3. IDENTIFICATION AND APPLICATION OF CIRCULATION-TYPE/RAINFALL RELATIONSHIPS

3.1 THE GUADALENTIN RAINFALL REGIME

3.1.1 The Guadalentin Basin

The Guadalentin Basin is located in the Murcia region of southeast Spain (Figure 1.1). This region, together with the neighbouring areas of eastern Andalucía and southern Valencia, has the lowest mean annual rainfall of any region in Spain (Rodriguez-Puebla *et al*., 1998; Romero *et al.*, 1998), and indeed of any region in Europe, and is characterized by long periods without rain (Martin-Vide and Gomez, 1999).

The Guadalentin Basin was one of the target areas in the Mediterranean Desertification and Land Use (MEDALUS) research project (Brandt and Thornes, 1996; Geeson and Brandt, 2000) and has been used to develop and test the downscaling approach described in this thesis. Daily rainfall series for the period 1958-1987 were obtained for 22 stations in the Guadalentin Basin area through the MEDALUS project. A subset of six stations was initially identified for the development of the downscaling methodology. Five stations within the Guadalentin Basin itself were selected: Alcantarilla, Alhama de Murcia, Fuente Alamo, Lorca and Totana. The sixth station, Aguilas, is located on the Mediterranean coast just outside the Basin. Station details are given in Table 3.1 and their location is shown in Figure 3.1. The figure also shows mean annual rainfall contours plotted using the 1958-1987 time series for all 22 stations.

3.1.2 Annual and seasonal rainfall

Figure 3.1 and Table 3.1 indicate that there is considerable spatial variability in mean annual precipitation within this relatively small region. The distance between Alcantarilla and Lorca, for example, is about 53 km. It is about 30 km from Lorca to Aguilas, and about 10 km from Alhama de Murcia to Totana. Mean annual rainfall ranges from 178 mm at Aguilas to 418 mm at Alhama de Murcia. The mean annual number of rain days ranges from 28 days at Totana (and 29 days at Aguilas) to 48 days at Alcantarilla.

The varying precipitation regimes of the six stations reflect the effects of complex topography in this region (Figure 3.2). The main river valley runs from southwest to northeast, from Lorca, through Totana, to Alcantarilla and Murcia. At Murcia, the main river channel becomes known as the Segura. The land rises steeply to the north of the valley, reaching about 1500 m in the Sierra de Espuña just to the northwest of Alhama de Murcia. A series of mountain/hill ranges lies to the south of the valley, extending down to the Mediterranean coast. These reach a maximum altitude of about 900 m in the Sierra de la Almenara to the northeast of Aguilas. Fuente Alamo lies between the coastal ranges to the south (which reach about 500 m here) and the Sierra de Carrascoy and Sierra del Puerto, which run parallel to the Guadalentin river (terminating about half way between Alcantarilla and Totana) and reach a little over 500 m.

The seasonal cycle of mean monthly rainfall for the wettest (Alhama de Murcia) and driest (Aguilas) of the six stations is plotted in Figure 3.3. The rainfall regime of all stations in the Basin is typically Mediterranean in that winter rainfall is at least three times the summer rainfall (Köppen, 1936) but differs from that across much of the Mediterranean Basin in having two peaks: a major peak in October and a slightly lower peak in April (Figure 3.3). Strong seasonal variation is a typical feature of much of the western Mediterranean, which lies in the transition zone between the mid-latitude low pressure belt and the subtropical highs (Romero *et al*., 1998). The two rainfall peaks are due, in part, to the seasonal migration of the polar and subtropical jets (Linés Escardó, 1970; Wigley and Farmer, 1982). In autumn, the southern branch of the polar jet stream lies over the Iberian Peninsula, between 40° and 50° N. In winter it moves south of the Peninsula, as far as 25° N. In spring, it migrates northwards, passing over the Peninsula again and bringing a second precipitation maximum (Linés Escardó, 1970).

3.1.3 Standardised anomaly indices

Changes in annual and seasonal rainfall in the Guadalentin Basin over the period 1958-1987 were investigated using standardised anomaly indices. By compositing data from a number of stations, it is often possible to obtain a clear signal of trend or pattern in the data, which would not be apparent by examining time series from individual stations. Because the means and standard deviations of individual records differ, it is necessary to standardise prior to compositing (Nicholson, 1983). The formula for the calculation of standardised anomaly indices (SAIs) is:

$$\mathrm{SAI} = \frac{1}{n}\sum_{i=1}^{i=n}\left[\left(x_{ij} - \bar{x}_i\right)/\sigma_i\right] \qquad \text{Equation 3.1}$$

where *n* is the number of stations, *x* is the precipitation at station i for year *j*, $\bar{x}$ is the station mean and σ is the standard deviation.

Annual and seasonal SAIs (Figure 3.4) were constructed for precipitation amount and the number of rain days using the six stations listed in Table 3.1. Linear trends were calculated for each annual and seasonal SAI but none were statistically significant and are not therefore shown. Although significant linear trends cannot be identified, a number of distinctive sub-periods are apparent, most notably in the SAI for annual precipitation amount. The relatively dry periods of, on the one hand, the early and mid 1960s and, on the other, the late 1970s and 1980s, are separated by the relatively wet early 1970s. The seasonal SAIs indicate that this pattern of change is seen throughout the year but is less apparent in the winter months.

In order to provide a wider spatial context for the Guadalentin rainfall variations, annual and seasonal SAIs were constructed for precipitation amount using 36 station records from the Iberian Peninsula (Figure 3.5). No statistically significant linear trends can be identified over the period of record, 1958-1987, but distinctive sub-periods are again evident. The late 1960s/early 1970s are relatively wet, while the late 1970s/early 1980s are relatively dry. These sub-periods are most evident in the annual and summer SAIs and least evident in the winter and autumn SAIs. The annual SAI indicates more year-to-year variability in the earlier part of the record (the late 1950s/early 1960s), reflecting the different patterns in individual seasons.

The SAIs for the Guadalentin Basin and the Iberian Peninsula reflect the general trend towards decreasing rainfall over the Peninsula and the Mediterranean region as a whole (Palutikof *et al*., 1996; Esteban-Parra *et al*., 1998; Rodriquez-Puebla *et al*., 1998; Goodess and Palutikof, 2000). Both SAIs end in 1987. An analysis of 410 rain gauge records from the Mediterranean regions of Spain for the period 1964-1993 provides information about more recent changes (Romero *et al*., 1998). Romero *et al*. describe rainfall changes for the three decades, 1964-1973, 1974-1983 and 1984-1993. In areas most sensitive to Atlantic influences (western Catalonia, and central and western Andalucía), each decade is successively drier. In areas more sensitive to Mediterranean influences, including the Guadalentin Basin, the middle decade is driest. This is largely attributed to the occurrence of anomalously dry autumns (Romero *et al*., 1998), which are also evident in the Guadalentin SAI (Figure 3.4).

An analysis of precipitation time series from 15 Spanish stations (including Murcia in the Guadalentin) for the period 1958-1998 undertaken by the author of this thesis as part of the ACCORD (Atmospheric Circulation Classification and Regional Downscaling) project funded by the European Commission, also indicates a general tendency towards decreasing mean seasonal precipitation in all seasons except summer, although relatively few of the trends are statistically significant (see the Final Report of Partner 01, January 2000, at http://www.cru.uea.ac.uk/cru/projects/accord/contents.htm). The only exceptions to this general tendency towards decreasing precipitation occur along the southeastern Mediterranean coast at Malaga, Murcia and Valencia. However, the only significant positive trend occurs at Malaga in summer. Despite the lack of marked downward trends for Murcia in the ACCORD analysis, some notably dry seasons have occurred in recent years. In autumn 1995, for example, only 15 mm of rain fell at Murcia, compared with a seasonal mean (for the period 1956-1997) of 131 mm. No rainfall at all was recorded at Murcia during summer 1998, and only a trace on one day in summer 1994.

3.2 RELATIONSHIPS BETWEEN THE CIRCULATION TYPES AND DAILY RAINFALL

3.2.1 Introduction

In Chapter 2 it was demonstrated that the eight circulation-type groups (Table 2.3) provide a legitimate basis for downscaling because each has a characteristic pressure pattern which produces the expected type and direction of surface flow over the Guadalentin Basin. However, before implementing the downscaling scheme to generate rainfall scenarios it must be shown that meaningful and distinct relationships exist in the observations between the eight circulation-type groups and precipitation.

As a first step, correlation coefficients were calculated between seasonal time series of circulation-type frequency and rainfall amount/number of rain days. Three sets of seasonal rainfall series were used:

i. SAIs of precipitation amount for the Iberian Peninsula (36 stations, see Section 3.1.3 and Figure 3.5);
ii. SAIs of precipitation amount and number of rain days for the Guadalentin Basin (six stations, see Section 3.1.3 and Figure 3.4); and,
iii. Individual time series of precipitation amount and number of rain days for the six Guadalentin Basin stations (standardised using the station mean and standard deviation).

All correlation coefficients which are significant at the 5% level are listed in Table 3.2. The circulation type with the greatest number of significant correlations is the C-type. With the exception of the number of rain days for the Guadalentin SAI in summer, the C-type correlations are all positive. However, no significant C-type correlations occur in winter. Other circulation-type/rainfall correlations are less consistent, although all significant HYC, UC, E/NE and S/SE correlations are positive.

With one exception, all significant A/HYA and UA correlations are negative.

Table 3.2 indicates that there are differences in circulation type/rainfall relationships in the Guadalentin Basin and over the Iberian Peninsula as a whole. For example, in winter, rainfall amount over the Iberian Peninsula is positively correlated with the frequency of the W/NW/SW/N-group. In the Guadalentin Basin, correlations with this circulation-type group are either non significant or negative. These relationships reflect the fact that Atlantic influences are less important in the southeast corner of Spain than over other parts of the Iberian Peninsula (Rodriguez-Puebla *et al*., 1998; Romero *et al*., 1998; Serrano *et al*., 1999).

3.2.2 Rainfall contributions

The mean frequencies of the eight circulation-type groups vary considerably from group to group (Figure 2.4, Table 2.4). For downscaling purposes, it is interesting to know whether there are any particular circulation types which contribute more (or less) to rainfall than might be expected on the basis of their frequency of occurrence alone. Initially, this was investigated by comparing the mean frequency of each circulation type with the percentage contribution to total annual rainfall at each of the six Guadalentin Basin stations (Figure 3.6).

It is possible to identify those of the eight circulation-type groups for which the contribution to annual rainfall is significantly greater (or less) than average (Figure 3.6). The percentage contribution to annual rainfall from the UC-type is the same as the percentage of days which are of this type (about 25%). In contrast, the E/NE-type also contributes about 25% of annual rainfall, but occurs on less than 10% of days. The percentage contributions to annual rainfall of the C, HYC and S/SE-types are also greater than the percentage of days on which they occur. The rainfall contribution from the A/HYA, UA and W/NW/SW/N-types is considerably lower than their percentage occurrence.

Seasonal circulation-type frequencies and rainfall contributions are shown in Figure 3.7. Some relationships are clearly consistent from season to season. The percentage contributions to seasonal rainfall of the A/HYA-type and the W/NW/SW/N-group are lower than the percentage of days on which they occur in every season, while the percentage contributions of the HYC and E/NE-types are higher than the percentage of days on which they occur in every season. Relationships for the other circulation types are not so consistent from season to season. The percentage contribution of the S/SE type, for example, is greater than its frequency of occurrence in winter, summer and autumn, but about equal in spring. The contribution from the UC-type is greater than its frequency of occurrence in winter, spring and autumn, but less in summer.

3.2.3 Rainfall probabilities/intensities

The high percentage rainfall contribution from the C, HYC, E/NE and S/SE-types (Figures 3.6 and 3.7) may be because a high proportion of days of a particular type are wet, or because there are only a few wet days, with a large amount of rainfall on each. It is important to distinguish between the two, because the potential impacts are quite different. For example, runoff and erosion may be limited when rainfall is spread over a large number of low-intensity days but may be a serious problem where there are a few high-intensity rain days.

The first possibility, that a high proportion of type days are wet, is indicated by the ratio $PROP_{ct}/PROP_{tot}$, where $PROP_{ct}$ is the proportion of type days which are wet and $PROP_{tot}$ is the proportion of all days which are wet. The second possibility, that a large amount of rain falls on each type day, is indicated by the ratio $PREC_{ct}/PREC_{tot}$, where $PREC_{ct}$ is the mean amount of rain which falls on a wet type day and $PREC_{tot}$ is the mean amount of rain which falls on any wet day. Annual and seasonal ratios have been calculated for each station and are plotted in Figures 3.8 and 3.9 for $PROP_{ct}/PROP_{tot}$ and $PREC_{ct}/PREC_{tot}$ respectively. For a circulation type with a ratio greater (less) than 1.0, the likelihood of rain or the amount of rain per rain day is greater (lower) than the station mean.

The ratios indicate considerable between-season variability, but a number of consistent relationships can be identified. While the C, HYC, and (in winter) the UC-types tend to have a high proportion of wet days of average intensity, the E/NE and S/SE-types also tend to have a high proportion of wet days but of high intensity. The amount of rain per rain day tends to show greater variability from station to station than the proportion of wet days, particularly in summer and autumn.

The similarity of the pressure patterns underlying the C and HYC-types was noted in Section 2.3.2 and it was concluded that it would be legitimate to combine them if they share a similar rainfall regime. At the annual level, the rainfall regimes of the two types are similar. Both have a higher than average proportion of wet days, for example. The rainfall regimes are broadly similar in winter and spring, but are different in summer and autumn when both the probability of rain and the amount of rain per rain day are consistently higher for the HYC-type. For these reasons, it was decided not to combine these two types.

3.3 EVALUATION OF CIRCULATION TYPE/RAINFALL RELATIONSHIPS

A number of consistent relationships can be identified between the circulation types and the rainfall regime and are summarised in Table 3.3. The important high-rainfall circulation types are the C, HYC, UC, E/NE and S/SE-types whereas the A/HYA, UA and W/NW/SW/N-types are the most consistent low-rainfall types. The extent to which these relationships can be explained by the synoptic situation underlying each type (Section 2.3) is discussed here.

The cyclonic types (C, HYC and UC) have a higher than average proportion of rain days, in at least some seasons (Table 3.3), but, except in spring for the HYC-type and in autumn for the UC-type, do not have a higher than average amount of rain per rain day. This may be because the rain is associated with frontal events rather than more 'explosive' convective events, and/or because of the short sea track across the Mediterranean (Figure 2.5). In Section 2.3.2, it was noted that the C and HYC-type anomaly patterns (Figure 2.6) resemble the Greenland Above mode of the NAO (van Loon and Rogers, 1978). This circulation mode produces high-pressure blocking in the Northeast Atlantic, and a more meridional circulation (Jacobeit, 1987; Moses *et al.*, 1987; Maheras, 1988). Upper-air troughs and incursions of polar air over the Mediterranean are more frequent, and the Atlantic storm tracks are displaced south. All these factors are conducive to wetter conditions in the western Mediterranean (Perry, 1981; Jacobeit, 1987; Moses *et al.*, 1987; Maheras, 1988; Kutiel *et al.*, 1996).

The A/HYA anomaly pattern (Figure 2.6) resembles that associated with the Greenland Below mode of the NAO (van Loon and Rogers, 1978) and with high positive values of the NAO pressure index (Hurrell, 1995). During times of high NAO index, moisture transport across the North Atlantic has a more southwest-to-northeast orientation and extends further into northern Europe and Scandinavia. In contrast, moisture transport, and hence rainfall, is reduced over southern Europe and the Mediterranean (Hurrell, 1995; Hurrell and van Loon, 1997; Moulin *et al.*, 1997). Thus the NAO index is negatively correlated with rainfall in the Iberian Peninsula (Hurrell, 1995; Rodo *et al*., 1997; Esteban-Parra *et al*., 1998). The southwest-to-northeast orientation of prevailing flow is evident in the composite SLP maps for the A/HYA-type (Figures 2.5 and 2.6). The high-pressure centre over the Iberian Peninsula, together with the relatively short sea track of the prevailing circulation (Figure 2.5), is unlikely to cause precipitation over southeast Spain. The synoptic conditions associated with the W/NW/SW/N-group (Figure 2.5) also result in zonal flow which, in this case, will bring rain to the Atlantic coast of the Iberian Peninsula, but not to the sheltered southeast Mediterranean coast (Linés Escardó, 1970; Wheeler and Martin-Vide, 1992; Serrano *et al.*, 1999). A number of studies confirm that rainfall tends to be below average across the western Mediterranean when zonal circulation dominates (Jacobeit, 1987; Maheras, 1988; Bardossy and Caspary, 1990; Kutiel *et al.*, 1996).

High-pressure blocking in the Northeast Atlantic occurs in the Greenland Above mode of the NAO (van Loon and Rogers, 1978) and is also seen in the cyclonic and E/NE-type anomaly patterns (Figure 2.6). In comparison with the cyclonic types, the E/NE-type positive anomalies are associated with a much stronger and more clearly-defined high-pressure centre (Figure 2.5). Moreover, the area of below average pressure is much smaller, and is located over the central-southern Mediterranean rather than over the Iberian Peninsula (Figure 2.6). This configuration gives a longer sea track across the Mediterranean (Figure 2.5), allowing surface and near-surface air masses to pick up more moisture and heat. The prevailing winds are onshore along the southeast Spanish coast and over the Guadalentin Basin. Rainfall, often convective in nature, is likely to occur when warm, moist air masses meet the coastal mountains (Linés Escardó, 1970; Dalu and Gregorio, 1987; Fernández Mills, 1995; Romero *et al*., 1998; 1999a,b).

Onshore flow over the Guadalentin Basin is also produced by the S/SE-type although the direction of approach is somewhat different, with a shorter track over the Mediterranean (Figure 2.5). Flow from this direction is sometimes associated with Atlantic depressions, approaching from the southwest and funnelled through the Straits of Gibraltar (Tout, 1991; Wheeler and Martin-Vide, 1992), or with depressions formed in the Gulf of Cadiz and moving eastwards (Linés Escardó, 1970). These systems can bring high rainfall to the Andalucía region, but are less likely to be associated with high-intensity rainfall in the Guadalentin.

The synoptic conditions underlying the E/NE-type resemble those associated with the most destructive high-rainfall events in this region of Spain (Linés Escardó, 1970; Wheeler, 1988; Lawson, 1989; Tout and Wheeler, 1990; Wheeler, 1990; Tout, 1991; Sumner *et al*., 1993). These storm events are a characteristic feature of the Spanish Mediterranean coast from Catalonia in the north to Andalucía in the south, a distance of about 1000 km, and of the Balearic Islands (Romero *et al*., 1998). They are most likely to occur in the autumn, particularly in October. Three processes essential for their initiation have been identified (Linés Escardó, 1970; Wheeler, 1988; Tout and Wheeler, 1990; Sumner *et al*., 1993). The first is the advection from the east/northeast towards the coast of very warm and moist air across the western Mediterranean Sea, which is at its warmest in the autumn. The second is the advection of cold air in the middle and upper-atmosphere from the north to the Iberian Peninsula, often associated with Northeast Atlantic blocking and the development of cut-off lows. The third is orographic uplift over the coastal mountains. All three processes are likely to occur on E/NE-type days. It is noted that severe storms were reported across southeast Spain and the Guadalentin Basin in October 1973 (18^{th}-19^{th}) and 1982 (19^{th}-20^{th}) (Tout and Wheeler, 1990) on days classified as E/NE. But severe storms also occur on other type days and not all E/NE days are associated with storms. The October 1988 (13^{th}-19^{th}) storms which affected most of southeast Spain (Lawson, 1989), for example, occurred on days classified as HYC.

The UC-type also appears as a high intensity rainfall type in autumn, and has a higher than average proportion of rain days in winter and spring (Table 3.3, Figures 3.8 and 3.9). In autumn, both the UC and E/NE-types are associated with a greater than average number of days with more than 20 mm rainfall (50-60% of these type days), although these types only occur on about a third of all autumn days. The appearance of the UC-type as a high-rainfall type is unexpected from the anomaly patterns, although they do tend to produce easterly/northeasterly flow over southeast Spain (Figure 2.6). It is a common circulation type in spring and autumn (Table 2.4) when the polar jet stream is closest to the Iberian Peninsula (Wallén, 1970; Wigley and Farmer, 1982), but the anomaly pattern is weak (Figure 2.6).

It is not, therefore, possible to identify a unique “storm-type day” from analysis of the rainfall characteristics and the synoptic situation at the surface associated with each circulation type. This is not surprising, given that some of the worst storms which have been experienced in southeast Spain were considered hard to forecast in real time (Linés Escardó, 1970; Wheeler, 1988; Tout and Wheeler, 1990). Nonetheless, it is concluded that the important high-rainfall circulation types in the Guadalentin Basin are the C, HYC, UC, E/NE and S/SE types. The A/HYA, UA and W/NW/SW/N types are all low-rainfall circulation types. Although there are some outstanding questions concerning the underlying causes, and the stability, of the circulation type/rainfall relationships (Chapter 4), they provide an appropriate basis for the next stage in the development of the downscaling methodology: the construction of a conditional weather generator.

3.4. DEVELOPMENT OF A CONDITIONAL WEATHER GENERATOR

3.4.1 Introduction

A weather generator is a statistical model which can be used to simulate time series of variables such as daily precipitation (Wilks and Wilby, 1999). Many of these models are based on a Markov Chain process in which the probability of a wet day depends only on whether the previous day was wet or dry (Richardson, 1981; Wilks, 1989; Wilks, 1992; Katz, 1996; Mearns *et al*., 1996; Riha *et al*., 1996; Wilby *et al*., 1996; Mearns *et al*., 1997; Skiles and Richardson, 1998; Wilby *et al*., 1998a). A common problem with these stochastic models is that, while the mean rainfall statistics are simulated reasonably well, the extremes and low-frequency variability are underestimated (Gregory *et al*., 1993; Mearns *et al*., 1996; Semenov *et al*., 1998; Katz and Zheng, 1999). They can be used to generate climate change scenarios by adjusting the parameters which control the frequency and intensity of precipitation, together with the variability if desired (Wilks, 1992; Katz, 1996; Riha *et al*., 1996; Mearns *et al.*, 1997; Semenov and Barrow, 1997; Wilks, 1999a). The parameters can be adjusted using grid-box precipitation output as a guide, or to fit some arbitrary scenario (such as a 10% increase in mean rainfall).

A number of studies have used stochastic techniques for downscaling daily precipitation to derive regional scenarios (Wilks, 1992; Conway *et al*., 1996; Katz and Parlange, 1996; Perica and Foufoula-Georgiou, 1996; Semenov and Barrow, 1997; Wilby and Wigley, 1997; Wilby *et al*., 1998b; see also Section 1.2). However, the most relevant studies for the purposes of this thesis are those which use statistical models in which rainfall occurrence is conditional upon the circulation pattern of each day, and in which the transition from one circulation type to another may also be modelled as a Markov Chain process (Bardossy and Plate, 1991; Hay *et al.*, 1991; Bardossy and Plate, 1992; Wilson *et al.*, 1992; Hughes *et al.*, 1993; Wilby, 1993; Hughes and Guttorp, 1994; Wilby *et al.*, 1994; Katz and Parlange, 1996; Corte-Real *et al*., 1999a; Hughes and Guttorp, 1999; Katz and Zheng, 1999). Many of these studies stress the potential of such models, referred to here as conditional weather generators (CWGs), for downscaling and scenario development. In these studies, climate-change scenarios are driven by the simulated changes in circulation patterns. The first published study in which a CWG was run using parameters calculated from GCM output was that of Hughes *et al*. (1993). In this case the CWG was developed and tested in the temperate oceanic region of the Colombia River Basin, northwest USA. The sensitivity studies described below were designed to determine whether a CWG can perform reasonably well in a very different, Mediterranean, rainfall regime and whether it can, therefore, be used to produce plausible daily rainfall scenarios for such a region.

3.4.2 The conditional weather generator

The CWG used here follows the approach of Hay *et al.* (1991) and Wilby (Wilby, 1993; Wilby *et al.*, 1994). It is a first-order, two-state Markov model, i.e. rainfall is dependent on the condition of the previous day and has only two possible states, wet or dry. Rainfall occurrence is defined by two parameters calculated for each of the eight circulation types and for each season: the cumulative probability ($PROBct_{1\text{-}8}$) (expressed as a transition matrix) of the next day being circulation-type 1 (C) to 8 (S/SE), and the mean probability of rain (*PROBPRECct*) related to each type. The $PROBct_{1\text{-}8}$ transition matrix and *PROBPRECct* values for Alcantarilla for each season calculated from the observations are shown in Table 3.4. On each day, a random number is selected (from a uniform distribution, 0 to 1) and used to determine the next day's circulation type from the transition matrix. A second random number is selected, and used to determine whether the day is wet or dry. (For the purposes of the sensitivity experiments described here, only the number of rain days (NRD) is of interest. The amount of rain can, however, be simulated by additional sampling from an appropriate distribution (as described in Chapter 6.)

The CWG was used to produce climate-change rain day scenarios based on the assumption that changes in circulation-type frequency will be propagated through to changes in rainfall frequency. This assumption cannot be tested for the future but can be tested, in part, for the past by looking at observed circulation-type/rainfall relationships. The proportion of circulation-type days which are wet at Alcantarilla is shown in Figure 3.10 for each season and for overlapping decades during the period 1958-1987. The greatest variability occurs in cases where there are very few (less than three) type-days (C in winter and autumn, and S/SE in summer). Figure 3.10 demonstrates that there are coherent and stable relationships between the circulation-type frequencies and rainfall occurrence. Thus it is reasonable to assume that changes in circulation-type frequency should be reflected as changes in rainfall occurrence, even under conditions of global warming.

For the CWG to be used to generate rainfall scenarios, it is necessary to overcome the problem that the UKTR GCM fails to simulate the frequency of circulation types realistically (Section 2.4). Therefore, the $PROBct_{1\text{-}8}$ transition matrix generated from the GCM control run must also be unrealistic. Two approaches could be adopted:

(a) calculate transition matrices from GCM output, and express climate change as the difference between the results for the perturbed run and control run simulations; or,

(b) perturb the observed transition matrices in a way which is consistent with the percentage changes in circulation-type frequency indicated by the model.

It is not obvious how the second approach could be implemented in a self-consistent manner. The first approach was, therefore, adopted in the sensitivity studies described below.

3.5 SIMULATIONS PERFORMED WITH THE CONDITIONAL WEATHER GENERATOR

3.5.1 Description of the three simulation sets

Three sets of 100 30-year long simulations were performed for the six Guadalentin Basin stations listed in Table 3.1. In all simulations, the CWG was run for 30 days to remove the memory of the starting point before starting to record results. The sequence of circulation types in each 30-year simulation is dependent on the transition matrix and the random number generator. These will vary if a different initial seed is chosen for each of the 100 runs. Here, the PC clock is used the provide the initial seed. Thus the 100 sequences making up each simulation set will be different. Each simulation was run for 30 years in order to match the length of the observed record. Since the circulation-type sequence is generated by the model, each simulation could be run for a much longer period, say 100 or even 1000 years (to allow the calculation of extreme events with very long return periods, for example). Whereas if the circulation types are taken directly from the GCM, the simulation length is restricted by the availability of GCM output (here, 10 years).

In the first simulation set (*Gen.*, Section 3.5.2), the CWG parameters ($PROBct_{1\text{-}8}$ and *PROBPRECct*) were calculated from the observed data. All available days for 1958-1987 with both MSLP and rainfall data were used in order to maximise the sample sizes (i.e. 1958-1960, 1965-1976, 1978-1987, minus various missing days during these 25 years). The output from these simulations cannot, therefore, be used for independent validation in the conventional way. Validation of a stochastic model is, however, somewhat different to validation of a deterministic model. It can be difficult, for example, to separate inherent problems with a weather generator from the inherent variability of weather that occurs even if the model is perfectly representative of the real climate (Hayhoe, 2000). Given the nature of these models, it has been argued that validation should focus on the ability to reproduce variance and persistence rather than mean values (Gregory *et al*., 1993; Zorita and von Storch, 1999).

In the second set of simulations (*Cont.*, Section 3.5.3), the $PROBct_{1-8}$ parameters were calculated from control-run output of the UKTR GCM and *PROBPRECct* was calculated from the observations. These simulations allow further investigation of the GCM's ability to simulate the frequency of circulation types. In the final set of simulations (*Pert.*, Section 3.5.4), the $PROBct_{1-8}$ probabilities were calculated from perturbed-run GCM output and *PROBPRECct* was again calculated from the observations. The differences between the *Pert*. and *Cont*. simulations provide the rain-day climate change scenarios (Table 3.7).

The performance of the CWG is similar at all stations. The discussion in Sections 3.5.2 and 3.5.3 is, therefore, restricted to results for one station, Alcantarilla. These results are summarised in Table 3.5 (circulation types: *CT*) and Table 3.6 (number of rain days: *NRD*). Results for the other five stations are not shown, except for the mean rain day changes in Table 3.7. The mean (*M*) and standard deviation (σ) were calculated for every 30-year time series from the *Gen.* (*g*), *Cont.* (*c*), and *Pert.* (*p*) simulation sets. Thus, for each season, the vectors indicated by notation such as $M_{g(CT)}$ or $\sigma_{\mathrm{p(NRD)}}$ contain 100 values. Means of the *CT* vectors are shown in Table 3.5. Maximum and minimum values of $M_{c(CT)}$ and $\sigma_{c(CT)}$ were also calculated but are not shown. Mean frequencies and standard deviations taken directly from the observed series ($\overline{\mathrm{Obs}}_{(CT)}$ and $\sigma_{\mathrm{obs}(CT)}$) and for UKTR control-run output ($\overline{\mathrm{UKTR}}_{(CT)}$ and $\sigma_{\mathrm{uktr}(CT)}$) are shown in the first two rows for comparison.

In Table 3.6 the following values are shown for the observed Alcantarilla rainfall series: mean NRD ($\overline{\mathrm{Obs}}_{(NRD)}$) and standard deviation ($\sigma_{\mathrm{obs(NRD)}}$), and length in days of the longest wet (LW_{obs}) and dry (LD_{obs}) periods. The *LW* and *LD* parameters provide an indication of rainfall persistence. The means of the $M_{g(NRD)}$, $M_{c(NRD)}$, $M_{p(NRD)}$ and $\sigma_{g(NRD)}$, $\sigma_{c(NRD)}$, $\sigma_{p(NRD)}$ vectors are also shown, together with the maximum and minimum vector values. The right-hand columns show vector means for the *LW* and *LD* parameters.

The 100 individual time-series from the *Gen*. and *Cont*. simulations were each compared with the observed series using the Mann Whitney/Wilcoxon rank sum test (a non-parametric equivalent of the *t* test). The variance of these individual series was compared using the Siegel-Tukey rank sum dispersion test (a non-parametric equivalent of the *F* test; Kanji, 1993). Tables 3.5 and 3.6 show the number of times out of 100 simulations that the mean or standard deviation of the simulated series is significantly greater (Sig+) or smaller (Sig-) than that of the observed series. The M_c and M_p vectors were compared using the Mann Whitney-Wilcoxon rank sum test. A '+' (-) in the Sig row of Table 3.5 indicates that the mean of the M_p vector is significantly greater (smaller) than the mean of the M_c vector. The equivalent for Table 3.6 is the symbol '**' in either the Sig+ or Sig- row. A 5% significance level was used for all tests.

3.5.2 Evaluation of the *Gen.* simulations

The $PROBct_{1\text{-}8}$ parameters used in the *Gen*. simulations were calculated from the observations so the simulated circulation-type frequencies ($M_{g(CT)}$) were expected to agree well with the observations ($\overline{\text{Obs}}_{(CT)}$). Table 3.5 confirms that agreement is good. The greatest differences occur in winter for the C-type: 25 simulations have means significantly below observed. This discrepancy may be related to the low probability of the C-type in winter (on average only 2 days per winter (Table 2.4)). The most infrequent circulation type is the S/SE-type in summer (1.2 days) and this type is also underestimated by the CWG (23 simulations are significantly lower than observed). However, in all seasons and for every circulation type, the simulated maximum and minimum values (not shown) fall either side of the observed mean, i.e. the observed means are within the simulated range.

Circulation-type standard deviations ($\sigma_{g(CT)}$) are generally underestimated by the CWG (Table 3.5). The greatest number of significant differences (54 underestimates) occurs in summer for the UA-type. For most circulation types the simulated maximum and minimum values (not shown) fall either side of the observed standard deviation, but in summer the simulated maximum is smaller than observed for five circulation types. Thus the CWG has a tendency to underestimate the observed variance but, except in summer, the effect is not great.

The mean NRD ($M_{g(NRD)}$) is very well simulated, with a maximum of five out of 100 significant underestimates in summer and no significant differences in spring and autumn (Table 3.6). The effect of the CWG on rain-day variance is much greater. With the exception of summer the simulated maximum standard deviation ($\sigma_{g(NRD)}$) is always smaller than observed ($\sigma_{\text{obs}(NRD)}$). The CWG also underestimates the *LW* and *LD* parameters. The CWG simulates a wet or dry day only on the basis of the circulation type for that day, with no memory of previous rainfall occurrence. A possible way to improve performance would be to include a persistence parameter (Hay *et al.*, 1991; Wilby *et al.*, 1994). A number of sensitivity experiments were performed using a range of arbitrary persistence parameters. Although it was possible to increase the persistence of wet and dry spells, because the NRD is well simulated to start with, new errors were introduced. Similar difficulties were encountered by Wilby *et al*. (1994), who ended up with a compromise between good reproduction of mean values and higher persistence. This approach was not, therefore, pursued further.

3.5.3 Evaluation of the *Cont.* simulations

The $PROBct_{1-8}$ parameters used in the *Cont*. simulations were calculated from UKTR control-run output. Hence good agreement was expected, and found, between the *Cont*. ($M_{c(CT)}$) and *UKTR* ($\overline{\text{UKTR}}_{(CT)}$) circulation-type frequencies (Table 3.5). For the same reason, the *Cont*./*Obs*. differences in Table 3.5 ($M_{c(CT)}$ / $\overline{\text{Obs}}_{(CT)}$) closely follow those identified in Section 2.4.2. All circulation types with more than 90 out of 100 significant differences in Table 3.5, with the exception of the C-type in spring, are also shown as significantly different in Table 2.5. The CWG performance is worst in winter, when none of the eight circulation-type mean frequencies fall within the simulated range (not shown), and best in autumn when five are within range.

The mean *Cont*. circulation-type year-to-year standard deviations ($\sigma_{c(CT)}$), calculated over 100 weather generator runs, tend to be lower than the *UKTR* standard deviations ($\sigma_{\text{uktr}(CT)}$), except in summer. They also tend to be somewhat lower than the *Gen*. standard deviations ($\sigma_{g(CT)}$). In summer the observed standard deviations ($\sigma_{\text{obs}(CT)}$) of only three circulation types are within the simulated range while seven circulation types are within range in winter.

In spring, almost all of the 100 simulated means ($M_{c(NRD)}$) are significantly lower than observed and the overall mean NRD is 24% lower than observed (Table 3.6). About a quarter of the simulated means are significantly lower than observed in winter with a percentage error in the overall mean NRD of 13%.

The mean NRD is reproduced well in the *Gen*. simulations ($M_{g(NRD)}$). Thus the discrepancies between the *Cont*. and *Obs*. means ($M_{c(NRD)}$ and $\overline{\text{Obs}}_{(NRD)}$) must be due to errors in the GCM simulation of circulation-types. The largest errors in the *Cont.* time-series occur in winter and spring. The frequency of the UC and E/NE-types (both high rainfall types) is underestimated in these seasons (Tables 2.5 and 3.5). The low-rainfall A/HYA and W/NW/SW/N-types are overestimated.

The smallest circulation-type errors occur in autumn and tend to balance each other out. For example, underestimation of the dry W/NW/SW/N-type is offset by overestimation of the dry A/HYA-type. Hence the smallest NRD errors also occur in autumn.

The *Cont*. standard deviations of NRD, and the *LW* and *LD* parameters, are underestimated in all seasons and are similar to the *Gen*. values. This indicates that loss of variance and persistence is an inherent feature of the CWG and that the relatively small underestimation of circulation-type variance in the GCM has little effect on the rain-day series. It is concluded that, for NRD, while problems with the simulated variance are related primarily to the effects of the CWG, problems with the simulated means are related primarily to errors in the underlying GCM output.

3.5.4 The climate-change scenarios

The change in the mean NRD (calculated as the mean of vector $M_{p(NRD)}$ minus the mean of vector $M_{c(NRD)}$) and in the NRD standard deviation (calculated as the mean of vector $\sigma_{p(NRD)}$ minus the mean of vector $\sigma_{c(NRD)}$) for each season and each station is shown in Table 3.7. Changes which are significant at the 5% level are shown (calculated using the Mann Whitney-Wilcoxon rank sum test). The pattern of change is consistent for all stations. These scenarios indicate that the average NRD in the Guadalentin Basin could increase by 10-18% in summer in a future warmer world, and decrease by 5-9% in spring. A very small increase (2-4%) is indicated in winter, and little change in autumn (0-2%).

The rainfall scenarios in Table 3.7 can be compared with the changes in circulation-type frequency shown in Table 2.6. The largest circulation changes occur in summer. Of the high-rainfall types, there is a significant increase in the frequency of the C and HYC-types. The frequency of both the E/NE and S/SE high-rainfall types increases in summer, but the changes are not significant. Of the low-rainfall types, the A/HYA and UA-types show a significant decrease in frequency in summer and the W/NW/SW/N group shows a non-significant decrease. The combined effect of these changes is expected to be an increase in the number of rain days in summer, as seen in the downscaled rainfall scenarios (Table 3.7). Few significant or consistent changes in circulation-type frequency are predicted in other seasons. In spring, however, decreases in the high-rainfall C, HYC, E/NE and S/SE-types, together with increases in the low-rainfall UA and W/NW/SW/N-types, suggest a reduction in the number of rain days, as indicated in Table 3.7.

The scenarios in Table 3.7 are calculated as the difference between the means of 100 simulated series. Alternatively, differences between pairs of simulations could be used to produce a range of scenarios. For the NRD, the maximum-possible range of these scenarios is provided by the maximum $M_{p(NRD)}$ minus minimum $M_{c(NRD)}$ value given in Table 3.6 (upper limit) and by the minimum $M_{p(NRD)}$ minus maximum $M_{c(NRD)}$ value (lower limit). For the example of summer rain-day changes at Alcantarilla, this range is +2.9 to -1.4 days, indicating uncertainty about the sign of change. The upper limit of 2.9 days is greater than the observed summer standard deviation ($\sigma_{obs(NRD)}$). The lower limit of -1.4 days is slightly smaller than the observed standard deviation. This pattern occurs at all stations in summer.

The rain-day scenarios presented here are intended as illustrative results rather than as reliable projections. The underlying UKTR GCM changes in MSLP and circulation-type frequency between the control and perturbed runs are generally small and, except in summer, not significant. Nonetheless, the cumulative effect of these changes is such that the CWG results do indicate changes in the number of rain days which are significant (in terms of model variance but not observed variance) in spring and summer. Such a pattern of change is unlikely to be beneficial for the Guadalentin Basin. Fewer rain days are indicated during spring which is an important season for agriculture and groundwater recharge. An increase in the number of rain days is indicated outside the main growing season and during the period of highest evaporation (summer) when the soil surface is most vulnerable to erosion.

3.6 SUMMARY OF CONCLUSIONS

- A number of consistent relationships can be identified between the eight circulation-type groups and the rainfall regime of six stations in the Guadalentin basin. These relationships are supported by the underlying synoptic situation associated with each circulation-type group.
- A conditional weather generator (CWG), in which rainfall occurrence is conditional on the circulation type of each day and the daily sequence of circulation types is modelled as a Markov Chain process, is used to simulate the number of rain days for six stations in the Guadalentin.
- The impact of errors arising from the poor UKTR simulation of circulation-type frequency and from the inherent nature of the CWG itself are both evident in the CWG output.
- The CWG is used to investigate future changes in rain-day occurrence. The largest changes occur in summer, but in general the changes are small and only significant in terms of model, not observed, variability.

Table 3.1: Details of the six Guadalentin stations. Means are for the period 1958-1987.

	Lat.	*Long.*	*Alt.(m)*	*Mean annual rainfall (mm)*	*Annual rainfall: standard deviation*	*Mean number of rain days*	*Rain days: standard deviation*
Aguilas	37.4	-1.6	5	178	74	29	11
Alcantarilla	38.0	-1.2	75	289	113	48	12
Alhama de Murcia	37.9	-1.5	760	418	145	44	13
Fuente Alamo	37.7	-1.2	200	272	107	34	8
Lorca	37.7	-1.7	335	234	83	38	11
Totana	37.8	-1.5	200	293	121	28	7

Table 3.2: Significant correlations (at the 5% level) identified between rainfall amount (prec.) and number of rain days (NRD), and circulation-type frequency time series. Guad. = Guadalentin, IP = Iberian Peninsula, SAI = standardised anomaly index.

	Guad. SAI	*Aguilas*	*Alcan-tarilla*	*Alhama de Murcia*	*Fuente Alamo*	*Lorca*	*Totana*	*IP SAI*
Winter prec.								
HYC								+0.44
A/HYA		-0.44						-0.43
W/NW/SW/N								+0.43
E/NE	+0.42		+0.51					
Winter NRD								
HYC			+0.51					
UC		+0.48						
A/HYA	-0.55	-0.45	-0.46	-0.44				
Spring prec.								
C	+0.63	+0.47	+0.65	+0.57	+0.63	+0.52	+0.59	+0.78
UA								-0.58
Spring NRD								
C	+0.71	+0.56	+0.64	+0.71	+0.70	+0.60	+0.53	
HYC	+0.40		+0.43		+0.43			
UA	-0.49		-0.59	-0.51	-0.52	-0.45		
W/NW/SW/N					-0.40		-0.43	
Summer prec.								
E/NE	+0.47		+0.41	+0.47			+0.42	
Summer NRD								
C	-0.45							
A/HYA							+0.45	
E/NE	+0.40	+0.45						
S/SE			+0.46					
Autumn prec.								
C					+0.47		+0.42	+0.43
HYC								+0.41
UA								-0.44
Autumn NRD								
C	+0.47	+0.44	+0.48		+0.40	+0.41	+0.50	
W/NW/SW/N		-0.41						

Table 3.3: High-rainfall circulation types with a higher than average proportion of wet days at every station (+) and a higher than average amount of rain per rain day at every station (*).

Low-rainfall circulation types with a lower than average proportion of wet days at every station (-) and a lower than average amount of rain per rain day at every station (x).

	C	*HYC*	*UC*	*A/HYA*	*UA*	*W/NW/ SW/N*	*E/NE*	*S/SE*
High rainfall								
Annual	+	+					+ *	+
Winter	+	+	+				+ *	+
Spring	+	+*[1]	+				+ *	
Summer		+					+ *	+
Autumn	+	+	*				+ *	+
Low rainfall								
Annual				-	-	-x		
Winter				-		-x		
Spring				-	-x	-x		
Summer	x		x	-x	-	-		
Autumn	x	x		-	-	-x		

[1] Rain per rain day is higher than average at every station except Aguilas.

Table 3.4: The circulation-type transition matrix (*PROBct*$_{1\text{-}8}$) for Alcantarilla and the probability of rainfall (*PROBPRECct*) calculated from the observations for each season.

Next day / *current day*	*C*	*HYC*	*UC*	*A/HYA*	*UA*	*W/NW/SW/N*	*E/NE*	*S/SE*
WINTER:								
C	.1481	.3704	.5000	.5370	.6481	.8519	.9815	1.000
HYC	.1236	.2921	.4045	.4607	.4944	.7416	.9551	1.000
UC	.0500	.1250	.2938	.4063	.6563	.8313	.9125	1.000
A/HYA	.0066	.0116	.0314	.4645	.6430	.9273	.9570	1.000
UA	.0108	.0280	.1312	.3634	.7720	.8860	.9462	1.000
W/NW/SW/N	.0187	.0576	.1058	.3092	.3681	.9304	.9866	1.000
E/NE	.0045	.0090	.0769	.2353	.4796	.5701	.9819	1.000
S/SE	.0459	.1284	.2110	.3761	.5780	.7248	.7431	1.000
PROBPRECct	00.40	00.38	00.29	00.06	00.15	00.12	00.22	00.29
SPRING:								
C	.3111	.5278	.7389	.7444	.8000	.9556	.9944	1.000
HYC	.1457	.3046	.5563	.5695	.6093	.8609	.9934	1.000
UC	.0940	.1744	.5949	.6239	.7949	.9009	.9709	1.000
A/HYA	.0100	.0100	.0697	.3085	.6070	.8806	.9254	1.000
UA	.0305	.0521	.3106	.3842	.7522	.8887	.9515	1.000
W/NW/SW/N	.0197	.0538	.1434	.2778	.4391	.9122	.9928	1.000
E/NE	.0149	.0410	.2090	.2575	.5187	.5784	.9739	1.000
S/SE	.0957	.1565	.3565	.3652	.5043	.6174	.6348	1.000
PROBPRECct	00.41	00.33	00.18	00.03	00.06	00.11	00.29	00.13
SUMMER:								
C	.3420	.5238	.9048	.9048	.9264	.9784	.9957	1.000
HYC	.1940	.4179	.6915	.6915	.7413	.8408	.9801	1.000
UC	.0815	.1561	.7590	.7607	.8877	.9297	.9974	1.000
A/HYA	.0000	.0204	.1633	.3673	.9184	.9796	1.000	1.000
UA	.0059	.0255	.4479	.4774	.8939	.9411	.9862	1.000
W/NW/SW/N	.0145	.0290	.2029	.3406	.6957	.8841	1.000	1.000
E/NE	.0185	.0694	.3519	.3704	.6157	.6250	.9352	1.000
S/SE	.2188	.3438	.7813	.7813	.8438	.8750	.9063	1.000
PROBPRECct	00.06	00.11	00.06	00.00	00.02	00.02	00.10	00.16
AUTUMN:								
C	.2133	.3467	.6400	.6400	.6933	.8533	.9867	1.000
HYC	.1319	.3077	.5824	.5934	.6264	.8352	.9560	1.000
UC	.0382	.0816	.6042	.6302	.8594	.9253	.9826	1.000
A/HYA	.0068	.0136	.0340	.4320	.7313	.9490	.9592	1.000
UA	.0044	.0204	.2336	.3387	.8117	.9255	.9723	1.000
W/NW/SW/N	.0180	.0563	.1239	.2838	.4302	.9234	.9865	1.000
E/NE	.0190	.0284	.1185	.2275	.4597	.5261	.9716	1.000
S/SE	.0805	.1724	.3218	.3333	.5057	.6437	.6552	1.000
PROBPRECct	00.30	00.33	00.18	00.03	00.09	00.10	00.31	00.28

Table 3.5: Summary of CWG circulation-type results for Alcantarilla for each season.

	NUMBER OF CIRCULATION-TYPE DAYS								***STANDARD DEVIATION***							
	C	*HYC*	*UC*	*A/ HYA*	*UA*	*W/NW/ SW/N*	*E/ NE*	*S/ SE*	*C*	*HYC*	*UC*	*A/ HYA*	*UA*	*W/NW/ SW/N*	*E/ NE*	*S/ SE*
WINTER																
$\overline{Obs}_{(CT)}/\sigma_{obs(CT)}$	2.1	3.1	5.7	21.6	16.8	28.0	8.7	3.9	1.3	1.7	2.2	6.5	6.4	7.1	4.8	1.9
$\overline{UKTR}_{(CT)}/\sigma_{uktr(CT)}$	4.0	4.1	3.8	24.6	8.5	41.3	1.8	1.9	2.0	2.5	1.5	6.8	3.4	7.0	1.2	1.7
Mean of $M_{g(CT)}$ / $\sigma_{g(CT)}$	2.1	3.5	6.1	21.6	16.5	28.3	7.9	4.1	1.6	2.2	2.6	5.1	4.8	6.4	3.6	2.4
Sig+	2		1	1	2		1		1	3	2					3
Sig-	25	6	7					6				3	4	2	7	
Mean of $M_{c(CT)}$ / $\sigma_{c(CT)}$	4.1	4.2	3.9	24.3	8.5	41.3	1.7	2.0	2.2	1.9	2.0	4.5	3.4	6.0	1.5	1.8
Sig+	92	11		34		100										
Sig-			100		100		100	100		4		12				
Mean of $M_{p(CT)}$ / $\sigma_{p(CT)}$	3.5	4.3	3.0	24.9	12.0	36.9	1.6	4.0	2.2	2.0	1.6	5.1	3.9	5.8	1.4	2.3
Sig	-	+	-	+	+	-		+	+	+	-	+	+			+
SPRING																
$\overline{Obs}_{(CT)}/\sigma_{obs(CT)}$	6.1	5.6	20.3	7.2	19.7	19.4	9.6	4.1	3.7	3.0	5.3	3.5	5.5	6.3	2.7	2.7
$\overline{UKTR}_{(CT)}/\sigma_{uktr(CT)}$	3.7	4.6	11.7	19.1	21.2	23.5	3.8	4.5	2.7	3.0	4.6	5.4	5.8	8.0	2.1	2.9
Mean of $M_{g(CT)}$ / $\sigma_{g(CT)}$	5.8	5.5	21.1	6.8	19.4	19.9	9.5	3.9	3.0	2.5	5.2	2.9	4.7	5.5	3.9	2.6
Sig+			3										1		48	
Sig-	3	1		3	2	3	12	4	5	6	2	5	12			5
Mean of $M_{c(CT)}$ / $\sigma_{c(CT)}$	3.7	4.7	11.7	19.2	21.3	23.4	3.7	4.4	2.3	2.5	3.6	4.6	5.1	5.5	2.5	2.7
Sig+				100	12	61										1
Sig-	97	30	100				100	3	8	5			5			7
Mean of $M_{p(CT)}$ / $\sigma_{p(CT)}$	3.0	3.1	12.1	18.1	23.8	26.2	2.5	3.2	1.9	1.9	3.7	4.3	5.2	5.8	2.1	2.3
Sig	-	-	+	-	+	+	-	-	-	-	+	-		+	-	-
SUMMER																
$\overline{Obs}_{(CT)}/\sigma_{obs(CT)}$	7.9	6.9	42.3	2.0	19.1	4.9	7.8	1.1	5.3	4.2	9.4	3.1	9.1	2.6	3.3	1.1
$\overline{UKTR}_{(CT)}/\sigma_{uktr(CT)}$	2.8	5.9	27.4	9.8	24.2	4.6	16.2	1.1	1.5	2.5	4.4	2.7	3.4	2.9	5.3	1.2
Mean of $M_{g(CT)}$ / $\sigma_{g(CT)}$	8.3	7.5	43.9	1.4	16.9	4.8	7.9	1.3	3.8	3.0	6.1	1.3	4.8	2.4	3.4	1.2
Sig+					1			10							1	1
Sig-	1	3	2	9		5		23	1	3		12	54			4
Mean of $M_{c(CT)}$ / $\sigma_{c(CT)}$	2.8	6.1	27.6	9.3	23.8	4.8	16.5	1.1	1.6	2.6	5.6	3.7	5.6	2.4	4.9	1.3
Sig+				100	100		100	21						1		3
Sig-	100	66	100			11		53	15	2			26			2
Mean of $M_{p(CT)}$ / $\sigma_{p(CT)}$	7.5	9.3	30.6	5.1	16.8	3.5	17.6	1.6	4.0	3.7	6.1	3.0	4.9	2.0	4.8	1.3
Sig	+	+	+	-	-	-	+	+	+	+	+	-	-	-		
AUTUMN																
$\overline{Obs}_{(CT)}/\sigma_{obs(CT)}$	2.7	2.9	20.9	11.1	25.2	17.2	8.1	3.0	2.2	1.7	6.2	4.4	7.7	7.4	3.5	2.6
$\overline{UKTR}_{(CT)}/\sigma_{uktr(CT)}$	2.8	3.5	20.4	16.7	27.4	6.9	6.5	6.8	1.8	1.4	7.5	7.4	8.4	3.7	2.7	4.6
Mean of $M_{g(CT)}$ / $\sigma_{g(CT)}$	2.8	3.4	20.7	11.5	24.5	17.7	7.2	3.1	2.0	2.1	6.2	4.4	5.5	5.7	3.5	2.3
Sig+	1	10		3		4				2		3			1	
Sig-	13	8	9	1	1		15	2	5				2	21		8
Mean of $M_{c(CT)}$ / $\sigma_{c(CT)}$	2.8	3.5	19.6	17.1	27.6	7.2	6.4	6.9	2.0	2.1	5.6	4.9	6.0	3.0	2.6	3.6
Sig+	1	14		100	47			100		3						
Sig-	12	6	36			100	36		6				20			2
Mean of $M_{p(CT)}$ / $\sigma_{p(CT)}$	1.9	3.1	22.4	14.5	24.7	10.8	5.7	8.0	1.4	1.8	5.7	5.2	5.8	4.1	2.9	3.6
Sig	-	-	+	-	-	+	-	+	-	-		+	-	+	+	

Table 3.6: Summary of CWG rain-day results for Alcantarilla. See text for full explanation.

	NUMBER OF RAIN DAYS				*STANDARD DEVIATION*				*LW*				*LD*			
	$\overline{\text{Obs}}_{(NRD)}$	$M_{g(NRD)}$	$M_{c(NRD)}$	$M_{p(NRD)}$	$\sigma_{obs(NRD)}$	$\sigma_{g(NRD)}$	$\sigma_{c(NRD)}$	$\sigma_{p(NRD)}$	LW_{obs}	LW_g	LW_c	LW_p	LD_{obs}	LD_g	LD_c	LD_p
Winter																
Mean	14.8	14.1	12.9	13.2	6.4	3.5	3.3	3.4	9	3	3	3	59	35	37	39
Max		15.8	14.2	15.0		4.9	4.2	4.5								
Min		12.3	11.2	11.8		2.4	2.3	2.3								
Sig+				**				**								
Sig-		1	26			73	74									
Spring																
Mean	14.7	14.9	11.2	10.5	6.0	3.6	3.3	3.1	9	4	3	3	59	34	43	46
Max		16.8	12.5	12.1		4.7	4.8	4.4								
Min		13.5	9.7	9.2		2.6	2.2	2.3								
Sig+																
Sig-			97	**		96	94	**								
Summer																
Mean	5.2	5.4	5.0	5.7	2.1	2.2	2.1	2.2	4	2	1	2	89	68	68	64
Max		6.6	6.1	7.0		3.3	2.8	3.4								
Min		4.3	4.1	4.7		1.5	1.5	1.3								
Sig+				**				**								
Sig-		5	22			1	1									
Autumn																
Mean	13.3	13.2	13.2	13.5	6.3	3.4	3.4	3.6	7	3	3	3	59	39	39	38
Max		14.7	14.9	15.3		4.6	4.7	4.6								
Min		11.5	11.6	11.9		2.2	2.5	2.4								
Sig+				**				**								
Sig-						100	100									

Table 3.7: Mean change (*Pert*. minus *Cont*.) from the 100 simulations, of the mean (mean of $M_{p(NRD)}$ minus mean of $M_{c(NRD)}$) and standard deviation (mean of $\sigma_{p(NRD)}$ minus mean of $\sigma_{c(NRD)}$) of the number of rain days simulated by the CWG for six stations in the Guadalentin Basin. Significant changes are shown in bold.

	WINTER	*SPRING*	*SUMMER*	*AUTUMN*
Mean				
Aguilas	**+0.3**	**-0.7**	**+0.3**	00.0
Alcantarilla	**+0.3**	**-0.7**	**+0.7**	**+0.3**
Alhama de Murcia	**+0.3**	**-1.0**	**+0.6**	+0.1
Fuente Alamo	**+0.2**	**-0.5**	**+0.6**	**+0.1**
Lorca	**+0.3**	**-0.8**	**+0.6**	+0.1
Totana	**+0.3**	**-0.7**	**+0.4**	00.0
Standard deviation				
Aguilas	**+0.1**	**-0.2**	00.0	00.0
Alcantarilla	**+0.1**	**-0.2**	**+0.1**	**+0.2**
Alhama de Murcia	00.0	**-0.2**	**+0.2**	00.0
Fuente Alamo	00.0	**-0.1**	**+0.2**	00.0
Lorca	00.0	**-0.1**	**+0.2**	**+0.1**
Totana	**+0.2**	**-0.2**	**+0.1**	00.0