Chapter 5

EFFECT OF TEMPORAL SCALES OF STORM DATA ON EROSION

5.1 Introduction

When modelling soil erosion, finding suitable input data for the simulation is an important part of model-based researches but it is not easy. Ideally, input data need to be measured directly from a study site and parametrized for a model simulation. However, this process requires a great effort and time. It is also frequently affected by geographical and financial situations of research. All these reasons affect how rainfall data are made available in different scales either spatially, temporally or both. Thus, we often end up using what is readily available rather than what is really required by erosion models.

Rainfall intensity is highly variable depending on data scales and where they are measured from (Nyssen *et al.*, 2005). Consequently, using rainfall data that have a undesired data scale for erosion simulations may produce unknown implications that may later lead to inaccurate model outputs. Therefore, this chapter aims to investigate effects of different temporal scales of rainfall data on erosion model simulation processes.

In addition, which data format between CLIGEN and breakpoint data is more suitable for current research was looked at.

The results of this chapter and the subsequent chapters attempts to provide some answers for Research Question 2:

> Assuming that we use a model to predict erosion rates under the future climate which may have different rainfall intensities from the present, what information do we need to make predictions in terms of both climate and process understanding?

5.2 Data Preparation and Method

Two storms that occurred on 4 July 2000 and on 11 October 2000 were selected from Plumpton event rainfall dataset (P) (Table 3.2). The storm on 11 October 2000 was selected because the rainfall amount of this event was exceptionally high (133.8 mm) for the area and was related to severe erosion and property damage (Boardman, 2001). The return period for such a event is estimated at around 300 years (Saunders *et al.*, 2001). All three stations that record event rainfalls in the region observed a exceptional rainfall on the same day (Figure 3.15). However, Plumpton station (P) recorded the highest rainfall amount. This "October" storm was typical of frontal, low-intensity event that occur in winters in South Downs, UK. In comparison, the "July" storm that occurred on 4 July 2000 was selected from the same year in order to increase the diversity of storm patterns that are investigated in this chapter. This storm is typical of summer storm that has a shorter duration than "October" storm (Table 5.1) and has a distinctive high intensity peak in the middle of storm duration. Rainfall amount of this storm also is comparably high and distinctive.

The duration of "October" event was 1208 minutes (i.e. 20 hours and 8 minutes). Average intensity for this rainfall was 6.65 mm/hr with 1-min peak intensity of 84 mm/hr. The "July" rainfall, on the other hand, was recorded with total rainfall amount of 74.8 mm and duration of 808 minutes (i.e. 13 hours and 28 minutes). Average intensity for this event was 5.5 mm/hr with 1-min peak intensity reaching to 60 mm/hr. The details of two events are summarised in Table 5.1.

Table 5.1 Details of two rain storms observed in Plumpton

	11 October 2000	4 July 2000
Amount (mm)	133.8	74.8
Total duration (min)	1208	808
Average intensity (mm/hr)	6.7	5.5
Effective duration (min)	460	313
1-min peak intensity (mm/hr)	84	60

Tipping-bucket data for both events were aggregated into 5 different temporal scales—1, 5, 15, 30 and 60 minutes. This was done to simulate different temporal scaled rainfall data. Each temporal scale was treated as if it was the "baseline" scale for the data with these being the only records available. Two sets of temporally varying "July" and "October" storm data were prepared into CLIGEN and breakpoint data format for erosion estimations.

CLIGEN rainfall data describe a rainfall storm with four parameters: total rainfall amount (R, inch), effective rainfall duration (D, minute), normalised time to peak (t_p) and normalised peak intensity (i_p). Effective daily rainfall duration was calculated by summing the number of temporal bins with rainfall on the event day, after removing temporal bins without rainfall. Effects of removing these "gaps" are investigated in the following section, Chapter 6. Normalised time to peak is a relative time of peak intensity after the removal of gaps. Normalised peak intensity is a peak intensity that is relative to average rainfall intensity of the storm. These four parameters were calculated individually for each time-scaled data (Table 5.2), and weather inputs for WEPP were built (cf. Appendix A).

Breakpoint data, on the other hand, consist of two parameters: (accumulated) rainfall time and (accumulated) rainfall amounts or intensity. Each dataset was converted into these two parameters, and the number of breakpoints was counted. Breakpoint weather inputs for WEPP are also shown in Appendix A.

Then, two process-based erosion models, WEPP and EUROSEM, are used at the current stage to simulate runoff and soil loss. RillGrow is not used in this chapter because of the data scale and computational time issues involved with using RillGrow. Temporal scales that RillGrow simulates with is very small so that it requires a considerably long computational time compared to the duration that is simulated for. To give an idea, RillGrow2 requires almost 7 hours, for example, for running a 45-min simulation. This makes using RillGrow for this set of investigations very impractical considering the number of simulations and the total duration of computational time required. Thus, only two models, WEPP and EUROSEM, are used in this chapter.

CLIGEN data and breakpoint data prepared from rainfall data with 1, 5, 15, 30 and 60-min temporal scale were used for the simulations to investigate the effect of different temporal scale. EUROSEM was designed to use only breakpoint rainfall data so that it would be a good comparison to WEPP which has been originally designed to use CLIGEN data as well as breakpoint data.

As pointed out, EUROSEM uses breakpoint rainfall data only. This means that, unless the EUROSEM code was rewritten, using CLIGEN data directly with EUROSEM is not possible. Rewriting of EUROSEM code would not be viable for the scope of this research. Thus, to use CLIGEN data for EUROSEM simulations, an additional procedure was carried out to make sure that the same rainfall data were used as for

WEPP simulations.

According to WEPP model document, WEPP disaggregates CLIGEN data into ten breakpoints using a double exponential equation before calculating erosion related parameters (see Flanagan and Nearing, 1995, §2.2). These disaggregated breakpoint data can be found in one of WEPP output files. For EUROSEM simulations, these breakpoint data from WEPP outputs were used in place of CLIGEN data. This makes the rainfall data used for WEPP and EUROSEM essentially the same for both simulations (Figure 5.1).

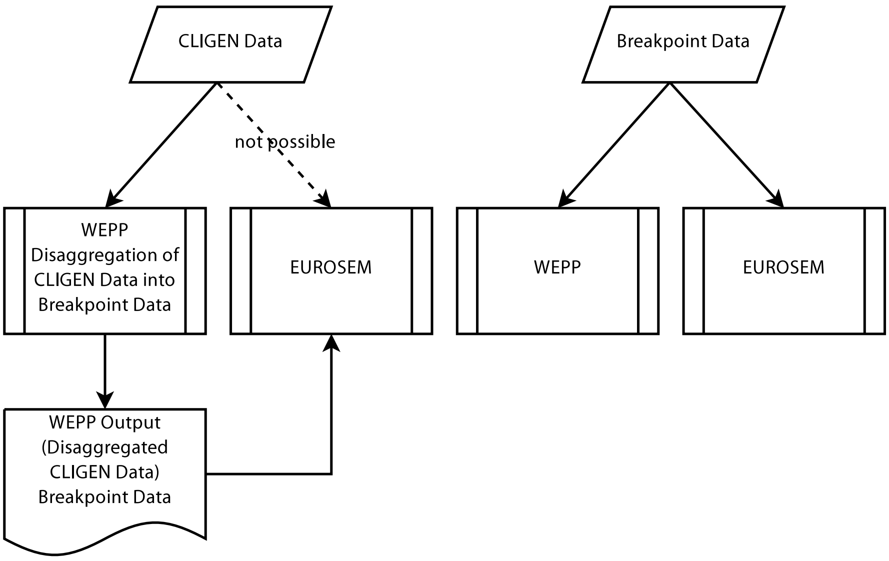


Figure 5.1 A diagram of WEPP and EUROSEM simulations with CLIGEN and breakpoint data

Other inputs for EUROSEM were adopted from WEPP outputs as no direct measurements were available to build EUROSEM inputs from scratch. This approach may be problematic for certain modelling studies. However, in this research, it permits a workaround to problems of unavailable factors for EUROSEM simulation. It needs to be noted again that the emphasis of this research is not on assessing the performance of models against measured data.

The effect of the temporal scales on rainfall intensity, runoff and soil loss were examined. For comparison purpose, 15-min data were used as a reference scale when comparisons were done to highlight the effects. 15-min scale is the scale that were used for the CLIGEN development.

5.3 Effects on Rainfall Intensity Information

CLIGEN data for two storms were built by calculating rainfall amount, duration, peak intensity and time to peak. These values are individually calculated for each temporal scale. The details of the input parameters are shown in Table 5.2.

Table 5.2 CLIGEN data parameters for two rain storms observed in Plumpton

	11 October 2000				4 July 2000			
	amount (mm)	duration† (hr)	t_p	i_p	amount (mm)	duration† (hr)	t_p	i_p
1-min	133.8	7.4	0.12	4.64	74.8	5.2	0.63	4.20
5-min	133.8	12.8	0.46	5.53	74.8	11.1	0.58	6.41
15-min	133.8	15.5	0.49	2.87	74.8	13.3	0.54	3.69
30-min	133.8	17	0.93	2.69	74.8	14	0.52	2.95
60-min	133.8	18	0.64	2.23	74.8	14	0.54	2.65

† effective rainfall duration, t_p: normalised time-to-peak, i_p: normalised peak intensity

As shown is Table 5.2, each set of temporally varying rainfall data shows different total rainfall durations. This is because of their time intervals being in different sizes. Therefore, effective rainfall duration increases as temporal data scale increases. With rainfall amounts remaining the same, the changes in duration mean that rainfall intensity information is also affected by the temporal scale of rainfall data. Peak rainfall intensities are affected by the data scale too. Moreover, the change of temporal scale shifts the temporal location of peak intensity (t_p). This means that the shape of a storm may change from, for example, ascending intensity to descending intensity. Effects of storm shapes on soil erosion are further investigated in Chapter 7.

Table 5.3 Number of time intervals (breakpoints) for each temporal scale

Temporal scale (min)	1	5	15	30	60
4 July 2000	315	135	55	30	16
11 October 2000	460	152	63	35	19
Max. no. of intervals (per day)	1440	288	96	48	24

For breakpoint data, the maximum numbers of time intervals per day as well as the number of breakpoints for each storm are shown in Figure 5.3. The number of breakpoints for the storms decreases as the temporal scale increases. Also, the rainfall data with different temporal scales show different rainfall intensity information (Figure 5.2 and 5.3). Higher temporal resolution data show higher instantaneous peak rainfall intensities. With 1-min data of the "October" storm, for example, a peak rainfall intensity was over 80 mm/hr (Figure 5.3a). In comparison, 60-min data of the "October" storm show no peak rainfall intensity higher than 20 mm/hr (Figure 5.3e). This is because rainfall intensity is averaged over the length of each time step. Time to peak rainfall intensity is also different for each temporal scale depending on which two bins (i.e. breakpoints) added together and averaged (Figure 5.2 and 5.3).

5.4 Effects on Simulated Runoff and Soil Loss

The breakpoint data prepared for both "October" and "July" events with 1 and 5-min time intervals could not be used for WEPP and EUROSEM because of model limitations. During investigation, it was found that WEPP and EUROSEM limits the total number of breakpoints that they can process (Flanagan and Livingston, 1995; Morgan *et al.*, 1998*a*). These limitations are discussed further later in the chapter. Thus, no runoff and soil loss rates were estimated with 1 and 5-min breakpoint data. Instead, CLIGEN data with 1 to 60-min scales and breakpoint data with 15 to 60-min scales were used to estimate runoff and soil loss rates.

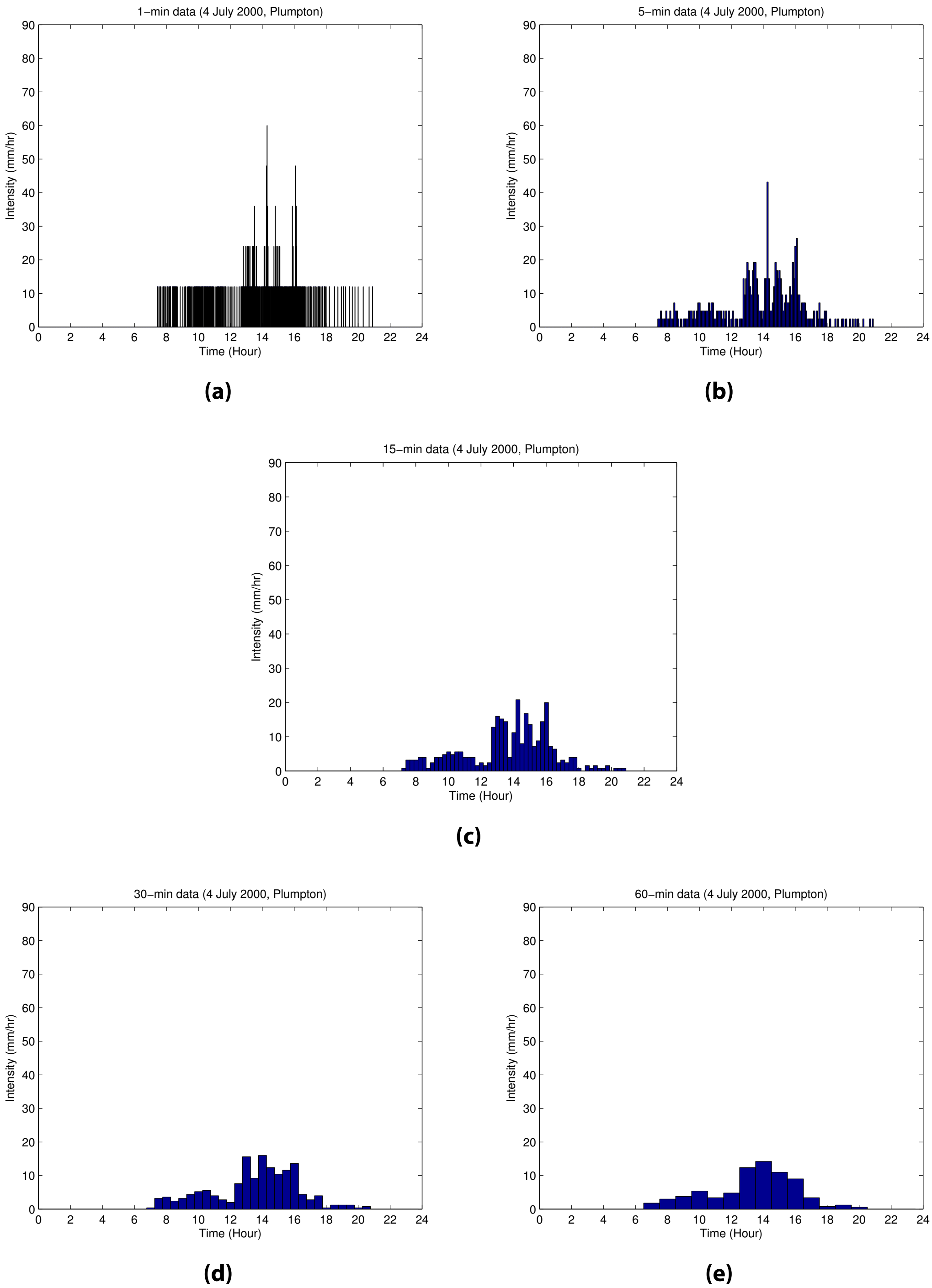


Figure 5.2 Various temporal scales of original breakpoint data for 4 July 2000 storm in Plumpton

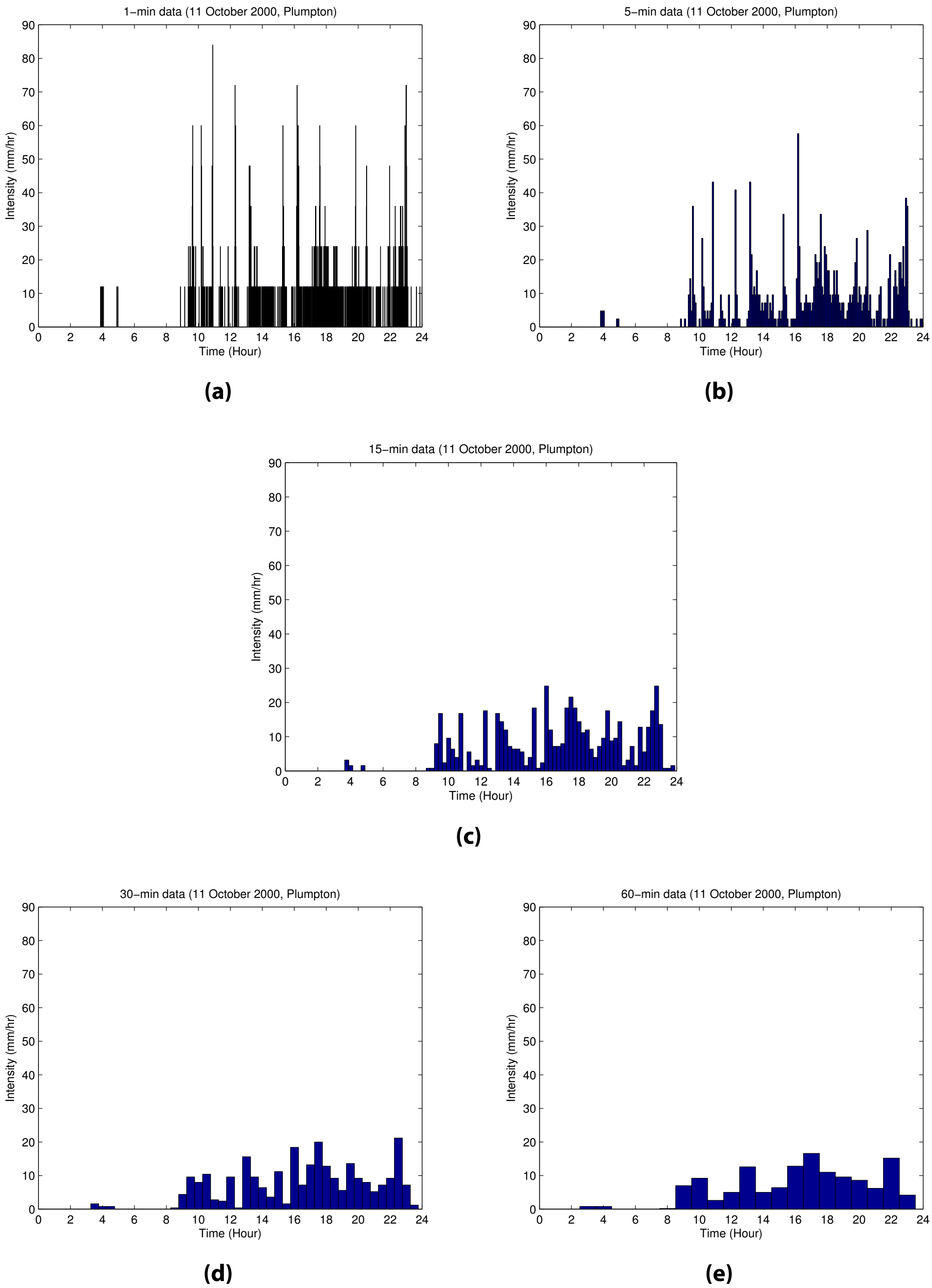


Figure 5.3 Various temporal scales of original breakpoint data for 11 October 2000 storm in Plumpton

5.4.1 Effect of Temporal Scales on Runoff

In overall, WEPP and EUROSEM estimated greater runoff when rainfall data with high temporal scales were used than when rainfall data with low temporal scales were used. However, this is only true for CLIGEN data type. For breakpoint data format, the effect of temporal data scales is rather unclear for both models.

Runoff amounts estimated by WEPP with CLIGEN and breakpoint rainfall data for each time scale are shown in Table 5.4. Results from WEPP simulations show that the changes of runoff rates from the runoff rates simulated with 15-min CLIGEN data are greater when simulated with 1-min CLIGEN data than with 5-min CLIGEN data. For example, using 1-min data instead of 15-min data of “July” storm resulted in about 45% increase in runoff and 30% increases for “October” storm (Table 5.4). Using 60-min data, on the other hand, of the same storms results in about 20% and 10% decreases in runoff amounts compared to using 15-min data, respectively (Table 5.4). The effect of changes of temporal scales are greater when CLIGEN data of the July event are used than the October event.

Table 5.4 WEPP estimated runoff (mm) with different temporal scales of CLIGEN and breakpoint rainfall data

		Temporal Scale				
Data type	Event	1-min	5-min	15-min	30-min	60-min
CLIGEN	4 Jul 2000	49.7 (+44.5)	44.5 (+29.4)	34.4	29.3 (−14.8)	27.0 (−21.5)
	11 Oct 2000	97.4 (+29.9)	89.4 (+19.2)	75.0	75.0	67.5 (−10.0)
Breakpoint	4 Jul 2000	–	–	30.4	29.8 (−2.0)	29.7 (−2.3)
	11 Oct 2000	–	–	63.9	68.5 (+7.2)	69.9 (+9.4)

Figures in ( ) are the % changes from the result with the 15-min data. +/− indicates a increase or decrease.

When breakpoint data are used, the opposite is observed—the magnitude of the changes are greater for the October event even though these changes are upward changes. In other words, WEPP-simulated runoff rates are greater when 30 or 60-min breakpoint

Table 5.5 EUROSEM estimated runoff (mm) with different temporal scales of CLIGEN and breakpoint rainfall data

		Temporal Scale				
Data type	Event	1-min	5-min	15-min	30-min	60-min
CLIGEN	4 Jul 2000	53.3 (+54.1)	42.2 (+22.0)	34.6	31.5 (−9.0)	30.7 (−11.3)
	11 Oct 2000	102.1 (+22.6)	93.6 (+12.4)	83.3	80.1 (−3.8)	75.9 (−8.9)
Breakpoint	4 Jul 2000	–	–	33.2	32.6 (−1.8)	37.0 (+11.5)
	11 Oct 2000	–	–	62.7	69.1 (+10.2)	74.4 (+18.7)

Figures in ( ) are the % changes from the result with the 15-min data. +/− indicates a increase or decrease.

data of the October event are used than when 15-min breakpoint data of the same storm are used. For the July event, decreases in runoff are observed when breakpoint data with the same temporal scales (i.e. 30 or 60-min) are used. Also, the magnitude of changes in simulated runoff rates from 15-min data scale are slightly greater for 60-min data scale than for 30-min data scale. Despite these contrasting responses, changing temporal scales of breakpoint data for both rainfall events resulted in changes of WEPP runoff generations.

Runoff results generated by EUROSEM for CLIGEN and breakpoint rainfall data with each time scale are shown in Table 5.5. Runoff results from EUROSEM simulations show closely similar results to those from the WEPP simulation. Particularly, when CLIGEN data are used, increases and decreases of runoff rates as well as the magnitude of changes in runoff rates depending on temporal scales of the data show the same tenancy as WEPP simulations: The higher the temporal scale is used, the greater the effect is. Also, simulations with breakpoint data of the October storm show the corresponding results to WEPP simulations which show increased runoff rates for the coarser temporal scale. However, when breakpoint data of the July storm are used, EUROSEM interestingly generates over 11% greater runoff rate with 60-min scale than with 15-min scale while still generating the downward change in runoff rate with 30-min scale (Table 5.5).

5.4.2 Effect of Temporal Scales on Soil Loss

Soil loss results generated by WEPP with CLIGEN and breakpoint rainfall data for the different time scales are shown in Table 5.6. WEPP estimates greater soil loss rates with high temporal scales and lesser soil loss rates with coarse temporal scales than with 15-min temporal scale—with one exception of 30-min breakpoint data of the October storm. Soil loss is increased almost 20% when 30-min breakpoint data of the October storm are used in comparison to when 15-min breakpoint data of the storm are used.

For WEPP simulations, soil loss rates are affected more dramatically by the change of temporal scales than runoff rates. For example, with 1-min CLIGEN data of the July event, WEPP estimates almost a 300% increase in soil loss rate and almost a 90% decrease with 60-min CLIGEN data for the same event in comparison to the estimation result with 15-min CLIGEN data (Table 5.6). The effect of changes in temporal scale for the breakpoint data of July storm is also similar to the change patterns with the CLIGEN data which is inversely proportional to the temporal scale. However, 30-min breakpoint data of the October storm show the opposite result that is almost 20% increase in soil loss rate compared to 15-min breakpoint data while 60-min breakpoint data for the same event result in an over 55% decrease in soil loss.

Table 5.6 WEPP estimated soil loss (t/ha) with different temporal scales of CLIGEN and breakpoint rainfall data

		Temporal Scale (minutes)				
Data type	Event	1	5	15	30	60
CLIGEN	4 Jul 2000	47.9 (+283.2)	37.1 (+196.8)	12.5	3.5 (−72.0)	1.6 (−87.2)
	11 Oct 2000	101.6 (+163.2)	86.3 (+123.6)	38.6	29.1 (−24.6)	13.0 (−66.3)
Breakpoint	4 Jul 2000	–	–	17.0	11.4 (−32.9)	3.0 (−82.4)
	11 Oct 2000	–	–	37.7	45.0 (+19.4)	16.9 (−55.2)

Figures in ( ) are the % changes from the result with the 15-min data. +/− indicates a increase or decrease.

Table 5.7 EUROSEM estimated soil loss (t/ha) with different temporal scales of CLIGEN and breakpoint rainfall data

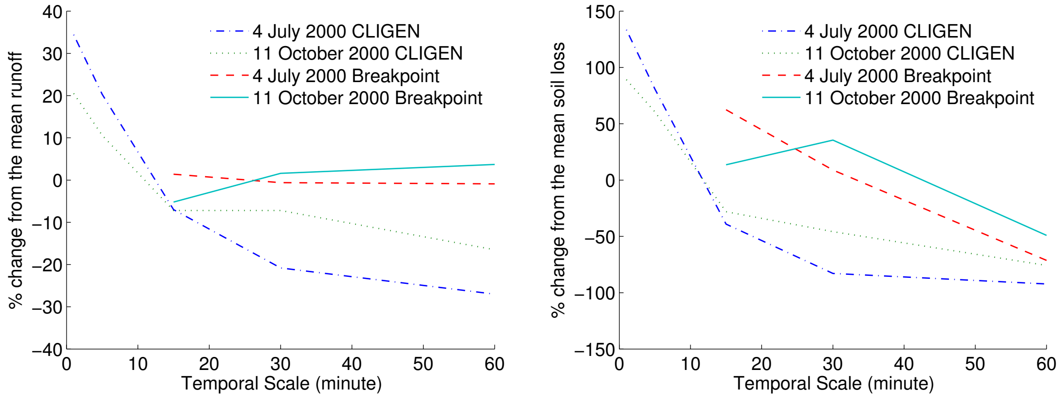
		Temporal Scale (minutes)				
Data type	Event	1	5	15	30	60
CLIGEN	4 Jul 2000	13.0 (+26.2)	10.0 (−2.9)	10.3	10.7 (+3.9)	10.9 (+5.8)
	11 Oct 2000	24.7 (+5.6)	21.5 (−8.1)	23.4	23.8 (+1.7)	25.4 (+8.6)
Breakpoint	4 Jul 2000	–	–	10.0	10.2 (+2.0)	12.0 (+20.0)
	11 Oct 2000	–	–	19.4	21.9 (+12.9)	23.3 (+20.1)

Figures in ( ) are the % changes from the result with the 15-min data. +/− indicates a increase or decrease.

Soil loss rates generated by EUROSEM with CLIGEN and breakpoint rainfall data for each temporal scale are shown in Table 5.7. The result of simulations using EUROSEM shows unanticipated responses to the changes of temporal scales. Except soil loss rates estimated with 5-min CLIGEN data, all soil loss rates estimated with CLIGEN data are increased from the rates estimated with 15-min data (Table 5.7). This means that, with an exception of 1-min CLIGEN data, the simulation results of soil loss rates do not correspond to the runoff rates estimated by EUROSEM with CLIGEN data (Table 5.5). EUROSEM estimates increases in soil loss while estimating decreases in runoff when 30 and 60-min scales of CLIGEN data are used. Also, decreases in soil loss are estimated while increases in runoff are estimated with 5-min scale of CLIGEN data. For breakpoint data, the effect of changes in temporal data scale on soil loss rates is almost—except for the 30-min breakpoint data of "July" storm—consistent with the effect on runoff rates simulated by EUROSEM with breakpoint data.

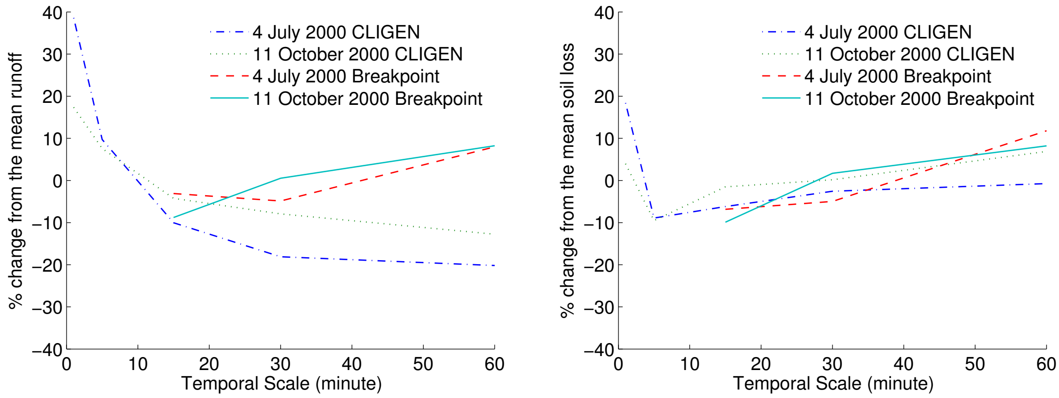
The changes (%) from the mean values of runoff and soil loss simulated by WEPP and EUROSEM are also plotted in Figures 5.4 and 5.5, respectively. These figures show overall responses of runoff and soil loss rates to the changes of temporal data scale.

Changes of temporal scales of CLIGEN rainfall data are inversely proportional to WEPP-simulated runoff and erosion rates (Figure 5.4). CLIGEN data with higher temporal resolutions (i.e. 1-min and 5-min scales) resulted in greater WEPP-simulated



(a) Runoff **(b)** Soil Loss

Figure 5.4 The changes of WEPP simulated runoff and soil loss from average runoff and soil loss. Note the different scale of y-axis in (b) Soil Loss.



(a) Runoff **(b)** Soil Loss

Figure 5.5 The changes of EUROSEM simulated runoff and soil loss from average runoff and soil loss runoff and erosion rate than CLIGEN data with lower temporal resolutions (30-min and 60-min scales). For breakpoint data, temporal data scales have a varying effects on WEPP-simulated runoff and erosion rates and do not show clear correlations with the simulation result (Figure 5.4).

Temporal data scales also have certain effects on runoff and erosion rates simulated by EUROSEM as seen in Figure 5.5. However, EUROSEM-simulated erosion rates show rather different results from results of WEPP simulations. Results of EUROSEM simulations for erosion rates are mostly the opposite from WEPP simulations with some exceptions. Using CLIGEN data generally resulted in decreasing runoff and increasing soil loss rates as temporal scales increase. This is rather unexpected because decreasing runoff rates are normally accompanied by decreasing soil erosion rates. Also, 1-min CLIGEN data is the only temporal scale that show increasing soil loss rates as well as increasing runoff rates (Figure 5.5). For breakpoint data, changes of temporal resolutions resulted in a moderate increasing trend in both runoff and erosion rates. However, the correlation is rather weak because of the lack of data points to consider.

5.5 Discussion

Although WEPP documents states that 15-min data are to be used (Flanagan and Livingston, 1995), 15-min data are not always available for the erosion modelling studies. Thus, the effect of other temporal scales have been investigated. The results were compared against those of 15-min data and average values of runoff and soil loss in terms of the rates of changes (%) to highlight the relative effects of the changes.

Maximum number of breakpoints As mentioned previously, breakpoint data that were prepared for both July and October events with 1-min and 5-min data could not be used for WEPP and EUROSEM. This was because WEPP have a limit on the maximum number of breakpoint which is 50 points per day according to the model document (see Flanagan and Livingston, 1995, page 10). This means that, for a rainfall event that last for a whole day, for example, 30-min data is the highest resolution we can use for WEPP simulations because there are only 48 (24 hr/0.5 hr) intervals available per day. This prohibits the use of breakpoint data with temporal resolution higher than 30-min in theory. In practice, any temporal scale could be used as long as the total number of breakpoints does not exceed 50 points.

Testing with WEPP (v2004.7) revealed that up to 100 breakpoints may be used without a problem. However, when the number of breakpoints exceeds 100 points, WEPP does not recognise the start and end of a rainfall event correctly, and re-aggregates the rainfall with multiple starting points (i.e. 0 minute point). Thus, the maximum number of breakpoints it can handle should be increased to at least 1440 points or more to enable the use of 1-min data or higher temporal data—that is, when daily event is assumed. EUROSEM have the same limitation which prevent from using more than 100 breakpoints. When tested with more than 100 breakpoints, EUROSEM simply does not yield any meaningful output. Also, EUROSEM has a limit on the total number of time increments which should not be more than 1000 per simulation (Morgan *et al.*, 1998*a*). This may pose more difficulties when a storm with an extensively long duration is used for detailed simulations. Therefore, both models need to increase their dimension of breakpoint data array to meet the need.

WEPP vs EUROSEM In terms of soil loss rates estimated by two models, WEPP exhibited greater responses than EUROSEM to the changes of temporal data scales. Although EUROSEM was not as much sensitive as WEPP to the temporal scale of rainfall data, it showed some responses. The biggest change, which was 26.2 %, in soil erosion estimations was observed when 1-min CLIGEN data were used (Table 5.7). In comparison to the WEPP's response (i.e. 283.2 %) for the same CLIGEN data, the change was considerably small (Table 5.6). Even with breakpoint data, 20.1 % change for 60-min breakpoint data was the largest change for EUROSEM (Table 5.7). Again, WEPP estimated 55.2 % change for the same breakpoint data (Table 5.6).

Moreover, EUROSEM results for CLIGEN data were contradictory to the physical process of soil erosion. As shown previously, EUROSEM generated increased soil loss when runoff was decreased (Figure 5.5).

A close examination of EUROSEM model outputs revealed that the estimated amount of "Gross Interrill Eroison" was substantially greater for 1 and 5-min CLIGEN data than for 15, 30 and 60-min CLIGEN data (Table 5.8) while the amount of "Net Erosion Rate" was roughly the same. This means that smaller amounts of "Gross Rill Erosion" were estimated for 1 and 5-min data scales than for the bigger temporal scales. Thus, it seems that there is a certain change in the way EUROSEM calculates rill and interrill erosion rates when the temporal scale of data changes from 15-min to 5-min and vise versa.

As reviewed previously in Chapter 1 (see page 37), the model document indicated that EUROSEM uses separate transport capacity relationships for rill and interrill flows: Govers (1990) for rill transport capacity and Everaert (1991) for interrill transport capacity. In EUROSEM, one flow seems to play more important role than the other on erosion processes depending on the surface condition:

- The surface may contain no rills, but have some surface irregularities

  → Interrill erosion is simulated with a high proportion of the soil surface covered by shallow overland flow.

- The surface may be rilled, with interrill flows routed toward the rills

Table 5.8 Summary of detailed EUROSEM outputs estimated with CLIGEN data

		Temporal Scale (min)				
Output	Event	1	5	15	30	60
Gross Rill Erosion (t/ha)	04 July 2000	10.4	8.8	10.3	10.7	10.9
	11 October 2000	17.5	16.9	23.4	24.1	25.6
Gross Interrill Erosion (t/ha)	04 July 2000	2.8	1.2	0.011	0.009	0.008
	11 October 2000	7	4.6	0.028	0.024	0.02
Net Erosion (t/ha)	04 July 2000	13	10	10.3	10.7	10.9
	11 October 2000	24.7	21.5	23.4	23.8	25.4
Net Rainfall (mm)	04 July 2000	73.9	73.9	73.9	73.9	73.9
	11 October 2000	132.9	132.9	132.9	132.9	132.9
Rain Duration (min)	04 July 2000	312	666	798	840	840
	11 October 2000	444	768	930	1020	1080
Peak Intensity (mm/h)	04 July 2000	55.9	40.5	19.7	14.7	13.5
	11 October 2000	79.4	54.6	22.8	19.5	15.7
Runoff Duration (min)	04 July 2000	199	210	336	415	451
	11 October 2000	433	355	704	656	848
Peak Runoff Rate (mm/h)	04 July 2000	51.7	35.5	15.8	11.1	10.1
	11 October 2000	73.3	51.8	19.8	16.8	12.8
Time to Peak Runoff (min)	04 July 2000	202	389	444	461	473
	11 October 2000	63	359	459	936	722
Infiltration (mm)	04 July 2000	20.2	31.9	39.5	42.5	43.4
	11 October 2000	31.2	40	50.3	52.7	57.5
Runoff (mm)	04 July 2000	53.5	42.1	34.6	31.5	30.7
	11 October 2000	102.1	93.6	83.3	80.1	75.9

→ both shallow flow between rills and downslope flow with bigger carrying capacities are simulated.

- The surface may be furrowed, or have very dense rills, such that interrill routing is illogical due to the short distance traversed by interrill flows

  → "overbank" flow is considered. The two areas (i.e. rill and interrill) are connected as surface elevations become equal. The unified rill profile model can be used.

Therefore, when temporal scale of rainfall data changes from 15-min to 5-min, the slope surface condition, which EUROSEM simulates, shifts from the latter to the second one from the list above. Then, EUROSEM changes its simulation mode so that interril erosion becomes noticeable. This explains why the relatively large interrill erosion was estimated for 1 and 5-min scale. Actually, it seems that the transition of the simulation mode occurs somewhere between 5-min and 15-min of temporal scales.

Yet, reasons for the disagreement between runoff and soil loss rate can not be explained by this "mode-shifting". An in-depth investigation is needed to explain this finding fully.

CLIGEN vs Breakpoint data Rainfall parameters in the CLIGEN input file were originally calculated from 15-min breakpoint data. CLIGEN then used this statistical information to simulate continuous long-term daily rainfall data, which have similar statistical characteristics as the observed data, or individual storm data could be manually calculated to be in the form of four unique parameters: rainfall amount, rainfall duration, normalised peak intensity and normalised time to peak. These four parameters were then used by WEPP to disaggregate the daily rainfall data into ten breakpoint data using a double exponential function.

In total, original breakpoint data had gone through two parametrisation processes effectively. Thus, this procedure of "parametrisation and disaggregation" seems highly inefficient in retaining original rainfall intensity information, particularly for the event with a long duration and low intensity which is similar to the event occurred on 11 October 2000. The rainfall information can be distorted and lost during these data "parametrisation and disaggregation" processes.

One reason why WEPP-CLIGEN use such method seems to be because of the ease of use and data storage for long-term rainfall records. This method—statistically summarising historical climate data and maintaining it—is a very efficient way of storing a large amount of rainfall data. One file (i.e. CLIGEN input file) per weather station requires much less space than tipping-bucket data for, say, 10 to 20 years. This however does have a couple of disadvantages:

1. The concept of CLIGEN data is only suitable for convective storms which do not have many intermittent rainfall phases (no-rain periods) during rainfall.
2. For WEPP to disaggregate CLIGEN data realistically using a double exponent function, each storm should have one distinctive high rainfall peak. Such storms are not typical of many parts of the world, and may be seasonally dependant.

It is, however, evident that CLIGEN data type make it easier to deal with vast amounts of data. It also requires considerably less space to store such data. Also, CLIGEN data are very easy to use with WEPP as it is designed specifically for this purpose.

When only two extreme ends of the scale are considered from the result shown previously in Table 5.6 and 5.7, for example, between 1-min and 60-min CLIGEN data, simulated erosion rates with 1-min data are almost 30 times greater at most than those with 60-min data. This certainly is problematic as far as the effect of temporal scales of rainfall data on erosion rates is concerned. Also, when erosion rates estimated with 15-min and 60-min breakpoint data are compared, erosion rates with 15-min data is over 5 times greater at most than those with 60-min data. Again, a greater difference is observed when erosion rates estimated with CLIGEN data for the same temporal scales are compared. Erosion rates with 15-min CLIGEN data are 7.5 times greater at most than those with 60-min CLIGEN data. Therefore, breakpoint data generally produce smaller changes in erosion rates when temporal scales are changed. This however is not conclusive by any means as the responses of two models (i.e. WEPP and EUROSEM) are rather contradictory for both CLIGEN and breakpoint data.

Data aggregation and rainfall intensity The intensity information of rainfall data is heavily dependant on how they are aggregated. When rainfall data such as tipping-bucket data are aggregated into certain time steps, they are usually stored in a digitized data format. It means the averaged rainfall intensity is dependant on the start time as well as time-steps which is temporal scales. Time-steps and start time are important as the rainfall intensity is averaged over the given time-steps and start point when they are archived. This method, however, unintentionally discards rainfall intensity information by averaging rainfall peaks over the given time step.

The effect of discarding rainfall intensity information has been clearly shown when both rainfall events—i.e. 4 July 2000 and 11 October 2000—were aggregated into varying time steps. Distinctive high intensity peaks in 1-min data (Figures 5.2a and 5.3a) was no more visible because intensities were averaged out over the longer time-steps (cf. Figures 5.2e and 5.3e).

Effect of temporal scale changes Two effects can be noted when temporal scale increases. One is that it lowers of the actual instantaneous peak intensity and average intensity of rainfall storms. The other is that it changes the location of peak intensities during storm durations.

Lowering the average intensity means a reduced average power of erodibility of the rain. Also, lowering the peak intensity means a reduced instantaneous peak power of erodibility of the the rain. These reductions in erodibilities may be a significant reason for the underestimation of the runoff and soil loss generations. Equally, the opposite can be expected when temporal scale decreases. Some of these responses are observed in this chapter (see Figures 5.4 and 5.5).

Shifting the location of the peak rainfall intensity can occur when temporal scales are changed regardless of increase or decrease. Also, the placement of the peak intensity do not seem to be related to the direction of changes (see Table 5.2 and Figures 5.2–5.3). However, When the location of the peak intensity changes, it too changes rainfall shapes (or patterns) which may be closely related to the timing of the runoff generations and amount of the runoff (This is further investigated and discussed later in Chapter 7.). Thus, changes in temporal scales of rainfall data affect the shape of rainfall storm.

All these changes—lowering of intensities and shifting the location of peak intensities—will of course occur simultaneously when the temporal scale of rainfall data is altered. Thus, what we observed in this chapter may well be the end product from compound effects of these two changes. Effects of lowering of intensities and shifting the location of peak intensities on runoff and soil loss rates therefore need to be investigated separately to be understood further.

Within-Storm Intensity Variation (WSIV) The variation of rainfall intensities within a storm could be termed as Within-Storm Intensity Variation (WSIV) for convenience. WSIV may include the magnitude and number of peak intensities and average intensity of a storm. As suggested previously, WSIV is related to temporal scales of rainfall data as well as types of storms (e.g. convective and frontal). WSIV changes when rainfall intensities are decreased (or increased) by increasing (or decreasing) temporal scales of rainfall data.

Wainwright and Parsons (2002) carried out numerical experiments to test if temporal variability of rainfall intensity during a storm can cause the decrease in runoff coefficients with increasing slop length. They found that variability of temporal scale in rainfall is a significant factor in controlling the scale-dependency of runoff coefficients. Also, overland-flow models which use mean rainfall intensities may notably underpredict the runoff. High rainfall intensity is closely related to high rainfall kinetic energy, which controls runoff generation and soil loss. Yet the way of archiving and aggregating long term rainfall data into a manageable data format may let important rainfall intensity details to be missed out as shown in this chapter.

Boardman and Spivey (1987) also pointed out that short period high intensities probably important for soil erosion processes. However, short duration rainfall intensities are subject to a large uncertainty, especially when they are produced during extreme convective rainfall events (Garcia-Bartual and Schneider, 2001). In the study by Garcia-Bartual and Schneider (2001), 408 rainfall events have been statistically analysed for the period 1925-1992 in Alicante, Spain. Maximum intensities for durations ranging from 2 minutes up to 240 minutes were extracted from the series (Garcia-Bartual and Schneider, 2001). Considerable differences are found in the behaviour of the empirical functions for short durations (t < 10 minutes) (Garcia-Bartual and Schneider, 2001). The energy of individual storms could only be predicted with limited accuracy because of natural variations in rainfall characteristics (van Dijk *et al.*, 2002).

Thus, high temporal resolution data are needed in order to describe WSIVs of storms realistically. High temporal resolution data can provide great details of WSIVs including high instantaneous intensity peaks. However, high resolution data even as sub-hourly data are very rarely available. As Allott *et al.* (2002) pointed out, rainfall data with high resolutions permit a more detailed assessment of the storm structure and evolution of localised intense storms, but storms are rarely stored by sub-hourly.

Even though storms are often originally recorded as sub-hourly data by tipping-bucket gauges, the original records are rarely kept as they are. Instead, they are usually aggregated into hourly or daily data for data storage. Thus, only hourly or daily data are available in many cases. Therefore, a little is ever known about the storm structure, evolution and, of course, WSIVs. With hourly (or more generally daily) data, the detail of actual rainfall intensity can not be obtained. This has been shown previously by comparing Figure 5.3a and Figure 5.3e, for example. The differences in WSIVs between hourly data and 1-min data may have been particularly responsible for the great dissimilarities in runoff and soil loss rates between two temporal scales.

Therefore, it is evident that temporal scales of rainfall data play a crucial role in runoff and soil loss modelling. Changes of temporal scales affect the amount of details on WSIVs which, in turn, affect runoff and soil loss estimations. Sub-hourly data hold more details of WSIVs than hourly data. Thus, it would be logical to choose sub-hourly data over hourly data (i.e. 60-min scale) for erosion modelling. Also, because breakpoint data are less affected by the changes of temporal scales than CLIGEN data, breakpoint data can be preferred to CLIGEN data. In addition, breakpoint data maintains the detail of WSIV better.

Among the investigated sub-hourly scales, 1-min and 5-min scales of breakpoint data cannot be used, however, because WEPP and EUROSEM have the limited number of rainfall data points they can handle. Now there are only two choices left: 15-min and 30-min breakpoint data. There could be other sub-hourly scales available, for example, 10-min, 20-min and so on. However, these other sub-hourly scales were not considered here because investigations were only carried out with the ones used in this chapter: 1, 5, 15, 30 and 60-min. Therefore, within the temporal scales investigated in this chapter, 15-min data were chosen. This temporal scale will be used for the subsequent analyses in this research because they have greater details of WSIVs than 30-min data. Moreover, WEPP and EUROSEM can easily use 15-min breakpoint data.

It is also recognised that different ways of expressing rainfall intensity have the tenancy of desirability for erosion modelling. This is summarised in Table 5.9.

Even though breakpoint data hold more information and are closer to real rainfall than CLIGEN data, it still has some problems. The temporal scale of breakpoint data limits their closeness to real rainfall since rainfall intensity is averaged between starting

Table 5.9 Desirability of different ways of expressing rainfall intensity

Similarity to Reality	Desirability	Method of Rainfall Data Representation
Dissimilar	Most	Amount, Duration, Time-to-Peak & Peak Intensity
↑	↑	Breakpoint Data without 'no rainfall periods'
↓	↓	Breakpoint Data with 'no rainfall periods'
Similar	Least	Tipping Bucket Data

and ending time of breakpoints.

Lastly, it is important to note again that a erosion model should be able to take high resolution data such as 1-min breakpoint data. Once this limitation is resolved, other sub-hourly data scales may also become available for the similar investigation conducted in this chapter. This, in turn, extend the findings presented in this research.

5.6 Conclusion

This set of investigations evidently showed that temporal scale of rainfall data have certain impacts on runoff and soil loss estimations. However, it could not answer if rainfall data with a high resolution always give better simulation results than rainfall data with a low resolution. This is because there are no measured runoff and soil loss rates to compare. Despite the absence of the measured data to be compared with, this chapter identifies the close relationship between temporal scales and WSIVs of rainfall data. When temporal scales of rainfall data increase (or decrease), rainfall intensities are decreased (or increased). WSIVs are also changed when rainfall intensities of storms change.

If there are no available high resolution data but only low resolution data (e.g. 60-min data), we will never know what the intensity was like during those 60 minutes because the disaggregation of rainfall data is no plausible. Also, simulation results can be up to about 30 times different from the "original results" if these low resolution data are used. This magnitude is so great that it might mean from almost no erosion to disastrous events.

In this chapter, the following was found:

- Temporal scales of rainfall data affect Within-Storm Intensity Variations (WSIVs)
- Temporal scales of rainfall data are closely related to the estimated results of runoff and soil loss
- In terms of soil loss, WEPP is more sensitive to the change of temporal data scales than EUROSEM
- Erosion estimations with CLIGEN data are more affected by the change of temporal scales than those with breakpoint data
- Breakpoint data are preferred to CLIGEN data as far as investigations on effects of rainfall intensity on erosion are concerned
- For the subsequent analyses of this research, 15-min breakpoint rainfall data are chosen

As stated previously, this chapter is followed by a further investigation which aims to answer the research question: '*What is the consequence of removing the no-rain periods within a storm duration?*'. The removal of no-rain periods—that is later termed as Within-Storm Gaps (WSGs)—is required during CLIGEN data preparation processes. However, it raises a concern that the removal of WSGs may lead to a loss of rainfall intensity information. More worryingly, a distortion of rainfall patterns and feeding this wrong information into soil erosion models could also occur. In the next chapter, therefore, effects of WSGs on soil erosion estimations are investigated.