Institut für Hydrologie der Albert-Ludwigs Universität Freiburg i. Br.

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Single event modelling in the small (0.6 km^2) catchment of Rouffach, Haut-Rhin, France

Diplomarbeit unter Leitung von Prof. Dr. Ch. Leibundgut

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Contents

List of figures in the text

List of tables in the text

Contents of the annex

Notations

A	cross-section area
α	gradient of the riverbank
B	width of the water surface
b	width of the channel
C(h, dim)	coefficient dependant on the water level h and the dimensions of the Venturi channel
$C_{1, 2, 3}$	auxiliary variables
ca	pesticide concentration in the soil
ce	concentration of the pesticide in the soil solution
C_{org}	content of organic carbon
h	water level
I_L	initial loss
K	storage constant
K_{OC} /K_D	adsorption coefficients
n	Manning roughness coefficient
$P_{(1,2,3)}$	precedent rainfall of 1 to 3 days before
P_{prec}	total precedent rainfall of the event
Q	discharge
$Q_{i+1,j}$	unknown discharge at the next node at the present time step
$Q_{i, j}$	discharge at the present node at the present time step
$Q_{i+1, j-1}$	discharge at the next channel node at the last time step
$Q_{i, j-1}$	discharge at the present node at the last time step
Q_{REF}	reference discharge
R_{hy}	hydraulic radius
rp	runoff percentage
S_0	energy slope
Δt	time step
v	flow velocity
v_K	kinematic wave celerity
$W_{i+1,j}$	unknown pesticide load at the next node at the present time step
$W_{i, j}$	pesticide load at the present node at the present time step
$W_{i+1, j-1}$	pesticide load at the next channel node at the last time step
$W_{i, j-1}$	pesticide load at the present node at the last time step
X	weighting factor
x	difference of the width of the channel at the bottom and at the water level
Δx	distance step
ξ	constant dependant on the geometry of the cross section
ω	width of the element on the downslope face

Summary

In the present study the ZIN-Model developed by LANGE (1999) is applied to simulate the hydrological response of the small Rouffach catchment (0.6 ha) in the upper Rhine valley. The catchment area is mostly used as a wine-growing area. However, there are also some patches of orchards. At the western end of the catchment, the area is covered by forest and fallow land with bush and little trees. This is why only 0.4 ha of the total catchment area is runoff contributing. Although the catchment is mostly covered by wine, it is characterised by very steep peak discharges with short concentration times. This can be explained by its rather steep average slope of about 14 % and the presence of a very dense road network. As there are no natural streams in the catchment, the road network functions as a channel network and runoff occurs intermittently in the form of Hortonian overland flow.

The present model is adapted to the small and humid catchment of Rouffach similar to a study at the Eastern Kaisertuhl (WAGNER 2002). The conceptual structure of the spatially distributed model includes sub-systems for runoff generation, runoff concentration and channel flow. For the years 2004 and 2005, the rainfall as a model input has been derived with a spatial resolution of 1m x 1m by a meteorological station in the middle of the catchment. This point data is used as model input for the whole catchment and each grid of rainfall intensity is applied on different land use types. The runoff generation routine is carried out using the runoff coefficient method in conjunction with an initial loss. The catchment area is subdivided into different land use zones such as wine-growing area and orchards and the roads are divided into different road types depending on their coverage. For each of these landuse types and road types, the parameters initial loss and runoff percentage needed to be determined to calculate the runoff generation. In order to determine these parameters, the rainfall and runoff data of two events on the 9th October 2005 at two experimental plots in the middle of the catchment is used. Runoff percentages and initial losses for both of these events are calculated and thus, the parameters for the wine-growing region and the orchards can be determined using a relationship between the precedent rainfall amount and the initial loss and runoff percentage. The wine-growing region and the orchards parameterization is carried out for each event separately to take into account the different soil moistures due to precedent rainfall amounts. For very low rainfall intensities, no runoff from the wine-growing region and the orchards is assumed, based on observations in the field. On the roads two different sets of parameters are applied. One set is derived by experiences in a similar catchment, the Löchernbach catchment at the Eastern Kaiserstuhl (WAGNER 2002) and the second set of parameters with a lower runoff percentage is estimated to achieve a lower runoff volume. However, these two sets of parameters however stay constant during a number of events as it can be assumed that precedent rainfall does not influences the runoff percentage and the initial loss significantly.

To derive model elements for the runoff concentration procedure, 330 different sub-catchments are delineated with the help of a digital elevation model, aerial photographs and a topographic map. As the measured peak discharges occur almost simultaneously after the maximum rainfall intensity, no timelag is implemented into the runoff concentration routine. The flow routing was accomplished using the Muskingum-Cunge- procedure, accounting for channel geometry and roughness of the channel bed. Apart from the channel routing, each event is routed by a second technique too. Beside the assumption of channel flow, where runoff is a function of the water level height, another formula that takes into account the broad sheet flow is applied. Parameters describing the channel geometry are derived from measurements in the field or by literature. Apart from regarding all roads and the wine-growing area as runoff contributing, three different runoff contributing source areas are outlined to investigate the origin of the runoff water. These three source areas are the wine-growing area together with the orchards and concrete roads or roads covered by grass. Each of these source areas is looked at separately and the percentage of the total runoff volume of each source area is assessed.

Because various herbicides are applied on the vines of the Rouffach catchmentand and the fast runoff component of the roads leads to high herbicide concentrations in the runoff water, a simple pesticide transport module is incorporated into the present model. Pesticide data is derived by data of a survey among wine- growers and measurements at the experimental plots. As there is a relationship between the appliance of herbicides and their concentration in the runoff water, it is possible to calculate the herbicide input for the model for the herbicides Glyphosate and Diuron. The model assumes that the herbicide concentration at the outlet of the catchment is directly proportional to the generated runoff volume. The runoff concentration procedure calculates a loadograph which gets routed during the flow routing procedure in the same manner as the hydrograph. Only the wine-growing area was seen as “pesticide contributing” however.

The simulation results show that the ZIN-Model is applicable in humid and small catchments and even for low intensity rainfall events. Furthermore the modelling work shows the ability of the model to reproduce the very steep rise of the peak discharges. Simulating the runoff of the single runoff contributing areas reveals the relationship between the runoff generation on each source area and the maximum rainfall intensity during each event. During high intensity rainfall events however, relatively more runoff was provided by the wine-growing region and the roads covered by grass. Running the model taking into account the pesticide transport outlines the importance of the roads to dilute the pesticide concentration. It is also shown that during events with no precedent rainfall, a part of the herbicide concentration must also originate from the roads whereas during events with precedent rainfall, eventual rests of herbicide concentration may have been washed away.

Key words: wine-growing region - rainfall-runoff modelling - Horton overland flow - parameterization - pesticide transport

Zusammenfassung

In der vorliegenden Arbeit wurde das ZIN-Modell (entwickelt von LANGE 1999) angewendet, um das hydrologische Verhalten des kleinen Rouffach-Einzugsgebietes (0.6 km^2) zu untersuchen, das sich im oberen Rheintal befindet. Die Fläche des Einzugsgebietes wird vor allem für den Weinanbau, jedoch teilweise auch für den Obstanbau genutzt. Da der westliche Bereich des Einzugsgebietes von Wald und Brachland bewachsen ist, die nicht zur oberflächlichen Abflussbildung beitragen, beträgt die abflussbeitragende Fläche nur 0.4 km^2. Trotz der starken Bepflanzung ist das Abflussverhalten durch steil ansteigende Abflussspitzen charakterisiert. Dieses Verhalten kann durch die steile Hangneigung von ungefähr 14 %, aber auch durch das Vorhandensein eines dichten Straßennetzes erklärt werden. Da es kein natürliches Gerinne im Einzugsgebiet gibt, bildet das Straßennetz eine Art Gerinnenetz, auf dem intermittierender Abfluss auftritt. Es wird davon ausgegangen, dass der Horton'sche Oberflächenabfluss der dominierende Abflussbildungsprozess ist.

Ähnlich wie bei einer Studie am Ostkaiserstuhl (WAGNER 2002), wurde das Modell an das kleine und humide Einzugsgebiet von Rouffach angepasst. Die konzeptionelle Struktur des flächendetaillierten Modells beinhaltet Teileinzugsgebiete für die Abflussbildung, die Abflusskonzentration und den Wellenablauf. Niederschlagsdaten der Jahre 2004 und 2005 dienen als Eingangsgröße in Form eines 1m x 1m großen Niederschlagsmusters im 6- Minuten Zeitschritt. Diese Punktmessungen, die von einer Wetterstation in der Mitte des Einzugsgebietes aufgezeichnet wurden, werden als Modellinput für die gesamte Einzugsgebietsoberfläche angenommen. Das Niederschlagsmuster trifft im Rahmen der Abflussbildungskomponente auf unterschiedliche Oberflächen des Weinanbaugebietes und der Straßen, welche hinsichtlich ihrer Neigung zur Abflussbildung im Gelände klassifiziert wurden. In der Abflussbildungskomponente wird das Abflussbeiwertverfahren in Verbindung mit einem Anfangsverlust angewendet. Für jede dieser unterschiedlichen Oberflächen müssen somit die Parameter Abflussbeiwert und Anfangsverlust bestimmt werden. Dies wird durch Niederschlag-Abfluss Messungen an zwei Versuchsparzellen im Einzugsgebiet während zweier dicht aufeinander folgender Ereignisse am 9. Oktober 2004 ermöglicht. Die Parameter Abflussbeiwert und Anfangsverlust werden für jedes Ereignis bestimmt. Indem eine Beziehung von Abflussbeiwert und Anfangsverlust zur vorhergehenden Regenmenge erstellt wird ist es möglich, Parameterwerte für die Weinanbaufläche und den Obstanbau zu berechnen. Somit wird die Parametrisierung für die Weinanbau- und Obstanbaufläche für jedes Ereignis neu erstellt, um der unterschiedlichen Vorfeuchte durch vorhergegangen Regen Rechnung zu tragen. Während Ereignissen mit sehr geringen Niederschlagsintensitäten wird kein Abfluss von der Weinanbaufläche oder den Obstanbauflächen angenommen, der gebildete Abfluss entspringt dann allein den Straßen. Um das Abflussverhalten der Straßen nachzubilden, werden zwei verschiedene Abflussbeiwerte in die Abflussbildung eingesetzt. Einer der Werte wurde der Studie vom Löchernbach-Einzugsgebiet am Ostkaiserstuhl entnommen (WAGNER 2002), der andere Wert wurde abgeschätzt, da sich der Abflussbeiwert des Löchernbaches bei zahlreichen Ereignissen als zu hoch erweist. Diese Abflussbeiwerte sind konstante Werte, da angenommen wird, daß der vorhergegangene Niederschlag die Abflussbeiwerte und den Anfangsverlust nicht signifikant verändert.

Um Modellelemente für die Abflusskonzentration zu erhalten, werden 330 verschiedene Teileinzugsgebiete, mit der Hilfe eines digitalen Höhenmodells, anhand von Luftbildern und einer topographischen Karte, ausgewiesen. Da die gemessenen Durchflussverläufe meist kaum verzögert auftreten, wird keine Zeitverzögerung in der Abflusskonzentration berücksichtigt. Der Wellenablauf wird unter Inbezugnahme der Gerinnegeometrie und der Rauhigkeit des Gerinnebettes mittels Verwendung der Muskingum-Cunge Technik berechnet. Außerdem wird jedes Ereignis ein weiteres Mal in der Wellenablaufprozedur berechnet, da neben dem Fließen im Gerinne ebenfalls Schichtfließen angenommen wird, um dem Fließprozess auf den Straßen Rechnung zu tragen. Gerinneparameter werden durch Feldmessungen oder durch Literaturwerte erhoben. Neben den Modelldurchläufen, während denen die gesamte Einzugsgebetsfläche als abflusswirksam angesehen wird, wird das Modell dazu verwendet, den Anteil des von verschiedenen Herkunftsräumen gebildeten Wassers am Gesamtabfluss zu bestimmen. Die Weinanbaufläche zusammen mit der Obstanbaufläche, sowie die geteerten Straßen und die bewachsenen Straßen bilden jeweils einen Herkunftsraum.

Die Weinreben des Rouffach-Einzugsgebietes werden mit verschiedenen Herbiziden gespritzt. Da das Einzugsgebiet durch schnelle Fließwege gekennzeichnet ist, werden am Auslass des Einzugsebietes regelmäßig erhöhte Pestizidkonzentrationen im Abfluss gemessen. Um diesen Prozess genauer zu untersuchen, wird neben dem bestehenden hydrologischen Modell ein Pestizidtransportmodell angewendet. Herbiziddaten wurden durch eine Umfrage unter Weinbauern aus der Region erhoben, aber auch durch Messungen an bereits erwähnten experimentellen Parzellen. Da eine Beziehung zwischen der eingebrachten Herbizidmenge und der Herbizidkonzentration im Abfluss am Auslass des Systems besteht, ist es möglich, den Herbizidinput der Stoffe Glyphosat und Diuron für das Modell zu berechnen. Das Pestizidmodell nimmt an, dass die Herbizidkonzentration direkt proportional zum gebildeten Abflussvolumen ist. Der in der Abflusskonzentration berechnete „Loadograph“ wird analog zum Hydrograph in der Wellenablaufroutine berechnet. Ein Input von Herbiziden wird lediglich auf der Weinanbaufläche angenommen.

Die Modellierungsergebnisse zeigen, dass das ZIN-Modell in humiden und kleinen Einzugsgebieten anwendbar ist. Selbst bei geringen Niederschlagsintensitäten konnten gute Modellierungsergebnisse erzielt werden und selbst die für das Gebiet typischen sehr steilen Abflussspitzen sind gut nachbildbar. Die Trennung des Abflusses hinsichtlich seiner Herkunftsräume zeigt außerdem, dass die Abflussbildung jedes Herkunftsraumes von der Niederschlagsintensität abhängig ist. Ereignisse mit hohen Niederschlagsintensität führen zu relativ mehr gebildetem Abfluss der begrünten Flächen (Weinanbaugebiet und begrünte Straßen). Die Ergebnisse der Pestizidmodellierung dienen zum einen der Validierung der Modellergebnisse, sie zeigen aber auch die Rolle der Straßen zur Pestizidverdünnung auf.

Stichworte: Weinanbaugebiet - Niederschlags-Abfluss Modellierung - Horton'scher Oberflächenabfluss - Parametrisierung - Pestizidtransport

1 Introduction

The foothills of the Vosges are among the most favourable wine-cultivation areas in middle Europe. The wine was imported by the Romans and had its maximal expansion during the 17th century. Until 1950, the wine-growing areas had declined and since then have increased again because of quality improvement and better management strategies (SICK 1994). The Alsatian wine-growing region has a North South alignment, extends over 130 km from Thann to Nordheim and comprises an area of 15.000 hectares where it is normally cultivated on an altitude of 200 to 350 m. The use of pesticides in the wine-growing region of the Alsace however, seems to threaten the drinking water quality of the Alsace aquifer which provides 80 % of the drinking water of the region. In former times, it was possible to use the water of the aquifer without any special treatment. Today, at 45 % of the groundwater sampling sites a special water treatment is necessary (IFEN 2003). The pesticide transport in the Alsace region is governed by geographic, hydrologic, hydrogeologic and anthropogenic factors. These factors are the confluence of runoff at the foot of the Vosges mountains, a geologic fracture which increases infiltration, coverage of the aquifer with permeable soil, the shallow depth of the aquifer leading to higher evaporation and thus to less dilution and, high demographic pressure of former times and fast runoff components.

The Rouffach catchment is a part of the Alsace wine-growing region and possibly also a part of the recharge zone of the Alsace aquifer (DOMANGE 2005). The Rouffach catchment is characterised by a dense road network where only little infiltration and fast runoff components take place. During summer, convective storm events are predominant. As soon as the rainfall intensity exceeds the infiltration capacity of the sealed surface, Hortonian overland flow occurs. As the catchment reacts very quickly on rainfall and there are no subsurface flow paths, the runoff can be regarded as two–dimensional and only runoff water of the present rainfall event reaches the outlet of the catchment.

Just like on wine-growing regions in general, various herbicides are applied on the Rouffach catchment to weed the rows between the vines. These herbicides contribute to the groundwater pollution as well as to the surface water contamination. The peak discharges carry the pesticide load which is especially important in summer as the pesticides are applied during the vegetative period. The scope of this study is to apply the ZIN-Model for a better understanding of the Roffach catchment as well as of the hydrological behaviour of different cultivation areas and roads and also their impact on pesticide transport processes.

The ZIN-Model has been developed for the 1400 m^2 arid Zin-catchment in Israel (LANGE 1999). Normally the rainfall which falls during convective rain events infiltrates and mixes with the sub-surface water. This mixed water reaches a channel and forms a discharge peak at the outlet of the catchment. It is very difficult however, to estimate the sub-surface flow paths. But as in arid catchments the dominant runoff process is the Horton overland flow, the model takes into account surface runoff only. As a result, the model seems only applicable in regions with convective rainfall events and in catchments with a quick and simultaneous reaction on these rainfall events.

Apart from the Rouffach catchment, the model has been applied in humid areas before successfully. It has been applied in the urban Glasbach catchment in Freiburg (GUWANG, 2004) and in the Löchernbach catchment which forms part of the wine-growing region in the Eastern part of the Kaiserstuhl (WAGNER 2002). In contrary to the Rouffach catchment, the surface of Löchernbach catchment is terraced. These studies have also shown the applicability of the model for very small catchments, as the Glasbach catchment comprises an area of only 0.13 km^2 and the Löchernbach catchment an area of 1.8 km^2.

For the modelling undertaken within this thesis, 16 events of the years 2004 and 2005 have been chosen for the model simulation. Emphasis was laid on maintaining the physical meaning of the model, so that only the parameters runoff coefficient and initial loss were changed during some events. Because of the high variability of the rainfall and the runoff behaviour, the simulations are carried out event based and the simulated hydrographs should be verified with the help of measured runoff and pesticide concentration data.

The present study has been possible because of the cooperation of the ENGEES (Ecole Nationale du Génie de l'Eau et de l'Environnement de Strasbourg) in Strasbourg, France and the Institute of Hydrology in Freiburg, Germany. The local field experience ENGEES staff and their kind provision of data, which should be treated confidentially, as well as the hydrological guidance and modelling support of the Institute of Hydrology were indispensable.

2 General aspects

2.1 The Rouffach catchment

2.1.1 Location and Topography

Rouffach is an Alsace community in the upper Rhine valley with 4300 citizens and is situated 14 km South/South-East of Colmar. The experimental site is part of the vineyard of Rouffach which is located to the West of the urban part of Rouffach. The vineyard at Rouffach consists of several catchments which are cultivated in different ways. Some of the wine-growing plots get treated with herbicides out of technical reasons, as the distance between the single vines is very narrow and does not allow the passage of agricultural machines. Some plots are covered by herbs between the vines completely. At most of the plots however, only every second row is treated with herbicides, so that ´green´ and ´non-green´ rows are alternating. The catchments on the Rouffach vineyard are bounded by the urban part of Rouffach in the East, by a ridge from West to North and by a river in the South. The northernmost catchment has been chosen as an experimental site for further studies (TOURNEBIZE 2001, DOMANGE 2002).

The altitude of this northernmost catchment varies between 230 and 370 m. The mean length of the catchment is 888 m, the width 446 m and the average slope 14 % with a South East expansion. Most of the catchment area is covered by wine but there are also some patches with orchards. Although the catchment is a rural catchment, a strong anthropogenic influence has taken place. A dense road network was established in order to have better and faster access to the vines. As a result the generated runoff does not necessarily follow the greatest slope, as the roads are diverting the runoff. The topographic catchment comprises an area of 0.6 km^2, whereas the hydrological catchment comprises an area of about 0.4 km^2 (TOURNEBIZE 2001). Figure 2-1 shows the location of Rouffach and also the location of the northernmost catchment which has been chosen for the modelling.

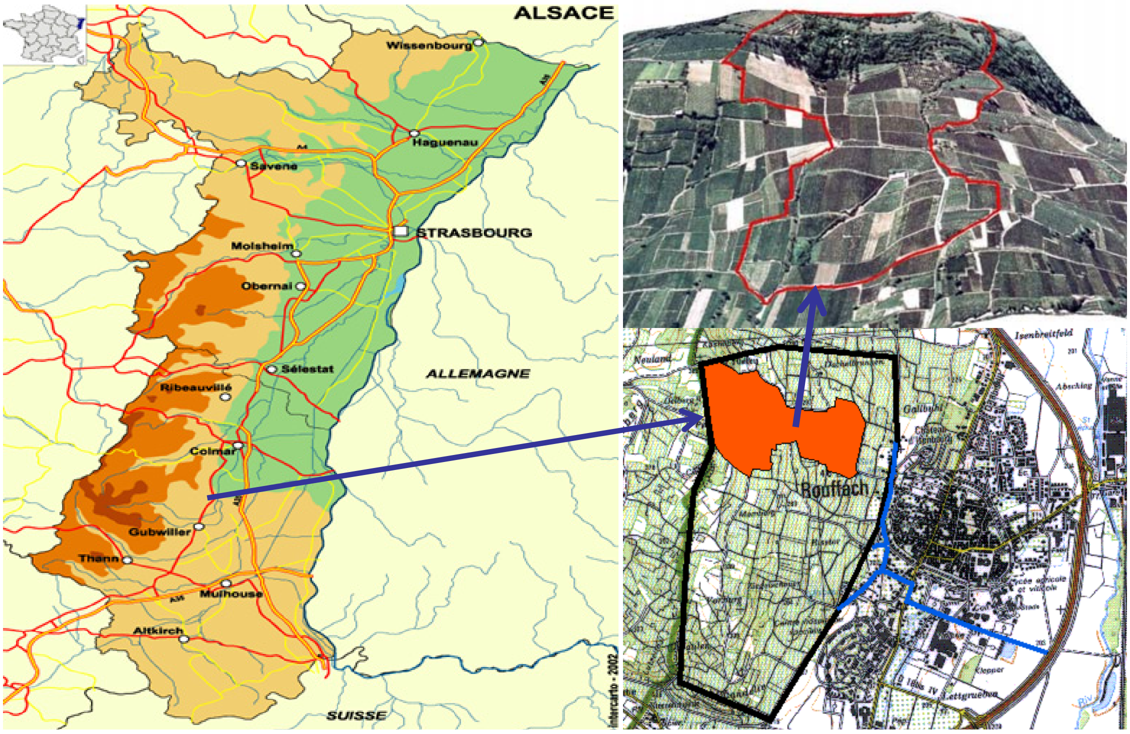

Fig. 2-1: **Location of Rouffach and ist experimental catchments**

To reduce peak discharges, a storm tank has been installed at the outlet of the catchment. Due to its dense natural vegetation cover the storm tank acts as a biological filter so that even pesticides such as Glyphosate can be degraded (HUNAULT 2005). The installation of the storm tank was necessary because of the limited capacity of the sewage plant and the sewage network.

2.1.2 Experimental plots

Beside the cultivation plots, two experimental plots have been build up artificially in order to get *in situ* data of the different pesticide transport and runoff processes. Both plots are cultivated in a different way. Because of technical reasons as the distance between the single vines is very narrow, one plot is weeded chemically on the whole surface. It consists of 3 inter-rows, has a width of 4.1 m and is 25 m long. Its surface comprises an area of 102.5 m^2 and it is planted with Riesling vines. The other plot has been weeded on only every second row since over 15 years. This plot consists of 6 inter rows (3 weeded and 3 covered with green) with a width of 10.2 m, a length of 25 m and an area of 255 m^2. Tokay Pinot Gris vines are planted on this plot. The mean slope of the two plots is 13 %. The plots are located near the outlet of the catchment which is shown in Figure 2-2.

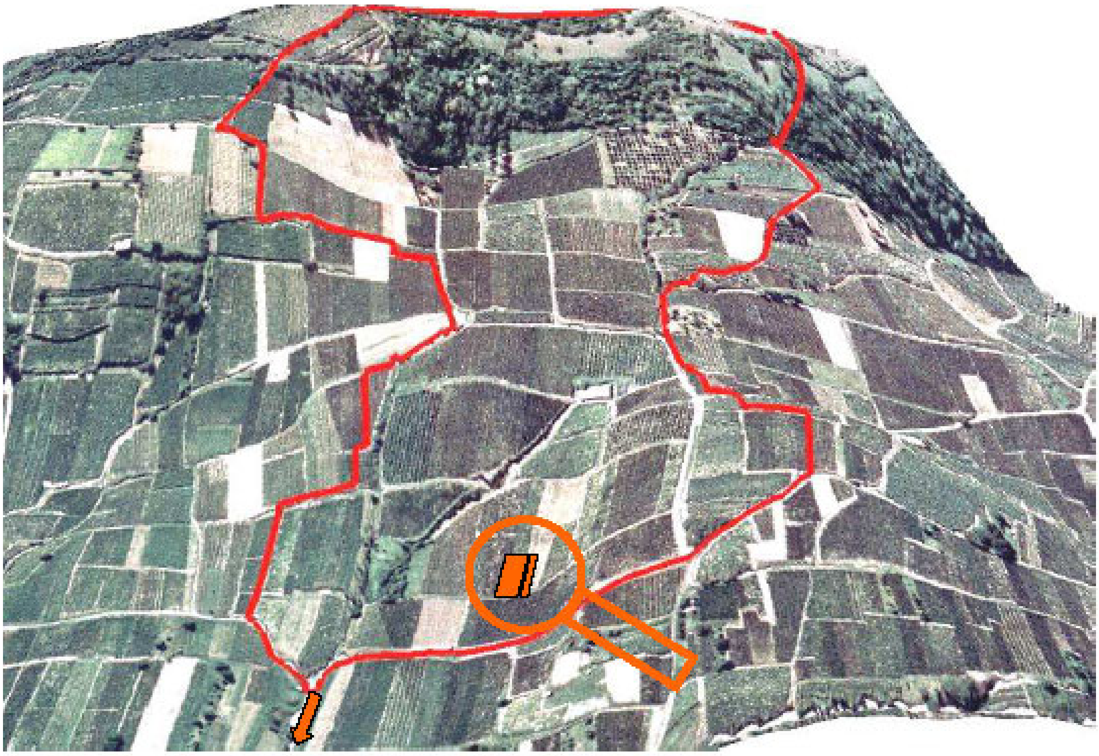

Fig. 2-2: Location of the experimental plots in the Rouffach catchment

2.1.3 Climate

The Massif of the Vosges blocks the Western winds to some extent and thus the climate shows a strong variation from West to East. In general it can be said, that the region of Alsace is influenced by a semi-continental climate with oceanic influence which is characterised by cold winters (1°C mean monthly temperature in January) and hot summers which are usually accompanied by thunderstorms (20°C mean monthly temperature in July). The mean annual temperature varies between 10 and 11 °C with a maximum variation of 18 °C per year which is typical for the continental climate.

The rainfall of the Alsace shows a high variability. On the ridges of the Vosges more than 2000 mm rainfall is measured per year and about 750 mm on the altitude of Strasbourg. The region around Colmar shows an anomaly of precipitation distribution due to foehn effects. The mean annual rainfall in Colmar is 550 to 600 mm. Therefore Colmar is often called „Colmar dry island". Since 1946 the station "Rouffach CHS" which is located one kilometre next to the Rouffach catchment, has measured 599.3 mm rainfall per year on average. As shown in Figure 2-3 the maximum rainfall amount was 867.3 mm in 1999 and the minimum rainfall amount 361.2 mm in 1953.

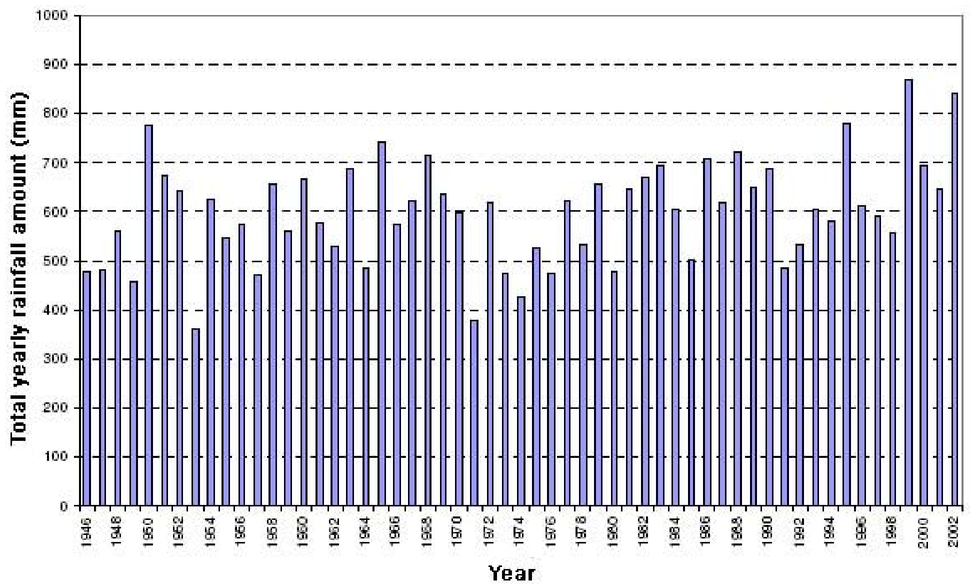

Fig. 2-3: **Total yeary rainfall amount from 1946 to 2002 at Rouffach-CHS (68, France)**

Two different hydrological seasons can be distinguished, a hydrological summer and a hydrological winter (GREGOIRE 1998). The first hydrological season lasts from May to October and the second one from November to April (Figure 2-4). The seasons are distinguished by the total monthly rainfall amount. In Rouffach there is 35% more rainfall during summer than during winter. The summer is characterised by strong convective rain events, whereas in winter weak persistent rain is predominant (PASQUET 2003). During summer there are also the longest intervals between single rainfall events.

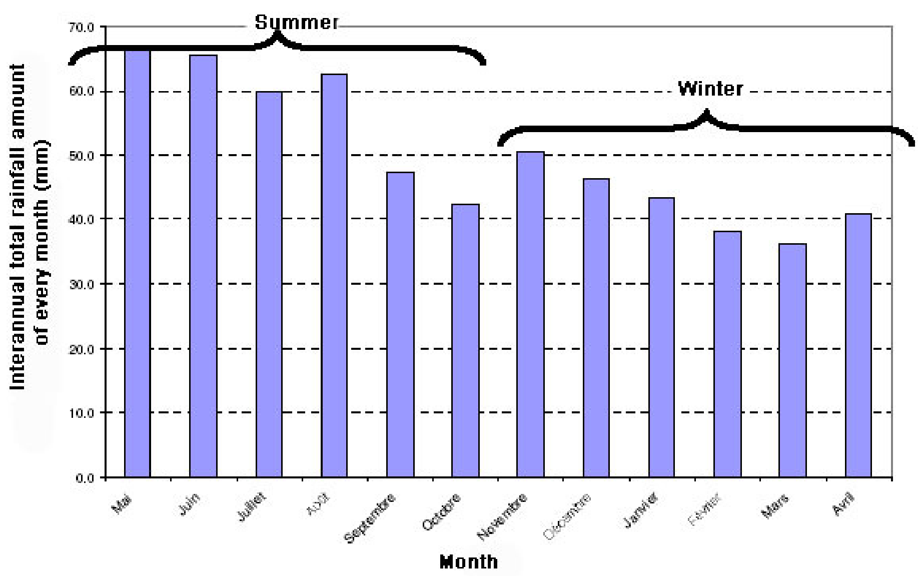

Fig. 2-4: **Total mean monthly rainfall amount of the years 1946 to 2002 at Rouffach-CHS and the separation into two hydroclimatic seasons (68, France)**

The hydrologic seasons coincide well with the different stages of the vegetative cycle (Tournebize 2001). The hydrological summer is characterized by the maximum growth of the wine, whereas the hydrological winter is characterized by the absence of leaves. As the vegetation cover enhances interception and transpiration, the hydrologic seasons have an impact on the amount of runoff generated (PASQUET 2003).

2.1.4 Geology and Pedology

The wine-growing region of the Alsace can be subdivided into three major parts separated by the two faults of the Vosges (FV) and the Rhine (RV) valley as shown in Figure 2-5. These three major regions are the Vosges mountains with a height of about 450 m, the foothills of the Vosges which are 200 to 400 m high and the Rhine valley which is 150 to 230 m high on average (PARTY 1990).

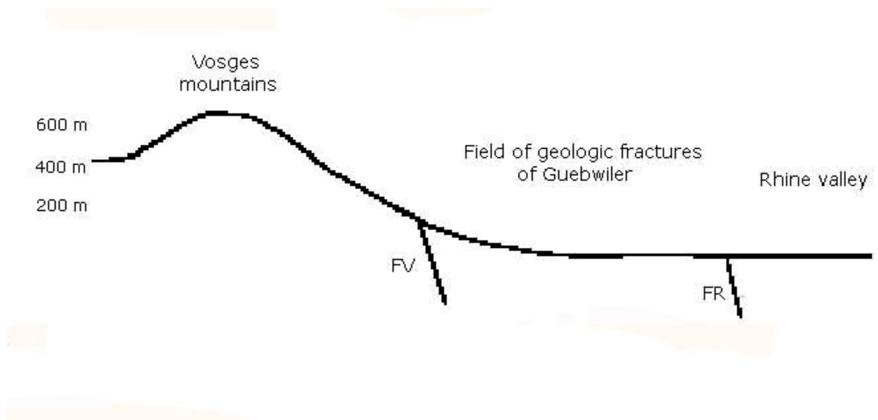

Fig. 2-5: Geological cross-section of the field of fractures of Rouffach-Guebwiler, Upper Rhine, France (after PARTY 1990)

The soil of the Alsace region shows a very heterogeneous pattern. In the Rouffach catchment the soil consists of a profound aeolian loess layer bedded on limestone. The loess has been drifted with the wind from the Rhine valley into the lower parts of the Vosges during the Würm ice age and a calcosol has developed (FAO UNESCO 1981). In the loess layer inclusions of detrital shell limestone can be found. The young stage of the soil is characteristic for wine-growing areas as the development of the soil is interrupted by cultivation methods (DUCHAUFOUR 1988).

Typical attributes of the soil are a high porosity of 50 %, good water retention capacity and good rooting qualities. The soil density varies between 1.22 g/cm^3 and 1.41 g/cm^3 and increases towards the surface due to the passage of agricultural machines. The soil consists of 70 % fine to coarse limestone, 15- 32 % clay and less than 2 % sand. The organic content of the soil is highest close to the surface and varies between 1.3 and 1.6 % (TOURNEBIZE 2001).

2.1.5 Hydrogeology

The upper Rhine valley near the Alsace between the Vosges and the Black Forest has slowly been filled up by alluvial material by the river and its tributaries during the Quaternary. This alluvial material is characterised by a very good water storage capacity and belongs to one of the most important fresh water source in Europe. The Alsace part of the aquifer is bounded by the foot hills of the Sundgau in the South, in the West by the Vosges and in the North by the aquifer of the Hagenau. The Alsace aquifer comprises an area of 2735 km^2. Its thickness varies from some metres near the Vosges, to 200 m in the valley and is 80 m thick on average. The storage volume of the aquifer is 214 billion m^3. The water circulates in the hollow space of the alluvial material with a mean velocity of 1-2 m/day and follows a flow axis of South North. Recharge takes place mainly via the Rhine and its tributaries, whereas rainfall makes up only 20 % of the total recharge volume.

The Alsace aquifer is the most important drinking water resource of the region and contributes about 80 % of drinking water to the local people. Furthermore it supplies 50 % water of the total water demand of the industry and the whole water demand for irrigating the agricultural areas in the region. Today the removal of water out of the aquifer is still less than the recharge but due to an increasing anthropogenic pressure the aquifer is threatened by pollution (see chapter 2.2.1). The wine-growing region at the foothill of the Vosges however, is one important zone of recharge for the aquifer. Because the wine-growing region lies on a field of geologic fractures, it is assumed that there is a strong exchange between the runoff water and the subsurface water. The runoff water infiltrates quickly into the aquifer when it reaches the valley, where the aquifer is rather thick (DOMANGE 2005).

2.1.6 Hydrology

The Rouffach catchment shows no perennial runoff. Runoff occurs only during rainfall events and the roads function as channels as there are no natural streams in the catchment. As Rouffach lies on the field of geologic fractures of Guebwiler, a part of the infiltrating water is lost, so that the soil of the wine-cultivation area hardly saturates (TOURNEBIZE 2001). Furthermore the good infiltration capability of the soil does not allow the development of subsurface flow paths. Neverthless the runoff events show high peak discharges due to the dense road network and the rather steep slope. In the Rouffach catchment, the dominant type of runoff is the Hortonian overland flow. Hortonian runoff occurs mainly during very strong precipitation events on soils with little infiltration capacity or on very fine textured soils with no or only clogged macro pores (BAUMGARTNER & LIEBSCHER 1996). Hortonian overland flow is applicable for impervious surfaces in urban areas or for natural surfaces with low infiltration capacity. In the Rouffach catchment, the Hortonian overland flow occurs mostly on the paved and compacted roads (TOURNEBIZE 2001). Runoff from the wine-growing region is generated during rainfall events with very high rainfall intensities when the rainfall intensity exceeds the infiltration rate. The runoff generated however, is dependent on the rainfall amount and the rainfall intensity.

Apart from the fact that only little runoff is generated on the wine-growing plots, the runoff behaviour is also dependent on the type of cultivation. Hydrological conductivity is dependent on the water saturation and the water content as well as the matrix potential which are all factor governing the retention of runoff water. Soil parameter measurements at two different cultivation methods of non weeded and weeded plots reveal, that the plots covered by herbs have a better water holding capacity and thus the hydrological conductivity is 2 to 3 times higher than on the plots treated with herbicides. Especially during summer, the retention capacity increases on non weeded plots as the herbs form a kind of dry straw and thus enhance superficial retention. This can lead to a higher infiltration rate on the green plots, although the infiltration capacity is the same on the two different plots. However, measurements at two experimental plots which are treated with herbicides on the whole area and only on every second row reveal that there is no significant difference in runoff behaviour. Although a higher runoff volume on the weeded plots would be expected. This can be explained by an emerging moss cover on plots treated with herbicides which works like a sponge and thus could be responsible for reducing the Hortonian overland runoff (TOURNEBIZE 2001). Another explanation is the quick infiltration in cracks and crevices of the loamy soil which can be observed especially during hot and dry periods.

2.2 Pesticides

The European guideline 91/414 CEE (1991) defines pesticides as substances which should protect plants from destructive insects or their actions. Pesticides can also ensure the plants' conservation or destroy weeds, slow down or prevent non-wanted growth. Normally pesticides contain a solution out of one or more active. Especially in wine-growing areas the application of pesticides is very wide distributed, with a high amount applied. As the pesticides are mainly transported via surface water from agricultural areas, especially the wine-cultivation areas represent a risk for contaminated surface water because of their weak coverage, which supports fast runoff components and erosive processes.

On forested, agricultural catchments and on roads herbicides are applied, whereas insecticides are applied mostly on urban catchments (LEONARD 1990). In many cases it is hard to determine the source of the pesticides. In Rouffach the risk of pesticide transport is highest during summer because of the strength of rain events and the appliance of pesticides during the vegetative period. Pesticides used in wine-growing areas are primarily herbicides which are organic molecules and consist of three families: the amino acids as for example Glyphosate, the Triazines like Atrazin and Simazine and Urea compounds like Diuron, Isoproturon or Linuron (TRAUSCH 2002). Today Glyphosate is the most used herbicide around the world with an applied amount of 55.000 tons per year (COX 2004). It is widely distributed because of its positive properties and low costs.

There are two sources of pesticide pollution, the punctual pollution and the diffuse pollution via the runoff. Punctual pollution takes place at the localisation of appliances, at the areas where the filling up and rinsing of the gear takes place. Since 12 to 15 years a fight against diffuse pollution of pesticides has taken place. One important improvement is the use of altered pesticides molecules. In former times, pesticides have been almost non soluble and they have been adsorbed very strongly by organic matter. Today emphasis is laid on using pesticides which are more mobile. The efficiency of these products has improved too (MÜLLER et al. 2002).

2.2.1 Pesticides as a risk for groundwater

The monitoring of the pesticides is conducted by the "l'institute français de l'environnement" (IFEN). Samples have been taken out of 3000 different sites in the year 2000. In 90% of the surface water samples and 58% of the ground water samples the critical value of 0.1µg/l for a single substance or 0.5 µg/l for more than one substance has been exceeded. These thresholds were enacted by the "European framework direction". Furthermore 142 different types of pesticides in the surface water and 62 different types in the groundwater have been detected. The most common pesticides tested are Diuron, Athrazin and Glyphosate. In subsurface waters 3% of tested Glyphosate samples and 5 % of tested AMPA samples have exceeded the legal limit, although Glyphosate is a rather immobile herbicide. This can be explained by the fact, that Glyphosate molecules can be transported on colloids with only little organic material (DIREN 2003). Furthermore Glyphosate and Diuron are part of a priority list of researched pesticides in the surface waters of the Alsace of the GREPPA (Groupe Régional Eaux et Produits Phytosanitaires en Alsace). The Diuron is also part of this list for surbsurface waters.

Wine-growing areas however, are the predominant consumers of pesticides in France. In the groundwater and surface water samples, there are high concentrations of pesticides measured which are predominantly used in wine-growing areas. This can partly be explained by the sparse vegetation cover of the wine-growing areas. Furthermore the vines are planted parallel to the slope of the hillside which leads to an increased erosion, stronger runoff events and thus to an enhanced pesticide transport. It can be assumed that the pesticides of the wine-growing areas get transported as far as to the edge of the Alsace aquifer which lies at the foot of the wine-growing mountain (GAILDRAUD 1996). Figure 2-6 shows points of measurements at the Alsace aquifer where groundwater samples are strongly contaminated with Diuron concentrations of over 0.1 µg/l (LFU-APRONA 2000).

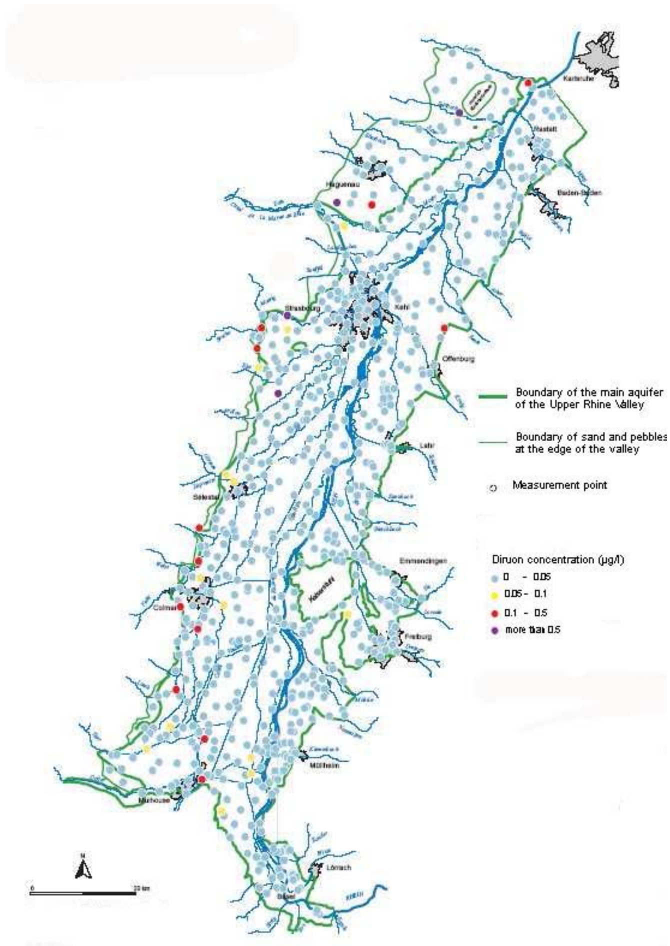

Fig. 2-6: Diuron concentration in the Alsace aquifer in 1997 (LFU-APRONA 2000)

2.2.2 Behaviour of the pesticides

Pesticides are developed to act via the interface air soil, or in the first centimetres of the soil layer. Especially on wine-growing areas, the access of the pesticides into the soil shows a very high variability. The sorptive properties of the soil determine the fixation of pesticides however, when pesticides solved in the soil solution are adsorbed by soil particles. Thus the adsorption is dependent on the content of organic and clay material of the soil. The adsorption can be described by the adsorption coefficient K_D which describes the ratio between the adsorbed pesticide concentration in the soil *ca* [mg/kg] and the concentration of the pesticide in the soil solution *ce* [mg/kg] in an equilibrium state.

$$K_D = \frac{c_a}{c_e} \qquad (2.1)$$

The K_D coefficient is dependent on the specific surface of the pesticide, its physio-chemical properties, its concentration, molecular weight, the polarity and structure of the pesticide as well as the temperature, pH of the soil solution and the atmospheric pressure. The content of organic carbon has the strongest influence on adsorption however. Thus the adsorption coefficient K_D is often related to the content of organic carbon C_{org} [%] which leads to another adsorption coefficient K_{OC}.

$$K_{OC} = \frac{K_D \cdot 100}{\%C_{org}} \tag{2.2}$$

The value K_{OC} can be seen as a direct measure of the mobility of a pesticide. Apart from the adsorption coefficient, the water content of the soil influences the mobility of a pesticide too (SCHEFFER & SCHACHTSCHABEL 2002). As soon as the pesticides are transported into deeper soil layers however, there is a risk for groundwater contamination (HOCK et al. 1995).

Glyphosate for example is easily adsorbed via the leaves' surface of the herbs to act quickly and effectively. Because of its high K_{OC} coefficient of over 5000 it is almost immobile and the residues which stay in the soil can be decomposed microbiologically (HOCK et al. 1995). Microbiological decomposition in the storm water tank of the Rouffach catchment lead to a decrease of Glyphosate concentration of about 30-80 % for example depending on the kind of the storm event. The Glyphosate metabolite AMPA is even more persistent with a half life of 76 to 240 days (HUNAULT 2005). Due to its stronger mobility it can be measured in the groundwater more often. Diuron is a total herbicide which can be decomposed microbiologically as well. It has a K_{OC} coefficient of 397 and thus shows a medium mobility. Diuron concentrations can be measured throughout the year (HOCK et al. 1995).

2.2.3 Transport with the runoff

As the roots of wine are quite deep and the leaves are above the ones of other plants the herbicides act very selective on the weeds at the soil-air interface. The highest herbicide concentration can be found in the first centimetres of the soil layer and decreases with depth which has also been proved by infiltration tests (TOURNEBIZE 2001). But these first centimetres are also most affected by runoff and erosion. LEONARD (1990) proved that there is a correlation between the concentration of pesticides in the runoff water and the concentration of pesticides in the surface layer of the soil. Thus the most important variable for pesticide concentration in the runoff water is the pesticide concentration in the active soil layer at the moment of the onset of runoff.

The pesticides can either be transported in suspended or particular form. As only suspended pesticides can be measured, it is very difficult to evaluate the exact amount of pesticides in the runoff water. Rainfall characteristics such as rainfall amount, time between single events but also the coverage of the soil have a very strong impact on the pesticide concentration in the runoff water (ANGOUJARD et al. 2001). Interception by the plants enhances the retention and thus the degradation of the intercepted pesticides is increased. The runoff however is the main factor influencing the contact time of the pesticides at the liquid-solid interface (BROWN ET AL. 1995). In general it can be stated that weeded rows between the vines lead to more and faster runoff and erosion but also to less infiltration of the pesticides. Because of this, it can be beneficial to alternate weeded and non weeded rows between the vines how it is mostly done in the Rouffach catchment (DOMANGE 2005).

2.2.4 *Pesticides applied on the vineyard of Rouffach*

Since 2001 surveys among wine-growers have been conducted. The first survey in 2001 was carried out in order to investigate the different procedures of pesticide application and possible sources of punctual pollution. With the help of later surveys in 2003 and 2004, the date of application, the name of the commercial product and the applied quantity of the product has been determined for single plots. Figures 2-7 and 2-8 show the declared matters and their applied quantity on the Rouffach catchments.

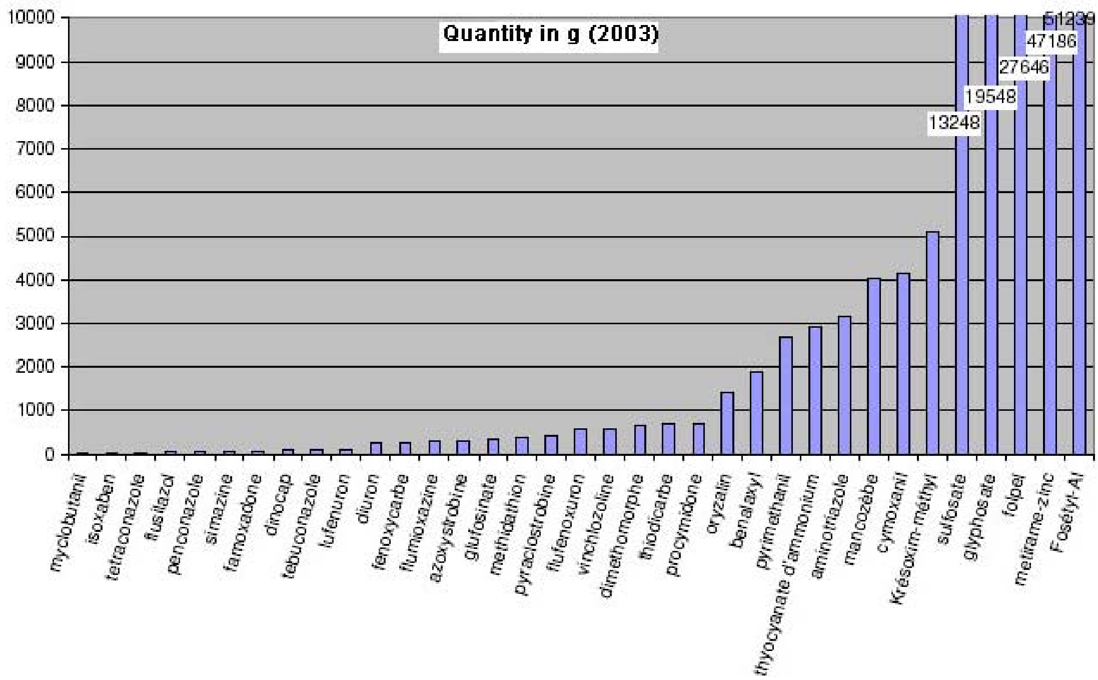

Fig. 2-7: Total quantity of pesticides applied on the area surveyed at the Rouffach catchments in 2003 (68, France)

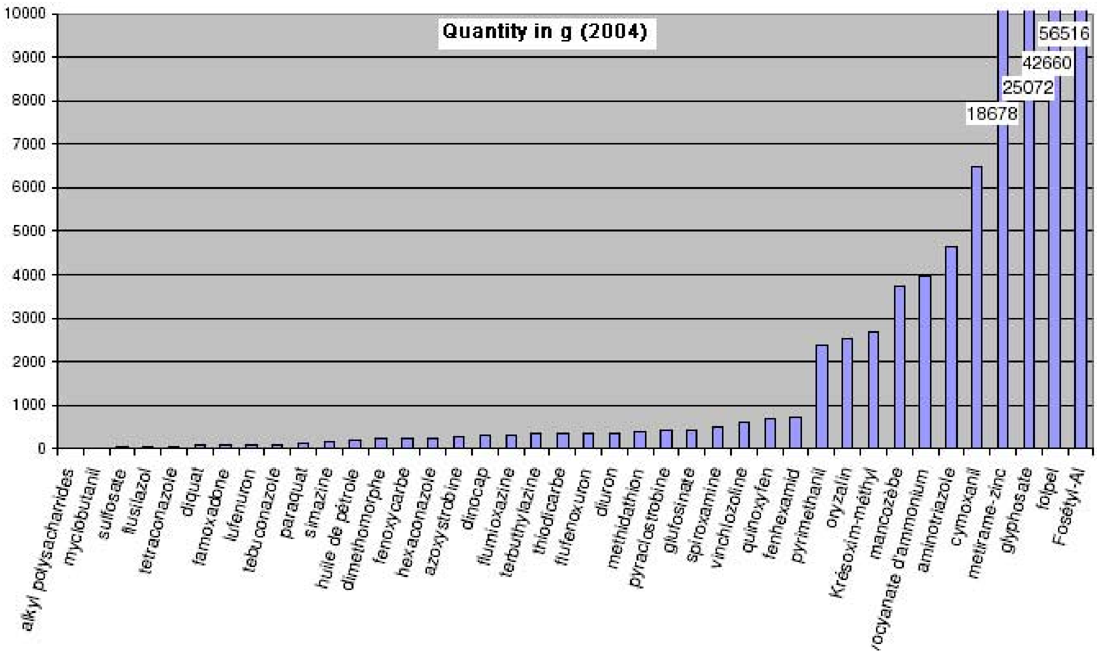

Fig. 2-8: **Total quantity of pesticides applied on the area surveyed at the Rouffach catchments in 2004 (68, France)**

Although 2003 was an extreme dry year, there is not a strong variation of the total quantity and the percentage of each pesticide applied however, between the two years. More than 35 different pesticides have been applied with a quantity of about 180 kg. The glyphosate is the most used herbicide with 20 kg per year and is used on the whole surface of the basin whereas insecticides with a total amount of less than 1 kg can be neglected. Table 2-1 gives an overview of the percentage of the wine-growing plots surveyed and the percentage of the different pesticides used.

Table 2-1: **Results of the surveys on pesticide application during the years 2003 and 2004**

Year	**2003**	**2004**
Percentage of the surveyed wine-growing plots [%]	69	62
Percentage of the surveyed wine-growing area [%]	81	73
Percentage of the answering wine-growers [%]	42	42
Total quantity applied [kg]	190	177
Percentage of fungicides [%]	77	78 %
Percentage of herbicides [%]	22	21 %
Percentage of insecticides [%]	1	1

The herbicide application is dependent on how the wine-plots are cultivated. On plots where every second row is weeded, herbicides are applied two times a year and it can be assumed that the herbicides are applied on about 1/3 of the surface. On the plots which are weeded completely, the surface does not need to be worked on and their vines are planted a little bit denser. Weeding the whole surface, the appliance of herbicides has to take place after the end of April and the herbicides are applied on about 80% of the surface (COUCHART1999 cited in DOMANGE 2005).

2.3 Conclusion

The Rouffach catchment is part of the Alsace wine-growing region and lies on the altitude of the Vosges foothills. The climate is characterised by convective storm events during summer, whereas during winter continuous rain with a lower rainfall intensity is predominant. The main type of soil at the foothills of the Vosges is aeolian loess which has good water holding properties. The geology however, is characterised by numerous geologic fractures, leading to high infiltration losses. In the catchment, a dense road network replaces a natural channel network. On these roads Hortonian overland flow occurs intermittently leading to fast peak discharges, which is the dominant type of runoff in the catchment.

Pesticides applied on the wine-growing region however, are threatening the quality of the Alsace aquifer. Their transport is governed by their adsoptive properties and furthermore by their solubility. At the outlet of the Rouffach catchment high concentrations especially of Glyphosite, its metabolite AMPA and Diuron are measured in the surface runoff water.

3 The Zin-Model

The Zin-Model has been developed for arid zone hydrology to model high magnitude events in dry environments where Hortonian overland flow is the dominant runoff component and underground storage can be neglected. To determine parameters calibration is not necessary as all parameters are derived directly from the field or can be transferred from other catchments with similar characteristics. Thus the model is also called a physical or field based model (LANGE 1999).

Apart from arid catchments, the model has been tested in the urban Glasbach catchment in Freiburg (GUWANG 2004) and also at the Löchernbach catchment, situated at the Eastern Kaiserstuhl (WAGNER 2002). The Löchernbach catchment is a wine-growing region too and due to drainages and a high road network it shows a hydrologic behaviour comparable to that of the Rouffach catchment.

3.1 Model conception

As in arid zone catchments variable convective rain and long dry periods are predominant, the ZIN-Model is an event based model and parameterization is carried out for each event separately. The model uses rainfall intensity as an input in mm in a time step of 6 minutes. Although the rainfall intensity decreases with increasing distance from the storm centre and there are mostly convective rain events, the measured rainfall data of one meteorological station in the middle of the catchment is chosen as input for the whole catchment. This is possible because of the small size of the catchment and because there are no orographic obstructions in the catchment. As output the model provides a discharge hydrograph in l/s every 20 to 30 m along the waterway and finally at the outlet of the catchment. Figure 3-1 shows the different procedures of the model such as runoff generation, runoff concentration and flood routing.

The model is very flexible and allows a very good accuracy with a minimum spatial resolution. This is due to the aggregation of spatially homogenous areas into model sub-units which are independent from each other. For each of these sub-systems, parameters need to be determined (LANGE 1999). Arc View has been used to generate the model sub-units and with the GIS (grass54) a transfer of data between the sub-systems was carried out.

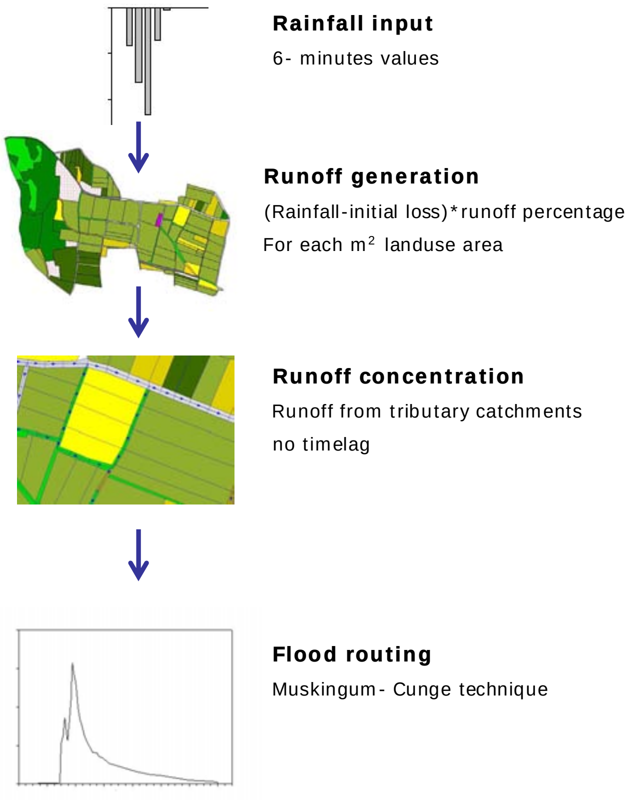

Fig. 3-1: **Flow chart of the non-calibrated rainfall-runoff model (after LANGE 1999)**

Runoff generation: The catchment is divided into different land use and terrain types with different initial losses and runoff coefficients. They determine the amount of effective rainfall and represent the spatial sub-units for runoff generation.

Runoff concentration: The waterways network is divided into different channel segments. The adjacent basins of the channel segments which provide runoff are the spatial sub-units for the runoff concentration routine.

Flood routing: The same channel segments as in the runoff concentration procedure are used and represent the spatial sub-units of the flood routing. Each channel segment is characterised by two nodes where the runoff is summed up and hydrographs are provided.

3.2 Runoff generation

In the model the runoff generation is determined by the parameters runoff coefficient and initial loss for each land use type and event. The runoff generation process determines the portion of rainfall which is transformed into direct runoff (DYCK & PESCHKE 1995). In the Rouffach catchment however, Hortonian overland flow is the predominant form of runoff generation. After the concept of HORTON (1933), surface runoff is that part of the rainfall which is not adsorbed by the soil by infiltration. The surface runoff is dependent on the nature and the intensity of the rainfall and generates runoff as soon as the rainfall intensity exceeds the infiltration capacity of the surface. The magnitude of the runoff is also dependent on the nature of the terrain or land use type. As subsurface flow paths are neglected by the model, infiltrated rainfall water is lost for runoff generation. The runoff coefficient governs the amount of runoff generated on each land use type and the initial loss is the part of the rainfall which is intercepted by vegetation or trapped in small surface depressions and which will eventually evaporate back to the atmposphere (PILGRIM & CORDERY 1993). As the Rouffach catchment is used as a wine-growing area, each of the different land use types represents a spatial sub-unit. The catchment is divided into 1m x 1 m raster cells and for each sub-unit a value for initial loss and runoff coefficient is chosen.

3.3 Runoff concentration

Runoff concentration is the process where effective rainfall is transformed into direct runoff (DYCK & PESCHKE 1995). In the model runoff concentration describes the transformation of runoff generated at each model element to lateral inflow into the adjacent channel. In order to determine spatial sub-units, the road network is subdivided into segments of about 10 to 25 m length. The amount [l] and onset [min] of Hortonian overland flow calculated by the runoff generation routine is distributed to the different sub- catchments which are adjacent to the road segments and provide runoff. Although the length of the sub-catchment polygons is rather long, measured hydrographs show that the runoff from the sub-catchments is not delayed. Thus no time lag is implemented into the model.

3.4 Flood routing

Flood routing procedures calculate the distortion of a high flood wave due to flow patterns along a channel. In the flood routing, the same road segments are used as in the runoff concentration procedure. Every segment represents a homogenous type of road and each road segment is delimited by channel nodes. The flow is routed from node to node, accounting for lateral inflow and a flow hydrograph at the respective stream section is provided. The geometry of the roads is described by the parameters channel length [m], channel width [m], slope [-], and their hydraulic behaviour by the Manning roughness coefficient n [$s/m^{1/3}$].

There are two different types of flood routing, the lumped routing procedures and the distributed routing procedures. Using the lumped routing procedures, the runoff is measured at only one point along the channel and the storage is described by an empirical equation. Thus the storage needs to be calibrated with measured runoff data. The distributed routing procedures however, describe the flow process at several points along the channel taking into consideration their geometry. Although this procedure is more labour intensive it allows modelling in catchments where no measured runoff data is available as it does not need calibration. The ZIN-Model uses a distributed routing procedure which is based on the differential equations of one- dimensional unsteady flow, the Saint-Venant equations. The Saint- Venant equations consist of two equations: the continuity part which describes mass conservation and the momentum part which describes physical processes governing the flow momentum such as acceleration, pressure, gravity and friction forces (FREAD 1993).

The continuity equation is part of every flood routing model. As the solution of the whole Saint- Venant equation is very complicated, different simplifications for the solution of the momentum part exist. The simplest flood routing model, the *kinematic wave* model, was introduced by LIGHTHILL and WHITHAM (1955). The model neglects pressure and acceleration and assumes that friction slope and surface slope are equal. It does only incorporate translation but no retention. The *diffusion wave* model incorporates the pressure term but neglects the term for acceleration. The *dynamic wave* model considers the whole Saint- Venant equations (FREAD 1993). With slow rising hydrographs, there is not a significant difference in accuracy between using the dynamic wave model or a simplified flood routing model however. The kinematic wave model for example is not able to reproduce fast rising limbs as it neglects retention (ANDERSON & BURT 1990).

The ZIN-Model uses a method based on the diffusion wave model which has been developed by CUNGE (1969) modifying the Muskingum procedure. The Muskingum method is used for calculating the outflow hydrograph at the downstream end of a channel reach given the inflow hydrograph at the upstream end. The channel reach is subdivided into different segments and the outflow of one segment provides the inflow for the next segment. In the Muskingum method the lumped channel parameters K and X do not have a precise physical meaning and are normally treated as fitting parameters which are difficult to estimate. This problem is overcome in the Muskingume-Cunge-Method (CUNGE 1969) by expressing the storage constant K and the weighting factor X in terms of various physical channel characteristics (equation 3.5 and 3.6) (AKAN & HOUGHTALEN 2003). The Muskingum- Cunge procedure is capable of predicting hydrograph attenuation and has been used as a distributed flood routing technique most effectively (FREAD 1993). With the following algebraic equations, the Muskingum-Cunge procedure calculates the flow from channel node to channel node in a space and time discretised network at different time steps (LANGE 1999).

$$Q_{i+1,j} = C_1 Q_{i,j} + C_2 Q_{i,j-1} + C_3 Q_{i+1,j-1} \tag{3.1}$$

With

$$C_1 = \frac{\Delta t - 2KX}{2K(1-x) + \Delta t} \tag{3.2}$$

$$C_2 = \frac{\Delta t + 2KX}{2K(1-x) + \Delta t} \tag{3.3}$$

$$C_3 = \frac{2K(1-x) - \Delta t}{2K(1-x) + \Delta t} \tag{3.4}$$

$$K = \frac{\Delta x}{v_K} \tag{3.5}$$

$$X = 0.5 \cdot \left(\frac{Q_{REF}}{B \cdot v_K \cdot S_0 \cdot \Delta x} \right) \tag{3.6}$$

$Q_{i+1,j}$	unknown discharge at the next node at the present time step	[m³/s]
$Q_{i,j}$	discharge at the present node at the present time step	[m³/s]
$Q_{i+1,j-1}$	discharge at the next channel node at the last time step	[m³/s]
$Q_{i,j-1}$	discharge at the present node at the last time step	[m³/s]
Δt	time step	[s]
K	storage constant	[s]
X	weighting factor (expresses the relative importance of inflow and outflow on the storage)	[-]
$C_{1,2,3}$	auxiliary variables	[-]
Q_{REF}	reference discharge	[m³/s]
Δx	distance step	[m]
B	width of the water surface	[m]
S_0	energy slope	[-]
v_K	kinematic wave celerity	[m/s]

The following approximation is used if the channel is wide and its hydraulic radius approaches the flow depth:

$$v_K \approx 5/3 \cdot v \tag{3.7}$$

Where v is the flow velocity [m/s] which can be calculated by solving the Manning equation:

$$v = \frac{R_{hy}^{\ 2/3} \cdot S_0^{\ 1/2}}{n} \tag{3.8}$$

R_{hy}	hydraulic radius	[m]
n	Manning roughness coefficient	[s/m$^{1/3}$]

There is a linear and a non-linear mode of the Muskingum-Cunge Method for calculating the reference discharge Q_{REF} in equation 3.6 depending on the value chosen for Q_{REF}:

- The linear mode assumes a constant reference discharge Q_{REF}. The parameters X and K stay constant during all time steps. With this mode an a-priori estimation of runoff data is needed and wave steepening is not accounted for.

- The more accurate non-linear mode calculates the routing parameter for each time step using available Q-values of previous time- and distance steps to determine Q_{REF}. Unlike the linear mode this mode considers the steepening of a flood wave accounting for the fact that different discharges travel at different velocities. Thus a change of runoff leads to a change in flow velocity with a constant cross- section of the channel.

The ZIN-Model uses the non-linear MVPMC3- method which calculates the reference runoff Q_{REF} [m^3/s] out of three runoff values in an iterative way (PONCE & CHAGANTI 1994).

$$Q_{REF} = \frac{Q_{i,j} + Q_{i,j-1} + Q_{i+1,j-1}}{3} \tag{3.9}$$

The wave steepening is indirectly dependent on the magnitude of the reference runoff as the reference discharge is used to determine the weighting factor X (equation 3.6).

3.5 Conclusion

A summary of the performances of the ZIN-Model is given in this chapter by describing the different modelling procedures, such as runoff generation, runoff concentration and flood routing. The model allows a high degree of flexibility as sub-catchments are considered for each procedure. As the model has been developed for arid catchments, the Hortonian overland flow is considered to be the only process of runoff generation. The runoff generation takes into account the runoff coefficient and the initial loss of each sub-catchment which have to be determined for each event separately. Based on channel geometry parameters, the flood routing is carried out applying the hydrologic Muskingum-Cunge flood routing procedure.

4 Data Analysis

In order to understand the hydrologic behaviour of the catchment, a closer look has to be taken on the rainfall and runoff events during the measuring period of the two years of 2004 and 2005. First of all, the rainfall measurements of these two years are presented. Subsequently, the runoff and the pesticide measurements at the outlet of the catchment and the experimental plots are looked at in more detail.

4.1 Rainfall

4.1.1 Measurements

The rainfall data used for the modelling has been measured by the “Rouffach-Hohrain” meteorological station which is situated in the middle of the catchment. The automatic station ‘Météo- France’ measures temperature, air moisture, solar radiation and wind velocity. It is situated in the middle of the catchment on an altitude of 284 m. Since 1991, the rainfall amount has been measured on a hourly basis and since the 1st of July 2000 every 6 min as well (ROETHLISBERGER 2004). For modelling, the Rouffach catchment rainfall data of the years 2004 and 2005 is used. The timestep of the input for the present model has been chosen to be 6 minutes like the recording time step of the meteorological station. As the catchment is very small, the rainfall data of the station is used for the whole catchment. Thus, no alteration of the rainfall data has been carried out. Figure 4-1 shows the total monthly rainfall measured in the years 1946 to 2000.

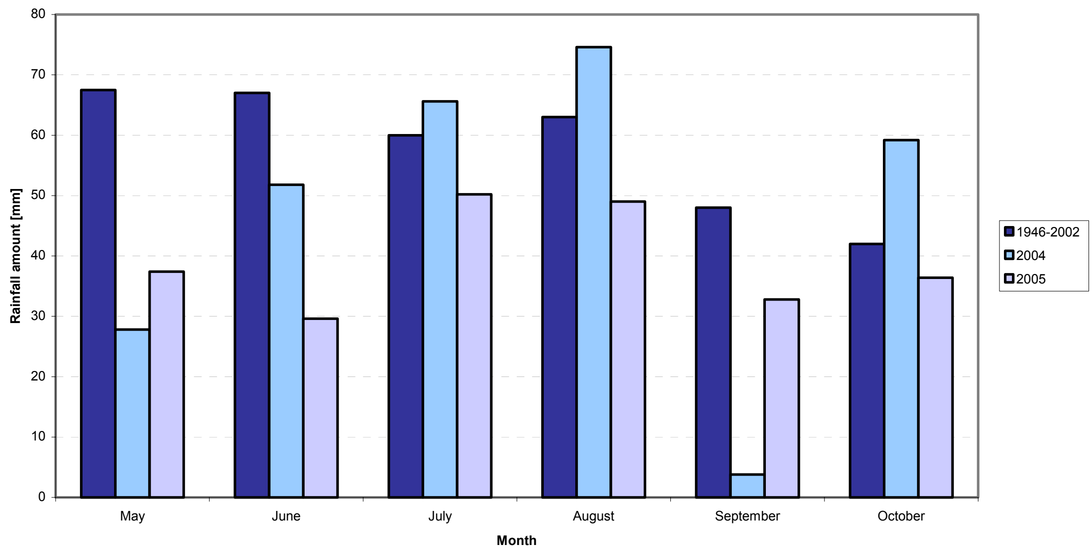

Fig. 4-1: Mean monthly rainfall amount at the Rouffach catchment during the measuring period from May to October

4.1.2 *Analysis*

2004

The total rainfall amount of the year 2004 during the measuring period from the 5th April 2004 until the 14th October 2004 is comparable with the mean rainfall amount of the last 50 years. During the measuring period, 283 mm have been measured which is about 19 % less than the average rainfall amount of the last 50 years. The distribution is not comparable to other years however. The months April, May and September have been very dry. In contrary to this the summer months June, July and August and also the October have been very moist months. There are 6 events with a rainfall volume of more than 10 mm and 8 events with a rainfall intensity of more than 20 mm/h. These strong events occured during the end of May and at the beginning of June and July, mid of August until the end of August and in October. The maximum rainfall volume of one event is 25.6 mm and the maximum rainfall intensity is 56 mm/h.

2005

As shown in Figure 4-1, less rainfall has fallen in 2005 than in 2004. The measuring period lasted from 3th May 2005 until the 14th October 2005. With a total rainfall volume of 235.4 mm, there was 32.5 % less rainfall compared to the mean monthly values of 1946 to 2000. However, there is not such a strong variation of the rainfall volume of different months as in 2004. July and August have been the wettest months whereas June, September and October have been rather dry. Especially the month June has been exceptionally dry, as this month has been rather moist over the last 50 years. Just like in the year 2004, there have been 6 events with a rainfall volume of over 10 mm in 2005 as well. However, there are less numerous events with high rainfall intensities. Only 5 of the measured events have a rainfall intensity of over 20 mm/h. These strong rainfall events have occurred at the end of June, from the end of July until the beginning of August, in the mid September and at the beginning of October. The maximum rainfall volume is 23.4 mm and the maximum rainfall intensity 78 mm/h.

4.2 Runoff

4.2.1 Catchment

4.2.1.1 Measurements

To measure the runoff at the outlet of the catchment and at the experimental plots, a Venturi channel has been used together with a pressure transducer which measures the water level. The Venturi channel has been developed especially for polluted water or water which transports solid particles as its cross-section is not easily obstructed. A part of the Venturi channel is narrowed so that the flow velocity changes from fluvial flowing into torrential flowing which leads to a change in water level (DYCK & PESCHKE 1995). If the change of water level before and after the narrowing of the channel exceeds a treshold, the discharge is a function dependent on the water level and can be calculated applying the following relation:

$$Q = C(h, \dim) \cdot h^{3/2} \tag{4.1}$$

Q	discharge	[m^3/h]
h	measured water level height	[m]
C(h, dim)	coefficient dependent on the water level h and the dimensions of the Venturi channel	[-]

From the 21th September 2004 until the 9th October 2004, there was a technical problem of the runoff measuring gauge, so that the runoff data at the outlet of the catchment is missing during this time.

4.2.1.2 Analysis

2004

During the runoff measuring period of 2004 which lasted from the 5th April 2004 until the 3th September 2004, 37 events have been detected. In most events, runoff occurred directly after the onset of rainfall. During the measuring period a total runoff volume of 1068 m^3 has been measured at the outlet of the catchment. This corresponds to 16 % of the total rainfall volume which has fallen on the roads. The measured runoff volume at the outlet of the catchment varies between 0.16 m^3 and 240 m^3 and the peak discharges vary between 0.1 l/s and 64.9 l/s.

During the events of the 11th June and the 24th August 2004, maximum measured runoff volumes exceed 132 m^3. The other events have runoff volumes of less than 77 m^3. The five events of the 11th June, the 8th, 13th, 21th July and the 24th August 2004 have maximal runoff values of over 37 l/s and rainfall intensities exceeding 24 mm/h. The other events have maximum runoff values of less than 22 l/s and their maximum rainfall intensities stay below 22 mm/h. As shown in Figure 4-2 the rainfall intensity decreases steadily after the first main event on the 11th June 2004.

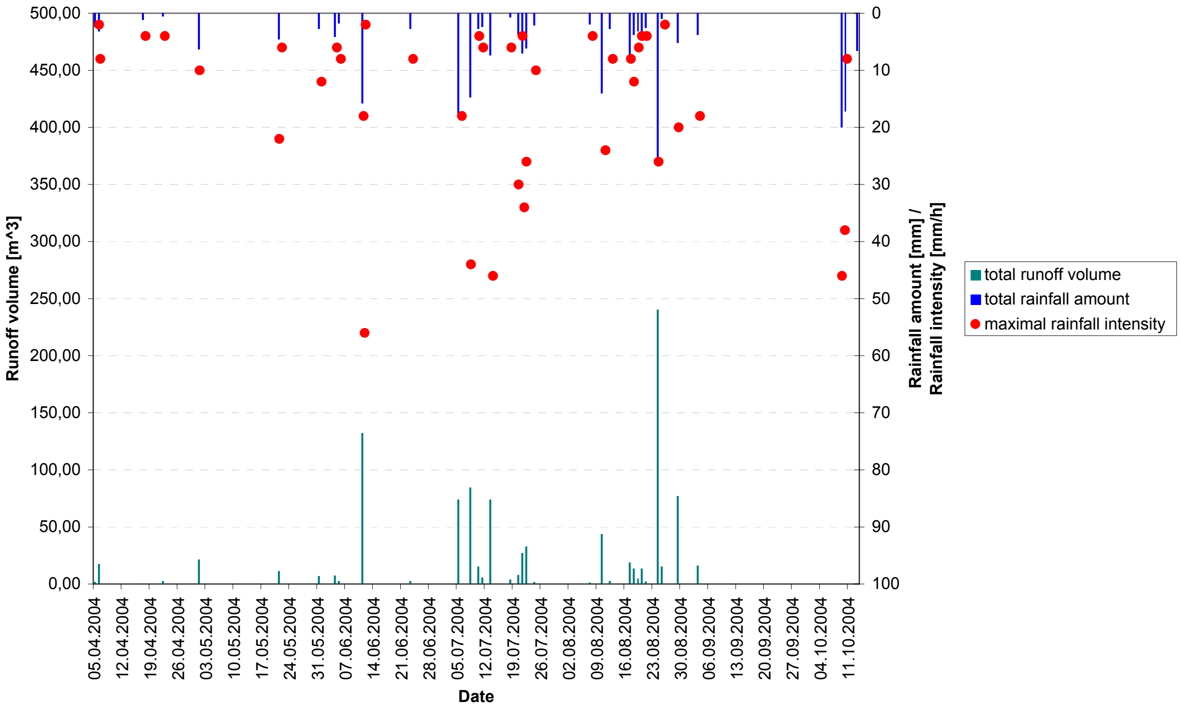

Fig. 4-2: **Runoff events with rainfall amount measured at the outlet of the Rouffach catchment during the measuring period in 2004**

2005

The measuring period of the year 2005 lasted from the 5th May 2005 until the 4th October 2005. During this time, 33 runoff events have been detected. A total runoff volume of 1331 m^3 has been measured at the outlet of the catchment which is 18 % of the total rainfall amount on the roads and about 20 % more than during the year 2004. The measured runoff values are lower than these measured in 2004 and vary between 0.58 m^3 and 132.12 m^3. Peak discharges show a higher variability than in 2004, ranging from 0.3 l/s to 91.9 l/s.

During four events, the 29th June, the 25th July, the 1st August and the 4th October 2005, the runoff volume has exceeded the value of 106 m^3. The other events have runoff volumes of less than 82 m^3. During the events of the 5th May, 29th June and the 12th July, the maximum runoff values are more than 31 l/s whereas during the other events the peak discharge is below 22 l/s. A rainfall intensity of over 26 mm/h have been measured during four events, on the 5th and the 23th May and on the 12th and the 18th July 2005. The rainfall events on the 1st August, the 16th September and the 4th October had high rainfall volumes varying from 15.4 mm to 23.4 mm, but lower rainfall intensities varying from 12 to 18 mm/h.

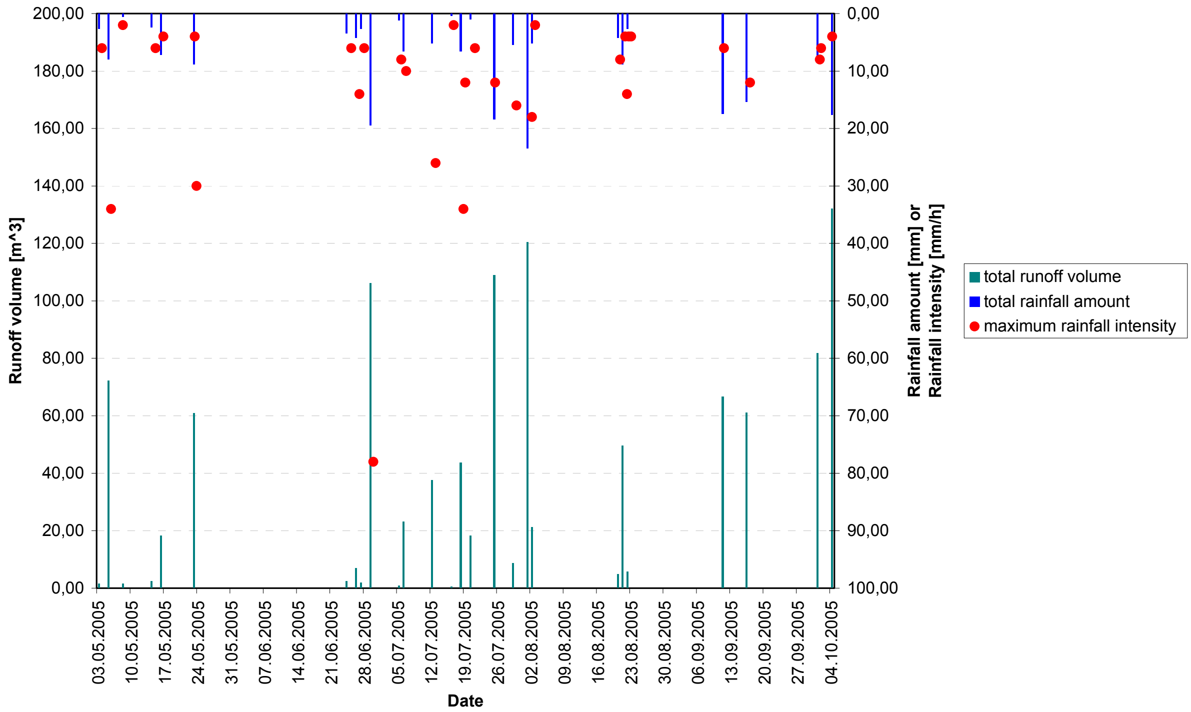

Fig. 4-3: **Runoff events and rainfall amount measured at the outlet of the Rouffach catchment during the measuring period of 2005**

Table 4-1: **Characteristics of the two runoff measuring periods from the 5th April 2004 to the 3rd September 2004 and from the 3rd May 2005 to the 4th October 2005**

		Maximal rainfall intensity [mm/6 min]	Rainfall volume on roads [m³]	Rainfall amount [mm]	Maximal runoff [l/s]	Measured runoff volume [m³]	Runoff coefficient for roads [%]
2004	**Mean**	1.4	178.0	4.6	10.2	28.9	13.6
	Sum	-	6585.3	224.8	-	1068.4	-
	Maximum	5.6	799.7	25.6	64.9	240.2	48.4
	Minimum	0.2	18.7	0.6	0.1	0.2	0.4
2005	**Mean**	1.4	222.8	7.4	10.5	37.0	14.0
	Sum	-	7353.8	266.3	-	1330.8	-
	Maximum	7.8	731.0	23.4	91.90	132.1	59.0
	Minimum	0.2	12.5	0.4	0.30	0.6	2.0

Table 4-1 summarizes the hydrological characteristics of the two years during the measuring period. Although the rainfall events have higher maximum rainfall intensities during the year 2004, the year 2005 is characterised by stronger runoff events due to rainfall events with higher rainfall volumes. The measurements show that a rainfall amount varying from 0.4 to 25.6 mm or a maximum rainfall intensity varying from 20 mm/h to 78 mm/h leads to a detection of a runoff event. This leads to the conclusion that even very weak rainfall volumes or very low rainfall intensities can lead to a detection of runoff generation in the Rouffach catchment.

4.2.2 Experimental plots

4.2.2.1 Measurements

Runoff measurements at the two experimental plots, described in chapter 2.1.2, have been recorded since 2002. Although the rows between the vines canalize the runoff water and are almost independent of each other, the plots have been separated hydrologically with plastic garden trenches which are digged 10 cm deep in the soil and jut out 20 cm above the surface. The runoff water which reaches the bottom of the plot is diverted into PVC tubes which are below the soil surface. The gradient of the PVC tubes allows the water to flow into tanks with a storage capacity of 230 to 250 l. Additional tanks have been established in order to collect all the runoff water, even during very strong rainfall events. The runoff is measured with a Venturi channel in conjunction with a pressure transducer as described in chapter 4.2.1. Emphasis was laid on disturbing the wine cultures as little as possible while installing the measurement gauges (DOMANGE 2005).

At both measurement gauges the runoff volume is measured after each runoff event, and the loss of soil is estimated every week. In order to avoid altering the measured runoff water, variables like temperature and pH are measured in situ. During 12 events in 2004 no runoff has been measured and the runoff coefficient did not exceed 2 %. This could be due to small rainfall intensities but also to the fact that the Venturi channel is not usable for very little runoff volumes because of the risk of blockage by sediment load. In the following however, only the measurements of one of the experimental plots is presented. Every second row between the vines is weeded, like on most of the wine-growing plots of the catchment.

4.2.2.2 Analysis

On the 9th October 2004, two events have been recorded on the experimental plots The first event lasted from 5:24 am to 8:06 am with an average rainfall intensity of 7.4 mm/h and the second event lasted from 11:18 pm to 1:12 am on the next day with an average rainfall intensity of 7.7 mm/h. The runoff volume of the two events measured at the outlet was 746.3 l and 815.9 l respectively. Before the first event has started, the soil was dry and thus there has been a high initial loss of 7.8 mm with a low runoff coefficient of 1.32 %. Before the second event has started, the soil was almost saturated and thus the initial loss of the second event was very low (1.4 mm) and the runoff coefficient with 1.84 % higher than during the first event. As can be seen in Figures 4-4, the onset of runoff is delayed for the first event.

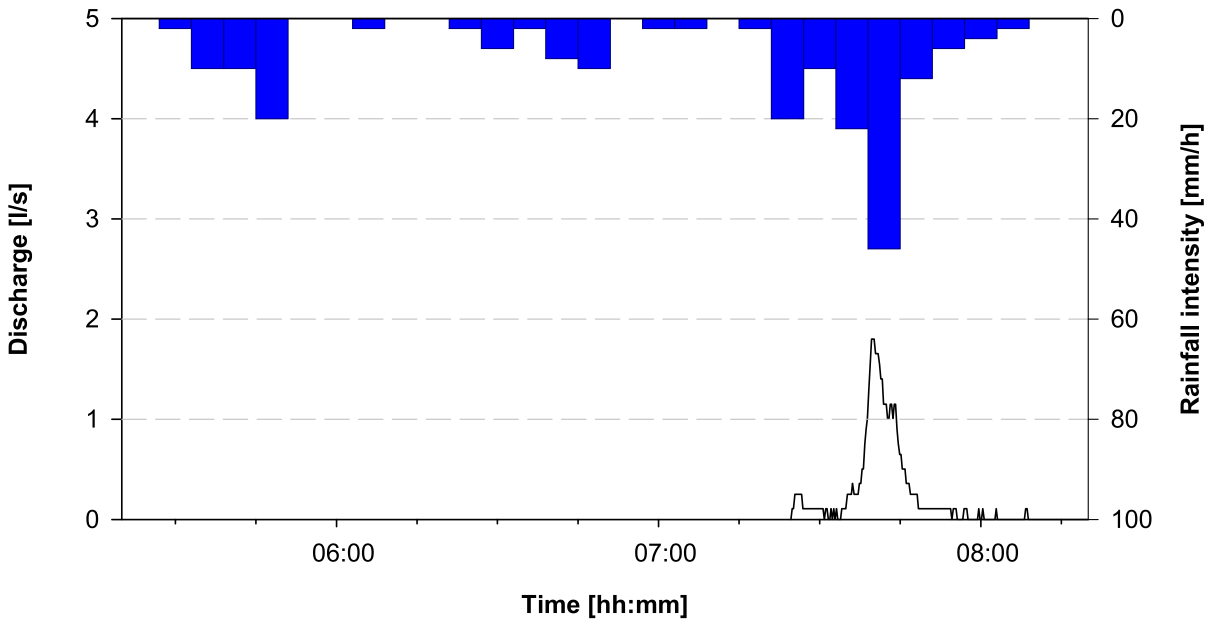

Fig. 4-4: First rainfall-runoff event of the experimental plot on the 9th October 2004

Figure 4-5 however shows that during the second event, the runoff event starts almost simultaneously because of the saturation of the soil. Later rainfall does not lead to another runoff peak anymore which could also be due to a measuring problem because of the very little runoff volume.

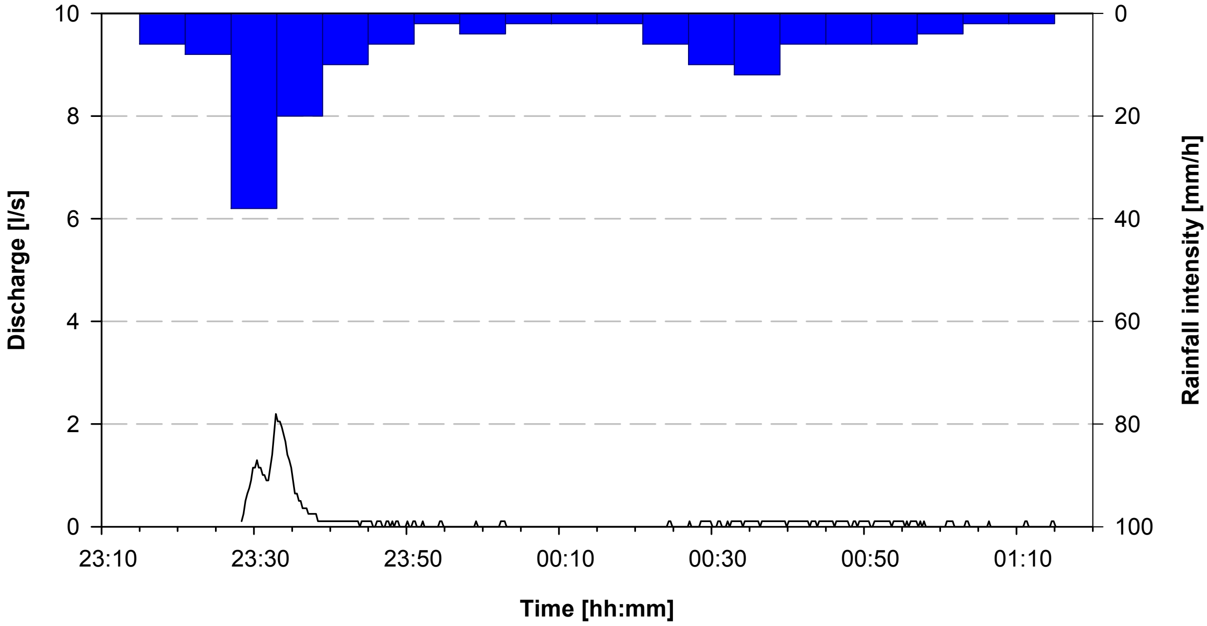

Fig. 4-5: Second rainfall-runoff event of the experimental plot on the 9th October 2004

4.3 Pesticide concentration

4.3.1 Catchment

4.3.1.1 Measurements

Since May 2003, samples are taken out of the Venturi channel with an automatic sample collector. The sample collector consists of a carousel of 24 bottles with 0.9 l volume. The volume of the samples is fixed at 500 ml. During most events only few samples can be taken at the beginning of the event, as the runoff water is carrying a high sediment load.

In addition to these measurements, a survey among the wine-growers has been conducted in order to determine the pesticide products applied on each plot during the year, the name of the product and the date of application. In 2004, 70% of the winegrowers answered which made it possible to get an approximation of the applied product and quantity for 75% of the catchment surface (ROETHLISBERGER 2004).

4.3.1.2 Analysis

The measurements of the Glyphosate and Diuron concentrations at the Rouffach catchment during the years 2003 and 2004 show that the pesticide transport with the runoff is not negligible. The measured herbicides are transported by the runoff in a soluble form (DOMANGE 2005).

Table 4-2: Herbicide concentrations measured at the outlet of the Rouffach catchment in 2003 and 2004

		Glyphosate [µg/l]	AMPA [µg/l]	Diuron [µg/l]
2003	**Middle**	7.6	4.2	1.0
	Maximum	86.0	23.0	11.0
	Minimum	0.4	0.5	0.2
2004	**Middle**	18.3	4.5	0.8
	Maximum	70	44.0	14.0
	Minimum	0.7	0.9	0.1

In 2004, the first two peaks of the Glyphosate concentration (Figure 4-6) can be explained by the two applications in May and June, July. The second peak is stronger in both years although less Glyphosate has been applied before. This can be explained by the shorter time gap between the appliance of the Glyphosate and the rainfall events on the 21st July 2003 and the 20th to 22nd July 2004 which leads to higher concentrations in the runoff water. The Glyphosate concentration is decreasing quasi-exponential after the peaks with time, whereby the values of the first events after application are extremely high.

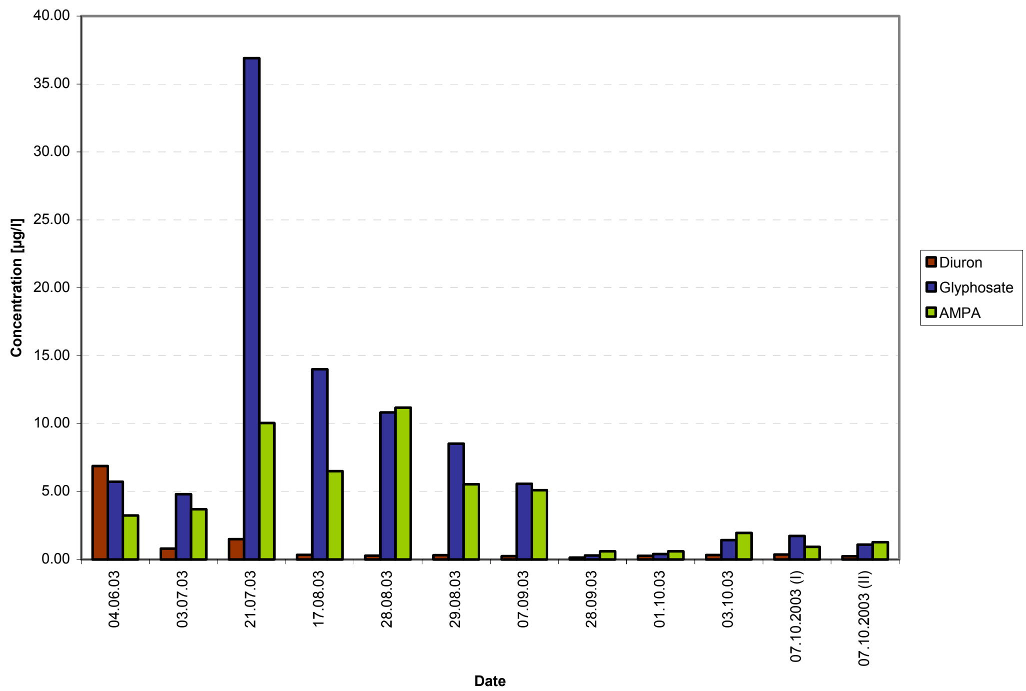

Fig. 4-6: Evolution of average herbicide concentration in the Rouffach catchment measured in 2003.

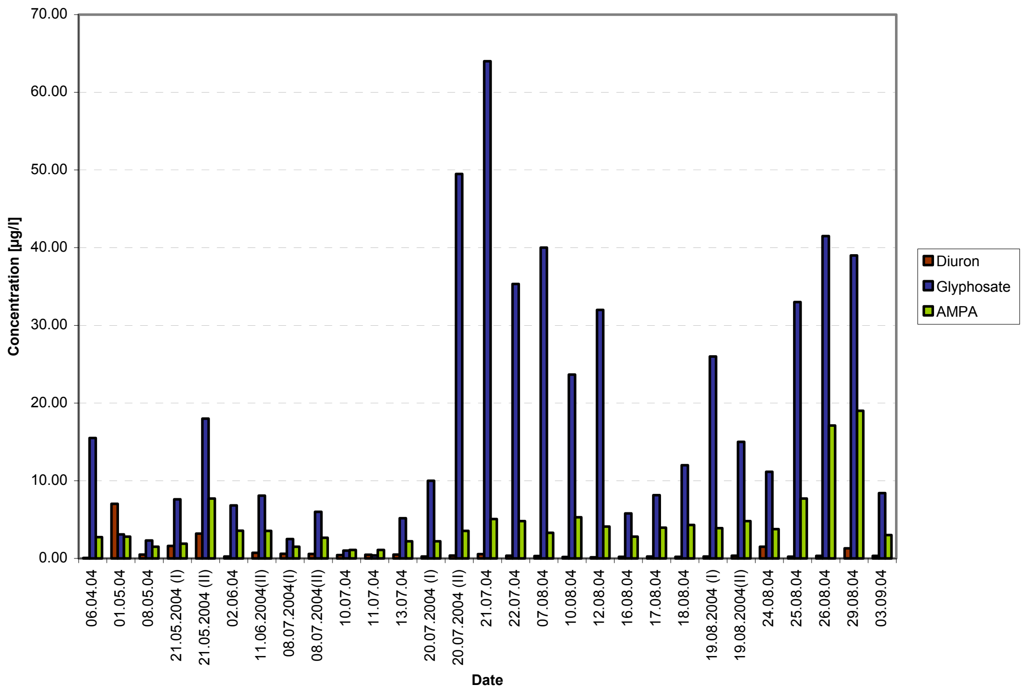

Fig. 4-7: **Evolution of average herbicide concentrations in the Rouffach catchment measured in 2004.**

The highest Diuron concentrations occur just after the applications at the end of April until mid of May. A Diuron concentration can be measured during the whole year and even before the first peak, showing that the Diuron is mobile throughout the year. This can be explained by its long half-life (50-120 days) which is responsible for the creation of long-term residues even until the following year (HOCK 1995). The applied quantities of Diuron on all the Rouffach catchments are rather low, with 245 g in 2003 and 342 g in 2004. The measured average concentration is generally below 1 µg/l. Like the Glyphosate, Diuron is only adsorbed very poorly on impermeable surfaces (RAMWELL et al. 2002). So it is very likely that residues of former events are transported to the outlet of the system during later events.

AMPA the metabolite of Glyphosate can be measured during the whole measuring period as well. The ratio AMPA/Glyphosate seems to increase during the time after the Glyphosate peaks. As described previously, AMPA is more persistent and not as much adsorbed as Glyphosate. In general, the peaks of Glyphosate and AMPA in 2004 are higher which can be due to the fact that about 30% more herbicides have been applied. As adsorption decreases with increasing rainfall intensity (RAMWELL et al. 2002), the numerous rainfall events with their higher intensities in 2004 lead to higher concentrations too. The high herbicide concentration at the end of the year 2004 can be explained by the rainfall events on the 24th and 29th August 2004 which are characterised by very strong rainfall intensities and which lead to an increased mobilisation of the AMPA. As AMPA is easier to mobilize than Glyphosate, it has to be taken into account when studying the transport capability of Glyphosate, as very often only AMPA is measured in groundwater samples for example.

4.3.2 *Experimental plots*

4.3.2.1 *Measurements*

In order to derive pesticide samples, two automatic portable sample collectors with a carousel of 12 bottles of 1 l are connected with the runoff measurement gauges. The bottles are thermically isolated and consist of dark glass in order to limit the change of temperature and to prevent degradation. The sample volume is 500 ml. After a constant runoff volume one sample is taken, but during the runoff peak, more samples are taken. Just like in chapter 4.2.2, only the data derived of the experimented plot is analysed where every second row between the vines is weeded.

4.3.2.2 *Analysis*

In Figure 4-8 it is shown, that at the beginning of the first event on the 9th October 2004, high Glyphosate and high Diuron concentrations are measured at the start of the discharge peak. The Glyphosate concentration decreases after reaching its maximum, whereas the Diuron concentration increases again slightly towards the end. This behaviour can be explained that the precedent rain has probably led to a mobilization of the pesticides.

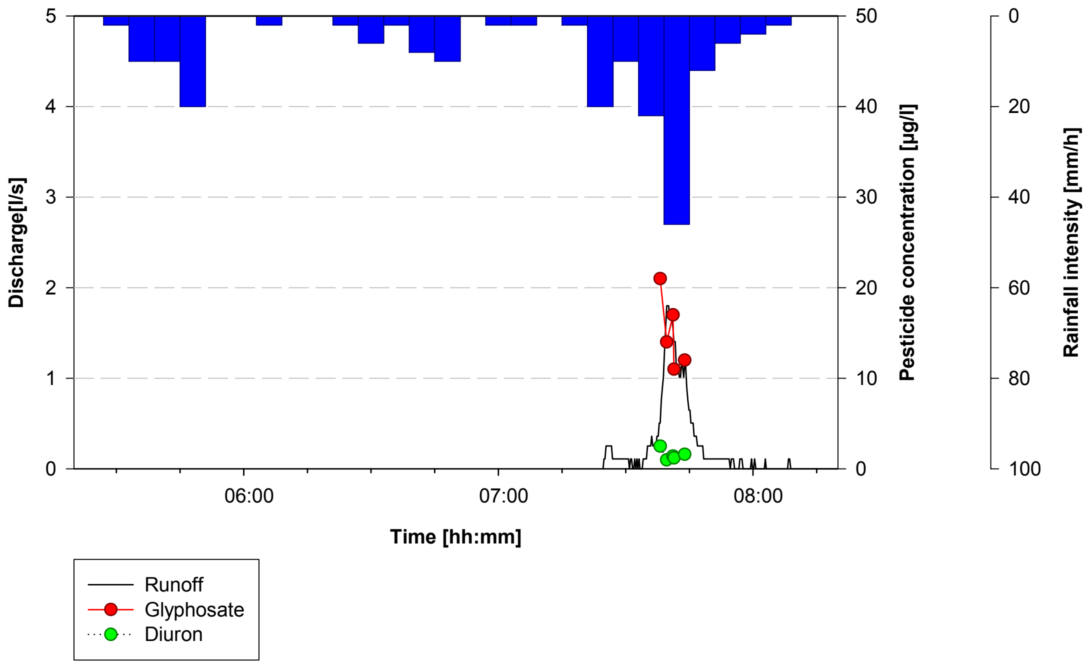

Fig. 4-8: **Pesticide measurements during the first event at the experimental plot on the 9th October 2004**

During the second event however, the Gyphosate and Diuron concentrations are low at the beginning of the peak discharge and increase after some water has run off as it is shown in Figure 4-9.

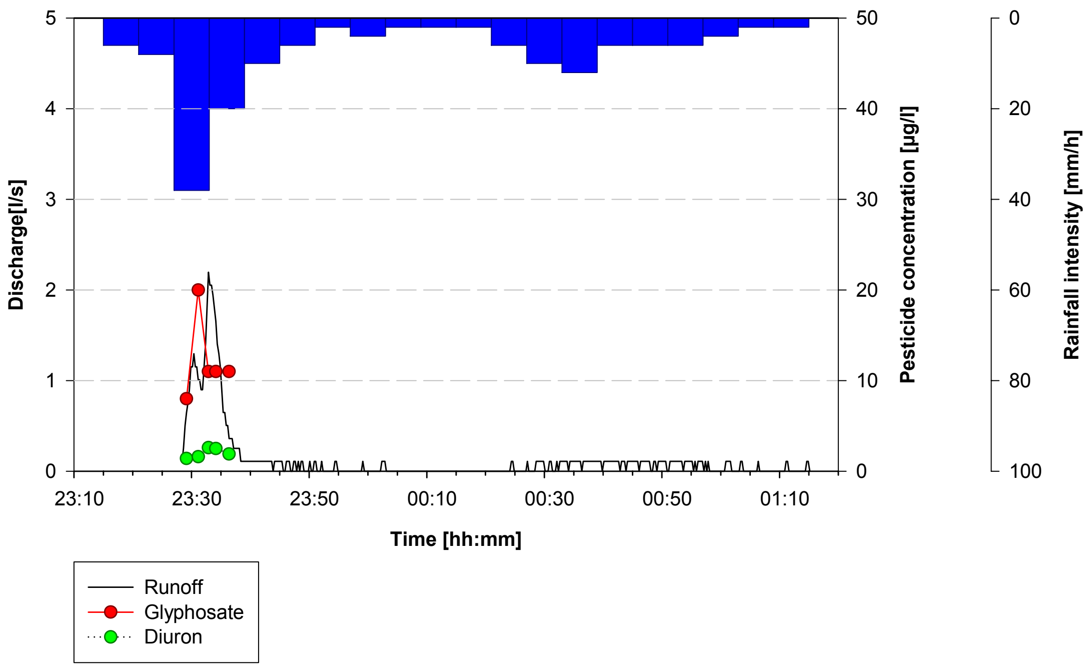

Fig. 4-9: **Pesticide measurements during the second event at the experimental plot on the 9th October 2004**

4.4 Classification of events

Observations in the field as well as the experiences of the similar Löchernbach catchment have shown that the roads deliver most of the runoff. This is why the runoff coefficient of the roads is used for classification of the events which show a very high variability how it is typical for urban catchments (HOLLIS & OVENDEN 1988). The runoff coefficient of the roads is calculated dividing the measured runoff amount at the outlet of the catchment through the rainfall volume which reaches the roads. Figure 4-10 and 4-11 show that the runoff coefficient is not really dependent on the rainfall intensity and the rainfall amount. Exceptional high runoff coefficients during low rainfall intensities or during events with a low rainfall volume are due to a high amount of precedent rainfall. This is valid for the events on the 11th June 2004 and the 20th July 2005. Figure 4-10 however shows, that there is a little correlation between the runoff coefficient and the rainfall intensity. This relationship is not sufficient however, to allow a classification of events.

During a study at an urban catchment with a similar high variability of events, HOLLIS and OVENDEN (1988) tried to explain the event variability with different event specific parameters but they did not find a relationship between the runoff coefficient and the maximum rainfall intensity or the rainfall amount. They concluded that impermeable surfaces do not respond in a simple and unchanging manner to rainfall. It was also shown that percentage of runoff originating from the roads is cyclic with a peak during the summer months which could be due to the expansion of the roads because of the heat. As in the Rouffach catchment only summer events are regarded, this effect is rather marginal.

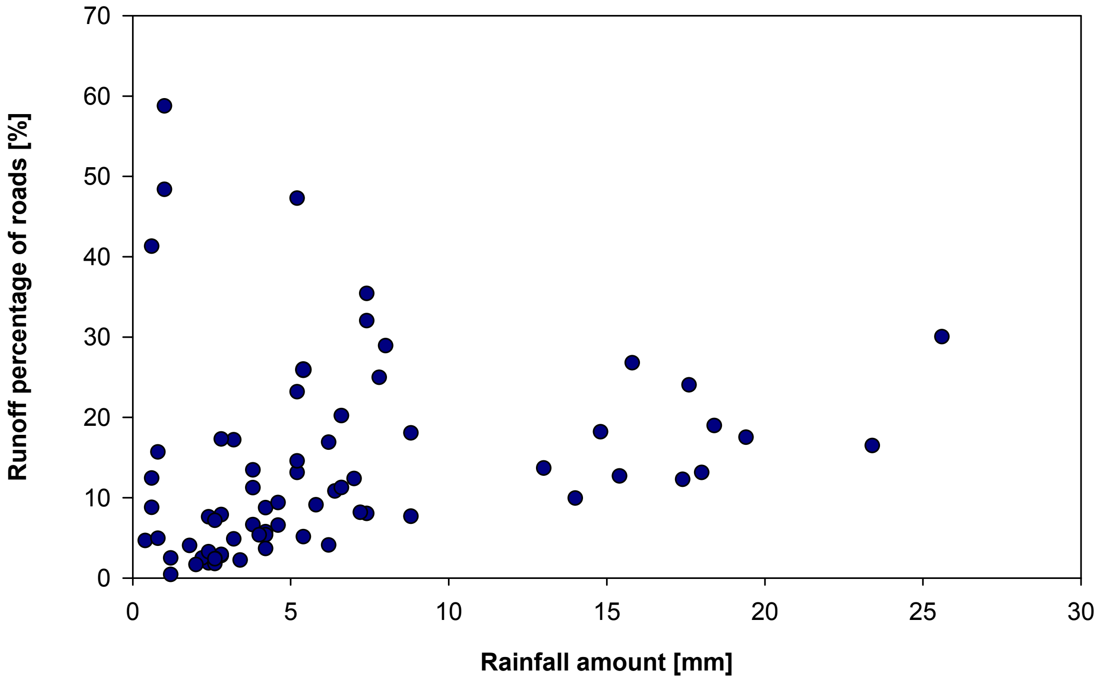

Fig. 4-10: Runoff coefficient versus Rainfall amount of the roads in the Rouffach catchment during 2004 and 2005

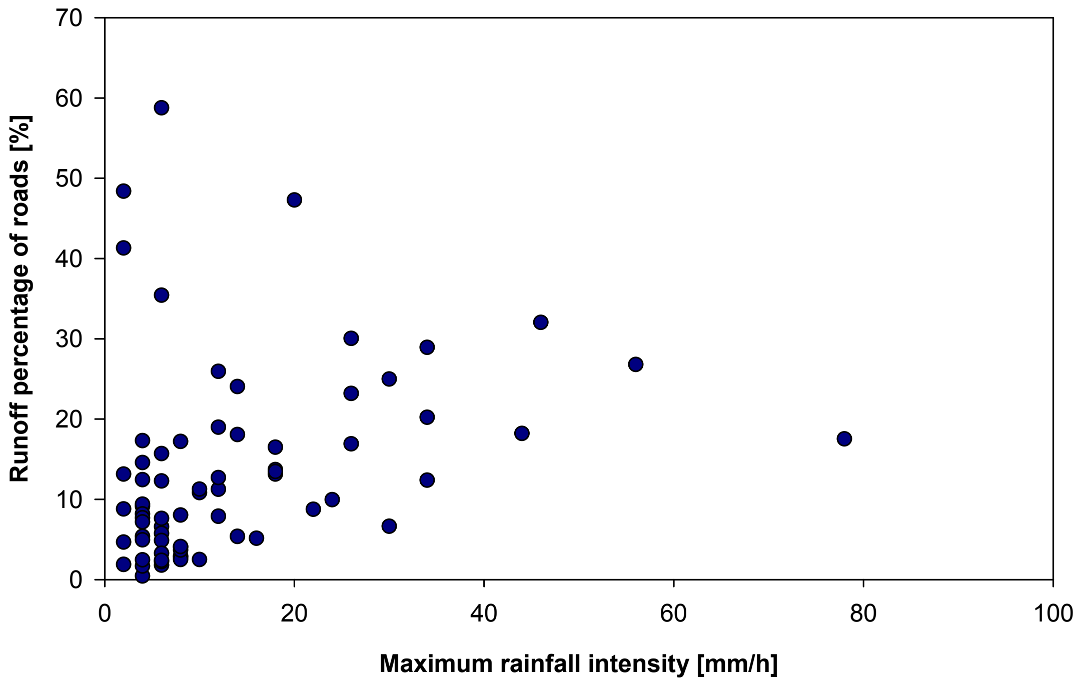

Fig. 4-11: Runoff coefficient versus maximal rainfall intensity of the roads in the Rouffach catchment during 2004 and 2005

A stronger correlation can be seen between the rainfall intensity and the concentration time however as it is shown in Figure 4-12. Observations in the field show that rainfall intensities of over approximately 12 mm/h are leading to runoff on the experimental plots, whereas during events with lower rainfall intensities, only the roads are runoff contributing. The concentration times of the events during 2004 and 2005 are varying between 3 and 22 minutes depending on the rainfall event. Short rainfall events with high rainfall intensities lead to a fast response of the catchment, whereas long rainfall events with a low rainfall intensity lead to a delayed response of the catchment.

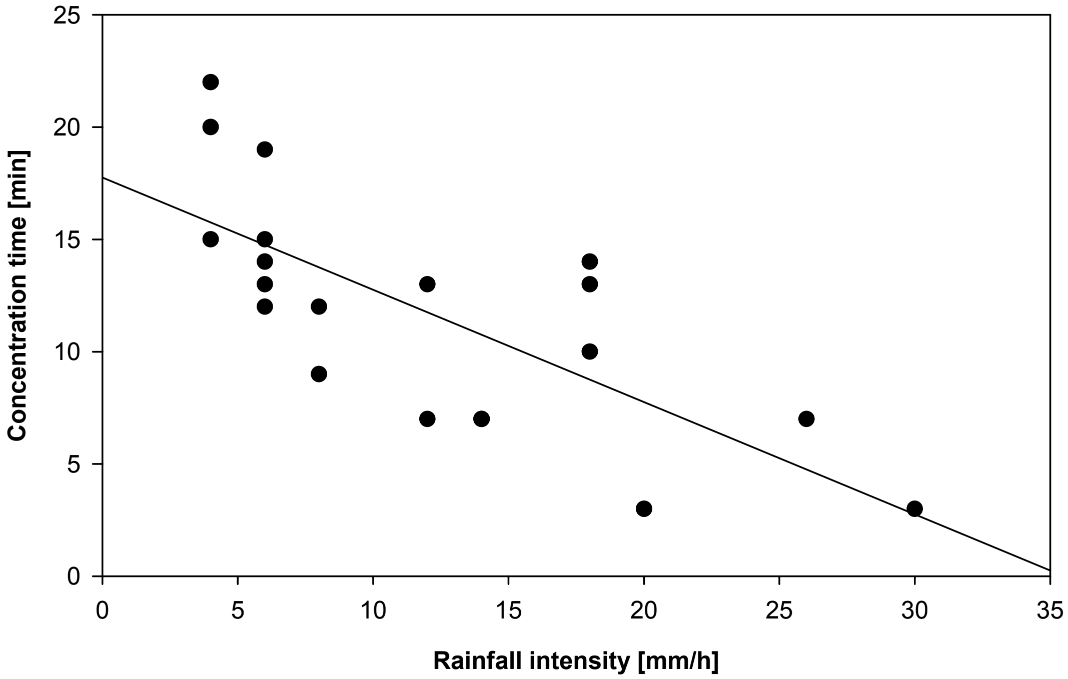

Fig. 4-12: Concentration time versus maximal rainfall intensity in the Rouffach catchment during 2004 and 2005

4.5 Uncertainty assessment

The main factor influencing the accuracy of a model is the quality of the input data. There are four different sources of model uncertainty (MELCHING 1995):

- *Natural uncertainty* due to the random variability inherent in hydrologic systems.
- *Data uncertainties* such as systematic and random errors inherent in the input data.
- *Model uncertainty* depending on how accurately natural processes are represented by equations in the mathematical model
- *Parameter uncertainties* depending on how accurately the values of model parameters may be determined.

Natural uncertainties are influencing every hydrologic model. It is possible to group different events depending on their hydrologic behaviour. They affect the input data, model parameters as well as the model structure. In the case of the Rouffach catchment however, the classification of events is very difficult due to the high event variability as was shown in the previous chapter.

4.5.1 Data uncertainty

Data uncertainty has the strongest effect on the simulation results. The ZIN-Model requires input data on precipitation and surface morphology whereas the runoff measurements are only needed to evaluate the model results. Deriving parameters of the surface morphology by mapping in the field, with the help of a topographic map and by orthographic photographs, leads to uncertainties because of generalisation adapted to the modelling scale. These uncertainties are irrelevant however, compared to that of rainfall input. MELCHING (1995) for example, made out precipitation as the main source for model uncertainty. Uncertainties based on rainfall data may evolve because of measurement errors at the meteorological station. The predominance of convective rain leads to increased measuring errors as well. The rainfall uncertainty at the Rouffach catchment however, can be seen as rather small. As the meteorological station is located in the middle of the catchment, spatial resolution plays a minor role, as the catchment is very small and it can be assumed, that the point data measured at the station is the same all over the catchment. Furthermore the recording resolution is quite high with 0.1 mm in a 6 minutes interval. For urban hydrologic modelling for example a resolution of 0.5 mm is regarded as sufficient (MAHEEPALA et al. 2001). Furthermore there are no noticeable irregularities in the rainfall input data. Some events however, show discharge prior to the rainfall measurements. But this can be due to a time shift during runoff measurement too. Errors in runoff data however, do not have the same impact on model accuracy as the rainfall data, as it is used to validate the model. Uncertainties during low intensity rainfall events may arise because the measurement gauges are build for strong runoff events (DOMANGE 2005). In the Rouffach catchment a lot of sediment is transported with the runoff water leading to measuring errors as well, especially of the pesticide measurements.

4.5.2 *Model uncertainty*

Model uncertainty is mainly influenced by the structure of the model. As a model is always a simplified representation of a natural system, the extent of model uncertainty has to be assessed by comparing simulated model outputs with measured ones. In the present model uncertainties already arise in choosing a raster grid and in the delineation of sub-catchments. For a realistic simulation of runoff, the knowledge of the real size of the catchment is important, as the runoff generated is directly proportional to this area.. Uncertainties in the flood routing procedure arise, as each channel segment is regarded as homogeneous and its cross-section is strongly approximated (Lange 1999). Like every mathematical formula, the Muskingum-Cunge Technique is an approximation of natural processes too. The flood routing does not account for different travel times and the flow is regarded as one-dimensional.

4.5.3 *Parameter uncertainty*

In order to avoid parameter uncertainties, it is important to choose the right parameters which represent the hydrologic behaviour of the model accurately. For running the ZIN-Model, parameters like the runoff coefficient and the initial loss are assessed directly in the field through measurements. The different land use areas and the channel geometry can be differentiated by mapping in the field, topographic maps and aerial photographs. Parameters like the Manning roughness coefficient are derived from literature. Although uncertainties of the model vary from event to event and should be evaluated for each flood (LANGE 1999), sensitivity analysis can give a broad overview about the influence of the parameters on the simulated hydrographs. LANGE (1999) and WAGNER (2002) carried out a sensitivity analysis in varying each parameter over its maximum range of uncertainty while all other parameters were kept constant. Subsequently, the effect of varying a single parameter on the simulated hydrograph was assessed. The sensitivity analysis shows that the runoff generation procedure has the largest impact on the modelling results because of the parameter runoff coefficient and initial loss. Furthermore the use of a constant runoff coefficient in conjunction with an initial loss is a strong simplification of the natural runoff generation process as well. But because of the fast response on rainfall events at the Rouffach catchment, implementing a course of time of infiltration would have only little impact on the overall behaviour of the catchment. Although the runoff generation procedure influences the velocity of the flood wave indirectly, as the velocity increases due to higher water levels, it has no real influence on the timing of the discharge peak. Normally the runoff concentration routine has the main influence on the timing of the peak discharge when a time lag has been implemented into the model. For the present model, the flood routing procedure is most responsible for a correct timing of the peak discharge especially because of the Manning roughness factor.

4.6 Conclusion

The rainfall data is recorded by a meteorological station in the middle of the catchment in a 6 minutes time interval. The runoff at the outlet of the catchment and at the outlet of the experimental plots is measured with a Venturi channel accounting for the high sediment load in the runoff water. The runoff measurements at the outlet of the catchment show a high variability whereas the measurements at the experimental plots are only derived during two events which follow each other during a short period of time. The measurements reveal, that a precedent rainfall event strongly influences the initial loss and the runoff coefficient of a following event. Because of the high variability of runoff coefficients and rainfall intensities however, it is not possible to group the events. There is a correlation however between the rainfall intensity and the delay of the peak discharge.

Since 2003, various pesticides have been detected in the runoff water of the Rouffach catchment. The Glyphosate concentrations are highest during the events following the application and the Diuron concentration can be measured during the whole year and even at the beginning of the next year.

Thorough sensitivity analysis have been carried out by LANGE (1999) and WAGNER (2002). They have shown that the uncertainty of the model is most dependent on the model input, which is the rainfall intensity. Considering the different model procedures, the runoff generation procedure has the strongest influence on the simulation results as its parameters are governing the runoff amount.

5 Parameter determination

5.1 Runoff generation

5.1.1 Spatial disaggregation

Spatial disaggregation of the Rouffach catchment is done with the help of aerial photographs, topographic maps and ground thruthing in the field. As Rouffach is a wine-growing area the spatial sub-units are different land use types. Most of the catchment area is used as a wine cultivation area. On some wine-cultivating plots only every second row between the vines is weeded (wine 1/2) or they are weeded completely (wine no green) and some cultivating plots are completely covered by herbs (wine with green). The land use type wine ploughed describes an area of former wine cultivation which is often treated with herbicides too, to keep it free from weeds. Figure 5-1 shows the different land use types of the catchment.

Fig. 5-1: Land use types of the Rouffach catchment

About 7.5 % of the catchment area is covered by roads. The dense road network functions as channels but also as a runoff contributing area. Depending on their coverage, the roads have been subdivided too. Larger roads which are used more frequently are paved (road concrete). Some of these roads are covered by larger stones and debris (road fosse) and some by pebbles (road gravel). The roads in the wine-growing area are of bare soil (road soil), they can have one stripe of grass in the middle (road mixed) or they are completely covered by grass (road grass). Grass coverage is predominant on roads which are not used by vehicles very frequently. However all the different types of roads have endured a strong compaction (GREGOIRE, personal communicaton). The percentage of the land use area and the road type area is shown in Table 5-1.

Table 5-1: Catchment area covered by different land use and road types

Land use type	Area covered [%]	Road type	Area covered [%]
wine 1/2	43.52	concrete	1.80
wine with green	11.48	fosse	1.21
wine no green	4.62	grass	1.65
wine ploughed	3.29	gravel	1.50
orchard	5.45	mixed/soil	1.30
fallow land/forest/grassland	31.63		

5.1.2 Parameterisation

The runoff of the Rouffach catchment is primarily influenced by the dense impermeable road network which leads to the formation of Hortonian overland flow. In order to determine the runoff generated on the different land use areas, the runoff coefficient method is applied. This method assumes that one part of the catchment is non-permeable and the rest of the catchment is completely permeable and that there is no temporary storage of water on the surface of the drainage basin. It has been developed for urban hydrology and has proved to give good results in catchments with a high degree of non-permeable surface (MANIAK 1997). Thus the runoff generation is calculated taking into account the initial loss and the runoff coefficient of each land use type. As there are no measured infiltration rates of the Rouffach catchment available, the chosen initial loss does not only consider water retained in surface depressions and intercepted water by vegetation, but also water lost to infiltration.

The runoff coefficient ψ is defined as the percentage portion of the rainfall which forms effective rainfall after each rainfall interval or as direct runoff divided by total runoff. To calculate the direct runoff Q_D [l/m^2] of each time step, the total rainfall P [mm] minus the initial loss I_L [mm] is multiplied with the runoff coefficient ψ [%] for each time interval:

$$Q_D = (P - I_L) \cdot \psi \tag{5.1}$$

Thus the rainfall amount in mm is added to each of the raster cells every 6 minutes after subtraction of the initial loss. The effective rainfall amount is subsequently multiplied with the runoff coefficient. So that without any subtractions, one millimetre of rainfall generates one litre of runoff on each raster cell.

Parameterization of the wine-growing area and the orchards

Parameterization is done for each event for the wine-growing area and the orchards. As the initial loss and the runoff coefficient are influenced by the soil moisture and there are no soil moisture measurements in the catchment they are calculated dependent on the precedent rainfall amount. This correlation between the parameters and the precedent rainfall amount has been derived by the data of the two events of the experimental plot described in chapter 4.2.2.

Before the second event on the 9th October has started 20 mm rain has fallen before. The 20 mm of precedent rain lead to a decrease of initial loss of 6.4 mm and an increase of runoff coefficient of 0.52 %. With the help of this correlation it is possible to calculate the runoff coefficient and initial loss for each event (equation 5.2 and 5.3). As the modelled events are summer events, the precedent rain is only considered when it has fallen within three days before. In equation 5.4 the mean precedent rainfall is calculated in adding the rainfall of one day before plus the mean rainfall of 2 and 3 days before respectively. This takes into consideration the hot climate during summer and the quick evapotranspiration of rainfall water. As the runoff behaviour of the different wine-cultivating methods are quite similar and because parameters derived from measurements at the experimental plots are the best approximations to reality the calculated runoff coefficient and the initial loss have been used for the whole wine-growing area and also for the orchards. Applying this relationship, runoff coefficients ranging from 1.32 % and 1.84 % and initial losses ranging from 1.4 mm to 7.8 mm are calculated for the wine-growing area and the orchards. During rainfall events with a rainfall intensity lower than 12 mm/h no runoff is generated from the wine-growing region as the whole runoff water infiltrates or is lost by interception.

$$I_L = 7.8 - \left(\frac{6.4}{20 * P_{prec}} \right) \tag{5.2}$$

$$rp = 0.0132 + \left(\frac{0.0052}{20 \cdot P_{prec}} \right) \tag{5.3}$$

$$P_{prec} = P_1 + \frac{P_2 + P_3}{2} \tag{5.4}$$

P_{prec}	total precedent rainfall of event	[mm]
$P_{(1,2,3)}$	precedent rainfall of 1 to 3 days before	[mm]
I_L	initial loss	[mm]
rp	runoff coefficient	[%]

Parametrization of the roads

Runoff measurements in a wine-growing region at the Eastern Kaiserstuhl, the Löchernbach catchment, reveals that the runoff coefficient of the roads is much lower than it is described in literature. Values of about 32 % have been measured for concrete roads (WAGNER 2002). These values correspond very well with an irrigation study of HOLLIS and OVENDEN (1988). They have measured runoff from roofs and roads in England and measured a mean runoff coefficient of 33 % of the roads from May to October and a mean initial loss from 0.5 mm to 1.2 mm. The runoff coefficient value of 32 % derived from the Löchernbach catchment has been used for the concrete, gravel and fosse roads of the catchment and the initial loss was set to 0.5 mm according to the study of HOLLIS and OVENDEN (1988).

For the roads covered by grass, bare soil or both, a lower runoff coefficient value of 20 % has been chosen and the initial loss was set to 1 mm. Table 5-2 gives an overview about the parameters chosen for the different types of roads. It is assumed that the water retention capacity of roads does not decrease significantly when the road is wetted and that there is no clear relationship between the initial loss and the slope of the roads. Thus the initial loss and the runoff coefficient of the roads stay constant during all events (HOLLIS & OVENDEN 1988). Observations in the field show that the forest and fallow land are not contributing to the overland flow and thus the runoff coefficient of this area was set to zero. Patches of grassland area is distributed in the middle of the forest. The generated runoff infiltrates during its passage through the forest so that no runoff reaches the roads as well.

Table 5-2: Runoff generation characteristics of the different road types

Type of road	Runoff coefficient [%]	Initial loss [mm]
concrete	32	0.5
fosse	32	0.5
gravel	32	0.5
grass	20	1
mixed / soil	20	1

5.2 Runoff concentration

5.2.1 Spatial disaggregation

The surface morphology governs the spatial concentration of runoff as only overland flow is considered. The roads representing the channel network, were divided into different distance steps. With the help of topographic maps and a digital elevation model two runoff providing sub-catchments have been assessed for each road segment. One of the two catchments delivers water from the cultivation plots, the second one covers only a little area of road. In the present model 660 sub- catchments have been identified which have been numbered and assigned to the road segments. The length of the distance step of the road was chosen to be about 20 m long, as the catchment is very small and most of the plots are between 10 and 30 m broad.

As a guideline for the chosen time step the Courant Condition for explicit numerical solution schemes of the Saint- Venant equations for open channel flow was used. The Courant Condition verifies that the distance travelled by the wave or hydrograph in one time step Δt must never exceed the distance between computational nodes otherwise computational instability may evolve (COURANT & FRIEDRICH 1948). The length of the time step Δt [s] can be calculated with the following equation:

$$\Delta t \leq \frac{\Delta x}{v_K} \tag{5.5}$$

where Δx is the length of the distance step [m] and v_K is the kinematic wave celerity [m/s]. The kinematic wave celerity was set to maximal 2 m/s, according to the Löchernbach study (WAGNER 2002). In order to satisfy the Courant condition and prevent an accumulation or spilling up of water (CHOW et. al. 1988) a constant time step of 10 seconds was chosen.

5.3 Flood routing

5.3.1 Spatial disaggregation

The flood routing calculates the hydrograph from node to node and does not consider the runoff contributing area any more. The time step and the spatial subdivision are the same as in the runoff concentration procedure. As there are no natural streams in the catchment, the roads function as channels. The flow direction of the single road segments is assessed using a topographic map, and a digital elevation model. The 330 road segments are divided by channel nodes which account for confluences.

5.3.2 Parameterisation

The form of the flood wave is influenced by the Manning roughness coefficient [$m/s^{1/3}$], the slope [-] and the cross-section area [m^2]. In the Rouffach catchment, the impact of rainfall and obstructions such as rocks, grass and litter are disturbing the flow so that it is not laminar anymore although the runoff has a very shallow depth. Normally the Manning roughness factor varies with the flow depth but this is negligible for turbulent flow. Because of these characteristics the Manning roughness factor for overland flow can be quite different than that of channel flow. The so called effective Manning roughness factor which was chosen for the flood routing procedure incorporates all the factors affecting the flow resistance (AKAN & HOUGHTALEN 2003). The roughness coefficients have been derived from literature (see Table 5-3), the slope out of a digital elevation model and the width of the roads have been measured in the field.

Table 5-3: Chosen Manning roughness parameters for the flood routing routine

Type of road	Manning roughness coeff.	literature
concrete	0.015	BROWN et al. (1996)
fosse	0.015	BROWN et al. (1996)
gravel	0.015	BROWN et al. (1996)
mixed / soil	0.023	BROWN et al. (1996)
grass	0.023	BROWN et al. (1996)

Channel flow

In order to solve the equations of the Muskingum-Cunge Technique (chapter 3.4) a hydraulic radius needs to be calculated. One assumption used for the flood routing routine is to regard the roads as trapezium cross-sections whose area can be calculated with the following equation:

$$A = b \cdot h + x \cdot h \tag{5.6}$$

With $x = h \cdot \tan\alpha$ follows:

$$A = b \cdot h + h^2 \cdot \tan\alpha \tag{5.7}$$

b	width of the channel	[m]
h	water level	[m]
A	cross-section area	[m^2]
x	difference of the width of the channel at the bottom and at the waterlevel	[m]
$\tan\alpha$	gradient of the riverbank	[-]

The gradient of the riverbank alpha is chosen as small as possible to get an almost rectangular cross section where the width of the channel does not change significantly with water depth. The geometry of the assumed cross-section for the flow on the roads is shown schematically in Figure 5-2.

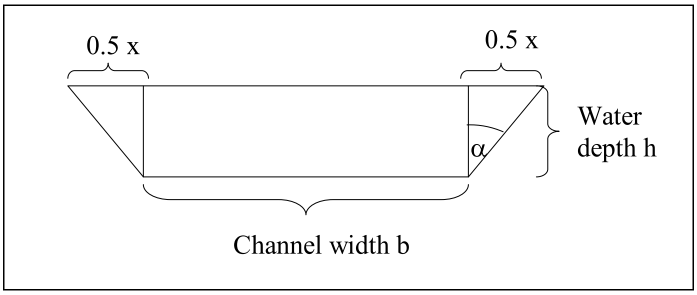

Fig. 5-2: Assumed cross-section of the roads (after WAGNER 2002)

After calculating the area of the trapezium cross section, the water level can be determined solving the Manning equation which describes the resistance relationship:

$$Q = n^{-1} \cdot A \cdot R_{hy}^{\ 2/3} \cdot S_0^{\ 1/2} \qquad 5.8)$$

Q	runoff	[m^3/h]
n	Manning roughness coefficient	[$m/s^{1/3}$]
A	cross-section area	[m^2]
R_{hy}	hydraulic radius	[m^2]
S_o	energy slope	[-]

For channelized flow ANDERSON & BURT (1990) made the following assumption:

$$Q = n^{-1} \cdot A \cdot R_{hy}^{\ 2/3} \cdot S_0^{\ 1/2} = n^{-1} \cdot A^{4/3} \cdot \xi^{2/3} \cdot S_0^{\ 1/2} \qquad (5.9)$$

In this equation ξ is a constant which is dependent on the geometry of the cross section. For assuming an almost rectangular cross section ξ is 0.354 (ANDERSON & BURT 1990). Except of the runoff Q all parameters are channel constants. This is why the water level and the water filled cross-section are directly dependent on the runoff. In inserting the cross-section area A [m^2] in equation 5.9 the water level h [m] can be calculated in the following way.

$$h = \frac{-b + \sqrt{b^2 + 4 \cdot \tan\alpha \cdot \left(\dfrac{Q \cdot n}{\zeta^{2/3} \cdot S_0^{\ 1/2}} \right)^{3/4}}}{2 \cdot \tan\alpha} \qquad (5.10)$$

Broad sheet flow

But a second method has been applied as well. Flow on roads is often described as open-channel flow with a free surface at atmospheric pressure when rainfall excess takes the form of sheet flow. Sheet flow is expressed by the discharge per unit width. As sheet flow has a very shallow depth, it can be seen as flow in a wide rectangular channel with a flat bottom. (AKAN & HOUGHTALEN 2003). For the assumption of a rectangular channel the cross section area can be calculated as:

$$A = b \cdot h \tag{5.11}$$

where A is the cross-section area [m^2], b is the width of the channel [m] and h is the water level [m]. As flow on street pavements generally takes the form of broad sheet flow, the following alteration of the Manning equation can be applied:

$$Q = n^{-1} \cdot \omega^{-2/5} \cdot S_0^{\ 1/2} \cdot A^{5/3} = n^{-1} \cdot \omega^{-2/5} \cdot S_0^{\ 1/2} \cdot (b \cdot h)^{5/3} \tag{5.12}$$

where ω is the width of the element on the downslope face [m] (ANDERSON & BURT 1990). The water level height can thus be calculated with the following equation:

$$h = \left(\frac{Q \cdot n}{\omega^{2/5} \cdot S_0^{\ 1/2}} \right)^{3/5} \cdot \frac{1}{b} \tag{5.13}$$

5.4 Pesticide transport modelling

5.4.1 Pesticide input

The pesticide input data for the modelling work was calculated with the help of the pesticide measurements of the experimental plot on the 9th October 2004. On the 9th October both events have been considered as it was done for the parameterisation of the runoff generation parameters (see chapter 5.1). After analysing a survey among wine-growers about the pesticides applied on the wine-growing plots, a relationship between the applied quantity and the measured concentration at the experimental plot was established. On the plot a Diuron input of 55.4 mg/m^2 leads to a mean concentration of 1.5 µg/l and 2 µg/l in the runoff water at the outlet of the plot for the first and second event respectively. And the appliance of 48.5 mg/m^2 of Glyphosate leads to a mean concentration of 13.5 and 12.2 µg/l in the runoff water. Because of this the following relationship can be applied to calculate the pesticide input in µg/l for each cell and each wine-cultivation area:

1st event:	1g/m^2	Diuron input leads to	27.1 µg/l on each raster cell	[m^2]
	1g/m^2	Glyphosate input leads to	278.6 µg/l on each raster cell	[m^2]
2nd event:	1g/m^2	Diuron input leads to	36.1 µg/l on each raster cell	[m^2]
	1g/m^2	Glyphosate input leads to	251.8 on each raster cell	[m^2]

As data for pesticide input is not available for the whole catchment, the pesticide data is regionalised. In doing so the different cultivation methods are considered. The calculated concentration of each raster cell of the different cultivation methods is used as an input for the runoff generation routine with the pesticide module. The range of pesticide concentration used as an input for the different wine-cultivation areas and the orchards is given in Table 5-4. As the pesticides are only applied on the wine-cultivating area and the orchards, the pesticide input on the roads is set to zero.

Table 5-4: Calculated pesticide concentrations as model input for different wine-cultivation areas

	Diuron [µg/l]		Glyphosate [µg/l]	
	1st event	2nd event	1st event	2nd event
wine 1/2	1.4 - 1.9	1.8 - 2.6	3.7 - 25.2	3.3 - 22.8
wine no green	1.5 - 3.1	2.0 - 4.1	17.0 - 32.3	15.4 - 29.2
wine green	-	-	3.6 - 114.0	3.3 - 103.0
wine	2.0	2.6	15.7	14.2
orchard	-	-	17.0 - 17.1	15.4 - 15.5

5.4.2 Pesticide model

The pesticide generation is calculated parallel to the runoff generation. At the end of the runoff generation routine, the pesticide concentration [µg/l] of each runoff contributing area is multiplied with the generated runoff to get the pesticide amount [µg] generated on each m^2. Thus the pesticide concentration is directly dependent on the runoff volume. In the runoff concentration procedure the pesticide amount of each sub-catchment in µg/s at every timestep is calculated. Thus the runoff concentration routine provides not only a hydrograph but also a loadograph (load rate versus time).

The Muskingum-Cunge routing procedure can be used as well if pollutant routing is required (MC CUEN 1998). Given the discharge hydrograph and the loadograph at the upstream end of a channel, first the discharge hydrograph is routed using the Muskingum-Cunge method. Subsequently the loadograph is routed in solving equation 5.14. The same parameters (C_1, C_2 and C_3) as for routing the discharge hydrograph (see chapter 3.4) are used. Thus the parameters C_1, C_2 and C_3 are independent of the pesticide concentration and only dependent on the runoff and the channel geometry. At the end of the flood routing procedure the pesticide load [µg/s] is divided by the runoff [l/s] to get the pesticide concentration in µg/l.

$$W_{i+1,j} = C_1 W_{i,j} + C_2 W_{i,j-1} + C_3 W_{i+1,j-1} \tag{5.14}$$

$W_{i+1,j}$	unknown pesticide load at the next node at the present time step	[µg/s]
$W_{i,j}$	pesticide load at the present node at the present time step	[µg/s]
$W_{i+1,j-1}$	pesticide load at the next channel node at the last time step	[m³/s]
$W_{i,j-1}$	pesticide load at the present node at the last time step	[µg/s]
$C_{1,2,3}$	auxiliary variables calculated during the flood routing routine	[-]

5.5 Conclusion

The spatial disaggregation of the ZIN-Model is carried out for each of the model sub-systems independently. The catchment area is divided depending on the coverage such as the wine-growing area and the roads for example. For the runoff generation procedure, parameters for the wine-growing area are derived by measurements of the experimental plot and calculated for each event separately. Runoff generation parameters for the roads however, are chosen similar to a study at the Löchernbach catchment (WAGNER 2002) and a second set of parameters provides lower runoff coefficients.

For the runoff concentration procedure the catchment is divided into different runoff contributing sub-catchments. The runoff concentration does not consider a delayed response of the different land use areas, as the measured peak discharges react almost simultaneously on the onset of rain. Parameters describing the channel geometry are used by the Muskingum-Cunge Technique to route the hydrograph. They are partly derived by measurements in the field and also by literature. The roads which function as a channel network are grouped depending on their coverage. To take into account the pesticide transport, a pesticide module is incorporated into the model which simulates the pesticide concentration in the runoff water at the outlet of the catchment. Input parameters have been calculated based on measurements at the experimental plots and based on a survey among wine-growers.

6 Model application

6.1 Model results and analysis

For model application, 16 events of the years 2004 and 2005 have been chosen. During other events, the runoff was too low or the measuring data incomplete. In the following, a selection of the simulated hydrographs is discussed in more detail.

As during most events the runoff coefficient of 32 % for concrete roads leads to a strongly overestimated runoff volume, a second set of runoff coefficients was chosen. Figures 6-1 to 6-3 show the simulated hydrographs derived by the appliance of the Löchernbach parameters, whereas during the events shown in Figures 6-4 to 6-7 a better model fit is achieved, using a lower runoff coefficient of 20 % for the concrete roads and only 10 % for the roads covered by grass. The runoff coefficients from the wine-growing region are calculated for each event separately, based on *in situ* measurements at the experimental plot. Thus no estimated or unrealistic values have to be implemented into the model, in order to achieve the best approximation of the simulated and measured hydrograph. Tables 6-1 to 6-7 give an overview of the measured and simulated peak discharges and the corresponding runoff volumes.

To take into account different assumptions of runoff behaviour on the roads, two different flow equations, simplifying the Manning equations are used in the flood routing procedure. One considers the flow in channels and thus assumes a trapezium cross section how it was done by WAGNER (2002) before, whereas the other equation describes broad sheet flow which is typical for runoff on roads (AKAN & HOUGHTALEN 2003). On some days two different rainfall events and runoff events occurred which are looked at separately.

6.1.1 Event on the 5th May 2005

The runoff event of the 5th May 2005 shows a strong variation of rainfall intensities how it is typical for convective rainfall events. The maximum rainfall intensity exceeds values up to 34 mm/h and the total rainfall event lasts 5:12 hours. During this time a total rainfall amount of 8 mm reaches the catchment. The high rainfall intensity leads to a steep rising hydrograph and after two hours after the first spell of rain, a second spell of rainfall with a lower intensity leads to a low runoff peak. Because of the high rainfall intensity of up to 34 mm/h, runoff coming from the wine-growing region and the orchards is taken into consideration too for the model simulation.

As can be seen in Figure 6-1, the measured hydrograph is simulated well by the model using the channel routing equation. The rise of the hydrograph is almost as steep as the measured one. The simulated peak discharge is 4 % higher and thus slightly overestimated. The recession of the simulated and the modelled hydrograph are quite similar too, and the runoff volume does only differ 3.3 %. The timing of the peak however, is 18 minutes too late compared to the measured one. This can be seen in relative terms as the measured peak discharges occurs 2 minutes prior to the maximum rainfall intensity and thus a mistake in recording the time at the Venturi channel or the meteorological station can be assumed. The simulation of the broad sheet flood routing shows that this technique is not capable to simulate the fast rise of the hydrograph during this event.

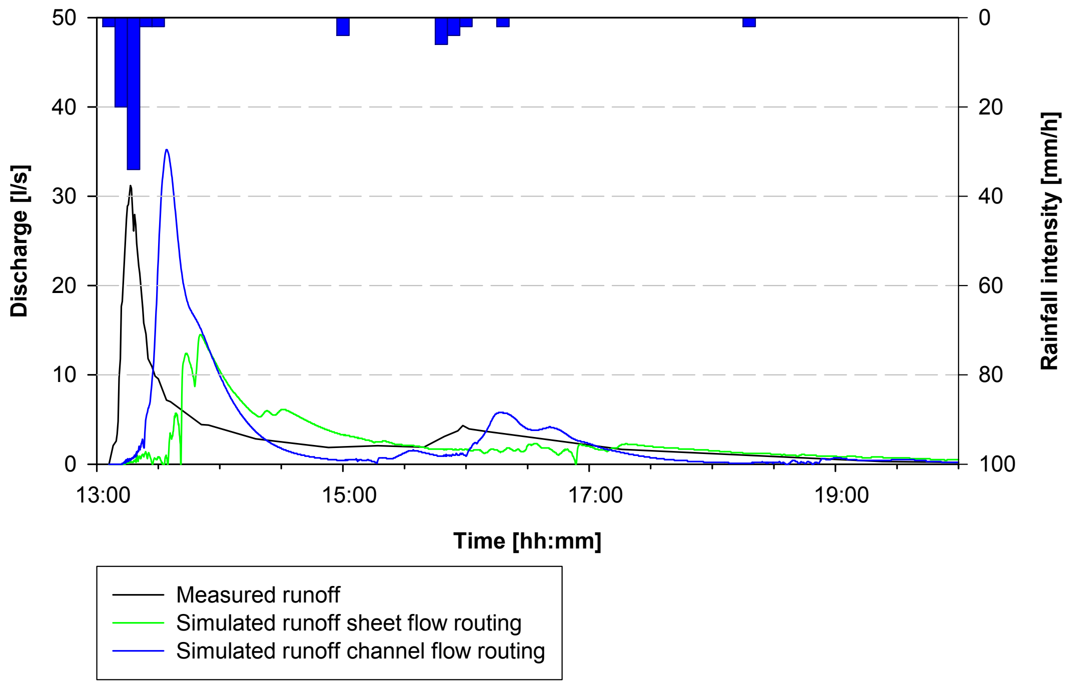

Fig. 6-1 : Model results of the event on the 5th May 2005

Table 6-1: Comparison of the modelled and measured hydrograph

	peak runoff [l/s]	time of peak [hh:mm]	runoff volume [m^3]
channel flow	35.2	13:34	74.7
sheet flow	14.5	13:50	66.5
measured	31.2	13:16	72.3

6.1.2 *Event on the 12th July 2005*

Just like on the 5th May 2005, the runoff event is characterised by a short and intense rainfall interval. The rain spell, which lasts only 24 minutes and exceeds a maximum rainfall intensity of 26 mm/h, leads to a fast rising hydrograph too. During this short and intense rainfall event 5.2 mm rainfall are reaching the catchment surface. Although the rainfall intensity is high, no runoff from the wine-growing area is assumed, as the duration of the event is very short. The simulated hydrograph, routed with the channel flow equation, shows a good alignment with the measured hydrograph as the simulated peak discharge is only 1 % higher than the measured one. But the rise and the decrease of the simulated hydrograph are not steep enough and the simulated runoff volume is 15.9 % overestimated. 4 minutes after the maximum rainfall intensity, the simulated peak discharge reaches its maximum which is 9 minutes later compared to the measured peak discharge. As well as during the event on the 5th May 2005, an error in recording the time can be assumed, as the measured peak discharge occurs 5 minutes prior to the rainfall event. The broadsheet flow however does not deliver satisfying results.

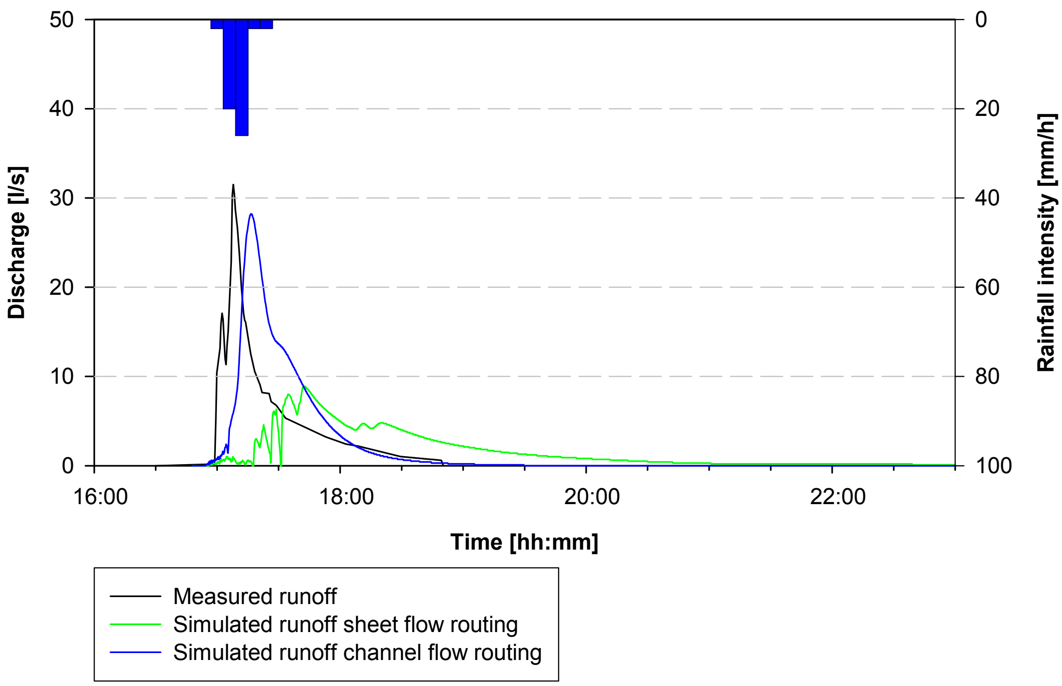

Fig. 6-2 : Model results of the event on the 12th July 2005

Table 6-2: Comparison of the modelled and measured hydrograph

	peak runoff [l/s]	time of peak [hh:mm]	runoff volume [m³]
channel flow	28.2	17:16	44.8
sheet flow	8.9	17:42	36.7
measured	31.5	17:07	37.6

6.1.3 Second Event on the 1st October 2005

Unlike the events described before, the rainfall intensity on the 1st October 2005 shows little variation with a low rainfall intensity which is typical for steady rain. The rainfall event lasts over a period of 3:12 hours with maximum rainfall intensities of 6 mm/h. Although the rainfall intensity is very low, the measured hydrograph shows a rather steep rise and reaches its maximum 19 minutes after the maximum rainfall intensity. Due to the very low rainfall intensity it can be assumed that no runoff is generated by the wine-growing region and thus only the roads are regarded as runoff contributing.

Although the ZIN-Model has been developed to simulate high intensity events (LANGE 1999), the modelled hydrograph using the channel flow equations matches the rise and decrease of the measured hydrograph quite well. The peak however is not reproduced by the model and the simulated hydrograph reaches a maximum and stays constant for almost an hour, until it decreases again. This can be explained by the fact, that another rainfall event with a rainfall volume of 6.2 mm and a low rainfall intensity of 8 mm/h has occurred before, on the same day. Thus a very high saturation of the catchment surface can be assumed and no initial loss takes place at all which has not been taken into consideration for modelling. The missing initial loss could also explain the under estimation of the measured total runoff volume. Just like during the other events, the broad sheet flow equation does not show satisfying results. Even during this low intensity rainfall event, the rise and the decrease of the simulated hydrograph is too slow.

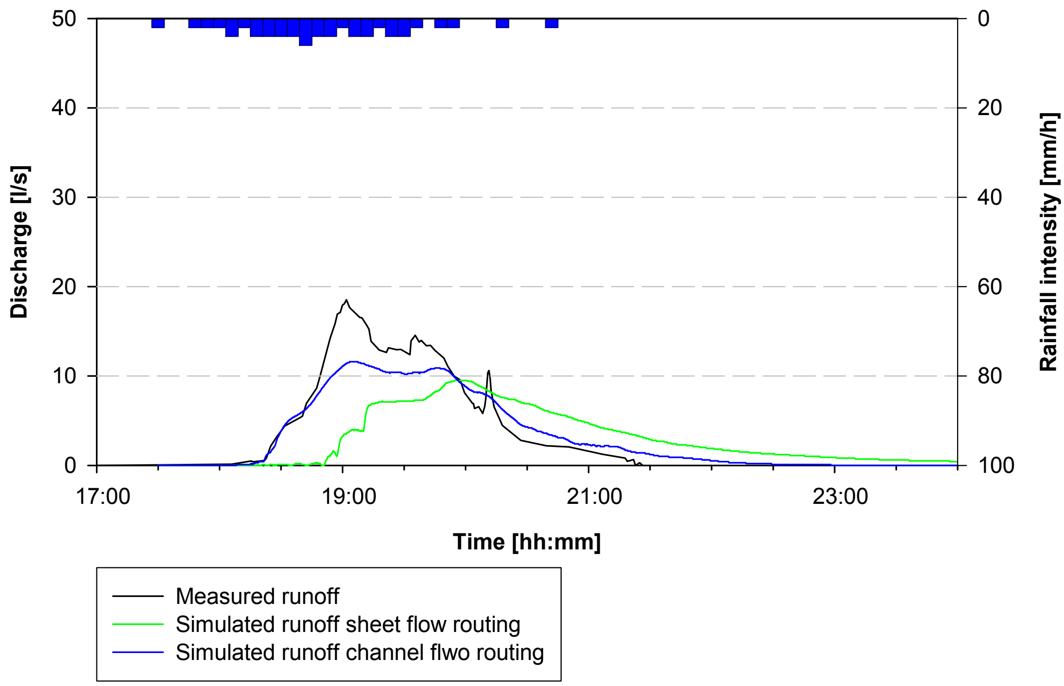

Fig. 6-3: Model results of the event on the 1st October 2005

Table 6-3: Comparison of the modelled and measured hydrograph

	peak runoff [l/s]	time of peak [hh:mm]	runoff volume [m^3]
channel flow	11.6	19:04	76.1
sheet flow	9.5	19:57	71.6
measured	18.5	19:01	81.9

6.1.4 Event on the 24th August 2004

The event on the 24th August 2004 is characterised by two extraordinary high rainfall spells with a total rainfall amount of 25.6 mm. The total rainfall duration of both peaks and in between lasts about 10 hours. During the first rainfall spell, a maximum rainfall intensity of 26 mm/h is yielded and after 1:42 hours the second rainfall spell yields a maximum rainfall intensity of 18 mm/h. The double peak rainfall event leads to a double peak runoff event too. Compared to the first maximum rainfall intensity, the first peak discharge is delayed by 7 minutes, whereas the second peak by 12 minutes. The rise of both peaks is very steep accounting for the high rainfall intensity and the high rainfall amount. In between the two discharge peaks, the runoff is continuous and decreasing with time until the second discharge peak is rising. The second discharge peak is characterised by fluctuations and a lower decline than during the first peak.

Because of the short time lag between the two rain intervals, the model is run for all rain spells together. Using the channel routing equation, the continuous character of the flow can not be reconstructed and the model simulated two distinct peaks. Although the steep increase of the hydrographs is reproduced correctly, the steepness of the decrease of the first peak discharge is not simulated well. The simulated peaks however show only a short time lag of 5 to 6 minutes compared to the measured ones. The peak discharge of the second event however is overestimated by 7.4 % which is higher than during the first peak. The decline of the peak discharge is better simulated during the first peak, although towards the end the simulated one decreases too rapidly.

The method applying the broad sheet flood routing shows quite good simulation results too. The steepness of the peak discharges and their height is not as good reconstructed as with the channel flow equation. But using the broad sheet flood routing there are not two separate peak discharges and continuous runoff is simulated like it is measured. Furthermore the hydrograph decreases very slowly and the runoff event lasts longer as with the channel flood routing equation.

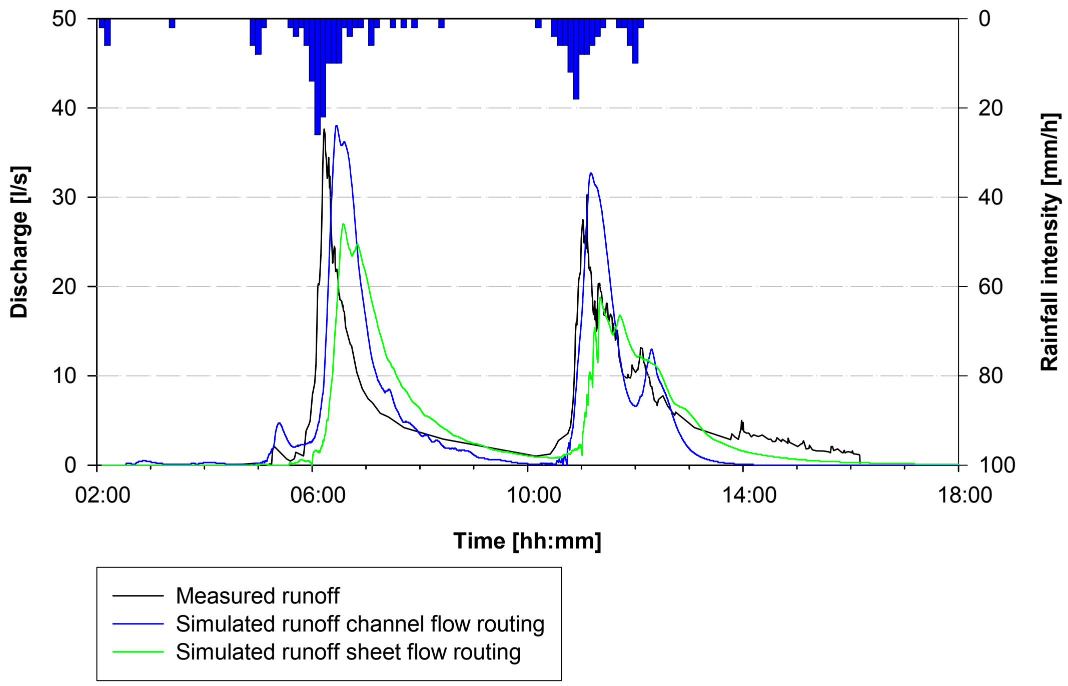

Fig. 6-4: **Model results of the event on the 24th August 2005**

Table 6-4: **Comparison of the modelled and measured hydrograph**

	peak I		peak II		
	peak runoff [l/s]	time of peak [hh:mm]	peak runoff [l/s]	time of peak [hh:mm]	runoff volume [m³]
channel flow	38.0	06:27	32.7	11:11	237.7
sheet flow	41.3	06:33	26.6	11:19	223.5
measured	37.6	06:13	30.3	11:06	240.2

6.1.5 Second Event on the 23th May 2005

The event on the 23th May 2005 shows various rainfall events with medium to high rainfall intensities ranging from 6 to 31 mm/h. The different rain spells have two breaks in between ranging from 1:12 hours to 1:54 hours and the total rainfall volume is 7.8 mm. These three events occur within a time span of 5:42 hours and each of these rain intervals leads to a formation of a peak discharge. The first runoff peak follows the rainfall peak after 7 minutes, the second peak after 3 minutes and the third peak after 12 minutes. The rise of the main peak is very steep. Because of the low rainfall volume of the first peak, the runoff between the first and the second peak is not continuous. Between the second and the third peak however, runoff takes place. Although the maximum rainfall intensity of the first rainfall event is very low, it leads to a detection of runoff which can be explained by the soil moisture originating from an event of the same day. This precedent event with a total rainfall amount of 8.8 mm and a maximum rainfall intensity of only 4 mm/h had ended about 9 hours before the second event has commenced. Because of the high maximum rainfall intensity and the moisture of the soil, runoff from the wine-growing region was considered in the runoff generation.

Just like the measured hydrograph, the three rainfall spells lead to three simulated runoff discharges, using the channel flow equation. The simulated peaks of the hydrographs are delayed however, compared to the measured ones. The simulated main peak discharge for example is delayed by 13 minutes. Although the main peak discharge is overestimated by 21.7 %, the simulated runoff volume is only 8.9 % less than the measured runoff volume. The steepness and the overall form of the hydrograph are represented correctly. In contrast to the measured hydrograph, the model simulates continuous runoff between the first and the second peak and no continuous runoff between the second and the third peak. Apart from this, the decrease of the peaks is simulated in a better way than during the other events and the end of the simulated hydrograph coincides well with the measured one. Using the broad sheet flood routing, the first peak does not get simulated and the second peak discharge is decreasing too slowly. But unlike the channel routing, runoff takes place between the two last peaks.

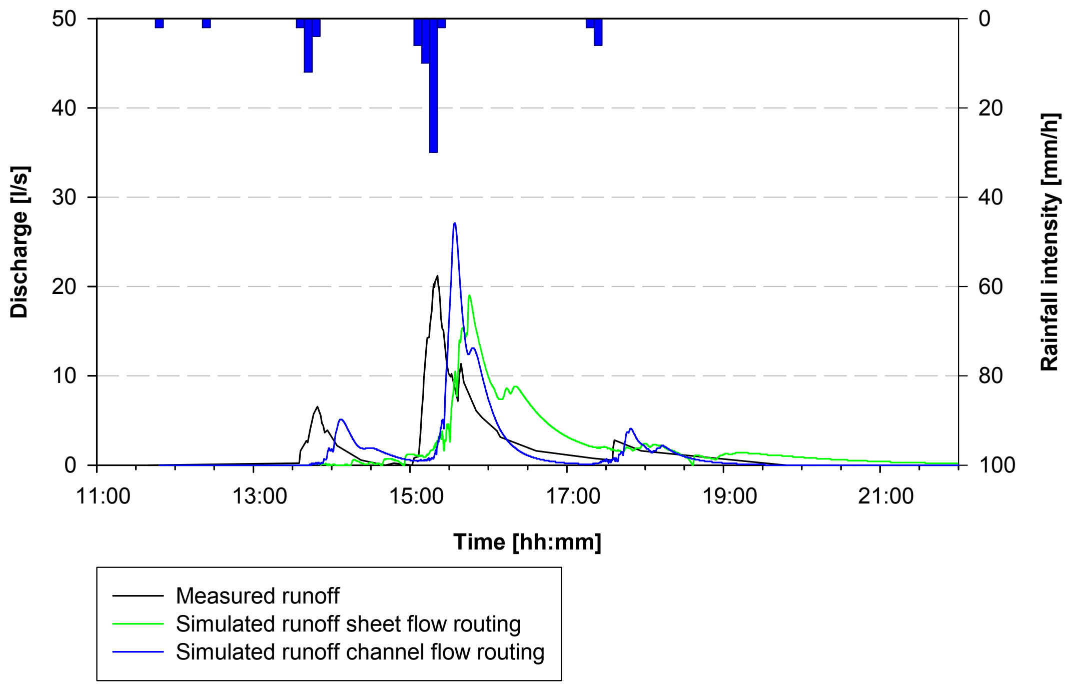

Fig. 6-5: Model results of the event on the 23th May 2005

Table 6-5: Comparison of the modelled and measured hydrograph

	peak runoff [l/s]	time of peak [hh:mm]	runoff volume [m^3]
channel flow	27.1	15:34	55.4
sheet flow	19.0	15:45	72.1
measured	21.2	15:21	60.9

6.1.6 Event on the 18th August 2004

The 18th August is characterised by a small rainfall event with a total rainfall amount of 3.8 mm and low mean rainfall intensities of 3 mm/h. The rain spell with a maximum rainfall intensity exceeding 12 mm/h has been measured over a period of 1:42 hours. The maximum rain intensity leads to an increase of the measured hydrograph and to a discharge peak after 22 minutes. The measured hydrograph shows a medium rise due to precedent rain prior to the onset of runoff and a slow recession. The low rainfall intensity as well as the short duration of the rainfall event are not leading to runoff originating from the whine-growing area however.

Applying the channel routing equation for simulating this event seems to reproduce the shape of the measured hydrograph quite well, although the runoff volume is overestimated by 26.43 % and the simulated rise of the peak is less steep. In addition to this the modelled peak is delayed by 9 minutes and also 9.7 % higher compared to the measured peak. The steepness of the simulated recession is reproduced quite well, although the simulated event lasts longer which is due to the delay of the peak discharge. The simulated hydrograph obtained by the sheet flow however, leads to a poorer reproduction of the measured hydrograph. The simulated peak is even more delayed and the runoff event lasts too long.

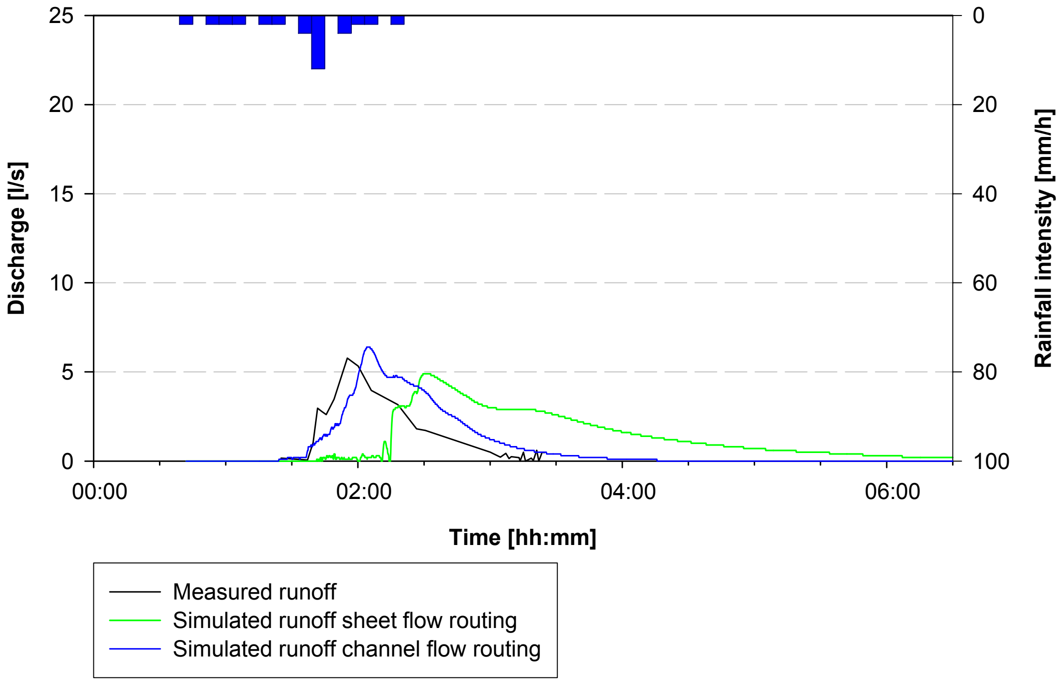

Fig. 6-6: **Model results of the event on the 18th August 2004**

Table 6-6: **Comparison of the modelled and measured hydrograph**

	peak runoff [l/s]	time of peak [hh:mm]	runoff volume [m^3]
channel flow	6.4	02:04	18.1
sheet flow	5.0	02:35	25.8
measured	5.8	01:55	13.3

6.1.7 *First Event on the 4th October 2005*

The first event on the 4th October 2005 shows a rainfall event with very low intensities of maximal 4 mm/h and yields a rainfall amount of 5.2 mm. The rainfall interval is broken up by a 24 minutes rainless break which leads to two separate peaks of runoff. As the break is very short however, the runoff measured during the rainless period is continuous and does not fall below 1.2 l/s. The two spells of rainfall lead to quite low runoff events with a maximum peak discharge of 2.9 and 3.4 l/s respectively. Although the rainfall intensity is very low, the first peak discharge increases very abruptly. The two peaks are delayed by 20 minutes and 15 minutes, compared to the maximal rainfall intensities during each rain spell. As this event is representing a very small runoff event with low rainfall intensities, it can be said that the rain falling on the wine-growing area and the orchard is lost by infiltration and interception and no runoff reaches the roads.

As is shown in Figure 6-7, the simulated hydrograph matches the measured one surprisingly well. The steep increase of the first event, as well as the shape of the second event are reproduced quite well. The whole simulated hydrograph derived by the channel flood routing, seems to be delayed about 10 minutes. The height of the peak discharge however, does only differ 2.7 % and 1 % respectively and the runoff volume is overestimated by 7.9 %. Not like the appliance of the channel flood routing equation, using the sheet flow equation is not capable of reproducing the two separate peaks and the quick and steep rise of the first peak discharge. Furthermore the second peak lasts too long and is too small.

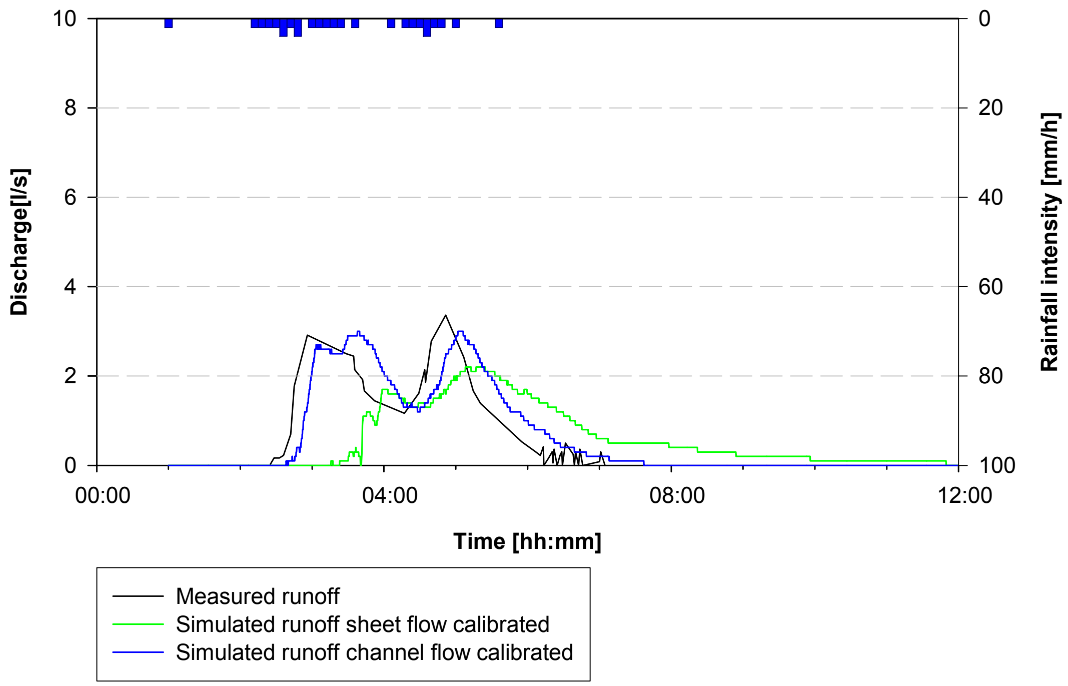

Fig. 6-7: Model results of the first event on the 4th October 2005

Table 6-7: Comparison of the modelled and measured hydrograph

	peak I		peak II		
	peak runoff [l/s]	time of peak [hh:mm]	peak runoff [l/s]	time of peak [hh:mm]	runoff volume [m^3]
channel flow	3.0	03:38	3.0	05:01	25.7
sheet flow	1.7	04:00	2.2	05:20	22.5
measured	2.9	02:56	3.4	04:51	23.7

6.2 Delineation of source areas

During the previous modelling the whole catchment was regarded as runoff contributing. Except for the low intensity events, where the wine-growing areas and the orchards do not generate runoff. In order to determine the hydrological behaviour of different source areas and the amount of runoff generated, the different land coverages are grouped into three units with similar hydrologic behaviour: the wine-cultivation areas and the orchards, the roads covered by grass or soil and the roads covered by pebbles or concrete. For some events two or three different model runs are carried out during which only one of the following source areas is runoff contributing:

- wine and orchard
- roads concrete, gravel and fosse
- roads grass, soil or mixed

The flood routing is conducted using the channel flow equations as they have already proved to lead to better results. In applying the model, the percentage of runoff generated on each source area can be determined, as well as the onset of runoff originating from each source area. In the following, the outcome of the source area modelling is presented for different rainfall types. Strong intensity rainfall events with single or multiple peaks, as well as low intensity rainfall events with low runoff volumes at the outlet of the catchment are regarded. First of all, the outcome of the high intensity rainfall events is presented in Figures 6-8 to 6-10 where a varying amount of runoff water comes from the wine-growing region too, depending on the chosen runoff coefficient and the initial loss. Subsequently the simulations of the low rainfall events are shown in Figure 6-11 and 6-12 where runoff is only generated by the roads. During both rainfall patterns, only the most representative events were chosen for showing the results.

6.2.1 High intensity rainfall events

During the event on the 29th June 2005, extraordinary high rainfall intensities occur with up to 78 mm/h leading to a very fast rising peak. As can be seen in Figure 6-8, most of the runoff is coming from the concrete roads. It is also shown that the runoff from the concrete roads is mostly responsible for the timing of the peak and for the short time lag. During this event a high runoff amount originating from the wine-growing area and the orchards is generated as well, although a quite low runoff coefficient of 1.41 % and an initial loss of 5.85 mm have been chosen. Because of the huge rainfall amount, the initial loss is filled up very quickly and the rise of the hydrograph coming from the wine is quite steep tool. It is remarkable however, that the low runoff coefficient of 1.41 % leads to a total runoff volume coming from the wine-growing area of 37%.

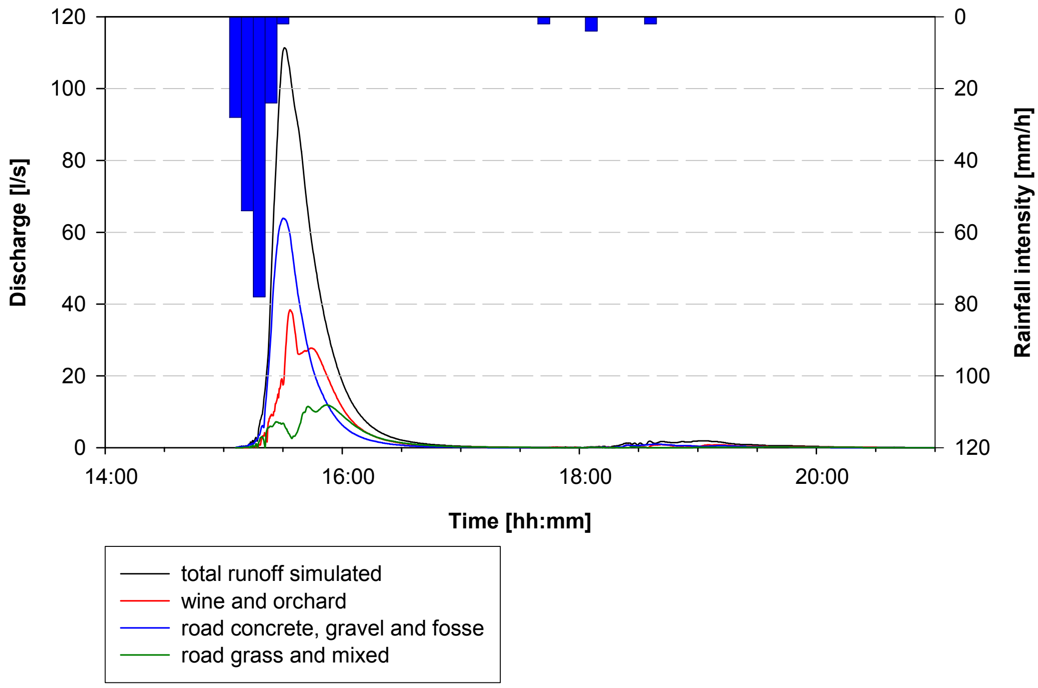

Fig. 6-8: Different source areas on the 29th June 2005

To summarize the behaviour of the catchment during high rainfall intensities which generate one peak discharge the following values have been derived:

Table 6-8: Different source areas and their percentage of the total runoff volume during strong intensity rainfall events with a single peak

	range of percentages of the total runoff volume [%]	mean percentage of total runoff volume [%]
wine and orchard	37.0 - 53.8	43.3
road concrete and gravel	37.0 - 49.3	44.0
road grass and mixed	12.8 - 17.2	15.3

The event on the 24th August 2004 which has been discussed previously in chapter 6.1.4, shows two maximum rainfall intensities which are simulated by the model as two separate discharge peaks. As can be seen in Figure 6-9, the runoff water coming from the wine-growing area is delayed during the first peak and achieves its maximum after the maximum of the hydrograph of the concrete roads which is responsible for the steep rise of the total hydrograph. Just like during the event on the 29th June 2005, a low runoff coefficient of 1.35 % and an initial loss of 7.38 mm are leading to a rather high portion of 28.1 % of runoff from the wine-growing area. The runoff coefficient and the initial loss have been chosen to take into account the dry weather condition prior the onset of this event. As can be shown as well, the runoff coming from the wine and orchard is most postponed during the first peak discharge. During the second peak however, the saturation of the soil leads to a fast reaction of the wine-growing region as well and the maximum discharge arrives at the outlet almost as fast as the water of the concrete roads. The roads covered by grass contribute the smallest portion of runoff and react more slowly than the wine-growing area. The concrete roads however are most strongly influenced by an increased rainfall intensity.

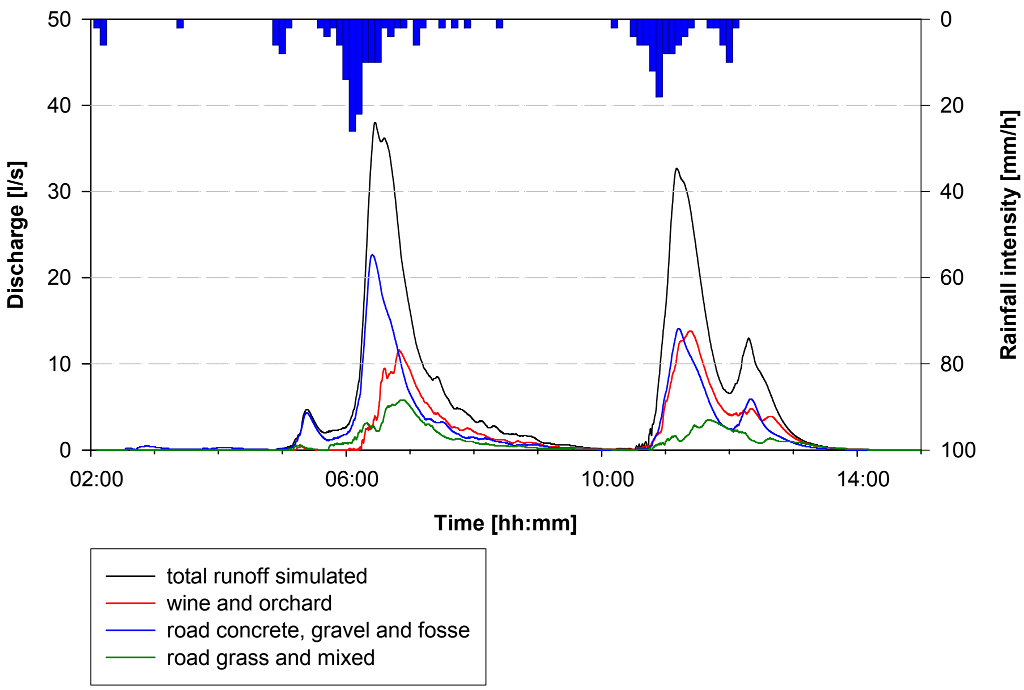

Fig. 6-9: Different source areas on the 24th August 2004

The following table summarizes the minimum, maximum and mean percentages of runoff from the different source areas. These values have been derived for high rainfall intensity events, generating multiple peaks.

Table 6-9: Different source areas and their percentage of the total runoff volume during strong intensity rainfall events with multiple peaks

	range of percentages of the total runoff volume [%]	mean percentage of total runoff volume [%]
wine and orchard	04.3 - 38.1	24.5
road concrete and gravel	46.5 - 68.8	75.2
road grass and mixed	16.6 - 27.5	20.3

In order to discuss the influence of precedent rainfall on the runoff volume originating from the different source areas, the event of the 4th October 2005 is shown in Figure 6-10. Before the main peak commences a rainfall volume of 12.6 mm is yielded. The first rise is due to the runoff generated on the concrete roads, like during the other events as well. At the beginning, there is no runoff generated by the wine-growing region and the orchards. The water takes two hours until it reaches the outlet of the catchment. The water coming from the roads covered by grass however, reaches the outlet one hour before. The time lag of the onset of runoff originating from the wine-growing area and from the roads covered by grass, characterize the time when the storage capacity described by the parameter initial loss is used up.
The increase of the main peak is characterized by a strong increase of the roads and wine hydrographs however, as the soil moisture has increased due to the precedent rainfall. The water coming from the roads covered by grass and mixed coverage are not influenced very strongly by precedent rainfall and the fluctuations of rainfall intensity.

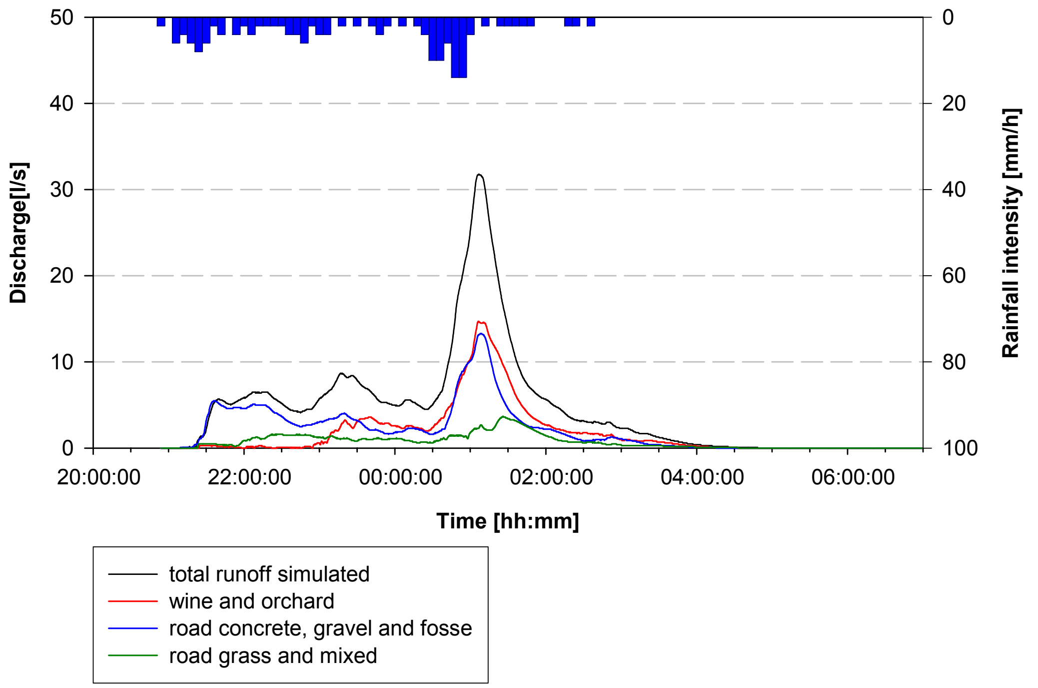

Fig. 6-10: Different source areas of the second event on the 4th October 2005

6.2.2 *Low rainfall intensity events*

The following events represent rainfall events with a quite homogeneous pattern and a low rainfall intensity during which no very distinct peak discharge is generated unlike during the events with high rainfall intensities. No runoff from the wine-growing region has been assumed however. Figure 6-11 shows that like during strong rainfall events, the concrete roads are responsible for the onset and the steep rise of the overall hydrograph. As no runoff from the wine-growing region is generated, relatively more runoff is originating from the roads covered by grass. The hydrograph representing the runoff water of the roads covered by grass is rising slower and its peak is delayed and lower than that of the concrete roads. Table 6-11 gives an overview about the minimum, maximum and mean percentages of the two source areas of the total runoff volume.

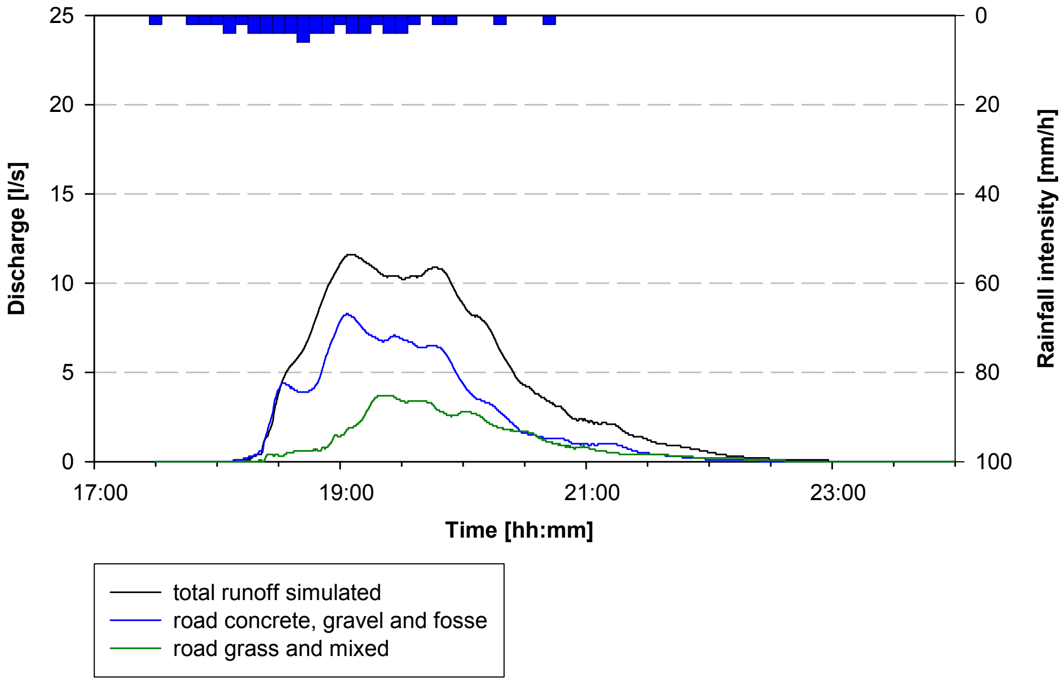

Fig. 6-11: Different source areas on the second event of the 1st October 2005

Table 6-11: Different source areas and their percentage of the total runoff volume during low homogeneous rainfall events with a low rainfall intensity

	range of percentages of the total runoff volume [%]	mean percentage of total runoff volume [%]
road concrete and gravel	58.0 - 76.2	71.1
road grass and mixed	22.7 - 26.4	25.3

Figure 6-12 shows a further low rainfall event. This event however leads to one peak discharge unlike the event on the 4th October 2005. During this event almost all the water originates from the concrete roads. As the rainfall event is very short and the intensity low, it takes some time until water coming from the roads covered by grass arrives at the outlet of the catchment due to its higher initial loss.

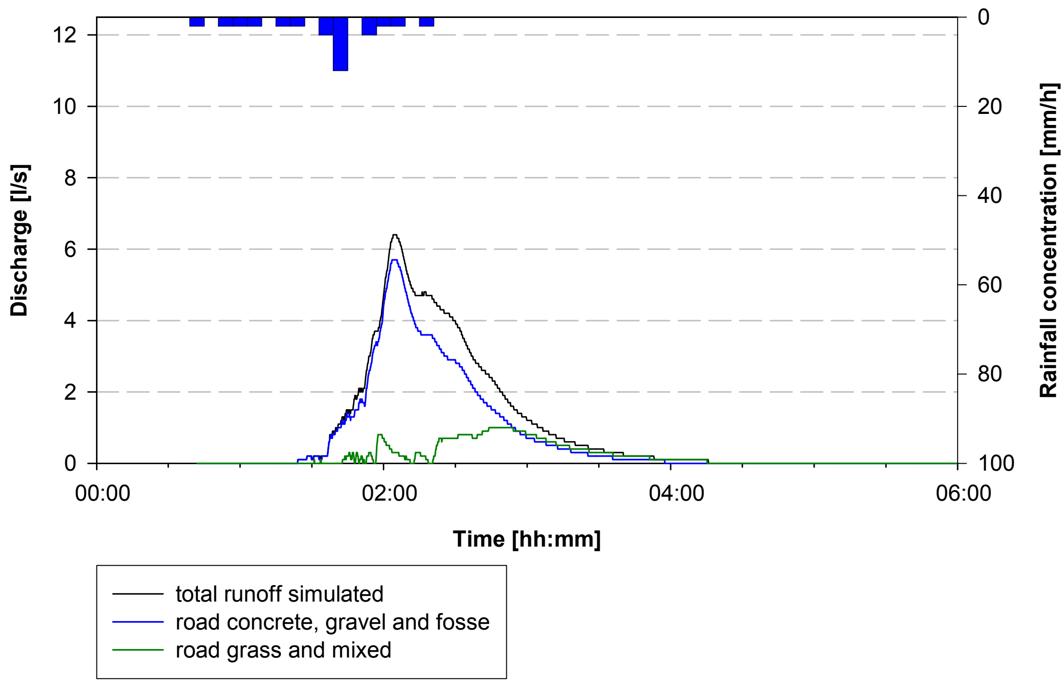

Fig. 6-12: Different source areas on the 18th August 2004

Table 6-12: Different source areas and their percentage of the total runoff volume during little varying rainfall events with a low rainfall intensity

	range of percentages of the total runoff volume [%]	mean percentage of total runoff volume [%]
road concrete and gravel	71.4 - 76.8	75.0
road grass and mixed	17.0 - 27.6	22.0

6.3 Pesticide transport modelling

6.3.1 Second event on the 11th June 2004

The measured Glyphosate concentration shows a quite homogeneous pattern as shown in Figure 6-13. As soon as runoff is recorded at the outlet of the catchment, Glyphosate concentration is detected as well. At the beginning of the rise of the hydrograph, the Glyphosate concentration increases up to 10 µg/l and decreases again as the hydrograph increases further. As shown in chapter 6.2 the concrete roads are responsible for the steep rise of the peak discharge and runoff from the wine-growing area is rather delayed. During this event however, the runoff originating from the wine-growing area is not delayed significantly. This is due to the increased soil moisture because another rainfall event has occurred prior to this. Towards the end, the Glyphosate concentration is increasing again, taking into account the decreasing amount of runoff from the roads which leads to a smaller dilution effect.

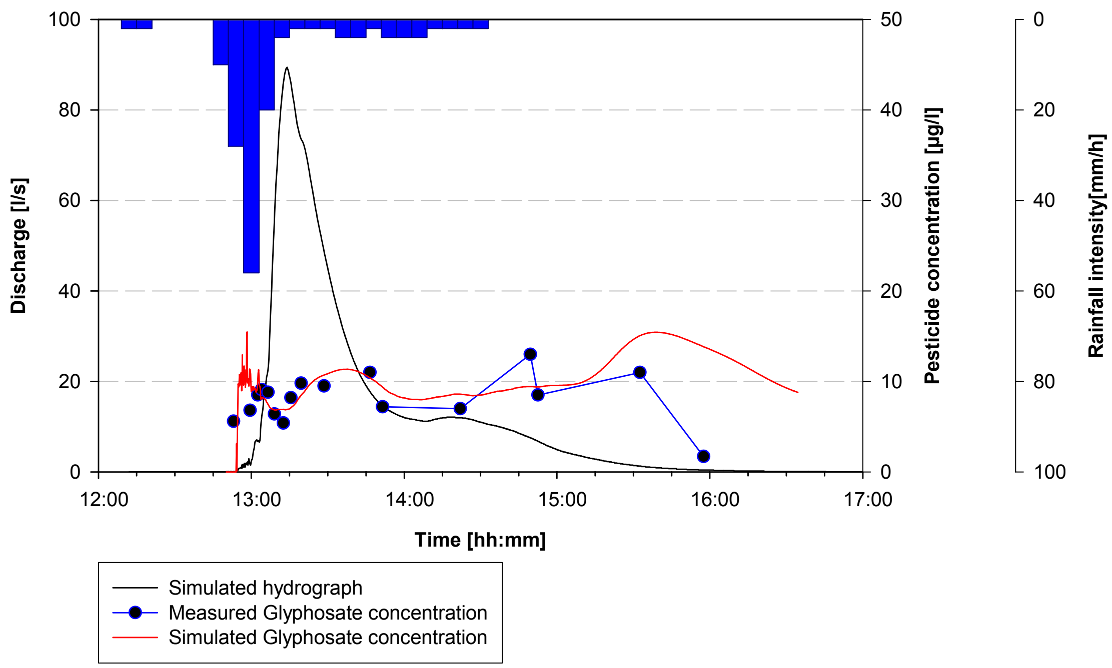

Fig. 6-13: Modelled and measured Glyphosate concentration on the 11th June 2004

The simulated Glyphosate concentration curve is characterised by a detection of the Glyphosate concentration right from the beginning as well. The decrease of the concentration due to the dilution effect of the roads is reproduced correctly as well as the next increase of the Glyphosate concentration which could be due to a higher percentage of runoff water originating from the wine-growing region. During this event a rather high proportion of 54 % of the runoff water is generated by the wine-growing area, leading to a maximal pesticide concentration of 13 µg/l.

Similar to the measurements of the Glyphosate concentrations, the Diuron concentration is detected in first sample of runoff as shown in Figure 6-14. During the peak discharge the concentrations are rather low, varying between 0.2 and 0.4 µg/l. As soon as lower runoff volumes are measured, the Diuron concentration increases with maximum values exceeding 2 µg/l. The increase towards the end can be explained by a smaller dilution effect, as the roads are only contributing a little of the runoff volume. But it can also be explained by lower flow velocities which could lead to a higher wash out rate of the Diuron on the roads.

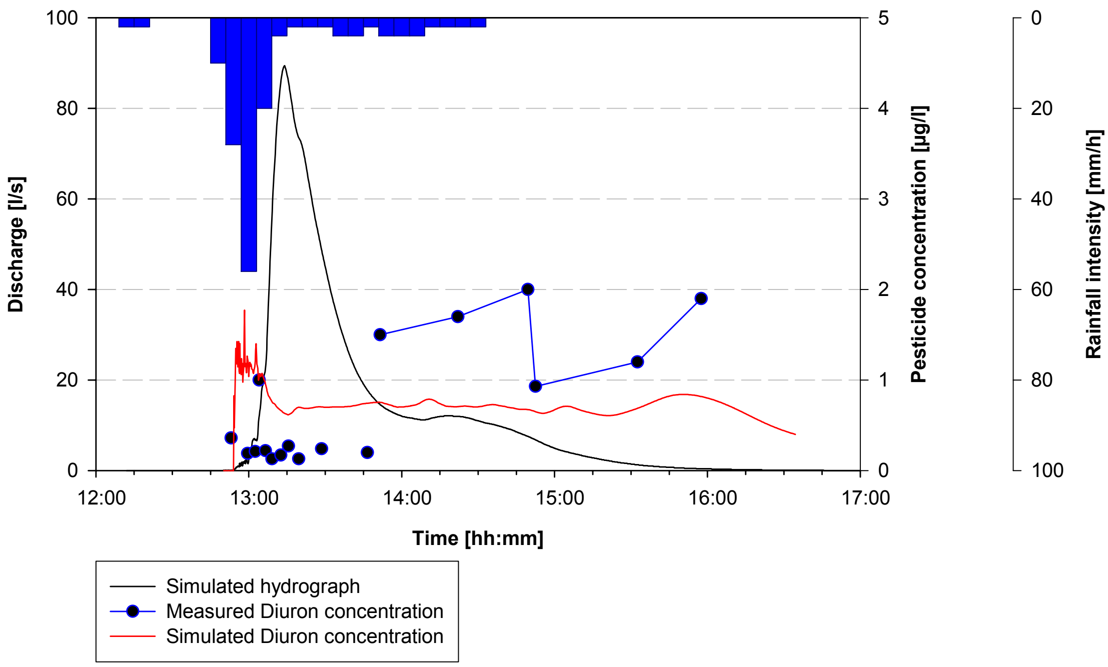

Fig. 6-14: Modelled and measured Diuron concentration on the 11th June 2004

The modelled Diuron concentration curve however, does not reproduce the measured Diuron fluctuations. The simulated Diuron concentrations do not account for the strong dilution effect of the roads, although a Diuron concentration of 2 µg/l has been measured before the onset of the peak discharge. Model uncertainties can be due to the very low Diuron concentration and as the model assumes the pesticide concentration to be directly proportional to the runoff, differences of the Diuron concentrations cannot be reproduced correctly.

6.3.2 Event 24th August 2004

Unlike during the event on the 11th June 2005, the Glyphosate concentration is proportional to the runoff volume of the first peak discharge as it is shown in Figure 6-15. With increasing discharge the Glyphosate concentration increases as well, exceeding a concentration of 22 µg/l. Just before the second rainfall spell commences very high Glyphosate concentrations area measured again. The correlation between the runoff amount and the Glyphosate concentration can only be explained the roads delivering pesticides as well. This is possible however, because a certain amount of pesticides of former events can be stored on roads as they are only poorly adsorbed on impermeable surfaces (RAMWELL et al. 2002). The rainfall event on the 24th August occurs after a dry period. And so it is possible that there is still Glyphosate on the roads as no precedent rainfall has washed it away. The second hydrograph however, leads to a decrease of the pesticide concentration due to the dilution effect of the roads. This is possible because of the poor adsorptive properties of the roads so that the Glyphosate is washed away quickly and only the runoff water of the wine-growing area does still transport Glyphosate molecules. The high Glyphosate concentration in between the two peak discharges is due to the very low runoff volume which has been measured during the two events and thus a very low dilution effect. It can be considered that during these two events all the runoff is coming from the wine-growing area which provides the highest Glyphosate concentrations.

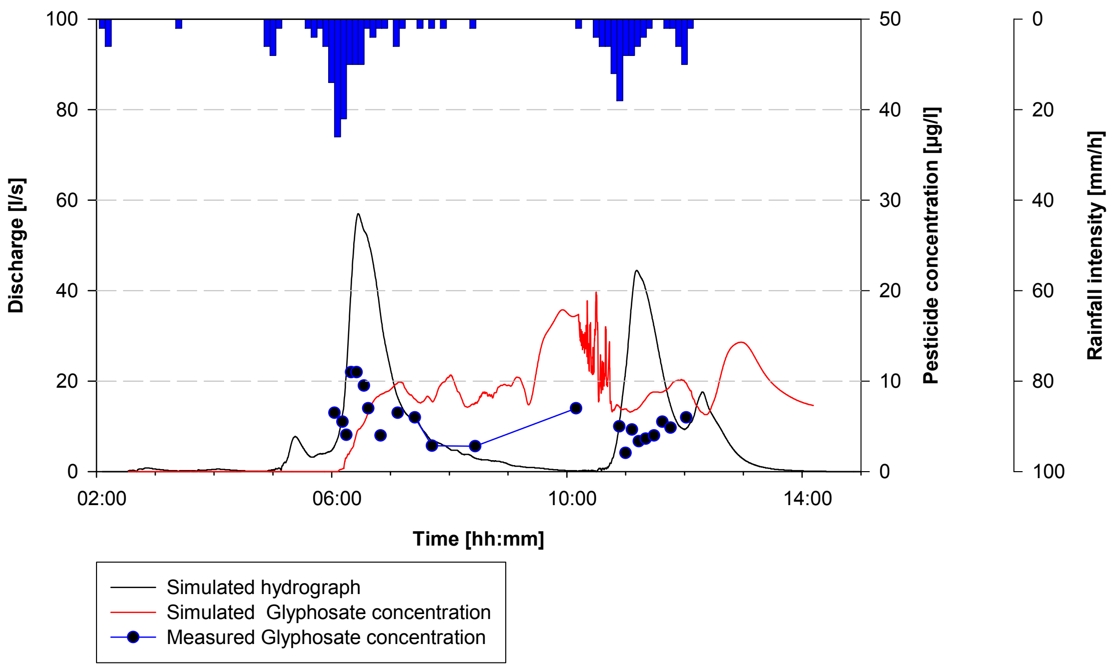

Fig. 6-8: Modelled and measured Glyphosate concentration on the 24th August 2004

Figure 6-16 however shows, that the simulated Glyphosate concentration does not increase during the first runoff peak like the measured one. This is because the model assumes only the wine-growing region as "pesticide" contributing. The Glyphosate concentration between the two runoff peaks increases however, taking into account the small runoff volume and thus the little dilution effect. As the second peak discharge begins to increase, the simulated Glyphosate concentration decreases as well like the measured one accounting for a stronger dilution effect of the runoff water from the roads. The increase of Glyphosate during the end may be explained by a very faint dilution effect as the runoff volume is decreasing.

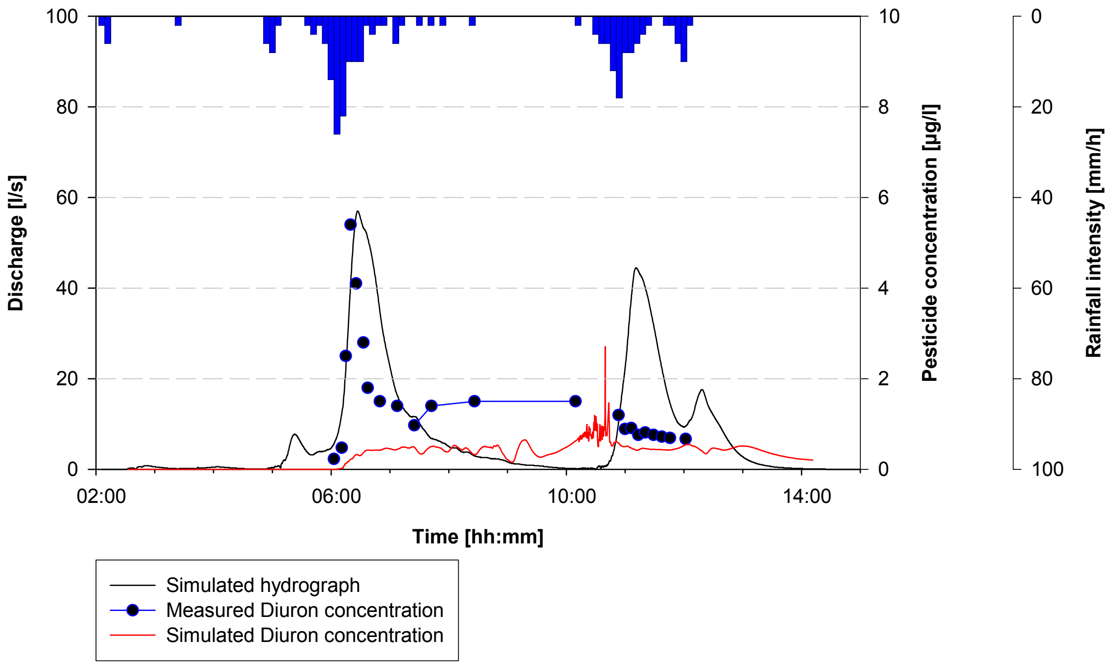

Fig. 6-9: **Modelled and measured Diuron concentration on the 24th August 2004**

Compared to the Glyphosate concentration measurements, the Diuron concentration is increasing even stronger at the beginning of the peak discharge and exceeds a maximum value of 5.8 µg/l. This can be explained by the fact, that the Diuron is more mobile than the Glyphosate (see chapter 2.2.2) and so a relatively higher amount of Diuron is washed off from the roads with the same rainfall amount. As the model does not consider the leftover amount of Diuron and the fast mobilisation on the roads, the simulated concentration is much too low.

6.4 Conclusion

Because of the strong variation of rainfall events, it is not possible to use the same runoff coefficient during all events. In order to maintain the physical basis of the model, only the runoff coefficient of the roads.is changed in a manner that it is still in the range of these observed in the field. The runoff coefficient for the wine is calculated for each event separately based on measurements at the experimental plots. During rainfall events with low rainfall intensities however, no runoff from the wine growing region is assumed. The simulated events are grouped depending on their rainfall behaviour and each event is routed by a second technique too. The simulation results are representing the measured hydrographs quite well especially during high intensity rainfall events.

Three different source areas are delineated and the percentage of generated runoff of each source area is calculated. The simulated events are divided into groups of high and low intensity rainfall events. Concrete roads make out most of the runoff volume and are responsible for the steep rise of the hydrograph. The percentage of the wine-growing area is variable as different runoff generation parameters are determined for each event. Furthermore the wine-growing area does not contribute runoff during low intensity rainfall events. Especially the runoff behaviour of the concrete roads is strongly influenced by the rainfall intensity. During high intensity rainfall events however, relatively more runoff is originating from the wine-growing region.

The pesticide transport model is applied for two events on the 24th August 2004 and the 11th June 2005. The simulated pesticide concentrations show reasonable good results, especially for the Glyphosate concentration. Pesticide input is applied on the wine-growing area only, not taking into account a possible leftover of herbicides on the roads. The event on the 11th June is characterised by a high saturation of the soil and the measured and simulated pesticide concentration reveals that the pesticide amount is mainly originating from the wine-growing area probably because a former rain event has washed away the pesticides on the roads. On the 24th August however, pesticides which have been stored on the roads are measured at the outlet of the catchment. The appliance of the pesticide model does also serve as a validation tool for the hydrological modelling.

7 Discussion

7.1 Model application

Using the sheet flow equation leads to delayed hydrographs and low peak discharges. This could be due to very fast waterways which the sheet flow procedure does not take into consideration. On the roads however, differential erosion due to shear stress leads to the filling up of some patches of roads with sediments, whereas others erode, leading to the occurrence of microchannels or rills. MOSS et al. (1982, cited in ANDERSON & BURT 1990) for example, showed in laboratory experiments that in even very idealized conditions non-uniform flow, erosion and sediment transport occurs. They observed that sheet flow over erodible plane beds is inherently unstable because of the development of secondary flows or circulation cells. In the Rouffach catchment a very high sediment load transported with the runoff and observations in the field show that very often the runoff on streets erodes the sediment and pebbles to form small channels where fast runoff occurs. This could explain the very quick response and very fast rising hydrograph of the catchment and why the assumption of flow in a channel is more beneficial and leads to better modelling results. Flow in rills which is frequently analysed as broad sheet flow, is often best described by channel flow equations (ANDERSON & BURT 1990). The simulation results show that only during very strong intensity rainfall events with a high maximum rainfall intensity, the assumption of the sheet flow leads to reasonable results. This is shown during the event on the 24th August 2004 for example, where the rainfall volume yields a total amount of 25.6 mm. As the best results during all simulated events have been achieved using the channel flood routing equation, the following discussion refers to the results derived from the channel routing equation.

As described earlier, using the same runoff coefficient for all events leads to an over- or underestimation of the runoff volume. In choosing a lower runoff coefficient, the model can be applied on most events, as only the simulated runoff volume is too high and the overall shape of the hydrograph is well simulated. During most events however, the simulated peak shows a tendency to be too late and is slightly overestimated. The concentration time and thus the time lag is dependent on the rainfall intensity as already described in Chapter 4.4. The simulated event on the 24th August 2004 for example shows almost no time lag compared to the measured peak discharge because of the high maximum rainfall intensity, whereas the time lag between low rainfall intensity events is higher. Thus it can be concluded that the time lag increases with decreasing rainfall intensity. But there are also errors in the time synchronization at the rainfall measuring gauge or at the Venturi channel as during some events runoff has been recorded prior to the onset of rainfall and peak discharges prior to the maximum rainfall intensities.

However, the delay of the time lag is rather small and the model reproduces the very fast rising time lags quite well. Furthermore, the simulated hydrograph of the 4th October 2005 shows that the event is also capable to predict low flow events due to low rainfall intensities. Multiple-peak events are simulated quite well too, although the Model is not capable of simulating low continuous runoff between two events and very often the recession of the simulated hydrograph is too steep. This is due to the fact that the model does not consider different flow velocities. The steeper rise of a second peak during the same event is reproduced quite well however, accounting for the increased soil moisture. Oscillations of the simulated hydrograph can be explained by the limitation of the Muskingum-Cunge-Technique for very steep rising limbs which can lead to these oscillations (FREAD 1993).

7.2 Source areas

The simulation of the different source areas shows that the concrete roads are the main reason for the fast rising hydrographs. The amount of water which is generated by the wine-growing area is variable, depending on the precedent rainfall amount. As the roads do not have a high storage capacity, their runoff coefficient stays more or less constant during the events. Throughout dry periods the onset of the water coming from the wine is delayed because of the high initial loss. First of all the soil of the wine-growing area has to be saturated before surface runoff takes place. This is why this runoff component reacts slower and is retarded. Because of this, the wine is also responsible for the slower recession of the hydrograph. During moist periods however the runoff coming from the wine-growing area can even start before the onset of runoff from the roads covered by grass. The onset of runoff from the different source areas is quite variable however, depending on the initial soil moisture and the rainfall intensity. The delay of the runoff water coming from the wine-growing area varies between 7 and 68 minutes and the delay of the runoff coming from the roads covered by grass varies between 2 and 45 minutes. Table 7-1 shows the percentage of runoff generated during each event and of each source area.

Sub-dividing the events into different groups depending on the rainfall characteristics, different percentages of the source areas are contributing runoff water. During convective rain events with high rainfall intensities, the wine-growing region is generating runoff as well. There seems to be a difference in runoff behaviour however, depending on the number of peaks during a strong convective rain event. The modelling results show, that the amount of the runoff water coming from the wine-growing area during a single peak event is higher than during a multiple peak event. The percentage of the runoff water coming from the roads covered by grass increases 10% during single peak events, compared to multiple peak events.

Table 7-1: Simulated runoff portion of each source area

Date	wine and orchard [%]	road concrete, gravel and fosse [%]	road grass and mixed [%]
06.04.04	-	77	17
11.06.2004 (I)	-	75	26
11.06.2004 (II)	54	37	13
18.08.2004	-	77	21
24.08.04	38	47	17
29.08.2004	-	71	28
05.05.05	4	69	27
23.05.05	27	56	18
29.06.2005	37	49	17
12.07.05	-	72	29
25.07.05	-	75	26
21.08.2005	29	57	19
01.10.2005	-	58	26
04.10.05	-	76	23
4.10.2005 (II)	39	46	16

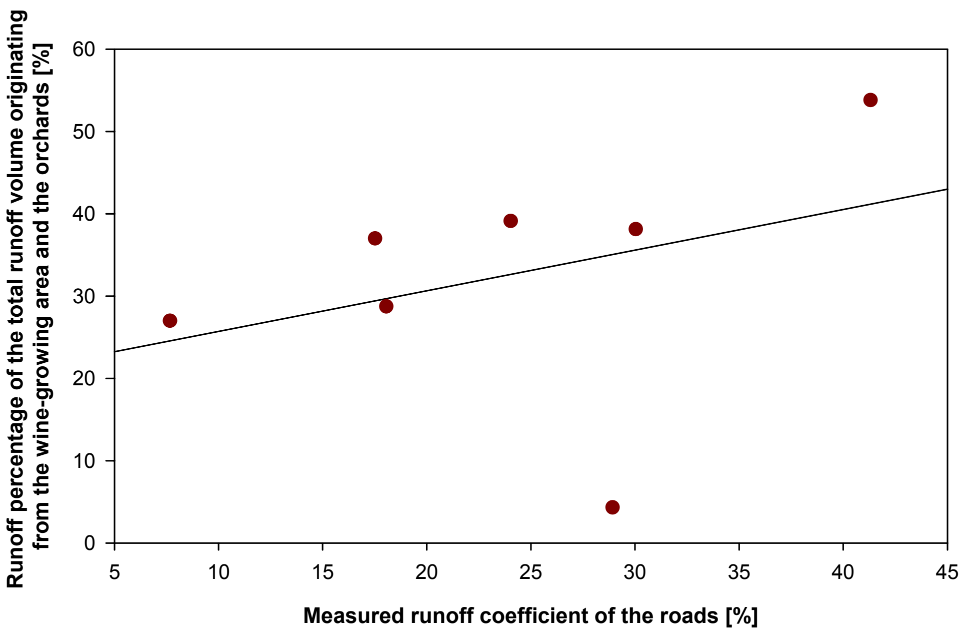

Fig.7-1: Runoff percentage generated on the wine-growing region and the orchards in dependency of the measured runoff coefficient of the Rouffach catchment

For representing different runoff portions of the source areas, they are plotted against the runoff coefficient of the roads of the Rouffach catchment as it was done in chapter 4.4 before. Figure 7-1 shows that the higher the portion of effective rainfall of the total rainfall amount, the more runoff is generated on the wine-growing area. As there is also a faint correlation of the runoff coefficient and the rainfall amount (see chapter 4.4), it can be concluded that with increasing rainfall amount, saturation of the surface takes place and more runoff is generated by the wine-growing region where Hortonian overland flow forms.

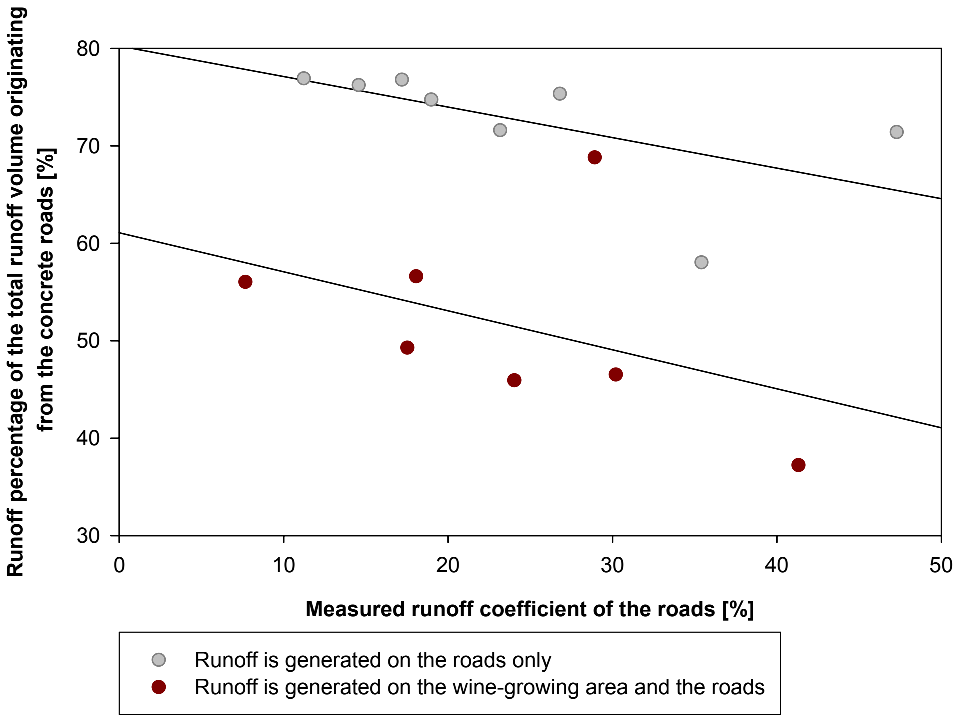

Fig.7-2: Runoff percentage generated on the concrete roads or on the roads covered by pebbles in dependency of the measured runoff coefficient of the Rouffach catchment

With increasing effective rainfall, the relative amount of runoff generated on the concrete roads is decreasing. This is due to the increased portion of runoff coming from the wine-growing region as explained before. The upper line in Figure 7-2 shows the relationship between the runoff generated on the concrete roads and the measured runoff coefficient during low intensity rainfall events, where the total runoff amount is generated on the roads only. The second line shows the same relationship but during high intensity rainfall events, where the wine-growing region does contribute to the runoff generation as well. As can be seen, low intensity events lead to a higher portion of runoff generated on the concrete roads, as the runoff originates from the roads only.

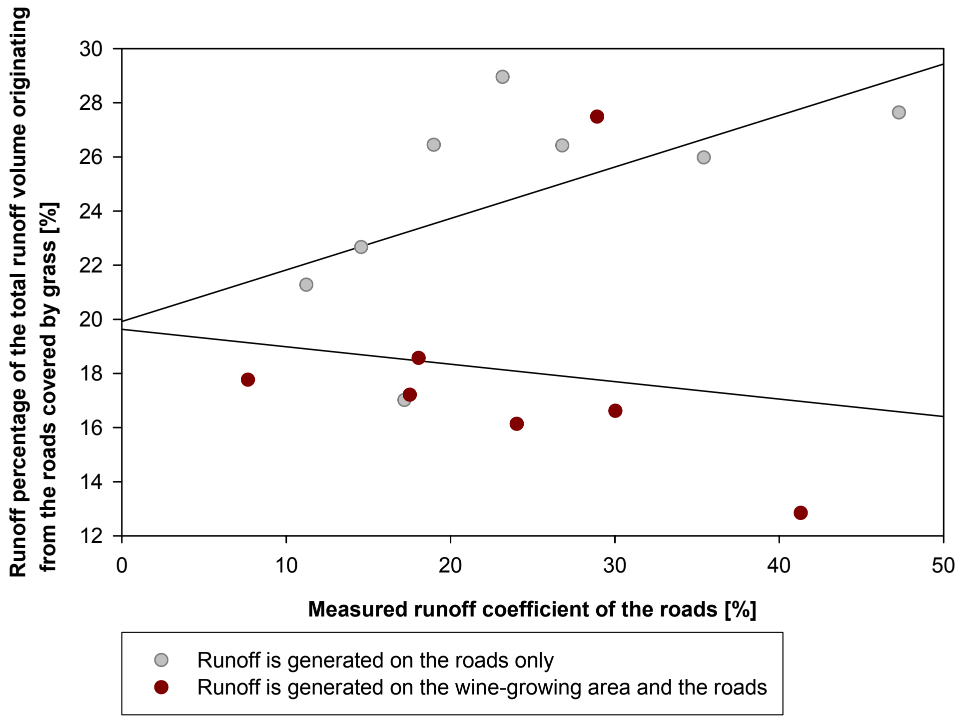

Fig.7-3: Runoff percentage generated on the roads covered by grass, soil or both, in dependency of the measured runoff coefficient of the Rouffach catchment

In Figure 7-3, it is shown that during events, where no runoff is assumed from the wine-growing area, the runoff amount originating from the roads covered by grass increases with increasing runoff coefficient of the Rouffach catchment. During events where runoff is generated by the wine-growing region too however, relatively more runoff is generated on the vines than on the green roads. To conclude it can be said that the higher the soil moisture and the higher the rainfall intensity, the more runoff is generated by the wine-growing area and even relatively more than on the roads covered by grass.

This can be seen as an assumption of natural processes only, because of the high variation of rainfall events and because there is no strong relationship between the runoff coefficient of the catchment and the rainfall intensity or the rainfall amount. It is remarkable however, that the concrete road contribute such a huge portion of runoff varying from 71 to 77 % during low rainfall events and from 37 to 57 during high intensity rainfall events although they do only cover about 10 % of the total catchment area.

7.3 Pesticide transport

The application of the pesticide transport model on the events of the 24th August 2004 and the 11th June 2005 shows the influence of precedent rainfall on the pesticide transport. The event on the 11th June however shows a pesticide concentration curve how it is expected when the pesticides are mainly coming from the wine-growing area. The former rainfall event has removed the leftover of herbicides on the roads. On the 24th August however, this effect can be seen during the second peak when the dilution effect of the roads takes place. During the first peak however, the pesticide concentration does also originate from the roads. Adsorption of pesticides on roads is rather low, as there is only very little organic and clay material. Thus pesticides stored on roads can be transferred to the outlet of the catchment in function of their persistence during later events. This is especially true for the Diuron as it is less adsorbed than the Glyphosate. The modelling results do also reveal the importance of the roads to dilute the herbicide concentration which is shown by the increase of pesticide concentration as soon as the runoff volume decreases. The higher runoff concentrations towards the end however, can also be explained by a decreasing flow velocity as the fast runoff from the roads has already gone. The measurement of herbicide concentration with the first detection of runoff leads to the conclusion that there is probably always a small leftover stored on the roads, because the runoff generated by the wine-growing region arrives delayed.

It seems that the pesticide concentration is washed away after some rainfall has reached the roads. This is shown during the second peak on the 24th August, when the herbicide concentration decreases with increasing runoff from the roads. In contrast to this, the herbicides originating from the wine-growing area do not seem to be washed out, as the concentration is still increasing towards the end. As the pesticide model assumes only pesticides applied on the wine-growing region and unlike in reality it assumes a constant concentration of pesticides during each rainfall interval, it is not capable to account for the washing out of the pesticides on the roads.

There are different actions which can be implemented in order to reduce the risk of pesticide contamination of the surface water. A lower amount applied can be achieved by adapting the date and frequency of application to the duration of the vegetative period. This is rather difficult however in a region like the region around Rouffach as there is a very high variability of meteorological factors. Apart from the quantity applied, the transport of pesticides is also influenced by various cultivating methods. One possibility to prevent the use of pesticides is to remove weeds mechanically or thermically or to plant plants which do not compete with the vines and thus do not need to be removed (RAVANEL & TISSUT 2002). The magnitude of the water flux however, governs the pesticide transport to a very high extent. With a decrease of water flux the pesticide transport can be limited as well (PANTONE et al. 1992). Furthermore, all efforts to increase the infiltration such as mulching or a denser plant cover is favourable. Mechanical weeding of the vines for example, leads to a decrease of runoff. Although this procedure can help to limit the potential of pesticide mobilisation, erosion processes can be enhanced. To leave the litter on the soil decreases the risk of erosion, leads to more infiltration and to a longer travelling time of the pesticides which is important for the retention and thus their degradation.

7.4 Mass balance

After PONCE & CHAGANTI (1994), flood routing procedures which simulate the rise of hydrographs can led to a faint loss of mass. Because of this, the model does not account for the total effective rainfall. In order to quantify this loss, the effective rainfall amount is calculated for each event, taking into account the runoff coefficient and the initial loss. The sum of these percentages is the total runoff volume. The calculated portions of runoff listed in Table 7-2 show, that there are no significant differences between calculated and modelled results. Although a loss of runoff volume due to the food routing procedure can be assumed, the simulated results are often higher. Differences in the calculated and the simulated results are due to the chosen accuracy which is especially important because of data output are integer values. The differences of the outcomes however, is still in a range that the ability of the flow routing and the model in general can be verified.

Table 7-2: Water balance of the simulated events

Date		Rainfall amount [mm]	Effective rainfall [m³] wine-growing area and orchards	concrete roads	roads covered by grass
06.04.2004	measured	4.2	-	14.0	4.0
	simulated			11.4	2.5
11.06.2004 (I)	measured	13.0	-	47.2	14.8
	simulated			55.3	19.4
11.06.2004 (II)	measured	15.8	75.8	57.7	18.3
	simulated		97.6	67.5	23.3
18.08.2004	measured	3.8	-	12.5	3.5
	simulated			13.9	3.9
24.08.2004	measured	25.6	67.3	94.7	30.4
	simulated		90.6	110.6	39.5
29.08.2004	measured	5.2	-	28.4	10.4
	simulated			31.8	12.3
05.05.2005	measured	8.0	2.4	45.3	17.3
	simulated		3.2	51.4	20.5
23.05.2005	measured	7.8	12.5	27.6	8.4
	simulated		15.0	31.0	9.8
29.06.2005	measured	19.4	51.2	71.3	22.8
	simulated		63.1	84.0	29.3
12.07.2005	measured	5.2	-	28.4	10.4
	simulated			0.0	0.0
25.07.2005	measured	18.4	-	67.6	21.5
	simulated			0.0	0.0
21.08.2005	measured	8.8	12.5	31.3	9.6
	simulated		18.0	35.4	11.6
01.10.2005	measured	6.2	-	34.4	12.9
	simulated			44.1	19.8
04.10.2005 (I)	measured	5.2	-	17.7	5.2
	simulated			19.6	5.8
04.10.2005 (II)	measured	17.6	47.9	64.5	20.5
	simulated		64.0	75.2	26.4

7.5 Comparison with the Löchernbach catchment

Like the Rouffach catchment, the Löchernbach catchment is used as a wine-growing area too. It is located at the Eastern Kaiserstuhl and comprises an area of 1.8 km^2. The climate is characterised by 716 mm rainfall per year on average, which is 16.3 % more than measured at the Rouffach catchment. Similar to the climate of the Rouffach catchment, the climate at the Löchernbach catchment can be distinguished between summer maximum rainfall events with predominantly convective events and a winter minimum. Three geomorphologic units can be distinguished: The valley with a slope of 2° to 5 ° on an altitude of about 240 m, the terraces which comprise the largest portion of the catchment areas with a slope about 5° to 25° on an altitude of 300 m and steep hills with a slope of about 35° and up to 520 m above sea level. The Rouffach catchment is not characterised by different geomorpologic units however, as it consists of various hills with an average slope of 14°. Unlike the land surface of the Rouffach catchment, the land surface of the Löchernbach catchment has been changed in large terraces which are 30 to 60 m broad and where wine monocultures are planted. In the Löchernbach catchment 61 % of the total area is covered by wine, whereas 67,8 % of the Rouffach catchment area is used for wine-growing. In contrary to the Rouffach catchment however, the Löchernbach catchment is drained by perennial streams. In general it can be said that both streams are reacting very quickly and quick changes are due to a fast reaction on rainfall. In the valley of the Löchernbach catchment, various drainages are diverting the infiltrating water to the stream. And the terraces have been built in a way that the runoff water can be diverted quickly too.

For applying the ZIN-Model at the Löchernbch catchment, it has been divided into three runoff generation zones, the roads, the terraces and the valley area. In the Rouffach catchment the land surface is divided into the wine-growing area, the concrete roads and the roads covered by grass. Running the ZIN-Model at the Löchernbach catchment shows three different discharge peaks during each simulated event which are likely to originate from the three runoff contributing zones. The concrete roads react on the rainfall simultaneously. Because of their short distances to the drainage pipes or their discharge directly into the channel, they are the fastest runoff component. The runoff from the terraces however, is slightly delayed. The travelling time from the valley to the river, estimated with tracer studies by UHLENBROOK (1995) is 25 to 30 minutes. Although the roads do only cover 4.5 % of the total catchment's area they make out the main volume of the total runoff volume. But the strong branching of drainage pipes leads to the importance of the terraces as runoff contributing as well. The typical hydrograph is characterised by a large peak discharge with a precedent lower peak. In general it can be said that the fast reaction of the catchment on rainfall reveals the bad storage capacity of the catchment.

The runoff behaviour is very similar to this of the Rouffach catchment however. Like at the Löchernbach catchment, the runoff water coming from the roads is not delayed. The roads at the Löchernbach catchment do also provide most of the runoff, although they do only comprise about 10 % of the total catchment area. The area covered by the roads however, is double as large as at the Löchernbach catchment. The onset of runoff originating from the wine-growing area is very variable, varying between 7 and 68 minutes depending on the soil moisture. The Rouffach catchment shows an even lower storage capacity of the catchment because of the very steep rising hydrographs and unlike in the Löchernbach catchment only surface runoff is recorded.

During both simulations of the Löchernbach catchment and the Rouffach catchment, the important role of the roads, how KRÄMER (1999) and VOGELBACHER (1985) have already outlined before, has been proved. Unexpected low runoff coefficients of maximal 35 % have been derived by the Löchernbach study, and runoff coefficients of maximal 32 % for the roads of the Rouffach catchment. Furthermore, both studies reveal that the height of the rainfall intensity and its amount plays a major role for the runoff generation on the terraces and the wine-growing area respectively. Applying the ZIN-Model at both catchments reveals its capability to reproduce the dynamic of the runoff and the storage capacity of the catchments quite well during convective storm events.

8 Conclusion

In applying the ZIN-Model, it was possible to reproduce the hydrologic behaviour of the Rouffach catchment quite well, which is characterised by fast runoff components and very short concentration times. The modelling work verifies that the concrete roads are generating most of the runoff water and that they are also responsible for the almost simultaneous reaction of the catchment on rainfall. Furthermore it is shown that the roads are not pesticide contributing in general, but are leading to a strong dilution of the pesticides applied on the Rouffach catchment during runoff events. Although pesticides originate mainly from the wine-growing area, residues of former events can be remobilised on the streets, during a certain time in function of their persistence and be transferred to the outlet of the catchment (DOMANGE 2005). Precedent rainfall events seem to play a role for the pesticide mobilization on the roads however.

Although the simulated hydrographs match the measured ones quite well, the model can only be seen as a simplification and assumption of natural processes. The parameter determination leads to a high degree of uncertainty. The whole parameterisation of the years 2004 and 2005 for the wine-growing region is derived by data of two events on the same day at one of the experimental plots. This plot can not be seen as a perfect representation of the hydrological behaviour of the whole catchment, as it is isolated from its surrounding environment and thus cut off from contribution of water and alluvial material which is coming from above. But this sparse data can still be regarded as a better approximation to natural processes than parameters derived by calibration. Even the data of only two events were available, this study shows that hydrological *in situ* data of a catchment is a very valuable tool for modelling. Collecting data at these plots over a long term would help to classify the events according to the rainfall intensity and amount, whether the wine-growing region is runoff contributing or not. Furthermore, continuous runoff recording at the plots would enable parameterisation for the wine-growing region for each event, taking into account the natural high variability of the rain events. The present study has shown that even very low quantities of measured runoff volumes at the plots are valuable. The runoff coefficient of the plots has never exceeded 2 % before. Applying these low runoff coefficients to the wine-growing area leads to a low to high portion of runoff generated by the wine-growing plots. It was shown that with an increased rainfall intensity and amount, relatively more runoff is generated by the wine-growing region as the surface soil saturates and Hortonian overland flow occurs on the wine-plots which cover almost 70 % of the total catchment area.

Cross-sections of roads functioning as channels have to be strongly approximated. Observations in the field show that the runoff water is canalized in small gullies on the roads very often (AKAN & HOUGHTALEN 2003). But applying a hydraulic formula to take into account these gullies would lead to another effort to derive parameters and would not necessarily lead to better modelling results in the Rouffach catchment. Applying the sheet flow formula shows that it is not applicable for very fast responding catchments or for low intensity rainfall events. In contrast to the channel flow routing however, the sheet flow equation showed its capability of simulating continuous runoff between single peaks or slow decreasing hydrographs.

Although the ZIN-Model is further restricted to two -dimensional flow processes and subsurface flow processes are not accounted for, the ZIN-Model has proved to be applicable in humid and small catchments and has even proved to be able to simulate ff low intensity rainfall events. It would be very valuable however, to validate the presented simulation results with further measurements in the field or other event based models. The appliance and further development of the pesticide model could provide a validation tool for hydrological modelling however, as the pesticides can be used as tracers to determine the origin of runoff water and flow paths.

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Annex

A -1: Meteorological station in the Roufach catchment

A-2: Venturi channel at the outlet of the Rouffach catchment

A-3: Automatic sample taker for pesticide measurements at the outlet of the Rouffach catchment

A-4: Outlet of the Rouffach catchment with Venturi channel

A-5: Stormtank at the outlet of the catchment

A-6: Venturi channels at the outlet of the two experimental plots

A-7: Hydrological separation of the two experimental plots

A -8: Two automatic sample takers at the outlet of the experimental plots

A-9: Every row between the vine is green (wine green)

A-10: Every second row between the vines is green (wine 1/2)

A-11: No row between the vines is green (wine no green)

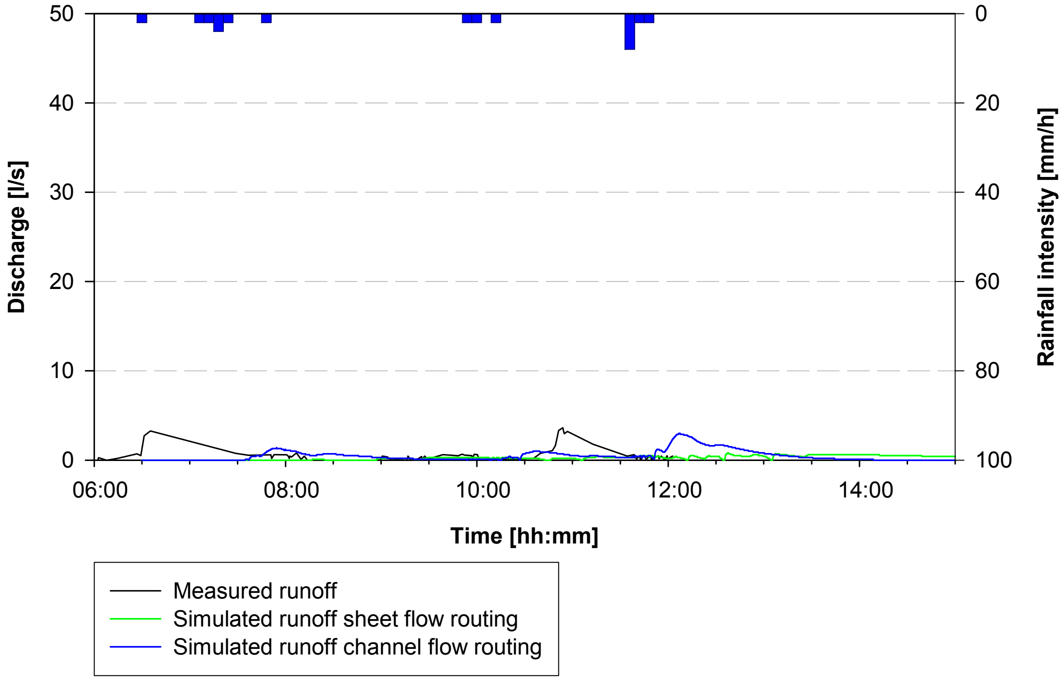
A-12: Wine cultivating area ploughed

A-13: Road concrete

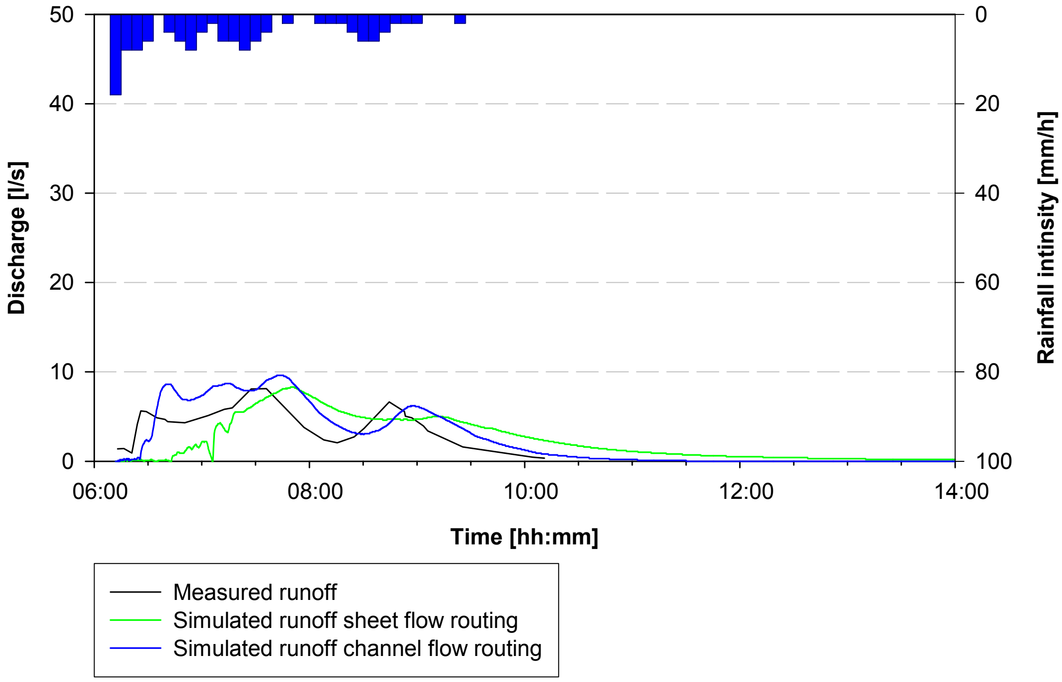
A-14: Road gravel

A-15: Road mixed

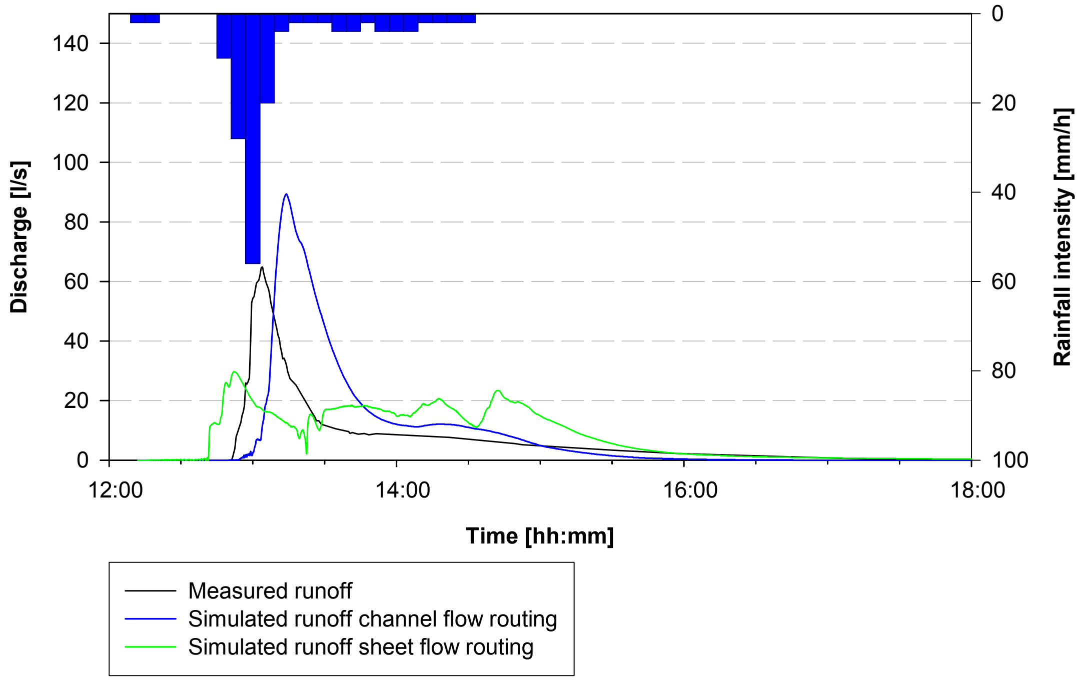
A-16: Road grass and soil



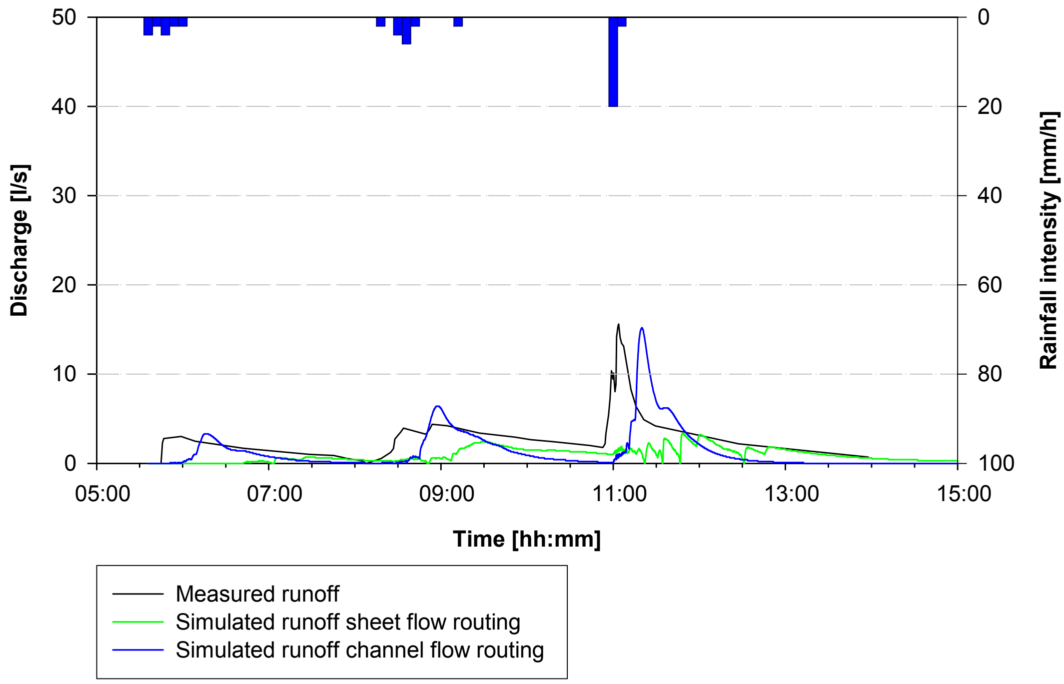
A-17: Model results of the event on the 6th April 2004



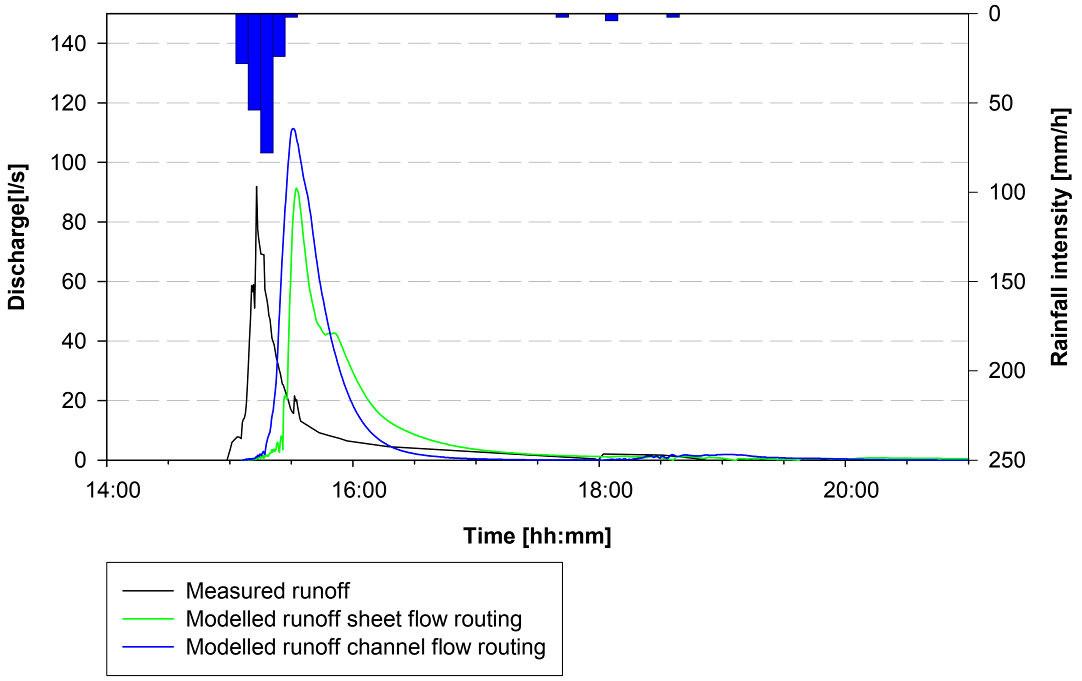
A-18: Model results of the first event on the 11th June 2005



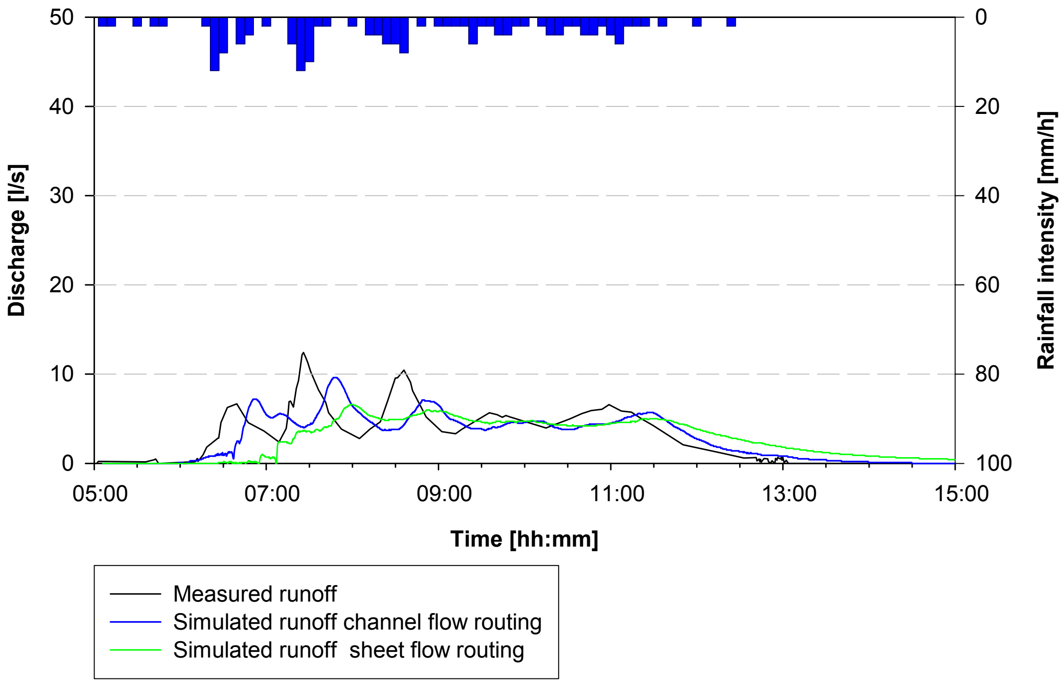
A-19: Model results of the second event on the 11 th June 2005



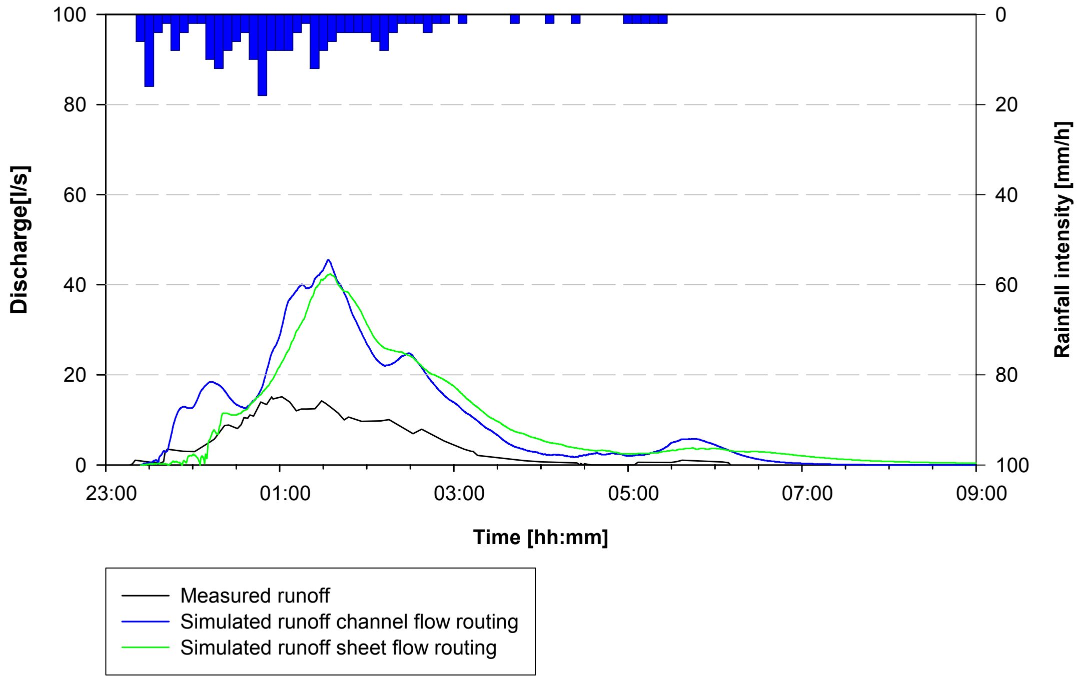
A-20: Model results of the event on the 29th August 2004



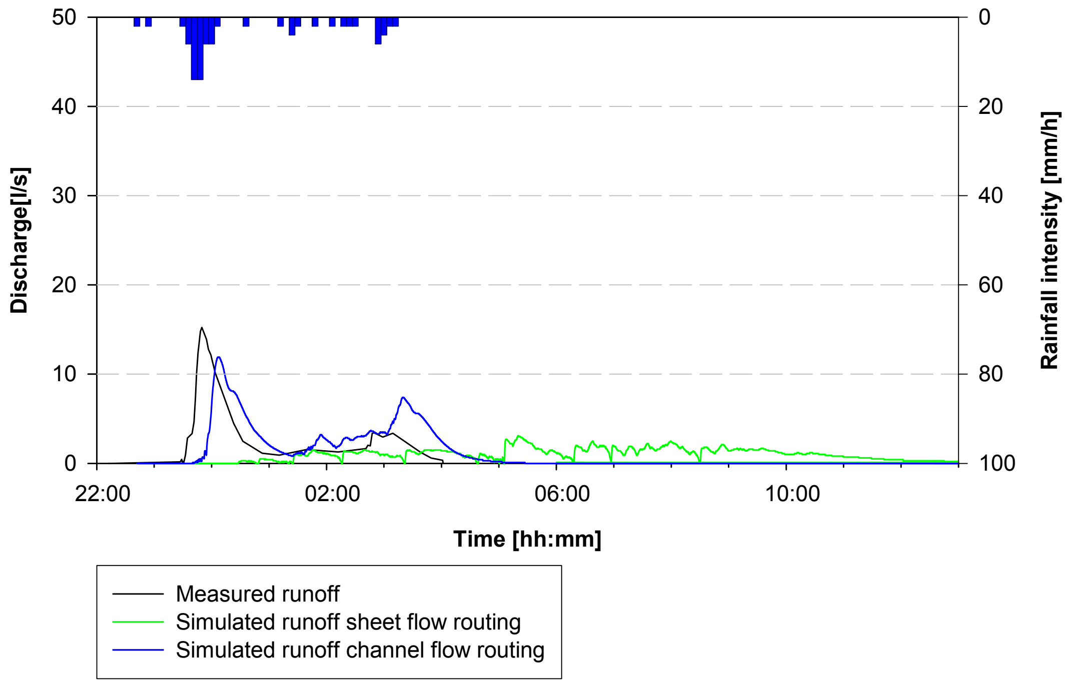
A-21: Model results of the event on the 29th June 2005



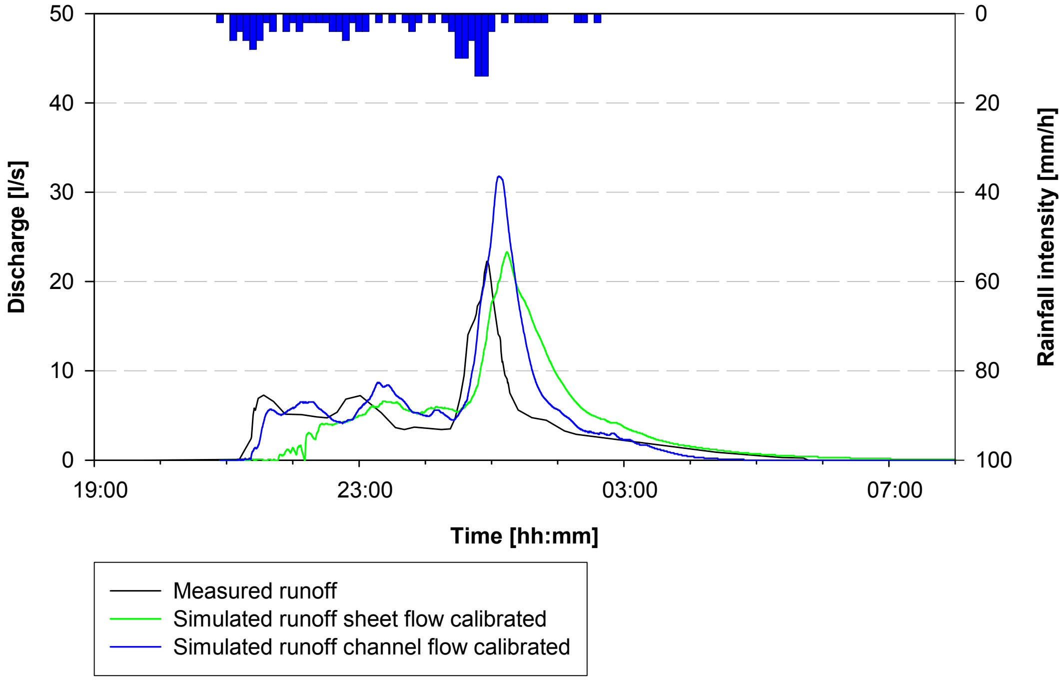
A-22: Model results of the event on the 25th July 2005



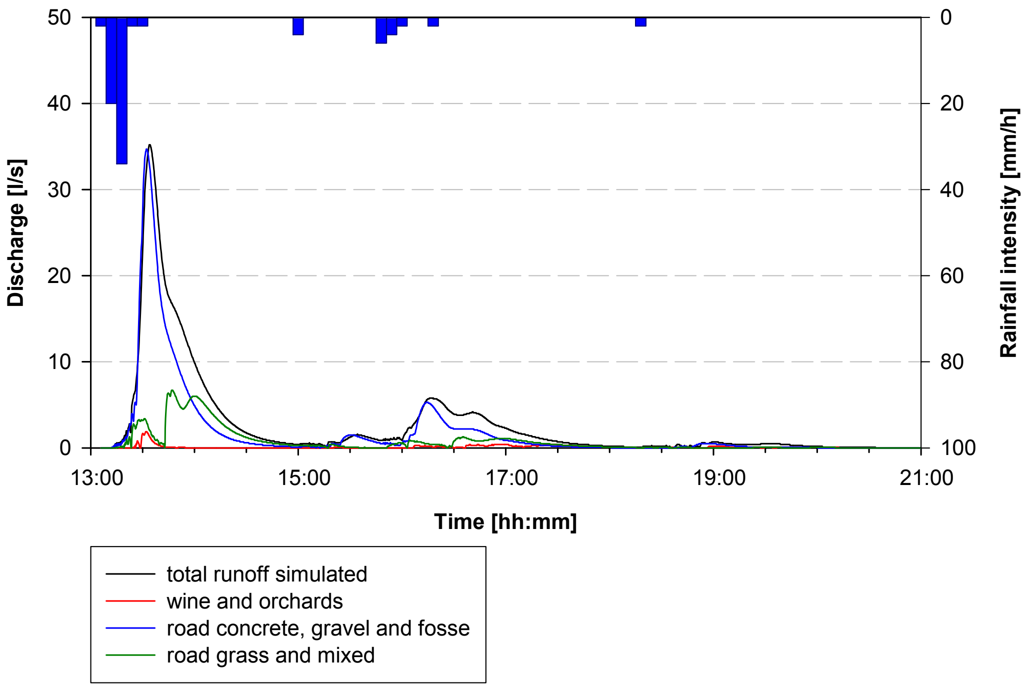
A-23: Model results of the event on the 1st August 2005



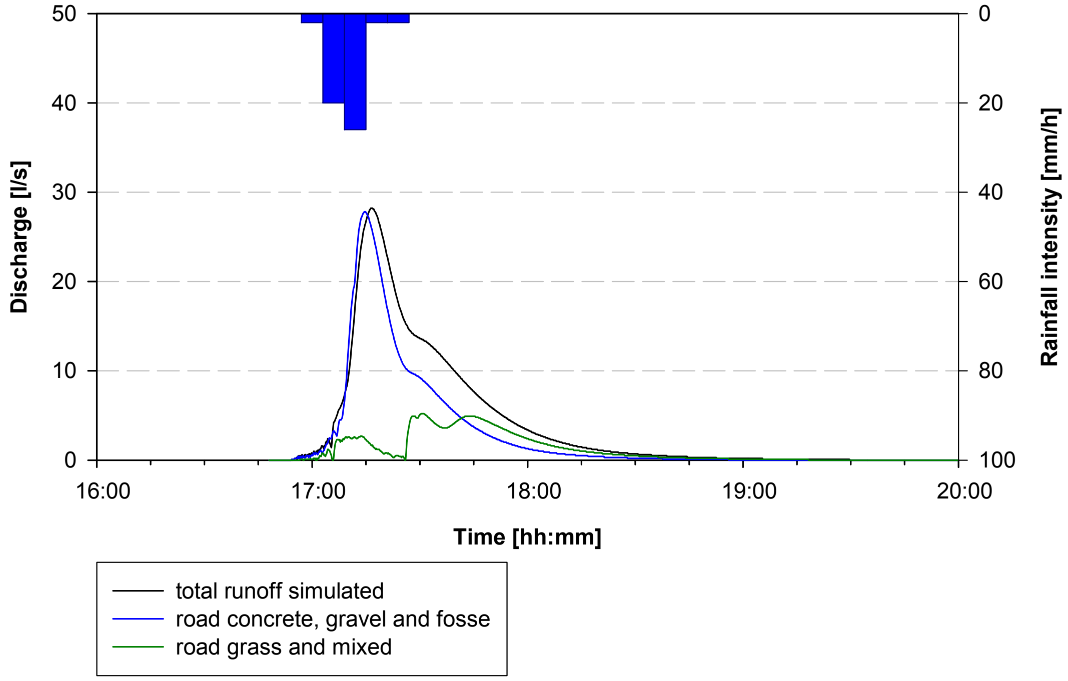
A-24: Model results of the event on the 21st August 2005



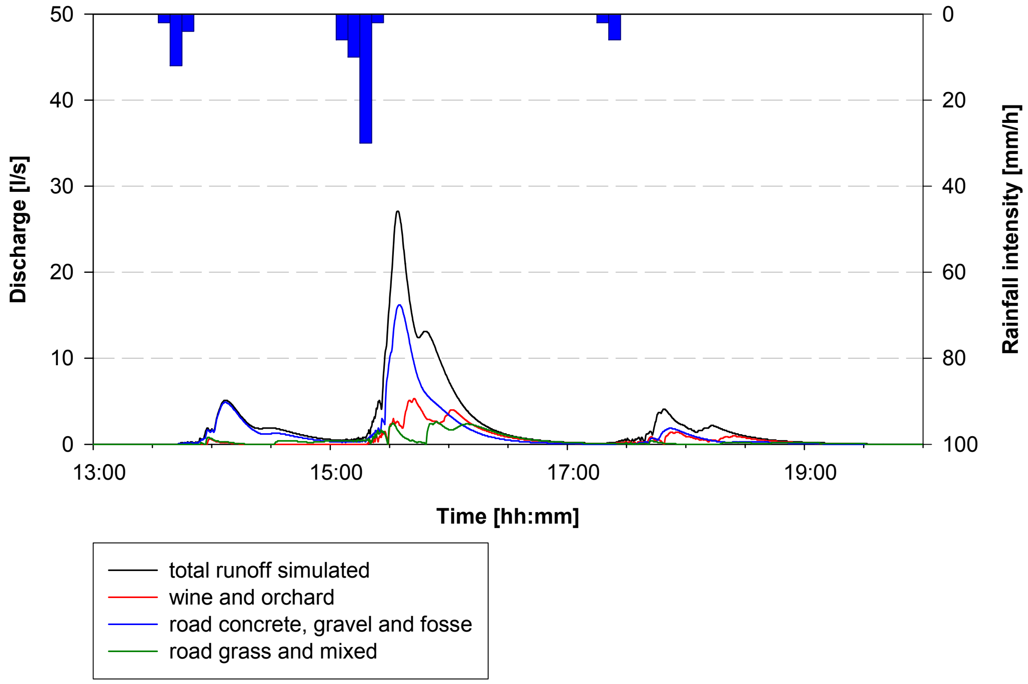
A-25: Model results of the second event on the 4th October 2005



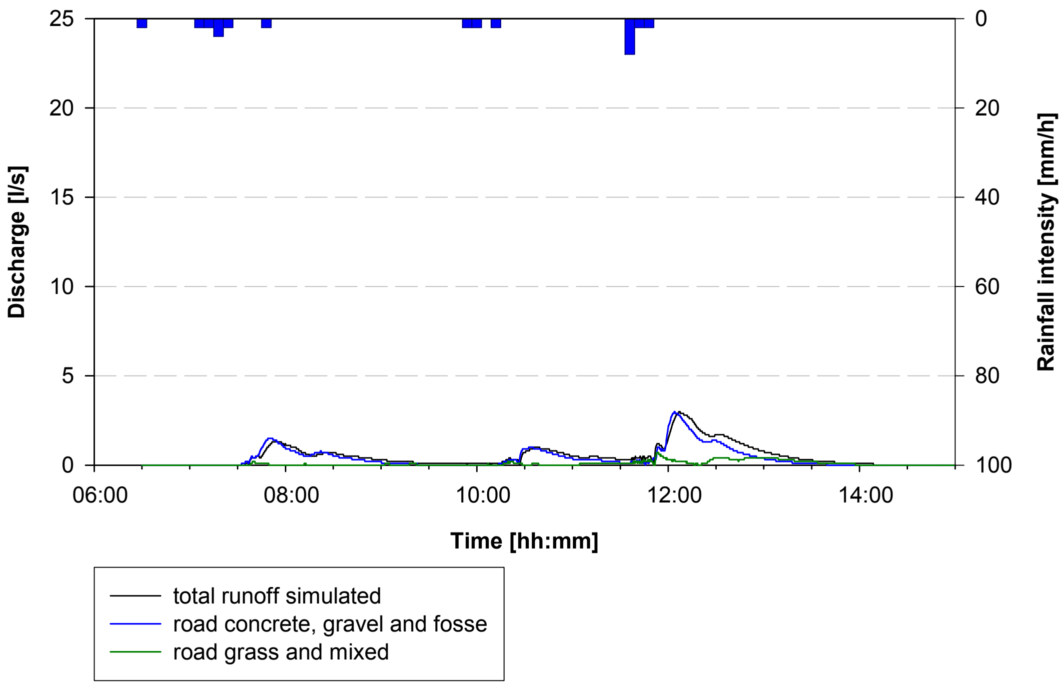
A-26: Different source areas on the 5th May 2005



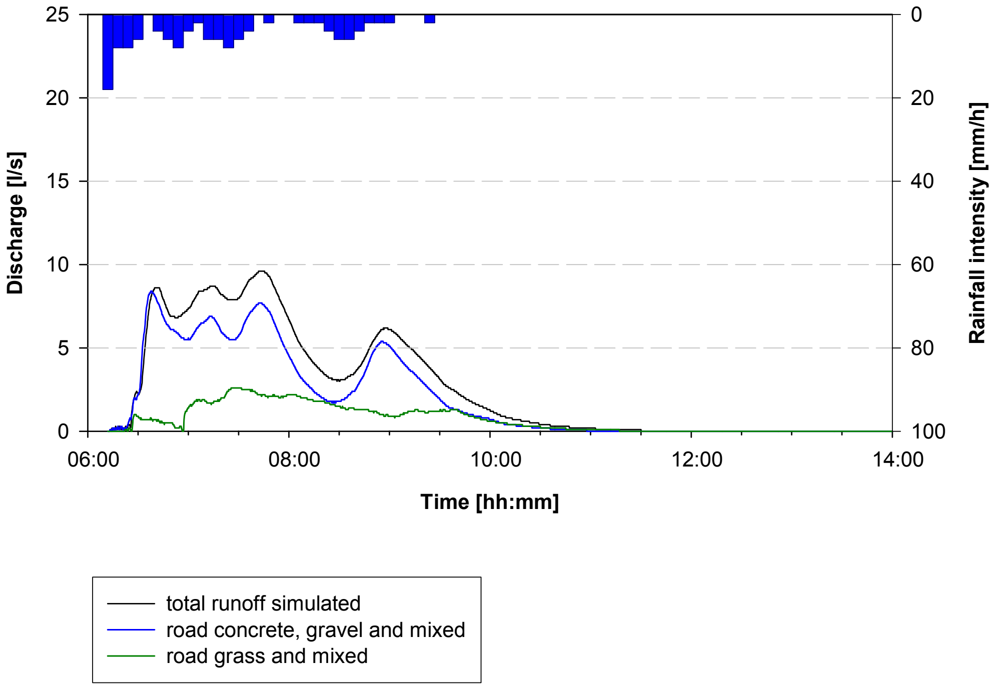
A-27: Different source areas on the 12th July 2005



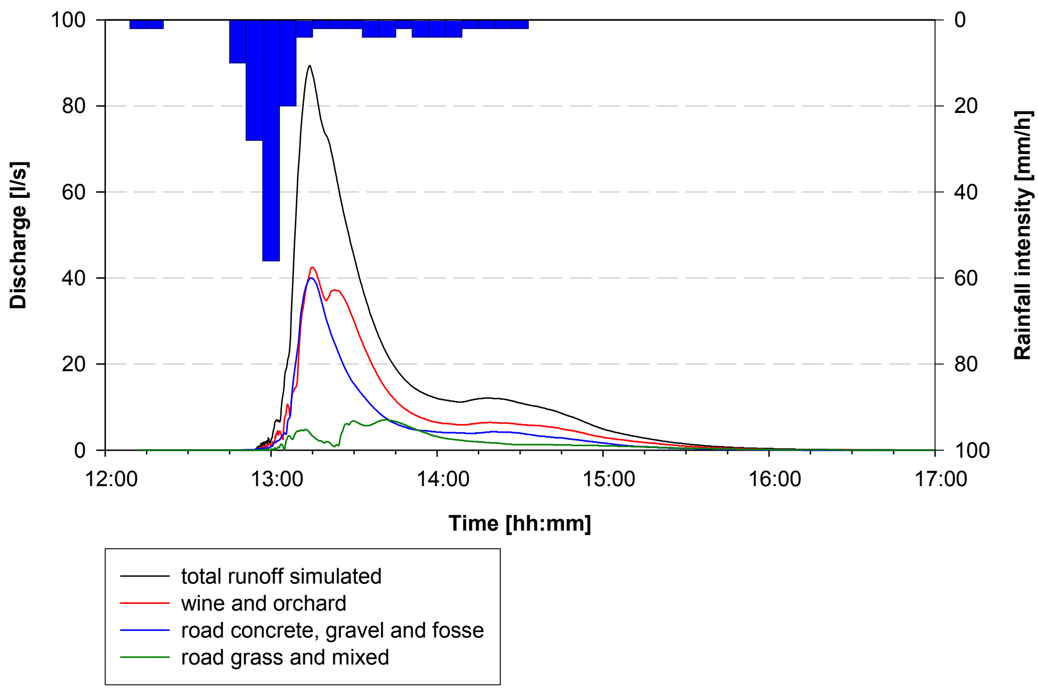
A-28: Different source areas on the 23th May 2005



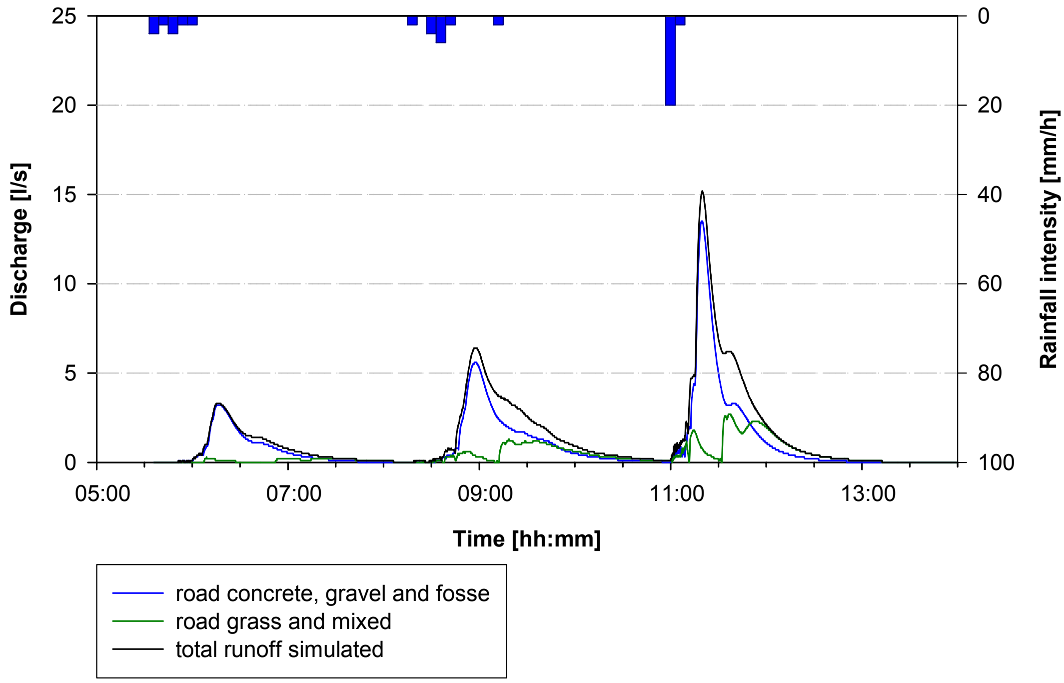
A-29: Different source areas on the 6th April 2004



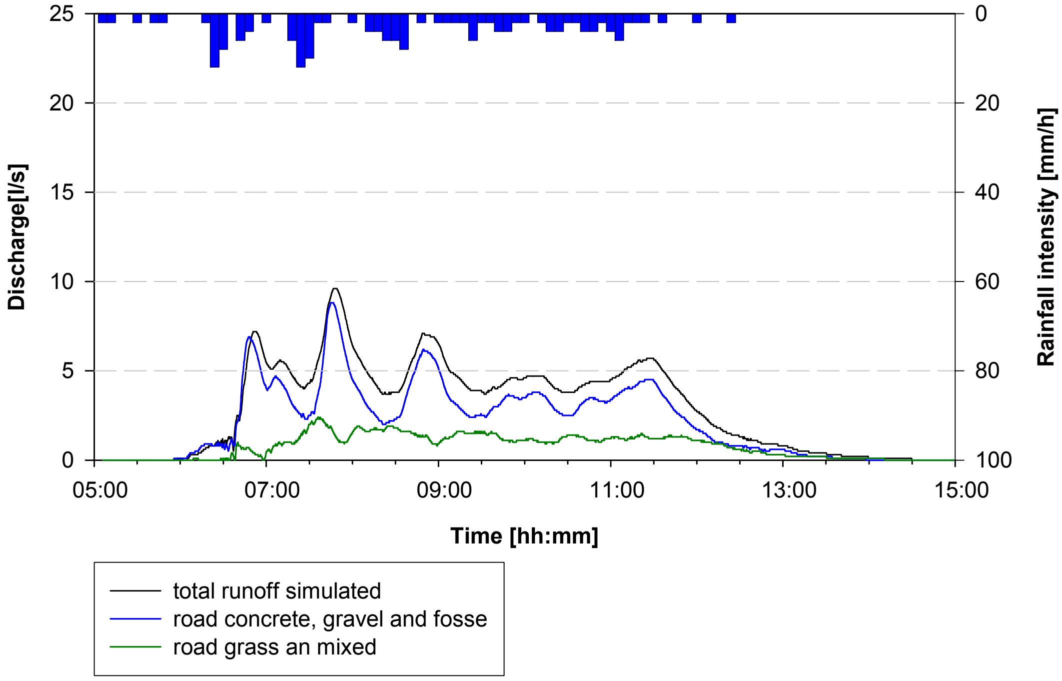
A-30: Different source areas on the first event of the 11th June 2004



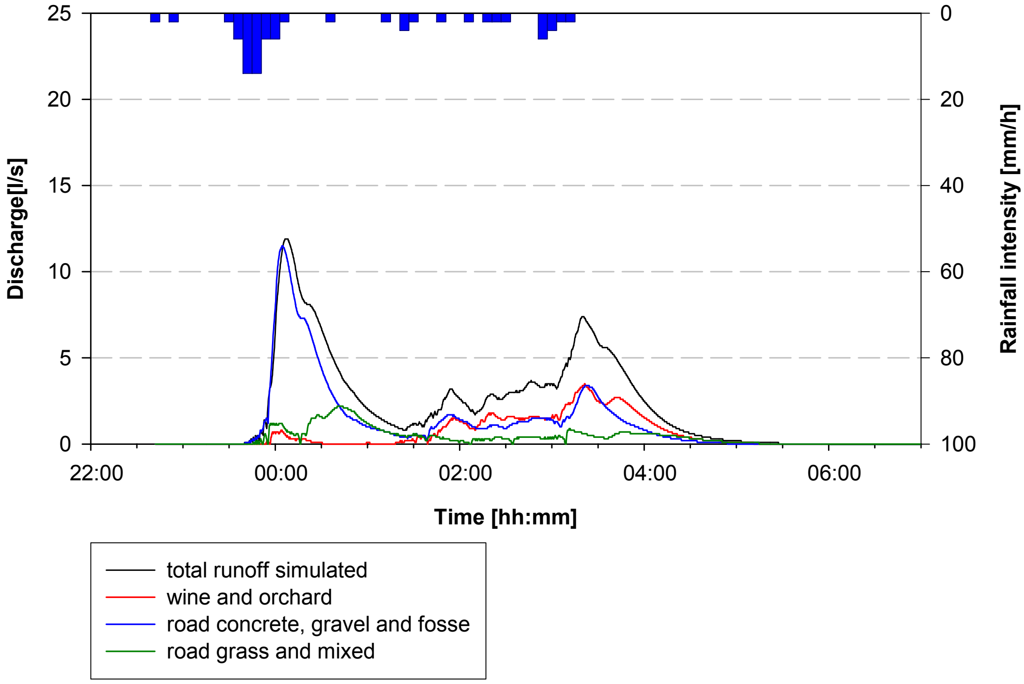
A-31: Different source areas of the second event on the 11th June 2004



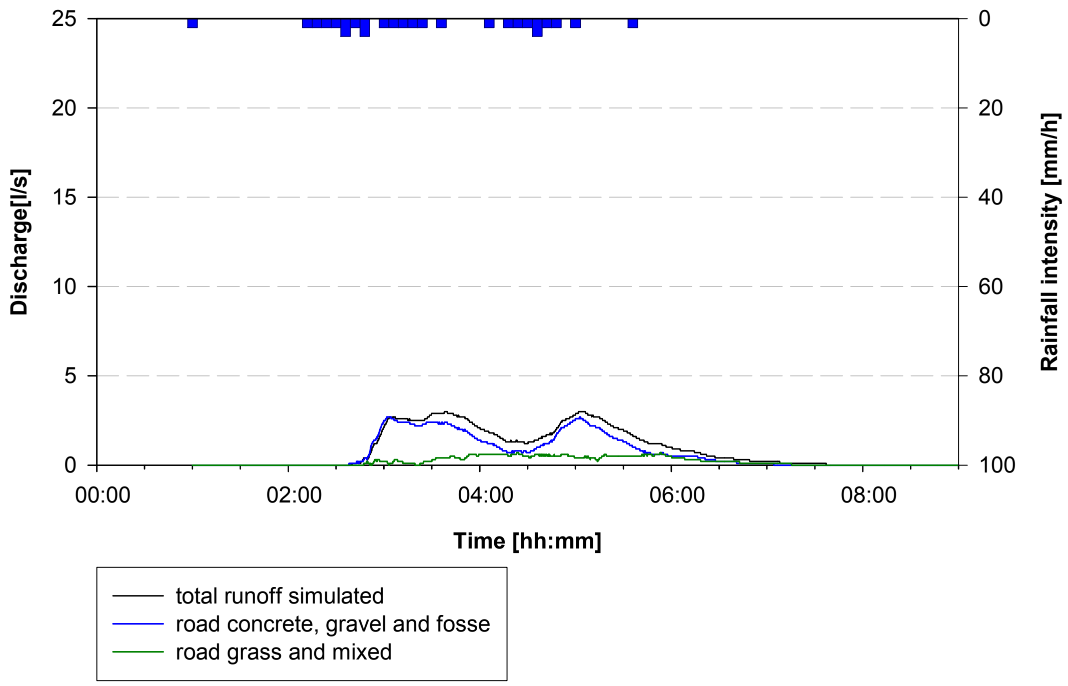
A-32: Different source areas on the 29th August 2004



A-33: Different source areas on the 25th July 2005



A-34: Different source areas on the 21th August 2005



A-35: Different source areas of the first event on the 4th October 2005

A-36: Parameters for the runoff generation procedure

	whine		road concrete		road grass	
	runoff coefficient [%]	initial loss [mm]	runoff coefficient [%]	initial loss [mm]	runoff coefficient [%]	initial loss [mm]
06.04.2004			20	1.0	10	0.5
11.06.2004(I)			20	1.0	10	0.5
11.06.2004(II)	0.0184	1.4	20	1.0	10	0.5
18.08.2004			20	1.0	10	0.5
24.08.2004	0.0132	7.8	20	1.0	10	0.5
29.08.2004			32	1.0	20	0.5
05.05.2005	0.0135	7.38	32	1.0	20	0.5
23.05.2005	0.0155	4.98	20	1.0	10	0.5
29.06.2005	0.0141	6.71	20	1.0	10	0.5
12.07.2005			32	1.0	20	0.5
25.07.2005			20	1.0	10	0.5
21.08.2005	0.0148	5.85	20	1.0	10	0.5
01.10.2005			32	1.0	20	0.5
04.10.2005 (I)			20	1.0	10	0.5
04.10.2005 (II)	0.0146	6.14	20	1.0	10	0.5

A- 37: Event characteristics during the years 2004 and 2005

Date	Total rainfall amount [mm]	Maximal rainfall intensity [mm/h]	Total runoff volume [m^3]	Maximum discharge [l/s]	Runoff coefficient of the roads [%]
6.4.04	3.2	8	17.2	3.6	17.2
17.4.04	1.2	4	0.2	0.4	0.4
1.5.04	6.4	10	21.6	3.3	10.8
21.5.04 (I)	4.2	22	11.5	2.8	8.7
21.5.04 (II)	4.6	6	9.4	2.8	6.6
31.5.04	2.8	12	6.9	4.8	7.9
4.6.04	4.2	6	7.5	3.2	5.7
5.6.04	1.8	8	2.3	1.1	4.0
11.6.04	13.0	18	55.6	8.1	13.7
11.6.04 (I)	15.8	56	132.3	64.9	26.8
11.6.04 (II)	0.6	2	7.7	3.3	41.3
23.6.04	2.8	8	2.4	1.5	2.8
5.7.04	18.0	18	73.8	15.9	13.1
8.7.04	14.8	44	84.1	41.1	18.2
21.7.04	7.0	34	27.0	38.9	12.4
22.7.04	6.2	26	32.7	20.4	16.9
7.8.04	2.0	4	1.1	0.7	1.7
10.8.04	14.0	24	43.5	12.5	9.9
17.8.04	7.4	8	18.6	4.5	8.0
18.8.04	3.8	12	13.3	5.8	11.2
19.8.04	3.2	6	4.9	2.3	4.9
20.8.04	4.6	4	13.5	4.3	9.4
21.8.04	2.6	4	2.0	0.8	2.5
24.8.04	25.6	26	240.2	37.6	30.0
29.8.04	5.2	20	76.8	15.6	47.3
3.9.04	3.8	18	16.0	13.4	13.5
3.5.05	2.6	6	1.5	1.4	1.8
5.5.05	8.0	34	72.3	31.2	28.9
8.5.05	0.6	2	1.6	0.7	8.8
14.5.05	2.4	6	2.4	1.7	3.3
16.5.05	7.2	4	18.4	2.3	8.2
23.5.05 (I)	8.8	4	21.1	4.1	7.7
23.5.05 (II)	7.8	30	60.9	21.2	25.0
24.6.05	3.4	6	2.4	0.3	2.2
26.6.05	4.2	14	7.0	5.1	5.4
27.6.05	2.6	6	1.9	1.3	2.4
29.6.05	19.4	78	106.2	91.9	17.5
5.7.05	1.2	8	0.9	0.8	2.5

6.7.05	6.6	10	23.2	7.3	11.3
12.7.05	5.2	26	37.6	31.5	23.2
16.7.05	0.4	2	0.6	0.9	4.6
18.7.05 (I)	6.6	34	41.7	13.1	20.2
18.7.05 (II)	5.4	12	43.7	14.0	25.9
20.7.05	1.0	6	18.4	3.2	58.7
25.7.05	18.4	12	109.1	12.4	19.0
29.7.05	5.4	16	8.7	3.3	5.1
1.8.05	23.4	18	120.4	15.1	16.5
2.8.05	5.2	2	21.3	2.6	13.1
20.8.05	4.2	8	4.8	1.6	3.7
21.8.05	4.0	4	6.7	1.4	5.4
21.8.05	8.8	14	49.6	15.2	18.1
22.8.05 (I)	0.8	4	1.2	0.7	4.9
22.8.05 (II)	2.6	4	5.8	1.6	7.2
11.9.05	17.4	6	66.7	5.8	12.3
16.9.05	15.4	12	61.1	7.4	12.7
1.10.05 (I)	6.2	8	7.9	3.0	4.1
1.10.05 (II)	7.4	6	81.9	18.5	35.4
4.10.05 (I)	5.2	4	23.7	3.4	14.6
4.10.05 (II)	17.6	14	132.1	22.3	24.0

A-38: Channel segments with corresponding sub-catchments

secment no.	left poly (road)	right poly (wine)	secment no.	left poly (road)	right poly (wine)
1	561	563	166	454	455
2	562	564	167	456	457
3	574	560	168	458	459
4	573	559	169	460	462
5	572	558	170	461	521
6	571	557	171	584	452
7	570	556	172	616	522
8	569	555	173	523	519
9	568	554	174	526	520
10	567	553	175	190	191
11	566	552	176	527	532
12	565	551	177	192	531
13	629	611	178	528	530
14	628	610	179	529	193
15	627	609	180	655	657
16	626	608	181	93	492
17	607	603	182	90	91
18	606	602	183	88	89
19	605	601	184	86	87
20	604	600	185	73	64
21	598	599	186	69	63
22	577	402	187	68	62
23	578	403	188	67	182
24	579	401	189	66	65
25	580	404	190	293	294
26	581	405	191	296	297
27	582	406	192	300	302
28	583	407	193	299	301
29	409	408	194	206	207
30	542	543	195	229	230
31	630	615	196	225	638
32	625	614	197	231	226
33	623	622	198	295	204
34	624	621	199	298	205
35	642	596	200	209	208
36	644	645	201	232	650
37	617	619	202	227	210
38	618	620	203	228	211
39	631	633	204	214	212
40	634	632	205	215	213
41	612	641	206	285	286
42	495	643	207	287	288
43	494	597	208	290	292
44	496	143	209	289	291
45	490	493	210	284	216
46	635	491	211	218	217
47	636	499	212	220	219
48	497	498	213	223	221
49	500	479	214	224	222
50	480	481	215	648	656
51	482	483	216	203	198
52	484	485	217	202	197
53	487	489	218	201	196
54	486	488	219	200	194
55	478	475	220	199	195
56	477	474	221	244	241
57	476	473	222	261	245
58	471	472	223	262	246

59	589	470	224	255	254
60	590	469	225	257	256
61	594	595	226	260	263
62	592	591	227	183	312
63	654	593	228	60	61
64	653	464	229	58	59
65	588	465	230	56	57
66	587	466	231	53	54
67	586	468	232	187	52
68	585	467	233	50	51
69	613	463	234	48	49
70	503	502	235	55	47
71	504	501	236	44	43
72	507	505	237	45	42
73	508	506	238	46	166
74	510	509	239	38	165
75	512	511	240	39	37
76	516	513	241	40	36
77	517	514	242	41	35
78	518	515	243	34	30
79	525	524	244	33	141
80	550	548	245	32	135
81	399	400	246	31	29
82	640	398	247	26	25
83	396	397	248	28	27
84	394	395	249	163	162
85	392	393	250	160	161
86	363	366	251	158	159
87	365	367	252	156	157
88	364	368	253	154	155
89	359	360	254	152	153
90	575	361	255	150	151
91	576	362	256	148	149
92	547	549	257	188	185
93	372	369	258	189	186
94	374	375	259	659	184
95	391	373	260	660	639
96	376	370	261	277	181
97	377	371	262	176	174
98	390	389	263	177	175
99	384	378	264	178	173
100	385	379	265	179	276
101	386	380	266	279	278
102	387	381	267	282	280
103	388	382	268	283	281
104	338	340	269	172	168
105	339	341	270	171	169
106	336	337	271	170	167
107	334	335	272	275	274
108	332	333	273	273	272
109	325	383	274	271	270
110	326	327	275	269	268
111	328	330	276	267	266
112	329	331	277	265	264
113	324	323	278	258	259
114	70	72	279	242	243
115	347	71	280	240	235
116	319	314	281	239	236
117	320	315	282	238	237
118	321	316	283	248	249
119	322	318	284	250	252
120	314	342	285	251	253

121	410	412	286	234	116
122	411	413	287	118	114
123	343	414	288	117	115
124	358	344	289	649	120
125	647	646	290	147	140
126	345	346	291	146	139
127	348	349	292	145	138
128	350	351	293	144	142
129	352	353	294	546	658
130	354	356	295	545	544
131	355	357	296	137	134
132	303	313	297	136	133
133	304	305	298	129	128
134	306	307	299	130	127
135	308	310	300	247	126
136	309	311	301	124	123
137	419	417	302	125	122
138	420	418	303	637	113
139	421	416	304	121	112
140	422	415	305	233	180
141	535	536	306	103	105
142	538	540	307	97	96
143	537	539	308	102	104
144	541	444	309	98	99
145	447	443	310	100	101
146	448	445	311	110	111
147	449	446	312	24	164
148	450	453	313	23	18
149	451	441	314	22	19
150	440	442	315	21	20
151	438	439	316	17	15
152	436	437	317	132	16
153	423	424	318	14	11
154	425	426	319	13	12
155	427	428	320	131	10
156	429	430	321	6	8
157	431	432	322	7	9
158	435	433	323	119	5
159	434	85	324	3	4
160	83	84	325	108	109
161	81	82	326	106	107
162	79	80	327	95	1
163	77	78	328	94	2
164	75	76	329	651	534
165	92	74	330	652	533

Ehrenwörtliche Erklärung:

Hiermit erkläre ich, dass die Arbeit selbständig und nur unter Verwendung der angegebenen Hilfsmittel angefertigt wurde.

Freiburg, den 18. 5. 2006 Unterschrift: