Are rainfall intensities changing, could climate change be blamed and what could be the impact for hydrologists?

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Abstract

The climate of the world varies from one decade to another, and a changing climate is natural and expected. The rapid human industrial development experienced since the early 1800s, may well have caused variations that exceed natural cyclic changes. Climate change can be defined as the natural cycle through which the earth and its atmosphere are going to accommodate the change in the amount of energy received from the sun.

Amongst other duties, engineering hydrologists are responsible for the determination of peak stormwater discharges to be able to size conduits to safely convey this water for given recurrence interval events. All hydrological predictions are indirectly or directly based on historical data. Empirical formulas and deterministic methods were developed and calibrated from known historical data. Statistical predictions are directly based on actual data. The question that arises is whether the historical data would still provide an accurate basis from which possible future events can be predicted?

Detailed analyses of 42 years of useable rainfall data at the Molteno rainfall station in the Western Cape at the foot of Table Mountain were carried out to address this question. The finding indicates that tendencies beyond the variation expected from natural climatic cycles have already been recorded at the Molteno rainfall station. This phenomenon could be as a result of the enhanced greenhouse effect. Notwithstanding the localised nature of this study, the study points to changing rainfall trends that have already been experienced, and the trend of these changes underlines the prediction that less, but more intense rainfall could be expected in the Western Cape.

Keywords: Climate change, rainfall, intensity, trend, design principles, greenhouse effect

Introduction

The climate of the world varies from one decade to another, and a changing climate is natural and expected. However, there is a concern that the unprecedented human industrial development activities of the past two centuries have caused changes over and above natural variation (Benhin, 2006). According to South Africa's National Climate Change Response Strategy, approved by Cabinet in September 2004, there is now more confidence than ever before that global climate change is a threat to sustainable development, especially in developing countries (Holtzhausen, 2006).

Climate change is the natural cycle through which the earth and its atmosphere are going to accommodate the change in the amount of energy received from the sun (SAWS, 2005). The climate goes through warm and cold periods, taking hundreds of years to complete one cycle. Changes in temperature also influence the rainfall, but the biosphere is able to adapt to a changing climate if these changes take place over many centuries. There is, however, a concern that human intervention could currently cause the climate to change too fast. Plants and animals may not be able to adapt as quickly to this 'rapidly' changing climate as humans can, and therefore the whole ecosystem could be in danger (SAWS, 2005).

Climate change research is both complex and uncertain. This is because climate itself is the result of complex interactions between the earth's atmosphere, oceans and land surfaces, which we do not fully understand. In order to simulate and predict climate, scientists have developed computer software known as general circulation models or GCMs. If, for example, information about the concentration of greenhouse gases in the atmosphere is given as input, these models can roughly predict the climatic conditions that will result from these atmospheric conditions.

Results from the above-mentioned mathematical models predict that climate will probably not change uniformly across the globe. Land areas will warm up faster than the oceans and polar latitudes faster than temperate latitudes. Coastal temperatures will generally rise slower compared to inland temperatures, thanks to the moderating effect of the ocean. In general, according to these models, summer rainfall will decrease by between 5% in the northern regions and 25% in the Eastern and Southern Cape. Predictions show that the Western Cape may lose as much as 25% of its current winter rainfall (Acosta et al., 1999).

The statements presented above illustrate the alarming forecast: the earth's climate could be changing more drastically and faster than what could be expected as a result of natural cyclic changes; and human activities could be responsible for, or at least contribute towards the predicted accelerated changes. The main emphasis of this paper is to establish, based on a detailed analysis of an existing historical data set, whether the predictions of the above-mentioned climate change models may already be evident, albeit on a very small scale. It must be noted from the outset that it is not the authors' intention to change any long-standing hydrological design principles. The objective is rather to highlight the possibility of changing rainfall trends, and to explore the theoretical consequence changing rainfall trends could have on existing design principles and assumptions.

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Methodology

The possible effects of climate change on storm rainfall events have been investigated through a detailed analysis of short rainfall events (5 min duration) at the Molteno rainfall station, in Gardens, Cape Town, at the foot of Table Mountain. The database used covers the period 1961 up to 2003, and provided the researchers with 42 years of usable data. The analysis includes both the actual rainfall depth recorded as well as the number of short rainfall events that occurred.

Rainstorms at Molteno rainfall station for the period 1961 to 2003

The historical rainfall data for the Molteno station were obtained from the City of Cape Town, Catchment Management Division.

Even though it is acknowledged that a period of 42 years of rainfall data is extremely short within the context of climate change, Molteno presented a very detailed rainfall database for short storm durations and it presented the authors with an opportunity for detailed trend investigations.

Figure 1 details the average of all 5 min duration storms for the full data set. It must be noted that zero measurements were not taken into account in the analyses, and that the averages shown are therefore the average of all periods where rainfall was actually recorded. For this reason, not too much significance should be assigned to the actual values on the vertical axes of Fig. 1. The important issue is rather the presence of an increasing or decreasing trend, as explained below.

It can clearly be seen that the average 5min duration rainfall recorded over the past 4 years is significantly higher than during any other period before that. The next step was to investigate the actual number of rainfall events resulting in the rainfall presented in Fig. 1. Figure 2 shows the number of events recorded at Molteno over the analysis period.

A clear decrease over the past 4 years in the number of events can be observed, as shown on Fig. 2. Important to note is that the measurement method did not change between 1997 and 1999. We must, however, acknowledge that natural variation in the annual rainfall will occur. In other words, the yearly average will not always equal the long-term mean annual precipitation, and dry as well as wet periods could be expected. These periods could last for several years. The question that has to be raised is whether the apparent trend towards increased average rainfall depth (from Fig. 1) and the apparent trend towards decreased number of events (from Fig. 2) could be ascribed to natural annual precipitation variations.

The annual precipitation as well as the mean annual precipitation for the period 1961 up to 2003 as measured at Molteno, is detailed in Fig. 3. The horizontal line shows the mean annual precipita-

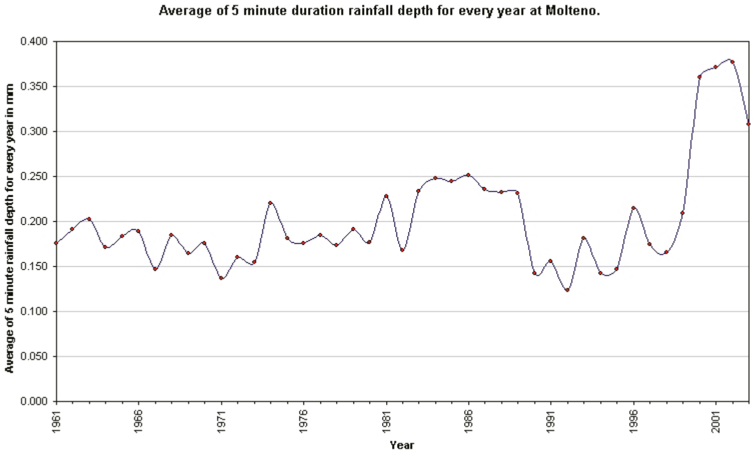

Figure 1
Graph detailing the average 5 min duration rainfall depth

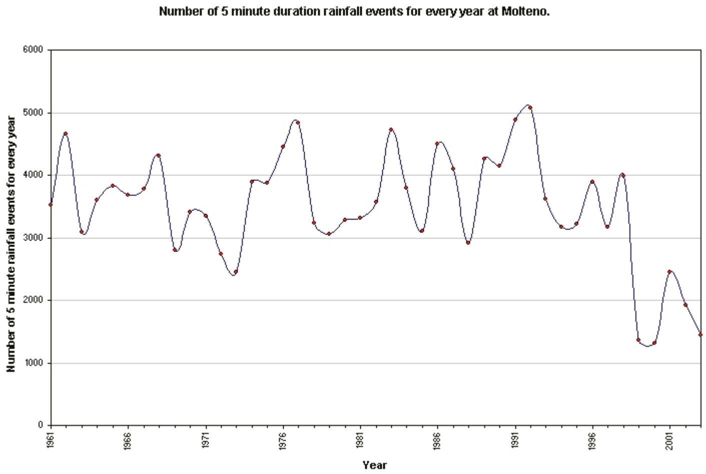

Figure 2
Graph detailing the number of 5 minute duration rainfall events

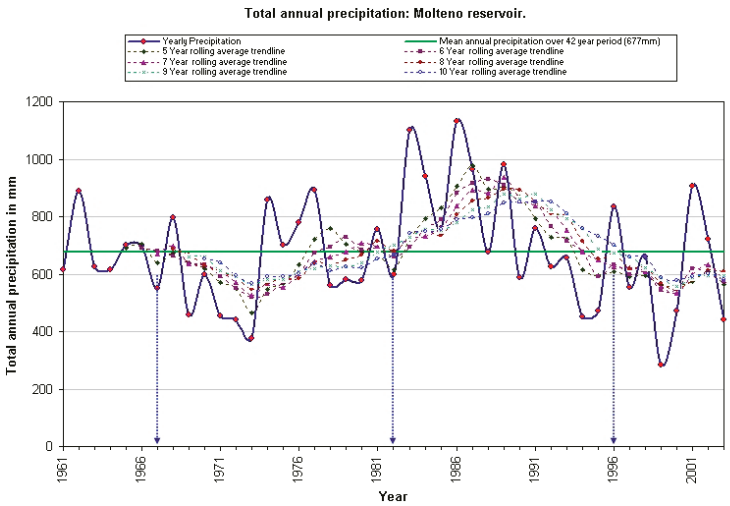

Figure 3
Graph detailing the total annual precipitation at Molteno

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tion at Molteno as calculated from the data set (1961 to 2003).

Various moving average trendlines were calculated for the total annual precipitation at Molteno. The purpose of these lines was to investigate the natural periodicity in the precipitation at Molteno, to verify whether the increasing rainfall intensities could simply be ascribed to natural variations. Alexander (2005) investigated a number of possible causes for periodicity in rainfall events and concluded that a 21-year cycle is clearly evident in rainfall data. Moving average lines for periods between 5 and 10 years were calculated and superimposed on the data set presented in Fig. 3. These lines indicate the average over the preceding years, i.e. a 5-year moving-average-line point, shows the average annual precipitation for the preceding 5 years.

It is clear from these trendlines that irrespective of the moving period used, the data seem to indicate a drier period between ±1968 and ±1982 (± 14 years), followed by a wetter period from ±1982 until ±1996 (also ± 14 years long). This represents a cycle of approximately 28 years, which is comparable with the 21 years determined by Alexander (2005).

Figure 2 shows that fewer rainfall events were recorded in the period from 1998 to 2003 in comparison with the rest of the data record. However, on **average** the annual precipitation, as shown in Fig. 3 with the trendlines, was not **significantly** lower in these years. If fewer events were recorded, but the annual rainfall was still more or less the same as in previous years, the obvious conclusion that can be reached is that the intensity of events must have increased. This is in accordance with the findings as detailed in Fig. 1.

The mean annual precipitation (MAP) as calculated from the 1961 to 2003 data is 677mm and the number of rainfall events responsible for this rainfall amounts to 3 690 events. The MAP for the period 1998 to 2003 is 581mm, representing a 'theoretical decrease' in MAP of 14% while the average yearly number of events responsible for rainfall during this period amounts to only 2 076 events, representing a decrease of 44%. It is thus clear that the number of events is decreasing much more rapidly than the total annual precipitation which, as explained, will constitute higher rainfall intensity.

This finding indicates that tendencies beyond the variation expected from natural climatic cycles have already been recorded at Molteno rainfall station, something that could be the result of the enhanced greenhouse effect.

Discussion

Generally it is expected and predicted by climate change models, that the number of rainfall events could decrease in the Western Cape as a result of climate change, but that the intensity of the events that do occur, could increase. The main focus of this study was to ascertain whether increased rainfall could be expected for the study area, which would result in increased runoff from sub-catchments. The study area was specifically chosen as an urban area, to eliminate the effect of antecedent moisture conditions, as it can be expected that most sub-catchments in the study area would exhibit nearly 100% hardened surfaces, with very little infiltration occurring. The result is that an increase in rainfall should manifest in a similar increase in runoff. As most of the stormwater systems in the study area have been developed, and sized from historical rainfall intensities, an increase in rainfall intensities could result in the functional failure of existing stormwater systems.

It is also important to note that hydrologists are understandably keen to utilise rainfall records that are as long as possible. This should generally ensure that any short-term climate or measuring 'irregularities or abnormalities' will be either identified and removed from the record (as could be the case with outliers in a data record), or will be 'diffused' by the long record.

If we find that a certain area's climate is changing as a result of 'external forces' – as is the case with climate change – the question arises whether the 'changing' patterns can be grouped together with the 'unchanged' patters. In other words, if climate change has an effect on rainfall patterns (be it an increase or a decrease), is it sensible to group rainfall data from the 'greenhouse era' together with data from the 'enhanced greenhouse era' and to establish long-term trends from the combined data set?

This might mean that hydrologists in the future could find themselves in a position where they have 100 to 150 years of data of which 50 years emanated from the period which is generally accepted to be the 'pre-enhanced greenhouse era'. The historical 1:10 year recurrence interval rainfall intensity (for a given storm duration) could, for argument's sake, be 30mm/h at a given position. If, for instance, rainfall intensities have increased at that particular site as a result of the enhanced greenhouse effect, the 'post-climate change' 1:10 year recurrence interval rainfall intensity for the same storm duration could perhaps have increased to 40mm/h. This is obviously the rainfall intensity that the hydrologist should design for, as it is the expected intensity at that time in the future. The average 1:10 year rainfall intensity from the full record may be calculated as 35mm/h, which would imply that the hydrologist is underestimating the intensity, and if antecedent moisture conditions can be excluded from the calculations (as explained earlier), the designer could under-design the stormwater system.

If rainfall intensities should in fact decrease, combining the 'pre- and post-climate change' data could over-estimate intensities. This could result in un-economical designs. It is therefore apparent that any change in rainfall patters, if not properly addressed in the analysis of the hydrologist, could either result in unsafe- or uneconomical designs. Hydrologists should therefore attempt to identify any shorter-term trends within their data set, and apply their minds as to the possible consequences of combining the whole data set, and statistically analysing the full data set. It is important to note that the use of short-duration rainfall records is not advocated, rather that hydrologists should be cautious when analysing long data sets.

The detailed analysis of all the rainfall events at Molteno station did yield very clear trends for the period analysed. It was clearly shown that despite the fairly constant total yearly precipitation, the number of rainfall events seems to be decreasing much more significantly, with a very apparent decrease in the number of events after 1998. The logical deduction is that rainfall intensities must have increased in this analysis period, to sustain the total yearly precipitation. This trend towards increased intensities was underlined when the average 5min duration rainfall depth was plotted.

Conclusions and recommendations

Climate change is unfortunately a very uncertain science. We are dealing with a highly complex climate system, with interaction from atmospheric gases, the effect of varying solar radiation as a result of the earth's seasonal orientation with regards to the sun, the earth's topography which might influence the formation of clouds and cloud cover subsequently influencing evaporation to name but a few. To add to this highly complex system, the effect of changing concentrations of greenhouse gases has to be taken into account. To even further enhance the uncertainties, we are trying to extrapolate the effect that enhanced greenhouse gases might have on this intricately balanced system, up to 100 years into the future!

It is clear that we are dealing with a topic which commands our respect, and one for which we could only claim to be marginally capable of extrapolating future trends.

Studies similar to this one should be repeated at regular intervals in the future, to verify if the expected trends are in fact occurring. We must, however, once again emphasise that natural climatic cycles (wet- and dry-cycles) do occur. We should endeavour to adapt to these natural cycles. This study focused on the possible consequence of the enhanced greenhouse effect on rainfall intensities (with reference to a specific rainfall station), in other words, the influence of humans' industrial actions on the climate systems. These influences should be identified, and we should attempt to slow down or reverse the negative consequences of the enhanced greenhouse effect. The important issue is to try and recognise the **super-imposed effect of mans' actions**, and to be aware of the result of our actions and to try and either reverse or slow down that effect. When more measured rainfall data become available emanating from the so-called 'climate-changed era', these data should be compared to data from the 'pre-climate change era.'

This could lead to an enhanced understanding of the effect that climate change has on rainfall intensities, and possible trends could become more evident. As this study focused on a very small urban catchment only, it is recommended that the study be expanded to include a wider spatial distribution of rainfall stations. By including more rainfall stations in the study and expanding the spatial distribution of the study area, the credibility of the study could be hugely enhanced, and clearer trends could become apparent.

As mentioned in the introduction, it must be remembered that it is not the authors' intention to change any longstanding hydrological design principles. The objective is rather to highlight the possibility of changing rainfall trends, and to explore the theoretical consequence changing rainfall trends can have on existing design principles and assumptions. Hydrologists should consider these possible changes in analysing rainfall data in the future, and should guard against the use of rainfall data or intensity formulas or intensity relationships which have been derived from historical data, as these may not display the same characteristics as the climate at that time.

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