intense short period rainfall. A preliminary examination of the changes in the probability of extreme events from the Hadley Centre GCM has revealed that the model results show an increase in the frequency of the more intense precipitation events and also some events of an even higher intensity than the most intense rainfalls in the control climate. It is important to remember that a global model gridbox covers a large area so model rainfalls are not the same as those expected at a point. These predictions are just indicative of the general trend we expect under increasing greenhouse gases: there is still much uncertainty in the prediction of extreme events, especially at the regional level. Further research will incorporate the results from the higher resolution Regional Climate Model.

Conclusions and Summary

Recent research has concluded that there is a discernible human influence on climate, and that climate is changing (IPCC, 1995).

Severn Trent Water places a great deal of importance on research into climate change and its potential impact upon our environment. The research reported in this paper is just one of a number of initiatives currently being undertaken by, or on behalf of, the Company.

The Hadley Centre models show that the impacts of climate change could be far-reaching and significant. The Hadley Centre regional and global climate models have considerable skill in simulating both the seasonal average climate and the probability distribution of precipitation over the Severn Trent Water region.

The research has also developed some techniques for transforming between rainfall events of different durations which will ultimately help obtain changes in extreme short-duration rainfall for the future.

An examination of annual maxima of hourly rainfall revealed no significant trend in the data over the past century.

This report describes research very much in progress but the results so far are encouraging and have laid a firm foundation upon which to build the work of the current and final stages. The final results will be used by Severn Trent Water for a thorough reassessment of storm sewerage design. This in turn will facilitate the development and implementation of a sewerage strategy which will help the Company to provide an acceptable service irrespective of climate change impacts.

References

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Discussion

Question Richard Kellagher HR Wallingford

The presentation said that analysis of 1 hourly data over 50 years showed no change. However there is a clear relationship of daily to sub-daily relationship. The prediction of 2080 daily rainfall depths are very significant. Can you clarify on the expected change of 1 hour rainfall depths for 2080?

Answer

The relationship between 1 hour and 24 hour is less clear than say 6 hour to 24 hour. The absence of any trend in hourly rainfall over the last century does not mean we do not expect a trend in the future. We are mid-way through the second stage of the project which looks into the expected changes in hourly rainfall for the future.

Written Question Richard Kellagher HR Wallingford

The rainfall depth is only half of the case of an event. The other unknown affecting sewerage analysis is the spatial extent of extreme short term events. Does the study attempt to study this element?

Answer

We're looking at changes in point rainfall. We have made use of Areal Reduction Factors to obtain results for different areas, but note we are assuming that the ARFs remain constant under climate change. We are not looking directly at the change in spatial extent of events.

Question Dennis Dring Yorkshire Water

What is the time-scale for letting us know what events to use so we can get tanks the right size?

Answer

This is a 3 year project internal to Severn Trent. At the end of the project we will make a decision on how to incorporate the results into Severn Trent's corporate strategy. Obviously there are many factors which play a part in this process, one of which is the regulator's attitude to the climate change issues.