



# Met Office Fire Severity Index - Component Analysis

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## Executive Summary

The Fire Severity Index uses a combination of soil moisture codes at various depths, along with prevailing weather conditions, to determine fire severity conditions across England and Wales on a daily basis. There has been discussion about the impact that each of these moisture codes has on the overall severity index. It has been suggested that it is too reflective of, and places too much emphasis on, the deeper soil moisture conditions. This results in elevated fire severity predictions even when surface conditions may suggest otherwise. Alternatively, it has also been suggested that surface conditions are given too much weight, resulting in elevated fire severity predictions though the deeper soil layers are still moist.

This report examines the determination of the various moisture codes within the model. Initially, the aim of this project was to assess whether the weighting given to the moisture codes, or more particularly the intermediate fire behaviour codes, could be re-weighted. The aim of this would be to gain more accurate results across the variety of landscapes for which predictions are made. In reality, it has not been possible to readily do so, due to the complex interactions between the codes within the model. In any case, such changes or re-weighting could appear arbitrary, particularly without significant observations to support such an approach.

However, this paper does provide an insight into some of the inner-workings of the Met Office's FSI model and the assumptions made in compiling the drying and wetting curves used. Some of these assumptions are challenged for the UK environment and suggestions are made regarding the proposed work on validating the results from the FSI against soil moisture data. The conclusions drawn from this report will guide some aspects of the work involved in that project. Some of the other assumptions used within the model have been accepted. To verify them, or attempt to refine them, would be expensive and likely offer little improvement to the model.



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## 1 Introduction

The Fire Severity Index (FSI) published routinely each day by the Met Office is based on the Canadian Forest Fire Danger Rating System (CFFDRS), particularly, the Fire Weather Index (FWI) component of the system. The FWI is the result of two specific fire behaviour codes produced within the model – the Initial Spread Index (ISI) and the Build-Up Index (BUI). Respectively, these codes reflect the ability of a fire to spread and the energy with which any fire will burn. Both the ISI and the BUI are determined by underlying soil moisture estimates. These underlying soil moisture estimates are the Drought Code (DC), the Duff Moisture Code (DMC) and the Fine Fuel Moisture Code (FFMC), all of which are modelled within the framework of the FSI.

Figure 1 below shows the interrelationship between the different components which make up the final Fire Weather Index.

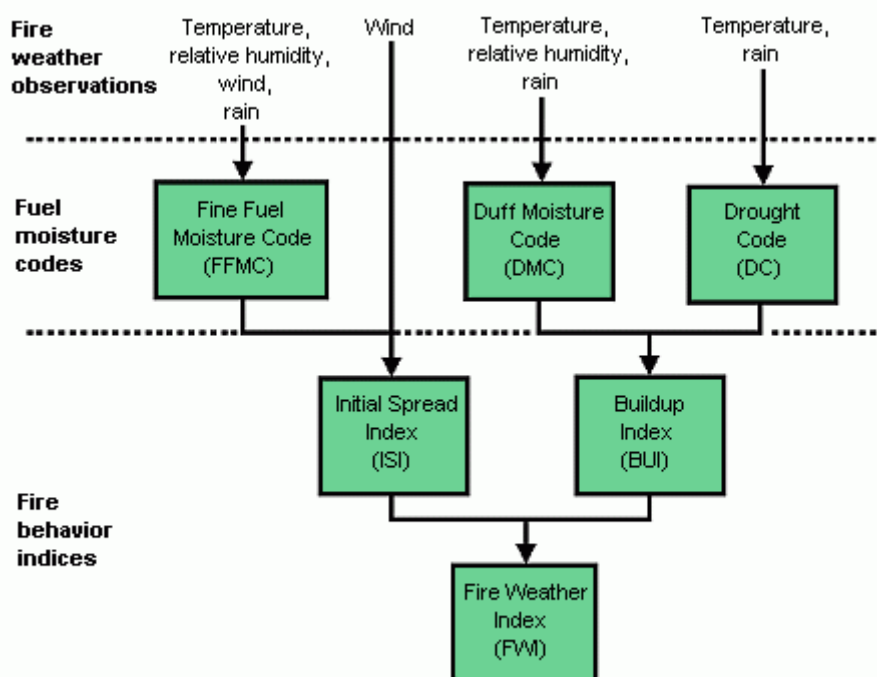


Figure 1 – Overview of the FSI

As can be seen, the ISI is a function of surface litter moisture conditions and the prevailing wind speed. When the FFMC is high, representing dry surface fuel conditions, and the wind is sufficiently strong, the ISI will be high. Even if the BUI is low, a relatively high ISI will be sufficient to drive the FWI to elevated levels. The BUI reflects the likely amount of energy at the flame-front, being determined by the moisture content of the duff and deeper layers. Even if the ISI is only moderate, a sufficiently high BUI can lead to elevated FWI levels.



The calculation used to determine the FWI from the ISI and BUI is shown below. As can be seen, there is no easy method of simply multiplying one code by a fraction whilst dividing the other by a similar fraction. The inter-relationship is more complex than a straight forward product of the two numbers.

For  $B < 1$ ,  $S=B$

For  $B > 1$ ,  $\ln(s) = 2.72(0.434 \ln(B))^{0.647}$

Where,  $B = 0.1 R f(D)$ , and

For  $U > 80$ ,  $f(D) = 1000 / (25 + 108.64e^{0.023U})$

For  $U < 80$ ,  $f(D) = 0.626U^{0.809} + 2$

Where,  $R$ =Initial Spread Index,  $U$ =Build Up Index and  $f(D)$  is the Duff Moisture Function

A number of the conditions in the algorithm could be tweaked, but there would be no real basis of evidence to justify any such approach. It would be arbitrary and open to criticism.

However, in investigating the underlying workings of the model as part of this project, a number of assumptions made within the model have been assessed. These assumptions relate to the conditions under which the wetting and drying curves used within the model were developed. It is possible that the model's performance may be enhanced by addressing some of these assumptions. It is outside the scope of this project to undertake such an exercise. However, conclusions drawn from this report should be bourn in mind when the FSI results are compared to soil moisture monitoring data, as planned in the near future. Without such monitoring data, it will not be possible to assess whether any model changes could lead to a material improvement to the results.

Also, to some extent, the rationale for the study has been overtaken by other studies; the ongoing investigation into grassland and peat-land fire behaviour models addresses the issue of dealing with different fuel regimes in a fundamental manner. It is hoped that these models will be introduced over the coming year or two.

## 2 Analysis

The chart for Linton, Cambridgeshire, below (Figure 2) is shown, by way of example, to demonstrate the behaviour of the various model components. The chart also highlights typical rates of change within each of the components. The FFM changes on a daily basis, sometimes by a very significant amount. The DMC usually tends to vary more slowly, though as can be seen around 20 July, it can sometimes respond very quickly to a significant rainfall event. The DC tends to increase gradually throughout the season in response to the warmer weather and longer daylight hours. However, even the DC can respond quickly to significant events, as again seen around 20 July. The sharpest fall can be seen in the DMC which is then replicated in the BUI, affecting the overall magnitude of the FWI.

The calculation of the FWI depends critically on whether the BUI has reached a value of 80. Different algorithms are adopted depending upon which side of this value the BUI lies.



Linton

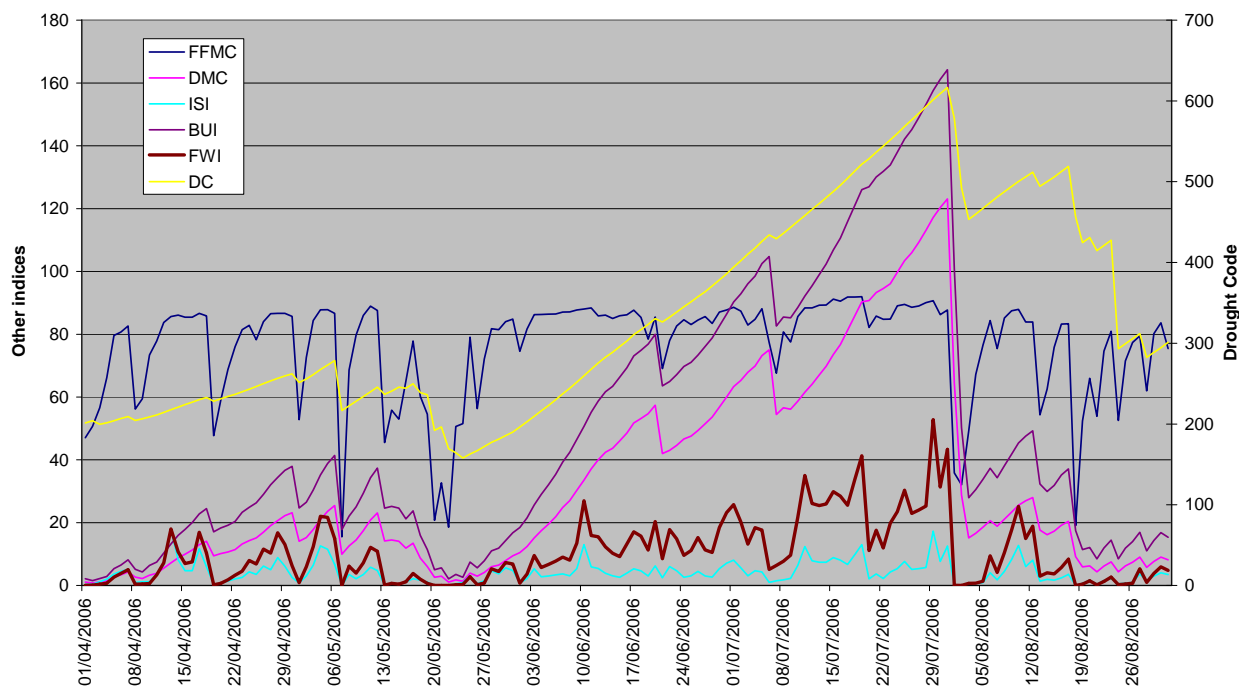


Figure 2 – FWI data for Linton showing typical behaviour of model codes.

### 3 Assumptions in the Canadian System

An alternative and more objective method to enhance the FSI is to consider the assumptions made in the Canadian model and their applicability to the UK. Empirical data and other assumptions have been used in developing the CFFDRS. This empirical data has been based on results from Canada where the model was developed. Earlier studies have shown that the Canadian model is suitable for a range of fuel types found within the UK and for the UK climate. However, it is still legitimate to address some of the underlying assumptions and ask whether more appropriate values and limits should be adopted for UK conditions. These could then be used to adjust the constants, variables and constraints in the component equations giving a model which better reflects the UK and its climate.

There are not many of these values to adapt and it should not be expected that significantly different and improved results would arise from these relatively minor tweaks. Nonetheless, they are worth pursuing as the effort required, once sufficient soil moisture data has been collected and analysed, is small in comparison to other improvements undertaken.

A number of assumptions used within the model are listed below, together with the scope for any changes which could be envisaged. For many of the assumptions shown, there is little that can be done without significant effort in replicating much of the work originally undertaken in Canada, which spanned some forty years. The recommendations which follow summarise the smaller number of issues which can be more readily addressed and tested.



*Assumption 1: The time lag for the drying of fine fuels is based on a normal day with a noon temperature of 21.1°C and relative humidity of 45% in July.*

The 1971-2000 long term average maximum temperature for July in England is 20.6°C and maximum temperatures usually occur 2 or 3 hours after noon, suggesting that 21.1°C may be a little high for the UK. Relative humidity can be variable (the chart below shows the pattern during June and July 2006 for South Farnborough, Hampshire) with a maximum of 89%, minimum of 32% and average of 56%. It seems that 45% is perhaps a little low for UK conditions.

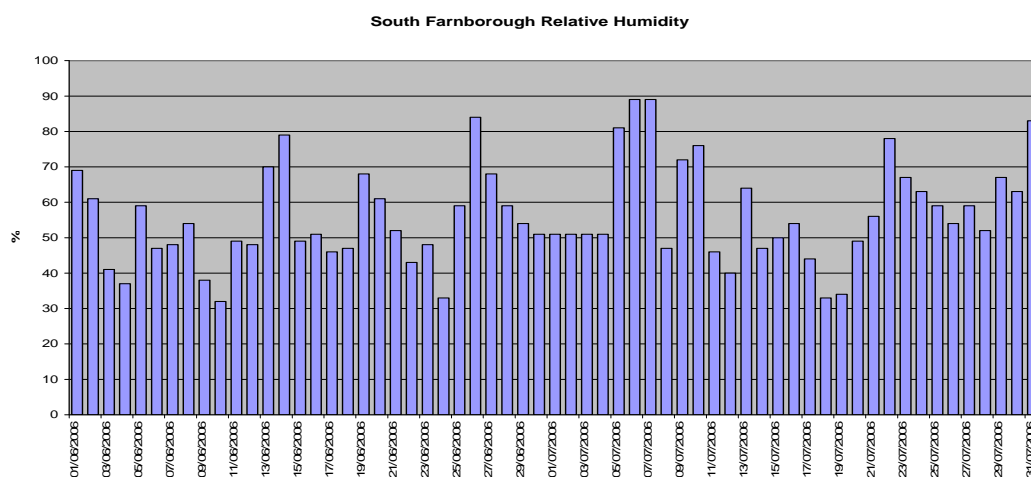


Figure 3 – Relative humidity in South Farnborough

*Assumption 2: The moisture content of pine needles varies by up to 250%.*

Again, the model is based upon experimental data collected from Jack pine needles and the ranges of fuel moisture found have been used to estimate the FFMC. However, without significant effort to reproduce the dry oven tests undertaken originally, it would be difficult to produce better estimates of fuel moisture fluctuations in typical litter found within the UK. Also, the types of litter found in the UK are potentially wide and varied, including dead matted grasses, decaying small twigs, fallen foliage and other needles from various species of plant. The variation in fuel moisture behaviour between these fuel types is likely larger than any error introduced by assuming a comparison against Jack pine needles.

*Assumption 3: The maximum effectiveness of rain in wetting litter is approximately 10%.*

Only 10% of the rainfall is assumed to have any effect on wetting the litter layer; the rest is assumed to evaporate, sink into the lower soil layers, or be caught in the canopy and therefore not reach ground level. It will be difficult to challenge this assumption without, again, undertaking a significant effort into performing further experiments in the UK involving dry oven tests across a range of fine fuel types together with collecting rainfall data within and outside of the forest canopy.

*Assumption 4: For the DMC, the increase in moisture content per unit of rainfall is inversely proportional to the amount of rainfall and the wetting effect of rainfall decreases with increasing moisture content.*



There is no reason to suspect that the duff layer in the UK responds particularly differently to that found within the Canadian forest floor. It is likely that the two main points made are valid for UK soils. Firstly, the higher the rainfall rate, the greater the surface runoff and the less impact each unit of rainfall is likely to have. Of course, even with the reduced impact per additional unit of rainfall, the higher rainfall totals still impact on the DMC more than a lower rainfall total would. Secondly, the more saturated the soil is initially, the less its ability to absorb yet further moisture. Once sufficient soil moisture data has been collected, the data can be averaged and this hypothesis tested further.

*Assumption 5: Rainfall totals of up to 1.5mm are ignored when calculating the DMC.*

The assumption that rainfall rates of less than 1.5mm per day have no impact on the moisture content of the duff layer is potentially open to question. Empirical data upon which this figure was determined would have included readings taken from densely forested areas. Hence, the cut-off limit includes data where potentially significant amounts of rainfall were captured within the canopy. Given that the main applications of the FSI in the UK are not restricted to forested areas, it may be sensible to reduce this value, compensating only for rainfall caught within the foliage canopy – which is likely to be less than that caught within a forest canopy.

With co-located rain gauges and soil moisture probes at a range of locations across England and Wales it should be feasible to test this hypothesis. The soil moisture data could be analysed in conjunction with the 24hour rainfall totals to assess the average amount of rainfall needed to impact on the duff layer. The source code behind the FSI could readily be changed to reflect any such new findings.

*Assumption 6: Day length has an effect on drying proportional to the number of hours between sunrise and sunset*

Day length has a direct influence on drying rates, as does the latitude of the location. Day length dictates the amount of solar radiation throughout the day, being greater during the summer than the winter season. The latitude has an impact as solar elevation varies from equator to pole, providing more intense values closer to the equator.

Both of the values, the day length and latitude, are accounted for within the model, and there is no reason to suspect that these are in error.

*Assumption 7: Rainfall totals of up to 2.8mm are ignored when calculating the DC.*

As with the DMC, there is a 24hour rainfall total limit which is judged to have no impact on moisture levels at lower depths. For similar reasons to those explained earlier, it is quite possible that a more appropriate value could be found. Again, this would rely on the information to be collected from the proposed soil moisture monitoring network. This task should also be very straightforward to undertake.

*Assumption 8: The validity of the wind function is uncertain at very high wind speeds,*



The ISI has been calibrated across a wide range of wind regimes. However, as with any event which occurs infrequently, it is difficult (and dangerous) to undertake experiments in such extreme conditions. Assumptions have necessarily been made in estimating fire behaviour at very high wind speeds. There is no evidence to assume that these extrapolations are in error and for the same reason that few others have undertaken experiments in these conditions, it would not be recommended within the umbrella of this project either.

*Assumption 9: The ISI assumed a standard wind speed of 13 km/hour.*

The ISI is based on the product of the wind and fine fuel moisture function weighted by a function based on a previous Canadian drought index for a standard set of conditions for British Columbia. These assumed a wind speed of 13 km/hour. As the map in Annex A shows, average wind speeds in the UK are between 8 and 12 knots (15-22 km/hour), suggesting that 13km/hour is an underestimate for the UK.

Again, without significant experimental work being undertaken, it is unlikely that this parameter could be easily tuned further. In any case, it is unlikely to significantly impact on the overall FWI and no further experimental work is recommended.

#### 4 Soil Moisture

The Met Office does not have significant amounts of soil moisture data, as it is not routinely collected as part of its operations. However, data is available from the Meteorological Research Unit at Cardington in Bedfordshire (52° 06' N, 00° 25' W, 29m amsl). These have been extracted for April to July 2006 and compared to rainfall measurements. The response of the soil moisture to rainfall events can be seen in Figure 4 at depths of 10cm, 22cm, 57cm and 160cm.

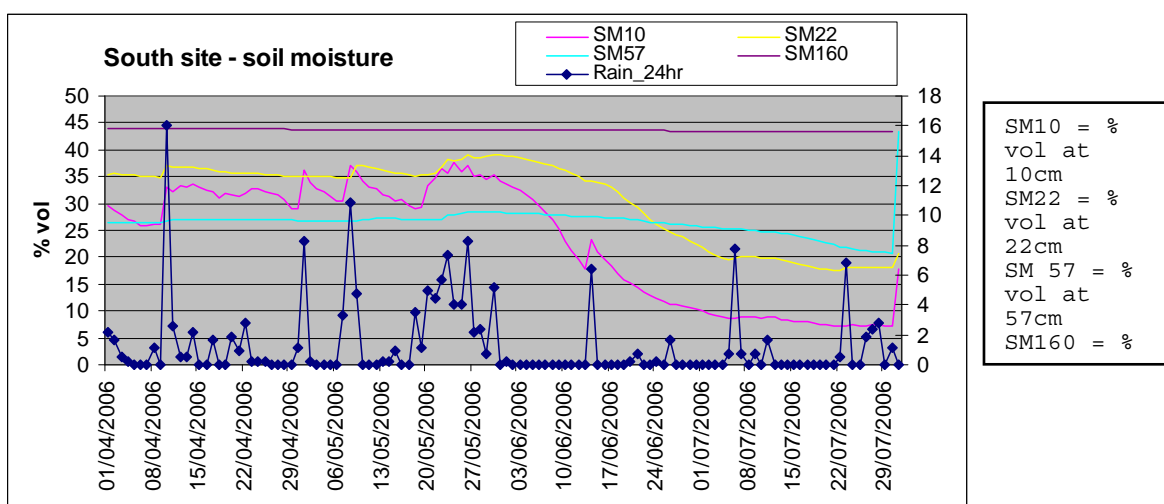


Figure 4 - Soil moisture data from Cardington

The chart shows that the variation in soil moisture is less dependent on the amount of rainfall once it falls below a certain level (20-25% moisture volume). The fairly significant, although isolated, rainfall events on 6th July and 23rd July 2006 had little effect on the soil



moisture content at either depth, if anything flattening out the profile rather than increasing it. This may be due to the top layers of soil being significantly dryer and hence absorbing more of the rainfall before it can dissipate to the lower layers.

Figure 5 shows the difference between soil moisture measurements and the components of the fire severity, which are much more sensitive to variation in weather parameters. The FWI data has been calculated using weather measurements from the Cardington site fed into the FSI model. The drought code level (down to 18cm) compares well, in shape and behaviour, to the soil moisture measurements at 10cm and 22cm. The variation seen in the DMC is not reflected in any of the soil moisture measurements.

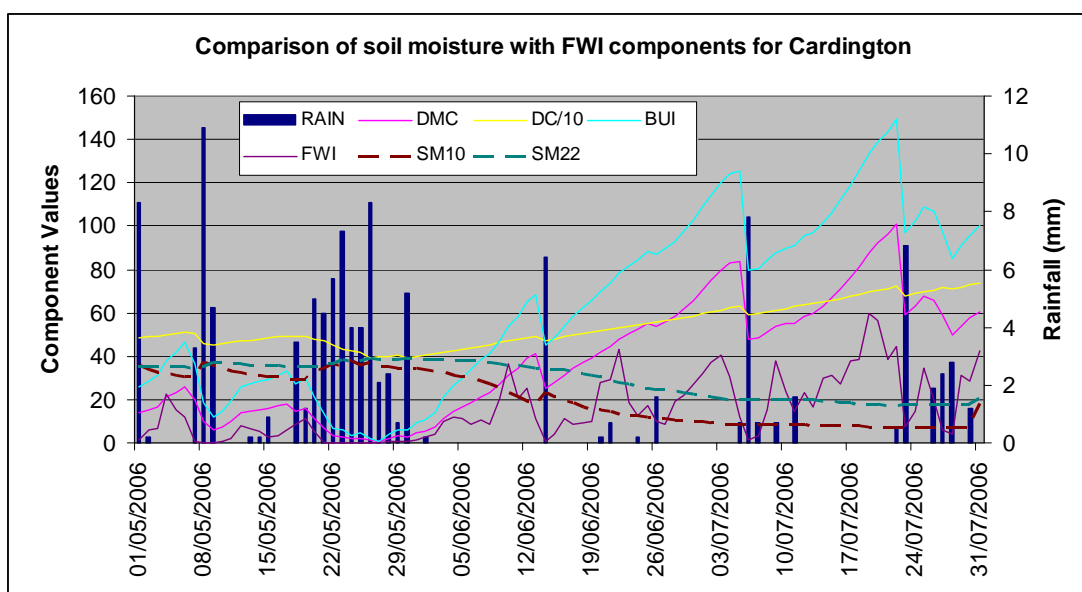


Figure 5 – FSI behaviour and soil moisture data, for Cardington (South Site)

Soil moisture data is important for assessing the performance of the model and testing whether any changes lead to a material improvement in results. As can be seen from the Cardington data, the FSI modelled moisture codes are not always reflected in the measurements taken. To test any of the model changes suggested, much more data would be required from a variety of sites.

## 5 Conclusions and Recommendations

It has been shown that there are a number of assumptions made within the CFFDRS (and therefore within the FSI). It is not likely that changing any of these assumptions will have a very significant effect on the results. However, some minor adjustments could be made which would lead to a slight overall improvement to the model. To validate any of these changes, further soil moisture data is required. Whilst some information is available from Cardington, more data from other sites would be required to test any changes.

It is recommended that any changes which are related to the moisture of the fine fuels are not undertaken. It is likely that the FFMC adequately reflects UK litter moisture states. In any case, as further validation would require significant investments in dry oven tests, it would prove expensive and unlikely be cost-beneficial.



There are a number of assumptions regarding the soil moisture content of the lower soil layers. These are reflected in the DMC and DC and could be readily tested against soil moisture data collected in the UK. Specifically, it is suggested that the following work is incorporated into any future analysis of the soil moisture data.

1. Assess the assumption that, for the DMC, increasing totals of 24hour rainfall do in fact have a decreasing contribution to moisture conditions within the duff layer. This can be done simply by comparing rates of change in the DMC against the rainfall totals. A logarithmic decay curve would be expected.
2. Assess the wetting effect of rainfall against the existing duff moisture content. The expectation is that the impact of rainfall is lower at higher moisture contents. Plotting rainfall against changes in the DMC at various DMC values should demonstrate that when DMC is high, equivalent rainfall totals have a lower impact.
3. Assess the impact of rainfall totals of less than 1.5mm against changes in the DMC. This should reveal a more appropriate value at which to set the trigger level allowing rainfall to have an effect.
4. Assess the impact of rainfall totals of less than 2.8mm on the DC. Again, this exercise will reveal a more appropriate value for the trigger level.



# Annex A

