Chapter 7

EFFECT OF WITHIN-STORM RAINFALL INTENSITY CHANGES ON SOIL EROSION

7.1 Introduction

In the last two chapters, the effect of temporal resolutions and WSGs on soil erosion have been investigated. In Chapter 5, first of all, it was shown that time-to-peak intensity (t_p) was affected by temporal resolution of rainfall data. When time-to-peak intensity changes, overall shape of rainfall storm, which can be termed as Within-Storm Intensity Pattern (WSIP), changes together. For example, when a peak intensity occurs at the later stage of a storm, WSIP becomes a skewed triangular shape towards the end of rainfall duration (cf. Figure 7.2a). As suggested previously, time-to-peak may have an impact on erosion estimations. Thus, WSIP may too have impacts on runoff initiation as well as soil loss amount.

Secondly, in Chapter 6, it was pointed out that WEPP changed WSIVs when modified the original rainfall intensity information. WSIVs are closely related to WSIP. For example, when "rainfall intensity" within a storm increases steadily from low to high (i.e. increasing intensity), WSIP becomes a skewed triangular shape towards the end of rainfall duration (cf. Figure 7.2a). The same principle applies to decreasing or constant, or more complex shapes. In addition, the change of WSIP may occur when WSGs are removed from original rainfall data as previously illustrated in Figure 6.1.

Therefore, this chapter investigates the effect of rainfall intensity changes (i.e. WSIVs) within storm duration in terms of WSIP by using WEPP, EUROSEM and RillGrow. In reality, rainfall intensity is constantly changing throughout the storm period. It may increase or decrease and changes in more complex ways. For the modelling purpose, however, design storms are used in this chapter. This is because design storms are easier to compare each other without any additional data preparation. Also, by using design storms, it is easier to separate out a factor that is in interest without changing other factors.

7.2 Simulation Data and Methods

Rainfall storms with varying WSIP—increasing, decreasing, increasing-decreasing and constant—are constructed as CLIGEN data by changing time-to-peak (t_p) values. The constant WSIP are achieved by setting both t_p and i_p to 1.0. Amounts of these rainfalls are also kept the same. In order to investigate only effects of WSIP changes on erosion estimation. Only one peak intensity (or no peak for the constant intensity) per storm is assumed for model simulations because of WEPP requirements.

Two designed storms with average intensity of 10 mm/hr (120 mm for 12 hr, Figure 7.1) and 60 mm/hr (120 mm for 2 hr, Figure 7.2) are prepared for WEPP and EUROSEM simulations . Two different intensities are used here in order to investigate effects of WSIP changes in storms with low and high rainfall intensities. Intensity of 10 mm/hr is selected because it is approximately the same as the average intensity (12.8 mm/hr) of the rainfall storm that occurs in the study area, South Downs, UK (see page 76, Chapter 3). Also, the higher intensity (i.e. 60 mm/hr) is selected because it is approximately the same level as the average maximum intensity (63 mm/hr) in the study area (see page 76, Chapter 3).

Firstly, for WEPP simulations, these two rainfall data are used as CLIGEN data format. Then, as described previously in Chapter 5 (see Figure 5.1, page 119), WEPP-disaggregated breakpoint data for the same rainfall storms are used for EUROSEM simulations. This enables the use of the same data sets for WEPP and EUROSEM simulations.

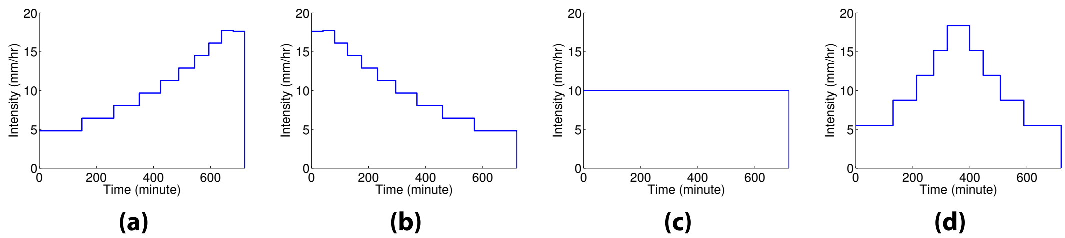

Figure 7.1 Intensity patterns of a stratiform storm for WEPP and EUROSEM simulations. All the inputs have the same total rainfall amount (120 mm) and duration (12 hour). Note the scales of the axes.

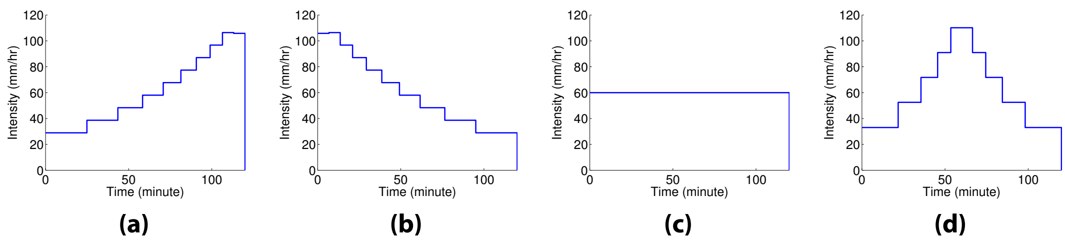

Figure 7.2 Intensity patterns of a convective storm for WEPP and EUROSEM simulations. All the inputs have the same total rainfall amount (120 mm) and duration (2 hour). Note the scales of the axes.

A separate storm with average rainfall intensity of 120 mm/hr (60 mm for 30 min) is designed for RillGrow simulations as shown in Figure 7.3. A separate designed storm is used because of the long computation time required with the version of RillGrow, which is version 2, as discussed previously. The main aim of this chapter is to investigate effects of WSIP on erosion modelling. Thus, in principle, using a separate storm for RillGrow should not have any effects on the investigation result—this is more discussed later in this chapter.

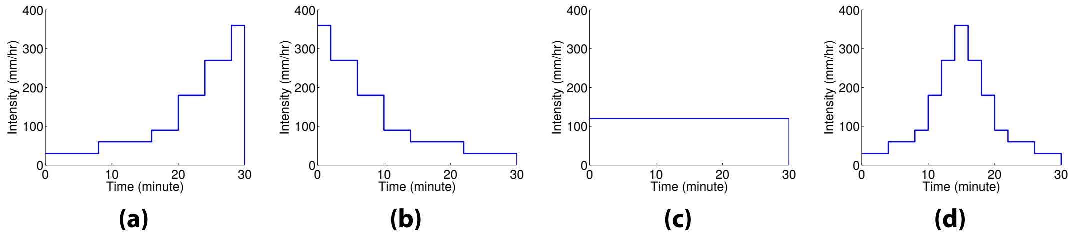

Figure 7.3 Intensity input patterns for RillGrow2 simulations. All the inputs have the same total rainfall amount and duration (i.e. 60 mm rainfall for 30 minutes). Note the scales of the axes.

The effects of WSIP changes on runoff and soil loss estimated by WEPP, EUROSEM and RillGrow are shown in the next section.

7.3 Effects of WSIPs on Runoff and Soil Loss

The summary of WEPP simulation results is shown in Table 7.1. The results are compared against the constant intensity storm in terms of % changes. When 60 mm/hr intensity is used, WEPP estimates the same runoff with all WSIPs. However, for the same intensity, WEPP estimates soil losses with about 5–9% increases with increasing, decreasing and increasing-decreasing WSIPs in comparison to those with the constant WSIP. In contrast, when lower intensity (i.e. 10 mm/hr) is used, WEPP simulates notably different results. While estimated runoff rates are almost the same—less than 2% changes—for all WSIPs, estimated soil loss rates are increased extensively by 5250%, 3750% and 5600%

for increasing, decreasing and increasing-decreasing WSIPs respectively from the soil loss rate for the constant WSIP (Table 7.1). This is because WEPP-estimated soil loss rate with the constant intensity pattern is dramatically small (0.4 t/ha). Runoff and soil loss rates estimated with 60 mm/hr intensity are generally lager than those with 10 mm/hr intensity regardless of WSIPs.

Table 7.1 Summary of WEPP simulation results for varying WSIPs

Storm Pattern	**60 mm/hr**		**10 mm/hr**	
	runoff (mm)	soil loss (t/ha)	runoff (mm)	soil loss (t/ha)
Constant	104.2	105	68.9	0.4
Increasing	104.2	114.6 (+9.1)	70.3 (+2.0)	21.4 (+5250)
Decreasing	104.2	110.4 (+5.1)	68.6 (−0.4)	15.4 (+3750)
Increasing-decreasing	104.2	114.7 (+9.2)	69.9 (+1.5)	22.8 (+5600)

Figures in ( ) are the % changes from the result with a constant intensity storm. +/− indicates a increase or decrease.

The summary of EUROSEM simulation results is shown in Table 7.2. For 60 mm/hr and 10 mm/hr intensity, EUROSEM shows the similar responses. When runoff rates estimated by EUROSEM with varying WSIPs with 60 mm/hr and 10 mm/hr intensities are compared to those estimated with the constant WSIP for both intensities, there are not much differences in estimated runoff rates. The magnitude of changes are around 0.3–3% although runoff estimated with 10 mm/hr intensity is smaller than runoff estimated with 60 mm/hr intensity. On the other hand, there are slight decreases in estimated soil loss rates with increasing, decreasing and increasing-decreasing WSIPs in comparison to those estimated with the constant WSIP. Unlike WEPP results, soil loss results show decreases, which are in the similar magnitude, for both intensities: 60 mm/hr and 10 mm/hr. Constant WSIP simulates the largest soil loss rates: 22.6 t/ha and 24.7 t/ha for 60 mm/hr and 10 mm/hr, respectively. The smallest soil loss rates are estimated with increasing WSIP: 19.7 t/ha and 22.1 h/ha for 60 mm/hr and 10 mm/hr, respectively (Table 7.2).

Table 7.2 Summary of EUROSEM simulation results for varying WSIPs

Storm Pattern	60 mm/hr		10 mm/hr	
	runoff (mm)	soil loss (t/ha)	runoff (mm)	soil loss (t/ha)
Constant	101.4	22.6	73.8	24.7
Increasing	98.7 (−2.7)	19.7 (−12.8)	75.5 (+2.3)	22.1 (−10.5)
Decreasing	103.5 (+2.1)	22.2 (−1.8)	74.0 (+0.3)	24.1 (−2.4)
Increasing-decreasing	103.3 (+1.9)	21.0 (−7.1)	76.0 (+3.0)	22.7 (−8.1)

Figures in ( ) are the % changes from the result with a constant intensity storm. +/− indicates a increase or decrease.

The summary of RillGrow simulation results is shown in Table 7.3. Again, runoff, which is simulated as "Totals lost from edges (litre)", for increasing, decreasing and increasing-decreasing WSIPs does not show much changes from that of the constant WSIP. However, estimated soil loss rates changes when the different WSIPs are used. The largest soil loss rate (90.5 t/ha) is estimated with decreasing WSIP while the constant WSIP produces the smallest soil loss rate (64 t/ha) (Table 7.3). Similar to WEPP results, increasing, decreasing and increasing-decreasing WSIPs result in increases (about 15–40%) in soil loss rates in comparison to the soil loss rates estimated with the constant WSIP.

Table 7.3 Summary of RillGrow simulation results for varying WSIPs

	Totals lost from edges† (litre)	Soil Loss (t/ha)
Constant	471.9	64.0
Increasing	472.4 (+0.1)	73.5 (+14.8)
Decreasing	471.2 (−0.2)	90.5 (+41.4)
Increasing-decreasing	472.2 (+0.1)	82.6 (+29.1)

† No infiltration was considered. Every rain runs off the edge of the simulated plot. Figures in ( ) are the % changes from the result with a constant intensity storm. +/− indicates a increase or decrease.

7.4 Discussion

Effect of WSIP on WEPP result In WEPP inputs, t_p represents normalised time-to-peak which is closely related to WSIP. This parameter, t_p, was previously considered not much sensitive (Nearing *et al.*, 1990). Nearing *et al.* (1990) performed sensitivity analysis on WEPP, which was still in the early stage of its development, by assessing various input variables such as soil, plant residue and canopy, hillslope topography, and hydrologic input variables. They calculated sensitivity parameter, S, as a relative normalised change in output to a normalised change in input. They concluded that *peak rainfall intensity*, *time to peak rainfall intensity*, rill spacing and width, and sediment transportability were not playing a major role in soil loss predictions.

Their findings may not be compared directly with the result presented in this chapter because their analysis was carried out on the developing version of WEPP while this chapter used more recent version of WEPP and the intensity value they used was much higher (100 mm/hr) than the intensities (10 and 60 mm/hr) used in this chapter.

However, as seen in Table 7.1, the timing of peak intensity (or WSIP in this chapter), had visible effects on the result of simulations. It became even more evident when rainfall with low intensity (10 mm/hr) was used with WEPP. For example, when the constant WSIP was used for WEPP simulations, WEPP greatly underestimated soil loss rates by about 50 times less than the average soil loss rate of other WISPs—increasing, decreasing and increasing-decreasing WSIPs (Table 7.1). Thus, it is essential to know about WSIP of the rainfall storm that is used for erosion simulations.

The difference in soil loss with this magnitude (i.e. 50 times) is worryingly large and raises considerable problems, for example, when GCM/RCM rainfall data are directly used for soil erosion modelling. This is because GCM/RCM data are usually used as daily data in which no peak intensity can be identified. In other words, they are used as constant WSIP. Moreover, as discussed previously, disaggregation of such data into sub-daily data is not viable as it increases uncertainty in erosion estimation results.

Effect of WSIP on EUROSEM result EUROSEM, however, resulted in rather different results from WEPP simulation results. Although EUROSEM estimation results were also affected by the change of WSIP, unlike WEPP, EUROSEM simulated less soil loss with increasing, decreasing and increasing-decreasing WSIPs than that with constant WSIP (Table 7.2). In fact, soil loss rates estimated with increasing WSIP was the smallest soil loss rate.

Detailed investigations of the EUROSEM output files showed that slightly less "Gross Interrill Erosion" was estimated with increasing WSIP than with other WSIPs while "Gross Rill Erosion" was estimated at the similar rate for all WSIPs. This was however only seen with 60 mm/hr intensity. When 10 mm/hr intensity was used, EUROSEM estimated slightly less "Gross Rill Erosion" with increasing WSIP than with other WSIPs. "Gross Interrill Erosion" was almost negligible for all four WSIPs when 10 mm/hr intensity was used. This confirms again that EUROSEM dynamically changes its modelling mode depending on the surface condition so that the proportion of rill and interrill erosion for the total erosion changes. Also, This shows that the responses of EUROSEM—in terms of total erosion rates—to the change of WSIP are the same regardless of the average rainfall intensity: the smallest soil loss rate is estimated with increasing WSIP.

In addition, in comparison to the previous chapter, Chapter 6, EUROSEM estimated increased soil loss with lower average intensity (10 mm/hr) than with higher average intensity (60 mm/hr). This increase of soil loss rates was even accompanied with decreased runoff rates. These EUROSEM simulation results are unrealistic and may imply that EUROSEM is subject to some model improvements in this regard.

Effect of WSIP on RillGrow result RillGrow simulated, for constant WSIP, about 78% soil loss from the average soil loss of storms with other WSIPs. RillGrow also estimated the largest soil loss with decreasing WSIP in comparison to those estimated with other storm patterns. Runoff simulated by RillGrow with varying WSIPs was, on the other hand, not affected because of no infiltration was considered as discussed in the previous chapter.

The result from RillGrow simulations with constant and decreasing WSIPs was consistent with the result from the study by Parsons and Stone (2006). Parsons and Stone (2006) conducted a series of lab experiments to investigate the effects of five different intensity patterns (i.e. constant, increasing, decreasing, increasing then decreasing and decreasing then increasing intensity) on soil erosion (Table 7.4). They found that the constant-intensity storm generated the least amount of soil loss which was about 75% of the average soil loss for the variable-intensity storms. Also, the largest soil loss amount was occurred when decreasing-intensity pattern was used.

Table 7.4 Experiment results (From Parsons and Stone, 2006)

Storm Pattern	Clay loam		**Sandy loam**		Sandy soil		**Total**	
	runoff (l)	loss (g)	runoff (l)	loss (g)	runoff (l)	loss (g)	runoff (l)	loss (g)
Constant	131.6	523	83.4	1256	110.2	2509	325.2	4289
Increasing	108.2	748	93.0	2435	72.2	1947	273.4	5130
Decreasing	101.3	456	114.0	3230	108.3	2862	323.6	6548
Rising-falling	110.4	631	95.8	2110	114.2	3584	320.4	6324
Falling-rising†	103.6	629	103.9	1645	108.1	3275	315.6	5549

† Not used in this research since only one peak intensity is assumed for all model simulations.

By comparing the soil loss results estimated with WEPP, EUROSEM and RillGrow with the result from Parsons and Stone (2006), it was found that RillGrow showed the similar results for constant and decreasing WSIPs with which the smallest and largest soil loss rates were simulated, respectively (Table 7.5). Also, WEPP showed the consistent results with Parsons and Stone (2006) for constant and increasing WSIPs with which the smallest and the second largest soil loss rates were estimated, respectively. However, some of other simulation results were not consistent with the result from Parsons and Stone (2006). For example, EUROSEM simulation results were completely inconsistent as the largest soil loss was estimated by EUROSEM with constant WSIP and the smallest soil loss was estimated with increasing WSIP.

Table 7.5 Magnitude of soil loss affected by WSIPs

Soil Loss	Parsons and Stone (2006) (Sandy loam)	WEPP (Mean)	EUROSEM (Mean)	RillGrow
High	decreasing	increasing-decreasing	constant	decreasing
⇑	increasing	increasing	decreasing	increasing-decreasing
⇓	increasing-decreasing	decreasing	increasing-decreasing	increasing
Low	constant	constant	increasing	constant

Despite WEPP and RillGrow simulation results were partially consistent with the results from Parsons and Stone (2006), they still showed inconsistent responses to the change of WSIP for, for example, WEPP with increasing-decreasing and decreasing WSIPs and RillGrow with increasing-decreasing and increasing WSIPs. This means that erosion models still simulate different responses to the change of WSIP compared to the measured responses. This difference need to be improved by more lab or field experiments that can be compared to the model results. As fas as this research is aware, there are no other lab or field experiments that can be compared against model responses to the change of WSIPs except the study by Parsons and Stone (2006). Thus, there is an urgent need for such research.

7.5 Conclusion

It was shown in this chapter that WSIP (or t_p for WEPP) is a important factor for erosion estimations. Without knowing details of WSIPs, erosion models could easily estimate soil erosion with great variabilities as shown in WEPP results. Effects of WSIPs on runoff estimations were however small implying WSIP affects soil loss rate more.

The change of WSIP with high intensity have less impacts on soil loss estimations than the change of WSIP with low intensity. Despite varying responses of the erosion models to the change of WSIP, constant WSIP produced the least soil loss when used with WEPP and RillGrow.

There are urgent needs for more lab or field experiments that can be compared with the model results in order to improve model predictabilities.