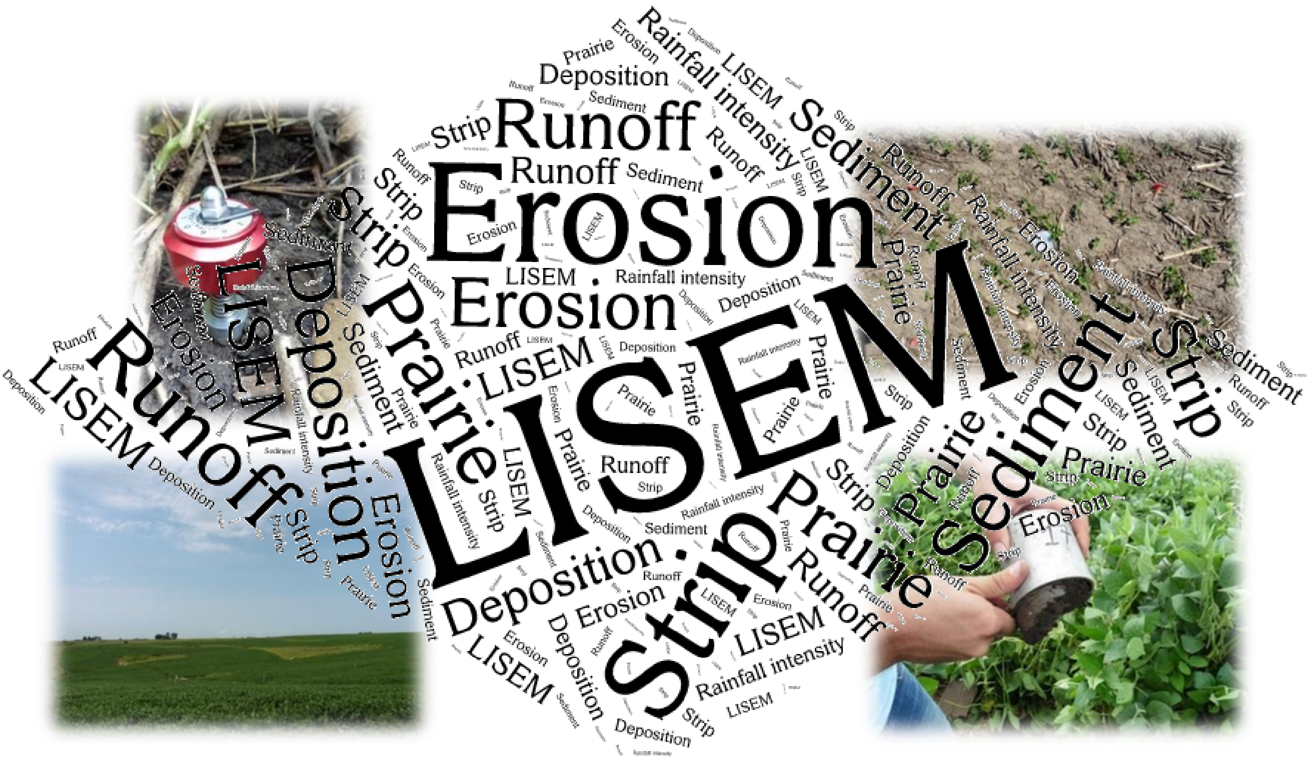
Estimating the effects of vegetative filter strip design on sediment movement in an agricultural watershed using LISEM



MSc Thesis by E.A. Luquin Oroz

April 2016

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Estimating the effects of vegetative filter strip design on sediment movement in an agricultural watershed using LISEM

Thesis report submitted to Wageningen University in partial fulfillment of the requirements for the degree of Master of Science in International Land and Water Management.

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ABSTRACT

Although restoration of native vegetation in agricultural watersheds would decrease soil loss, this approach is not feasible in communities that base their income on agriculture. However, an alternative exists: strategically placing a small percentage of vegetative filter strips (VFS) within agriculture fields for erosion control. Factors influencing their effectiveness are runoff conditions, vegetation type, filter strip width, slope, soil type, and rainfall characteristics. With the perspective of increasingly stronger rainstorms and hence higher runoff, there is a need to obtain new insights about VFS design and its influence on sediment dynamics. The objective of the study was to analyze strip width impact on soil and water movement. Different strip widths were analyzed under a range of rainfall intensities using the event-based, hydrological and soil erosion model LISEM. The results show that sediment trapping efficiency (STE) increased directly with width, however decrease with rainfall intensity. On average, STE increased by 8% as the width of the filter increased from 4 to 14 m. Detachment and soil loss mainly occurred in rills caused by concentrated flow. Overall the first meters of the VFS experienced the most sedimentation but in places where rills crossed the buffer, stream power and turbulence resulted in sedimentation along the VFS.

ACKNOWLEDGEMENT

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Eduardo Luquin Oroz

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1. INTRODUCTION AND BACKGROUND

Depletion of soil resources, where erosion rates are greater than renewal, has important implications even for developed countries. Because of the large amount of fertile soil being lost from farm land every year, soil loss is an increasing environmental problem. Loss of soil productivity is the main onsite effect, whereas sedimentation and eutrophication of nearby water bodies are common offsite effects (Mekonnen *et al*., 2014; FAO, 2015). Since the 1960s, 30% of agricultural soil has become unproductive due to erosion (Pimentel, 2006). The cost of environmental goods and services is an additional but subjective cost which depends on the perspective of different actors (FAO, 2015). In the United States, erosion removes 3 billion tons of cultivable soil each year, which results in a productivity reduction of $37.6 billion (Pimentel, 2006; Kabir *et al*., 2010). Sedimentation in rivers, reservoirs and other water bodies increases flood risk and maintenance cost. Water contamination with eroded sediment is one of the major environmental problems in United States (FAO, 1996a & b; Magdoff & Van Es, 2000; Cruse *et al*., 2006; Kabir *et al*., 2010 and Zhou *et al*., 2010). Therefore, reducing sediment export from agricultural fields and keeping soil on fields is essential to reduce offsite problems and maintaining productivity (Nearing *et al*., 2001).

Soil erosion is a complex dynamic process which implies soil particle movement from one place to another. It is caused by wind, water or gravitational forces and involves three processes; detachment, transport and sedimentation (FAO-SWALIM, 2009). The source of eroded sediments varies between watersheds due to soil type, topography, vegetation cover, extent of human agricultural activities and climate (FA0-SWALIM, 2009). Pathways of sediment transport are a function of hydraulic properties (slope, velocity, channel geometry and roughness) and sediment properties (grain size distribution and cohesiveness). Sediment deposition often happens in boundaries among areas within watersheds, such as lowland areas, floodplains, valley side slopes and river junctions (Bracken *et al*., 2015).

The term connectivity helps to explain an integrated physical and transfer connection of sediment from all sources and all sinks with a focus on watershed as a continuum system where the three phases of erosion occur (Bracken *et al*., 2015). Hooke (2003) sees connectivity as "the physical linkage of water and sediment flux within the landscape and the potential for particle to move through the system". Many factors influence connectivity: (i) characteristics of the path, vegetation cover, slope, soil type; (ii) distance from source to sink or watershed size; (iii) discharge, rainfall intensity, velocity; (iv) human impact, barriers, land management; (v) internal dynamics and (vi) type of erosion (Baartman *et al*., 2013). In hydrology and geomorphology there are three types of connectivity: (i) landscape connectivity, associated to topography; (ii) hydrological connectivity, associated to the flow of water through the watershed; and (iii) sediment connectivity, associated to the movement of sediment through the watershed (Bracken &Croke, 2007; Baartman *et al*., 2013).

The hypothesis that vegetation cover reduces connectivity was examined by Lee *et al*., (2000); Gumiere *et al*., (2011); Sandercock & Hooke (2011); Hooke & Sandercock, 2012; and Mekonnen *et al*., (2014) concluding that vegetated filters reduce connectivity because they reduce volume and flow velocity, which implies decrease of transport capacity enhancing sedimentation in filter areas. Sedimentation occurs due to a ponded area upslope the buffer where water slows and sediment deposit (Dillaha *et al*., 1988; Van Dijk *et al*., 1996; Yuan *et al*., 2009). Although restoration of native vegetation on agricultural watersheds would decrease soil loss, this approach is not feasible in communities that base their income on agriculture (Zhou *et al*., 2010; Helmers *et al*., 2012). However, there exists an alternative of strategically intercalating a small percentage of vegetative filter strips (VFS) within agriculture plots for erosion control (Zhou *et al*., 2010; Helmers *et al*., 2012). VFS are vegetation bands within rowcrop contour lines or at the bottom of watersheds with the goal to trap sediment and other particles such as pollutants from overland flow (Diallaha *et al*., 1989; Abu-Zreig *et al*., 2004). VFS trap sediment by filtration, deposition, infiltration, adsorption, absorption, decomposition, and volatilization (Diallaha *et al*., 1989) helping to reduce sediment export from agricultural fields (Helmers *et al*., 2012). Several studies have proven VFS effectiveness in sediment trapping (Diallaha *et al*., 1988 & 1989; Yuan *et al*., 2009; Zhang *et al*., 2010). For example, Magette *et al*. (1989) and Daniels & Gilliam (1996) analysed trapping efficiencies of vegetative filters showing that more than 50% of the total sediment load in the water flowing through the filter was trapped. Among many other reviews on vegetation sediment trapping efficiency, Yuan *et al*. (2009); Gumiere *et al*. (2011) and Mekonnen *et al*. (2014) showed efficiencies between 24 and 100% under various conditions. Lee *et al*. (2000) tested switchgrass and switchgrass-woody buffers trapping efficiency, showing they trapped 70 and 92% of the incoming sediment, respectively. Factors influencing effectiveness are flow conditions, vegetation type, filter strip width, slope, soil type, and rainfall characteristics (van Dijk *et al*., 1996; Lee *et al*., 2000; Helmers *et al*., 2012). In general, those factors influence infiltration and soil roughness which results in different runoff energy and volume (Magdoff & Van Es, 2000; Gumiere *et al*., 2011). “Buffer width alone explains 37, 60, 44 and 35 % of the total variance in removal efficacy for sediment, pesticides, N and P, respectively” (Zhang *et al*., 2010). Overall, studies have varied filter length from 0.61m to 40m (Abu-Zreig *et al*., 2004), Patty *et al*. (1997) studied buffers of 6, 12, and 18 meters wide showing sediment export reductions between 87 to 100%. The U.S. Natural Resources Conservation Service (NRCS) suggested a buffer widths of at least 8-10 m to reduce sedimentation and eutrophication of nearby water bodies. Several researches reported that sediment retention increase directly with strip width (van Dijk *et al*., 1996; Yuan *et al*., 2009; Zhang *et al*., 2010). Sediments are typically deposited in the first few meters of the strip. For slopes greater than 10 %, effectiveness decreases with increasing slope gradient (Dillaha*et al*., 1989; Liu *et al*., 2008; Zhang *et al*., 2010). Generally, high rainfall intensity and sediment load in overland flow decrease the effectiveness vegetative filter strips (Blanco-Canqui., 2006).

Over the last 100 years, the United States has gradually experienced increasingly stronger rainstorms and hence higher runoff (Fig. 1). Two cities in the state of Iowa (Des Moines and Cedar Rapids) have recorded such increments showing a continually increasing number of rainfall events exceeding 3 cm (Takle, 2011). On top of that, climate change is expected to increase rainfall erosive forces between 16 to 58% (Nearing, 2001) thus “soil erosion rates are expected to increase exponentially as precipitation continues to rise” (Rogovska and Cruse, 2011). Among others conservation practices, one of the tools that can be used against soil loss are VFS.

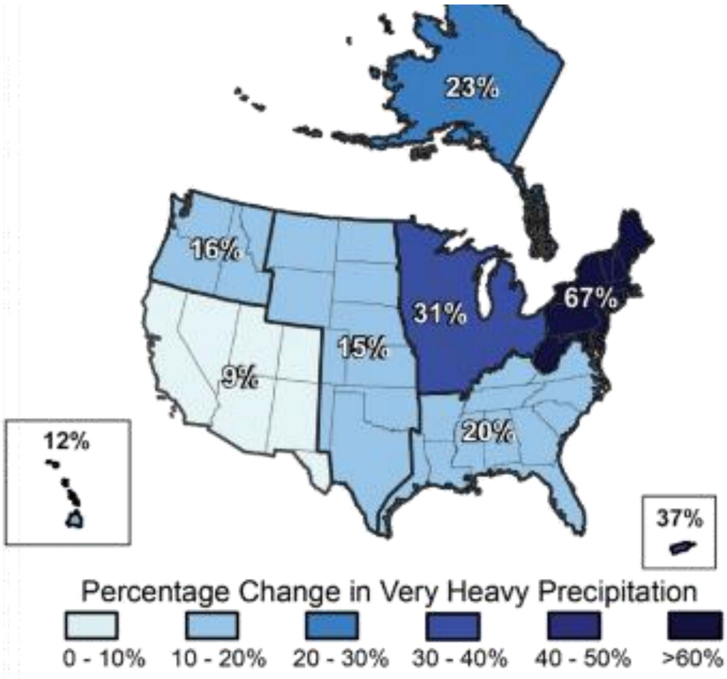


Fig. 1. Increment of very heavy rainfall events in the US from 1958 to 2007. Very heavy precipitation is defined as the heaviest 1% of all events (Karl *et al*., 2009).

Due to climate change and a prospect to increase rainfall intensities, there is a need to obtain new insights about VFS design and its influence on sediment dynamics. Therefore the objectives of the study were to assess the performance of VFS in reducing sediment export from an agricultural watershed and to analyze strip width impact on soil and water movement. To do so, different strip widths were analysed under a range of rainfall intensities using the event-based, hydrological and soil erosion model LISEM.

2. MATERIALS AND METHODS

2.1. Study area

The project STRIPS, aims to determine what combinations of field cover percentage and placement of reconstructed prairie strips within rowcrop agriculture helps the most to reduce erosion and improve the health and diversity of Midwestern agricultural landscapes. The experimental setup of the project consists of 12 small watersheds between 0.5 and 3.2 ha with similar slope, soil texture, and soil carbon and nitrogen concentration. The 12 watersheds are divided in 3 experimental sites within Neal Smith National Wildlife Refuge (NSNWR), state of Iowa, USA (STRIPS, 2012). Sites vary in location and percentage of perennial vegetation. Variations in percentage area of prairie vegetation intercalate within row crops are 0, 10 or 20%. The strip placement varies with this perennial vegetation either at the bottom of the watershed or distributed perpendicular to the slope in the farmed component of the watershed. Strips are no more than 4-10 m wide with 36m between strips to allow the maneuvering of agricultural machinery (STRIPS, 2012).

This study was conducted at the NSNWR located near Prairie City, Iowa (USA). The model has been run with data from the 3-ha 'Interim 1' watershed (Fig. 2), which is part of Walnut Creek watershed (Iowa, USA). Two different land covers can be defined within the watershed: (i) perennial vegetation, which has prairie vegetation covering patches and strips; and (ii) rowcrop agriculture where corn and soybeans are the main two crops in the area. Ten percent of the area is covered by prairie (3.3% footslope, 3.3% strip sideslope, and 3.3% strip upslope) with a slope of 7.7%(Fig. 2). Indian grass [*Sorghastrum nutans*(L.) Nash], little bluestem [*Schizachyrium scoparium* (Michx.) Nash], and big bluestem (*Andropogon gerardii* Vitman) are the main species of more than 20 seeded. Ladoga silt loam and Otley silty clay loam are the common soils in the area (Helmers, *et al*., 2012). The cropping system consists of a two-year corn soybean no till rotation using standard management practices (STRIPS Research Team, 2012). Iowa is characterized by a continental climate with marked seasonal variations. Long term annual precipitation of the NSNWR is 903.5 mm and is concentrated from April to September (Helmers *et al*., 2012), while average annual temperature is 8.9 degree Celsius (NOAA, 2006 & 2014).

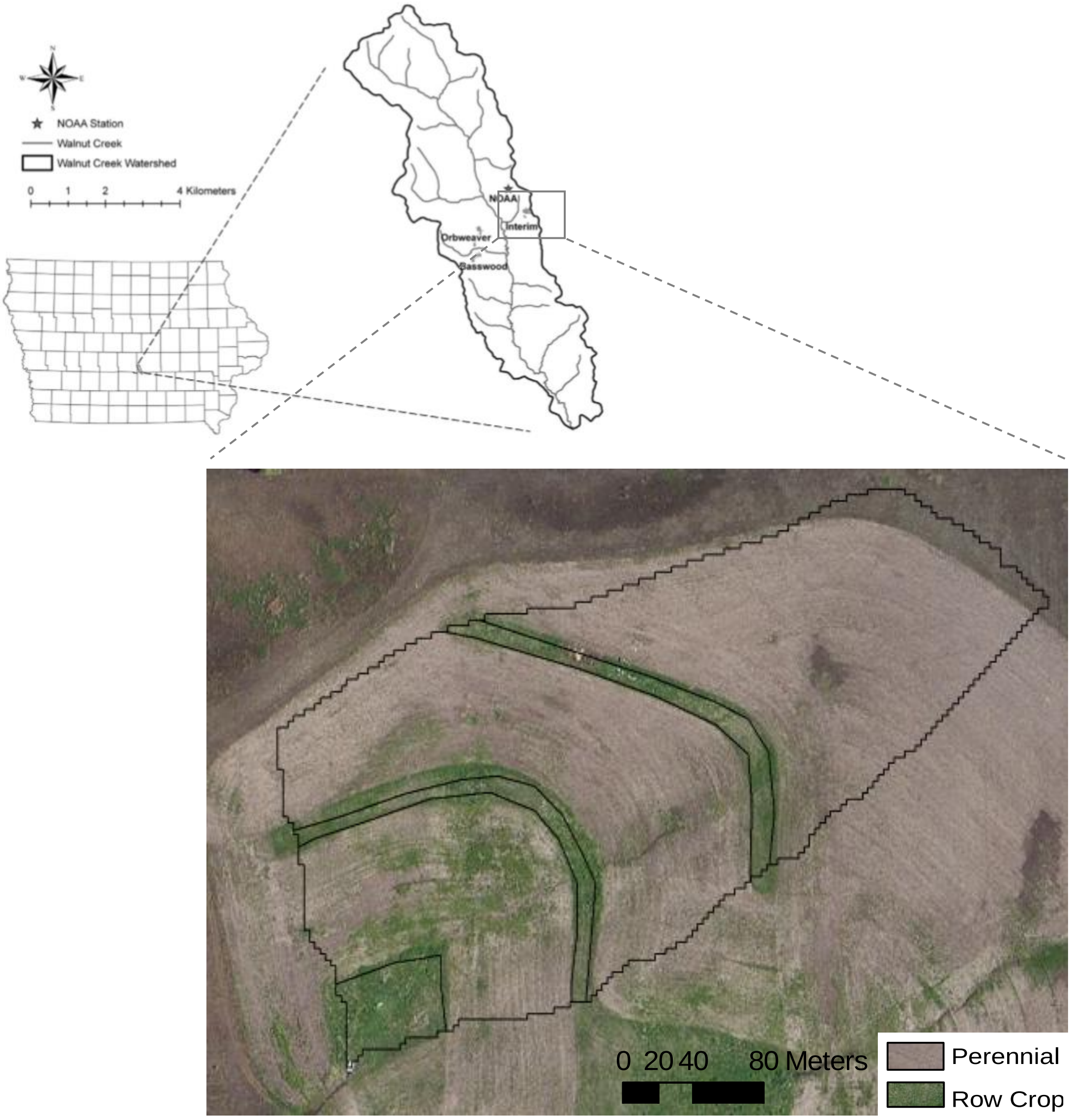


Fig. 2. Study area, Interim 1 location within Walnut Creek watershed.

2.2. Modeling

LISEM, the Limburg Soil Erosion Model, is a single event, physically based hydrological and soil erosion model for drainage basins (De Roo *et al.*, 1996a & b). It is defined as a single event model because it is limited to single rain events and physically based because it incorporates all major physical processes that are involved in generating sediment and runoff. All these processes imply the need for a large number of inputs to run the model. LISEM simulates the hydrology and sediment transport during and immediately after a single rainfall event in a small watershed. The model has been used in watersheds between 1 hectare up to 100 km^2 (De Roo & Jetten, 1999). Input parameters are rainfall, plant interception, surface storage in microdepressions, infiltration, vertical movement of water in the soil, overland flow, channel flow (in manmade ditches), detachment by rainfall and through fall, transport capacity and detachment by overland flow (De Roo *et al.*, 1995; De Roo, 1996a; De Roo & Jetten, 1999; Lamberink, 2010). All input and output maps are raster based (De Roo *et al.*, 1995). To run LISEM, at least 24 maps are required depending on the input options selected in the interface (De Roo *et al.*, 1995). LISEM outputs enable the user to evaluate any sediment dynamic in the scenario. LISEM provides: (i) erosion and soil loss maps in PCRaster format; (ii) numerical lists with totals; and (iii) a time series hydrograph and sedigraph of the main outlet (De Roo *et al.*, 1995).

2.2.1. Sampling points

A total of eight sampling points were taken on each field measurement day (Fig. 3). Samples were taken on each land unit using a combination of soil type (Clarinda, Ladoga, Otley or Shelby) and vegetation type (prairie or rowcrop).Field measurements were done approximately every two weeks as suggested by Hessel *et al.* (2002). In total, three days of field measurements were held, between late-July and mid-September 2015.

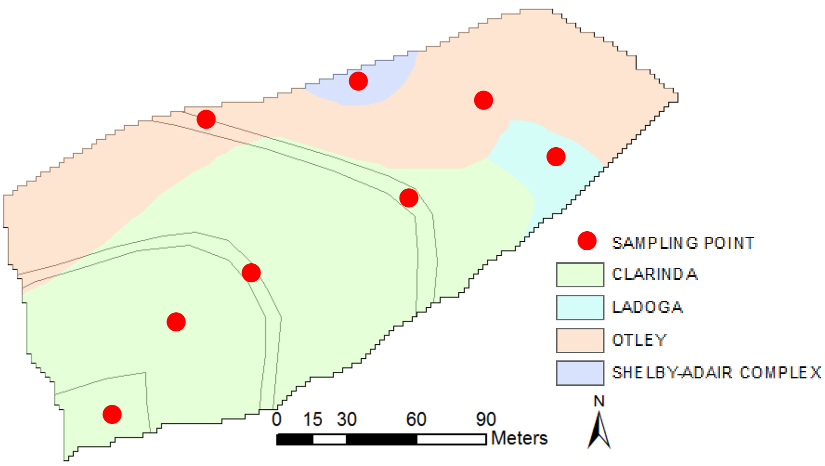


Fig. 3. Sampling points locations through Interim 1.

To run LISEM the average calculated over these three days was used.Rainfall and discharge data were retrieved from the STRIPS database. An automated water sampler and a flume were located at the bottom of the watershed to measure runoff and runoff components. One tipping bucket rain gauge was located at the bottom (Helmers *et al*., 2012).

2.2.2. Field and soil measurement procedures for LISEM

This section explains the methodology for measuring and processing input parameters to run LISEM. Field measurement procedures and lab processing were done according to Hessel *et al*. (2002). Annex 1 summarizes all input parameters used to run LISEM as well as their sources.

Vegetation maps

Leaf area index (LAI): The agronomy group at Iowa State University has been studying soybean and corn leaf area indexes for the last decades. LAI values were provided by professors S. Archontoulis and A. Van Loocke *(personal communication, September 26, 2015)* under similar soil types and between July and September 2015. Prairie LAI was retrieved from Redfearn *et al*. (1997) according to prairie maturity phase.

Fraction of soil covered by vegetation (PER): In order to estimate the percentage of soil covered by vegetation, pictures were taken on each site. In addition, initial appraisals were made in the field. To assess the percentage of coverage, the proportion form suggested by Hessel *et al*. (2002) was used (Annex 2).

Vegetation height (CH): Vegetation height was calculated by measuring the height of each plant and the weight (percentage coverage) in a representative area (6 ft^2):

$$CH_{average} = \Sigma(H_{plant} * W_{plant}) \quad \text{(eq. 1)}$$

$CH_{average}$= average plant height in a certain area (m)
H_{plant}=plant height (m)
W_{plant}= weight of the plant per unit area (%)

Soil surface maps

As stones and crust were not present, their soil surface maps were not created.

Manning's n (N): Manning's *n* was used for calibration. Initial values were derived from Arcement & Schneider (1989) for rowcrop and Weltz *et al*. (1992) for prairie vegetation.

Random Roughness (RR): On each site, random roughness was measured using the chain meter method. The measurement was executed horizontally and vertically with respect to the contour lines. Both the horizontal and vertical measurements were averaged. The following equation was used to calculate roughness:

Roughness (%) =(La-Lr)/La*100 (eq. 2)

La = Actual length of the chain (cm)
Lr = Reduced length of the chain (cm)

LISEM uses the standard deviation of the micro relief height of a pin meter (cm) (Hessel *et al*., 2002). Jester & Klik (2005) compared the pin and chain methods to measure soil surface roughness. To be able to compare them, they created a dimensionless profile index (PI):

PI=((La/Lr)-1) (eq. 3)

La = Actual length of the chain (m)
Lr = Reduced length of the chain (m)

The relationship between chain PI and pin random roughness calculated by Jester & Klik (2005) indicated a correlation coefficient of 0.956. To convert PI chain values to micro relief height, equation 4 obtained from Jester & Klik (2005) was used:

$y=-53.19x^2+50.58x$ (eq. 4)

where x is chain PI obtained from equation 3 and y is the random roughness in mm. As LISEM requires random roughness in cm, the result was divided by ten.

Infiltration related maps

Saturated hydraulic conductivity (KSAT1): Along with manning's *n*, saturated hydraulic conductivity was used to calibrate LISEM. The tool *Web Soil Survey* (USDA 2013) provides soil data properties at field level. In order to obtain K_{sat} values, Interim 1 watershed was selected on the map. The tool provided K_{sat} for each soil type within Interim 1.

Saturated volumetric soil water content (THETAS1): To measure initial soil water content, one 3-inch diameter Eulon corering sample was taken per sampling point. Samples were saturated in the laboratory. To do so, cores were put in a bowl containing water for 24 hours. When saturated, samples were weighed and dried for at least 24 hours at 105 ºC, then, weighed again. The saturated moisture content was calculated using equation 5:

$\Theta_s= (M_{saturated} - M_{dry})/ (V \times \rho_{water})$ (eq. 5)

Θs= saturated soil water content (vol %)
$M_{saturated}$= mass of the soil sample when saturated (kg)
M_{dry}= mass of the soil sample when dry (kg)
V= volume of the soil sample (m^3)
ρ_{water}= water density (kg/m^3)

Initial volumetric soil water content (THETAI1): The same procedure as described for THETAS1 was done to obtain samples for the initial soil moisture. Cores were weighed and dried in the laboratory for at least 24 hours at 105 °C, and, after drying, weighed again.

$\Theta_i=(M_{initial}-M_{dry})/ (V \times \rho_{water})$ (eq. 6)

Θ_i= initial soil moisture content (vol %)
$M_{initial}$= initial mass of the soil sample (kg)
M_{dry}= mass of the soil sample when dry (kg)
V= volume of the soil sample (m^3)
ρ_{water}= water density (kg/m^3)

Soil water tension at the wetting front (PSI1): Soil water tension values were retrieved from Boer & PuigdeFábregas (2005).

Soil depth (SOILDEP1): The tool *Web Soil Survey* (USDA 2013) was used to obtain soil depths.

Erosion/deposition related maps

Aggregate stability (AGGRSTAB): Aggregate stability was derived from literature (Cammeraat & Imeson, 1998), prairie and corn values were selected from the vegetation with similar percentage of plant cover, vegetation structure and soil type.

Cohesion of bare soil (COH): In both vegetation types, cohesion was measured using a pocket shear tester (torvane device) (Hessel *et al*., 2002). On each location four measurements were taken and averaged. The obtained values in kg/cm^2 were converted to kPa.

Additional cohesion by roots (COHADD): De Baets *et al*. (2008) studied Mediterranean vegetation root tensile strength in loamy soils. For prairie, cohesion by roots was derived from vegetation with similar physical characteristics: (i) vegetation type: grasses and herbs and (ii) root diameter (mm). The closest types of vegetation were *Juncus acutus*, *Brachypodium retusum* and *Stipa tenacissima*. On average, the cohesion of roots was 60 kPa, similar to values obtained by field measurement (bare soil). Taking into account this similarity, additional cohesion of roots was set to be equal to cohesion of bare soils. For corn, the same assumption was taken.

D50 value of the soil (D50): Table 1 shows soil texture percentages in the Interim watershed. Maximum sizes were chosen to calculate the median soil texture. Figure 4 provides the equation to calculate the median grain size of the soil.

Table 1. Soil texture (0-30 cm in depth) of Interim. Source Zhou *et al*. (2010).

	% of the watershed	Cumulative %	Size (mm)	Size (µm)
Sand	7	7	2	2000
Silt	25	32	0.05	50
Clay	68	100	0.02	20

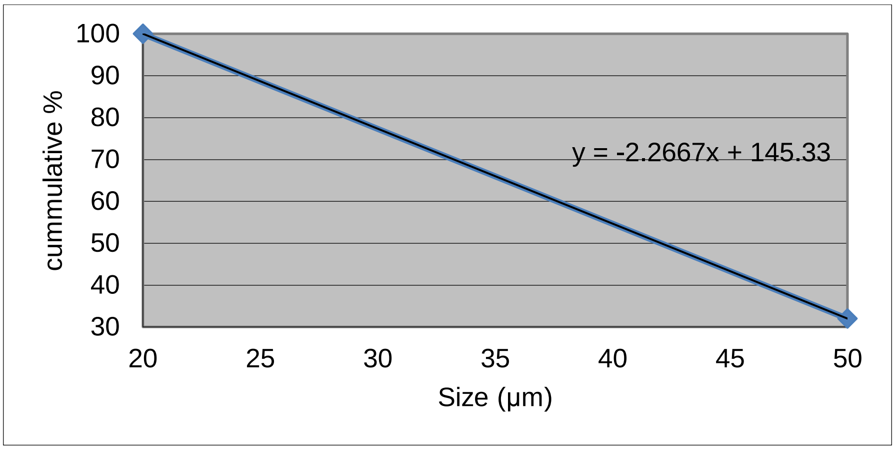


Fig. 4. Soil texture size (µm) distribution between the cumulative 30 and 100 %in Interim.

The median grain size is the average grain diameter of 50% of the particles in the sample. Thus *y* was substituted by 50% in equation 7.

y = -2.2667x + 145.33 (eq. 7)

x=(145.33-y)/2.2667 → x=(145.33-50)/2.2667→ x=42.05 µm

De Baets *et al*. (2008) also established a D_{50} of 42 µm for silt loam soil textures.

Tables2 shows an overview of all input parameters based on vegetation and soil type maps.

Table 2. Initial averaged vegetation and soil maps input parameters values.

Vegetation type	LAI (m2/m2)	PER (-)	CH (m)	N (-)	RR (cm)	AGGRSTAB (-)	COH (kPa)	COHADD (kPa)
Corn-2	5.34	0.7	1.8	0.05	0.54	39	57.69	57.69
Prairie-1	3.5	1	0.65	0.2	0.57	50	70.08	70.08
Soil type	THETAS1 (-)	PSI1 (-)	SOILDEP1 (mm)	D50 (um)	KSAT1 (mm/hr)	THETAI1 (-)		
Clarinda	0.47	30	290	42.06	10.80	0.26		
Otley	0.45	30	1715	42.06	10.60	0.29		
Shelby	0.46	30	340	42.06	21.28	0.29		
Ladoga	0.41	30	400	42.06	28.75	0.26		

2.2.3. Calibration

In order to increase model running velocity, LISEM´s calibration was divided into two processes, hydrology and sediment. In the hydrological part, the output hydrograph was used for calibration. Calibration was based on (1) peak discharge (l/s); (2) peak discharge timing (min) and (3) total discharge (m^3), prioritized in this order. LISEM provides the user an interface to easily vary saturated hydraulic conductivity, manning´s *n* and saturated volumetric soil water content. These three parameters were used to calibrate the hydrology part. For the sediment part, total erosion (Kg) was compared with sediment load (Kg) provided by the flume data. Cohesion of soil and roots, aggregate stability and median grain size were parameters adjusted during sediment calibration.

To quantify the goodness of the model, the Nash-Sutcliffe efficiency ratio (NSE) was used. To calculate it the software tool *Fiteval* was used (Ritter and Muñoz-Carpena, 2013).

Due to some technical issues rainfall data from years 2013 onwards was not available. Thus for this study, rainfall and discharge data was gathered from years 2009, 2010, 2011 and 2012. During the time frame of the study (mid July to mid September), the rainfall event of the 18th of July 2010 was selected as it fulfilled all requirements: (i) enough rainfall intensity to produce runoff; (ii) representative and assumed accurate discharge data; (iii) sediment export; and (iv) single event. The duration of the event was one hundred and forty minutes, intensities reached up to 80 mm/h with a total measured runoff of 11.86 m^3 and a peak discharge of 13.97 l/s (Fig. 5).

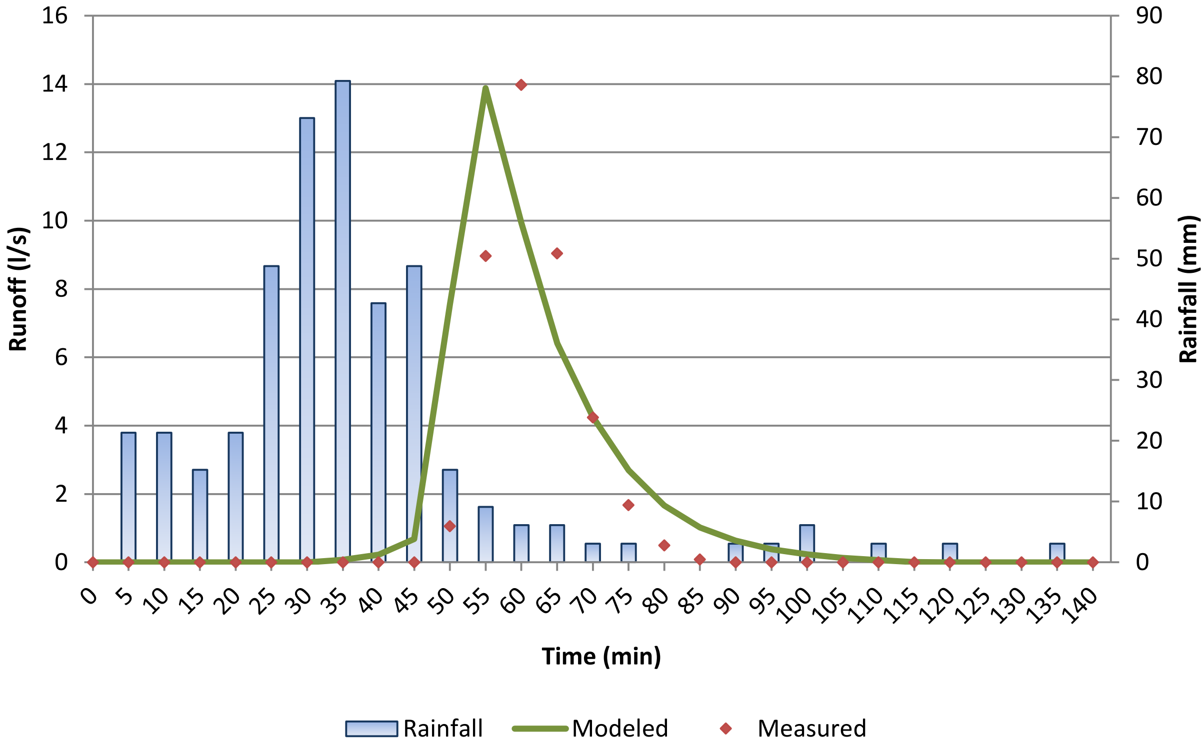


Fig. 5. Comparison of measured and modelled hydrographs for the selected single event (18th of July 2010) with intensities reaching up to 80 mm/h.

2.3. Scenarios

Once calibrated, a total of 25 scenarios were simulated consisting of the combination of five different vegetative strip configurations under five different rainfall intensities. Rainfall intensity increments were 10% (I1), 25% (I2), 50% (I3), 75% (I4) and 100% (I5) from the original intensity (I0) (Table 3 and Fig. 6). Annex 3 shows in detail numerical rainfall intensities (mm/h) every 5 minutes for each increase.

Table 3. Total rainfall and peak intensity for each simulated rainfall intensity scenario.

	I0- 0%	I1-10%	I2-25%	I3-50%	I4-75%	I5-100%
Total rainfall (mm)	36.32	39.95	43.59	54.48	63.56	72.64
Peak intensity (mm/h)	79	87	95	119	139	159

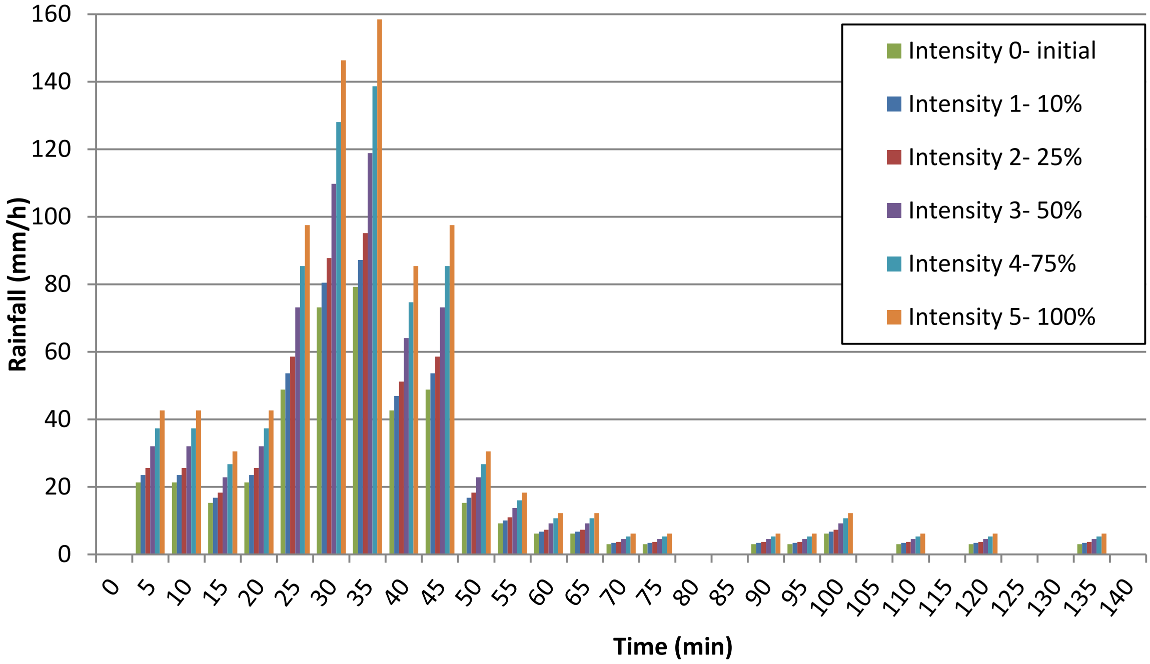


Fig. 6. Increments of rainfall intensities starting from the initial rainfall intensity of 18th July 2010.

“Buffer width” was defined as the dimension perpendicular to slope. Figure7 shows a sketch of the scenarios (land unit maps loaded by LISEM). Scenario 0 represents the actual strip configuration (10% prairie filter strips at the footslope and in contour strips), scenario 1 had no strips along the rowcrop agriculture contour lines but doubled area of the buffer at the toe position. For scenarios 2, 3, 4 and 5, vegetation at the toe position remained the same as the current situation, only differing on strip width:

1. Scenario 0 (S0): current situation
2. Scenario 1 (S1): only buffer at the toe position (doubled area).
3. Scenario 2 (S2): buffer at the toe position, strips width 4 meters.
4. Scenario 3 (S3): buffer at the toe position, strips width 7.5 meters.
5. Scenario 4 (S4): buffer at the toe position, strips width 10 meters.
6. Scenario 5 (S5): buffer at the toe position, strips width 14 meters.

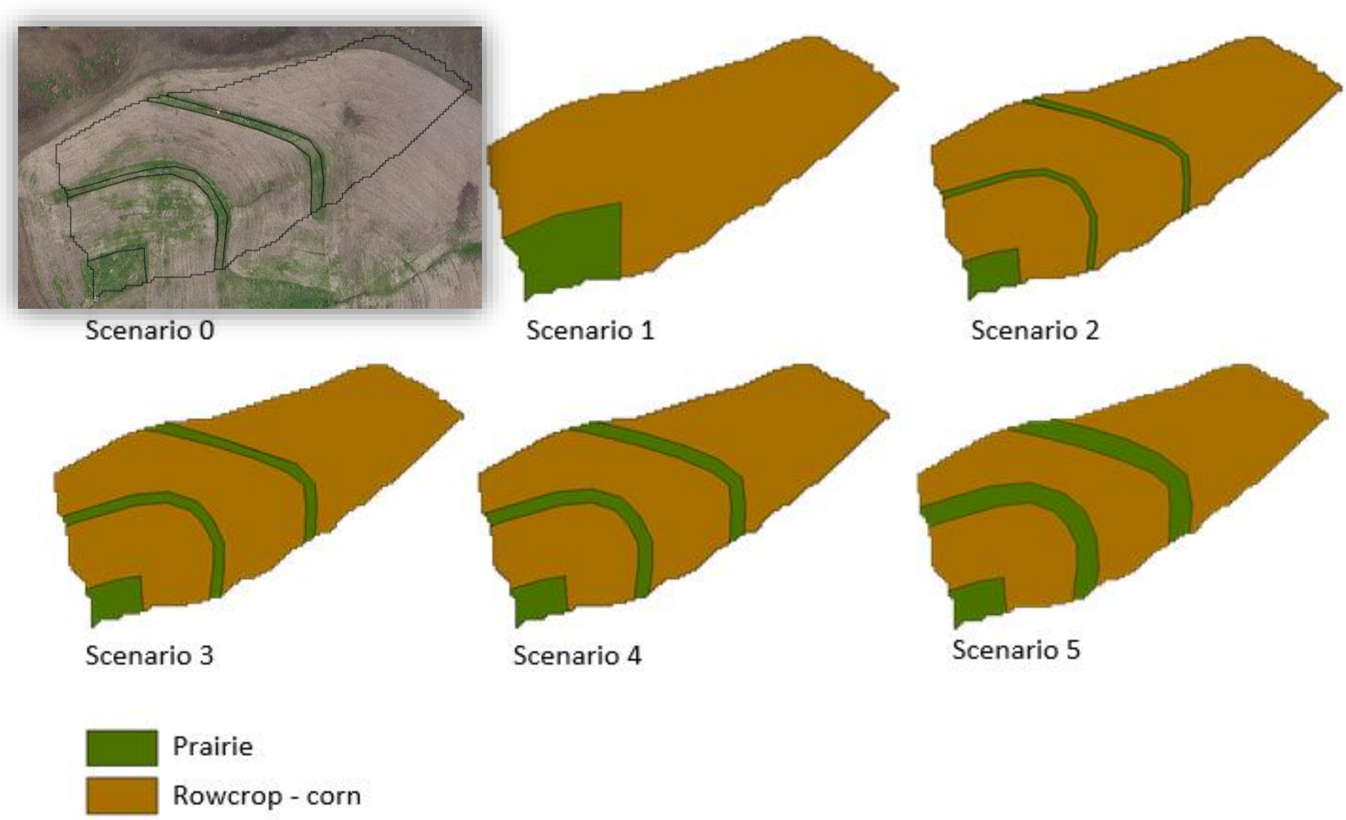


Fig.7.Strip width design for each scenario.

It could still be better to have even wider strips but a maximum strip width of 14 m was established in order not to compromises the workability and space left for agriculture. Sediment trapping efficacy (STE)is usually used to evaluate buffer effectiveness. It is defined as the capacity of a buffer to trap a percentage of sediment transported by runoff (Yuan *et al*., 2009; Mekonnen *et al*., 2014). The STE was calculated using equation 8 proposed by Yuan *et al*. (2009):

$$STE = (1 - SDR) * 100 \qquad \text{(eq. 8)}$$

Where:

STE: Sediment trapping efficiency (%)
SDR: Sediment delivery ratio (decimal point)

SDR is a value that gives an estimation of the percentage of how much sediment from the total eroded has reached a selected point (normally outlet of the watershed) (Baartman *et al*., 2013). Although in our case SDR value was provided by LISEM, the formula to calculate SDR is explained in equation 9:

$$SDR = SY / E \qquad \text{where } SDR\ [0.0\text{-}1.0] \qquad \text{(eq. 9)}$$

Where SY is sediment yield per unit area and E is the total erosion over the same area, both in same units.

3. RESULTS AND DISCUSSION

3.1. Calibration

Once calibrated, the model had a NSE efficiency index of 0.71 showing a good fit between modelled and measured values. A good correlation between the simulation and measured is reached when the ratio exceeds 0.7 (Bennis & Crobeddu, 2007), a NSE coefficient equal to one indicates that the simulation exactly matches the runoff measured by the flume. LISEM requires a substantial input data, being very sensitive to some input parameters (*Ksat* and *n*) (De Roo *et al*., 1996a & b). Differences between measured and modeled results could be related to the amount of input data available to choose from, some of them are spatially variable (*Ksat*). In addition, assumptions were used for unavailable data or average parameters, these could also influence the plausibility of the calibration. Sometimes parameters attributed to a certain land unit came from different sources, i.e. aggregate stability, D50 or additional cohesion by roots. It would be ideal to use data from one source per input type to at least have the relative differences correct. Input data should therefore be gathered with extreme care. Related to the sediment part, calibration was done comparing total erosion provided by LISEM with sediment load from flume measurements. Although the flume´s accuracy did not allow to compare sedigraphs, it is recommended to use this approach for future studies if possible.

Calibration of the model was not easy, a total of 45 runs (adding up hydrology and sediment parts) were needed to calibrate the model. The model was run with the standard input parameters first showing higher values than the measured ones. Table 4 shows final hydrology and sediment input parameters used to run scenarios. Some of them may not be common, such as a manning´s *n* of 0.8 for prairie, keeping in mind its importance in determining runoff calculations. However, manning´s *n* values for both vegetation types are within acceptable range established by FHWA (2009). Figure 8 provides an idea of how the prairie filter and rowcrop agriculture fields look like which may help to understand these high values. The model has many input parameters, thus many degrees of freedom to tune the model. This also means that the current calibration may not have found the (theorethical) optimal calibration combination as the present study did not try all the possible combinations of parameters. However, if counting previous calibrations, more than 100 runs were simulated. Based on that, it can be asserted that increasing manning´s *n* in our watershed was the most feasible solution to fit modelled and measured hydrographs.

Table 4. Calibrated vegetation and soil maps input parameters values used to run LISEM.

Vegetation type	LAI (m2/m2)	PER (-)	CH (m)	N (-)	RR (cm)	AGGRSTAB (-)	COH (kPa)	COHADD (kPa)
Corn-2	5.34	0.70	1.80	0.20	0.54	30.42	32.88	2.88
Prairie-1	3.50	1	0.65	0.80	0.57	39	39.95	3.50
Soil type	THETAS1 (-)	PSI1 (-)	SOILDEP1 (mm)	D50 (um)	KSAT1 (mm/hr)	THETAI1 (-)		
Clarinda	0.42	30	290	32.81	10.80	0.26		
Otley	0.41	30	1715	32.81	10.60	0.29		
Shelby	0.41	30	340	32.81	21.28	0.29		
Ladoga	0.37	30	400	32.81	28.75	0.26		

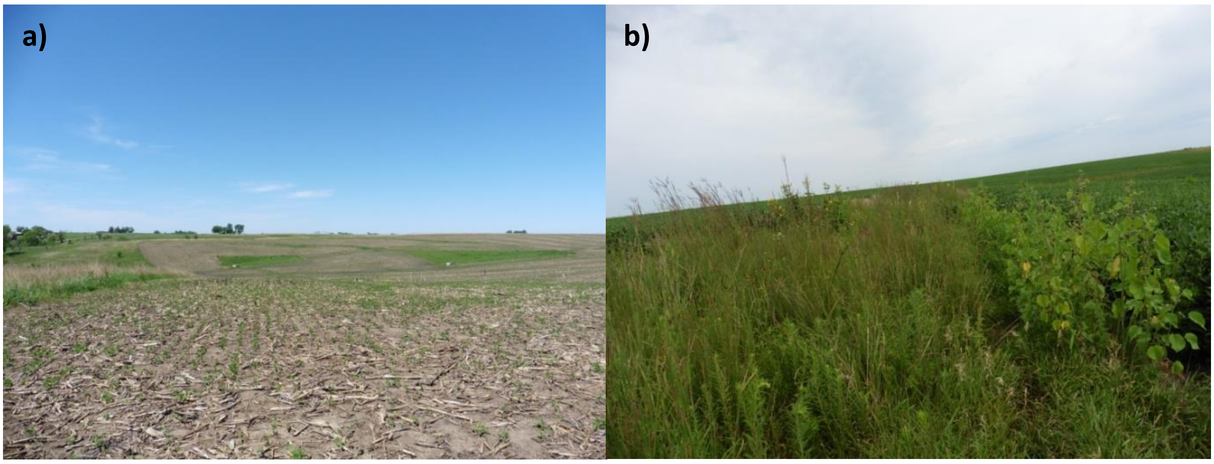


Fig. 8. (a)Upper view of Interim watershed where the cropping system consist on no till crop rotation and residues are left on the field; (b) Interim 1 upslope prairie filter strip characterized by high density of herbs and grass species with stiff stalks (photos by Eduardo Luquin Oroz).

3.2. Runoff

Runoff concentrates in rills where rainfall water gathers and flows downhill. There are two main rills which merge fifty meters northeast from the outlet (Fig. 9). Results show that among simulated scenarios a strip width of 14 meters is the most effective configuration to decrease runoff (Table 5). By prioritizing the order, the scenarios' efficiency on decreasing total runoff was S5>S4>S3>S1>S2.

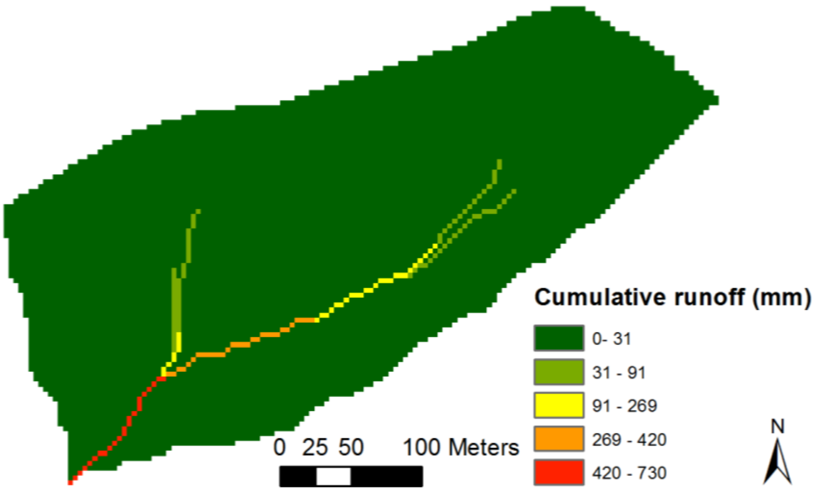


Fig. 9. Cumulative runoff distribution along Interim 1 for scenario S4 (strip width 10 m) under a simulated rainfall intensity reaching 159 mm/h as estimated by LISEM.

Comparing scenarios with strips within row crop contour lines (S2-5), increasing filter width decrease runoff volume (Table 5). According to this trend if wider strips would have been simulated, less runoff would be generated. However, this was not feasible because if doing so, the portion of cropland left for production and for agricultural machinery maneuvering would be low. In fact, the STRIPS project established strips no more than 4-10 m wide with 36m between strips to allow the manoeuvring of agricultural machinery (STRIPS, 2012). Abu-Zreig *et al*. (2004) studied filters of 2, 5, 10, 15 m reporting runoff reduction of 20 and 60% on the 2 and 10m strips respectively. In contrast to our study, they found that increasing filter width above 10 m did not necessarily decrease runoff, such trend was also mentioned by Robinson *et al*. (1996) who studied different strip widths (3-18 m) showing no clear runoff volume reduction as strip width increases. In this study no such trend was observed; simulated scenarios showed that runoff decreases directly with strip width.

Table 5. Hydrological results estimated by LISEM: peak discharge timing (min), peak discharge (l/s) and total discharge (m^3) from each scenario under a range of rainfall intensities.

Simulated rainfall intensity=	I0- 0%	I1-10%	I2-25%	I3-50%	I4-75%	I5-100%
	Runoff peak discharge timing(min)					
Scenario S1- buffer at the toe	66.73	56.10	52.27	48.00	46.07	45.00
Scenario S2- 4 m	58.53	52.30	49.27	45.17	43.40	42.00
Scenario S3- 7.5 m	62.70	55.47	50.50	47.23	44.30	43.07
Scenario S4- 10 m	63.90	54.50	51.47	48.77	46.10	44.23
Scenario S5-14 m	65.53	54.60	52.93	49.70	48.77	46.40
	Runoff peak discharge (l/s)					
Scenario S1- buffer at the toe	14.71	66.55	117.48	296.92	476.40	664.21
Scenario S2- 4 m	15.52	68.82	129.31	309.22	485.19	683.92
Scenario S3- 7.5 m	9.66	55.55	116.68	286.83	460.27	643.10
Scenario S4- 10 m	6.91	46.86	103.81	271.00	443.35	608.68
Scenario S5-14 m	5.81	37.24	84.57	244.13	403.80	559.27
	Total runoff (m^3)					
Scenario S0- current situation	14.69	60.50	122.69	324.50	524.34	734.12
Scenario S1- buffer at the toe	14.38	60.52	118.08	327.62	528.23	737.68
Scenario S2- 4 m	14.53	64.82	127.63	335.14	536.03	746.40
Scenario S3- 7.5 m	10.38	58.17	119.82	326.35	527.86	737.33
Scenario S4- 10 m	8.31	53.91	112.48	319.26	520.58	729.91
Scenario S5-14 m	7.40	49.91	103.56	305.98	506.11	716.05

Over a period of 4 years, Helmers *et al*., (2012) studied different strip configuration efficiencies on reducing agricultural runoff. The study was performed on watersheds within NSNWR under similar slope, soil texture, and soil carbon and nitrogen concentration. They tested three prairie filter strips (PFS) configurations (Fig. 10): (Fig. 10a) treatments with 10% of PFS at the footslope; (Fig. 10b) 10% PFS at the footslope and in contour strips; and (Fig. 10c) 20% PFS at the footslope and in contour strips, all compared with 100% cropland. Scenario S0 (actual strip configuration) of the present study is treatment b, 10% PFS at the footslope and in contour strips whereas scenario S1 tries to simulate treatment a, 10% of PFS at the footslope. The observed runoff exhibited a wide range of interannual variation during the four years studied. On average their study showed runoff reductions of 61, 29 and 28% for treatments a, b and c respectively compared with 100% cropland. When comparing total discharge between scenarios S0 and S1, scenario S1 shows more runoff under high simulated intensities (I3-5), which disagrees with Helmers *et al*., (2012). It is worth to point out that their results are averaged over four years and twelve watersheds whereas this study focuses only on one certain rainfall event and watershed. Related to VFS the study shows that for the type of rainfall event and watershed simulated it was better to have strips distributed along the watershed in order to slow runoff instead of having only one large buffer at the toe. If comparing all scenarios, scenario S5 produced significantly less runoff.

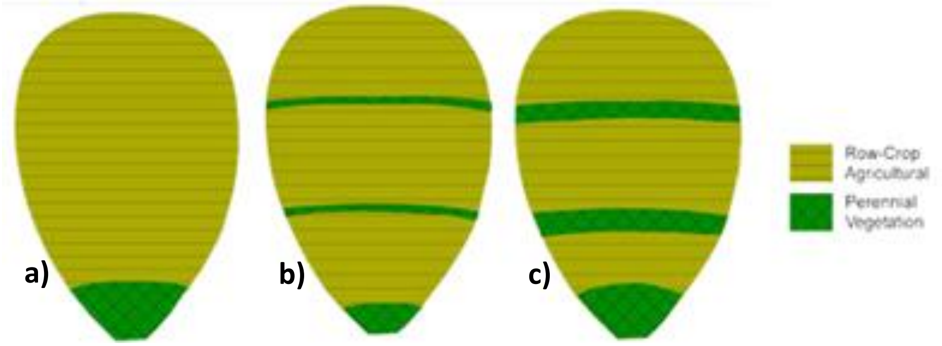


Fig. 10. Percentages and placements of PFS implemented by the STRIPS group within agricultural watersheds in NSNWR(Source: Zhou *et al*., 2010): (a) mixed agricultural-perennial system (10% - perennial at the footslope); (b) mixed agricultural-perennial system (10% - perennial PFS at the footslope and in contour strips); and (c) mixed agricultural-perennial system (20% - perennial at the footslope).

For high simulated intensities (I3-5), scenario S1 simulates higher values for peak and total discharge but shows similar peak discharge times as compared to scenarios S3, S4 and S5. It is hypothesised than in scenario S1, much more runoff volume arrives at the buffer at the toe than in other scenarios where water is previously infiltrated and slowed as it passes through the strip. Strips work as a barrier slowing runoff as it flows through the watershed (Hussein *et al*., 2007; Zhang *et al*., 2010). Under these high intensities, runoff volume arriving at the buffer at the toe is such that even doubling the amount of prairie area is not able to infiltrate enough runoff. Helmers *et al*. (2012) noticed higher infiltration rates when increasing buffer´s area at the toe and pointed out that more concentrated flow occurs on longer slopes (Helmers *et al*., 2012). In the present study runoff volume seems to be dominated by the length of continuous cultivated area.

Hydrographs in Figure 11a show the difference in response between the scenarios to one event, Annex 4 shows hydrographs for the other simulated intensities. Scenario S1 shows the greatest delay for intensities below I1 (95 mm/h) (Table 5). However, for higher intensities, scenario S1 has similar times to those of scenario S4. Overall, results show that a strip width of 14 meters produces the greatest delay. Figure 11b and Annex 5 show the different response of one scenario to different simulated rainfall intensities. As expected, increasing intensity leads to a gradually higher runoff volume and sooner peak discharge within the scenario (Table 5; Fig. 11b).

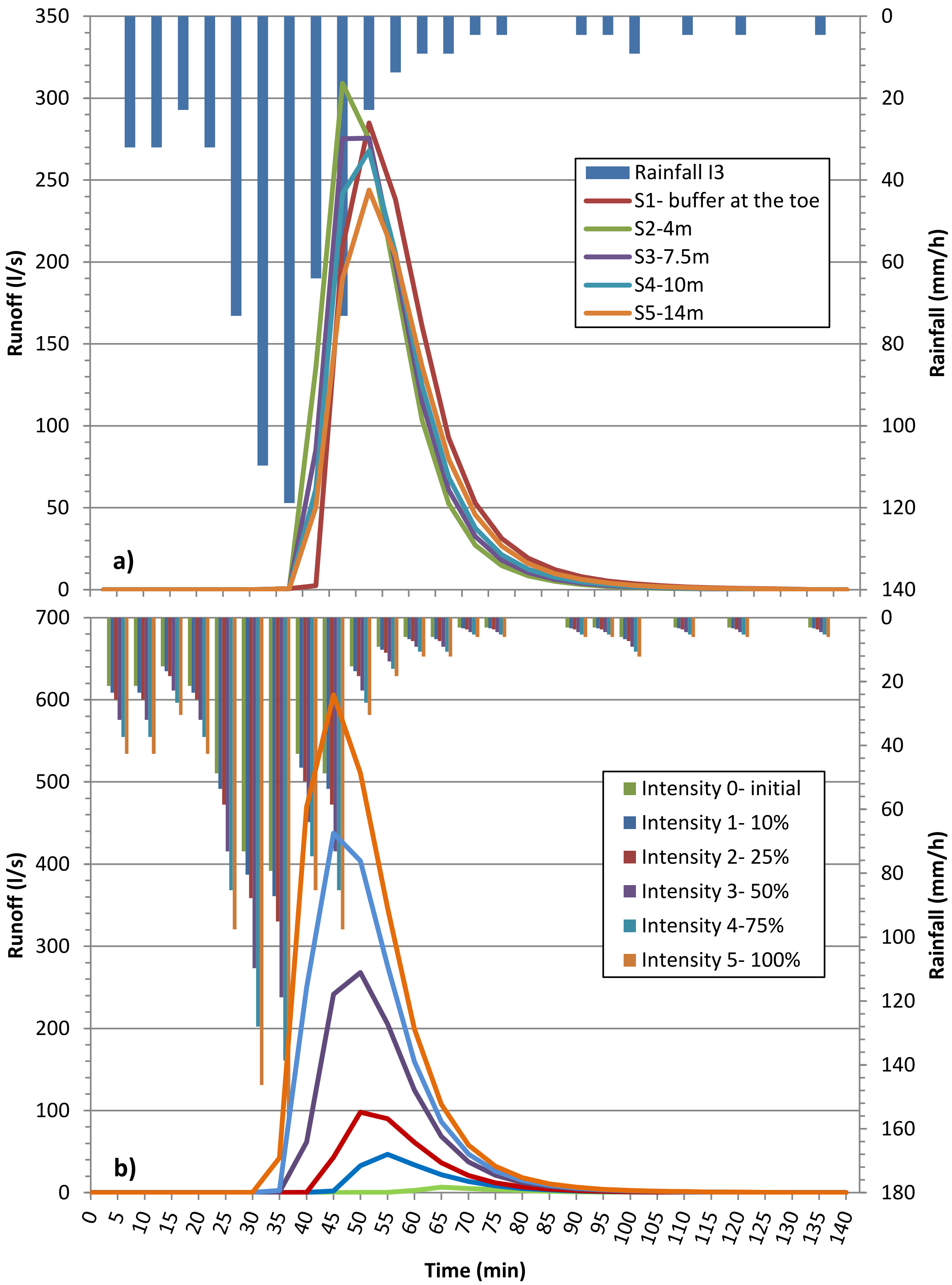


Fig. 11. (a) Hydrological response between the scenarios for a simulated intensity reaching up to 119 mm/h (I3) and (b) hydrological response of scenario S4 (strip width 10m) to the increased intensities as estimated by LISEM. Graph legend is shown in the right size of the graph.

3.3. Sediment

Increased rainfall intensities lead to higher simulated soil losses (Table 6). Among strip scenarios (S2-5), less soil losses are simulated with increasing strip width. From the simulated scenarios, results show that the most effective configuration to decrease soil loss is a strip width of 14 meters. The smallest strip width analyzed (4 m wide) remove significant amounts of sediment from agricultural runoff, showing sediment trapping efficiencies (STE) of 95, 84, 63, 55, 47% for intensities I1, I2, I3, I4 and I5 respectively (Table 6). Yuan *et al*. (2009) studied grass buffers as narrow as 3 m showing also very good STE. Besides, they founded that maximum trapping efficiencies were achieved on widths over 6 m as in our case. Figure 12 and Table 6 show that increasing the buffer width from 4 to 14 m would increase sediment trapping efficiency by 4.14, 9.29, 10.14, 8 and 7.41% for intensities I1, I2, I3, I4 and I5 respectively. The highest difference is reached with I3 (10.14%) (Fig. 12), over that intensity, the difference seems to decline. Effectiveness of vegetative buffers on sediment trapping is reduced when soils become saturated (Helmers *et al*., 2012). Vegetative buffers get saturated due to the continuous sediment delivery into the ponded area upslope the filter. After the ponded area cannot filter more sediment, sediment start flowing downhill through the filter (Dillaha *et al*., 1988). Helmers *et al*. (2012) reported STE reductions of 87 % on some of the 12 watersheds within NSNWR under extreme events. All strip scenarios (S2-5) performed well on reducing sediment export from agricultural fields. Moreover sediment removal efficiency of VFS varied directly with strip width, values are in agreement with those reported in literature (Diallaha *et al*., 1989; Robinson *et al*., 1996; van Dijk *et al*., 1996; Abu-Zreig *et al*., 2003; Yuan *et al*., 2009; Zhang *et al*., 2010).

Table 6. Total soil loss (Kg) and sediment trapping efficiency (%) from each scenario under a range of rainfall intensities as estimated by LISEM.

	Simulated intensity characteristics					
	I0- 0%	I1-10%	I2-25%	I3-50%	I4-75%	I5-100%
Total rainfall (mm)	36.32	39.95	43.59	54.48	63.56	72.64
Peak intensity (mm/h)	79	87	95	119	139	159
	Total soil loss (Kg)					
Scenario S1- buffer at the toe	0.08	179.65	1211.73	9148.43	20683.56	29221.90
Scenario S2- 4 m	3.74	559.64	2623.64	12870.75	22428.94	32727.79
Scenario S3- 7.5 m	0.24	319.61	2025.51	11414.81	21304.56	30443.23
Scenario S4- 10 m	0.04	167.10	1486.84	10058.39	19555.47	28213.80
Scenario S5-14 m	0.03	83.68	985.11	8325.07	16972.24	25412.33
	Sediment trapping efficiency (%)					
Scenario S1- buffer at the toe	100	98.24	91.6	67.63	52.21	44.69
Scenario S2- 4 m	99.4	94.99	83.61	62.57	55.38	46.78
Scenario S3- 7.5 m	100	97.12	86.96	65.83	56.97	49.24
Scenario S4- 10 m	100	98.44	90.28	69.06	60.47	51.84
Scenario S5-14 m	100	99.13	92.9	72.71	63.38	54.19

Hussein *et al*. (2007) relates STE with overland flow duration and characteristics i.e. flow rate, sediment concentration and particle size. Other studies noticed lower performance of VFS under concentrated flow too (Dillaha *et al*., 1988; Abu-Zreig *et al*., 2003; Hussein *et al*., 2007; Yuan *et al*., 2009); this could help to explain why there are not significant STE differences among scenarios as mainly concentrated flow occurred in simulations. Other factors such as rainfall intensity also influence efficiency (Robinson *et al*., 1996; Blanco-Canqui *et al*., 2006). STE is decreased by 50% if comparing I1 and I5 (doubled intensity). For intensities greater than I4, S1 shows the lowest STE of all scenarios which could be related as explained above due to buffer saturation. Sediment trapping efficiency seems to be more sensitive to rainfall intensity rather than strip width (Fig. 12). Another explanation of why scenarios have no significant STE differences under the same rainfall intensity could be related to the fact that as the buffer gets wider, it reaches a width where the efficiency approaches a maximum value (Abu-Zreig *et al*., 2003; Zhang *et al*., 2010). Similar rainfall characteristics as I4 were used by Blanco-Canqui *et al*. (2004a & b), supplying rainfall with a simulator during one hour at 66 ± 5 mm/h. They mentioned that buffers 4-6 m wide trapped more than 50% of the incoming sediment from runoff, similar STE values to the ones from scenarios S2 and S3 (strip width 4-7.5 m). Factors influencing effectiveness of VFS (flow conditions, vegetation type, filter strip width, topography-slope, soil type, land use and rainfall characteristics), i.e. to some extent watershed heterogeneity, makes it difficult to compare impact of VFS on sediment removal on the watershed scale (Helmers *et al*., 2012). In addition, caution should be exercised when comparing plot scale with assessments at watershed scale (Blanco-Canqui *et al*., 2006; Mekonnen *et al*., 2014), with this in mind, the study supports the idea of previous studies that STE increase directly with buffer width (Blanco-Canqui *et al*., 2004a & b, 2006; Zhang *et al*., 2010).

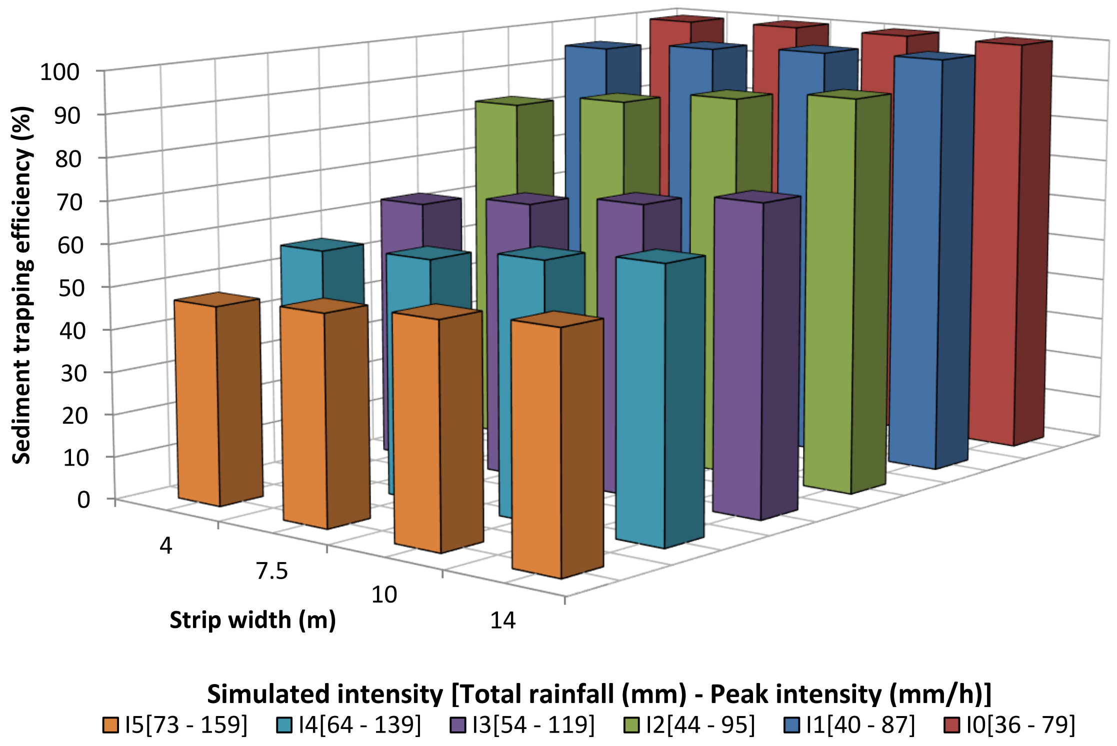
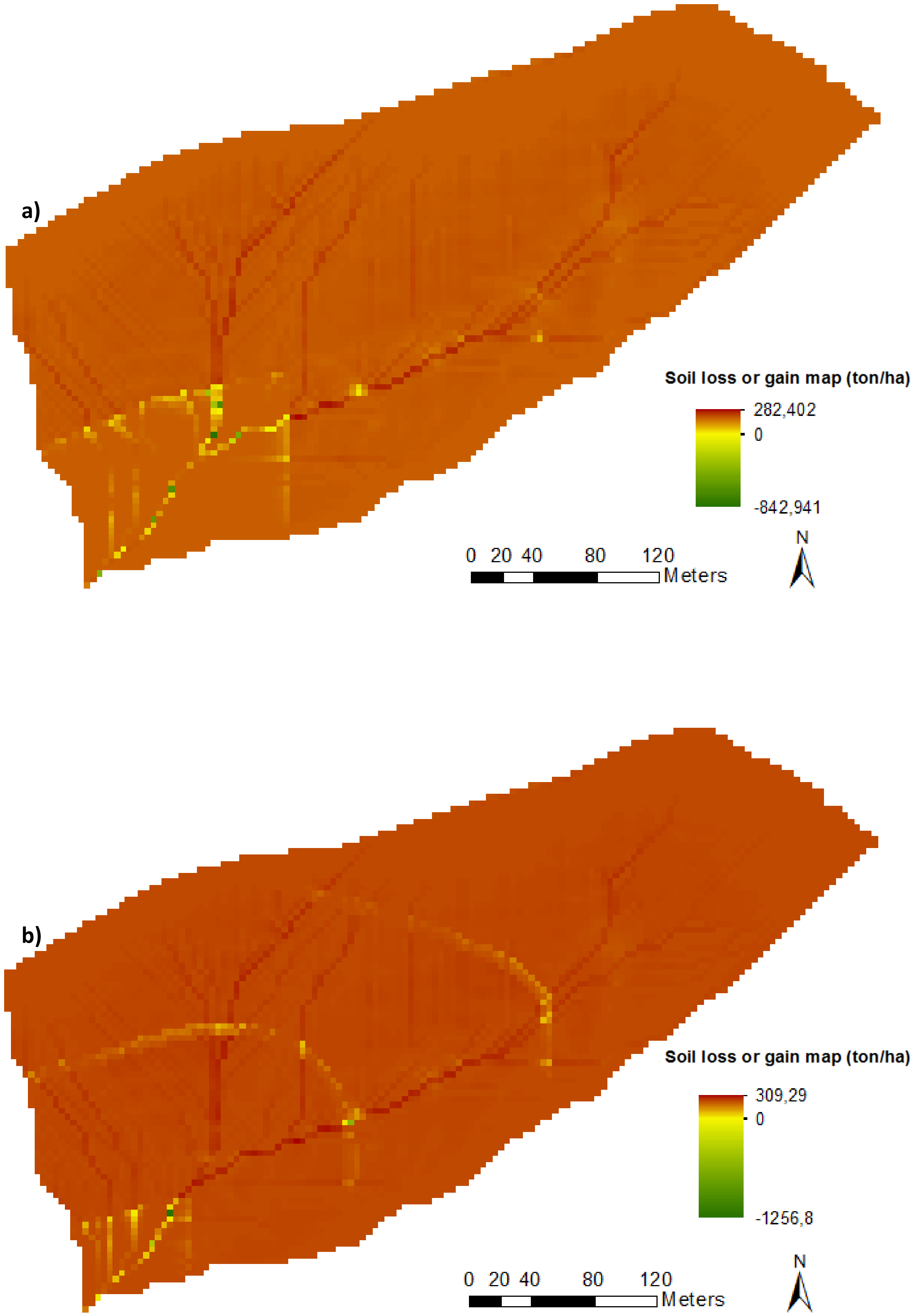


Fig. 12. Sediment trapping efficiencies for strip scenarios (S2-5) on Interim 1 under the increased intensitiesas estimated by LISEM.

Comparing scenario S1 (doubled buffer at the toe) with strip configurations (S2-5), scenario S1 is 0.89, 1.3, 5.08, 11.17 and 9.5% less efficient than scenario S5 for intensities I1, I2, I3, I4 and I5 respectively (Table 6). In terms of sediment movement, the study shows than it is better to have strips along the watershed than a significant amount of vegetation at the bottom of the watershed, especially under greater rainfall intensities. Even though a strip width of 14m shows the best sediment trapping efficiency, from the practical perspective its implementation in Interim 1 seems not feasible as the portion of cropland left to production and agricultural machinery manoeuvring is low.

Soil loss per cell comes from the balance between sediment arrived (deposition) and sediment eroded by runoff (detachment). Detachment was mostly produced by runoff instead of rain drops because corn fully developed its canopy for the time period modeled. Therefore, detachment and soil loss mainly occurred in rills caused by concentrated flow (Fig. 13). Higher erosion rates took place in the two main rills, which merge into one lower in the watershed. Minimal detachment occurred within prairie buffers (Fig. 13). According to Helmers *et al*. (2012) a wider buffer at the toe position produces higher infiltration rates which could explain the relatively low simulated soil loss values although the lowest STE for simulated high rainfall intensities (I4-I5) in scenario S1 (Table 6). Another hypothesis could be related to the fact that the buffer at the toe in scenario S1 reaches an area before the two main rills converge into one whereas on strip scenarios (S2-S5), the main two rills converge and flow downhill with greater erosive forces. Cells right after the strip showed high detachment rates (Fig.13). The term “clean” water refers to clean water that is much more erosive than water full with sediment (Mekonnen *et al*., 2014). After crossing the strip, runoff recovers its transport capacity being able to transport and erode again. “Clean” water could be expected to be more erosive downstream of the outlet and buffer, therefore special care should be taken with erosion on flumes´ outlet (Fig. 14). VFS slow runoff, causing a ponded area upslope the filter, where mainly coarse material are deposited while finer materials flows into the filter (Hussein *et al*., 2007). Sedimentation occurs upslope and in the VFS because vegetative hydraulic conditions quickly decreases erosion and transport capacities of overland flow enhancing deposition of soil particles transported with runoff (Dillaha *et al*., 1988; van Dijk *et al*., 1996; Hussein *et al*., 2007; Yuan *et al*., 2009; Mekonnen *et al*., 2014). Sedimentation mainly occurred within the first two meters of the buffer (Fig. 13) agreeing with previous studies asserting that mainly sedimentation takes place on the first meters (Dillaha *et al*, 1988; Gharabaghi *et al*., 2006; Liu *et al*., 2008). On places where rills cross the buffer, stream power and turbulence resulted in sedimentation along the VFS, although a large amount of sediment was trapped in the first meters too. Different sediment dynamics occurred among scenarios (Fig. 13), strip scenarios (S2-5) trap sediment across the strips and at the small buffer at the toe, whereas scenario S1 traps sediment on the larger toe buffer. Figure 13 shows that the establishment of strips on the farmer component of the watershed decrease sediment transfer to the footslope filter (Helmers *et al*., 2012). This study shows the two ways to decrease sediment export, either reducing runoff and/or sediment concentration in it (Yuan *et al*., 2009; Helmers *et al*., 2012). Scenario S1 shows high runoff volumes but good STE which explains the first instance whereas strip scenarios (S2-5) decrease runoff volumes which explains the second case.


a)
Soil loss or gain map (ton/ha)
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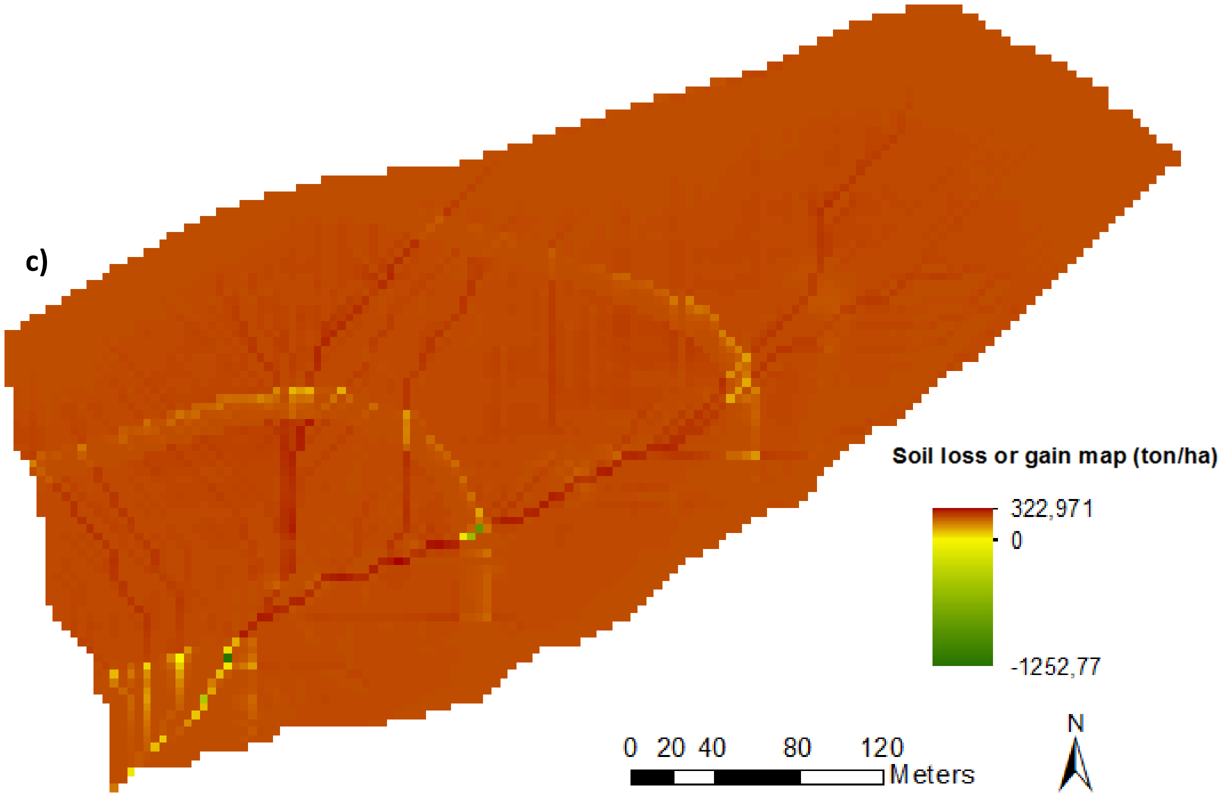
0
-842,941
0 20 40 80 120
Meters
N
b)
Soil loss or gain map (ton/ha)
309,29
0
-1256,8
0 20 40 80 120
Meters
N

c)


Soil loss or gain map (ton/ha)
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Meters
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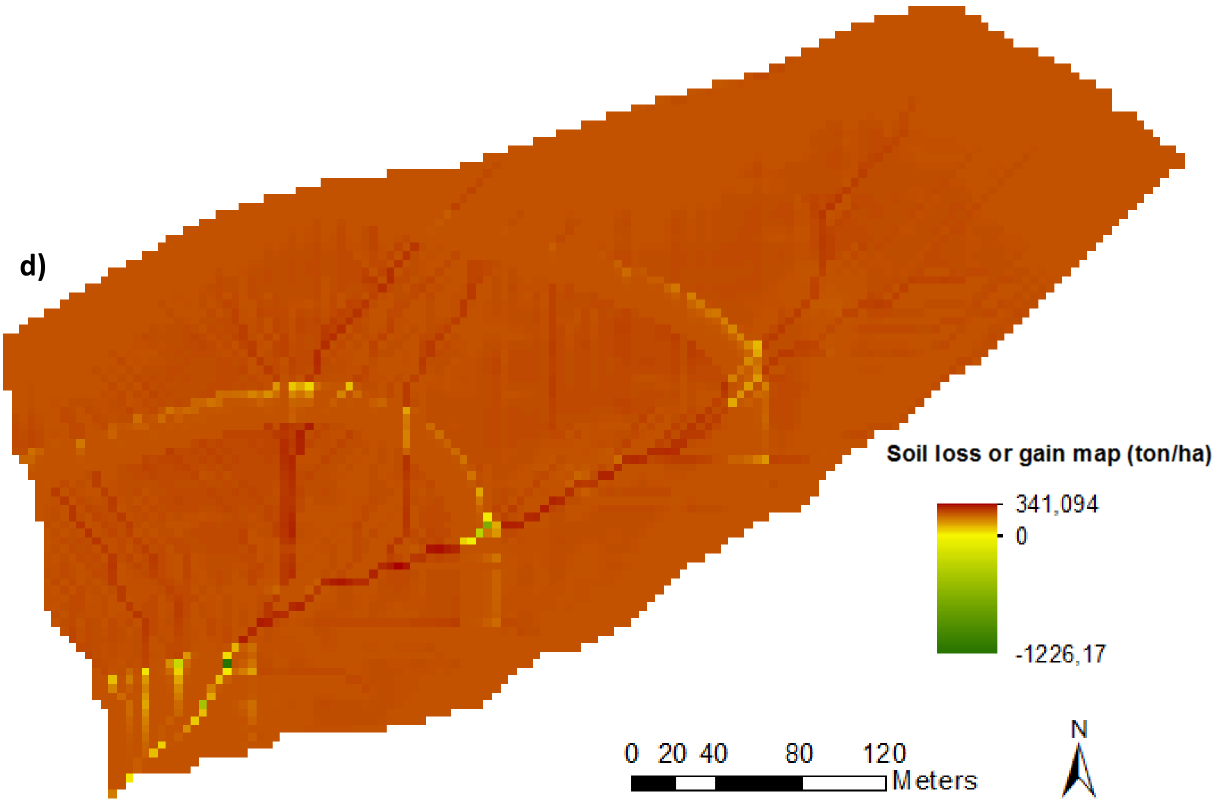
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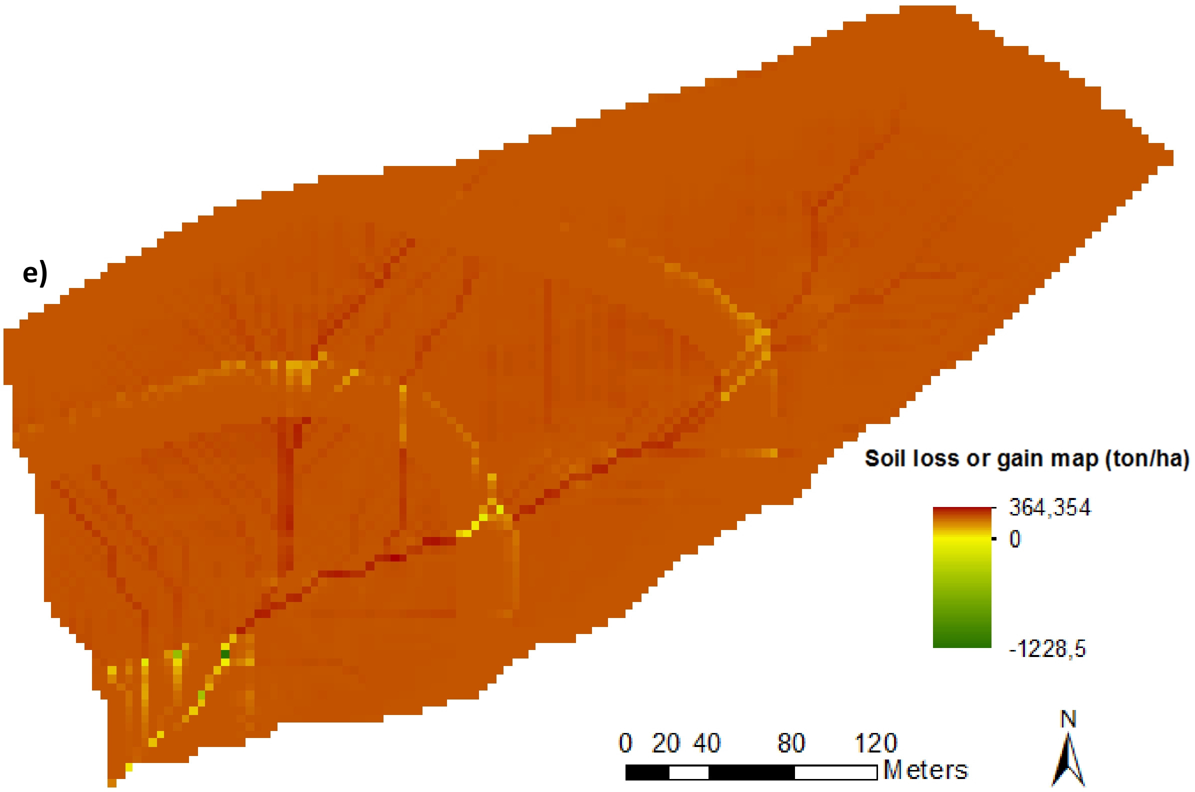

Fig.13. Soil loss maps for scenarios under the highest event with intensities reaching up to 159 mm/has estimated by LISEM: (a) S1-double buffer at the toe; (b) S2-4 m; (c) S3-7.5m; (d) S4-10m; and (e) S5-14m. A positive number indicates detachment whereas a negative value shows deposition. Zero values are cells where detachment is equal to sedimentation.

Fig. 14. Example of erosion related to the term "clean" water right after the flume on Interim 1 (photo by Eduardo Luquin Oroz).

From a practical perspective, converting 10% of cropland to PFS at the bottom of the field would be more convenient for field operations while taking relatively smaller amounts of land out of production. However, a disadvantage is that under high rainfall intensities, scenario S1 shows the lowest STE, possibly because the buffer at the toe gets saturated earlier than strip scenarios where runoff is previously slowed and infiltrated by the strips. On the other hand, wider strips such as 14 m trapped more sediment, however, from a practical point of view the portion of cropland left to production and to allow for field operations is low.Taken together, this lead us to conclude that for the simulated scenarios, a strip width of 10m is the best configuration in order to decrease sediment export from Interim 1.

4. CONCLUSION

This study analyzed vegetative strip width impact on soil and water movement under a range of rainfall intensities.The effect of increased rainfall intensities lead to sooner peak discharge and increased runoff volume and soil losses. Overall, prairie filter strips were effective in filtering sediment from agricultural runoff. Results showed that the smallest strip width analyzed (4 m wide) had a sediment trapping efficiencies (STE) of 95, 84, 63, 55, and 47% on simulated rainfall intensities reaching up to 79, 87, 95, 119, 139 and 159 mm/h respectively. STE increaseddirectly with strip width, results showed thatifthe width of the filter increased from 4 to 14 m, efficiency increased by 8%. However, STE decreased with greater intensity, if twice the intensity is simulated, efficiency drops by 50%.Trapping efficiency seems to be more sensitive to rainfall intensity rather than strip width. Astrip width of 10 meters was selected as the most effective configuration simulated in order to decrease soil and water export from the watershed.Wider strips such as 14 m trapped more sediment, however, from the practical point view the portion of cropland left to production and to allow agricultural machinery maneuvering was low. In terms of hydrology and sediment movement, it can be concluded from the simulated scenarios that it is better to distribute strips along the watershed in order to trap sediments and slow agricultural runoff instead of having only a large buffer at the outlet, especially under greater rainfall intensities.Detachment and soil loss mainly occurred in rills caused by concentrated flow and the first meters of the vegetative filter strip (VFS)were where most sedimentation occurred.On places where rills cross the buffer, stream power and turbulence resulted in sedimentation along the VFS.

Final considerations

Future research needs to be done at watershed scale over longer periods and against a distribution of storm sizes and intensities. Because of watershed heterogeneity (different land uses, soil types and topography) it would be useful to analyze whether the implementation of the current strip configurations would show similar STE on another watershed. Hypothesizing that strip width alone has more influence over the variance in STE before or right after planting, STE should be analyzed at these time points. Finally, although increasing the number of strips distributed along the watershed would compromise the workability and space left for agriculture, it would be helpful to determine its influence on STE.

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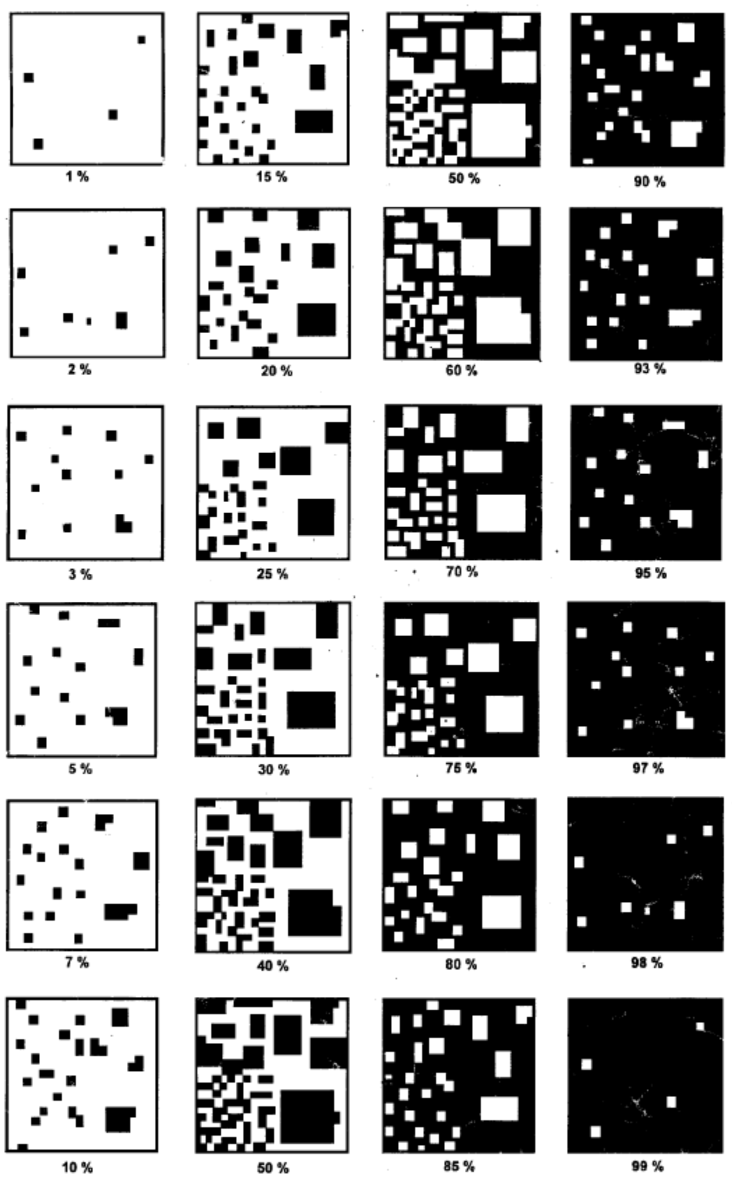
6. ANNEXES

Annex 1.Summarized information about input data.

Input parameter	Description	Unit	Source(s)	Linked to
LDD	Local drain direction	-	DerivedfromDEM	-
AREA	Watershedboundaries	-	Derived from DEM	-
ID	Areacoveredbyraingauges	-	Derived from DEM	-
GRAD	Slopegradient	-	Derived from DEM	-
OUTLET	Location of outlet	-	Derived from DEM	-
PER	Fraction of soil covered by vegetation	%	Field data	Land use
LAI	Leaf area index	-	Field data; STRIPS database	Land use
CH	Crop height	m	Field data	Land use
N	Manning’s n		Arcement& Schneider(1989); Weltz *et al*. (1992)	Land use
RR	Random roughness	cm	Field data; Jester &Klik (2005)	Land use
AGGRSTAB	Aggregate stability		Cammeraat and Imeson (1998)	Land use
COH	Cohesion of bare soil	kPa	Field data	Land use
COHADD	Additional cohesion by roots	kPa	Baets *et al*. (2008)	Land use
D50	median of the texture of the soil	µm	Zhou *et al*. (2010)	Soil type
KSAT	Saturated hydraulic conductivity	mm/hr	USDA(2013)	Soil type
THETAS	Saturated volumetric soil moisture content		Field data	Soil type
THETAI	Initial volumetric soil moisture content		Field data	Soil type
PSI	Water tension at wetting front	cm	Boer&Puigdefabregas (2005)	Soil type
SOILDEP	Soil depth	mm	USDA(2013)	Soil type

Annex 2. Proportion formsto estimate LAI develop by Hessel (2002).

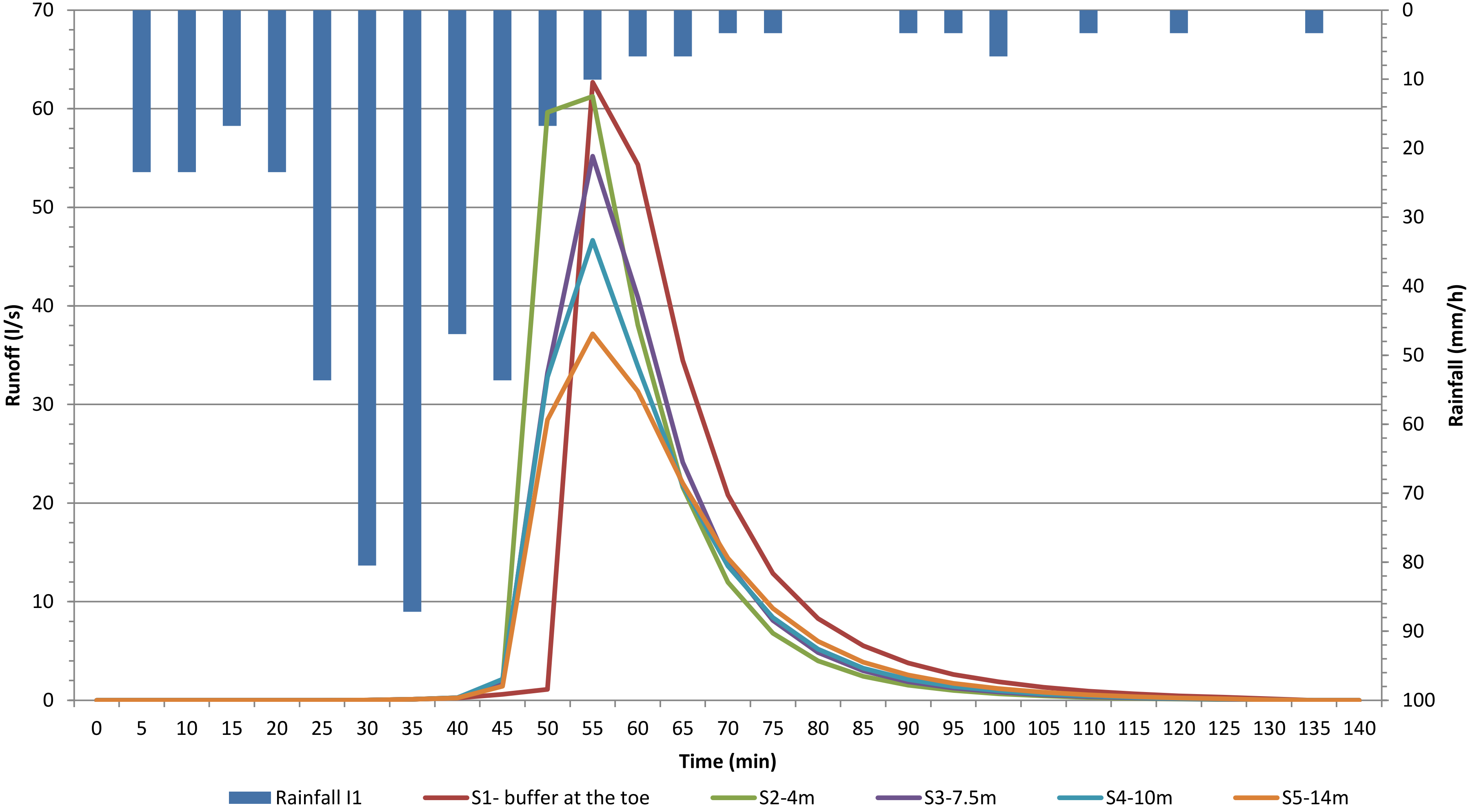


Annex 3. Five minutes increment rainfall intensity (mm/h) values for a 140 minutes rainfall. Peak rainfall intensity was on minute 35.

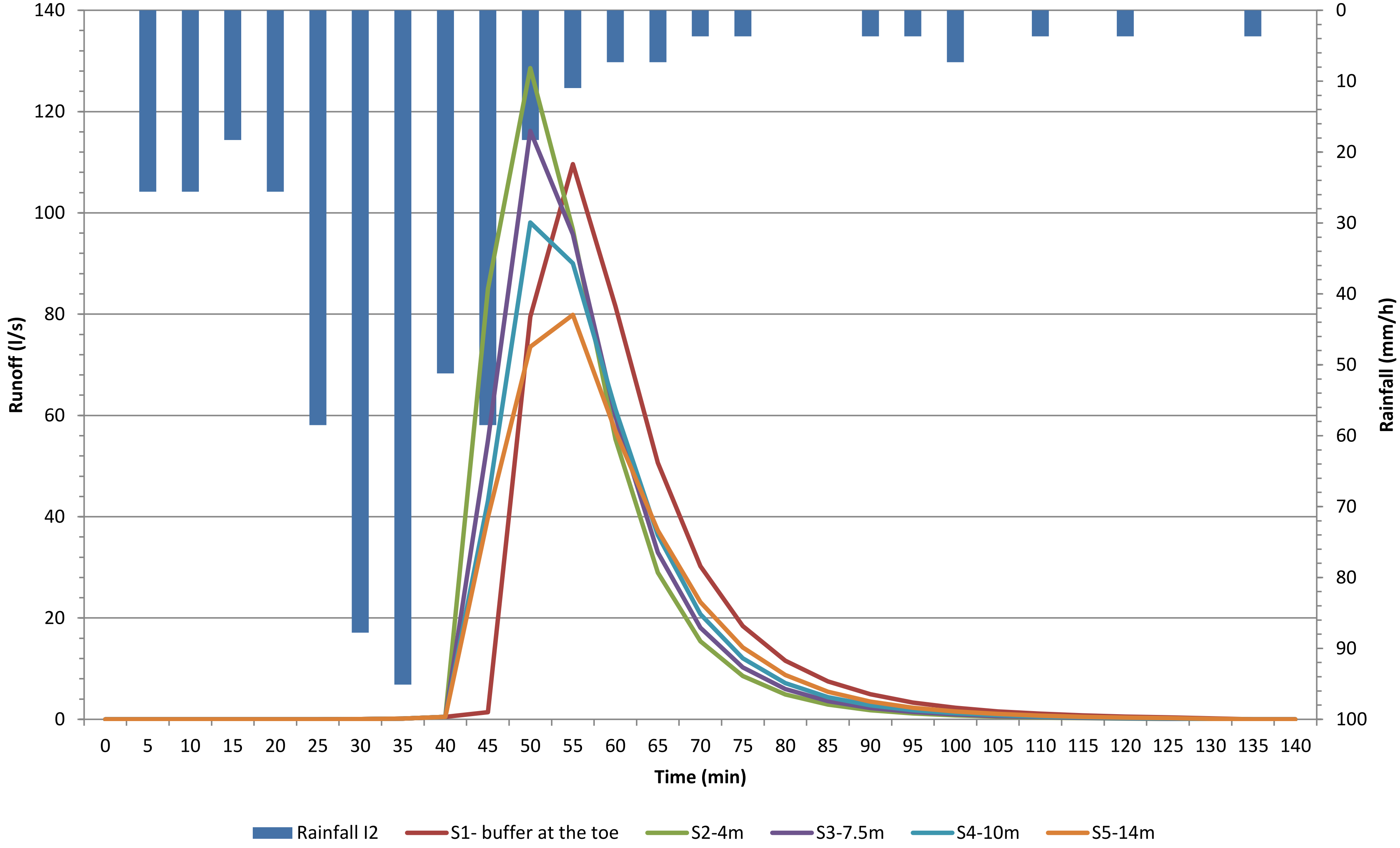
Time	Rainfall (mm/h)	Intensity 1-10%(mm/h)	Intensity 2-25%(mm/h)	Intensity 3-50%(mm/h)	Intensity 4-75%(mm/h)	Intensity 5-100%(mm/h)
0	0.00	0.00	0.00	0.00	0.00	0.00
5	21.34	23.47	25.60	32.00	37.34	42.67
10	21.34	23.47	25.60	32.00	37.34	42.67
15	15.24	16.76	18.29	22.86	26.67	30.48
20	21.34	23.47	25.60	32.00	37.34	42.67
25	48.77	53.64	58.52	73.15	85.34	97.54
30	73.15	80.47	87.78	109.73	128.02	146.30
35	79.25	87.17	95.10	118.87	138.68	158.50
40	42.67	46.94	51.21	64.01	74.68	85.34
45	48.77	53.64	58.52	73.15	85.34	97.54
50	15.24	16.76	18.29	22.86	26.67	30.48
55	9.14	10.06	10.97	13.72	16.00	18.29
60	6.10	6.71	7.32	9.14	10.67	12.19
65	6.10	6.71	7.32	9.14	10.67	12.19
70	3.05	3.35	3.66	4.57	5.33	6.10
75	3.05	3.35	3.66	4.57	5.33	6.10
80	0.00	0.00	0.00	0.00	0.00	0.00
85	0.00	0.00	0.00	0.00	0.00	0.00
90	3.05	3.35	3.66	4.57	5.33	6.10
95	3.05	3.35	3.66	4.57	5.33	6.10
100	6.10	6.71	7.32	9.14	10.67	12.19
105	0.00	0.00	0.00	0.00	0.00	0.00
110	3.05	3.35	3.66	4.57	5.33	6.10
115	0.00	0.00	0.00	0.00	0.00	0.00
120	3.05	3.35	3.66	4.57	5.33	6.10
125	0.00	0.00	0.00	0.00	0.00	0.00
130	0.00	0.00	0.00	0.00	0.00	0.00
135	3.05	3.35	3.66	4.57	5.33	6.10
140	0.00	0.00	0.00	0.00	0.00	0.00

Annex 4. Hydrographs difference in response between the scenarios for one event.

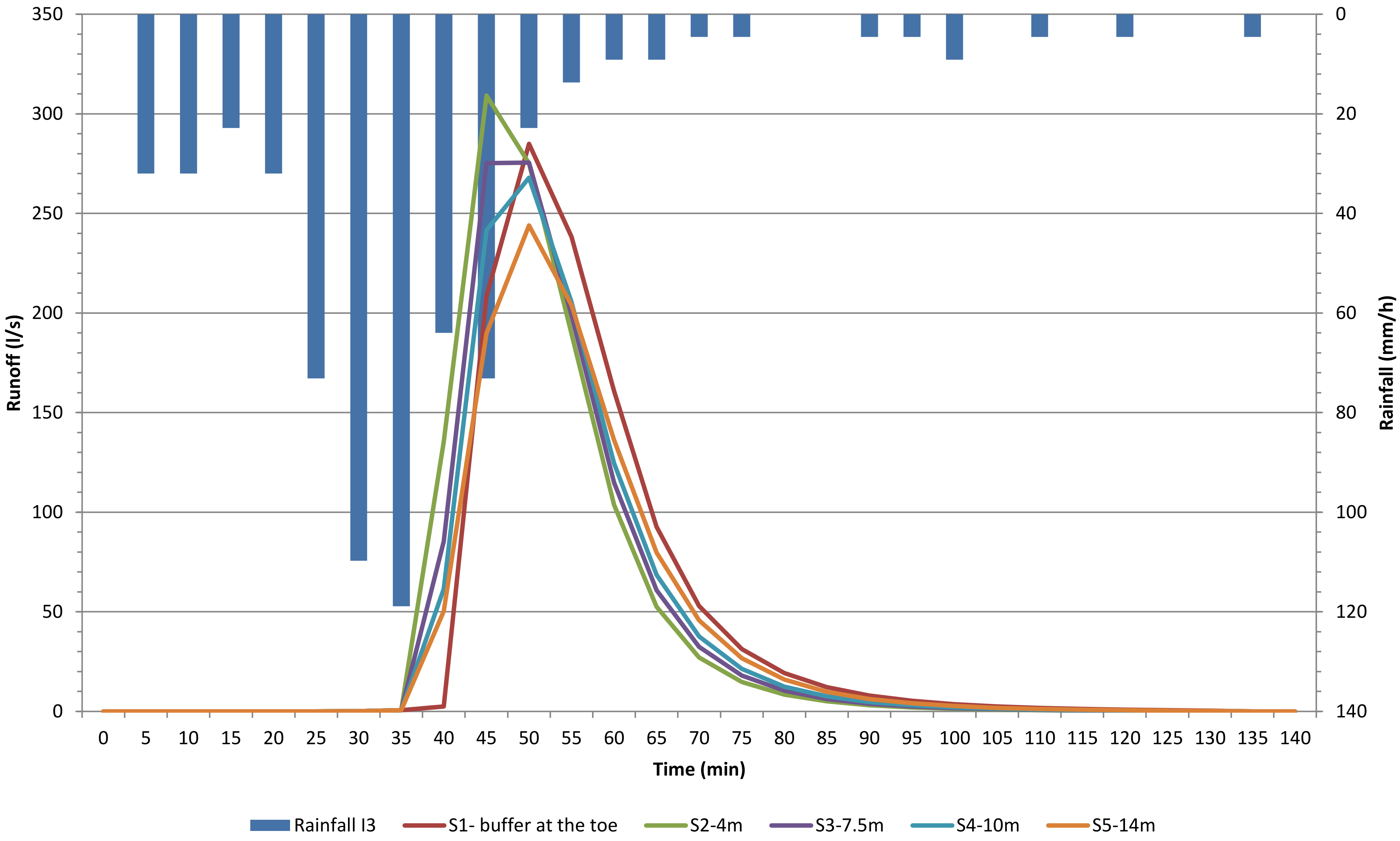
Annex 4.1. Response between the scenarios for an intensity reaching up to 87mm/h (I1).



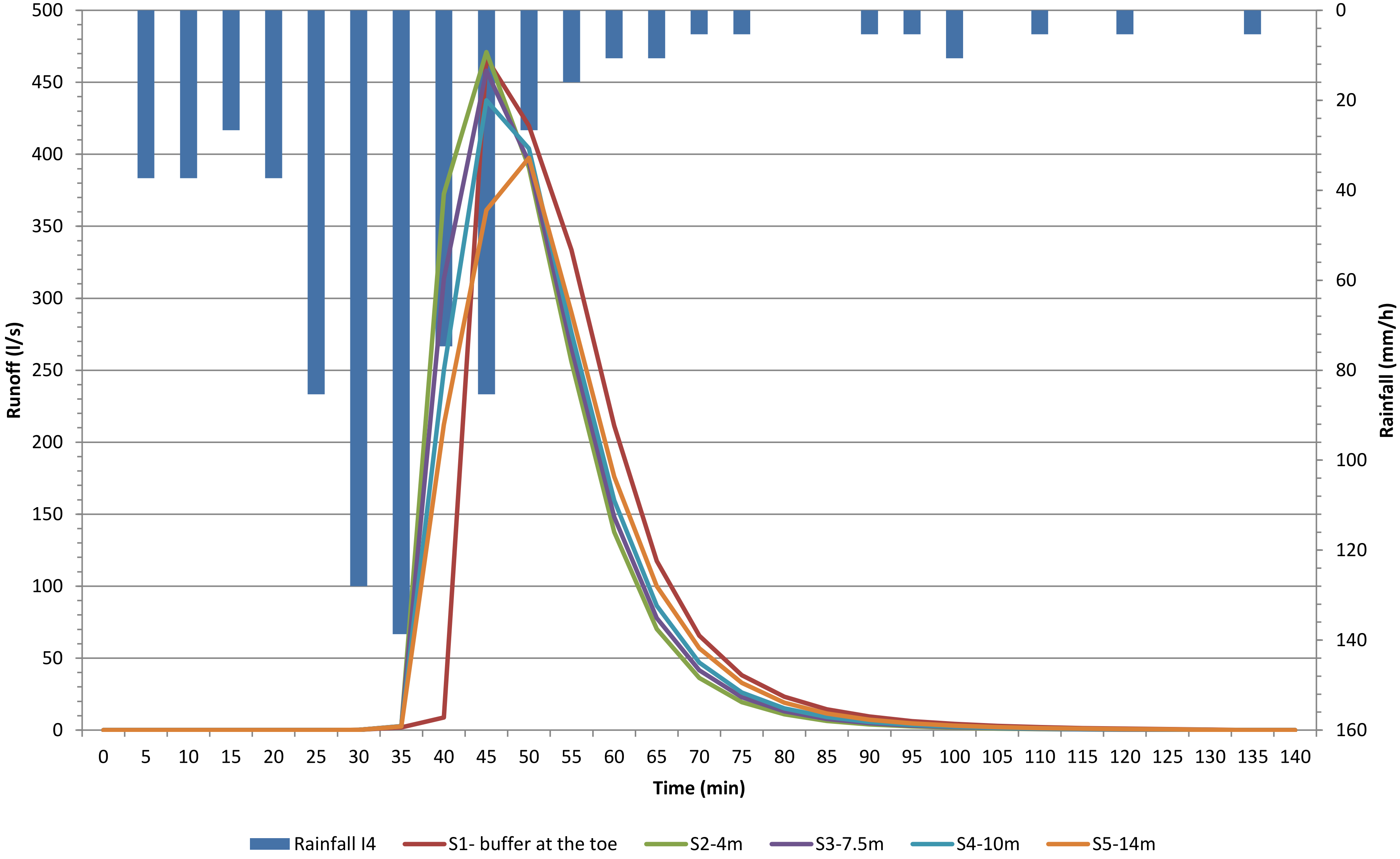
Annex 4.2. Response between the scenarios for an intensity reaching up to 95 mm/h (I2).



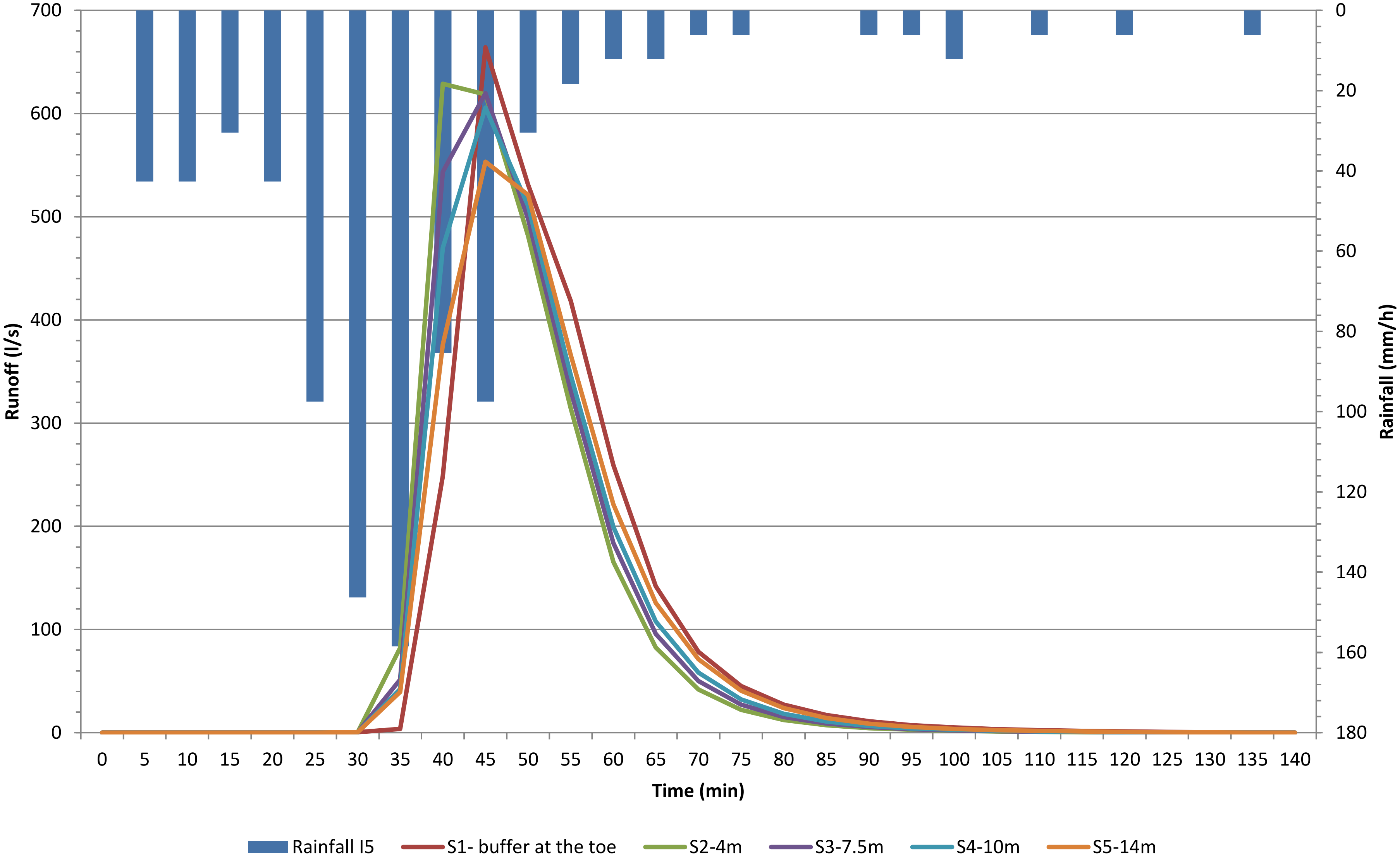
Annex 4.3. Response between the scenarios for an intensity reaching up to 119 mm/h (I3).



Annex 4.4. Response between the scenarios for an intensity reaching up to 139 mm/h (I4).

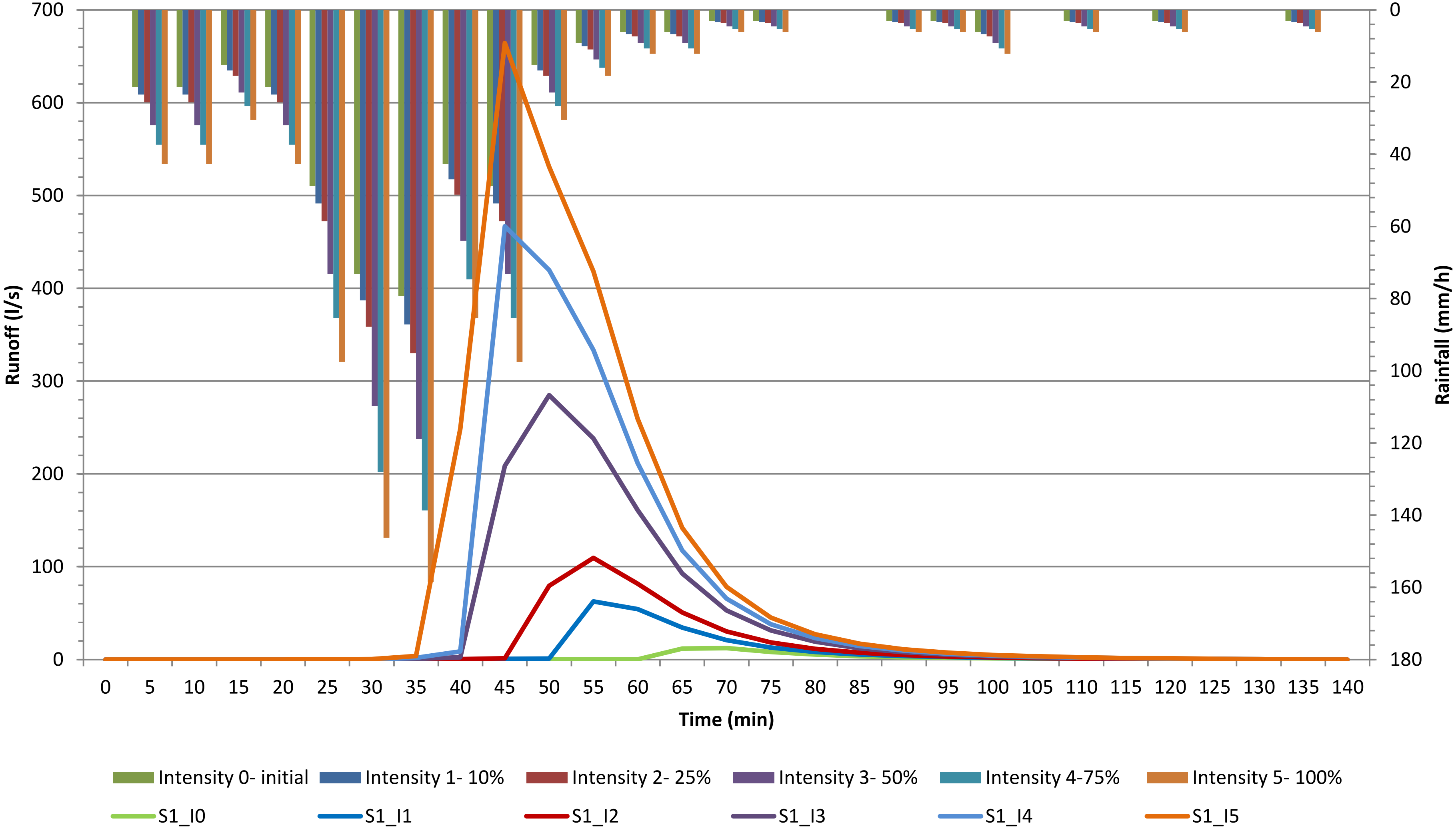


Annex 4.5. Response between the scenarios for an intensity reaching up to 159 mm/h (I5).

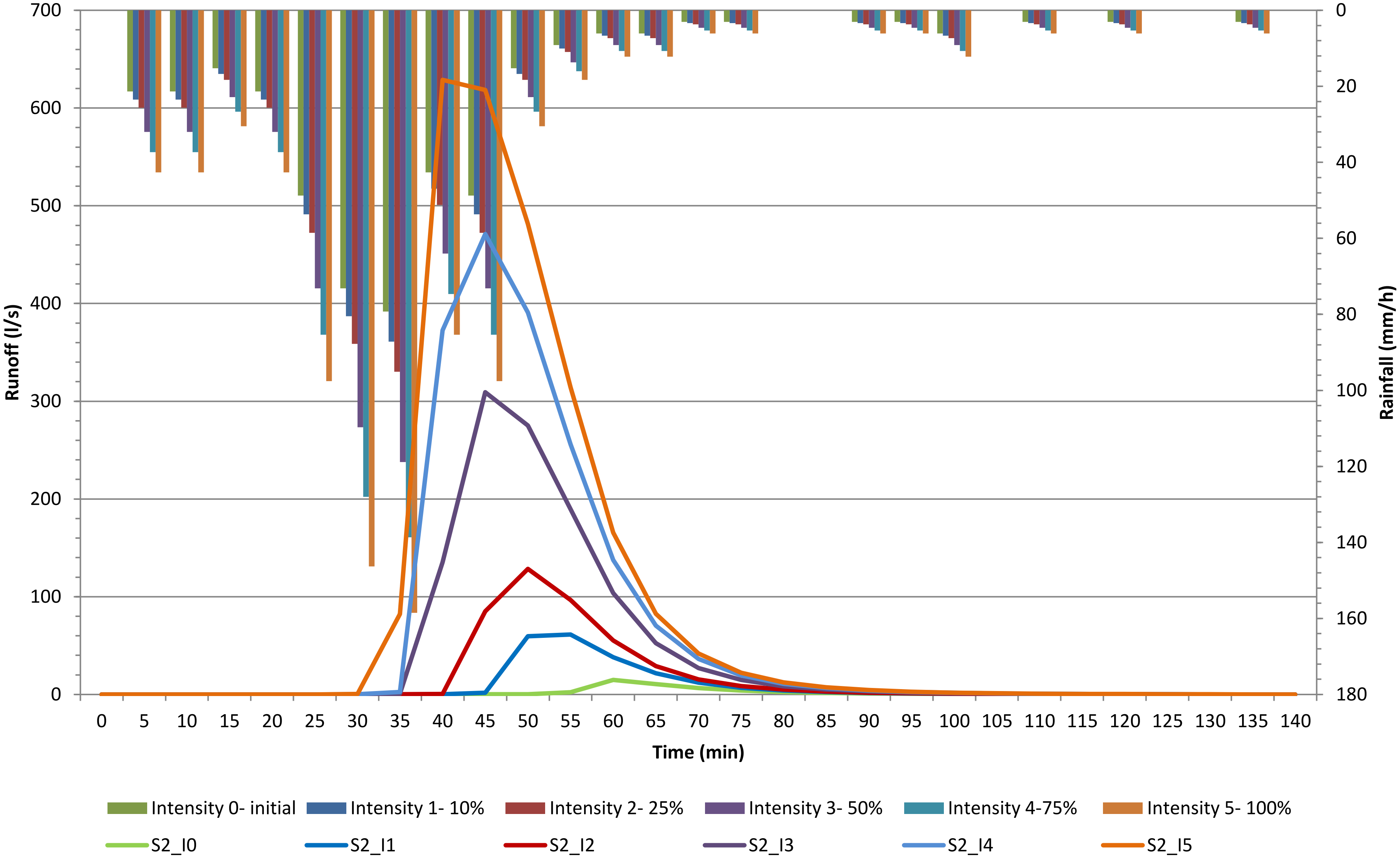


Annex 5. Hydrographs difference in response of one scenario to the different events.

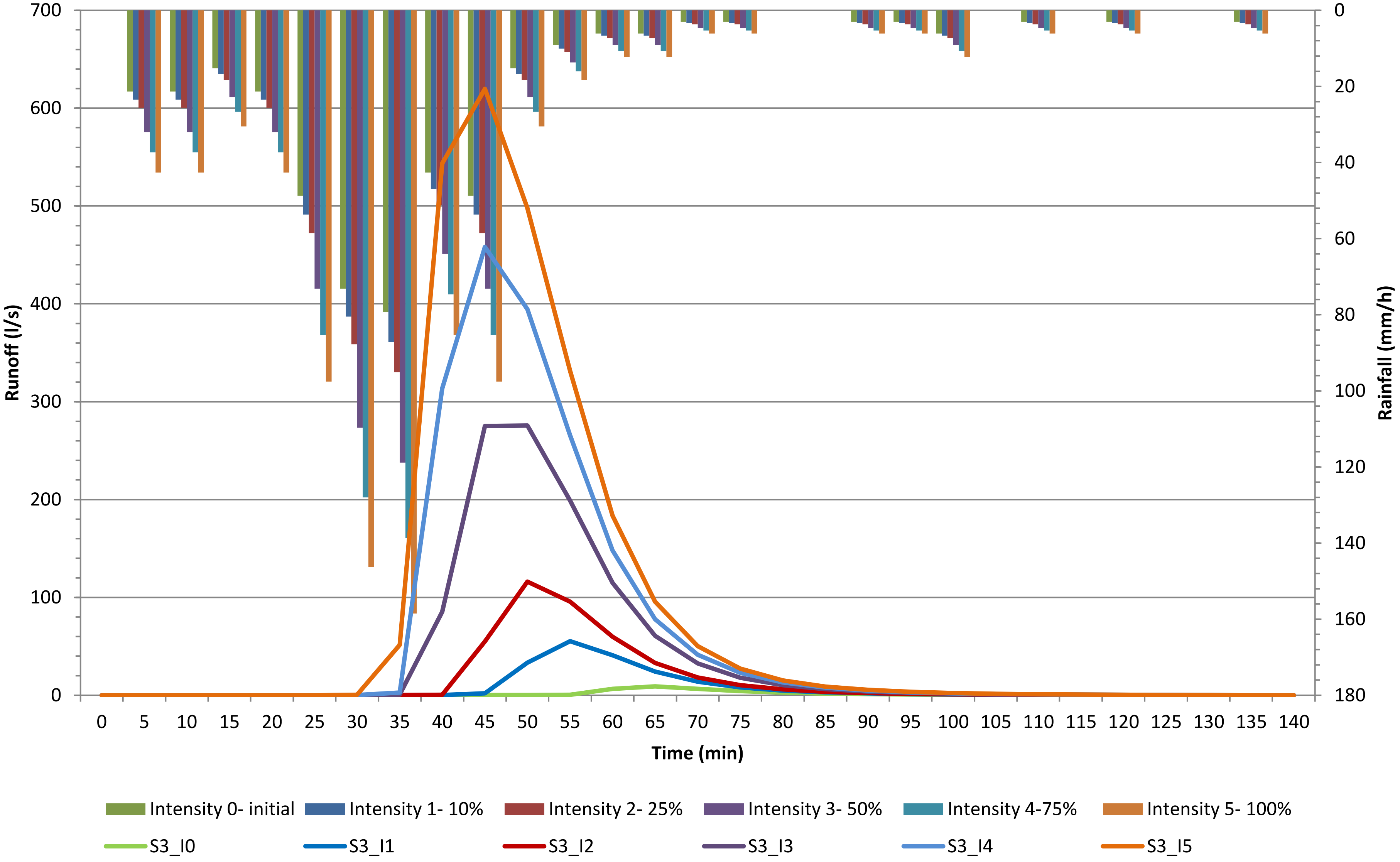
Annex 5.1. Response of scenario S1 (double buffer at the toe)to the different simulated intensities.



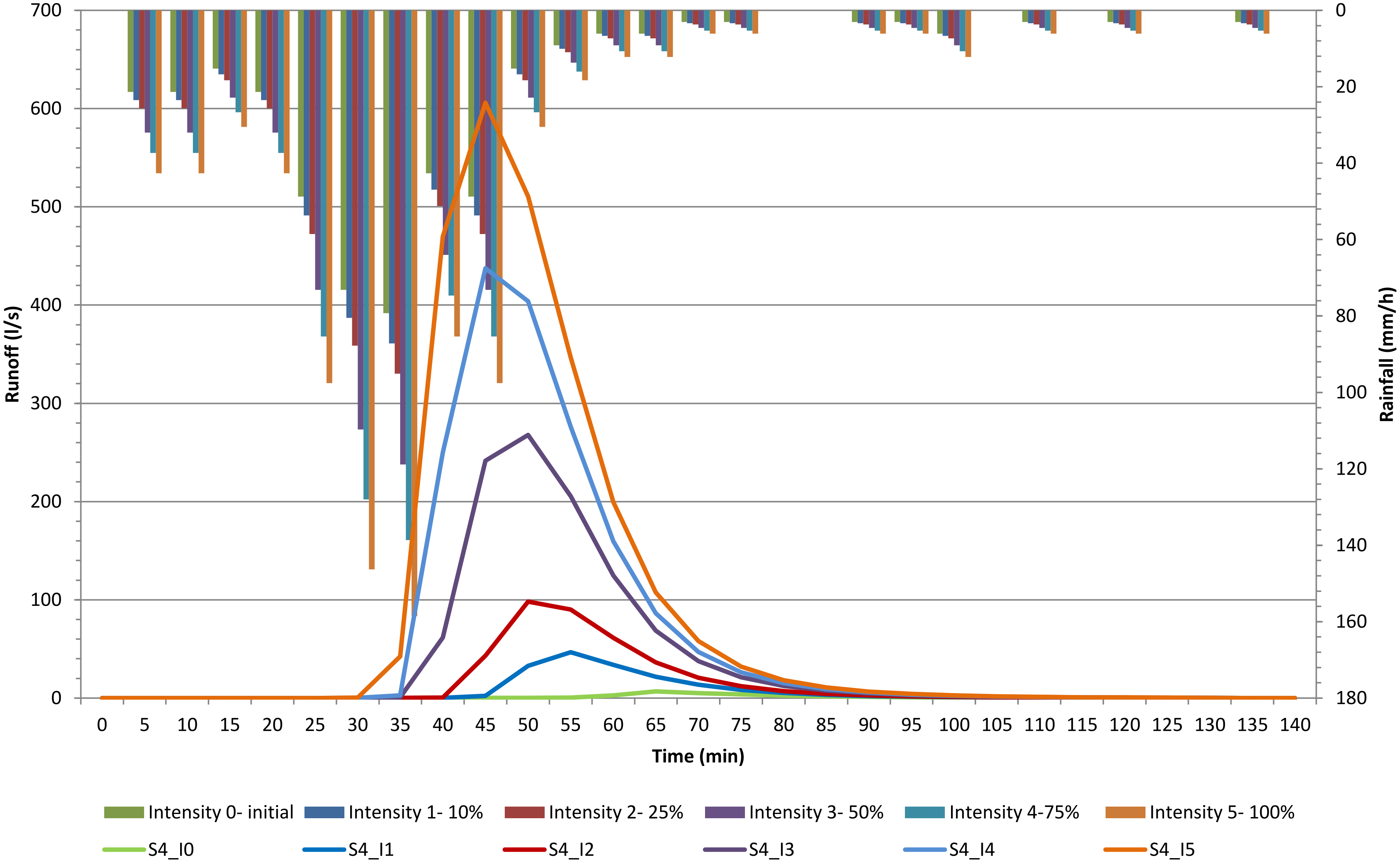
Annex 5.2. Response of scenarioS2(strip width 4m)to the different simulated intensities.



Annex 5.3. Response of scenario S3 (strip width 7m) to the different simulated intensities.



Annex 5.4. Response of scenario S4 (strip width 10m) to the different simulated intensities.



Annex 5.5. Response of scenario S5 (strip width 14m) to the different simulated intensities.