

**KASSELER WASSERBAU-MITTEILUNGEN**  
**HEFT 18/2009**

herausgegeben von Univ.-Prof. Dr.-Ing. Stephan Theobald



**Mohsen Masoudian**

**The topographical impact on  
effectiveness of flood protection measures**

KASSELER WASSERBAU-MITTEILUNGEN  
HEFT 18/2009

**Herausgeber:** Univ.-Prof. Dr.-Ing. Stephan Theobald  
Fachgebiet Wasserbau und Wasserwirtschaft  
Universität Kassel  
D-34109 Kassel (Briefpost)  
D-34125 Kassel (Lieferanschrift)  
Telefon: (0561) 804 2749  
Telefax: (0561) 8043952  
E-Mail: [wawi@uni-kassel.de](mailto:wawi@uni-kassel.de)

This work has been accepted by the faculty of Faculty of Civil Engineering of the University of Kassel as a thesis for acquiring the academic degree of Doktor der Ingenieurwissenschaften (Dr.-Ing.).

Supervisor: Prof. Dr.-Ing. Stephan Theobald  
Co-Supervisor: Prof. Dr.-Ing. Frank Tönsmann

Defense day:

13<sup>th</sup> July 2009

Bibliographic information published by Deutsche Nationalbibliothek  
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data is available in the Internet at <http://dnb.d-nb.de>.

Zugl.: Kassel, Univ., Diss. 2009  
ISBN print: 978-3-89958-790-6  
ISBN online: 978-3-89958-791-3  
URN: <http://nbn-resolving.de/urn:nbn:de:0002-7915>

© 2009, kassel university press GmbH, Kassel  
[www.upress.uni-kassel.de](http://www.upress.uni-kassel.de)

Printed by: docupoint GmbH, Magdeburg  
Printed in Germany

## Vorwort

Hochwasserereignisse sind sowohl natürliche als auch anthropogen geprägte Phänomene und die dadurch verursachten Hochwasserschäden bedeuten vielfach eine Belastung für die Volkswirtschaft und insbesondere für die persönlich betroffene Bevölkerung. Ein modernes Hochwassermanagement setzt daher auf die drei Elemente des technischen Hochwasserschutzes, des Flächenmanagements und der Hochwasservorsorge. Dabei ist festzustellen, dass jedes Einzugsgebiet hinsichtlich Topografie, Gewässernetz, Bodenart und Landnutzung einzigartig ist. Damit verbunden ist ein individuelles Hochwasserschutzkonzept als Kombination aus den zuvor genannten drei Komponenten des Hochwassermanagements. Die Übertragung eines Hochwasserschutzkonzeptes von einem Flussgebiet zum anderen ist daher nicht ohne weitere Untersuchung für das betrachtete Flussgebiet möglich.

Die von Herrn Dr. Masoudian vorgelegte Dissertation hat das Ziel, den Einfluss der Topografie in einem Einzugsgebiet auf mögliche Hochwasserschutzmaßnahmen zu quantifizieren. Als Untersuchungsgebiet wurde die Region Nordhessen gewählt. Zum Erreichen dieses Ziels werden die möglichen Hochwasserschutzmaßnahmen sowie die eingesetzten Simulationswerkzeuge, wie Niederschlagsabflussmodell und Geoinformationssystem, beschrieben. Schwerpunkt der Arbeit bilden die umfangreichen hydrologischen Simulationen für die zwei unterschiedlich großen Einzugsgebiete der Erpe und der Diemel, mit einem breiten Variantenstudium an Hochwasserschutzmaßnahmen und Topografieänderungen sowie ihren Auswirkungen auf den Hochwasserabfluss. Bei den Hochwasserschutzmaßnahmen handelt es sich mit Wasserrückhalt in der Fläche und Renaturierung des Fließgewässers um zwei Maßnahmen aus dem Bereich der Hochwasserflächenvorsorge und mit dem Bau von zentralen und dezentralen Hochwasserrückhaltebecken um zwei Maßnahmen des technischen Hochwasserschutzes. Die Untersuchungen zum Einfluss der Topographie erfolgten durch ein Variantenstudium für synthetisch erzeugte Einzugsgebiete.

Mit der vorliegenden Dissertation leistet Herr Dr. Masoudian einen guten Beitrag zum Themenkomplex des Einflusses der Topografie auf die verschiedenen Hochwasserschutzmaßnahmen. Aufgrund guter Kenntnisse über die eingesetzten Simulationswerkzeuge gelingt es Herrn Dr. Masoudian durch ein umfangreiches Variantenstudium unter Einbeziehung auch extremer Randbedingungen die Wirkung von Hochwasserschutzmaßnahmen zu quantifizieren.

Kassel, im September 2009

Prof. Dr.-Ing. Stephan Theobald

## Acknowledgments

The author wishes to express sincere appreciation to Prof. Dr.-Ing. Stephan Theobald and Prof. Dr.-Ing. Frank Tönsmann, for providing opportunity to pursue my Dr.-Ing. dissertation at Kassel University. Without their valuable advices, guidance, training, kind patient and mercifulness, this dissertation could not be fulfilled.

I would like to express sincerely acknowledge Dr.-Ing. Klaus Röttcher, for his sincere supports, cooperation, motivation and advices.

I am sincerely thankful to my office room-mate Dipl.-Ing. Bernd Saurwein and colleagues Dr.-Ing. Andreas Weiss, Dipl.-Ing. Tobias Rimpau (who kindly helped me to use of GIS program) and also Dipl.-Ing. Maria Carambia, Dipl.-Ing. Barbara Wagner, Dipl.-Ing. Frank Roland, Dipl.-Ing Michael Kaiser, Dipl.-Ing. Silke Müller, Dipl.-Hydrol. Anne Siglow, Dipl.-Ing. Alexander Rötz and Dipl.-Ing. Roberto Gering for their kind support to me.

I would like to express my special thanks to Mrs. Elke Hartmann the secretary of Department of Hydraulic Engineering and Water Resources Management for her extreme kindness and mercy to me.

I am extremely thankful to Mr. Farshid Parvizian, Mr. Saeed Roshani who edited some parts and Miss. Donna Diaz to edit the text as a native English language expert.

I am greatly thankful to Mazandaran University, Sari Agricultural Science and Natural Resources University and Ministry of Science, Research and Technology of Islamic Republic of Iran for supporting a research grant.

I would like to express my deepest cordial thanks to my wife Dr. Zohreh Hajheydari and my son Ali for their encouragements, understanding and motivation.

I would like to thank from Dr.-Ing. Jafar Zendehroud, Dipl.-Ing. Reza Hosseini, Dipl.-Ing Nasser Mohammadkhanlou, Dipl.-Ing Hamid Mohammadi, Dipl.-Ing. Amin Davazdahemami, Dr. Hossein Khorsand and other Iranian friends who live in Kassel and helped me during these times.

## Abstract

Topography elements (longitudinal river slope, catchment size and land surface slope) are one of the effective elements in natural floods. The topography of a catchment is the current terrain feature of the region and the land form caused by geomorphologic processes over millions of years. The effect of catchment topography on flood defense measures and their efficiency is the main question of this research. This study examines the topographical impact on the effectiveness of flood defense measures by using literature study and also a case study catchment. Flood defense measures are described as well as the relation between the topography and flood defense measures. In order to do so, Erpe and Diemel catchments have been used as a case area study. Erpe is a small subcatchment of Diemel. Diemel is a tributary of Weser River, located in the middle of Germany. The catchment area is about 1800 km<sup>2</sup>. The length of main river is about 90 km from Diemel Dam to Bad Karlshafen. Since rainfall runoff simulation model has been developed for Diemel and Erpe catchment by use of NASIM hydrological model. NASIM rainfall runoff model is used to connect the topography parameters to flood parameters for the catchment. To consider the effect of topography on a flood and also on flood defense measures, some artificial catchments are created from the base catchments (Diemel and Erpe) and then the output flood and also the flood defense measures will be examined for them. In the artificial catchments the topography of catchment is changed. So the altitudes of points are changed to produce the new topography maps.

According to the results of the Erpe catchment which are classified in two groups: subcatchments with areas less than 15 km<sup>2</sup> (10 subcatchments) and the area more than 15 km<sup>2</sup> (6 subcatchments). In a case in which the land surface slope increases, the maximum of the flood hydrograph goes up and left therefore the rising limb will be steeper. It would be reverse in cases where the land surface slope decreases. According to the results, catchments are divided to four categories.

- The first category is catchments with a mean land surface slope less than 3.5% (2 Deg). In this category the flood parameters are very sensitive to topography.
- The second category has a mean land surface slope from 3.5% to 10 % (6 Deg) called medium land surface slope. The flood parameters in this group are sensitive to topography but less than in the first category.
- The third category is called steep land. The mean land surface slope in this category is more than 10 % and less than 28.6 % (16 Deg).
- The fourth category is very high or very steep lands with a mean land surface slope more than 28.6%. It is possible that there are very small catchments in this category. The important point here is that the topography changes are not important and do not affect flood parameters.

The catchment topography is comprised of catchment land surface and flood plain. Flood defense measures which are done in land surface area are called catchment area planning and management. These methods reduce the runoff volume and make a reduction on maximum of flood discharge and increase time to peak. These methods have been based on the decreasing of runoff; therefore, they concentrate to increase infiltration, interception and surface storage. The efficiency of flood defense measures which lead to reduction in runoff volume and velocity has been increased by decreasing the land surface slope. In this way, land use has an effect on interception and runoff velocity. Most floods could be reduced by catchment land use management especially when using a suitable plant and agricultural operation on agricultural land. The combination of land surface slope and agricultural plants is important.

So make use of plants with more interception and also root depth is recommended by increasing the land surface slope to control erosion and decrease flood volume. The measures, which are done on flood plain area, aim to delay the flood wave and affect flood parameters such as maximum discharge and time to peak. Increases of infiltration rate in agricultural lands were considered for Erpe catchment. Results show if the infiltration rate in the agricultural land of the Erpe catchment increases only 10 mm/h then the maximum flood discharge decreases about 12%.

The influence of river network slope and river flow velocity on flood hydrographs were considered in the function of a flood defense measure via the river restoration. The relationship between flood hydrograph parameters and river slopes was considered by using the NASIM model for Erpe and Diemel catchments. The output flood hydrographs was calculated by the model for each subcatchment. Three important parameters (maximum discharge, flood volume and time to peak) are considered in the flood hydrographs of Erpe and Diemel catchments. When river slope increases then the flow velocity in the river also will increase, so the concentration time of catchment reduces and the maximum flood discharge is added. The results of Erpe catchments show that the gradients, or rate of changes of maximum discharge, depend on the catchment size. If the upstream river slope increases only 1% then the maximum flood discharge will add about 12.5% in the whole catchment.

Two conditions have been investigated for the Diemel catchment: First changes of the main river slope (from Diemel dam to Bad Karlshafen) and change of river slope of the entire upstream rivers network. The river bed slopes vary in main river span from 0.011 to 1.03 percent and the weighting average of the river slopes is 0.282%. When the river slope increases, consequently the mean flow velocity increases as well and the flood hydrograph is moved to the left and up. In other words, the maximum floods discharge increases and the time to peak decreases. Increasing the river slope is done by straightening the river and decreasing the length of meanders. Increasing the river slope would also cause a raise in the channel capacity and a decrease in the flow depth; therefore it decreases the inundated area. River slope deduction makes the flood hydrograph flatter and causes a decrease of the maximum flood discharge and an increase in time to peak. It is important to take into consideration the fact that decreasing the river slope causes a deduction of channel flow velocity and an increase in the flow depth and inundated areas.

Maximum flood discharge reduces about 35% (from 490 to 320 m<sup>3</sup>/s) when the weighting average of main river slope changes from 0.282% to 0.07%. The curve of flood discharge in the mouth of the Diemel catchment versus weighting average of river slope shows the rate of changes in low river slope is high (weighting average of river slope less than 0.2%). In other words, the gradient of the curve decreases by increasing the river slope. It is clear that the maximum flood discharge in rivers with longitudinal slope more than 0.6% has a lesser amount of sensitivity to changes in the river bed slope. In short, any increase or decrease in the river slope have a small effect on the maximum discharge of flood and time to peak in small catchments. Increase in the area of the catchment results in an increase of the influence of the upstream river slope.

The topographical site index is presented in this research to evaluate the central and decentral flood retarding dams. It is the ratio of volume of dam body to reservoir volume and it is an indicator which shows the topographical identification of dam sites according to flood defense measure. In general, the geometry of embankments dams make an example function of increasing the dam cost by dam height. The reservoir volume is determined by the ArcView program from the catchment topography.

In addition, the followings points are clear:

- Topographical site index is an indicator which shows the topographical identification of dam sites according to flood defense measure.
- The gradient of H-f curves is negative that demonstrates the value of f decreases while dam height increases.
- The curve gradient is small in low dam height and f value changes rapidly. In higher height of dams, f value changes slowly and it can be said that the curve has one asymptote line.

The above theory was used to compare the different dam sites and flood control for the Erpe (153 km<sup>2</sup>) and Diemel (1800 km<sup>2</sup>) catchments. Four artificial topographies (named A, B, D and E) were selected by the study of flood parameter changes for the Erpe catchment. These four topographies and the existing topography (called C) were examined to study the flood defense measures for the Erpe and Diemel catchments.

Six places were considered to construct decentral dams for the Erpe catchment. In addition, the topographical and flood parameters were calculated for the sites. The topographical site index was calculated for all sites and all five scenarios. Safe flood discharge in the catchment mouth was fixed in the Erpe scenarios. Therefore, the dams' height is changed to attain a safe discharge. The reservoir volume curves show that (rate of changes of dam height to reservoir volume) is high in the low dam heights and it decreases by raising the height. Whenever the catchment is converted into flatter surface slopes, the curve lies and decreases because of a decrease in river bank and longitudinal slopes. The curves of the topographical site index show the variation of flood volume cost. In other words, the total cost of flood retarding dam become equal to the scalar product of  $f \cdot \phi \cdot \lambda \cdot V_r$ . The results show the variations of different sites according to their effects on the flood. An investigation on the sites' information in the Erpe catchment shows that an increase in the land surface slope causes a shift in the H-f curve to the right and as a result, the f value is raised. Thus, the dam's height rises to achieve full flood control. It is converse for the decreasing land surface slope. This means that the f curve moves to the left by a decrease in the land surface slope, therefore f value is decreased, as well as dam height. This also applies to decentral dams. Central and decentral dams were compared by means of the topographical site index for all topographical scenarios of the Erpe catchment. The equivalent topographical site index was calculated for decentral dams and then compared with the central dam in each scenario. As a result, the central dams are appropriate for all scenarios.

Ten sites have been selected on the Diemel catchment and were examined to build decentral dams. Five systems of the Diemel catchment containing four artificial catchments and the existing catchment were modeled by way of the described conditions. H-f curves were determined and investigated to compare decentral dams and central dam. The heights of the dams were taken as constant values in the different scenarios. Therefore, the catchment has been modeled. The value of topographical site index considered for all dams and scenarios. So the comparisons of different sites are showing us the cost of flood retaining in every dam. For Diemel catchment sites No. 1, 2, 5, 12 are more expansive than others. According to the results, the flood defense cost by using the central and decentral dams in catchments with steep topographies is more expensive than flatter topographies. The results showed that the maximum decreases of flood in cases in which the land surface slope increases. By close look at the curves, it can be understood that the cost of retarded flood varies in different sites. The results show that the H-f curves are scattered on the sheet area in very steep catchments; conversely in flat catchments, h-f curves are close together. In other words, the differences of dam sites are more important in steep catchments than in flat catchments.

## Zusammenfassung

### Auswirkungen der Topographie auf die Wirksamkeit von Hochwasserschutzmaßnahmen

Hochwasserereignisse hängen von vielfältigen Einflüssen ab. Hierzu zählen neben der Art des Niederschlagsereignisses Kenngrößen des Einzugsgebietes, wie z.B. Topographie, Gewässernetz, Fließgefälle, Bodenart, Landnutzung, Vegetationsperiode, welche bei der Planung von Hochwasserschutzmaßnahmen eine wichtige Rolle spielen.

Gegenstand dieser Dissertation ist es, den Einfluss der Einzugsgebietstopographie auf die Leistungsfähigkeit von Hochwasserschutzmaßnahmen anhand von Fallstudien zu untersuchen.

Als Modellgebiet wurde beispielhaft das Einzugsgebiet der Diemel und der Erpe herangezogen. Die Diemel ist ein westlicher Nebenfluss der Weser in Hessen und Nordrhein-Westfalen mit einer Gesamtlänge von 110,5 km und einer Einzugsgebietsgröße von 1.800 km<sup>2</sup>. Für die anstehenden Untersuchungen wurde das Modellgebiet von der Diemel-Talsperre bis zur Mündung in die Weser bei Bad Karlshafen auf eine Länge von 90 km betrachtet.

Für Grundlagenuntersuchungen und Sensitivitätsanalysen wurde als pilothaftes Modellgebiet die Erpe als ein Teileinzugsgebiet der Diemel mit einer Größe von 153 km<sup>2</sup> herangezogen und in einem ersten Schritt losgelöst vom Diemeleinzugsgebiet betrachtet. Die Erpe ist mit 26 km Länge ein rechter Nebenfluss der Twiste, die in ihrem weiteren Verlauf in die Diemel mündet.

Um den Einfluss der Topographie auf natürliche Hochwasserereignisse und mögliche Hochwasserschutzmaßnahmen zu untersuchen, wurde für die Einzugsgebiete der Diemel und Erpe auf ein bereits bestehendes Niederschlags-Abfluss-Modell (NA-Modell) zurückgegriffen, welches mit dem Simulationswerkzeug NASIM erstellt wurde. Darauf aufbauend wurden Szenarien angelegt, in denen veränderte Topographien synthetische Einzugsgebiete bilden. Die modifizierten Topographien sind durch GIS-basierte Bearbeitung der Höheninformationen am bestehenden digitalen Geländemodell (DGM) erzeugt worden.

In einem ersten Schritt wurden am Einzugsgebiet der Erpe umfangreiche Szenarien unterschiedlicher Topographien aufgestellt und anschließend Niederschlags-Abfluss-Berechnungen durchgeführt. Dabei wurden hinsichtlich der Landnutzung keine Variationen im NA-Modell vorgenommen, gleichwohl bei veränderter Topographie auch mit vegetativen Wechseln zu rechnen ist.

Das Einzugsgebiet der Erpe besteht aus insgesamt 27 Teileinzugsgebieten, mit einer jeweiligen Fläche kleiner als 10 km<sup>2</sup>. Um den Einfluss des Abflussgeschehens in Abhängigkeit der Einzugsgebietsgröße bei Veränderung der topographischen Verhältnisse erkennen zu können, wurden daraus 16 Teileinzugsgebiete mit Abmessungen größer (6) und kleiner (10) 15 km<sup>2</sup> aufgestellt. Die künstliche Oberfläche dieser Einzugsgebiete wurde durch Faktorisierung der Höheninformationen aus der bestehenden Topographie generiert. Aus den Ergebnissen der durchgeführten Simulationen am NA-Modell der Erpe lässt sich ableiten, dass mit Zunahme des topographischen Gefälles der Hochwasserscheitel erhöht und die Anstiegszeit

der Hochwasserwelle verkürzt wird. Erfolgt hingegen eine Abflachung des Geländegefälles, so ist eine Umkehrung der Ergebnisse zu beobachten. Den Berechnungen ist zu entnehmen, dass die Geländeneigung bei Einzugsgebieten größer 15 km<sup>2</sup> einen höheren Einfluss auf die Abflussgeschehen hat. Aus den Erkenntnissen der durchgeführten Simulationen am Modellgebiet der Erpe lassen sich Einzugsgebiete in vier Klassen bezüglich ihrer durchschnittlichen Geländeneigung und hinsichtlich der Sensibilität des Abflussscheitels bei Veränderung der Topographie einteilen:

- erste Klasse (I - low land): das durchschnittlichen Gefälle der Einzugsgebiete ist kleiner als 3,5 %. In dieser Klasse reagiert das Abflussgeschehen sehr sensitiv auf topographische Veränderungen,
- zweite Klasse (II - medium land): umfasst Einzugsgebiete mit mittlerer Steigung von durchschnittlich 3,5 % bis 10 %. Das Abflussgeschehen in dieser Kategorie reagiert weniger sensitiv auf topographische Veränderungen,
- dritte Klasse (III - steep land): umfasst Einzugsgebiete steiler Topographie, welche eine mittlere Steigung von 10 % bis 28,6 % aufweisen. Der Einfluss von topographischen Veränderungen auf das Abflussgeschehen ist als gering einzuschätzen,
- vierte Klasse (IV - very steep land): die durchschnittliche Geländeneigung ist größer als 28,6 %. In dieser Kategorie sind die Einzugsgebiete meist sehr klein und Veränderungen in der Topographie haben keine signifikanten Auswirkungen auf den Ablauf eines natürlichen Hochwassers.

Aus den Ergebnissen der NA-Berechnungen am Einzugsgebiet der Erpe wurden für die weiteren Untersuchungen vier synthetische Topographien ausgewählt, welche die zuvor beschriebenen Kategorien mit Ausnahme der vierten Klasse - begründet durch geringe Auswirkungen auf das Abflussgeschehen - repräsentieren. Zwei Szenarien wurden aus der ersten Klasse, jeweils eins aus der zweiten und dritten Klasse ausgewählt. Das reale Einzugsgebiet ist der zweiten Klasse zugeordnet worden, welches im weiteren Untersuchungsprogramm ebenso Anwendung findet. Die Generierung der Topographien für das Einzugsgebiet der Diemel erfolgte auf Grundlage der verwendeten Überhöhungsfaktoren für die vier repräsentativen synthetischen Topographien der Erpe. Dadurch war eine kongruente Erstellung der vier künstlichen Topographien für Untersuchungen zum Abflussverhalten im gesamten Einzugsgebiet an der Diemel möglich. Zunächst wurde im Rahmen des Untersuchungsprogrammes unter Verwendung eines mit NASIM erstellten NA-Modells für die Diemel und Erpe die Auswirkung wechselnder Gefälleverhältnisse des Hauptgewässers auf die Hochwasserganglinie untersucht. Aus den Ergebnissen der durchgeführten Simulationen lässt sich ableiten, dass der ermittelte Maximalabfluss von der Einzugsgebietsgröße abhängt. Des Weiteren wurde für das Modellgebiet der Erpe bei einer Erhöhung des Fließgefälles um 1 % ein Anstieg des Hochwasserabflusses um 12,5 % festgestellt.

Für das Einzugsgebiet der Diemel wurden zwei Szenarien hinsichtlich der Variation des Fließgefälles untersucht. Zum einen die Veränderung des Fließgefälles ausschließlich im Hauptgewässer der Diemel, zum anderen die Modifikation des Fließgefälles im gesamten Gewässernetz des Einzugsgebietes. Dabei wurde das mit durchschnittlich 0,28 % angenommene Fließgefälle im Hauptfluss der Diemel im Bereich von 0,011 % bis 1,03 % variiert. Aus den Ergebnissen der durchgeführten Simulationen wird ersichtlich, dass mit Erhöhung des Fließgefälles eine Zunahme der Fließgeschwindigkeit einhergeht, wodurch eine Reduzierung der Fließzeit sowie eine Maximierung des Scheitelabflusses erfolgt. Hingegen verringert sich bei Abflachung des durchschnittlichen Fließgefälles auf 0,07 % der maximale Abfluss um ca. 35 %.

Der beispielhaft am Einzugsgebiet der Diemel vorgenommene Vergleich eines Hochwasserabflusses mit unveränderter Topographie und Ereignissen bei verändertem Fließgefälle zeigt auf, dass Veränderungen der Sohlneigung bei flachen Topographien starke Auswirkungen auf das Abflussgeschehen haben. Hingegen reagiert der maximale Abfluss bei Flüssen mit einem Längsgefälle von mehr als 0,6 % weniger empfindlich auf Veränderungen des Fließgefälles. Aus den Erkenntnissen der Berechnungsergebnisse lässt sich schlussfolgern, dass eine Veränderung des Fließgefälles in kleinen Einzugsgebieten geringe Auswirkungen auf den Hochwasserscheitel und auf die Zeitdauer bis zum Eintreffen der Hochwasserspitze hat, hingegen bei größeren Einzugsgebieten der Einfluss eines veränderten Fließgefälles von Bedeutung ist.

Um den Einfluss der Topographie auf Hochwasserschutzmaßnahmen aufzuzeigen, wurde der topographische Lage-Index (f-Index) hergeleitet, mit dessen Hilfe eine Bewertung der Lage von zentralen und dezentralen Hochwasserschutzmaßnahmen vorgenommen werden kann. Dieser Parameter kennzeichnet das Verhältnis des Dammkörpervolumens zum Rückhaltevolumen und verdeutlicht die Charakteristika der topographischen Lage von Hochwasserrückhaltebecken. Im weiteren Verlauf der Untersuchungen wurden beispielhaft an den Einzugsgebieten der Erpe und der Diemel unterschiedliche Standorte für Hochwasserrückhaltebecken anhand dieser Kenngröße miteinander verglichen. Das Volumen der Reservoirs wurde anhand der digitalen Geländemodelle für die Szenarien der ausgewählten Topographien ermittelt. Im Allgemeinen können durch eine auf die Geometrie des Dammes bezogene Beispielfunktion die mit der Dammhöhe steigenden Kosten veranschaulicht werden. Aus den Ergebnissen ist ersichtlich, dass bei geringen Dammhöhen eine starke Veränderung des f-Indexes zu verzeichnen ist, während im Bereich hoher Dammhöhen die Funktion asymptotisch verläuft, wodurch der Parameter nur geringe Änderungen aufweist.

Für das Einzugsgebiet der Erpe wurden sechs potentielle Standorte für Hochwasserrückhaltebecken in Betracht gezogen, an denen der topographische Lage-Index für alle fünf Szenarien verschiedener Topographien berechnet wurde. Im Vorfeld dieser Berechnungen wurde der maximal zulässige Abfluss der Erpe am Auslass des Einzugsgebietes festgelegt. Um diesen Abfluss aus den Ergebnissen der NA-Berechnungen zu generieren, wurden die Dammkronenhöhen variiert und im NA-Modell eingebunden. Die Ergebnisse der Simulationen zeigen, dass bei gleich bleibender Dammhöhe in flacheren Einzugsgebieten ein höheres Speichervolumen aktiviert werden kann. Weiterhin wird ersichtlich, dass eine Veränderung der Dammhöhe im niedrigeren Bereich große Auswirkungen auf das Rückhaltevolumen hat. Eine Gegenüberstellung der Graphen des topographischen Lage-Indexes in Bezug zum gewählten Szenario im Einzugsgebiet der Erpe zeigt, dass eine Erhöhung der Geländetopographie im Ergebnis den Wert des Lage-Indexes erhöht. Folglich ist die Dammhöhe zum Schutz vor Hochwasser zu erhöhen. Aus den Ergebnissen unter Betrachtung der Szenarien mit abgeflachter Topographie verringert sich der f-Wert ebenso wie die Dammhöhe. Diese Erkenntnis konnte sowohl bei den Untersuchungen zu dezentralen als auch zentralen Hochwasserrückhaltebecken gewonnen werden.

Analog zu den Untersuchungen am Einzugsgebiet der Erpe wurden für das Modellgebiet der Diemel insgesamt zehn potentielle Standorte für dezentrale Hochwasserrückhaltebecken ausgewählt und im NA-Modell eingebunden. Es lässt sich feststellen, dass der Bau von zentralen und dezentralen Hochwasserrückhaltebecken zur Gewährleistung des Hochwasserschutzes in Einzugsgebieten mit steilerer Topographie teurer ist als in Gebieten mit flacherer Geländestruktur. Ein Vergleich zwischen zentralen und dezentralen Hochwasserrückhaltebecken in den untersuchten Szenarien ergab, dass der zentrale Hochwasserschutz durch einen niedrigeren f-Wert vorteilhafter zu bewerten ist.

Aus den Erkenntnissen der im Rahmen dieser Dissertation durchgeführten Untersuchungen lassen sich folgende Aussagen treffen:

Einzugsgebietsflächenplanung und -management beinhalten eine Verringerung des Abflusses durch Erhöhung der Infiltration, Interzeption und Flächenrückhalt. Die Wirkung von Hochwasserschutzmaßnahmen, die zu einer Reduzierung des Abflussvolumens und der Abflussgeschwindigkeit führen sollen, ist in flachen Einzugsgebieten stärker einzuschätzen.

Der Hochwasserscheitelabfluss und die Zeitdauer bis zu seinem Erreichen stehen in exponentiellem Verhältnis zum Gefälle des Gewässernetzes. Bei gleicher Veränderung des Fließgefälles sind die Retentionseffekte in Gewässernetzen mit geringem Gefälle höher als in topographisch steileren Gebieten. Allgemein ist in großen Einzugsgebieten die Retention im Gewässernetz höher. Das heißt, die Möglichkeit, mit Flussrenaturierungen den Hochwasserscheitel zu reduzieren, nimmt bei einer Vergrößerung des Einzugsgebietes zu. In großen Einzugsgebieten hat das Gefälle des Hauptflusses in Abschnitten mit geringem Gefälle eine hohe Bedeutung für das Retentionsvermögen.

Der topographische Lage-Index wurde in dieser Forschungsarbeit entwickelt, um zentrale und dezentrale Hochwasserrückhaltebecken vergleichend bewerten zu können. Aus dem Vergleich der berechneten Lage-Indizes entsprechend der untersuchten Topographie lässt sich schlussfolgern, dass in steilen Einzugsgebieten die Standortauswahl für Hochwasserrückhaltebecken einen größeren Einfluss auf die Hochwasserschutzkosten hat als in flachen Einzugsgebieten. Dies zeigt, dass die Standortauswahl in bergigen Einzugsgebieten sehr wichtig ist.

## Table of contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Problem definition	3
1.2	The research objectives	4
1.3	Research methodology	5
<b>2</b>	<b>Flood and flood defense measures (Literature review)</b>	<b>6</b>
2.1	Measurable features of flood	6
2.2	Flood defense measures	7
2.3	Flood defense approaches and strategies in Germany	9
2.4	Flood defense measures in mountain areas	10
2.5	Flood defense measures in low land areas	12
2.6	Conclusion	13
<b>3</b>	<b>General relation between catchment topography and flood defense measures</b>	<b>14</b>
3.1	Introduction	14
3.2	Land surface topography and flood defense measures	15
3.3	Flood plain topography and flood defense measures	21
3.3.1	Flood plain topography and flood storage	21
3.3.2	Flood plain topography and river restoration	25
3.4	Conclusion	26
<b>4</b>	<b>Material and methods, investigate the effectiveness of topographical parameters on selected flood defense measures</b>	<b>29</b>
4.1	Introduction	29
4.2	NASIM rainfall runoff model	29
4.2.1	General structure	30
4.2.2	NASIM elements	30
4.2.3	Principle of cascade of storage	30
4.2.4	Components of NASIM	31
4.2.5	Input data	35
4.3	ArcView	36
4.4	Base catchment of study	36
4.5	Creation of the artificial catchments	39
4.6	Investigation of selected flood defense measures	40
4.6.1	Land surface retention	40
4.6.2	River restoration	41
4.6.3	Central and decentral dams	41
4.7	Conclusion	44
<b>5</b>	<b>Application of different scenarios for Erpe catchment as a pilot area</b>	<b>46</b>
5.1	Introduction	46
5.2	General information of Erpe catchment	47
5.2.1	Topography	47
5.2.2	Geology and soil types	48
5.2.3	Climatological data	48
5.2.4	Land use	49
5.3	System plan	51

5.4	Influence of upstream River slopes on flood parameters	51
5.5	Influence of Land surface topography on flood	56
5.6	Topography scenarios matched with flood defense measures	60
5.6.1	Land surface retention:	62
5.6.2	River restoration	64
5.6.3	Central and decentral dams	65
5.7	Conclusion	70
<b>6</b>	<b>General information of Diemel catchment</b>	<b>72</b>
6.1	Introduction	72
6.2	Climatological data	72
6.3	Diemel topography	72
6.4	Geology and soil types	72
6.5	Land use	73
6.6	River system	73
6.7	Model definition and calibration	73
6.8	Conclusion	73
<b>7</b>	<b>Rainfall runoff simulation of Diemel catchment scenarios</b>	<b>79</b>
7.1	Introduction	79
7.2	Influence of upstream main river slope on flood	80
7.3	Land surface slope scenarios	83
7.3.1	Retarding decentral and central dams	83
7.3.1.1	The existing topography (topography C)	85
7.3.1.2	Very steep topography (topography A)	86
7.3.1.3	Steep topography (topography B)	88
7.3.1.4	Flat topography (topography D)	89
7.3.1.5	Very flat topography (topography E)	90
7.3.2	Comparison of results	91
7.4	Conclusion	92
<b>8</b>	<b>Discussion of results and conclusion</b>	<b>95</b>
8.1	Introduction	95
8.2	Influence of land surface slope on floods	95
8.3	Topographical parameters and flood defense measures	96
8.4	Rivers restoration	97
8.5	Central and decentral dams	98
8.6	Final Conclusion	101
8.7	Recommendations	102
	<b>References</b>	<b>103</b>

## List of figures

Figure 1-1	Afsluitdijk Dike in the Netherland [50]	3
Figure 1-2	Problem definition, effective elements in natural flood	3
Figure 2-1	Measurable features of flood	6
Figure 2-2	Structural and non-structural flood defense measures	7
Figure 2-3	Flood defense related to river restoration [32]	8
Figure 2-4	Flood retention basin in Netherlands [33]	13
Figure 3-1	Flood retention on land surfaces	15
Figure 3-2	Effect of land surface slope on surface hole storage and infiltration rate	16
Figure 3-3	Groundwater table and land surface slope	17
Figure 3-4	Land surface slope and variation of different parameters	19
Figure 3-5	Agricultural type and land surface slope	20
Figure 3-6	On-line and off-line flood reservoirs	21
Figure 3-7	Dams classification according to DIN 19700-12	22
Figure 3-8	Hydraulics operation rule in flood mitigation dams [25]	23
Figure 3-9	Diagram of flood mitigation reservoir classification and topography	24
Figure 3-10	Broad level stream classification delineation showing longitudinal, cross section and plan views of major system type [41].	26
Figure 3-11	Flood defense measures related to the topographical elements	28
Figure 4-1	Main components of NASIM model [23]	32
Figure 4-2	Soil model in NASIM	33
Figure 4-3	Soil moisture sections [23]	33
Figure 4-4	Runoff concentration concept in NASIM	34
Figure 4-5	Isochrones, line of same travel time [23]	35
Figure 4-6	The Weser forms at Hann. Münden by the tributary (confluence) of the Fulda and Werra	37
Figure 4-7	Location of Diemel catchment on Weser catchment	38
Figure 4-8	Schematic view of artificial topographies	39
Figure 4-9	Parameters definition to create artificial topography	40
Figure 4-10	Operation rule of dam outlet	42
Figure 4-11	Earth dam and valley cross sections	43
Figure 5-1	Location of the Erpe in Diemel catchment	46
Figure 5-2	The executive flowchart for Erpe catchment	47
Figure 5-3	The topography map of Erpe catchment	49
Figure 5-4	Distribution of different soil type in Erpe catchment	49
Figure 5-5	Distribution of different land use in Erpe catchment	50
Figure 5-6	Erpe catchment subdivisions and its system plan	52
Figure 5-7	The maximum flood discharge versus slope of rivers network	53
Figure 5-8	Dimensionless maximum discharge versus river slope (E denotes to existing catchment)	54
Figure 5-9	Changes of relative maximum discharge versus relative rivers slope	54
Figure 5-10	Changes of relative flood time to peak versus relative river slope	55
Figure 5-11	Different artificial catchments	56
Figure 5-12	The selected subcatchments and their information	57
Figure 5-13	Flood hydrographs for different land surface scenarios (E is exist catchment)	58
Figure 5-14	Relation between relative discharge and mean land surface slope for small catchments (above) and large catchments (below).	59

Figure 5-15	$T_{\max}/(T_{\max})_E$ versus land surface slope for small catchments (above) and large catchments (below), T is the time to peak and $T_E$ is the same in existing condition.	59
Figure 5-16	Different land surface slope and flood defense measures scenarios for Erpe catchment	61
Figure 5-17	Flood hydrographs in the mouth of Erpe catchment for different value of extra infiltration rate	63
Figure 5-18	Effect of infiltration rate in agricultural lands on maximum flood discharge	64
Figure 5-19	Influence of flow velocity in rivers network (C.U is the velocity coefficient) on flood hydrograph.	65
Figure 5-20	Location of dam's sites on Erpe: a) central dam; b) decentral dams	66
Figure 5-21	Dam height and reservoir volume for deferent scenarios of dam site No. 1	66
Figure 5-22	The hydraulic operation rule of flood mitigation dam No 1	67
Figure 5-23	The H-f curve for dam site No. 1	67
Figure 5-24	Changes of topographical site index for different scenarios	69
Figure 5-25	Required reservoirs capacities for different topography	70
Figure 5-26	Comparison of equivalent f for decentral dams and central dams	70
Figure 6-1	Location of Diemel catchment	74
Figure 6-2	Topography map of Diemel catchment	75
Figure 6-3	The diversity and amount of different soil types in the Diemel catchment	76
Figure 6-4	Diemel land use map	77
Figure 6-5	Diemel river and its tributaries	78
Figure 7-1	Diemel catchment scenarios	79
Figure 7-2	Longitudinal bed profile of Diemel river from Bad Karlshafen to Diemel dam	80
Figure 7-3	Flood hydrographs at the mouth of Diemel catchment	81
Figure 7-4	Variation of maximum flood discharge against Diemel river slope	81
Figure 7-5	Maximum flood discharge along the Diemel main river	82
Figure 7-6	Comparing flow velocity changes in the Diemel river and in whole rivers network, U and $U_E$ are the flow velocity in the river and existing situation respectively.	82
Figure 7-7	Reservoir of Diemel dam (Google earth)	83
Figure 7-8	Location of decentral dams on the Diemel catchment	84
Figure 7-9	Dam volume and area curves	85
Figure 7-10	Effect of central and decentral dams on flood hydrograph, topography C	86
Figure 7-11	Maximum flood discharge along the Diemel river topography C	86
Figure 7-12	Effect of central and decentral dams on flood hydrograph, topography A	87
Figure 7-13	Maximum flood discharge along the Diemel river for topography A	87
Figure 7-14	Effect of central and decentral dams on flood hydrograph, topography B	88
Figure 7-15	Maximum flood discharge along the Diemel river for topography B	88
Figure 7-16	Effect of central and decentral dams on flood hydrograph, topography D	89
Figure 7-17	Maximum flood discharge along the Diemel river for topography D	89
Figure 7-18	Effect of central and decentral dams on flood hydrograph, topography E	90
Figure 7-19	Maximum flood discharge along the Diemel river for topography E	90
Figure 7-20	The variation of H-f curves for different scenarios in dam No 1	91
Figure 7-21	The variation of f for different scenarios of land surface slope	91
Figure 7-22	The comparison of equivalent f for decentral dams and central dams	92
Figure 7-23	H-f curves for selected dams on Diemel catchment with different topographies	94
Figure 8-1	Flood defense measures on catchment area and topography	97

Figure 8-2	An example of dam body and reservoir volumes curves	99
Figure 8-3	An example of the topographical site index curve	99
Figure 8-4	Variation of topographical site index with topography changes	100

## List of tables

Table 2-1	Categories of flood control measures (Higgins and Robinson 1993, [36])	8
Table 2-2	Flood defense strategies according to LAWA (2003)	10
Table 3-1	Different items which are affected to take flood in place	18
Table 5-1	Soil types information in the Erpe catchment	48
Table 5-2	Land use of Erpe subcatchment	50
Table 5-3	Land use parameters	51
Table 5-4	Relation between upstream rivers network slope and flood parameters	55
Table 5-5	$\gamma, \delta, \varepsilon$ and $\theta$ are function of the catchment area	58
Table 5-6	Classification of catchments topographies.	60
Table 5-7	Selected scenarios of land surface topography for more investigations.	62
Table 5-8	The soil characteristics of agricultural lands.	63
Table 5-9	Flood volume in m <sup>3</sup> for different land surface slope scenarios	64
Table 5-10	Topographical site index for different dam site and scenarios	69
Table 7-1	Information of decentral dams on Diemel catchment	84
Table 7-2	Reservoir volume and f value for decentral dam's scenarios	93
Table 8-1	Sensitivity of flood parameters according to land surface	96

## Glossary

**Catchment:** Catchment or river basin or watershed is the area tributary to a given point on a stream and is separated from adjacent basins by a divide, or ridge that can be traced on topography maps.

**Catchment topography:** Involves some elements such as flood plain topography (containing the longitudinal river slope and river cross section) and land surface slope. Topography of a catchment is constant and it doesn't change in a short period of time.

**Concentration time:** the time needed for water to flow from the most remote point in a catchment to the catchment outlet.

**Drainage network:** A drainage system is the pattern formed by the streams, rivers and lakes in a particular watershed.

**Evapotranspiration:** Evapotranspiration (ET) is a term used to describe the sum of evaporation and plant transpiration from the Earth's land surface to atmosphere.

**Field capacity:** Field capacity is the amount of soil moisture or water content held in soil after excess water has drained away and the rate of downward movement has materially decreased, which usually takes place within 2–3 days after a rain or irrigation in previous soils of uniform structure and texture.

**Flood:** A flood is an overflow or accumulation of an expanse of water that submerges land [50].

**Flood frequency:** It is knowledge of magnitude and probable frequency of recurrence of floods

**Flood defense measures:** The effort to reduce the effects of flooding is called “flood defense measures” or “flood protection measures.

**Flood plain:** Is a strip of land that borders a stream channel and that is normally inundated during seasonal floods. Flood plain is underlined by the deposit of river channel, of over bank floods and of lakes [8].” Flood plain width in natural rivers can vary from channel belt width to as many as ten folds of channel belt width.

**Hydraulic models:** In hydraulic models the flow in the reach is calculated by using the continuity and momentum equations together. In this case the characteristics of the flow and river, such as river topography and river roughness, are necessary. The results of hydraulic models to calculate the water depth and flood inundated area are more reliable than the results of hydrological models.

**Hydrologic cycle:** The hydrologic cycle or water cycle describes the continuous movement of water on, above and below the surface of the Earth. Since the water cycle is truly a "cycle," there is no beginning or end. Water can change states among liquid, vapor and ice at various places in the water cycle.

**Hydrologic models:** All methods of channel routing in which a channel reach is treated as a lumped system and the momentum equation is replaced either by black box representation or by a conceptual model. Such methods require estimated rain data and data from the past flood events for the upstream and downstream of the reach for their calibration and can be used even when nothing is known about the topographical or roughness characteristics of the intermediate channel sections [28].

**Interception:** The precipitation that is intercepted by plant foliage and eventually evaporates back to the atmosphere rather than falling to the ground.

**Infiltration:** The flow of water from the ground surface into the ground.

**Land surface area or slope:** A part of watershed which overland flow is formed upon. This part is under precipitation and is a place where water flows over the land surface toward streams.

**Land use:** Land use is the human modification of natural environment or wilderness into built environment such as fields, pastures and settlements.

**River restoration:** “The complete structural and functional return to pre-disturbance state” (Carins 1991); or “in essence, river restoration which is a process of recovery enhancement. Recovery enhancement enables the river or the stream ecosystem to stabilize (some sort or tropic balance) at a much faster rate than through the natural physical and biological processes of habitat development and colonization. Recovery enhancement should establish a return to an ecosystem which closely resembles unstressed surrounding areas (Gore, 1985) [9].”

**Runoff:** The variety of ways by which water moves across the land. This includes both surface runoff and channel runoff. As it flows, the water may infiltrate into the ground, evaporate into the air, become stored in lakes or reservoirs, or be extracted for agricultural or other human uses.

**Sodium adsorption ratio (SAR):** is a measure of the suitability of water for use in agricultural irrigation, as determined by the concentrations of solids dissolved in the water. It is also a measure of the sodicity of soil, as determined from analysis of water extracted from the soil.

**Soil:** The term soil is usually used to describe the surface layer of ground ranging in thickness from a few centimeters to a few meters.

**Soil texture:** Soil texture is a soil property used to describe the relative proportion of different grain sizes of mineral particles in a soil.

**Structural and non-structural flood defense measures:** The structural measures aim to reduce flood volume or peaks and thereby to protect people and other objects against flood damages. Non-structural measures comprise of regulations and policies and flood insurance. These measures strive to reduce flood impacts without altering flood characteristics and focus on policies and emergency measures.

**Topography:** The topography of a catchment is the current terrain feature of the region and the land form caused by geomorphologic processes and erosion over millions of years.

**Topographical site index:** The topographical site index is a ratio of the dam body to the reservoir volume which shows that they are affected by topography.

**Total pour volume:** is the total volume of empty spaces in soil that it is equal of total soil volume minus volume of solid materials.

**UTM:** The Universal Transverse Mercator coordinate system is a grid-based method of specifying locations on the surface of the Earth.

**Wilting point:** is defined as the minimal point of soil moisture the plant requires not to wilt.

## Abbreviations

Abbreviation	Description
DIN	Deutsches Institut für Normung
DTLR	Department of Transport Local Government Region
DVWK	Deutscher Verband für Wasserwirtschaft und Kulturbau e.V.
EC	Electrical Conductivity
FK	Field capacity
GIS	Geographical Information System
GPV	Total pour volume
gS	Debris Sand
HQ <sub>5</sub>	Five years flood
ICOLD	International Commission On Large Dams
In <sub>max</sub>	Maximum infiltration rate
Kf	Saturated hydraulic conductivity
M	Marsh
NASIM	Niederschlag-Abfluss-SIMulation
LAWA	German Working Group on Water Issues of the Federal State of Germany
LS	Poor sandy laom
SAR	Sodium Adsorption Ratio (SAR)
SCS	The Natural Resources Conservation Service (NRCS), formerly known as the Soil Conservation Service (SCS), is an agency of the United States Department of Agriculture (USDA) that provides technical assistance to farmers and other private landowners and managers.
T	Clay
U	Silt
UTM	The Universal Transverse Mercator (UTM) coordinate system
WHG	The law for water management
WP	Wilting point

## List of symbols

Symbol	Dim/ Unit	Definition
$a_d$	L	The crest width of dam
b	L	River width in the bottom of dam
$C_d$	€	The total cost of dam
$C_e$	€	The total cost of embankment
$C_t$	-	Coefficient of increasing or decreasing of elevation to produce the artificial topography
$C_u$	€	The ratio of total cost of dam to reservoir volume, or the cost of unit reservoir volume
CU	-	River velocity coefficient which used to increase or decrease the velocity
f	-	Topographical site index is the ratio of embankment volume to reservoir volume
$f_e$	-	Equivalent topographical site index: $f_e = \frac{\sum f_i V_r}{\sum V_r}$
Fk	-	Field capacity
GPV	-	Total pore volume
$H_d$	L	The height of dam
I	$L^3/T$	Inflow to reservoir or basin
K	T	The storage is linearly related to the outflow by storage constant K
Kf	$L/T$	Saturated hydraulic conductivity
$m_d$	L	Indicates the downstream side slope of embankment (slope is equal 1 vertical to $m_d$ horizontal)
$m_u$	L	Indicates the upstream side slope of embankment (slope is equal 1 vertical to $m_u$ horizontal)
M.Infilt.	$L/T$	Maximum infiltration rate
n	$L^{-1/3}T$	Manning river roughness coefficient
$n_l$	L	Indicates the left bank slope of valley at dam sight (slope is equal 1 vertical to $n_l$ horizontal)
$n_r$	L	Indicates the right bank slope of valley at dam sight (slope is equal 1 vertical to $n_r$ horizontal)
L	L	Length of river, the sum of $L_i$ or total river length
$L_d$	L	The crest length of dam
$L_h$	L	The length of crest at height of h
$L_i$	L	The river length for subcatchment i
$L_z$	L	the length of the dam crest at the height of z
P(X,Y,Z)	(L,L,L)	The point of topography with Cartesian coordinates
P'(X,Y,Z')	(L,L,L)	Artificial point of topography
Q	$L^3/T$	Outflow from reservoir or basin
$Q_{m+0}$	$L^3/T$	Maximum existing flood discharge when $\Delta I = 0$ in cubic meter per second

$Q_{In+\Delta I}$	$L^3/T$	Maximum flood discharge when infiltration rate increases $\Delta I$ in cubic meter per second
$Q_{max}$	$L^3/T$	Maximum flood discharge
$(Q_{max})_E$	$L^3/T$	Maximum flood discharge according to existing situation
R	L	Hydraulic radius
S	-	Artificial upstream river slopes
$\bar{S}$	$L^3/T$	Water storage
$S_i$	-	River slope for subcatchment i
$S_E$	-	Existing upstream river slopes
$S_e$	-	The weighting average of slopes of upstream rivers
$S_m$	-	Mean land surface slope
U	$L/T$	Flow velocity
t	T	Time variable
$T_{max}$	T	Time to peak of flood
$(T_{max})_E$	T	Time to peak of flood according to existing situation
$V_d$	$L^3$	Volume of embankment
$V_{max}$	$L^3$	Maximum flood volume
$(V_{max})_E$	$L^3$	Maximum flood volume according to existing situation
Wp	-	Wilting point
X	L	Longitude coordinate of every point
Y	L	Latitude coordinate of every point
Z	L	Altitude coordinate of every point
$Z_0$	L	The altitude or Elevation of the catchment mouth
$Z'$	L	Elevation of artificial point
$\alpha, \alpha', \alpha''$	-	Coefficient of Relationship between $Q_{max}$ and relative river slope, weighting average river slopes and relative maximum discharge respectively
$\beta, \beta', \beta''$	-	Constant value of Relationship between $Q_{max}$ and relative river slope, weighting average river slopes and relative maximum discharge respectively
$\gamma$	-	Coefficient of the equation between the relative maximum discharge and the mean land surface slope
$\delta$	-	Constant value of the equation between the relative maximum discharge and the mean land surface slope
$\Delta I$	$L/T$	Increasing maximum infiltration rate in millimeter per hour
$\varepsilon$	-	Coefficient of the equation between the relative maximum time to peak and the mean land surface slope dependent on the catchment size
$\theta$	-	The power of the equation between the relative maximum time to peak and the mean land surface slope depend the catchment size
$\lambda$	-	The ratio of total dam cost to embankment cost
$\Phi$	€	The cost of one cubic meter of embankment, including materials transportation, construction and...

# 1 Introduction

According to ICOLD committee investigation in several countries, floods in the world constitute the most significant natural hazard both for the number of victims and for the grave social and economic impacts that they produce [24]. They are natural disasters that have been affecting human lives since time immemorial. A flood happens when an area of land, usually low-lying, is covered with water and it is classified by the source of water that creates them:

**Sea flooding:** Floods from the sea can cause overflowing or overtopping of flood-defenses, like dikes, as well as the flattening of dunes or bluffs. Land behind the coastal defense may be inundated or experience damage. A flood from the sea may be caused by a heavy storm (storm surge), a high tide, a tsunami, or a combination thereof. As many urban communities are located near the coast, this type of flooding is a major threat around the world.

**River and stream flooding:** River floods are the most common floods in the world. They are caused by heavy rainfall or rainfall combined with snowmelt, followed by the slow development of flood flows, which exceed the capacity of natural waterways. Other causes of river floods are:

- Surcharge in water levels due to natural or man-made obstructions in the flood path (bridges, gated spillways, weirs)
- Sudden dam failure
- Landslide
- Mud flow
- Inadequate urbanization (excessive encroachment in the floodway)
- Ice jam
- Rapid snowmelt
- Deforestation of the catchment basin

River floods can affect the rural and urban areas located in the flood plain. Human activity in the catchment and flood plains has increased the risk of flooding from river and streams over many years. Development has increased the natural capacity of flood plains and increased the rate of surface water run off.

**Groundwater flooding:** Flooding from groundwater is most likely to occur in areas of chalk, limestone, or other aquifers. This type of flooding generally affects older buildings close to winterbourne streams or houses with basements that are particularly prone to groundwater flooding. Depending on the local geology, groundwater flooding can take a long time to recede. Properties can still be underwater many months after the heavy rains that caused the flooding [16].

**Flooding from overland flow:** Overland flow flooding happens when water flows over the ground surface, which has not reached a natural or artificial drainage channel. This can occur when intense rainfall exceeds the infiltration capacity of the ground, or the ground is so highly saturated that it cannot accept any more water.

**Flooding caused by blocked or overloaded drainage systems:** Blockage or overloading of the pipes, sewers, canals and drainage channels, or failure of pumping systems.

**Flooding from infrastructures failure:** Structural hydraulic or geotechnical failure of infrastructures that retain, transmit, or control the flow of water.

Flood damage can range from being relatively minor (in which case a very limited volume of floodwater enters the buildings, farms, infrastructures, etc) to severe cases of deep water Flooding (in which case extensive damage occurs to humans, buildings, farms and infrastructures).

Floods are a natural catastrophic disaster. They can be extremely horrific and serious, often causing great suffering or damage in both short and long periods of time. The typical effects of floods are classified to:

Primary effects:

- **Property damage:** Structures such as buildings are damaged due to flood water. Landslides can also occur.
- **Casualties:** People and livestock die due to drowning. Epidemics and diseases may also develop.

Secondary effects:

- **Water supplies Contamination:** Clean drinking water becomes scarce.
- **Food supplies shortage:** Due to losses of entire harvests.
- **Diseases:** Unhygienic conditions cause incidences of disease.

Tertiary - long term effects:

- **Economic:** Floods generate problems in terms of long-term economic activities, creating hindrances such as: a temporary decline in tourism, rebuilding costs etc.

The effort to reduce the effects of flooding is called “flood defense measures” or “flood protection measures.” Until the 1980s, flood protection in the world was mainly realized by means of technical measures: e.g. dikes, dams, retention basins and channel improvements. The increase of environmental awareness, an adapted legislation and modified requirement for flood protection almost decreased the role of these measures. For example, following the flood events at the Rhine River in 1993 and 1995, the “German Working Group on Water Issues of the Federal State of Germany (LAWA) elaborated “guidelines for forward-looking flood protection” according to which natural flood protection, such as building and risk provision, is to be predominantly realized. There are different measures connected with floods that can reduce the harmful effects caused by them. These measures are evaluated for every flood plain in the world. In western countries, rivers prone to droughts are often carefully managed. Defenses such as levees, bunds, reservoirs and weirs are used to prevent rivers from bursting their banks. Coastal flooding has been addressed in Europe with coastal defenses, such as sea walls and beach nourishment.

The biggest and most elaborate flood defenses can be found in the Netherlands, where they are referred to as the Delta Works with the ‘Oosterscheldedam’ (It is located on Oosterschelde estuary in Zeeland the Netherlands) as its crowning achievement. These works were built in response to the North Sea flood of 1953 of the south western part of the Netherlands. The Dutch had already built one of worlds largest dams in the north of their country called Afsluitdijk (English: Closure Dike). It is a major dike in the Netherlands, constructed between 1927 and 1933 and running from Den Oever on Wieringen in North Holland province, to the village of Zurich (municipality Wûnseradiel) in Friesland province,

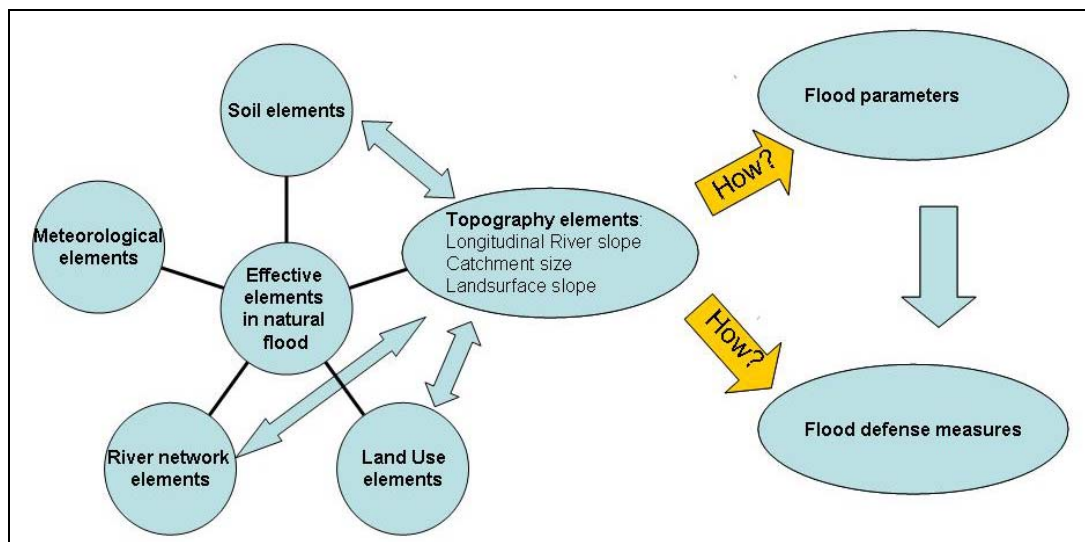
over a length of 32 km and a width of 90 m, at an initial height of 7.25 meters above sea-level (figure 1-1)[50].



**Figure 1-1 Afsluitdijk Dike in the Netherland [50]**

### 1.1 Problem definition

Effective elements in river and stream natural flooding are meteorological, soil, land use, river network and topography (figure 1-2). The meteorological elements contain rainfall, snow and hail and also climatic factors. Floods are created by rainfall or snow melt and sometimes rainfall on snow. The important climatic factors in floods due to rainfall are: amount, duration, intensity and distribution of the rainfall over the catchment. The meteorological characteristics depend on the situation of the earth and global and local weather circulation systems. Changing these elements by humans in order to control floods is not easy and almost impossible.



**Figure 1-2 Problem definition, effective elements in natural flood**

The term soil is usually used to describe the surface layer of ground ranging in thickness from a few centimeters to a few meters. Soil type and thickness are related to the land surface

slope and topography. Soil can affect floods by infiltration and surface retention. It changes by doing something on land surface like agricultural tillage operations. The agricultural tillage operations mix the surface soil and break sealed zones, causing the surface entry to be increased. On the other hand, plowing across the land surface slope will increase the infiltration of water volume and decrease the runoff volume.

The topography of a catchment is the current terrain feature of the region and the land form caused by geomorphologic processes over millions of years. Different kinds of erosion and also tectonic movements change the topography of a catchment during this time. The rate of these changes is very slow and for sensible feature change needs thousands of years. These changes in hydrological investigations are insignificant. The river network elements are formed by geological and topographical characteristics of the catchment. Their important role is to collect and convey the flood to their destinations. The physical materials at the surface of the earth (land cover) are connected to land use. They have a significant role to produce a flood. Usually in hydrological investigations, the combination of land use and soil elements is used to define the infiltration.

Flood defense measures contain some direct and indirect methods which meddle with flood elements such as: land use, drainage network and soil. During the last decades, numerous studies and research projects on different catchment areas have been carried out in the world, considering these elements and proposing different measures in order to provide an adequate flood protection. For example, there are many articles about the effects of land use changing, deforestation and housing on flood areas presented for different places in the world. Catchment topography affects, as direct or indirect parameters, the other flood elements; therefore it is a basic parameter for selecting and designing flood defense measures too. This research will consider the interactions of some flood defense measures with topography.

The catchment topography involves some elements such as flood plain topography (containing the longitudinal river slope and river cross section) and land surface slope. Topography of a catchment is constant and it doesn't change in a short period of time. Therefore, it is considered as a constant and stable factor in simulation models of rainfall-runoff. There are a wide range of methods to introduce topography to rainfall-runoff models. It can be done either with a few parameters or with total information of catchment topography. Rainfall-runoff models have been developed by use of total topography information, thanks to GIS programs and high power computers.

On the one hand, the main question here is the consideration of the effect of catchment topography on flood defense measures and their effectiveness. On the other hand, what will happen when all elements affecting a natural flood are constant and only change the catchment topography? Of course it is clear that in nature there are not two catchments with the same condition and different topography.

## **1.2 The research objectives**

The main aim of this research is to find out the impact of topography on a flood and the efficiency of flood defense measures. Perhaps in the small scale projects, the relations or effects of topography on flood parameters and flood defense measures are known but in this research such effects are investigated for wide catchment size ranging from a small catchment (4 km<sup>2</sup>) to a large catchment (1800 km<sup>2</sup>).

The objectives are as follows:

- Describing flood defense measures and topographical parameters according to past professional literatures.
- Combining flood defense concepts and topography parameters to find out the effects of topography changes on flood parameters.
- Finding the relationship between parameters of topography and a flood and also flood defense measures for Erpe and Diemel catchments by changing its topography.
- Comparing the central and decentral flood retarding dams for Erpe and Diemel catchments with various topography.

### **1.3 Research methodology**

This study shall examine the topographical impact on the effectiveness of flood defense measures by using literature study and also a case study catchment. In order to do so, Diemel catchment has been used as a case study area. The Diemel River is a tributary of Weser River, located in the middle of Germany. The catchment area is about 1800 km<sup>2</sup>. The main river length is about 90 km.

Since rainfall runoff simulation model has been developed for this catchment by use of NASIM hydrological model, it is used to connect the topography parameters to flood parameters for the catchment. This research will be done within the boundary of NASIM model capability. The utilizable program NASIM works mainly with physical parameters instead of the empirical approach of the SCS procedure. The soil parameters in particular, help to precisely display the runoff formation. Topographical data (digital terrain model 40·40 m) and data of the existing soil and land use are integrated into the model in high resolution and can be modified with Arc view.

To consider the effect of topography on flood and also on flood defense measures, some artificial catchments are created from the base catchment and then the output flood and also the flood defense measures will be examined for them. In the artificial catchments the topography of catchment is changed.

Different flood protection concepts for the various tributaries of the Diemel are to be integrated into the model. The methodical variation of the topography in combination with invariable boundary conditions shall help to confine the application area of the various measures. The objectification of the discussion about flood protection measures is an expected result of this research.

The approaches of the project is start with the general descriptions of fundamental concepts, continues with the methodology and finally use the model for Erpe and Diemel catchments and finally results investigation.

## 2 Flood and flood defense measures (Literature review)

### 2.1 Measurable features of flood

“Floods may be measured as to height (water level), area inundated, peak discharge and volume of flow. The height of flood (water level) is of interest to those planning to build structures along and across streams, the area inundated is of interest to those planning to occupy in any manner the flood plains adjacent to a stream; the peak discharge is of interest to those designing spillways, bridges, culverts and flood channels; and the volume of flow is of interest to those designing storage works for irrigation, water supply and flood control” [12]. There are some other important parameters such as time to peak of discharge, flood duration and flood return period. The elevation of flood peak discharge is the most frequently used fact of all flood data. The height, or flood elevation, is measured by special devices in the gaging stations at a point. The height of flood may also be calculated by hydraulic analysis of flow. Flood discharge can be measured by hydraulic methods or may be determined by analysis of hydrologic data for design of hydraulic structures and flood defense objects. The volume of flood may be measured directly by reservoir or calculated by flow discharge and time. It is important to calculate the volume of flood defense dams. The time that the stream remains at flood stage is called “flood duration” and it is important in many instances. A high peak and short duration usually have a relatively small volume of flow and thus may be completely controlled by reservoirs, while a lower peak and long duration and large volume will not be controlled by the same size reservoir. Flood frequency is knowledge of magnitude and probable frequency of recurrence of floods and it is necessary for the proper design and location of many structures. There are several statistical methods to determine the flood frequency that are described in reference books [12].

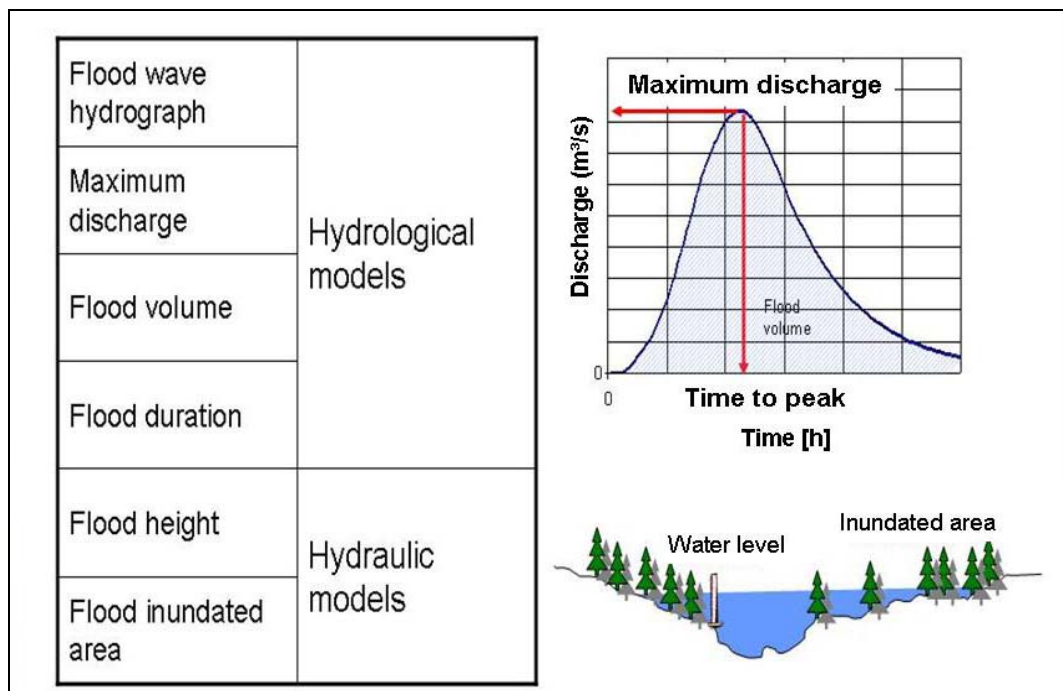


Figure 2-1 Measurable features of flood

There are two kinds of models that investigate the flood parameters called “hydraulic and hydrologic models” (figure 2-1). The term hydrologic model is applied to all methods of channel routing in which a channel reach is treated as a lumped system and the momentum equation is replaced either by black box representation or by a conceptual model. Such methods require estimated rain data and data from the past flood events for the upstream and downstream of the reach for their calibration and can be used even when nothing is known about the topographical or roughness characteristics of the intermediate channel sections [28]. In hydraulic models the flow in the reach is calculated by using the continuity and momentum equations together. In this case the characteristics of the flow and river, such as river topography and river roughness, are necessary. It is clear that the results of hydraulic models to calculate the water depth and flood inundated area are more reliable than the results of hydrological models.

## 2.2 Flood defense measures

Flood defense methods are categorized in different ways that are described in brief. The main classification of flood defense measures is structural and non-structural measures (figure 2-2).

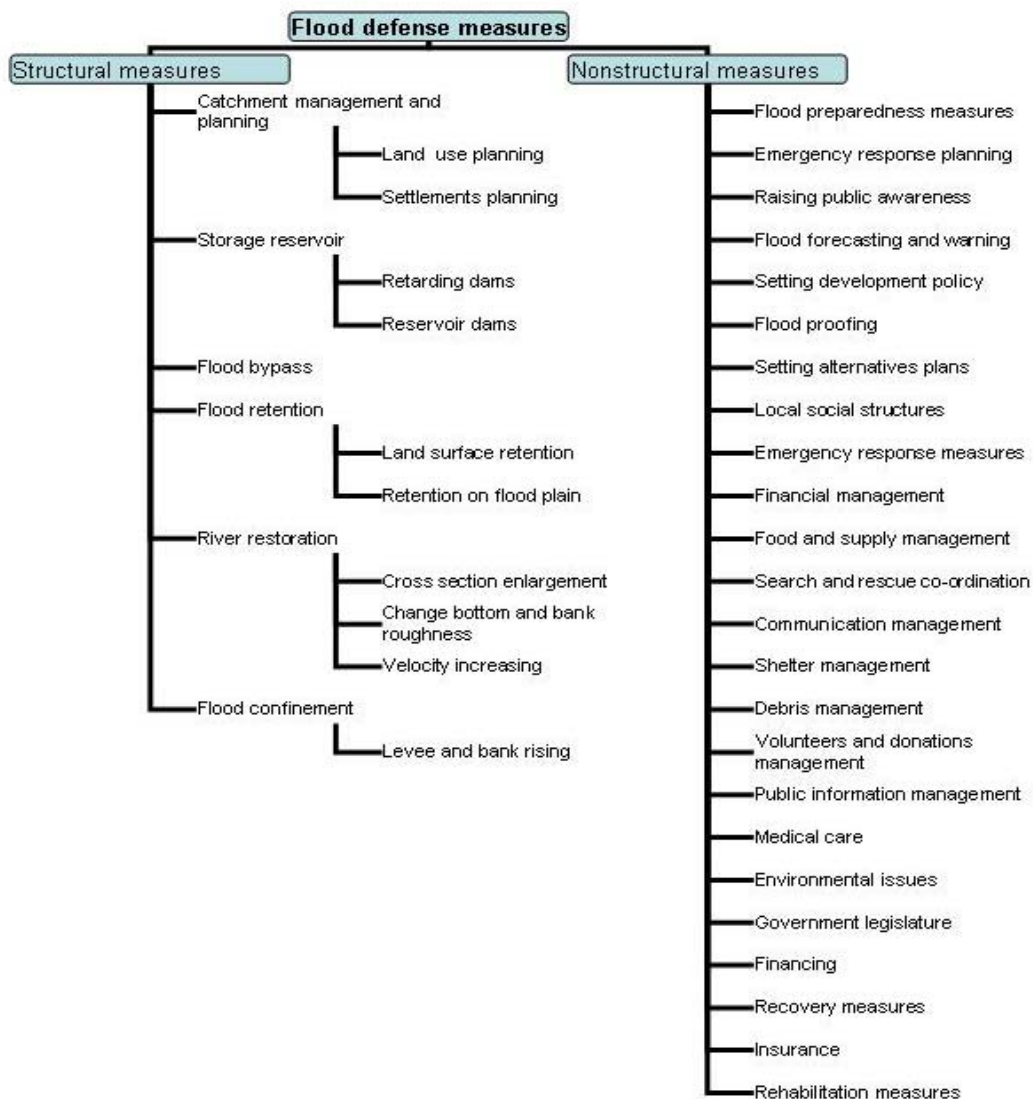


Figure 2-2 Structural and non-structural flood defense measures

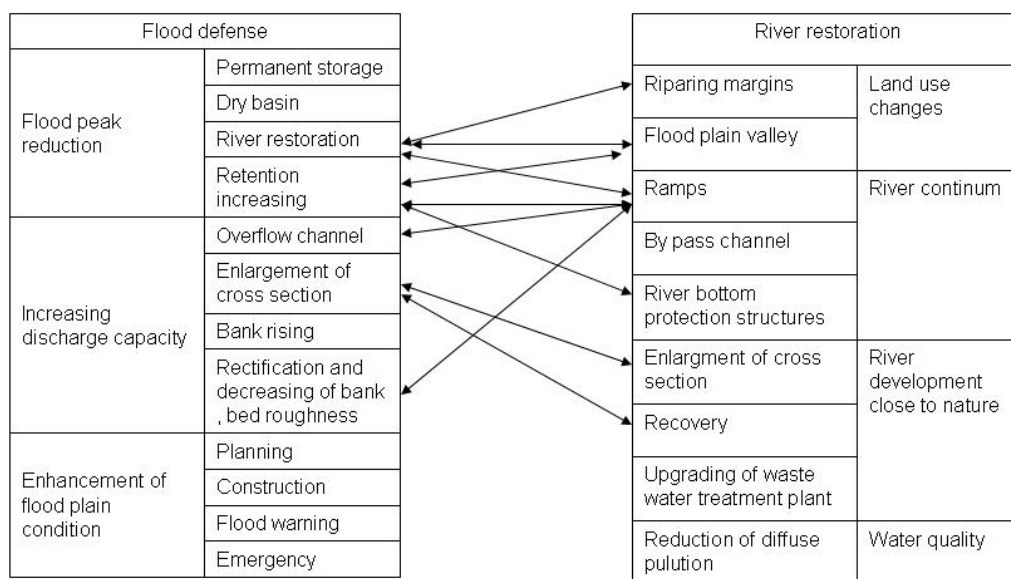
The structural measures aim to reduce flood volume or peaks and thereby to protect people and other objects against flood damages. Non-structural measures comprise of regulations and policies and flood insurance. These measures strive to reduce flood impacts without altering flood characteristics and focus on policies and emergency measures.

Furthermore, flood mitigation (defense) measures are divided into three main categories by Higgins and Robinson (1981) [36]. Handmer (1985) and Viljoen (1979) used the same classification. Although the order is changed, the same basis of classification is used (table 2-1). The first measure is concerned with the control of flood waters, namely keeping flood water out of developed flood plains. For these purposes structural measures like flood control dams and levees are usually used. Secondly, potential damage can be reduced in areas with the greatest flood damage potential by limiting settlement and development in these areas. This usually entails nonstructural measures, like land use regulations. Lastly, measures are associated with the risk actions by the inhabitants of floodplains, in accordance with and overlapping the first two measures. Public education and information programs are very important components of this [36].

**Table 2-1 Categories of flood control measures (Higgins and Robinson 1993, [36])**

Water control measures	Land use measures	Social measures
Flood storage Canal improvement Levees and flood ways Catchment area planning	Planning and building regulations Permanent evacuation Flood barricading	Training and information Warning and emergency services Flood insurance

The relationship between river restoration and flood defense measures is important and needs more attention. According to one river restoration definition, “restoration programs aim to create a system with stable channel, or a channel with dynamic equilibrium that supports a self sustaining and functionally diverse community assemblage (Osborne et al, 1993) [9].” The flood defense measure has to consider the concept of river restoration; especially hydrodynamic of flow and sediment transport conditions. Tönsmann (1996) described the flood defense measures related to river restoration (figure 2-3) [32].



**Figure 2-3 Flood defense related to river restoration [32]**

## **2.3 Flood defense approaches and strategies in Germany**

The history of floods is the prehistory of flood protection. Floods have occurred since unknown times. However, floods endangered people only when the people approached the river valleys to use the fertile lands or to settle at flood threatened places. As a matter of fact, due to the increasing population pressure, men had to go to such places to gain additional space for agriculture and grazing. Flood protection became necessary to avoid, or at least to reduce, the flood losses and damages. Flood protection was a matter of survival. There is a lot of information available about the human fight against floods in different places and countries.

Besides storms, flooding is one of the most significant natural hazards in Germany. Documents dating as far back as 722 A.D. report major floods in Germany [42]. According to these reports, people in Germany had had painful experiences with floods for over 1000 years. Even so, the area near the rivers has been the most interesting place for the establishment and development of cities while the low mountain range has often been the best land for agriculture located in the floodplain. For several years after World War II only a few big floods occurred in Germany, but since the 1990s the number of floods and the damages caused by these floods have increased dramatically. In December 1993 many towns on the Rhine and Moselle rivers were flooded (causing 530 million U.S. dollars in damage) and in January 1995 it happened for the second time (causing 280 million U.S. dollars in damage). In 1997 there was a large flood at the Oder River (causing 330 million U.S. dollars in damage). In 1999 there was another flood at the Danube River (causing 330 million U.S. dollars in damage). In 2002, at the Elbe and Danube Rivers, one of the biggest floods in German history occurred causing damages of 11 billion U.S. dollars. In 2005 a flood occurred again in the Danube catchment (the amount of damage is still unknown).

Generally, up to the 1980s flood protection in the world was mainly realized by means of technical measures: e.g. dikes, dams, retention basins and channel improvements. All flood defense projects were confined to building huge structures at a high cost. An increase in environmental awareness, an adapted legislation, a decrease in financial resources and modified requirements for flood protection all decreased the role of technical measures and increased the role of non structural measures.

Germany has a federal government structure. The federal states are responsible for the environmental and flood protection issues. Laws endorsed by the federal government provide a framework for acts implemented at the state level. The law on water management (WHG) works as a legislative framework set by the federal level and is implemented through regional water Acts in the individual states [17]. In recent years the European Union has also become an important factor in the field of water related laws and directives. In the year 2000 a water framework directive was agreed to with very ambitious aims in the field of river restoration for all waters in Europe, but this directive did not cover the problems which are connected with floods. Following the flood events at the Rhine River in 1993 and 1995 the German Working Group on Water Issues of the Federal State of Germany (LAWA) elaborated "Guidelines for forward-looking flood protection," based on natural flood protection measures, such as building and risk provision to be predominantly realized. In November 2003 the LAWA used the new experiences from the Elbe flood 2002 and revised their paper of 1995 about flood defense. The new LAWA paper verifies the old one and also offers more ideas about how the different points can be realized. The main result of the discussion about the Elbe flood of 2002 was that a lot of good ideas were not realized due to administrative problems. Even though there was a change in the classification of measures to the different parts of the strategies, it was more of a strategic change rather than an executive changes.

According to LAWA (2003) there are three strategies for flood defense approaches. As listed in table 2-2 they are land management for flood, technical flood protection and the precautionary action on flood.

**Table 2-2 Flood defense strategies according to LAWA (2003)**

- |  |
|--|
| <ul style="list-style-type: none"> <li>• <b>Land management for flood</b> <ul style="list-style-type: none"> <li>• Area precaution for inundation area by water law           <ul style="list-style-type: none"> <li>• Definition by water law</li> <li>• Consideration of the flood protection in planning on federal state, regional local level, including legal definitions and designation of the responsible participants</li> <li>• Adapting the land use</li> </ul> </li> <li>• Natural water retention           <ul style="list-style-type: none"> <li>• Preservation and recovery of water retention areas in the flood plain</li> <li>• River restoration and natural water body management</li> <li>• Consideration of the aspect of the water retention by land use, especially preservation and recovery of soil infiltration</li> <li>• Infiltrate the rain water in the settlement areas</li> </ul> </li> </ul> </li> <li>• <b>Technical flood protection</b> <ul style="list-style-type: none"> <li>• Dike and dams</li> <li>• Flood retarding dams</li> <li>• Keep free the flooded cross section area</li> <li>• River development in settlements area</li> <li>• Flood defense walls</li> <li>• Protection of single building</li> </ul> </li> <li>• <b>Precautionary action on flood</b> <ul style="list-style-type: none"> <li>• Building precautions by flood resilient buildings and infrastructure including an adapted use of rooms under the flood level</li> <li>• Behavior provision by early flood warnings and action plans during and after floods, Foundation of flood partnerships Risk provision</li> <li>• Risk provision by insurance and own sources</li> </ul> </li> </ul> |
|--|

Preventing land use means to stop building new developments in flood plains. The first step is the definition of flood zones and their return periods. In Germany 100 years flood is usually used for this. It is important that these natural flood zones are not reduced by any other uses. If the flooded areas are reduced the flood water flows downstream higher and more quickly. Precautionary building means adjusting modes of construction in areas susceptible to flooding so that they are able to cope with any flood which may arise. Most damages can be avoided by forward planning and building precaution. Precaution behavior means using the time between the onset of flooding and the incidence of critical flood levels well. Even so, after every investment has been made in flood defense measures, a real risk of flooding remains. Preventive action against risk must be taken here too [29]. The individual is often incapable of gathering reserves to cope with the situation if a large scale flood happens. In cases of low or medium risk areas insurance against flooding could compensate this risk.

## **2.4 Flood defense measures in mountain areas**

Roughly one quarter of the planet's area is covered by mountains. The hydrological processes in these areas are strongly influenced by the specific characteristics of mountainous

regions, such as temperature, precipitation, soil, vegetation, slope and windward/leeward [52]. The catchments located on the mountain areas have a special behavior to generate and transport floods because of their steep slopes and river slopes, thin soils and high rainfall intensity. River slope of more than one percent reduce the retention capacity of channels and the adjacent flood plain (Naef and Thoma, 2002) [52]. Thus, in these catchments the time of flood wave forming is too short. The land surface area has a steep slope that causes high land surface velocity and consequently more land surface erosion. The river bed and banks are eroded continuously. Sediment transport, high flow velocity in streams and erosion factors affect floods and flood defense measures in mountain areas.

There are some researchers who have investigated the flood defense measures in mountain areas. They have recommended some points for flood defense in these areas. The Alps mountain area in Europe is a good example for mountain catchments area. It stretches from Austria and Slovenia in the east, through Italy, Germany, Switzerland (Swiss), Liechtenstein and to France in the west.

The Savinja River is a tributary of Sava River in Slovenia located in the Alps mountain area. Flood protection measures were investigated by M. Brilly (1992) by the consideration of flash flooding in this area. According to this research, the potential for flood protection using storage in channel enlargement spaces occupied by urbanization or traffic connections, so flood defenses in this area should be based on hydrometeorological forecast service and public information system, together with the self organization of settlements and advice on flood proofing and flood safety rules [6]. R. Weingartner (et al 2003) discussed the basic aspects of flooding in mountain areas and illustrated with case studies mainly from Switzerland. These studies described the hydrological characteristics of mountainous areas. According to the above research, characteristics of floods and flood measures in mountain areas are:

**Heavy precipitation:** mountain areas in comparison with lowland areas have more frequent precipitation with greater total volume. Lower parts of mountain regions in particular are susceptible to convection and have short term heavy rainfall [52].

**Vegetation:** in the mountain area vegetation varies according to altitude, although the effect of a windward or leeward aspect can also be observed. However, vegetation type, aerial extent and canopy density can also affect flood parameters.

**Soil:** soil has an important role to absorb and retain water. Soil information such as type, hydraulic conductivity, pores volume, depth and so on affects the flood. The important parameters in mountain areas are soil thickness and infiltration rate which define the soil retention capacity.

**Drainage network:** in the mountain catchments the drainage network is denser than low land catchments and collects water very fast.

**Steep slope:** on steep slopes the lateral discharge component is exaggerated and accelerated, whereby the proportion of runoff components near the surface increases, leading to more erosion and the creation of more streamlets [52]. Slopes have an indirect influence on soil development and in turn on runoff generation.

**The importance of flood prone area:** in mountain catchment area the flood prone area is very low in comparison with the total catchment area but usually these areas include areas of intensive agricultural production, urbanized sections and vital traffic connections.

**Erosion:** surface erosion and river erosion in mountain catchments is high.

**Landslide potential:** in these regions landslide potential is high because of soil types, surface slope and river bank slope.

**Flood time to peak:** this time is short and in turn flood response time is also short.

## **2.5 Flood defense measures in low land areas**

Northern Germany and Netherlands are good examples of low lands. In these areas, the land surface slope is very small and in some places it is nearly horizontal. Flooding is the main natural disaster in this part of Europe. In 1850 engineer J.H. Van Rechteren published a book in which he advocated a dual system of resistance and dynamic solutions in order to protect the low lying land in the river area. He made the following recommendations:

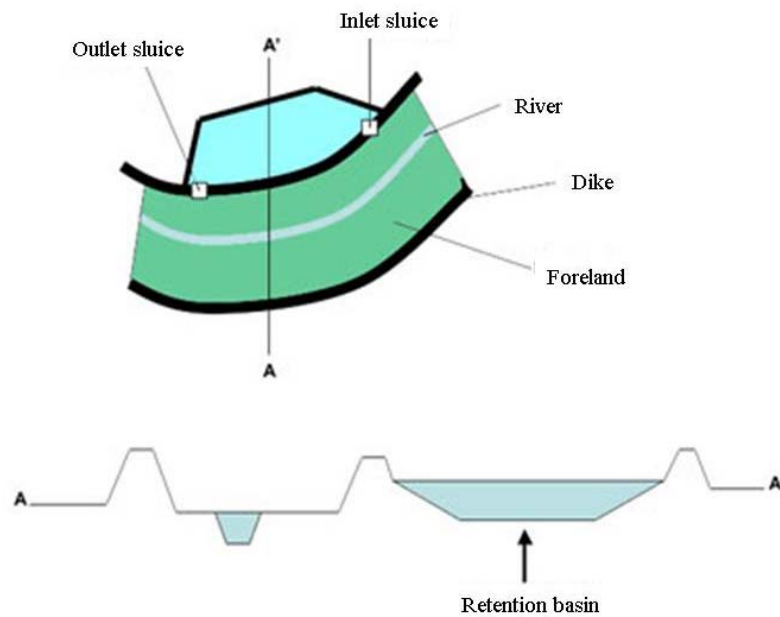
- improvement of riverbed, making it deeper and smoother
- the use of spillway and temporary channels
- Reinforcing and increasing the height of dikes

During the 19th century so-called “improvement projects” were carried out that implemented Van Rechteren’s ideas. Rivers were dredged and river channels were straightened to increase river flow velocity and discharge capacity. Numbers of spill channels were constructed in the second half of the 19th century, to minimize flooding of useful agricultural land. Around the turn of the 20th century most spillways were closed and the river defense strategy was adapted in the resistance and control type by higher and heavier dikes and locks to control the water and protect valuable agricultural land, towns and villages. The main reason for this shift in thinking was the fact that the disruption of flooding and the economic damage to farming was no longer regarded as acceptable. After the tremendous flood disaster of 1953 the Dutch government introduced the Delta plan project. This vast project aimed at protecting the coast and rivers in a manner that reduced the risk of a disaster such as the 1953 flood to a probability of one in three thousand years. In 1976 when people began to criticize the Delta plan, the Dutch government appointed a committee to look into the ways that the dike reinforcement in the river area was conducted. Over a year later this committee published its findings report. This report suggested that the dike reinforcement program in the river area needed to be reconsidered to lower the inundation protection from once in three thousand years to once in one thousand two hundred and fifty years.

After the 1980s the Dutch reconsidered the flood defense systems because of new urbanization and climate changes and introduced local water retention basins. Local water retention is a system based on the construction of retention basins that can be used to store water during periods of high water (figure 2-4). When the floods subside the water is drained from the basin to river. The downside of this river is that it only reduces the peak discharge downstream but it does not increase the discharge capacity of the rivers. Another way of reducing peak discharge is to slow the flow of water down. Widening the foreland and encouraging vegetation in these areas can achieve this. The first measure will increase the capacity of the river and the latter slows the flow of water down, decreasing the peak discharge downstream [33].

Overflow channels and lateral diversions do increase the capacity of the rivers and have been proposed to create new lateral diversions. However, in a densely populated region like the Netherlands it is difficult to do so since this means periodically flooding agricultural land or even residential areas that are in route of the lateral diversions. Therefore, these channels must be planned carefully and farmers must be compensated for the inundation of their land for longer periods. Residential areas can be protected with low levees surrounding them and

newly built solitary houses could be placed on low hills to lift them above the flood plain. After the near flood catastrophe of 1995, the construction of low levees around settlements began [21]. The high water discharges of the Rhine and Meuse rivers in 1993, 1995 and 1998 caused a considerable change in governmental policy, public awareness and international cooperation in terms of flood protection and inland water management. The Dutch introduced the rapid dike reinforcement program and issued new legislation for existing water discharge capacity. This led to a restricting policy on land use functions and the concept of room for river was developed, as well as the increase for river discharge capacity, international cooperation for flood defense measures, flood defense measures between and outside of a dike anchored in physical planning and relevant policy [51].



**Figure 2-4 Flood retention basin in Netherlands [33]**

## **2.6 Conclusion**

Floods are measured by height (water level), area inundated, peak discharge and volume of flow, as well as other important parameters such as: time to peak discharge, flood duration and flood return period. Hydraulic and hydrologic models are complementary ways to investigate the flood parameters. Flood height and inundated area are calculated more accurately by hydraulics models. Flood defense measures are classified in different ways such as structural and non structural methods, water control measures, settlement measures, social measures etc. There are many local experiences that have dealt with flood defense around the world. In Germany, besides storms, flooding is one of the most significant natural hazards. So, LAWA has issued some national documents that deal with future flooding. Characteristics of mountain area according to floods and flood measures are: heavy precipitation, light vegetation, thin soil layers, steep land slope, dense drainage network, high erosion potential and so on. These parameters affect flood defense measures. In low land area longitudinal river slope is usually low and the inundated area depends on the river banks slope and is high, so that water confined method like levee and bank rising is more usual. In these cases, it is also helpful to increase the river capacity.

## **3 General relation between catchment topography and flood defense measures**

### **3.1 Introduction**

There are five effective elements in every natural flood (figure 1-2); first of which is identified as the meteorological elements (e.g. temperature, rainfall, evaporation, sunshine, wind etc); the second group comprises the soil information (e.g. soil type, hydraulic conductivity, field capacity etc.); the third element is known as topographical elements; the fourth is the land use and finally the last and fifth is river network elements. The topographical elements influence land use and drainage network elements. For instance, the farm land and settlement area are located on the low land surface slopes, while mountain catchments have more condensed drainage network. Based on what was discussed in the last chapter, the flood defense measures are categorized in three major groups which consist of water control measures, settlement measures and social measures. Water control measures are comprised of four groups of measures. First are those which reduce the flood peak or volume (such as flood storage, planning and management of catchment's area, the increase of retention and river restoration). Second are the measures which increase discharge capacity of rivers or decrease the water stage in the river that will be done by enlarging the cross section of the river and rectification and decreasing the roughness of its bed and bank. Third are flood confinement measures which confine the flood in the river (such as bank risings and levee constructions). Finally, the fourth is flood bypass; a measure which is used to control flood water. Settlement flood defense measures consist of planning and building regulations, permanent evacuation and flood proofing of specific properties. The social measures have no connection with topography parameters although they may define some strategic legislation according to topography. Water control measures and settlement measures are directly affected by topography.

According to the general view of topography every catchment has two major parts. The first part is located in the mountainous areas. In these areas, the slope of the land surface is precipice. The streams in these regions have steep longitudinal slopes consequently; causes high flow velocity and short concentration time, hence in a short time after the rainfall starts, excessive quantities of water come together and form flood waves. Also the valleys are V-shaped with high slopes in the banks. The characteristics of floods and flood defense measures for mountain areas were described in section 2-4.

The second part of the catchment is located in low land areas. These spots have low land surface slopes, low river longitudinal slopes and therefore low flow velocities. The majority of these areas is suitable for agriculture and has good soil. Additionally there is a transition area between the mountainous and low land regions. These parts are located at the foot of the mountains. There are also some catchments which merely have one part. Flood defense measures for each catchment depend on the topographical condition of every catchment and also the target region. Catchment topography has an important role to generate the floods and it has a direct influence on runoffs. In other words, slopes intensify and accelerate the lateral discharge components. Besides the catchment area is divided into two parts; the first one being a part of watershed which overland flow is formed upon. This part is under precipitation and is a place where water flows over the land surface toward streams. Henceforth this will be called the land surface area. The second part, which is called the flood plain, is a part of watershed which contains streams, rivers and their borders which are

susceptible to being inundated by flood water. Waters come together in stream networks and flow toward the catchment outlet. Topography of the flood plain is comprised of the longitudinal profile of the river, which influences the flow velocity directly and the cross sectional profile of the river, which affects the river retention capacity. Hence, according to the new point of view, flood defense measures are categorized into two groups; first the measures which have been carried out on land surface area and affect overland flow parameters and second, the measures which have been carried out in the flood plain area. The rest of this research tries to describe land surface flood defense measures and flood plain flood defense measures separately.

### 3.2 Land surface topography and flood defense measures

Except for the flood plain, land surface areas comprise the entire catchment area. The land surface area forms the overland flow and also has an important role in concentration time and land surface retention. Consequently, it can influence flood parameters or flood hydrograph shapes and also flood defense measures which normally are going to be done on this area such as retention increasing by land use changing.

By attending hydrological water cycle (figure 3-1), interception, evaporation and evapotranspiration, infiltration and hole storage reduce the amount of runoff and influence floods. Evaporation and evapotranspiration directly depend on climatic data and vegetation, as a result are not considered here. Rainfall and snowfall are intercepted by vegetation. The amount of interception depends on vegetation factors (species compositions, age, density of stands and seasons) and storm size; in addition, it varies from ten to thirty-five percent of total of rainfall [12]. Changing the vegetation cover can affect interception as a flood defense measure. Normally, in a large scale, the vegetation properties of natural catchments depend on altitude. For instance, by increasing the altitude of catchments the density of vegetation cover will decrease and plant species will also change.

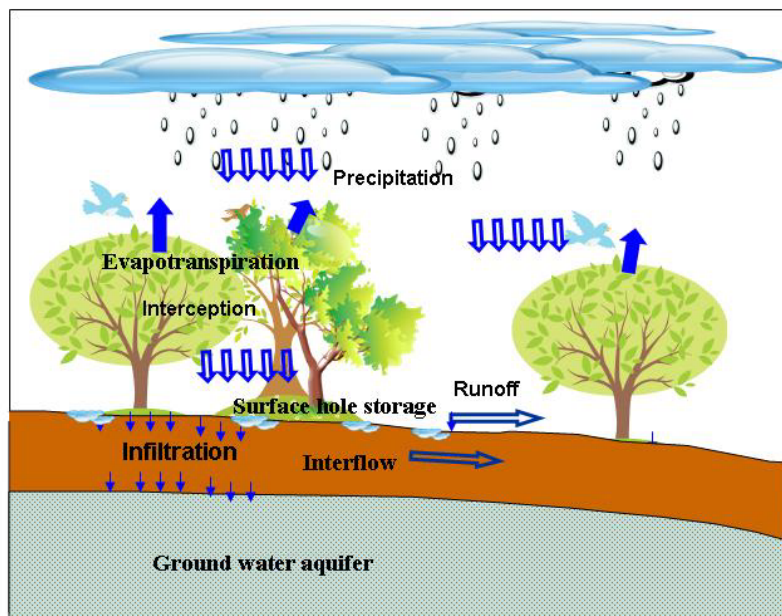
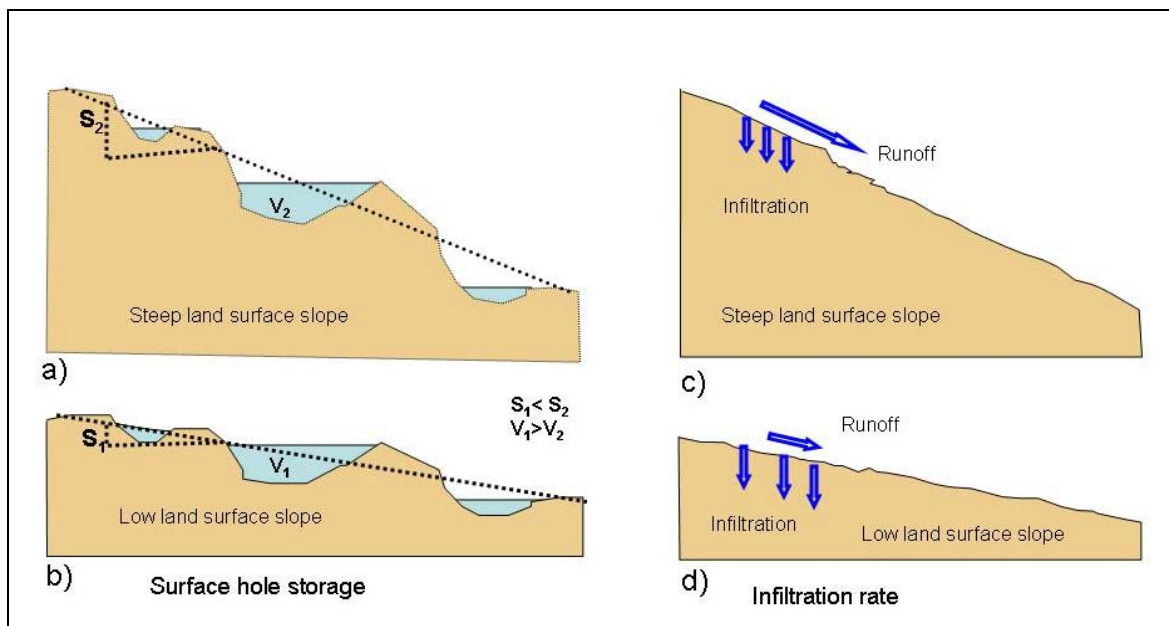


Figure 3-1 Flood retention on land surfaces

After arriving in the catchment area a part of the rainfall is intercepted by vegetation while the remaining part turns up on the soil surface (figure 3-1). On the soil surface water

tries to infiltrate into the soil with the help of gravity force. If the intensity of rainfall becomes more than the infiltration rate, some water is collected on the soil surface. At first water fills the storage holes on the land surface (figure 3-2 a and b) and then the surplus water moves on the soil towards streams as runoff. Infiltration concerns the movement of water into the soil [12]. Infiltration rate is influenced by soil texture and structure, which govern no capillary porosity, soil wetness and amount of protection from rainfall impact offered by vegetation [12]. Steep slopes encourage rapid runoff, which limits infiltration; thus, most infiltration amount occurs in low land slope areas (figure 3-2 c and d). In addition, Philip (1991) showed that infiltration rate for light clay is affected by hill slope. According to the results of his study the slope generates maximum variation of about 13% in infiltration rates [34]. The mentioned results were exercised on a laboratory scale and there is no practical experience on any large scale as a catchment. Infiltration may be considered as a three step process: surface entry, transmission through the soil and depletion of storage capacity in the soil. These are important factors affecting infiltration rate. In addition, one can name the characteristics of the permeable medium percolating fluid. The surface of the soil may be sealed by the inwash of fines or other arrangement of particles that prevent or impede the entry of water into the soil. Soil having excellent under drainage may be sealed at the surface and thereby have a low infiltration rate. Water can not continue to enter the soil more than it is passed on downward. The condition of the surface cannot increase infiltration unless the transmission capacity of the soil profile is adequate [12].

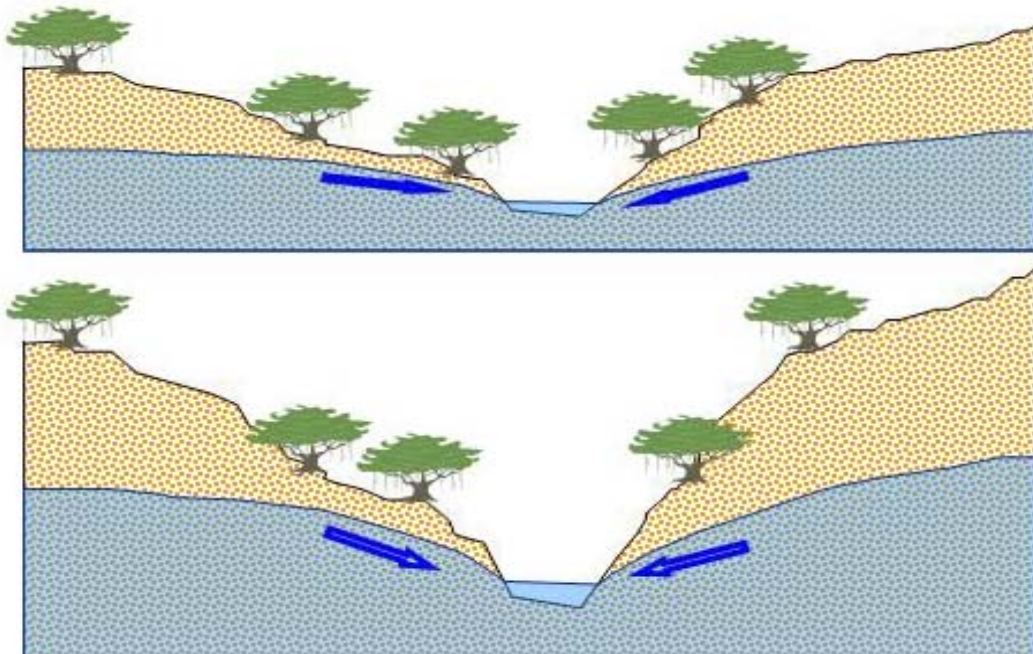


**Figure 3-2 Effect of land surface slope on surface hole storage and infiltration rate**

The infiltration rate depends on some physical properties of soil (e.g. soil aggregate stability, aggregate size distribution, hydraulic conductivity etc.), some chemical properties of soil (e.g. SAR, EC etc) and the percent of grass cover and tillage management in farm lands [27]. On the other hand, land surface slope can affect type and density of vegetation cover and indirectly influence the infiltration amount. The characteristics of groundwater aquifer, such as thickness and number of layers, influence infiltration rate and capacity. Usually the soil thickness is very low in mountainous catchment and there is no stable permanent water table. Therefore, interflow appears shortly after the beginning of rainfall. Runoffs are generated when the rainfall intensity is more than infiltration rate. In this situation, first the surface holes will be full and then excessive amounts of water will move toward the stream in

accordance with land surface slope. Hole storage capacity is a function of land surface roughness and material and slope. The force of gravity is the moving force that depends on land surface slope. When land surface slope becomes higher, the moving force also increases. The resistance force depends on normal vector of weight and surface roughness. An increase in the land surface slope causes the water velocity and water power to increase as well. Normally, in steep slope areas, the hole storage is less than the flat slope, as a result of the destruction power of holes by water. In other words surface holes are unstable in steep slope therefore the holes are destroyed early and cause to shape small gullies and increase the possibility of erosion. By attending figure 3-2 (a and b), it is clear that the amount of water volume in holes at the steep slope is less than low slope in the same surface roughness.

In addition, the water table usually follows the land surface slope. Thus, when the land surface slope is decreased, the hydraulic gradient of subsurface water also decreases leading to a decrease in underground flow velocity, which in turn decreases the channel recharge by under ground water as well (figure 3-3).



**Figure 3-3 Groundwater table and land surface slope**

The land surface topography can influence the peak of flood discharge or volume in the following ways:

- Land surface slope affects the infiltration; the more surface slope increases the more infiltration rate will decrease. As a result, flood volume will increase as well.
- Groundwater table usually follows the surface slope, so the more that the surface slope increases the more that the stream recharge by ground water increases and accordingly flood volume increases too.
- An increase in the altitude and surface slope causes a change in plants' type, diversity and density; it also decreases the interception.
- An increase in land surface slope causes an increase in runoff velocity; this way water that has more power to erode soil will make gullies, causing the floods to form more rapidly.

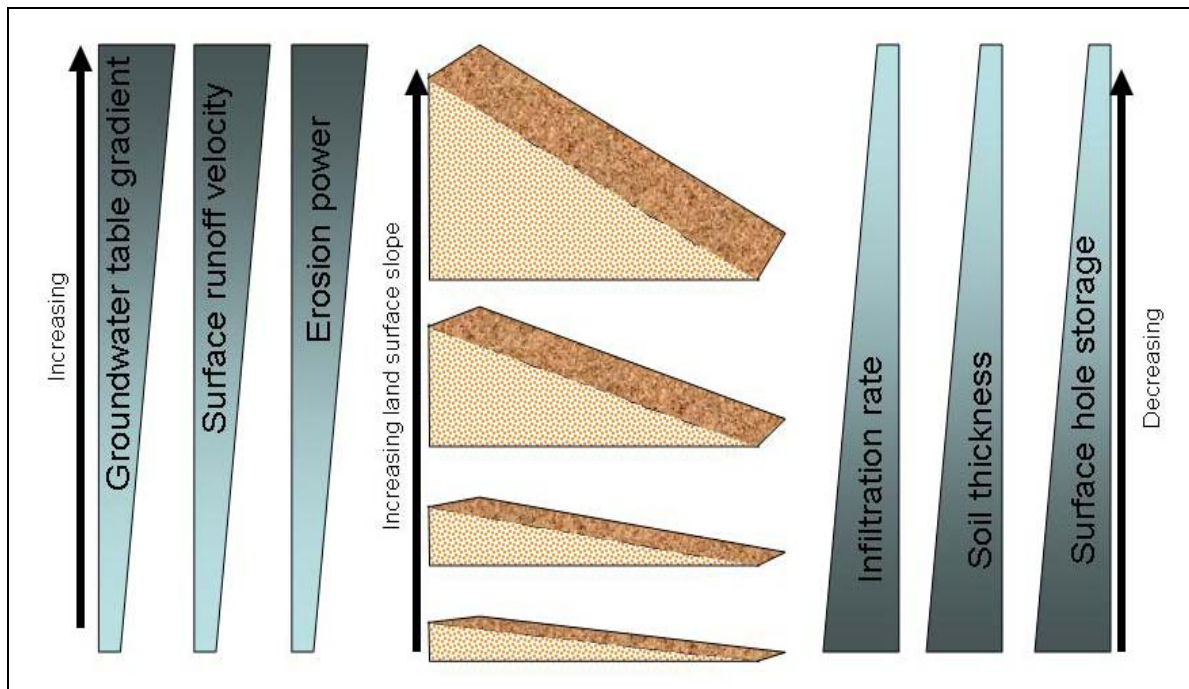
- Soil thickness usually decreases with the increase in land surface slope; accordingly infiltrated water volume will be limited.
- The more land surface slope increases, the more hole storage potential decreases.

Flood defense measures which consider retention of the water in place are called “catchment area planning and management” and aim to reduce runoff. They are comprised of all measures, tasks, rules and regulations which are done in a catchment to reduce the flood water (table 3-1). These measures influence the items of hydrological cycle in the function of flood volume and runoff velocity reduce. The objectives of these measures are to increase the interception, infiltration and hole storage as well as decrease the runoff velocity. Catchment area planning and management approves a series of rules to exploit the best land use and artificial actions and activities to prevent large floods and erosion in the catchment. According to the aforementioned considerations, every flood defense measure that is based on the above items is more efficient while the land surface slope decreases.

**Table 3-1 Different items which are affected to take flood in place**

<b>Items</b>	<b>Influencing factors</b>	<b>Influenced Topographic parameters</b>	<b>Description according to flood defense measures</b>
Evapo-transpiration	Vegetation Climatic factors	Altitude	Not considered as a flood defense measure.
Interception	Vegetation: species composition, age, stands density Season	Altitude Land surface slope	Type of plant species, density varies with altitude and also land slope, it appears in land use.
Infiltration	Soil texture Soil structures Vegetation Soil compaction Geological information Surface slope	Slope	Usually in mountain areas the soil thickness is much lower than flat areas so that increasing of the infiltration rate is limited, steep slope encourages rapid runoff, which limits infiltration.
Runoff velocity	Vegetation cover, Surface slope,	Slope	It influences water traveling time to stream.
Hole storage Surface retention	Surface holes Surface roughness	Slope	Amount of hole storage in steep land surface slope is lower than low slope.

Figure 3-4 shows the relationship between land surface slope and some significant parameters graphically. The land surface slope increases from down to up, after that the absolute values of groundwater table gradient, surface runoff velocity and erosion power increase too, but infiltration rate, soil thickness and surface hole storage decrease. Slope and surface orientation affect the moisture and temperature of soil and affect the rate of weathering of rocks. Steep slopes facing the sun are warmer. Steep land areas may erode faster than soil formation process or deposition rates add material, causing a net loss of topsoil. Low areas receive deposits from areas up slope, often producing deeper soils. Topography effects erosion and depositional rates; water moves materials from steep higher elevations to lower, flatter locations. Sediments along river banks, on flood plains and deltas have different textures, dependent on the rate and duration of water flow; fast moving water can move larger material along with fine material, while slow moving water moves finer material only.

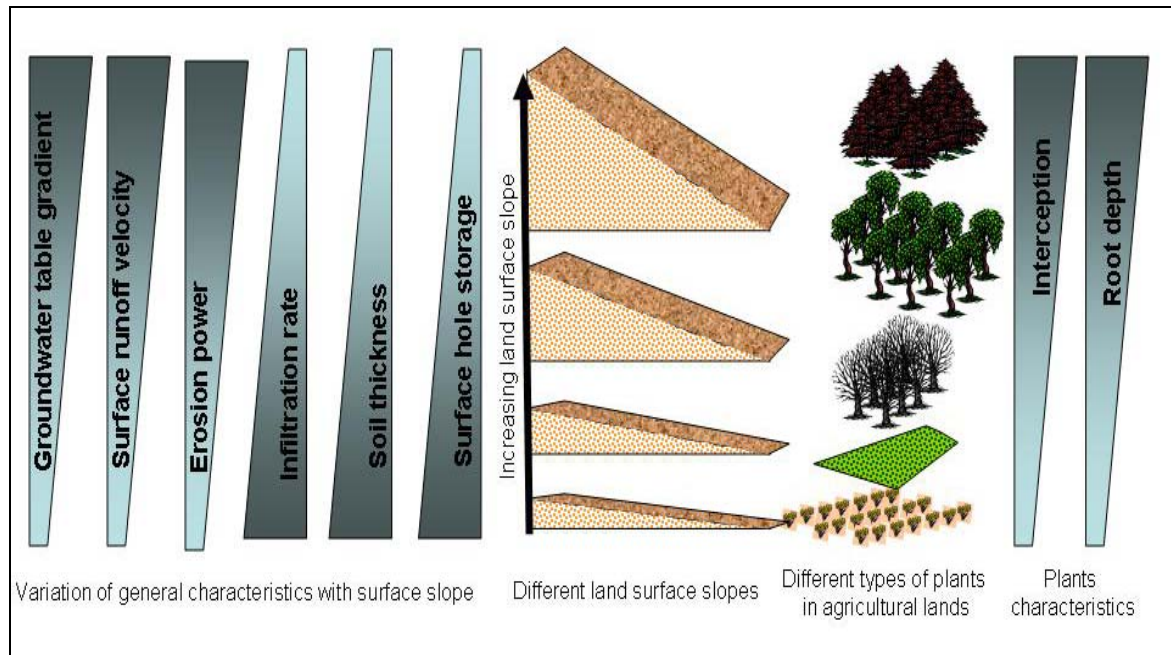


**Figure 3-4 Land surface slope and variation of different parameters**

Vegetation cover management plays an important role to increase infiltration rate, interception and to decrease erosion potential. An argument about the influence of vegetal cover has been in progress for many years. Experts have asserted that deforestation is the basic cause of flood problems. A complete vegetation cover helps to reduce flooding through the detention of rainfall by interception, increase infiltration and reduce runoff by enhancing evaporation and evapotranspiration. In other words, the vegetal cover removes moisture from the soil by transpiration and also promotes loose organic soil which is favorable for infiltration of rainfall. “The vegetation management includes actions as diverse as the reseeding of sparsely vegetated areas to the reduction of wildfires, which can have a devastating effect on sediment yield and flood flows” [44]. The management of agricultural land is very useful to reduce flooding. Cropping patterns can be important in avoiding bare soil during the main seasons of precipitation stress on the land. The amount and direction of cultivation also plays a role. The agricultural tillage operations mix the surface soil and break sealed zones; hence the surface entry will be increased. On the other hand, plowing across the land surface slope will cause an increase in the infiltrated water volume and will decrease the runoff volume. Trees play an important role in soil conservation and also in flood abatement. Numerous experiences have demonstrated changes in runoff regime resulting from more selective forest cutting and removal practices. There have been some experiments to measure the effect of deforestation on flooding but in the case of forestation there are not many studies.

Topographic manipulation seeks to minimize the flood producing abilities of rural terrain and reduce the runoff coefficient by changing or optimizing the surface geometry in a variety of ways such as terracing, contour ploughing and surface and underground water storage and gully control. Terracing and contour ploughing are built along the contour and are used to break up the length of hill slopes and reduce the water velocity thereby facilitating water infiltration and sediment deposition. Therefore, it is clear that the above flood defense methods are more efficient in low land surface slope areas. Figure 3-5 recommends the combination of land surface slope and agricultural plants. So make use of plants with more

interception and also root depth is recommended by increasing the land surface slope to control erosion and decrease flood.



**Figure 3-5 Agricultural type and land surface slope**

There are other flood defense measures that depend on land surface topography such as flood bypass, flood spreading and flood proofing. They will be described briefly.

**Land surface topography and flood bypass:** “A flood bypass, referred to as a floodway, is created by diversion works and topography that permits excessive amount of water in a river or stream to be directed into a depression that will convey the flood water across land which can tolerate flooding” [1]. Opportunities for the construction of a bypass area are limited by the topography of the valley and the availability of lowland which can be used for the bypass. Because of their characteristics, flood bypasses are more usable in low land areas than in steep land areas. Flood bypass channels can be made in the flooded river plain area or out of it to protect large flood prone areas such as towns and cities.

**Land surface topography and flood proofing of specific properties:** Flood proofing is a way to save and isolate the units of highly valuable structures that were built in the flood prone area. There are different kinds of flood proofing methods such as wet flood proofing and dry flood proofing.

**Flood spreading:** Flood spreading is a method which is used in arid low land regions. The infiltration area and time to infiltrate are increased by spreading the flood over the lands.

Catchment area planning and management is comprised of all sorts of actions that are done in the catchment against floods, such as controlling the deforestation, using suitable farming methods in agricultural lands and controlling the settlements area. Some of these methods are directly affiliated to topography (such as agricultural farming methods) and some are indirectly connected to topography. The flood defense measures that consider increasing the retention by adding the infiltration rate and hole storage are more efficient in low land than steep land surface slopes.

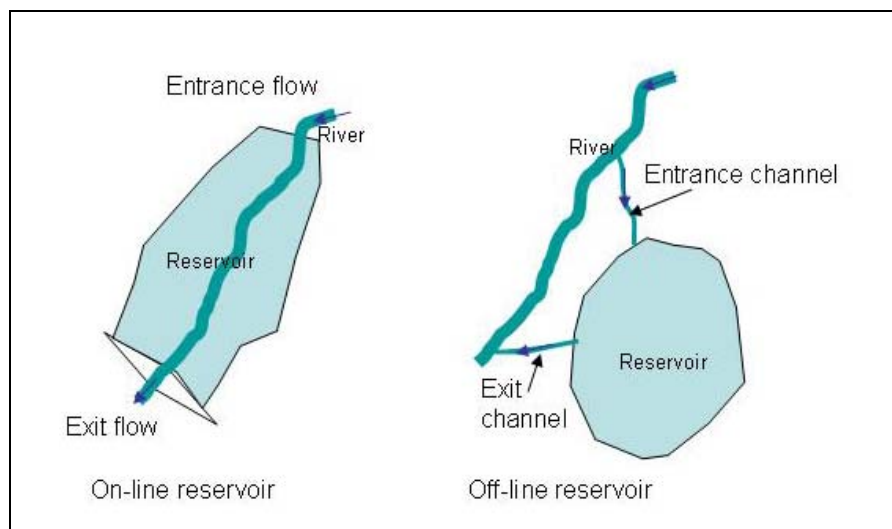
### 3.3 Flood plain topography and flood defense measures

“A flood plain is a strip of land that borders a stream channel and that is normally inundated during seasonal floods. Flood plain is underlined by the deposit of river channel, of over bank floods and of lakes” [8]. Flood plain width in natural rivers can vary from channel belt width to as many as ten folds of channel belt width.

The flood plain topography has a very important role to collect and pass on the flood water. The hydrological functions of flood plain are flood water regulation, base flow maintenance and sediment retention. Most of the flood defense measures, such as river restoration, retarding floodwaters and building reservoir dams, are done in this area. These measures have close connections with topography.

#### 3.3.1 Flood plain topography and flood storage

The capacity of reservoirs depends on the site topography. Generally, based on their position on the river, there are two categories of flood reservoirs: on-line reservoirs and off-line reservoirs. The online reservoirs are constructed across the river and are called dams, while off-line reservoirs are constructed beside the river with an intake structure to transfer water to the reservoir (figure 3-6). The entrance flow can not be controlled in on-line reservoirs while the outlet flow can be managed. Both entrance and exit flows are controllable in the offline reservoirs. The catchment topography should allow construction of the reservoirs. The volume and area are the two most important parameters which need to be taken into consideration for choosing the reservoir site.



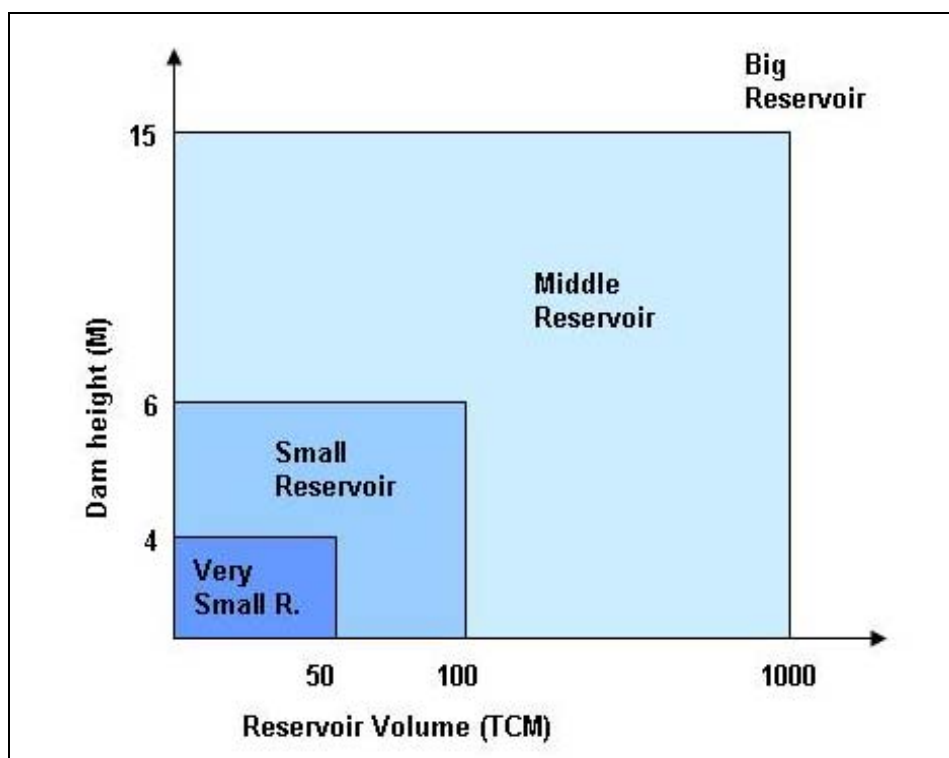
**Figure 3-6 On-line and off-line flood reservoirs**

According to Bulletin 125 of ICOLD [24], dams and reservoirs are classified in some categories listed below, depending on the flood control purpose:

- Reservoirs in which single principal purpose is regulation (water supply, irrigation, or hydropower), or those in which the incidence of flood control is small.
- Multipurpose reservoirs in which flood control is the primary objective, with a secondary purpose associated with water storage.
- Reservoirs in which the single purpose is flood control and the reduction of flood downstream damages.

All dams present flood control benefits, if they are well-designed and correctly operated. Flood control benefits are more important considering the relationship between the size of the reservoir and the dimensions of the flood [24].

Based on flood defense measures, there are two groups of dams. First, there are central flood defense dams which have big capacities and high in heights. Second, there are decentral dams comprise many small dams which are used to reduce the maximum flood discharge. The second type of dams is built with small reservoirs and low heights. They are also distributed in the catchment area. According to DIN 19700-12, the flood retarding basins are classified in four groups: very small reservoirs (height < 4 m, Volume < 50000 m<sup>3</sup>), small reservoirs (4 < height < 6 m, 50000 < Volume < 100000 m<sup>3</sup>), middle reservoirs (6 < height < 15 m, 100000 < Volume < 1000000 m<sup>3</sup>) and big reservoirs (height > 15 m, Volume > 1000000 m<sup>3</sup>). In this research the small and very small reservoirs are known as decentral middle and large reservoirs are identified as central measures.



**Figure 3-7 Dams classification according to DIN 19700-12**

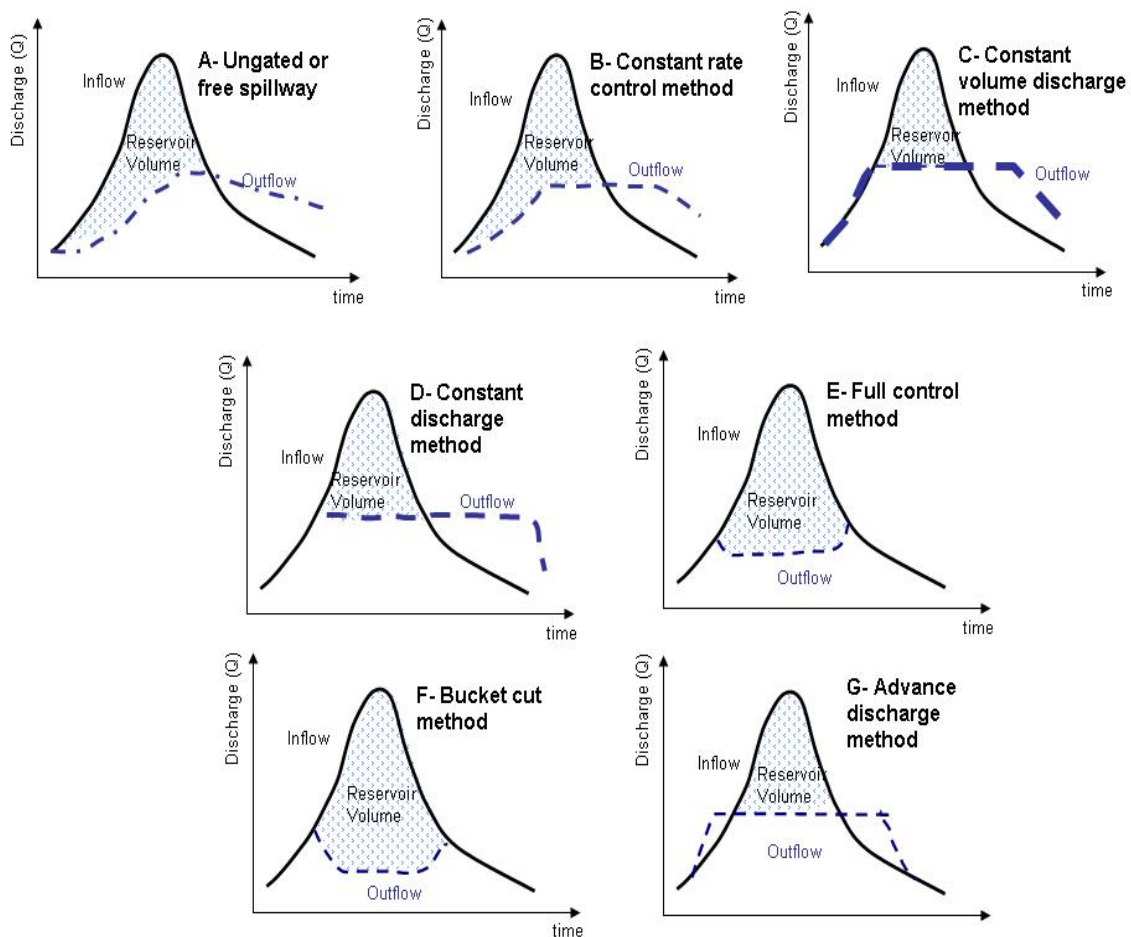
There are different criteria for dam site selection such as the topography of the site, possibility to make a reservoir, existence of enough land and others which are not considered in this research. In the design of flood mitigation dams, the hydraulic operating rule of a dam has to be well defined. Reservoir operation can be categorized to general methods which are shown in figure 3-8 [24]. In method A, it is not possible to control discharge or retention time after spillway flow begins. In methods B, C and D. Gated spillways or culvert are required to control flow. The culvert is located in the river bed and a part of flood will store in reservoir and rest flows to downstream (method B). In method C the capacity of outlet is controlled with gate and the outflow and inflow are equal when flood discharge is less than maximum controlled value. The full control methods (E) and the bucket cut methods can only provide flood protection for low-return-period floods because of economic, social and environmental considerations. In these methods all of flood volume store in reservoir. In cases where flood

forecasting systems are installed and provide dependable and timely information, it is possible to use advance discharge method for storage reservoirs.

Besides site specification, the selection of an operating rule depends on various factors such as:

- Characteristics of the basin and typology of the floods
- Form and characteristics of the hydrograph for design level of protection
- System operation of the various dams in the basin
- Existence of reliable real time flood forecasting systems
- Flood wave travel time
- Warning time

In case, the dam outlet is located in the bottom of dam and on river bed, it can conserve the river longitudinal slope.



**Figure 3-8 Hydraulics operation rule in flood mitigation dams [25]**

Figure 3-9 shows different classifications of flood mitigation reservoirs. According to this diagram the catchment topography plays an important role in all categories except classification on the basis of hydraulic of outlet.

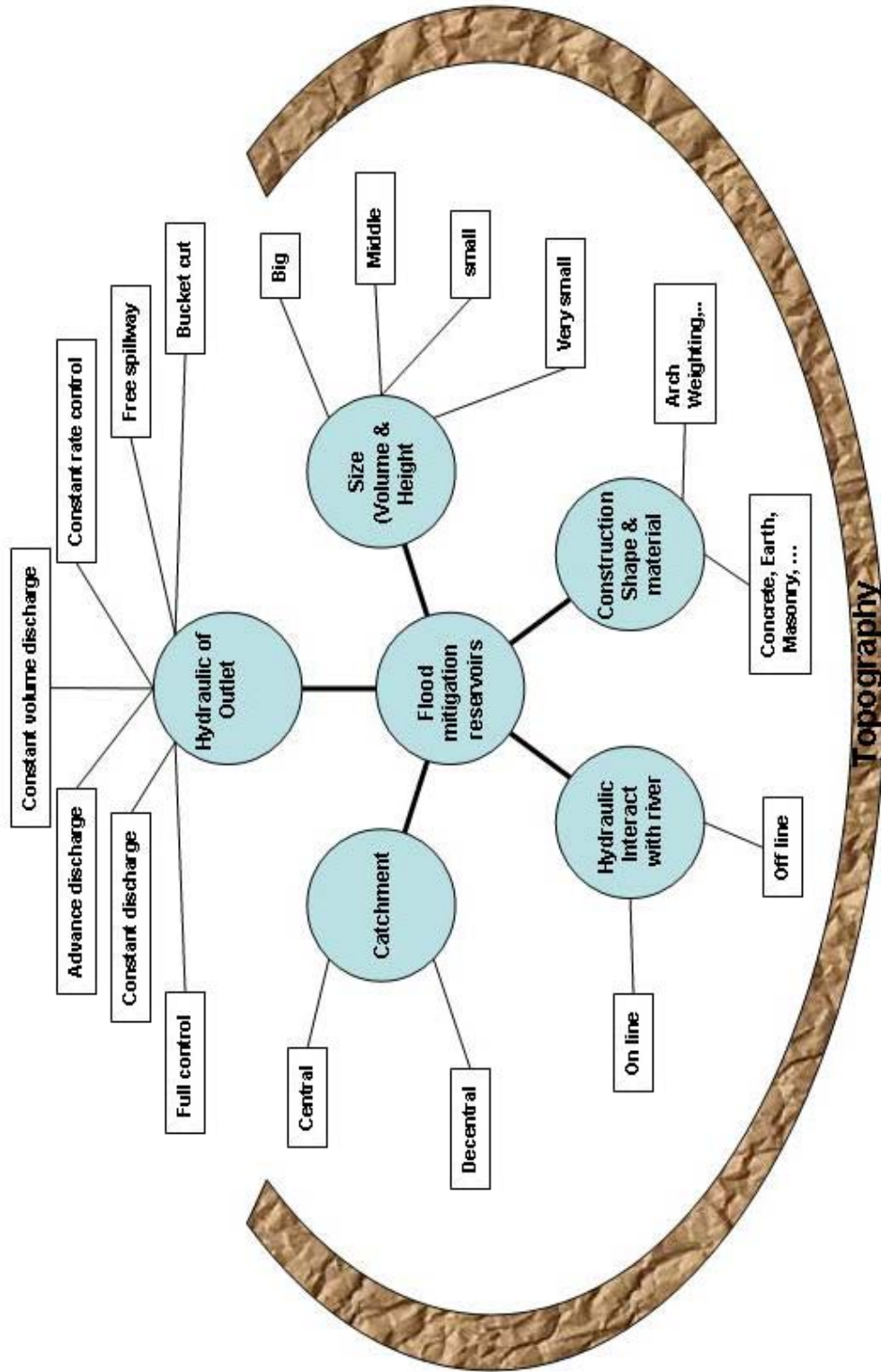


Figure 3-9 Diagram of flood mitigation reservoir classification and topography

### 3.3.2 Flood plain topography and river restoration

There are some definitions of river restoration such as “the complete structural and functional return to pre-disturbance state” (Carins 1991); or “in essence, river restoration which is a process of recovery enhancement. Recovery enhancement enables the river or the stream ecosystem to stabilize (some sort or tropic balance) at a much faster rate than through the natural physical and biological processes of habitat development and colonization. Recovery enhancement should establish a return to an ecosystem which closely resembles unstressed surrounding areas (Gore, 1985) [9].”

There are two points of view according to river restoration as a flood defense measure. One perspective views river restoration in the target part of the catchment and river (flooded areas) with a main aim to reduce the flood stage and inundated area. Thus, some measures (such as enlarging the live cross section and bypassing channels) are used to increase the river capacity and flow velocity. The second perspective views is river restoration in the upstream rivers network resulting in a reduction of maximum flood discharge and an increase in the river retentions.

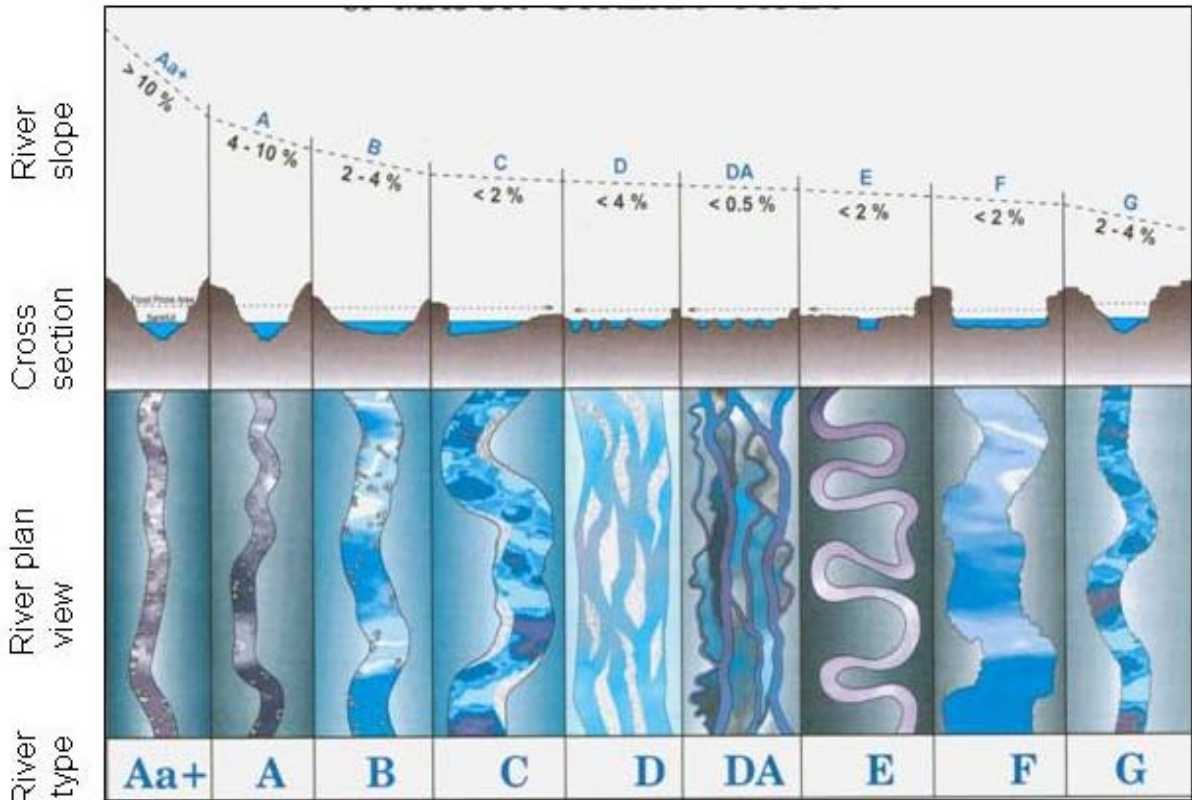
Therefore, increasing the river roughness or decreasing the riverbed slope influences river velocity and can cause a delay in peak of flood discharge and decrease the peak of flood hydrograph. On the other hand, the capacity of the river increases and the river can save more flood water in itself because by decreasing the velocity, the cross section will increase. Three parameters influence water velocity in the rivers: river longitudinal slope, river bed and bank roughness and river hydraulic radius. These parameters influence floods in two ways: first affecting the flood wave parameters; second influencing local features of the flood such as water level and inundated areas. Changing these parameters is known as a flood defense measure.

**Equation 3-1** 
$$U \propto \left( \frac{1}{n}, R, S \right)$$

Longitudinal river slope (S) is one of the most important topographical parameters that influence floods. It is the basic parameter which is considered in river restoration. The river power for sediment transport, scoring, aggradations and degradation are influenced by longitudinal river slope.

According to figure 3-10, the rivers can be classified in 9 types called Aa<sup>+</sup> to G. The longitudinal river slope for each type is shown in the figure. The forms of river valley and flood plain are connected to river slopes. Mountainous catchments have steep rivers in a straight line, but low lands have meandering flood plain with low longitudinal slope.

In reality, the value of river roughness is highly variable and depends on many factors. The factors that exert the greatest influence upon the coefficient of roughness are: vegetation, channel irregularity, channel alignment, silting and scouring, obstructions, stage discharge, seasonal changes and suspended materials [10]. Some of these factors can be changed artificially in the river as a flood defense measure. Changing land use of the flood plain is one of the river restoration methods that have a direct effect on river velocity. The topography of flood plain influences the land use. For example, plants cannot grow in deep valleys with steep banks. Most plants cannot endure in the rivers because of high velocity and erosion. Bank rising and levees have a good connection not only with topography, but also with the flood water level which is not considered in this research.



**Figure 3-10 Broad level stream classification delineation showing longitudinal, cross section and plan views of major system type [41].**

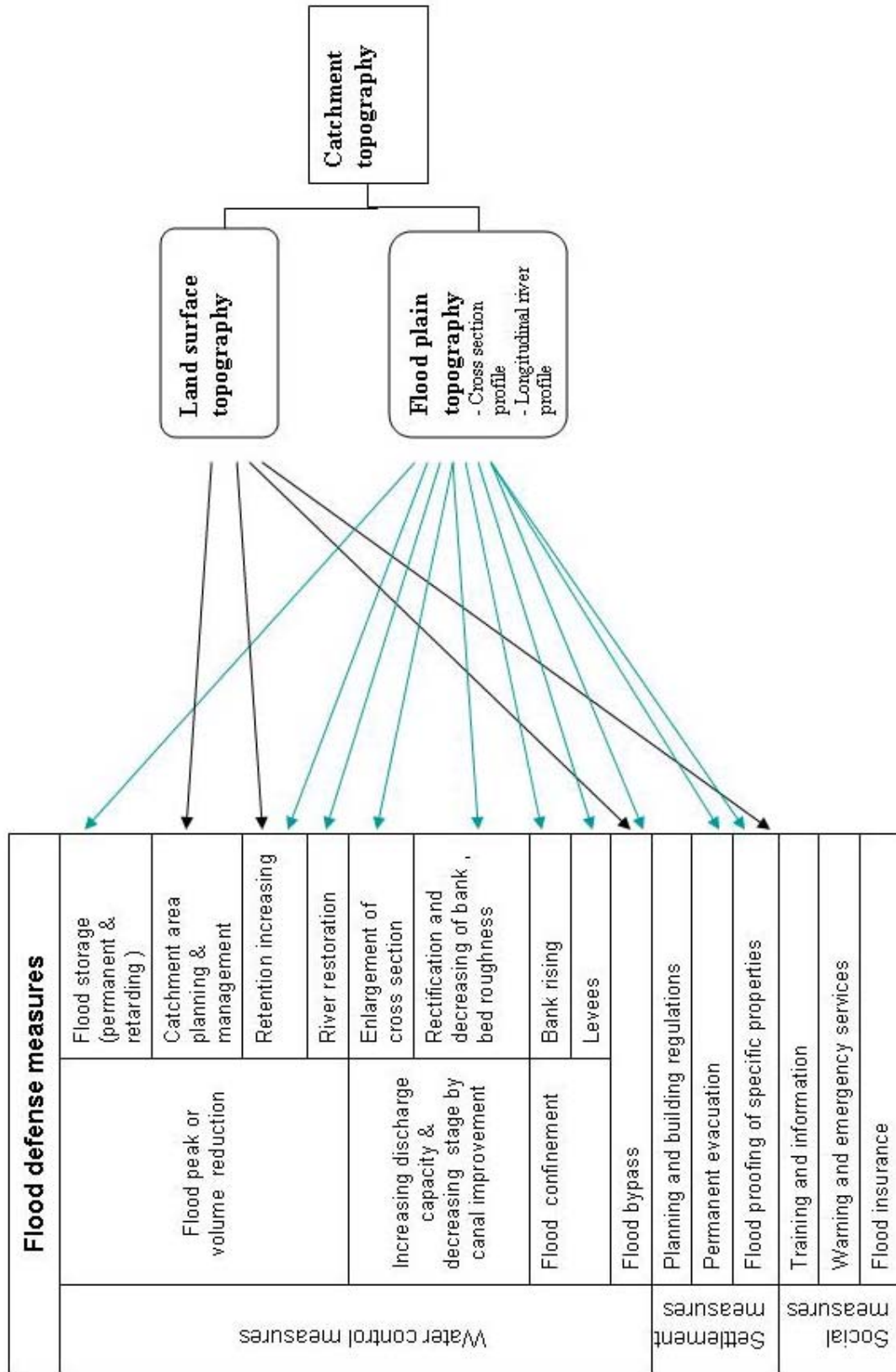
### 3.4 Conclusion

According to flood defense measures the catchment area is divided into two parts; the first one being a part of watershed which is under precipitation and overland flow is formed upon and flows over the land surface toward streams called the land surface area. The second part, which is called the flood plain, is a part of watershed which contains streams, rivers and their borders which are susceptible to being inundated by flood water. Hence, flood defense measures are categorized into two groups; first the measures which have been carried out on land surface area and affect overland flow parameters and second, the measures which have been carried out in the flood plain area. Figure 3-11 shows a link between flood defense measures and catchment topography. All flood defense methods which are established on the base of the retention of water in place (such as catchments planning and management and retention increase) are more efficient in low land surface slopes than in steep land surface slopes. Infiltration rate and hole storage capacity increase by decreasing the surface slope directly. Runoff velocity and erosion potential will decrease by decreasing the land surface slope. The management of land use affect on flooding in an agricultural areas. The usage of condense agricultural plants, which cover the whole area with deep roots in steep surfaces, causes an increase in interception and decrease erosion.

Most flood defense measures are done in flood plain area. Flood plain topography plays an important role in flood defense measures that are implemented in this area, such as dams, river restoration etc. The hydrological functions of the flood plain are flood water regulation, base flow maintenance and sediment retention. The flow velocity in the river and flood plain is linked to longitudinal river slope; moreover the volume of the flood water which is saved in the channel and flood plain (dead and live volume) is connected to topography.

Flood mitigation reservoirs classified as “on line” and “offline” (according to hydraulic interaction with the river), “central” and “decentral” (according to the location in the catchment), “very small”, “small”, “middle” and “big” (according to the size of the dam and reservoir) and also according to shape and construction masonry. Catchment topography influences all of these categories as a classification parameter (figure 3-9). Therefore, there are many flood mitigation reservoir scenarios for a catchment. In addition, these scenarios combine with outlet hydraulic condition.

According to river restoration there are two main points of view. The first views river restoration in the target part of the catchment and river (flooded areas) with a main aim of reducing the flood stage and inundated area. The second views river restoration in the upstream rivers network with resulting in a reduction of maximum flood discharge and an increase in the river retentions. Longitudinal river slope, river roughness and hydraulic radius are important parameters which influence flow velocity and the flood’s parameters. Longitudinal river slope is one of the most important topographical parameters of a river. It is the base parameter which is considered in river restoration. The river power for sediment transport, scoring, aggradations and degradation is influenced by longitudinal river slope.



**Figure 3-11 Flood defense measures related to the topographical elements**

## **4 Material and methods, investigate the effectiveness of topographical parameters on selected flood defense measures**

### **4.1 Introduction**

Based on what was discussed in the last section, this project aims to investigate the effectiveness of topography on flood defense measures and flood in a catchment. In order to investigate the impact of topography on flood defense measures, we are strived to get one real catchment as a base catchment then produce artificial catchments with new topography. Base catchment and artificial catchments are the same in all information except topography. It is worthwhile to mention that in the topography map the diversity of the hills and mountains is the same in both base catchment and artificial catchments and only the land surface slope changes. Diemel catchment is selected as base catchment. It has an area of about 1800 km<sup>2</sup> and is located in the center of Germany. It is situated in the north of Hesse and south of the North Rhine Westphalia. More information about this catchment is found in chapter six.

The NASIM rainfall runoff model is used to calculate the flood wave in every point of the catchment. Some of the input data for the rainfall runoff model are organized in ArcView. In addition, ArcView is used to produce the artificial catchment. The NASIM rainfall runoff model, ArcView and the method of creating artificial catchments and selected flood defense measures are described in this chapter.

### **4.2 NASIM rainfall runoff model**

Hydrological modeling is the simplified version of reality, a means of expressing the quantitative relationship between hydrological variables or parameters. Such models are used to diagnose or forecast processes that are difficult or impossible to evaluate quantitatively in the real world. Before the 1960s simple hydrological models were developed. However, with the start of the digital revolution, the advent of computers more sophisticated hydrological models were developed. The power of computers has since increased exponentially. The digital revolution also triggered two other revolutions, namely, numerical simulation and statistical simulation. As a result, advances in hydrological models have occurred at an unprecedented pace since the groundbreaking development of the Stanford Watershed Model (SWM) by Crawford and Linsley in 1966. SWM was the first attempt to virtually model the entire hydrologic cycle. During the 1970s and 1980s a number of mathematical models were developed. Indeed there has been a proliferation of watershed hydrology models since, with growing emphasis on physical based models. Instances of such models are seen in the Storm Water Management Model (SWMM), (Metcalf and Eddy, Inc, 1971); Precipitation Runoff Modeling System (PRMS), (Leavesley et al, 1893); Stream flow Synthesis and Reservoir Regulation (SSARR), (Rockwood 1982); System Hydrologique European (SHE), (Abbott et al 1986) and others [43]. There are several well-known general watershed models currently in use around the world. These models vary significantly in the model construct of each individual component process partly because these models serve somewhat different purposes. The Hydrologic Engineering Center's Hydrologic Modeling Systems (HEC-HMS) is considered the standard model in the private sector for designing drainage systems, quantifying the effect of land use change on flooding, etc. The National Weather Service (NWS) model is the standard model for flood forecasting. HSPF and its extended water quality model are the standard models adopted by the Environmental Protection Agency. The

Modular Modeling System (MMS) model of the USGS is a widely used model for water resource planning and management works, including a number of those under the purview of the U.S: Bureau of Reclamation. The University of British Columbia (UBC) and distributed hydrologic model (WATFLOOD) are popular in Canada for hydrologic simulation. The runoff routing model (RORB) and WBN models are commonly employed for flood forecasting, drainage design and evaluation of the effect of land use in Australia. TOPMODEL and SHE are the standard models for hydrologic analysis in many European countries. The HBV model is the standard model for flood forecasting in Scandinavian countries. The ARNO, LCS and TOPIKAPI models are popular in Italy. The Tank model is well accepted in Japan. The Xin'anjiang model is commonly used in China [43]. Finally, the NASIM model is a new model developed and used in Germany. Classifications of hydrological models are as follows: theoretical versus experimental and deterministic versus stochastic models.

#### **4.2.1 General structure**

NASIM is a distributed and physically based hydrological model for long term and single event simulation. The model provides a full partition of a drainage basin into a tree structure of tributaries with the fundamental runoff producing units (either hill slopes or subcatchments) arranged as leaves on the channel tree. Processes are available for reservoir hydrology, flood routing, flow concentration and water balance for soil and catchment. NASIM supports both simulations of rural and urban regions. The main purpose of the NASIM hydrological model is the “continuous simulation of the entire water balance and illustration of all fundamental physical process of storage and water movement (snow, soil humidity, groundwater and inshore waters)” [23]. The guiding principle is based on the hydrological calculation of the whole water cycle using long term simulation with statistical analysis of the calculated series of runoff events.

The model contains mainly hydrological (linear differential) equations. The model structure and algorithms defined aim for a compromise between a sufficient degree of sophistication and general applicability under the given condition.

#### **4.2.2 NASIM elements**

The following elements are used in NASIM rainfall runoff model for simulation:

- Subcatchments: the subdivision of the catchment according to the morphological, hydrological, or topographical criteria. Runoff concentration, retention and translation of different processes are simulated depending on the subcatchments.
- Elementary elements: hydrologically homogeneous areas distinguished by type of soil or land use. They are the smallest unit used to simulate the process of distribution of net rainfall and load separation.
- Simulation elements: the aggregation of elementary elements in order to reduce the duration of simulation process.

#### **4.2.3 Principle of cascade of storage**

The model process is based on a series of retention/storage basins, in which the output of one is the input of the other. For each storage, the amount of water stored in the hydrological system may be related to the rates of inflow and outflow by the integral continuity equation:

**Equation 4-1** 
$$\frac{d\bar{S}}{dt} = I(t) - Q(t)$$

Where  $\bar{S}$  is storage, I is inflow and Q is outflow.

The storage is linked to inflow and outflow by an arbitrary empirical storage function, which's specific form depends on the system which is being analyzed.

**Equation 4-2** 
$$\bar{S} = f\left(I, \frac{dI}{dt}, \frac{d^2I}{dt^2}, \dots, Q, \frac{dQ}{dt}, \frac{d^2Q}{dt^2}, \dots\right)$$

The simplest storage function is a single valued function of outflow Q:

**Equation 4-3** 
$$\bar{S} = f(Q)$$

That particular for linear reservoir becomes:

**Equation 4-4** 
$$\bar{S} = K \cdot Q(t)$$

Therefore, the storage is linearly related to the outflow by storage constant K. Coupling the storage function with the continuity equation provides a solvable combination of two equations with two unknown variables (t) and  $\bar{S}$  (t). This conception allows formation of the conceptual framework for numerical model to describe a particular part of the cycle. The effect of storage is to redistribute the hydrograph by shifting the centroid of the inflow hydrograph to that of the outflow hydrograph in a time of redistribution.

#### 4.2.4 Components of NASIM

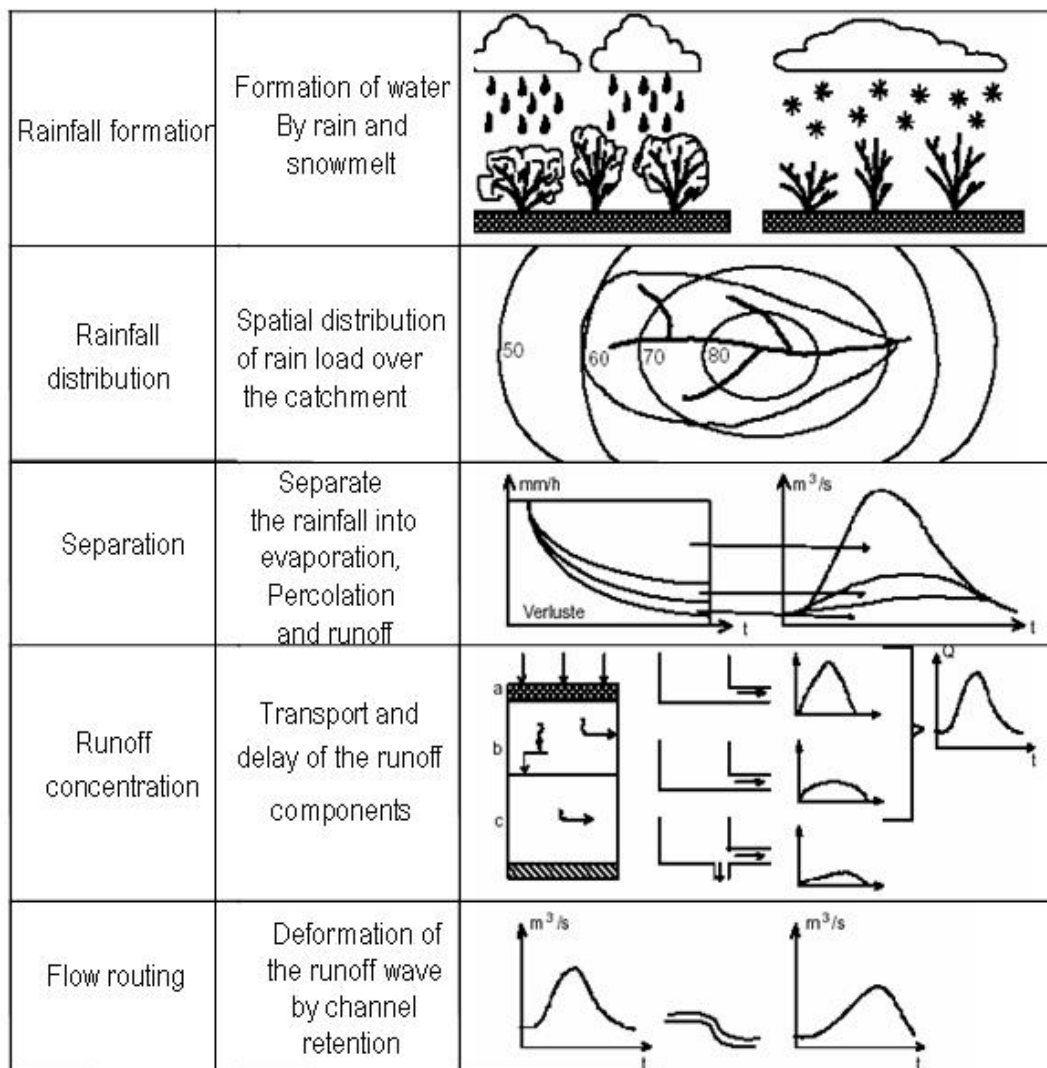
The components of NASIM are shown in figure 4-1 in which pictures represents hydrological cycle phases, into which the simulation procedure is divided.

**Load formation:** The water, infiltrated into the soil, flowing on the surface, intercepted by the vegetation, is called surface load. In accordance with the hydrological cycle, the computation of the simulation begins with the precipitation. The precipitation that lands on the ground is distinguished into load of rain and load of snowmelt. The amount of snow melt is determined by the snow compaction method: first the snow melting rate is computed depending on temperature and radiation. Then the snow density is determined and from a threshold density on snow melt is considered to leave the snow pack, reach the soil surface and hence contribute to the precipitation load.

**Load distribution:** Load distribution is the estimation of the rainfall spatial distribution in the catchment. NASIM offers three methods for the spatial distribution of precipitation in the form of time series: the “distance method”, in which the coordinate of precipitation recording station is used to determine the closest station in relation to each subcatchment, the “elevation method”, in which the elevation of each station is used to determine the station with the lowest elevation difference in relation to each subcatchment; or the “name method” in which the distribution is done by the name of stations. The distance method is very similar to the Thiessen Polygon method.

**Load separation:** This component divides the water load separation into evapotranspiration, percolation and runoff. Concerning the compartments and processes of the hydrological cycle, the rate at which each process takes place is closely linked to soil water

content (soil moisture) depending on some soil specific hydraulic characteristics. The essential processes influencing the soil moisture (infiltration, actual evapotranspiration and percolation) are schematized in figure 4-2.



**Figure 4-1 Main components of NASIM model [23]**

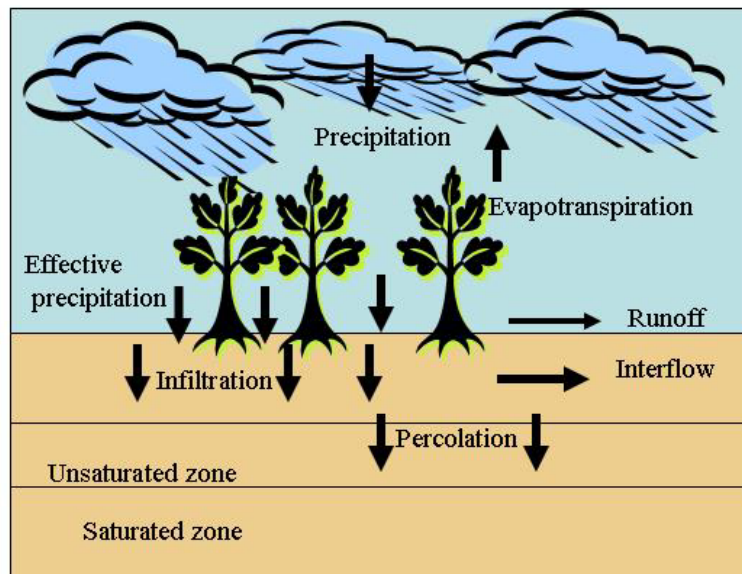
The soil properties affecting soil water movement are hydraulic conductivity and characteristics of water retention. Figure 4-3 shows the sections of soil moisture simulation:

A soil layer behaves as a single reservoir. Its content is the soil moisture, while inflows are infiltration and capillary suction and outflows are evapotranspiration and percolation.

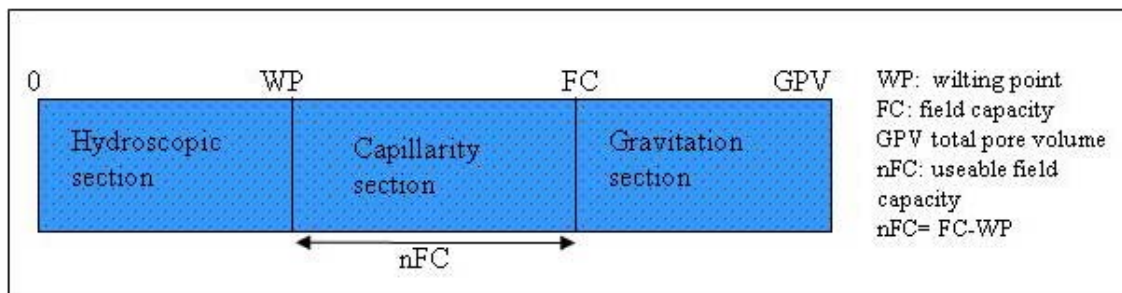
**Infiltration:** Infiltration is the process of water penetrating from the surface into the soil. Factors influencing the infiltration rate include the condition of the soil surface and its vegetation cover, the properties of the soil (such as the porosity and hydraulic conductivity) and the current moisture content of the soil. The infiltration rate is the rate at which water enters the soil. The potential infiltration is determined either linearly, in which the infiltration rate changes with the soil moisture, or nonlinearly by the equation of HOLTAN.

**Exfiltration (percolation):** Percolation is the process of water in the soil moving to the deep water table. This process is covered by the gravitational forces and occurs when the soil water content is higher than a certain threshold. The computation of percolation rate follows

depending on the soil moisture. Two approaches are implemented in NASIM: the linear approach, in which exfiltration initiates when the field capacity is reached and increases linearly up to the total pore volume; or the non linear approach using BEAR's equation.



**Figure 4-2 Soil model in NASIM**



**Figure 4-3 Soil moisture sections [23]**

Evapotranspiration is the combination of evaporation from the soil surface and transpiration from vegetation. Factors governing evapotranspiration are energy supply and vapor transport, plus the supply of the moisture at the evaporative surface. As the soil dries out, the rate of evapotranspiration drops below the level it would have maintained in well watered soil. Actual evapotranspiration is determined by the approach of OSTROWSKI, where the determining factors are potential evapotranspiration and actual soil moisture, assuming a linear relationship.

**Interflow:** For computing interflow, NASIM provides three approaches:

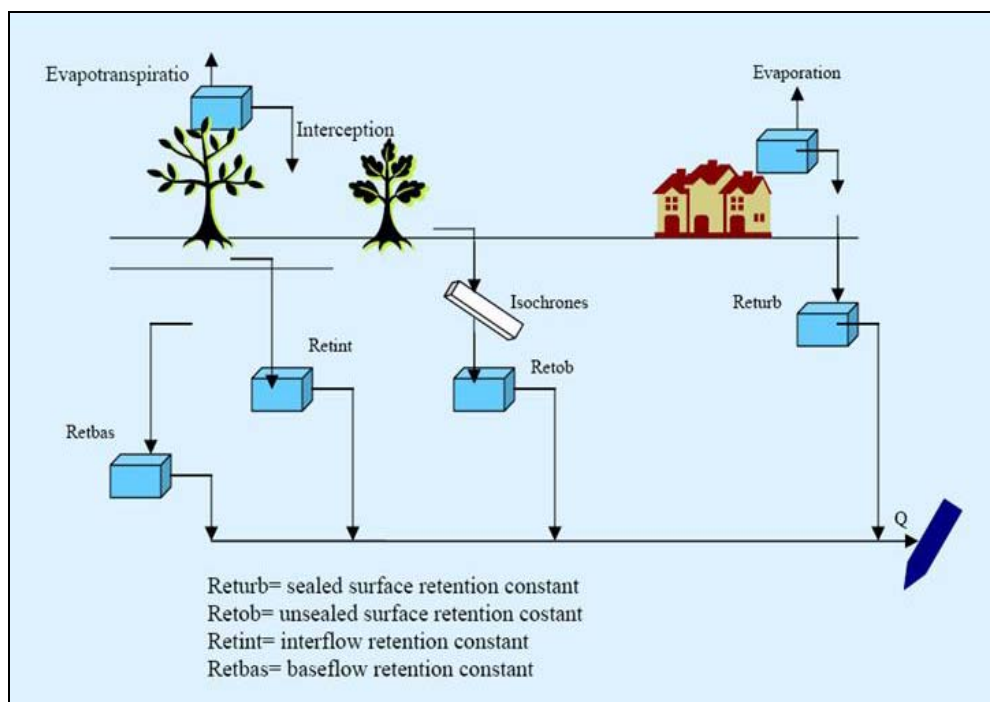
- Direct interflow: interflow occurs when the precipitation rate exceeds the infiltration rate. Up to a certain threshold, the non infiltration water becomes interflow while the rest becomes overland flow.
- Interflow in the first layer: interflow occurs in the first layer and is computed by a similar approach as percolation, but with a time lag.
- Interflow in all layers: interflow occurs in all layers and is computed as described before.

**Overland flow:** NASIM applies different procedures according to the surface characteristics. When the surface is sealed, surface runoff, evapotranspiration and channel flow are taken into consideration. Retention and translation are calculated according to the principal of linear cascades of storage. The constant storage is determined by the time of connection. In case of unsealed surface (besides surface runoff, channel flow and evapotranspiration), infiltration, interflow, percolation/infiltration and base flow are also taken into consideration. Translation is computed by unit hydrograph method and retention by a single linear storage. The unit hydrograph method is based on the translation determined after RIECK.

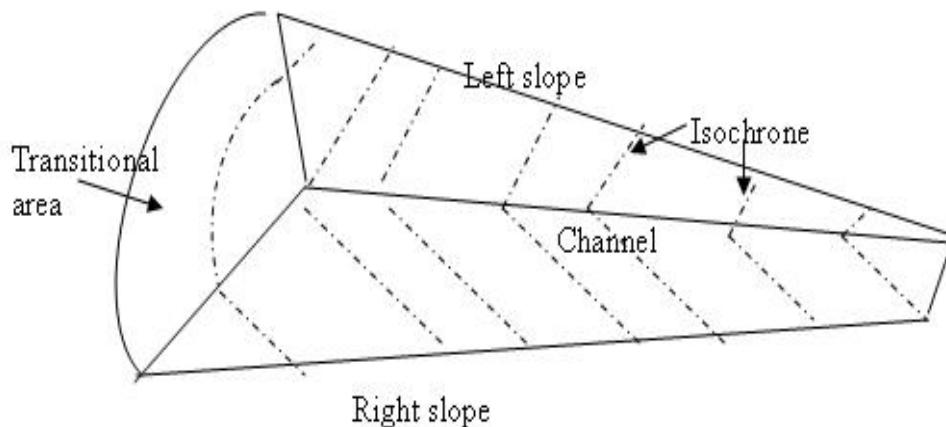
**Runoff concentration:** This component deals with the transfer and the delay of the various flow components and previous single linear reservoirs through which each flow would route and would be redistributed, before reaching the basin outlet. Transport and delay of surface runoff, interflow and base flow is described through single linear reservoirs (figure 4-4).

**Time area function:** For the overland flow a time area function is used to represent the morphology of the subcatchment in order to determine runoff concentration. The time area function is established by isochrones (line of same travel time, figure 4-5). NASIM provides two options for determining the time area function:

- a) The time area function can be calculated externally (e.g. by GIS, using a digital elevation model) and provided for NASIM as an external file (tape20).
- b) NASIM calculates the time area function based on an idealized description of the subcatchment. The natural watershed may be represented through an abstract idealized shape (triangle, trapezoid) described by the right and left slope and eventually also by a transitional area, linking the previous two. For each slope an average flow velocity (through the Manning- Strickler procedure) is estimated and then the isochrones may be fixed as the base of the computation of the time area function.



**Figure 4-4 Runoff concentration concept in NASIM**



**Figure 4-5 Isochrones, line of same travel time [23]**

**Flow routing:** Translation of wave (flow routing) is an analysis to trace the flow through a hydrologic system. In the method adapted in NASIM (due to Kalinin-Miljukov) a long channel is divided into several short segments; the flow is routed through each of these segments in turn, obtaining a series or cascade of storages representing the considered river.

#### 4.2.5 Input data

Time series: NASIM requires input time series for precipitation, temperature and potential evapotranspiration. Temperature and evapotranspiration have to be provided as daily values, precipitation can also be provided as daily values for a simulation with a step of one day, or as continuous recording of a precipitation gauge for a smaller time step.

Subcatchment data: For each subcatchment the following data have to be entered:

- Coordinate of the center
- Mean elevation
- Area size
- Percentage of sealed surface
- Snow parameters

The calculation of surface runoff concentration (time-area-function) requires information on the subcatchments morphology. If the digital elevation model is available, the time-area-function can be determined externally via GIS and entered as a file. Otherwise geometry data such as slope length, gradient, surface roughness, flow depth and angle have to be entered to enable an internal determination of the time- area-function.

Soil: The different soils in the catchment are described with the following parameters:

- Field capacity
- Wilting point
- Total pore volume
- Saturated hydraulic conductivity
- Maximum infiltration

NASIM requires two tables to determine the soil relevant functions. One table contains thickness and soil type of layers and the other table contains the parameters for each soil type.

Land use: Each land use type is defined with the parameters of root depth, interception storage and sealing. At least three type of land use have to be distinguished (forest, Greenland/farmland, urban area).

Transport elements: For each catchment that receives water from another subcatchment, a transport element has to be defined. This can be a stream segment or a pipe. For each stream segment the length and slope of the segment and the geometry data of the cross section, as well as roughness coefficient, have to be entered.

Further system elements: Depending on the structure and drainage of the catchment, further system elements can be defined (such as storage basins, channel separation devices, etc.) which require data concerning storage capacity, water level, outflow cure, etc.

### **4.3 ArcView**

ArcView is a geographic information system software product produced by ESRI. The same product name is used to describe an older desktop GIS program, often distinguished as ArcView GIS 3.x or ArcView 3.x. ArcView began as a graphical program for spatial data and maps made using ESRI's other software products. Over time more and more functionality was added to Arc View and it became a real GIS program capable of complex analyses and data management. ArcView GIS 3.3 is still currently available and many users still use the older version. ArcView GIS 3.3 is offered for both UNIX and Windows variants. Version 3.3 was released in May 2002, is currently sold and has "mature support" for multiple platforms. One of the basics of GIS is to provide a connection between data and imagery. All 3.x versions work with an underlying DBF database (dBase III, IV). The versions of ArcView 8.x and 9.x are part of the ArcGIS software suite. In ArcGIS the term ArcView is the lowest level of licensing for the ArcGIS system, offering less functionality than the middle level, ArcEditor, or the highest level, ArcInfo. All components are installed on the system, with only those that are licensed made functional. The current version of ArcView sold by ESRI is 9.2.

### **4.4 Base catchment of study**

Germany is located in the heart of Europe and its total area is 375026 km<sup>2</sup>. It is comprised of 53.5% agricultural land, 29.5% wood or forest, 12.5% city and traffic area, 1.8% water and 2.4% other land use. Around eighty million people live in Germany; the population density varies greatly between rural areas and the big cities.

Compared to Iran, Germany has a moderate climate without extreme cold or hot periods. However, there are big differences over the year during summer or winter seasons. The main parts of Germany are situated in the moderately cool west wind zone with damp westerly wind from the Atlantic Ocean. The average annual rainfall in the middle of Germany on a low mountain region is between 600 and 800 mm including rain, snow and hail. In the eastern parts of Germany the annual rainfall is between 400 and 600 mm and the climate is more continental. In the big river systems long rain periods during the winter season or special situations with big low pressure areas coming over the Mediterranean Sea (so called Vb weather conditions) cause big floods. In small catchments, especially in the low mountains, heavy thunder storm events in the summer season can also cause heavy floods, but this happens only locally. Germany as a whole can be divided into three major geographic regions: the low-lying North German plain, the central German low mountain range and in the south, the ranges of the Central Alps and other uplands. North Germany, drained by the

Ems, Weser, Elbe and Oder River, is heavily farmed, mostly flat and the soil contains all variants of sands. The central low mountain region includes, for example, the Rhine Slate Mountain (Rheinish Slate), the Harz Mountains and the Thuringian Forest. The Rhine River (the most famous river in Germany) runs through West Germany. The Rhine's source is in the Alps but the other rivers' sources are from the low mountain region. The southern part of Germany is drained by the Danube and its tributaries: Iller, Lech, Isar, Inn and the tributaries of the Rhine River Neckar and Main River [50]. Germany has a total of 400000 km of watercourse, of which 20000 km of rivers contain a catchment area of more than 1000 km<sup>2</sup>. Thus, in Germany there are over 7500 km of dike and flood protection walls and 500 impounding dam and larger retention basins with a total flood protection capacity of one billion m<sup>3</sup> all together [29]. The Diemel catchment is selected as the base catchment of this study. Diemel is located in Hesse and North Rhine Westfalia in the center of Germany. It is a tributary of Weser River. The Weser forms at Hann. Münden by joining together (confluence) the tributaries of Fulda and Werra (figure 4-6), it flows through the historic Hansa (Hanseatic League) port of Bremen and 50 km later, it enters the North Sea at Bremerhaven, which is also a seaport.



**Figure 4-6 The Weser forms at Hann. Münden by the tributary (confluence) of the Fulda and Werra**

On the opposite bank (west) sits the town of Nordenham at the foot of the Butjadingen Peninsula, which places the rivers mouth in Lower Saxony. It has an overall length of 452 km. The overall length of Weser River with its Werra tributary, which originates in Thuringia, together is 744 km. Diemel River begins near Willingen, in Sauerland and flows into the Weser in Bad Karlshafen. The Diemel generally flows northeast through the towns Marsberg, Warburg and Trendelburg. The total length of the Diemel is 106 km [50]. Its catchment area is about 1800 km<sup>2</sup> (figure 4-7). There is the digital map of the catchment with the resolution 40·40 m and also other information such as land use maps, topography maps, soil classifications map, river networks map and also the climatological data such as rainfall, temperature and other information necessary for modeling.

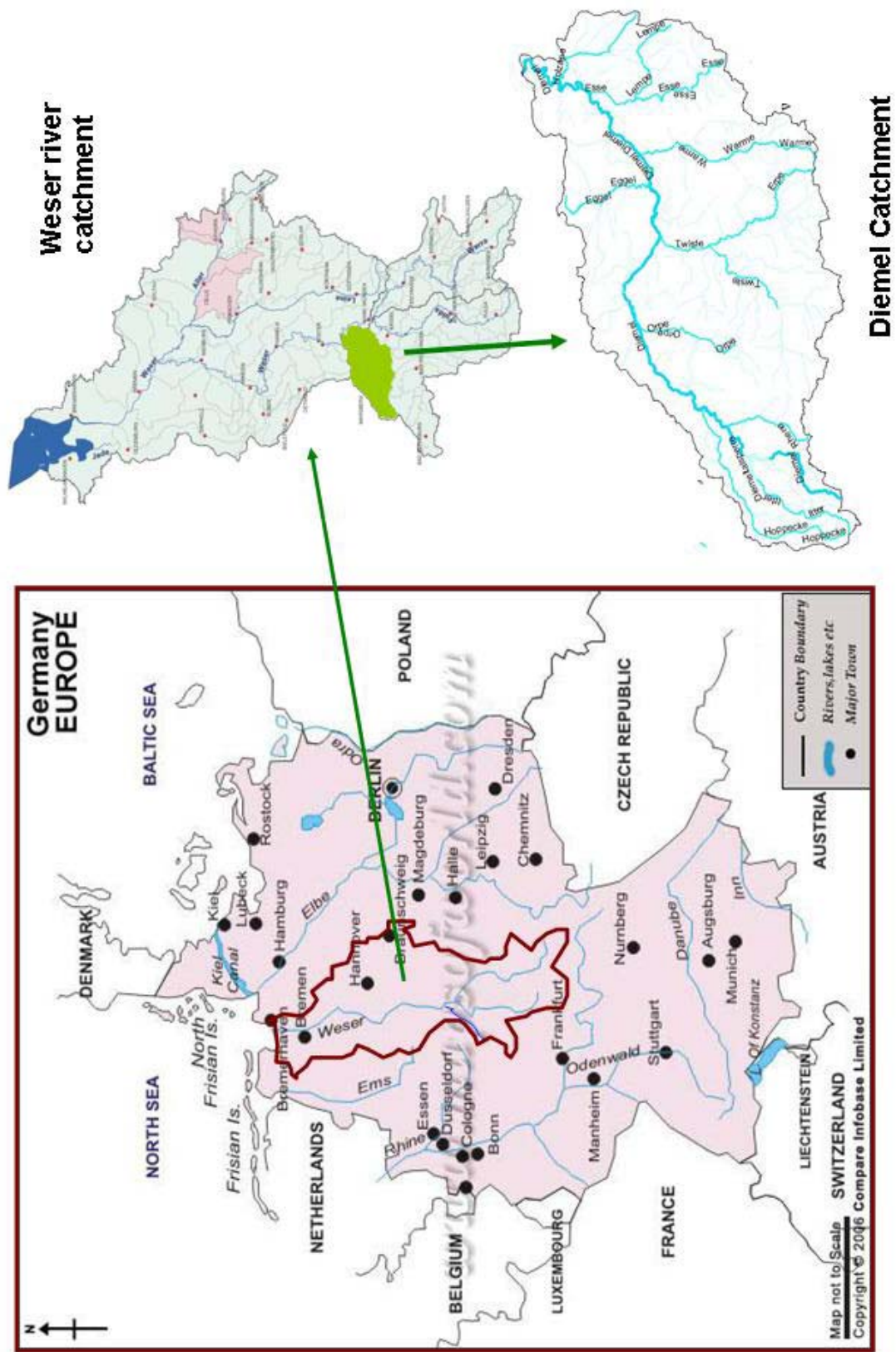
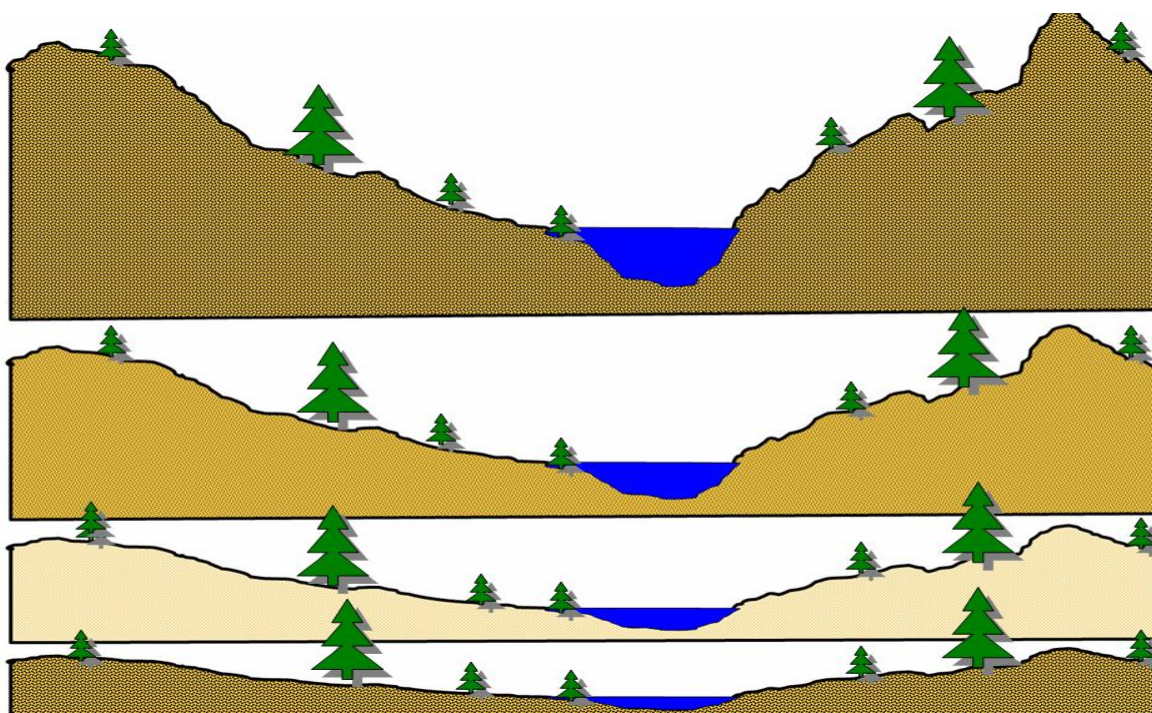


Figure 4-7 Location of Diemel catchment on Weser catchment

## 4.5 Creation of the artificial catchments

The aim of this research is to investigate the impact of topography on flood and flood defense measures. It is supposed that there are many similar catchments in all specifications and details except for topography (figure 4-8). It is clear that in nature there are not even two catchments that satisfy our objective. Therefore, artificial catchments are used. To produce the artificial catchments which are identical to the base catchment, the digital topographical maps are used. The digital maps contain a numeric matrix of discrete points which are 40 meters away from each other in plan view. Every point is defined with three parameters: longitude, latitude and altitude. In other words, each point has three coordinates that can be defined in geographical or Cartesian coordinates. The base point for these coordinates may be defined locally or globally (UTM system).



**Figure 4-8 Schematic view of artificial topographies**

The altitudes of points are changed to produce the new topography maps. In the ArcView program, every digital map is connected to a unique table in which the coordinates are shown. In this table every row is one record that it specifies one point with three fields for its coordinates (figure 4-9).

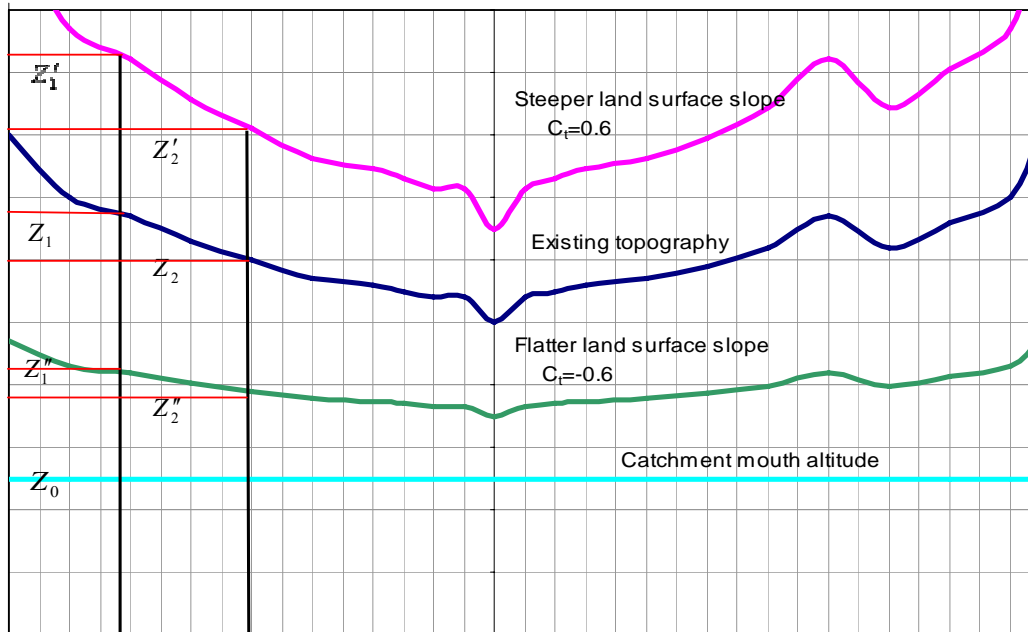
Existing coordinates:  $P(X, Y, Z) \rightleftarrows P'(X, Y, Z')$  Artificial coordinates

**Equation 4-5** 
$$Z' = Z + C_t \cdot (Z - Z_0)$$

$Z_0$ : The altitude or elevation of the catchment mouth (for the Erpe catchments  $Z_0 = 175$  m)

$C_t$ : Coefficient of increasing or decreasing of elevation and it is between -0.9 and +6

According to the above formula, the topography of catchment will be steeper or flatter by different value of  $C_t$ .



**Figure 4-9 Parameters definition to create artificial topography**

## **4.6 Investigation of selected flood defense measures**

Three flood defense measures are considered here. First, land surface retention based on increasing the infiltration rate is considered. Second, river restoration methods which make a reduction in the maximum flood discharge are examined. Third, central and decentral dam construction is studied. The conditions and methods of investigation of these measures are discussed in this part.

### **4.6.1 Land surface retention**

Flood defense measures which are considered retention water in place are called catchment area planning and management and it reduces runoff. These are comprised of all measures, tasks, rules and regulations which are done in the catchment to reduce the flood water. It is clear that these measures influence the hydrological cycle items that they reduce amount of runoff and flow velocity or cause a delay in peak of flood. The objectives of these measures are to increase interception, infiltration and hole storage and decrease the runoff velocity. Catchment area planning and management approve a series of rules to use the best land use and take artificial actions and activities to avoid erosion in the catchment from the big floods. According to the last chapter, every flood defense measure which is based on the above items is more efficient when the land surface slope decreases.

Infiltration increasing is one of the flood defense measures which lead to some modification of flood parameters. This research considers the sensitivity of flood parameters to infiltration rate changes for the catchments. The infiltration rate depends on some physical properties of soil (e.g. soil aggregate stability, aggregate size distribution, hydraulic conductivity, etc.), some chemical properties of soil (e.g. SAR, EC, etc) and the percent of grass cover and tillage management in farm lands [27]. There is more information about the effect of these parameters on infiltration rate and finally on flood parameters. Infiltration rate changes by manipulating the land surface such as agricultural tillage operations. The agricultural tillage operations mix the surface soil and break sealed zones. As a result, the

surface entry will increase. On the other hand, plowing across the land surface slope will cause an increase in the infiltrated water volume and decrease the runoff volume.

The model calculates the land surface retention by utilizing the catchment soil information (wilting point, field capacity, total pore volume, saturated hydraulic conductivity and maximum infiltration rate) and land use data. According to the literature, only infiltration rate is affected by land surface slope and other parameters depend on the physical parameters of the soil and are determined with soil testing. Usually in the rainfall runoff model the infiltration rate is parameter to calibrate the model. Therefore, it is not an absolute value in models. In the NASIM model, if the infiltration rate is kept constant, the flood volume will also be constant for the different land surface slope scenarios. It is due to the NASIM rainfall runoff model, because in this model the infiltrated water volume is not affected by land surface slope.

#### 4.6.2 River restoration

As mentioned before, river restoration methods are considered in this research, which are influenced by the flood parameters by means of affecting river flow velocity. According to the river discharge formulas there are different ways to change the river flow velocity, River roughness, hydraulic radius and longitudinal river slope are three parameters that can influence the river flow velocity.

**Equation 4-6** 
$$U \propto \left( \frac{1}{n}, R, S \right)$$

Longitudinal river slope is one of the topographical parameters which influence floods by affecting the flood wave parameters and changing the local features of floods (such as water level and inundated areas). The purpose of this part of the research is to discover the relationship between the flood hydrograph parameters and the upstream river network slopes. So, all of input data are fixed in the model except river slopes. The output flood hydrograph for each subcatchment is calculated by the model. Three important parameters are considered in the flood hydrograph (maximum discharge, flood volume and time to peak). To show the upstream river slope three indicators are used:

S: Artificial upstream river slopes

S<sub>E</sub>: Existing upstream river slopes

S<sub>e</sub>: Weighted average of the upstream river network slopes for whole catchment

**Equations 4-7** 
$$S_e = \frac{\sum L_i \cdot S_i}{L}$$

$$L = \sum L_i$$

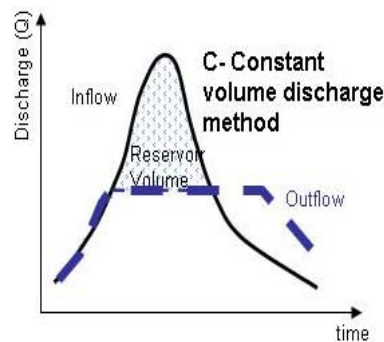
L<sub>i</sub> is the subcatchment river length with S<sub>i</sub> river slope and L is the sum of L<sub>i</sub>

#### 4.6.3 Central and decentral dams

Central and decentral dams are considered to be flood defense measures. The following assumptions are presupposed for all dams:

- Dams' reservoirs have a single purpose of flood control to reduce flood damages in the downstream.
- Type of retarding dams is embankment dams.
- Operation rule of outlet is constant volume discharge method.
- The flood discharge at the end of the catchment is considered a safe discharge when it is equal or less than HQ<sub>5</sub>.

A rough estimation of flood mitigation cost method is used to compare the different dam sites.



**Figure 4-10 Operation rule of dam outlet**

**Rough estimation of flood retarding dam site index:** Benefit and cost analysis is the best way to compare the different flood defense scenarios. It requires a lot of information. In this research a simplified method is developed to compare flood retarding dams in different sites.

The following assumptions are presupposed:

- The length of the dam crest has a linear function with the height of the dam; in other words the slope of the valley across the river in the dam site is constant: In which  $L_z$  is the length of dam crest at the height of  $z$  and  $L$  is length of dam crest at the height of  $H$  (figure 4-11).

**Equations 4-8**

$$L_z = b + (n_l + n_r) \cdot z$$

$$L = b + (n_l + n_r) \cdot H$$

- The total cost of dam is a function of the volume of embankment. This can state the additional costs (such as outlet structure, gats, free board and foundation improvement) which are a percentage of the embankment cost so.

**Equation 4-9**

$$C_d = \lambda \cdot C_e$$

**Equation 4-10**

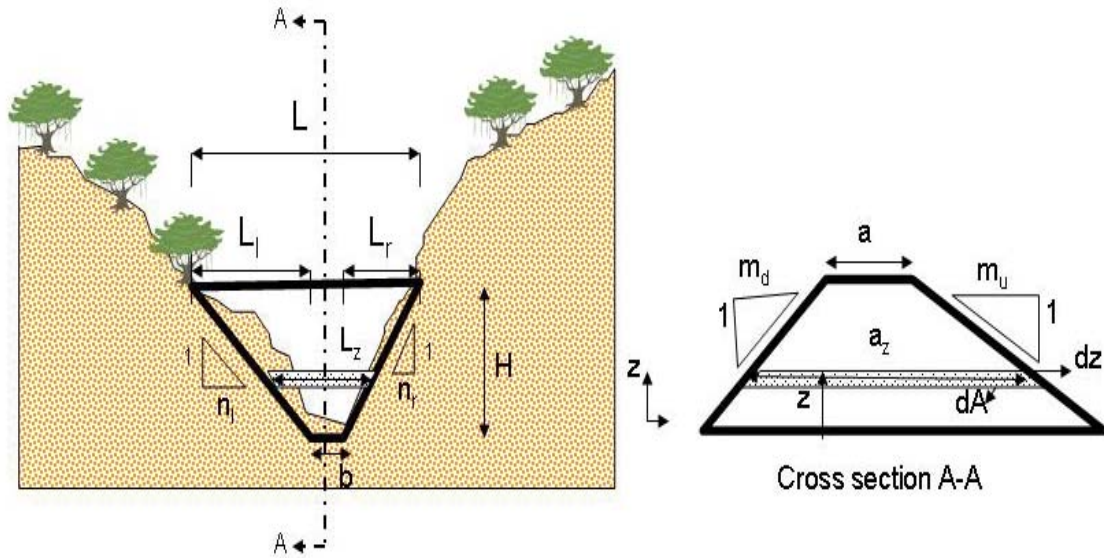
$$C_e = \phi \cdot V_d$$

**Equation 4-11**

$$C_d = \lambda \cdot \phi \cdot V_d$$

- In which  $C_d$  is the total cost of the dam,  $C_e$  is the cost of dam body,  $\lambda$  is the percent of cost for extra parts of dam such as foundation improvement etc,  $\phi$  is the cost of one cubic meter of dam body and  $V_d$  is the volume of dam body.

If the type of dam is an embankment or earth dam (as according to figure 4-11) then the embankment volume is:



**Figure 4-11 Earth dam and valley cross sections**

$$dA = a_z \cdot dz$$

$$dA = m_u \cdot (H - z)dz + a \cdot dz + m_d \cdot (H - z)dz$$

$$dA = [a + (H - z) \cdot (m_u + m_d)]dz$$

$$L_z = n_l \cdot z + n_r \cdot z + b$$

$$dV_d = L_z \cdot dA = (n_l \cdot z + n_r \cdot z + b) \cdot [a + (H - z) \cdot (m_u + m_d)]dz$$

$$V_d = \int_v dV_d = \int_0^H (n_l \cdot z + n_r \cdot z + b) [a + (H - z) \cdot (m_u + m_d)] dz$$

**Equation 4-12**

$$V_d = \frac{a \cdot (n_l + n_r)}{2} H^2 + (n_l + n_r) \cdot (m_u + m_d) \cdot \left( \frac{H^3}{2} + \frac{H^3}{3} \right) + a \cdot b \cdot H + b \cdot H^2 \cdot (m_u + m_d) - \frac{b \cdot H^2}{2} (m_u + m_d)$$

**Equation 4-13**

$$V_d = a \cdot b \cdot H + [a \cdot (n_l + n_r) + b \cdot (m_u + m_d)] \frac{H^2}{2} + [(n_l + n_r) \cdot (m_u + m_d)] \frac{H^3}{6}$$

If  $m_u = m_d = m$  and  $n_l = n_r = n \Rightarrow$  Then

**Equation 4-14:**

$$V_d = \frac{2a \cdot n}{2} H^2 + 4n \cdot m \cdot \left( \frac{H^3}{2} + \frac{H^3}{3} \right) + a \cdot b \cdot H + 2 \cdot m \cdot b \cdot H^2 - \frac{b \cdot H^2}{2} 2m$$

$$V_d = a \cdot b \cdot H + [2n \cdot a + 2 \cdot m \cdot b] \frac{H^2}{2} + [4n \cdot m] \cdot \frac{H^3}{6}$$

**Equation 4-15**  $V_d = a \cdot b \cdot H + (a \cdot n + b \cdot m)H^2 + \frac{2}{3}n \cdot m \cdot H^3$

The reservoir volume  $V_r$  is a function of the dam height and is calculated by the ArcView program from digital land surface maps.

**Equation 4-16**  $C_u = \frac{C_d}{V_r} = \frac{\lambda \cdot \phi \cdot V_d}{V_r}$

**Equations 4-17**  $f = \frac{C_u}{\lambda \cdot \phi} = \frac{V_d}{V_r}$

When  $C_u$  is the cost of one cubic meter of flood reservoir volume and  $f$  is a dimensionless value called “**topographical site index**”. The total cost of the dam is:

**Equation 4-18**  $C_u = f \cdot \lambda \cdot \phi$

**Equation 4-19**  $C_d = C_u \cdot V_r$

The topographical site index is a function of the dam body volume and reservoir volume. On the other hands, in the equations, two groups of the parameters affect the cost of flood mitigation dam. The first group of parameters depends on the valley topography while the second group of parameters depends on the cost of materials and construction. These two types of parameters are separated in the equations.  $\lambda$  can be calculated from the constructed dam and it is a function of the dam type, spillway and outlet structures. The value of  $\phi$  is calculated by price list books. It depends on the cost of materials, transport and construction acts, which remain constant for one site. The topographical site index shows the effect of topography of the dam site and reservoir and also the effect of the dam height and reservoir volume on the cost of flood mitigation system.

## 4.7 Conclusion

NASIM rainfall-Runoff model is used to simulate the flood. The model uses complete topography map as input data. It is a distributed and physically based hydrological model for long term simulation and single event simulation. The model provides a full partition of a drainage basin into a tree structure of tributaries with the fundamental runoff producing units, either hill slopes or subcatchments, arranged as leaves on the channel tree. Processes are available for reservoir hydrology, flood routing, flow concentration, water balance for soil and catchment. The guiding principle is based on the hydrological calculation of the whole water cycle using long term simulation with statistical analysis of the calculated series of runoff events. The hydrological model uses some input data which are produced by ArcView Gis outputs such as topographical information, soil and land use. The catchment of Diemel River is selected as the base catchment of this study. Diemel is a tributary of the Weser River and it is located in Hesse and North Rhine Westphalia in the center of Germany. It has an overall length of 106 km. The catchment area is about 1800 km<sup>2</sup>.

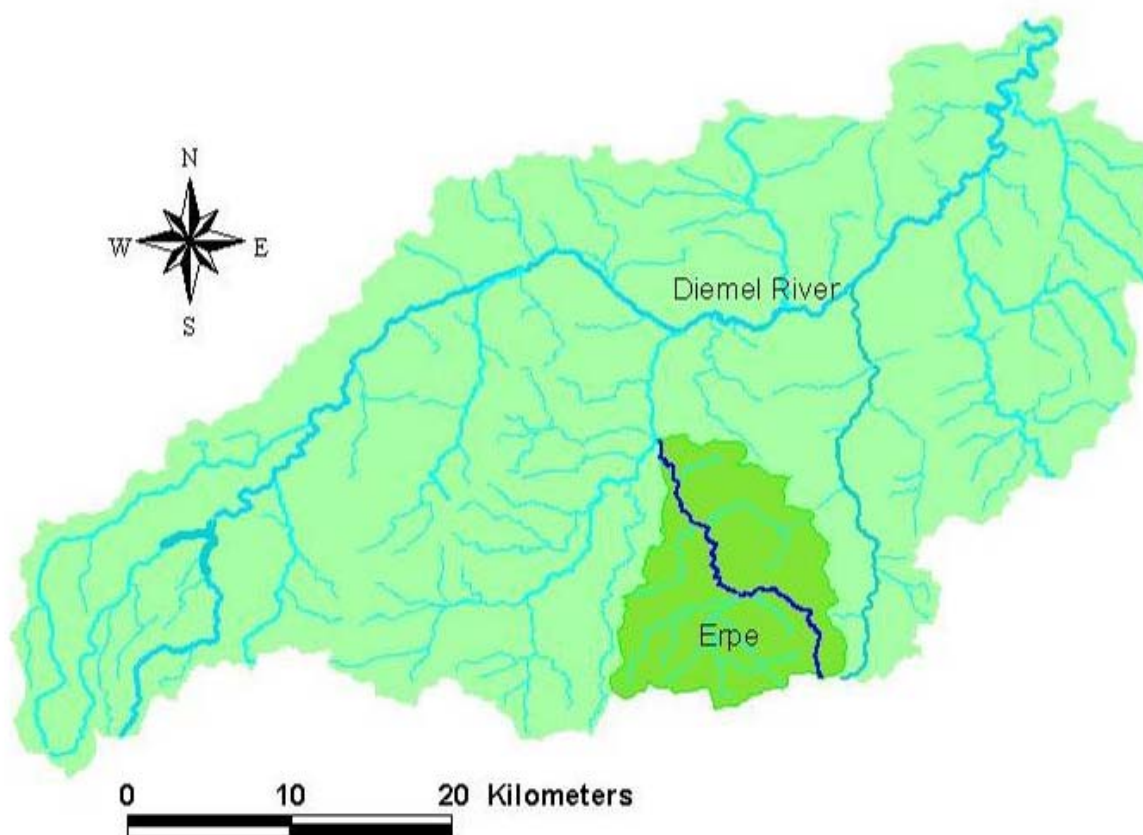
The digital topographical maps are used to produce the artificial catchments which are similar to the base catchment in area and river network. The altitudes of points are changed to produce the new topography maps. Three flood defense measures are selected to be considered. First, infiltration changes in agricultural land, as a flood retention measure, second, upstream river network slope and roughness change as a river restoration measure and third, central and decentral flood retainer dams.

The topographical site index introduced as a ratio of the dam body volume and reservoir volume. It shows the effect of topography of the dam site and reservoir and also the effect of the dam height and the reservoir volume on the cost of flood mitigation system. It used to compare the dams flood mitigation scenarios. These measures are used in an existing catchment and have results that compare with artificial catchments.

## 5 Application of different scenarios for Erpe catchment as a pilot area

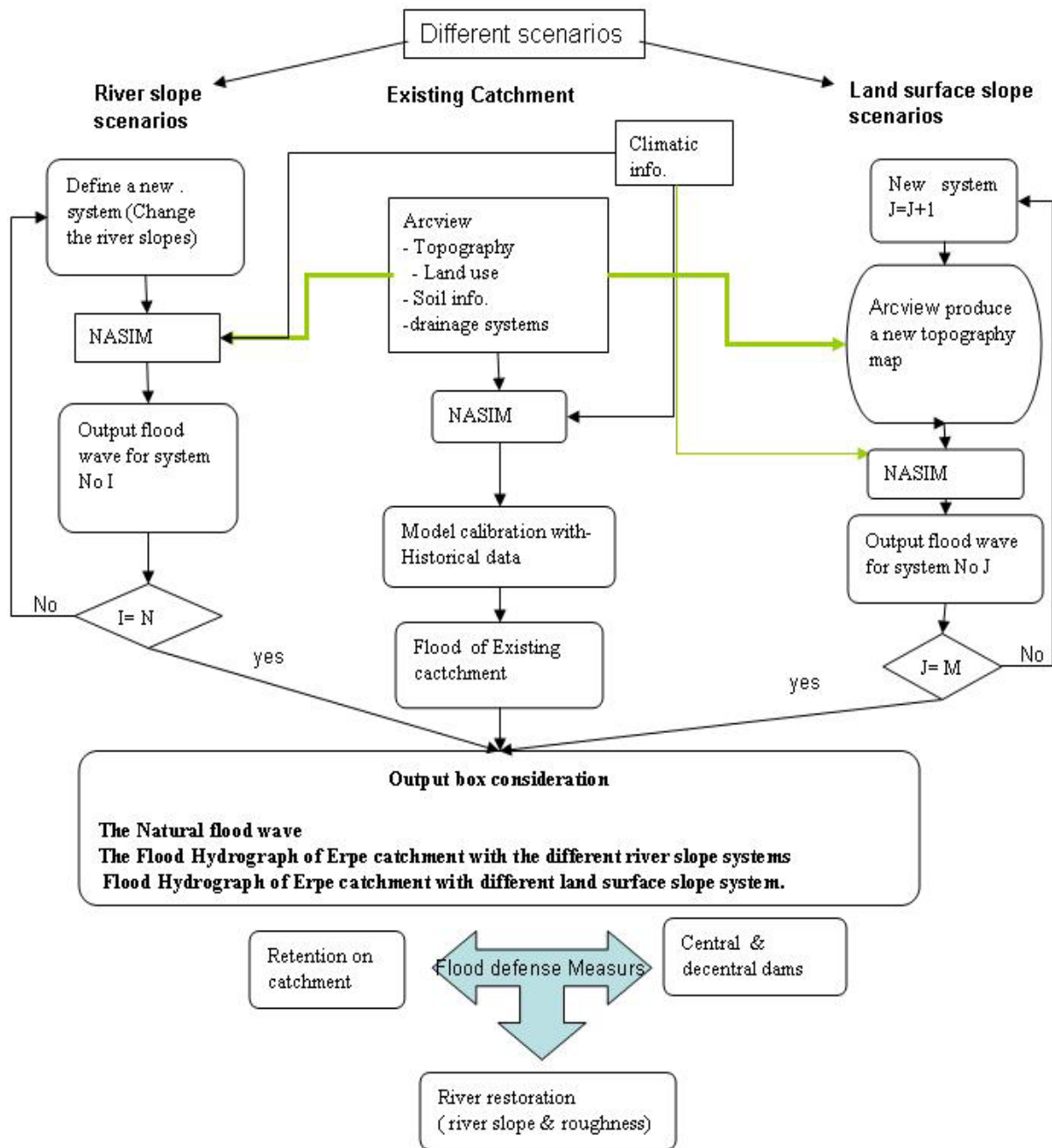
### 5.1 Introduction

In this section the Erpe subcatchment is considered as a small pilot catchment. Examination and application of methods (which are described in the previous section) are the main objectives of this section. In the first part, the Erpe subcatchment is considered as a base and then the NASIM model is applied to simulate flooding for the existing catchment as well as artificial catchments. The Erpe is a part of the Diemel catchment located in the south of the catchment (figure 5-1).



**Figure 5-1** Location of the Erpe in Diemel catchment

Figure 5-2 shows the executive chart to evaluate the connections between the flood and flood defense measures and topographical parameters. In this chart, the situation of software (NASIM and Arcview) and other data are shown. According to the executive chart, the catchment topography, land use, soil information and drainage system prepared in Arcview environment and then used by the model. Two groups of scenarios are defined, first, river slope scenarios and second land surface scenarios. The slope of drainage network will have changed in the river slope scenarios. There are 14 scenarios in this part (N=14). Right side of the chart shows the land surface slope scenarios. Artificial catchments with new land surface slope are modeled in this part. So, finally some elected scenarios are chosen and evaluate with different flood defense measures.



**Figure 5-2 The executive flowchart for Erpe catchment**

## **5.2 General information of Erpe catchment**

The Erpe catchment is located in the Northwest of Hesse near the border of North Rhine-Westphalia and flows from the South to the North. It joins to the Diemel River in the north of Volkmarsen. The catchment's area is about 153.27 km<sup>2</sup> (8.5% of the whole area of the Diemel). The biggest city in the Erpe subcatchment is Wolfhagen. There are also many small cities such as Breuna, Niederelsungen, Oberelsungen and Ehringen in this catchment.

### **5.2.1 Topography**

The Erpe located in a region with low height mountains and hills. The difference of altitude between the lowest point and the highest point is 425 m. The lowest point of the catchment is located at the catchment mouth which has an altitude of 175.4 m above sea

level. The highest point of the catchment is 599 m high and located on top of the hill in the east of the catchment. There are also some small hills located in the south and the east of the catchment. The majority of the slope is from south to north. In the light of low slope area and good soil, most of the area is farm land.

### 5.2.2 Geology and soil types

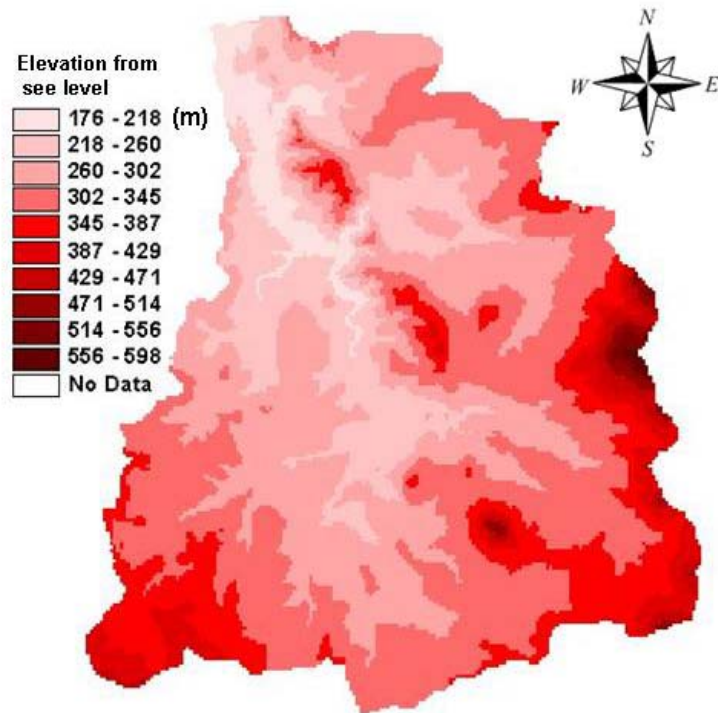
According to the Erpe catchment report [22], the soil information was derived from ATV-DVWK reports (2003). The Erpe catchment is covered by four soil types: debris sand (gS), poor sandy loam (Ls2), clay (T) and silt (U). In addition, the catchment soils are categorized by combination of soil type and landscape (shown in table 5-1).

**Table 5-1 Soil types information in the Erpe catchment**

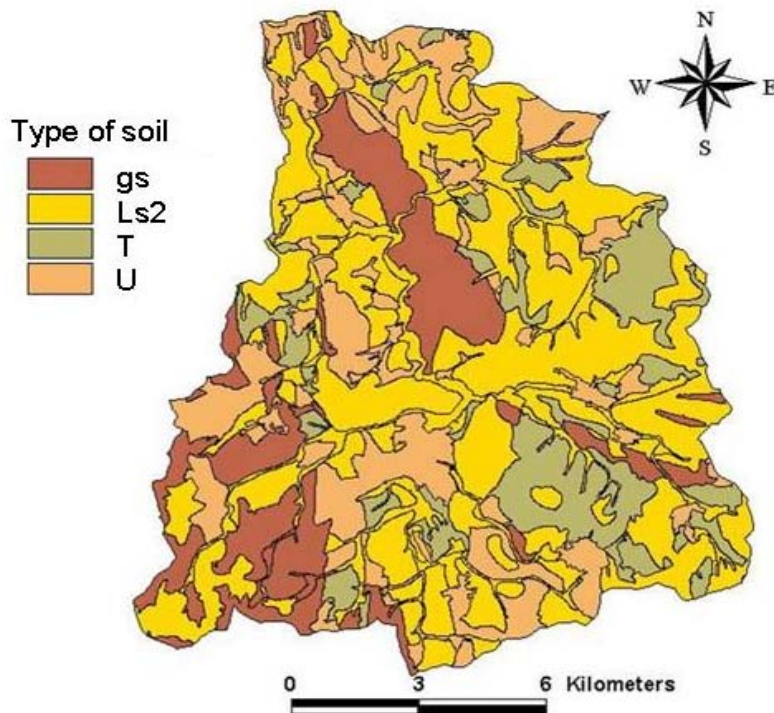
Short name	DVWK (Abb.)	Description	Wp (Wilting point) mm/m	Fk (Field capacity) mm/m	GPV (Total pore volume) mm/m	Kf (Sat. hydraulic conductivity) mm/h	M.Infilt (Max. infiltration rate) mm/h
Ls2	Ls2	Poor sandy laom	160	330	430	23	23
M1	M1	Marsh	190	560	670	11	11
gS	gS	Debrise Sand	30	90	380	125	125
T	T	Clay	390	540	580	5	5
U	U	Silt	90	340	440	11	11
Ls2 (Forest)	Ls2	Forest place	160	330	430	23	23
M1_Wald (Forest)	M1	Forest place	190	560	670	11	11
gS_Wald (Forest)	gS	Forest place	30	90	380	125	125
T_Wald (Forest)	T	Forest place	390	540	580	5	5
U_Wald (Forest)	U	Forest place	90	340	440	11	11
Ls2_Karst	Ls2	-	160	330	430	46	23
M1_Karst	M1	-	190	560	670	22	11
gS_Karst	gS	-	30	90	380	125	125
T_Karst	T	-	390	540	580	10	5
U_Karst	U	-	90	340	440	22	11
Ls2_Karst_Wald	Ls2	Forest place	160	330	430	46	23
M1_Karst_Wald	M1	Forest place	190	560	670	22	11
gS_Karst_Wald	gS	Forest place	30	90	380	125	125
T_Karst_Wald	T	Forest place	390	50	50	10	5
U_Karst_Wald	U	Forest place	90	340	440	22	11

### 5.2.3 Climatological data

For the rainfall- runoff simulation, the climatologic data (such as precipitation, temperature, evaporation and evapotranspiration) are needed. There are climatologic data for the Erpe catchment that is used in the reference No [22]. This research uses the one hour rainfall over the whole catchment. The intensity and diversity of rainfall are the same with the result of reference [22]. Accordingly, the rainfall with one hour duration and a one hundred year frequency for the Erpe catchment is 52 mm.



**Figure 5-3** The topography map of Erpe catchment



**Figure 5-4** Distribution of different soil type in Erpe catchment

#### 5.2.4 Land use

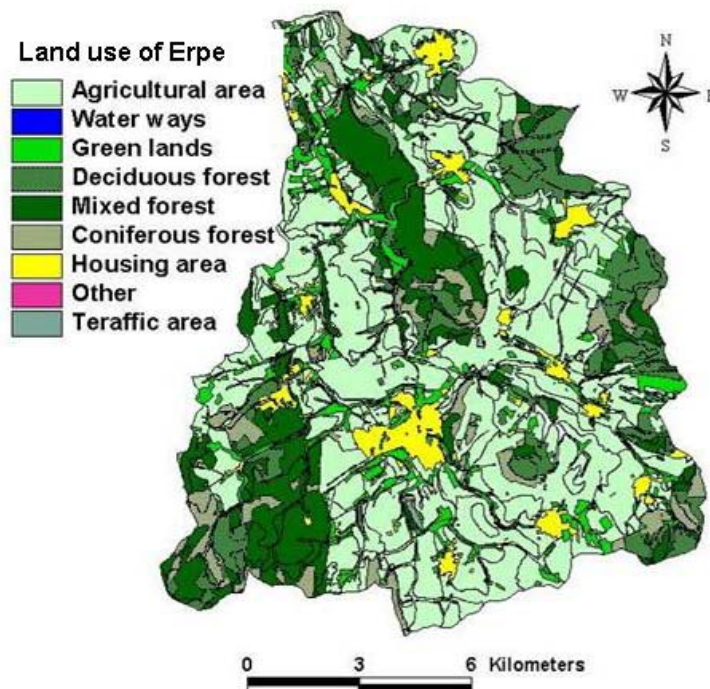
The Erpe catchment is located in the low mountainous region. It contains a rural structure with multiple independent villages that are united and form cities. The city of Wolfhagen,

part of Zierenberg and Breuna are located in the Erpe catchment. In comparison with other regions, the high portion of the catchment in the North Hesse area is agricultural lands. This is due to the good soil and low land surface slope. There are compositions of different land use that are shown in figure 5-5 and described in table 5-2. Farm lands covers 51.5% of the Erpe catchment and the rest area are, 16.1% mixed forest, 11.1% deciduous forest and 9.3% green land. The physical parameters of the individual land uses (root depth, interception, factor etc.) are represented in table 5-3. In this table, however, different kinds of forest and agricultural land are not considered. There are large differences in the maximum interception and in the seasonal process depending upon useful plant. In the context of the available treatment, the different agricultural lands are not differentiated but middle values are accepted. There are also the same situations for the different kinds of forests.

The factor of interception rises from April to July, from zero to one and returns to zero again. For the settlement surfaces, it is supposed that 30 % of the surface is sealed.

**Table 5-2 Land use of Erpe subcatchment**

No	Land use	Number of blocks	Area km <sup>2</sup>	Percent %
1	Housing area	200	8.79	5.7
2	Traffic area	6	0.01	0
3	Agricultural field	77	78.72	51.4
4	Green land (grass)	276	14.29	9.3
5	Deciduous forest	188	16.99	11.1
6	Coniferous forest	-	9.54	6.2
7	Mixed forest	-	24.66	16.1
8	Water	30	0.07	0.0
9	Other	104	0.19	0.1
10	Total		153.27	100



**Figure 5-5 Distribution of different land use in Erpe catchment**

**Table 5-3 Land use parameters**

Name	Root depth (m)	Interception (mm)	Factor
Agriculture	1.00	3.00	1.00
Mines	0.50	0.00	1.00
Water	0.00	0.00	1.00
Green lands	1.00	1.50	1.00
Industry	1.00	1.00	1.00
Housing area	1.00	1.00	1.00
Forest	2.00	8.00	1.00

### **5.3 System plan**

The system plan is the main window of the graphical user interface of NASIM. It visualizes the channel system including all features of the catchment such as subcatchments, channels, storage basins, etc. which are generally called “System Element” [23]. The Erpe catchment is subdivided into 27 subcatchments. Every subcatchment has a special ID number. The system plan is defined for the NASIM model at figure 5-6.

In this model, the hydraulic data (comprised of the river length, slope and cross section) are entered separately. Usually these data are determined by using GIS maps and field measurements. From these data, NASIM calculates a discharge.

The surface runoff concentration is determined by a time area function. With the digitalized subcatchment borderlines and the digital elevation model, a time area function is generated by using GIS. The result is a table containing travel time and corresponding area between the isochrones. This table (TAPE20) is used by NASIM.

Dr.-Ing. Klaus Roettcher (2004) has calibrated the catchment model which is used in this research.

### **5.4 Influence of upstream River slopes on flood parameters**

The goal of this section is to find out the sensitivity of the flood hydrograph parameters to the upstream river network slopes. River slope causes changes on flow velocity. Thus, the flood parameters will be changed. There are two ways (methods) to consider the upstream river slope in NASIM model: first, we can change the river slope directly in river transport parameters window; second we can consider the upstream river velocity changes. Since the results of both methods are similar, so the second method was used. In this method, the relationship between the river slope and velocity was considered. In addition, this method can be used for river roughness. Consequently, all of the input data in the model was fixed except for the upstream river slopes. The river slopes were changed regularly from 0.5 to 1.8 times of existing value, thus, 13 systems was defined and, along with this, natural conditions were taken into consideration. The model ran for these 14 conditions (13 systems and the natural condition). The output flood hydrograph for each subcatchment was calculated by the model. The examination of output flood hydrographs showed regular deformations in the flood wave shapes. Three important parameters of the flood hydrograph were considered comprise maximum discharge, flood volume and time to peak.

The peak of flood hydrograph is very important in order to design the hydraulic structures and flood defense projects. The effect of the river slope on flood parameters is examined for the Erpe catchment and the results are presented in figures 5-7 to 5-10 and also in table 5-4.

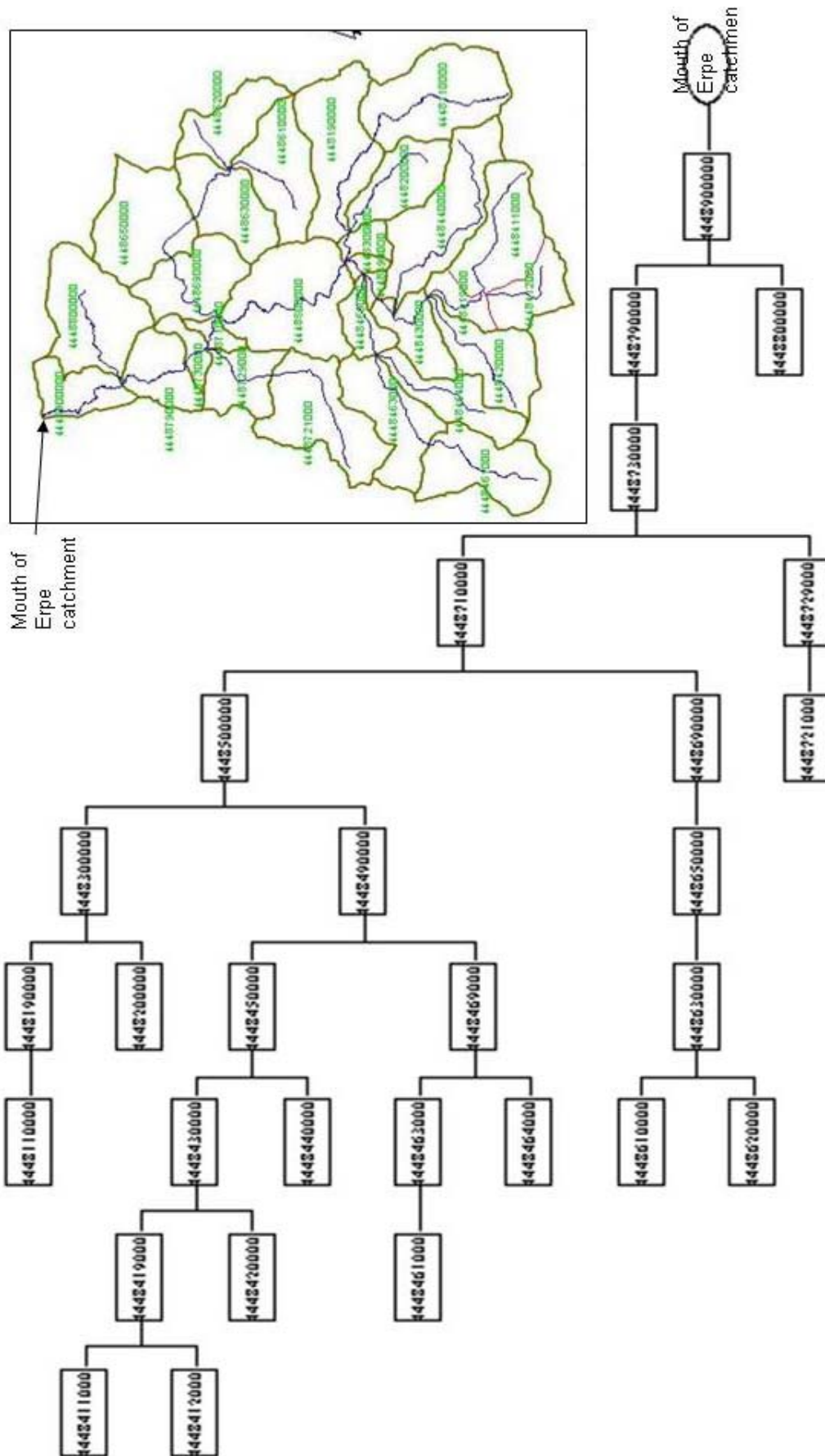
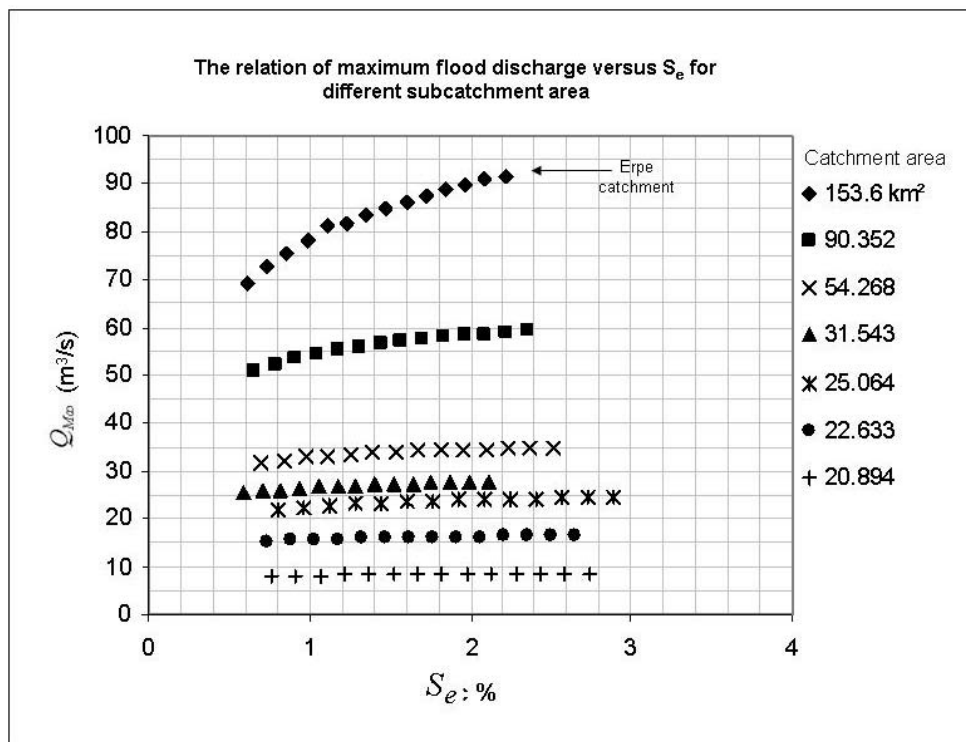


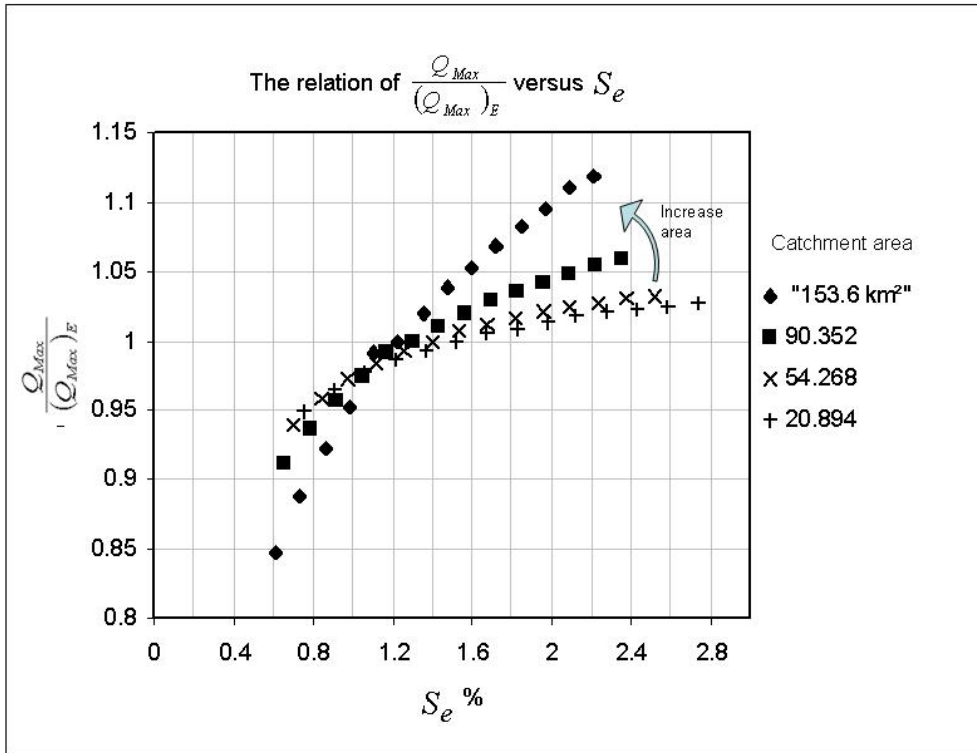
Figure 5-6 Erpe catchment subdivisions and its system plan

Seven catchments were investigated with areas from 20 to 153 square kilometers. The Erpe river drainage networks were considered to calculate the weighted average of river network slope (from equation 4-7). Sensitivity of flood wave parameters, such as maximum flood discharge and time to peak, were calculated for every catchment. Figure 5-7 shows the maximum flood discharge changes versus weighted average of river network slope. By attention in the figure the lozenge marks which depend to the whole catchment area are more responsive than others for the reason that the total length of rivers is more. Figure 5-8 shows it clear because it makes use of the relative amount of the maximum flood discharge. The curve gradient will be higher by an increase in the catchment area. There are good connections between the maximum flood discharge and the changes in the upstream river slopes. When the upstream river slope increases, then the river velocity increases and the maximum flood discharge is added as well. In other words, according to these graphs, the gradients of curves depend on the catchment size. Also, the absolute changes for small catchments are not sensible, but they are important for large catchments. Figure 5-9 shows the changes of maximum flood discharge compared to the existing situation ( $S/SE=1$ ). Two parts of this graph show the sensitivity of maximum flood discharge to decreasing and increasing of the upstream river slope. Figure 5-10 shows changes of time to peak versus relative river slope: the more the increase of the catchment area, the more the sensitivity of time to peak. In other words, in any small catchment flood reduction by decreasing of river slope is not so effective.

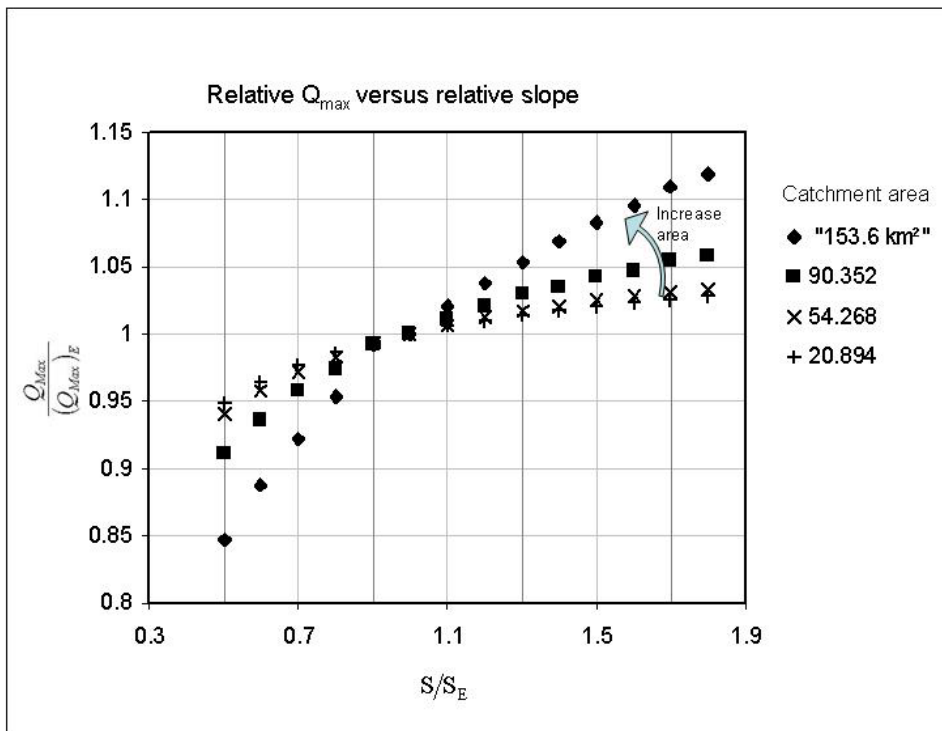
Equations 5-1 to 5-5 (in the table 5-4) also show the corresponding relationships between above parameters with high correlation factors. The coefficients of the equations are the function of catchment area. If the upstream river slope increases to only 1% then the maximum flood discharge will add about 12.5% for the whole Erpe catchment( Figure 5-7, the blue. marks) There are no meaningful differences on volume of flood when increasing upstream river slope because of the retention parameters and the fact that flood loss parameters are constant.



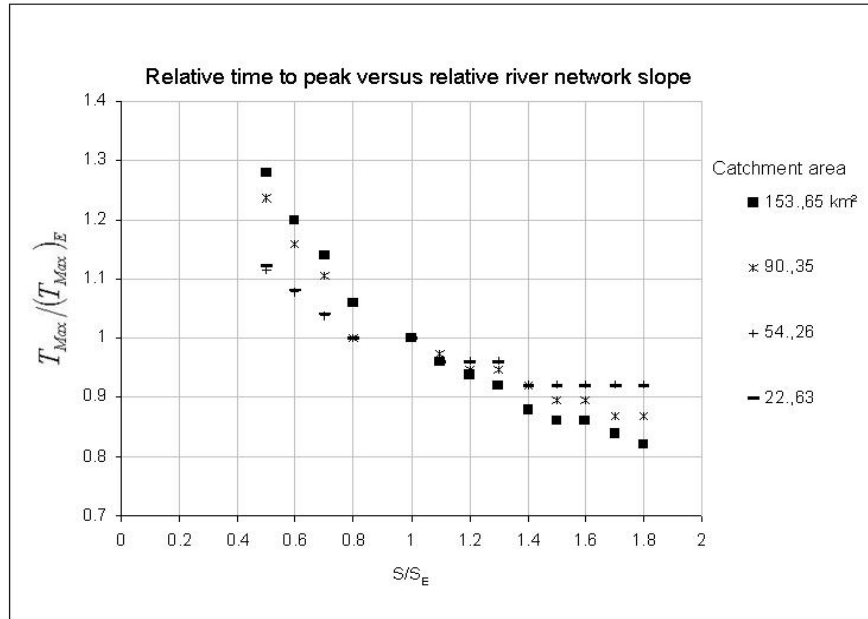
**Figure 5-7 The maximum flood discharge versus slope of rivers network**



**Figure 5-8 Dimensionless maximum discharge versus river slope (E denotes to existing catchment)**



**Figure 5-9 Changes of relative maximum discharge versus relative rivers slope**



**Figure 5-10** Changes of relative flood time to peak versus relative river slope

**Table 5-4** Relation between upstream rivers network slope and flood parameters

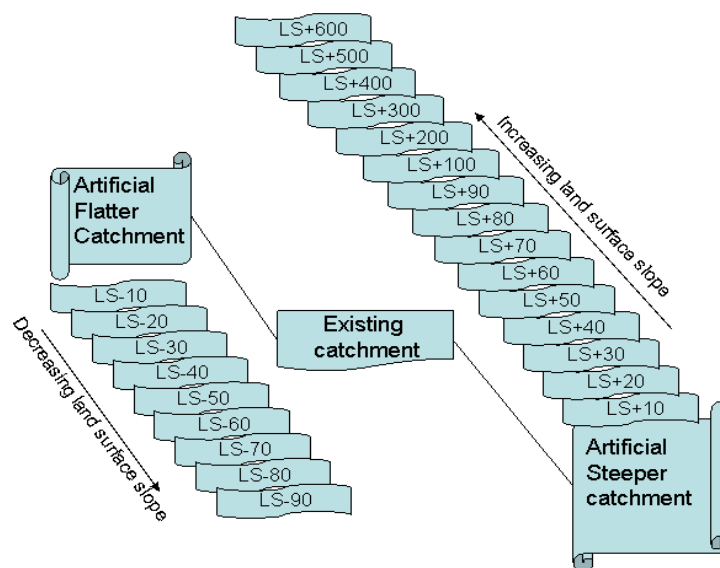
$0.5 \leq \frac{S}{S_E} \leq 1.8$ and $A \leq 154 \text{ km}^2$		
	Formula	Coefficients
Relationship between $Q_{\max}$ and relative river slope	<b>Equation 5-1</b> $Q_{\max} = \alpha \cdot \ln\left(\frac{S}{S_E}\right) + \beta$	$\alpha = 0.113 A + 1.673$ $R^2 = 0.97$ $\beta = 0.5208 A + 6.4865$ $R^2 = 0.98$
Relationship between $Q_{\max}$ and the weighting average river slopes (figure 5-7)	<b>Equation 5-2</b> $Q_{\max} = \alpha' \cdot \ln(S_w) + \beta'$ $0.98 < R^2 < 0.99$	$\alpha' = 0.1177 A + 2.261$ $R^2 = 0.95$ $\beta' = 0.4818 A + 6.665$ $R^2 = 0.96$
Relationship between relative $Q_{\max}$ and weighting average river slopes (figure 5-7)	<b>Equation 5-3</b> $\frac{Q_{\max}}{(Q_{\max})_E} = \alpha'' \cdot \ln(S_w) + \beta''$ $0.98 < R^2 < 0.99$	$\alpha'' = 0.0011 A + 0.031$ $R^2 = 0.96$ $\beta'' = 0.0002 A + 0.979$ $R^2 = 0.55$
Relative flood volume versus relative river slope	<b>Equation 5-4</b> $\frac{V_{\max}}{(V_{\max})_E} = a \cdot \ln\left(\frac{S}{S_E}\right) + b$	$a = 4 \cdot 10^{-6} \cdot A - 10^{-5}$ $b = 1$
Relative flood time to peak versus relative river slope	<b>Equation 5-5</b> $\frac{T_{\max}}{(T_{\max})_E} = a' \cdot \left(\frac{S}{S_E}\right)^{b'}$	$a' = 1$ $b' = -0.0014A - 0.1166$

As a short result of this section, in small catchments, river slope increasing or decreasing does not have a meaningful effect on maximum flood discharge and hydrograph time to peak.

Whenever the area of catchment increases the influence of the upstream river slope increases too. Reason for this result could be that the velocity in the main streams goes up and that the flood peaks of the tributaries which run in the existing situation on ahead overlay the flood peak of the Erpe.

### 5.5 Influence of Land surface topography on flood

This section has two main objectives: first, to examine the general effect of changes of topography on flood parameters and second, to select the number of artificial catchments to examine the flood defense measures. Thus, the Erpe catchment is taken as a base catchment and then some artificial catchments are produced that are dissimilar only in topography. Other information such as soil, land use and climate data are the same. As mentioned earlier, Arcview GIS software was used to produce the artificial topography maps (chapter 4-5). Twenty-four artificial catchments were created by ArcView. Nine out of twenty four have a land surface slope less than the existing condition (from 10% altitude decreased or  $C_t = -0.1$  to 90%, altitude decreased or  $C_t = -0.9$ ) and others (fifteen catchments) have a land surface slope steeper than existing conditions (from 10% altitude increased or  $C_t = 0.1$  to 600% altitude increased or  $C_t = 6$ ). The abbreviation of different artificial catchments is as follows: LS (meaning Land Surface Slope) plus or minus (meaning increase or decrease) of  $C_t$  multiple 100. For example, LS+100 indicates the artificial catchment with  $C_t = 1$  or the net elevation (from catchment mouth altitude) of which every point becomes twice as many ( $Z' = Z + 1 (Z - Z_0)$ ). Figure 5-11 shows the different artificial catchments with their short form names.



**Figure 5-11 Different artificial catchments**

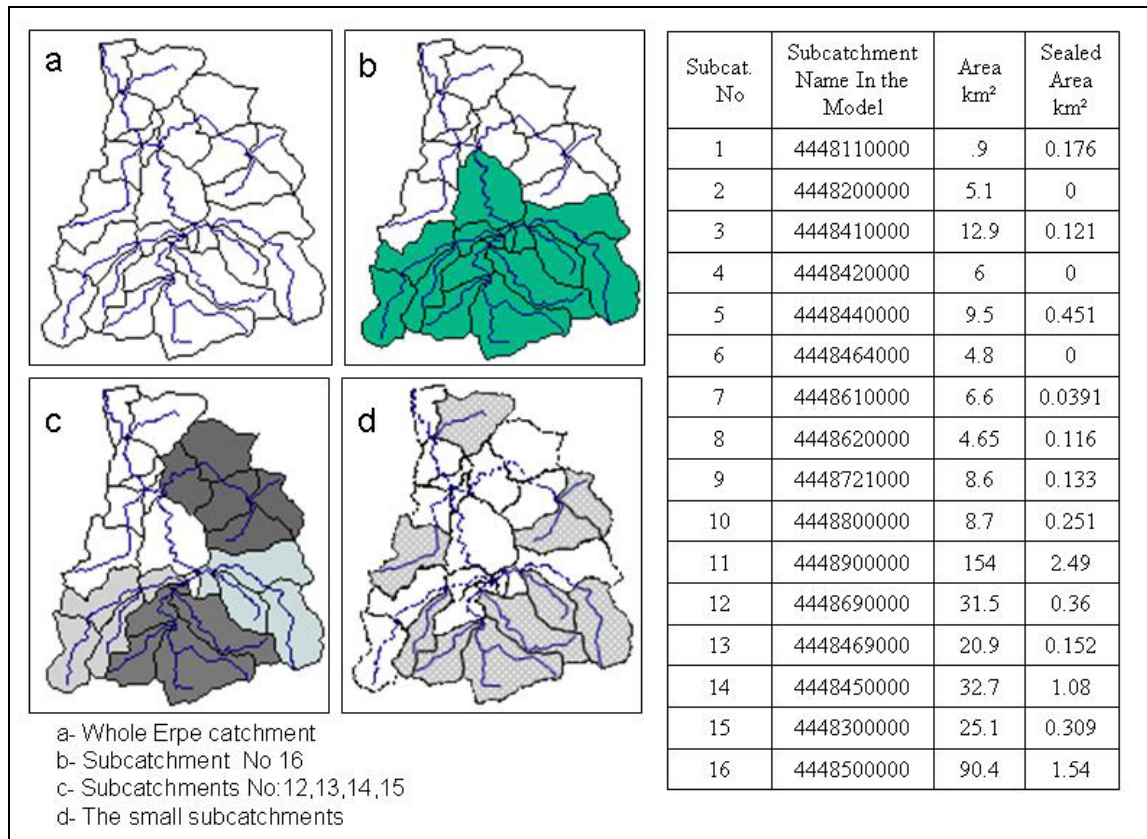
In the hydrological model, the Erpe catchment is divided into twenty-seven subcatchments with an area less than 10 km<sup>2</sup>. This system is used as a rainfall runoff model. Sixteen stations are selected to examine the flood parameters on the Erpe river system.

Figure 5-12 shows the selected points and their catchment areas. There are ten stations with catchment areas of less than 15 km<sup>2</sup> and six points with an area of more than 15 km<sup>2</sup>. Other than that there are 25 systems (the existing catchment and 24 artificial catchments) that are modeled by the NASIM rainfall runoff model. The model uses isochrones line of

concentration time as an input file called TAPE20. This file is produced by the special extension in ArcView and it uses the topography maps, subcatchment's borders definitions and drainage networks.

The results are classified in two categories in accordance with the catchment area:

- Catchments with area less than 15 km<sup>2</sup> (ten subcatchments)
- Catchments with area more than 15 km<sup>2</sup> (six subcatchments).



**Figure 5-12 The selected subcatchments and their information**

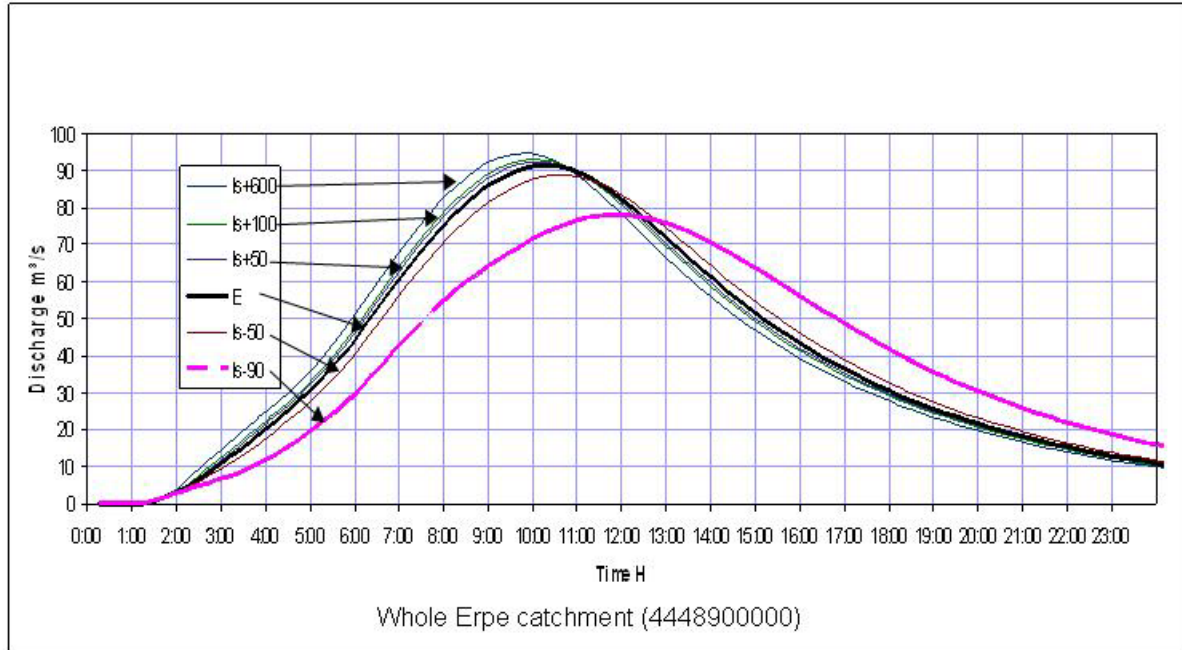
The results of flood parameters (e.g. the flood hydrograph, the maximum discharge and time to peak) are considered versus the mean land surface slope for each subcatchment. Figure 5-13 shows the general behavior of flood hydrograph. In the case of the land surface slope increasing, the maximum of the flood hydrograph goes up and left so that the rising limb will have been steeper and it reverses in the case of land surface slope decreasing. The sensitivity of falling limb to changes of topography is less than rising limb for all scenarios. Consequently, when the catchment becomes flatter, the flood hydrograph will be flatter too. In other words, the concentration time increases because of the reduction of land surface velocity.

Figures 5-14-a and b show the good connection between the relative maximum flood discharge and the average land surface slope for small and large catchment area respectively. It is obvious that the rate of changes for catchments with low land surface slope is very high and is very low for catchments with steep mean land surface slope. The relationship between the relative maximum discharge and the mean land surface slope is:

**Equation 5-6**

$$\frac{Q_{\max}}{(Q_{\max})_E} = \gamma \cdot \ln(S_m) + \delta$$

$Q_{\max}$  is the maximum flood discharge for artificial scenario with  $S_m$  mean land surface slope,  $(Q_{\max})_E$  is the maximum flood discharge for existing situation. The values of  $\gamma$  and  $\delta$  depend on the catchment size and their amounts are showed in the table 5-5.



**Figure 5-13 Flood hydrographs for different land surface scenarios (E is exist catchment)**

The results show that the catchment topography is not affected on maximum flood discharge for very steep catchments (mean land surface slope more than 20 degrees or 36%). The flow velocity on the land surface and also in the rivers is main reason for these behaviors. On the other hand, it is very important for low land surface slope (the mean land surface slope less than 3.5%).

The time to peak also has a good connection with the mean land surface slope. Figures 5-15-a and b show the relation between the relative times to peak for each scenario versus the mean land surface slopes. According to the data the following formula is determined:

**Equation 5-7**

$$\frac{T_{\max}}{(T_{\max})_E} = \varepsilon \cdot (S_m)^\theta$$

$T_{\max}$  is the time to peak for artificial scenario with  $S_m$  mean land surface slope,  $(T_{\max})_E$  is the time to peak for existing situation. The values of  $\varepsilon$  and  $\theta$  depend on the catchment size and are showed in table 5-5.

**Table 5-5  $\gamma, \delta, \varepsilon$  and  $\theta$  are function of the catchment area**

Catchment area	$\gamma$	$\delta$	$\varepsilon$	$\theta$
Small catchments ( $4 < A < 15 \text{ km}^2$ ):	0.0851	0.8575	1.2557	0.1406
Large catchments ( $15 < A < 155 \text{ km}^2$ ):	0.0561	0.899	1,159	0.084

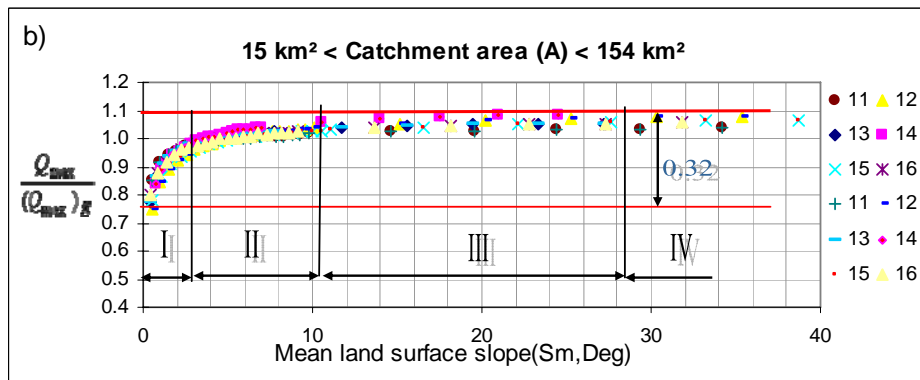
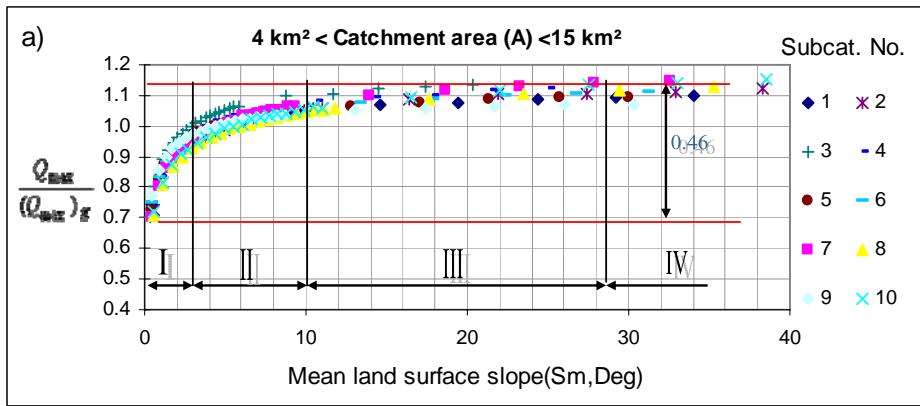


Figure 5-14 Relation between relative discharge and mean land surface slope for small catchments (above) and large catchments (below).

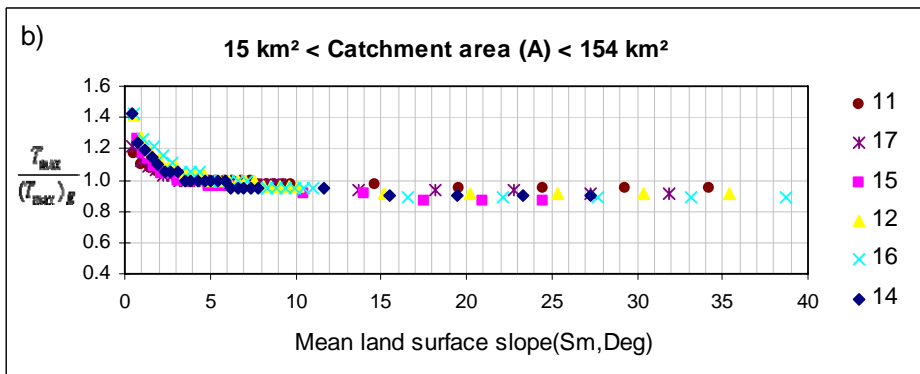
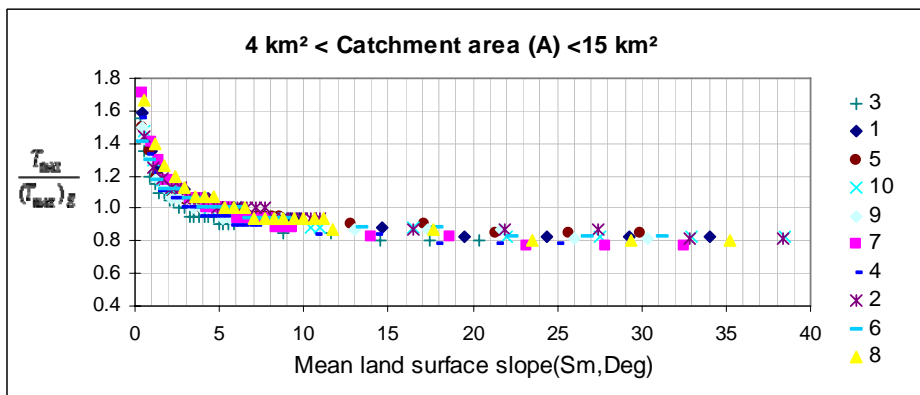


Figure 5-15  $T_{\max}/(T_{\max})_E$  versus land surface slope for small catchments (above) and large catchments (below), T is the time to peak and  $T_E$  is the same in existing condition.

According to the above results, the subcatchments are divided into four categories. The first category is catchments with a mean land surface slope less than 3.5% (2 Deg). In this category the flood parameters are very sensitive to topography. The second category has a mean land surface slope from 3.5% to 10% (6 Deg) called medium lands surface slope. The flood parameters in this group are sensitive to topography while they are less in the first category. The third category is called steep lands. The mean land surface slope in this category is more than 10% and less than 28.6% (16 Deg). The fourth category is very steep lands with mean land surface slope more than 28.6%. Perhaps there are very small catchments in this category. The important point here is that the topography changes are not important and do not affect the flood parameters.

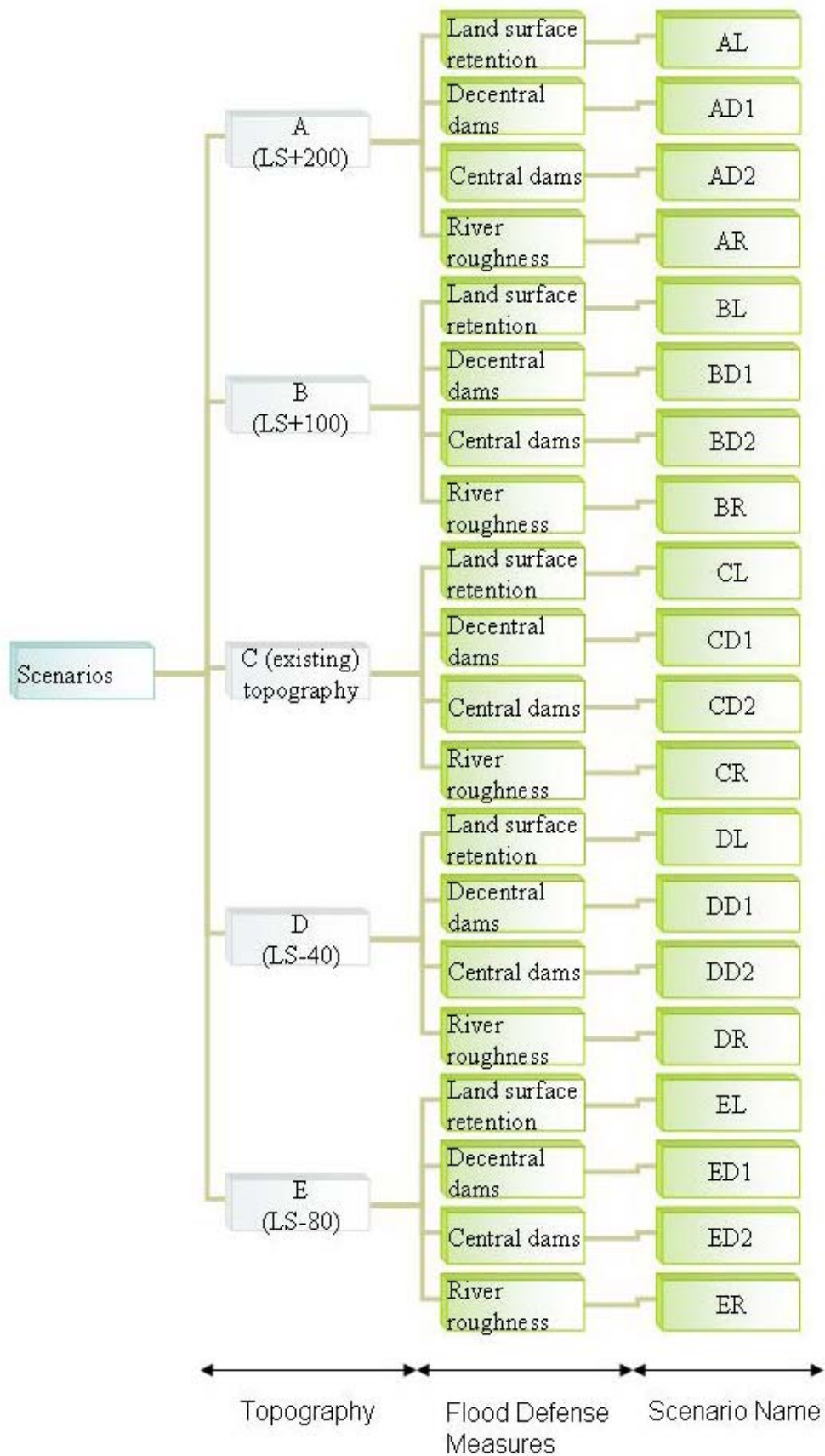
T

**Table 5-6 Classification of catchments topographies.**

Land surface category	description	Mean land surface slope %	Mean land surface slope DEG	$Q_{max}/(Q_{max})_E$
I	Low lands	$S_m < 3.5$	$S_m < 2$	Very sensitive
II	Medium lands	$3.5 < S_m < 10$	$2 < S_m < 6$	Sensitive
III	Steep lands	$10 < S_m < 28.6$	$6 < S_m < 16$	Low sensitive
IV	Very Steep lands	$28.6 < S_m$	$16 < S_m$	Not sensitive

## **5.6 Topography scenarios matched with flood defense measures**

The relationship between land surface topography and flood defense measures is considered here. According to the previous section, the catchment topographies are divided into four categories (described in Table 5-6). Selection of some of these topography maps is attempted to investigate for different flood defense measures. The mean land surface slope of the existing catchment is 4.89% located in medium land category (II). The variation of maximum flood discharge and time to peak related to topography is very sensitive in the low lands, so it is attempted, in this category, to select two topography maps which have  $S_m$  lower than the existing catchment. In addition, two artificial catchments selected with  $S_m$  greater than the existing catchment. The category IV is not used, because there was not found an influence in the investigation before. Table 5-7 shows the information of topographical scenarios. So, the land surface slope is steeper than the existing catchment in the scenarios A and B. It is twice (LS+100) in Scenario B and triple (LS+200) in Scenario A. The land surface slope is lower than existing situations in scenarios D and E. Besides the mean, maximum and standard deviation of land surface slope of each scenario are presented in the table.



**Figure 5-16 Different land surface slope and flood defense measures scenarios for Erpe catchment**

**Table 5-7 Selected scenarios of land surface topography for more investigations.**

Abbreviation Name	Land surface status	Land surface slope parameters (deg)			Description
		Mean	Max	St. Dev.	
A	LS+200	13.85	59.17	10.01	Category III
B	LS+100	9.55	48.16	7.29	Category II (upper band)
C	Existing	4.89	29.188	3.907	Category II
D	LS-40	2.95	18.53	2.38	Category I
E	LS-80	0.98	6.41	0.8	Category I

According to the flood defense measures, three measures (land surface retention, dam construction and river restoration) are considered. The combination of land surface scenarios and flood measures are shown in figure 5-16. So the left column shows the topography maps which existing topography (C) located in the center and two steep scenario (A and B) are over and two low land scenarios (D and E) placed below. The middle column indicates different flood defense measures which consider. Four flood defense measure comprise land surface retention, central and decentral dams and river roughness. The last column shows the scenario name which is a combination of the name of land surface topography and abbreviation of flood defense measure.

### 5.6.1 Land surface retention:

The sensitivity of maximum flood discharge to maximum infiltration rate is examined for different land surface slopes scenarios with the intention that in the NASIM model the infiltration rates are defined by the user for every soil and land use and it is an input data for the model. Consequently, there are not meaningful differences between the results of different land surface scenarios. Therefore, the results of each scenario are equal to different topography and same soil information. On the other hand, land surface slope can affect on infiltration rate. It is possible to change the infiltration rate in the catchment surface area through the use of land surface management. The land surface management tasks can used in agricultural land easier than other parts of catchment area by increasing the information of farmers and also using special laws. If so, the influence of changes on infiltration rate in agricultural land is considered. The significant aim is to find out the sensitivity of flood parameters to infiltration rate in these areas.

The Erpe catchment has 78.72 km<sup>2</sup> (51.4%) agricultural lands. The soil characteristics of the agricultural lands and their information are presented in the table 5-8.

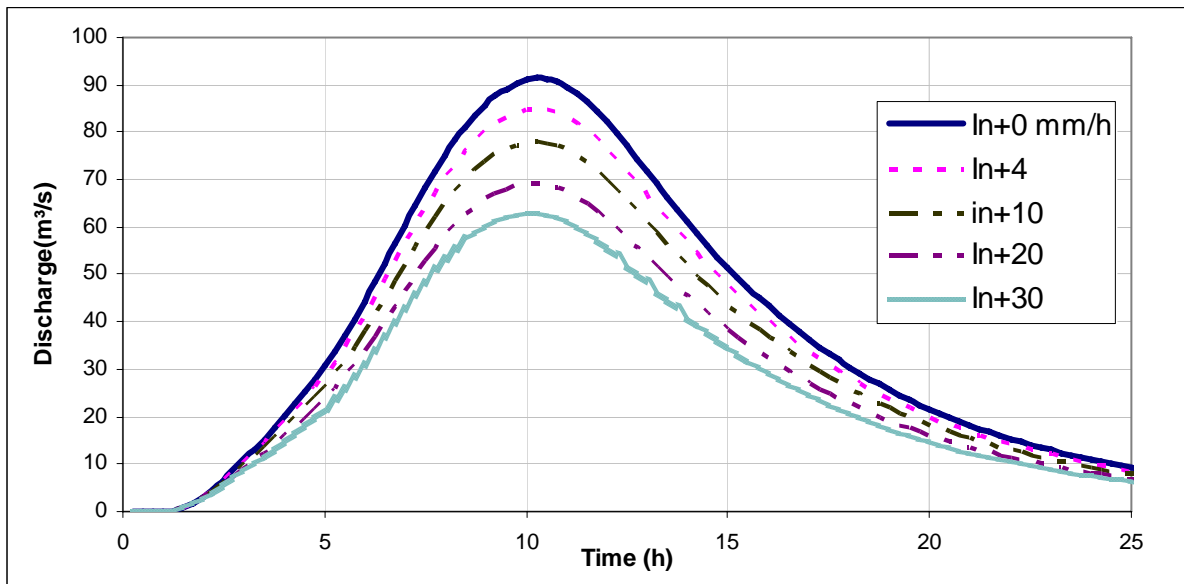
The infiltration rate in agricultural lands changes with agricultural tillage operations and grass cover as well as a kind of plants and species. The range of infiltration rate is very different. According to the DVWK report, the variety range of infiltration rate for agricultural land is very wide and as it is asserted by some researchers that it changes from 0.3 to +2.5 times the normal value [15].

There are 77 agricultural blocks in the Erpe catchment with an area of 78.72 km<sup>2</sup>. They contain four types of soil which are presented in the table 5-8. Most of agricultural lands are covered by poor sandy loam (40 km<sup>2</sup>) and silt and clay with 20.2 and 15.5 km<sup>2</sup> are in the second and third places. Also the maximum infiltration rate depends to debris sand and the minimum depends to clay.

**Table 5-8 The soil characteristics of agricultural lands.**

Soil description	Soil types	Area km <sup>2</sup>	Wp	FK	GPV	Kf	Max. infiltration rate (mm/h)				
			mm/m			mm/h	In+0	In+4	In+10	In+20	In+30
Poor sandy loam	Ls2	40.0	160	330	43	23	23	27	33	43	53
Debris Sand	S	2.7	30	90	80	125	125	129	135	145	155
Clay	T	15.5	390	540	58	5	5	9	15	35	45
Silt	U	20.2	90	340	40	11	11	15	21	31	41

Figure 5-17 shows the flood hydrographs of Erpe catchment with different value of infiltration rate in agricultural lands. In this figure the calibrated value has showed by “In + 0”, increasing in infiltration rate has demonstrated by “In + extra value”. For example “In + 30” demonstrates that the initial value of infiltration rate add 30 mm/h. The examination of the flood hydrographs shows that increasing the infiltration rate in the agricultural land has a significant effect on flood parameters. The peak of the flood hydrograph falls and the flood volume also decreases by increasing the infiltration rate.



**Figure 5-17 Flood hydrographs in the mouth of Erpe catchment for different value of extra infiltration rate**

Figure 5-18 shows the relationship between the relative maximum of the flood hydrograph ( $\frac{Q_{In+\Delta I}}{Q_{In+0}}$ ) and the rise of the maximum infiltration rate of agricultural land for the Erpe catchment. Thus, the maximum flood discharge reduction is obtained from:

**Equation 5-8** 
$$\frac{Q_{In+\Delta I}}{Q_{In+0}} = 0.00008\Delta I^2 - 0.013\Delta I + 1$$

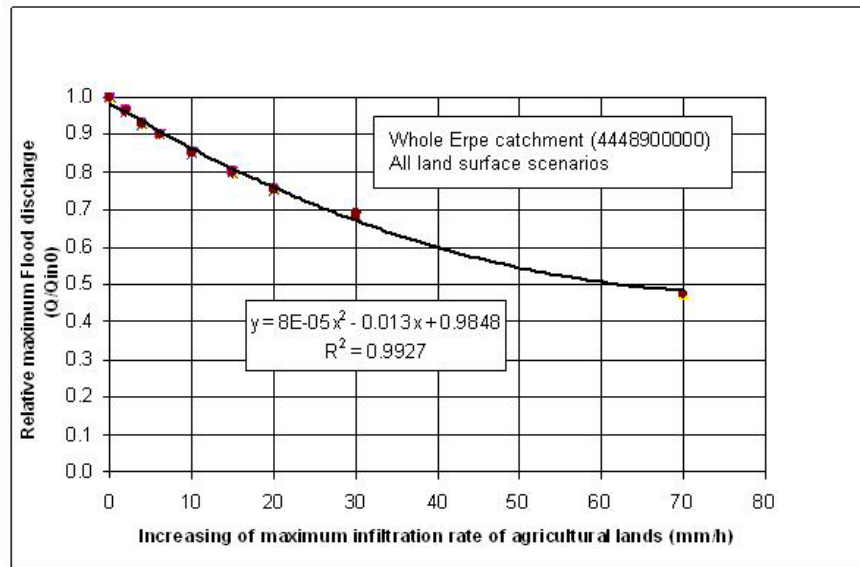
$Q_{In+\Delta I}$  : Maximum flood discharge with increasing of  $\Delta I$  infiltration rate [in cubic meter per second].

$Q_{In+0}$  : Maximum existing flood discharge or in  $\Delta I = 0$  in [cubic meter per second]

$\Delta I$  : Increasing maximum infiltration rate [in millimeter per hour]

$\Delta Q$  : Maximum flood discharge reduction [in cubic meter per second]

The above formula is defined only for the Erpe catchment and in the flood defense measures study this method is used to compare with other measures. If the infiltration rate in the agricultural land of the Erpe catchment increases only 10 mm/h then the maximum flood discharge decreases about 12%.



**Figure 5-18 Effect of infiltration rate in agricultural lands on maximum flood discharge**

**Table 5-9 Flood volume in m<sup>3</sup> for different land surface slope scenarios**

Ad. inf. Sce.	In	In1(In+4)	In2(In+10)	In3(In+20)	In4(In+30)
AL	3847888	3582982	3289497	2915699	2660924
BL	3849414	3582951	3289472	2915677	2660903
CL	3849341	3582881	3289414	2915625	2660853
DL	3841915	3576046	3283198	2910188	2655954
EL	3835385	3569990	3277691	2905332	2651507

### 5.6.2 River restoration

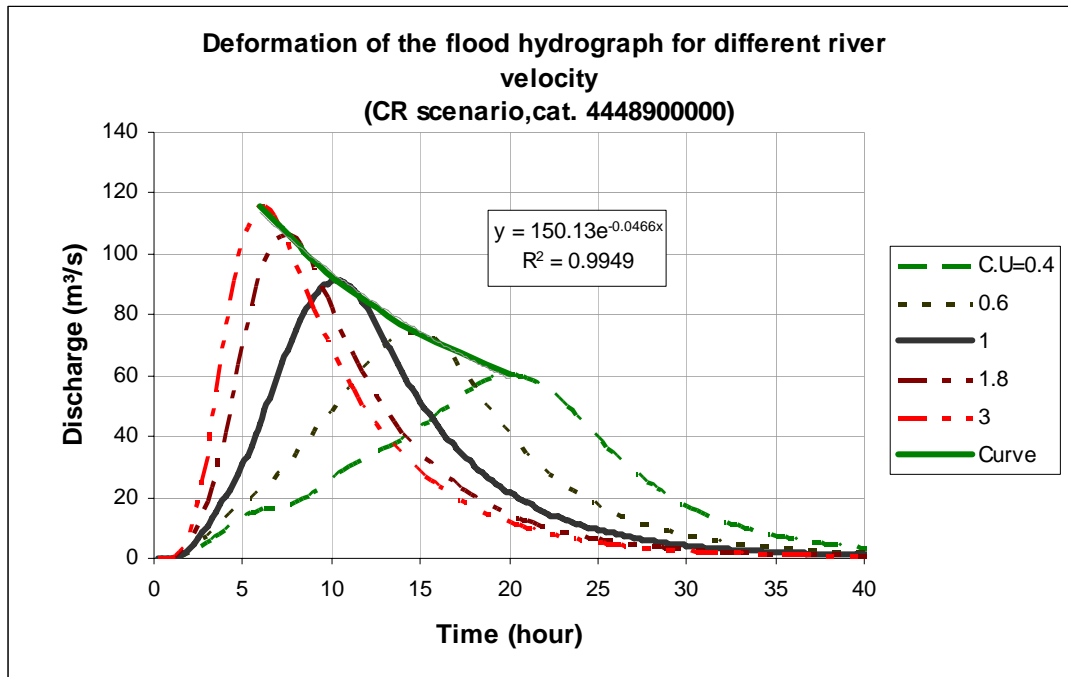
The indirect evaluation of roughness changes is considered by the hydrological models. River roughness affects river mean flow velocity and its changes cause deformation on the flood hydrograph. Thus, in this research, the mean flow velocity has been changed regularly from 0.4 to 3 times the existing value. The examination of output flood hydrographs shows regular deformations in the flood wave shapes. Two important parameters are considered in the flood hydrograph (maximum discharge and time to peak).

Figure 5-19 shows the deformation of the flood hydrograph intended for different upstream river velocities for existing land surface slope (CR scenario). In addition, the dislocation of the maximum flood hydrograph pointed for different land surface slope scenarios shows that they have same behavior.

The maximum flood discharge decreases when the flow velocity decreases. In other words, flood water has been reserved in the flood plain by decreasing the flood flow velocity

in the river. By decreasing the upstream river velocity the flood time to peak increases. The rising limb lie down and the maximum flood discharge take place later.

According to the above results, the upstream river network velocity can affect flood parameters efficiently. Therefore, the methods related to changing the river roughness are useful. Some factors (such as vegetation, channel irregularity and alignment and discharge stage) which affect river roughness are influenced by flood plain topography. Vegetation reduces the channel capacity and retards the flow. This effect mainly depends on height, density, distribution and type of vegetation. Changing the river vegetation in flatter catchments and river floodplains is easier than steep catchments.



**Figure 5-19 Influence of flow velocity in rivers network (C.U is the velocity coefficient) on flood hydrograph.**

### 5.6.3 Central and decentral dams

Central and decentral flood defense dams are examined for the Erpe catchment with different topography. The safe flood discharge in the Erpe catchment mouth is a five-year flood (HQ<sub>5</sub>) and it is thirty six cubic meters per second. In the next computations, the capacity of the river is supposed equal HQ<sub>5</sub> in the downstream of the Erpe catchment mouth [22]. In addition, the operation rule of flood mitigation dams is supposed “control discharge method.” Figure 5-20 shows the location of central and decentral dams on the Erpe catchment.

Dam No. 1 is a central dam to control the flood in the downstream part of the catchment mouth. Dam height - reservoir volume curves were calculated by ArcView for five land surface scenarios (AD, BD, CD, DD, ED). Then the model ran for each scenario and found out the requirement dam height to have a maximum discharge of 36 m<sup>3</sup>/s in the downstream. According to the results, the reservoir volume changes between 1316·10<sup>3</sup> m<sup>3</sup> and 1193·10<sup>3</sup> m<sup>3</sup>. In addition, the height of the dam changes from 3 to 14 meters, from steep land surface to flat land surface respectively (figure 5-21).

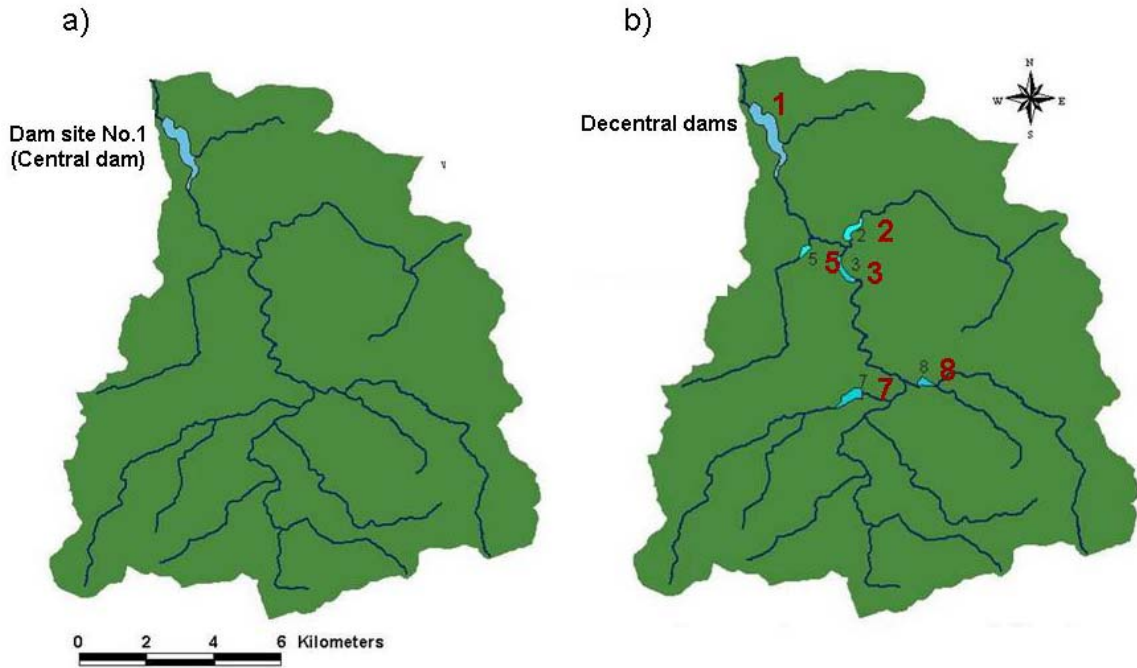


Figure 5-20 Location of dam's sites on Erpe: a) central dam; b) decentral dams

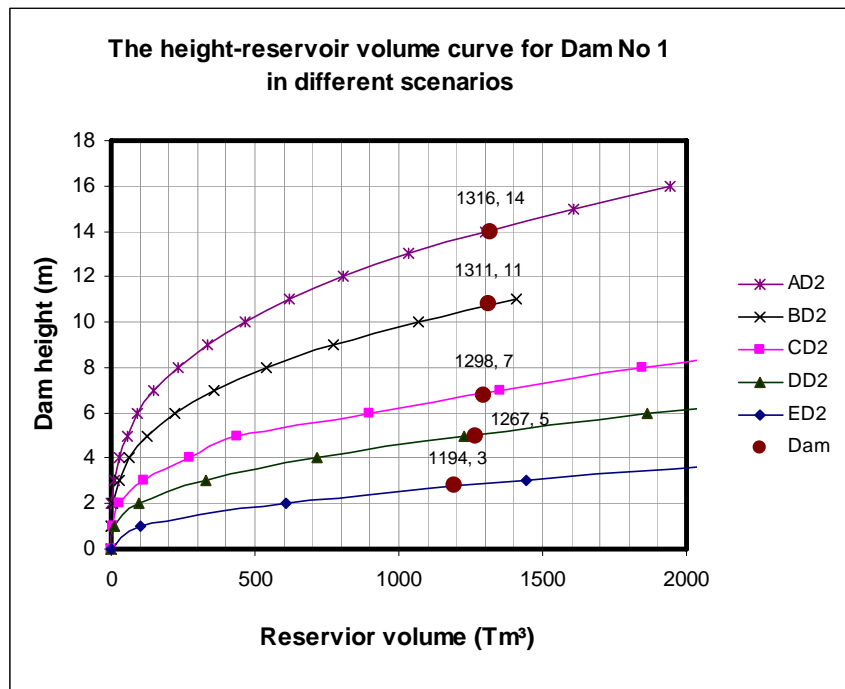


Figure 5-21 Dam height and reservoir volume for deferent scenarios of dam site No. 1

Figure 5-22 shows the input hydrograph to reservoir for every land surface scenarios. According to operation rule of dam, the output hydrographs has maximum discharge related to the safe flow discharge in downstream. The tail of outflow curve is variable for every scenario because of reservoir volume and flood hydrographs.

Figure 5-23 shows the variation of topographical site index (f) versus height of dam in site No 1 for the different land surface slope scenarios. According to this chart, when the height of the dam increases, the flood topographical site index decreases. So the following general points are highlighted:

- The gradient of  $f$  curves is negative. It demonstrates that the  $f$  index will decrease when the dam height increases.
- According to the figure, the curve gradient, in low dam height is small. Thus, the  $f$  value changes very quickly. However, in the higher dams it is converse and the  $f$  changes slower than dam height. It can be said that the curve has one vertical asymptote line.
- There is one point in the curve in which the variation  $f$  versus dam height is not sensible. This point is important for high dam height increasing.

When the catchment will be flatter the  $f$  index decreases. So the H- $f$  curve goes left. It is converse when the catchment will be steeper.

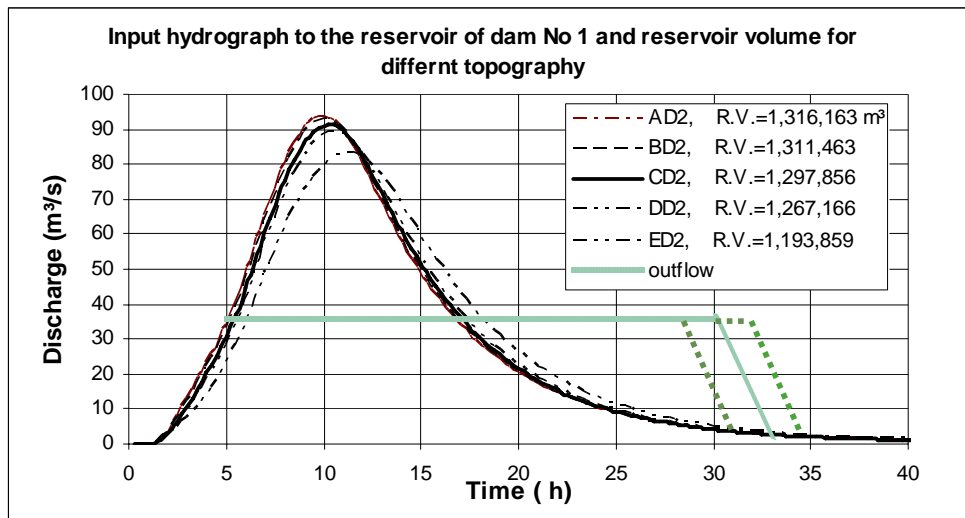


Figure 5-22 The hydraulic operation rule of flood mitigation dam No 1

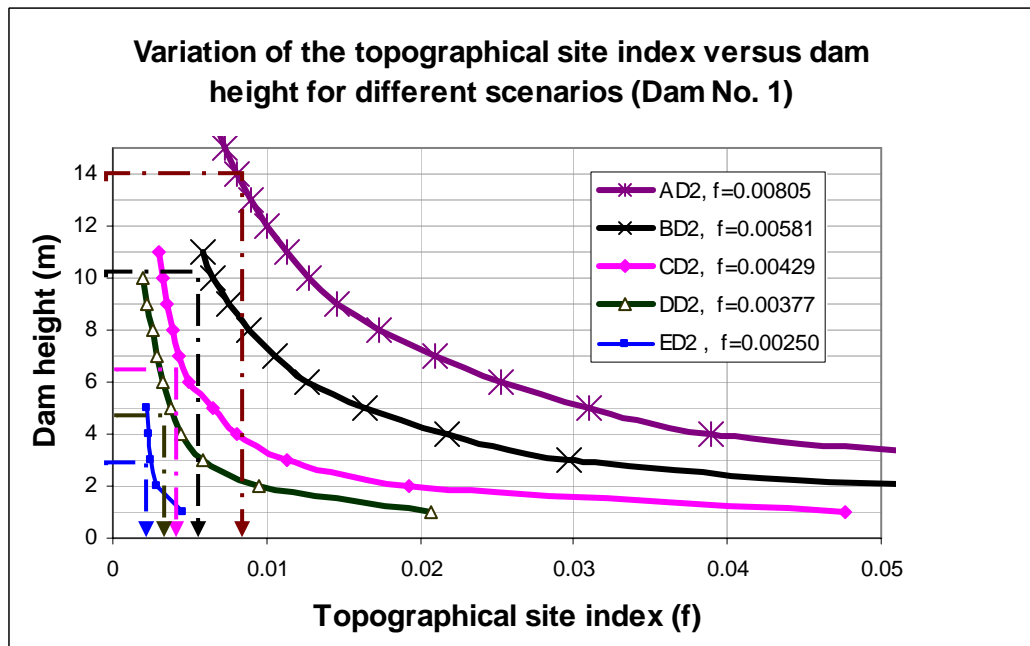


Figure 5-23 The H- $f$  curve for dam site No. 1

The required reservoir establishes the dam height to control the flood for dam No 1 as a central dam for every scenario. So,  $f$  value is determined from the corresponded curve.

Besides,  $f$  values for land surface scenarios AD2 to ED2 are determined by using the corresponded curves of figure 5-23. The heights of dam and  $f$  values for each scenario are: AD2 ( $h=14$ ,  $f= 0.00805$ ); BD2 ( $h=11$ ,  $f=0.00581$ ); CD2 ( $h=7$ ,  $f=0.00429$ ); DD2 ( $h=5$ ,  $f=0.00377$ ) and ED2 ( $h=3$ ,  $f=0.00250$ ). It is clear that the  $f$  value for scenario ED2 is less than others and by increasing the land surface slope the  $f$  value increases. That means the flood control cost will be increase by increasing the land surface slope. As a result, the investigation shows that in a mountain area it is necessary to build higher dams which are more expensive.

According to the topography and land use maps, six sites in the entire catchment area are selected as decentral dams. One is located in the mouth of catchment in the place of dam No. 1 (such as central scenarios) and locations of others are shown in figure 5-20-b. The object function of decentral dams scenarios is decreasing the maximum flood discharge at the end of Erpe catchment to  $HQ_5$ . In other words, it is supposed that there are no important places in the upstream to protect and the goals of flood protection are located in the downstream. Thus, the maximum flood in the mouth of the Erpe catchment will be less than  $36 \text{ m}^3/\text{s}$ . The dams' outlets are also gated culvert with the constant discharge. The culvert dimensions are calculated by the discharge. At first, it is supposed that the maximum height of decentral dams is six meters (there are no limitations on the reservoir volume and it depends on the dam height). The model ran for different scenarios (AD1, BD1, CD1, DD1 and ED1) and the results are collected in table 5-10. According to the results of the model, in the existing land surface catchment, the flood is controlled by six decentral dams that are a maximum of six meters in height. They form about  $1924 \cdot 10^3 \text{ m}^3$  reservoir capacity together. As stated by all six dams with six meters height, the river capacity for the scenarios BD1 and AD1 is decreasing to  $628 \cdot 10^3$  and  $337 \cdot 10^3 \text{ m}^3$  respectively. These volumes could not control the flood and in these cases, it is necessary to increase the dams' height and increase the reservoirs' volume. Thus, to obtain the results, the heights of decentral dams are increased to nine and eleven meters for BD1 and AD1 scenarios respectively.

In the flatter land surface scenarios, the reservoirs capacities are increased and the flood is completely controlled with small dams. In DD1 scenario, there are six dams of four meters height and  $1965 \cdot 10^3 \text{ m}^3$ . In ED1 scenario, there are five dams of three meters height and one dam of two meters height. To investigate decentral and central dams for every scenario, the rough estimation of flood retarding dam site method is used. According to this method, the topographical site index for all dams is finally calculated and compared for the different scenarios. Figure 5-24 shows the topographical site index for each site and scenarios. The  $f$  value decreases with land surface slope decreasing just as the figure shows.

Equivalent topographical site index is used to compare the central and decentral dams and it define as:

**Equation 5-9** 
$$f_e = \frac{\sum f_i \cdot V_i}{\sum V_i}$$

That  $f_i$  and  $V_i$  are the topographical site index and reservoir of dam No.  $i$ .

So  $f_e$  demonstrate the equivalent  $f$  value for several dams in one scenario. The topographical site index is determined for different dam sites and different scenarios (table 5-10).

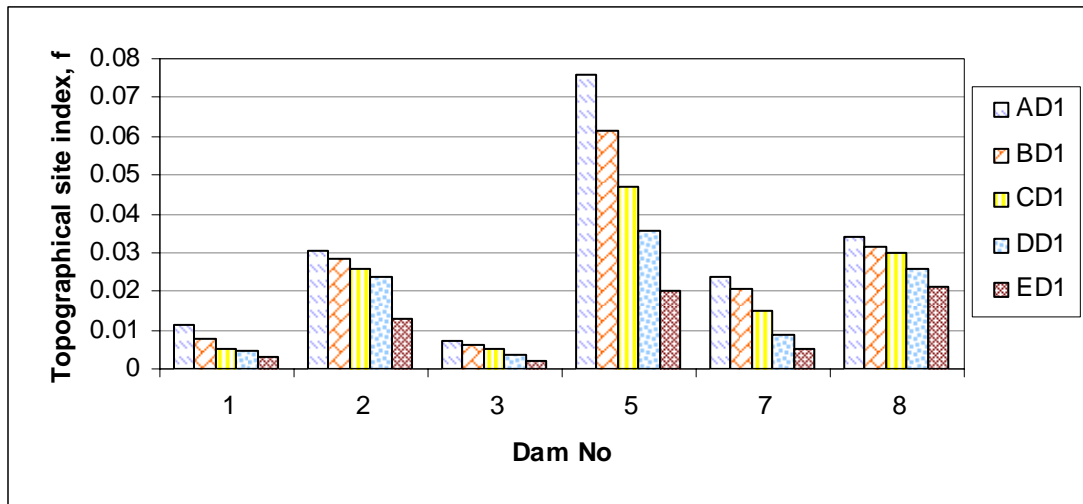


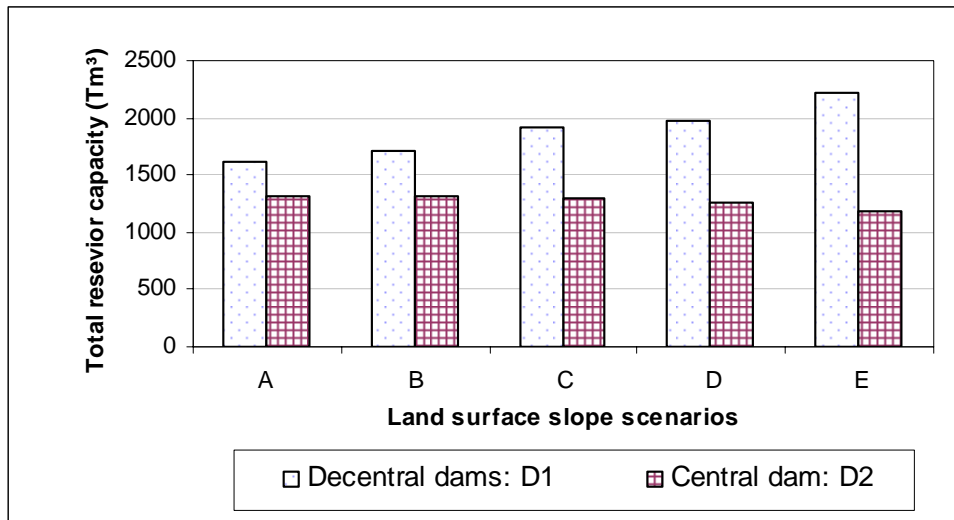
Figure 5-24 Changes of topographical site index for different scenarios

Table 5-10 Topographical site index for different dam site and scenarios

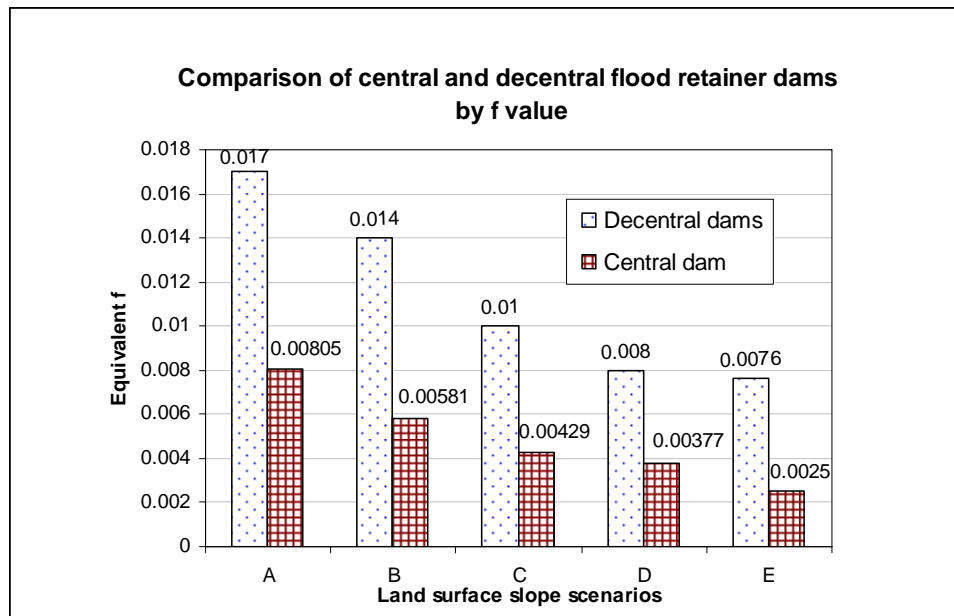
Dams	f/Vr	Dam 1	Dam 2	Dam 3	Dam 5	Dam 7	Dam 8	Total
AD1	$f_i$	0.011	0.031	0.007	0.076	0.024	0.034	$f_e=0.017$ *
	$V_i(\text{Tm}^3)$	650	180	391	25	248	123	1617
	$f_i \cdot V_i$	7.339	5.499	2.807	1.898	5.873	4.197	27.612
BD1	$f_i$	0.008	0.029	0.006	0.091	0.021	0.031	$f_e=0.014$ *
	$V_i(\text{Tm}^3)$	860	149	301	38	276	90	1715
	$f_i \cdot V_i$	6.509	4.249	1.888	3.531	5.733	2.830	24.740
CD1	$f_i$	0.005	0.026	0.005	0.047	0.015	0.030	$f_e=0.010$ *
	$V_i(\text{Tm}^3)$	869	137	485	57	310	93	1951
	$f_i \cdot V_i$	4.338	3.566	2.411	2.679	4.613	2.783	20.389
DD1	$f_i$	0.004	0.024	0.004	0.036	0.009	0.026	$f_e=0.008$ *
	$V_i(\text{Tm}^3)$	716	83	592	54	370	150	1965
	$f_i \cdot V_i$	3.190	1.953	2.261	1.919	3.330	3.900	16.553
ED1	$f_i$	0.003	0.013	0.002	0.020	0.005	0.021	$f_e=0.008$ *
	$V_i(\text{Tm}^3)$	608	179	671	154	269	339	2220
	$f_i \cdot V_i$	1.763	2.332	1.342	3.080	1.345	7.119	16.982

\* Equivalent topographical site index  $f_e = \frac{\sum f_i V_i}{\sum V_i}$

Figures 5-25 and 5-26 show the reservoir and the f value for different scenarios respectively. As figure shows in all scenarios the equivalent topographical site index for decentral dams are more than f in central dams. When the topography becomes steeper, f value is increased for one dam height. In other words, according to the topographical site index, we can say that the central retention dam is better than the decentral scenarios in this case.



**Figure 5-25 Required reservoir capacities for different topography**



**Figure 5-26 Comparison of equivalent f for decentral dams and central dams**

## 5.7 Conclusion

In this chapter the effect of topography on flood and flood defense measures was investigated. Three topographical parameters of river slope, land surface slope and catchment size were examined for the Erpe catchment with an area of 154 km<sup>2</sup>.

Changes on upstream river slope can affect flood parameters. The maximum flood discharge, as well as the flood time to peak, has a good connection with the river network slope however, there are no expressive differences on flood volume. The influence of river slope on discharge and time to peak depends on the catchment area; whenever the area of the catchment is increased the influence of the upstream river slope also increases.

According to effects of the land surface topography on flood parameters, the catchment can be divided into four categories:

Low lands: There are catchments with a mean land surface slope less than 3.5%. The flood parameters are very sensitive to topography in this category.

Medium lands: There are catchments with a mean land surfaces slope between 3.5% and 10%. The sensitivity of flood parameters to topography is less than low lands.

Steep lands: There are catchments with a mean land surface slope bigger than 10% and less than 28.6%. The sensitivity of flood parameters to topography is very small.

Very steep lands: There are catchments with mean land surface slope more than 28.6%. The flood parameters in this category do not depended on topography changes. In other words, the sensitivity of flood parameters to topography changes is very low or negligible.

The changes on topography do not affect soil retention in the NASIM model so it is impossible to find the relationship between topography and flood retention by catchment soil or infiltration rate. In other words, the infiltration rate is an input data for the NASIM model.

More than 50% of the Erpe catchment is agricultural lands. These areas can affect the reduction of flood volume and flood maximum discharge by using soil conservation and improvement. According to the results, by increasing the infiltration rate in agricultural land, the flood volume decreases. The maximum flood discharge goes down but the time to peak is constant.

The upstream river velocity can affect flood parameters efficiently so that the methods related to changing the river roughness are useful for flood defense. Some factors (such as vegetation, channel irregularity and alignment and stage of flow) which affect river roughness are influenced by flood plain topography. Vegetation reduces the channel transfer capacity and retards the flow. This effect mainly depends on height, density, distribution and type of vegetation. Changing the river vegetation in flatter catchment and river floodplain is easier than steep catchments. In addition, the results show that the effect of river flood velocity reduction on the floodplain with bigger catchments is higher than on small catchments. In other words, when the catchment size is bigger the sensitivity of maximum flood discharge to river velocity coefficient is high because of the length of the river network.

To compare the central dams for different land surface scenarios, the topographical site index was defined as the volume of dam embankment to reservoir volume ratio. The variation curve of topographical site index (f) versus height of dams for the different land surface slope scenarios shows that when the height of the dam increases, the flood topographical site index decreases. According to this curve the following points are highlighted:

The curve gradient is negative which demonstrates that the f index will decrease when the dam height increases. The curve gradient in low dam height is small that the f value changes very quickly. However, in the higher dams it is converse and the index changes slowly. It can be stated that the curve has one vertical asymptote line. There is one point in the curve in which the f variation is not sensible or important for high dam height increasing.

When the catchment will be flatter the f index decreases and the H-f curve goes to the left. Decentral dams for flood protection have been investigated because low reservoir capacity in steep catchments need higher dams than the flat catchments. In addition, when the topography is steeper then the topographical site index (f value) increases.

As mentioned earlier, land surface retention is not examined by the NASIM flood model and in this research is only described. Thus, for whole Diemel catchment model we use the central and decentral dams as well as the effect of upstream river network slope on flood parameters.

## **6 General information of Diemel catchment**

### **6.1 Introduction**

As it has brought in section 4-4, Diemel catchment is located in Hesse and North Rhine Westphalia states in the center of Germany (figure 6-1). It is a tributary of Weser which serves as an important artery of a highly industrialized area. The source of the Diemel is near Willingen, in Sauerland. The Diemel generally flows northeast through the towns Marsberg, Warburg and Trendelburg. It flows into the Weser in Bad Karlshafen. The total length of the Diemel is 106 km [50]. The catchment area is about 1800 km<sup>2</sup>. There is a digital map of the catchment with a resolution of 40 · 40 m and there are also other information such as land use, topography, soil classification and river network maps, as well as the climatologically data (such as rainfall, temperature, etc). This chapter explains the specification of Diemel catchment briefly.

### **6.2 Climatological data**

The climatologic data such as precipitation, temperature, evaporation and evapotranspiration are needed to simulate the flood in rainfall-runoff model. The climatological data have been used from the reference No. 22 as well as the Erpe catchment. This research uses the one hour rainfall over the whole catchment with one hundred year frequency. The intensity and diversity of rainfall are the same with the result of the reference [22].

### **6.3 Diemel topography**

The Diemel is located in the minor mountain range. The mouth of the catchment and lowest point is located in Bad Karlshafen in the north east of the catchment and its altitude is 99.2 m above sea level. There is a chain of low mountains called “Rothaargebirge” in the southwest in which the highest point of catchment is located with an altitude of 843 meters above sea level. It is believed that the “Rothaargebirge” must once have been “Rod Hard Gebirge” or “the cleared forest mountain range,” as the range has nothing whatsoever to do with the color red, nor with hair [50]. The difference between the lowest point and the highest point of the catchment is 745 meters and the direct distance between them is 74 kilometers. The majority of slope is from South-West to North-East. (Figure 6-2)

### **6.4 Geology and soil types**

The oldest geological map of Hesse was published in 1876 on a scale of 1:25000. The general map of the geological structure of Hesse defines the surface area of this region. According to the Hesse Environmental Atlas, north Hesse is comprised of prevalent silicate sediments and metamorphic equivalents, prevalent quartzes sediments and metamorphic equivalents carbonate stones and, in addition, there are some parts with loss loam [20].

Soil forms the highest layer of the Earth and it plays an important role in the hydrological cycle. The Diemel catchment is covered by five types of soil: poor sandy loam, marsh, clay, silt and debris sand. Figure 6-3 shows the diversity and amount of different soil types in the catchment.

Silt covers most of the catchment; it is about 836 km<sup>2</sup> equal to 47.6 % of catchment area. It is mainly distributed in the southwest and also in some parts in the north of the catchment.

Poor sandy loam places in second position with 584.9 square kilometers equal to 32.3% of the catchment area. It is expanding in the east and middle. Debris sand (gs), with 214.2 square kilometers equal to 12.2%, is in the third position. This type of soil covers some parts in the east and also a zone from south to north in the middle of the catchment. Clay lenses hold the fourth position of the soil type distribution in the catchment area. They are distributed in the south and east. Total areas of the clay are 120 square kilometers (about 6.8%). In addition there are some small areas covered by marsh, but they are very small (less than 1%)(figure 6-3).

## **6.5 Land use**

The Diemel catchment is located in the center of Germany with good soil and surface slope. Therefore, most parts of this area are covered by plants (e.g. agricultural land, forest and green land). When ranked by area, agricultural farms hold first place with 760.34 square kilometers or about 43% of the whole catchment area. Forest holds second place with 634 square kilometers and 36.1% of the catchment area. Furthermore, green land with 276.2 square kilometers and 15.7% is in third place. Housing area, with 79.8 square kilometers and 4.5% of whole catchment, places fourth. There are small areas that are used as construction material mines, dam reservoir (Diemel and Twiste dams) and also industries (figure 6-4).

## **6.6 River system**

The Diemel River originates in the southwest and flows to the northeast of the catchment. It joins the Weser River in the Bad Karlshafen. The Diemel River is 106 km long. The Itter River joins the Diemel in the Diemel reservoir dam and then the Rhene and Hopenke join it in the downstream of dam. The major tributaries of the Diemel are the Orpe, Twiste, Eggel, Warne, Esse and Holzappe of which Twiste is the largest. The Erpe River also joins the Twiste and then flows to the Diemel River (figure 6-5).

## **6.7 Model definition and calibration**

The NASIM model has the capability to model the flood for different rainfall duration time. In this research, the model first has been run for 1, 2, 3, 8, 12 and 24 hours duration time then the results were compared. One hour rainfall made the highest maximum flood discharge at the mouth of the Diemel catchment. As a result, one hour duration time was selected for all rainfall runoff scenarios. One hundred years flood is considered in all scenarios. The model which is used in this research was calibrated by Hydrotec Company.

## **6.8 Conclusion**

In this chapter the general characteristics of Diemel catchment was investigated. It is a tributary of Weser River with an area 1800 km<sup>2</sup>. The catchment area, climatology, topography, geology and soil types, land use and drainage network system, are input data for the rainfall-runoff model.

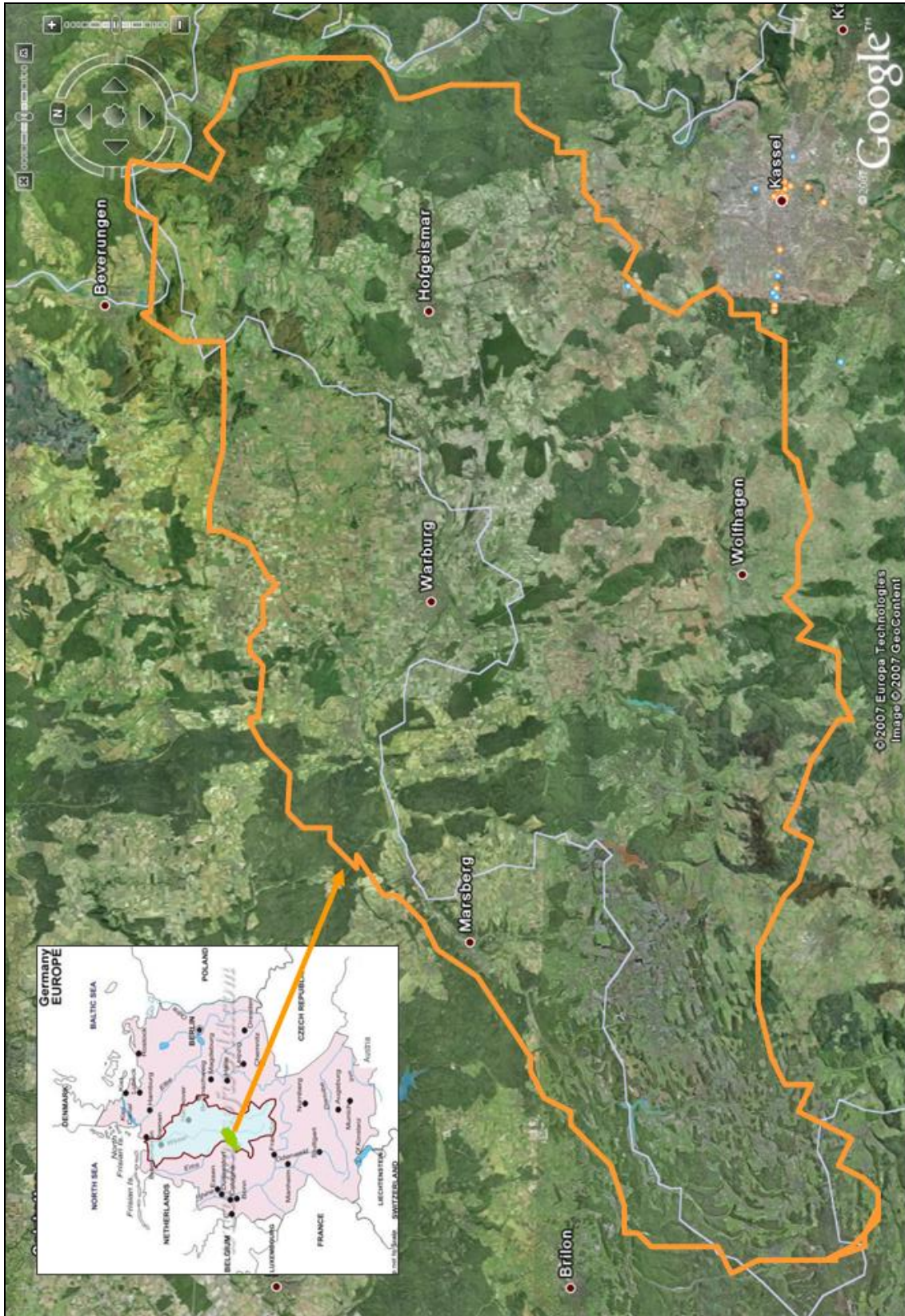


Figure 6-1 Location of Diemel catchment

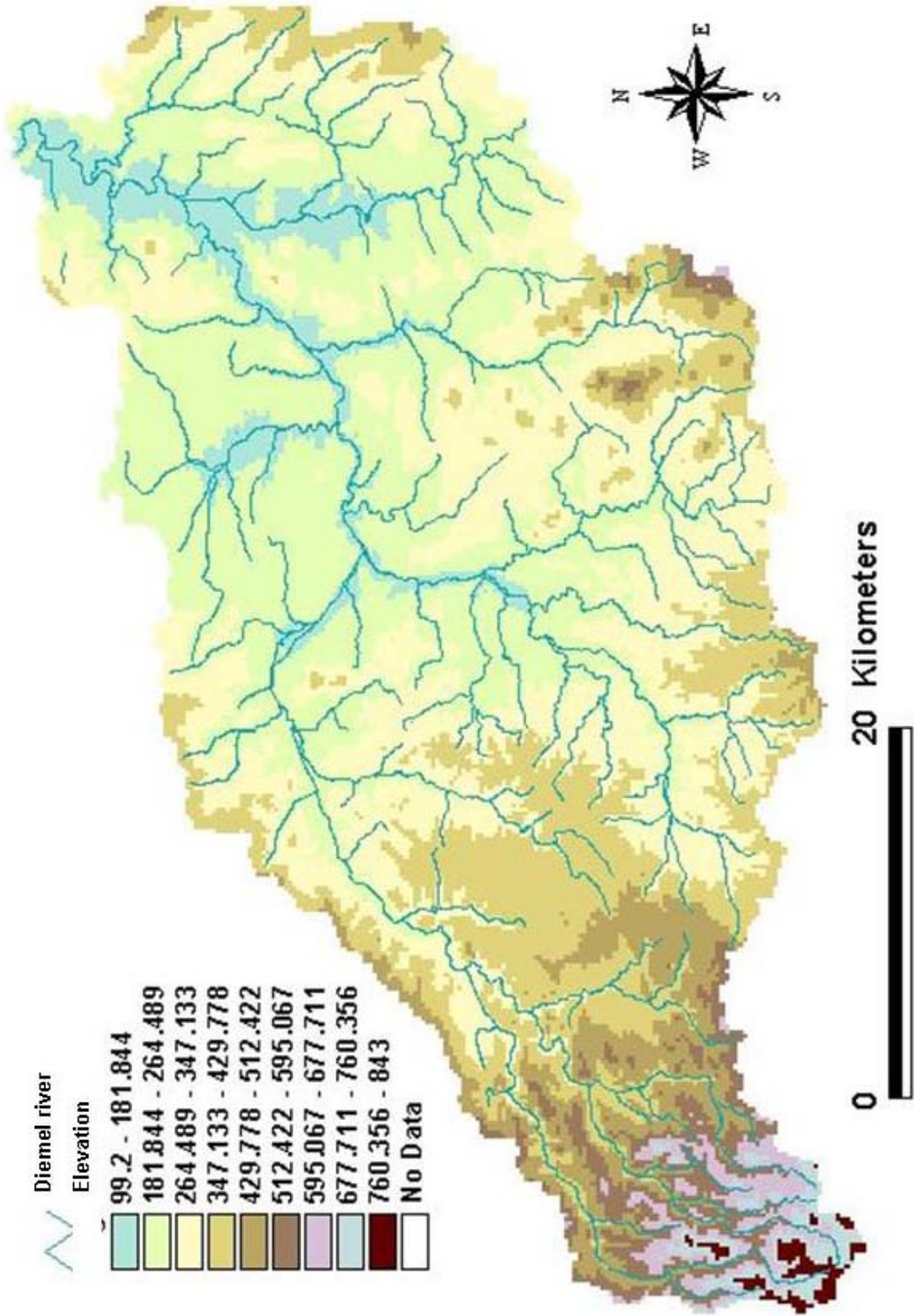


Figure 6-2 Topography map of Diemel catchment

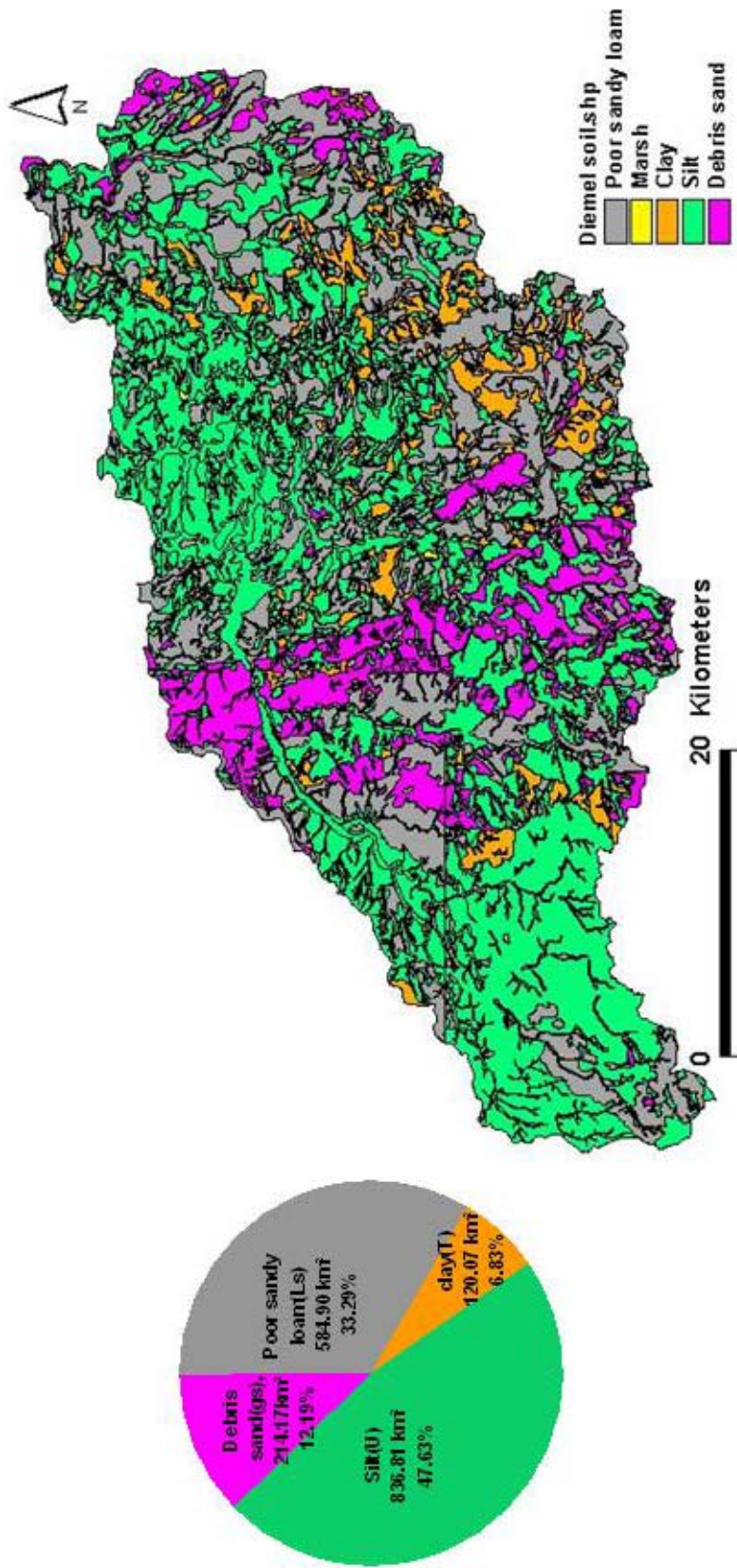


Figure 6-3 The diversity and amount of different soil types in the Diemel catchment

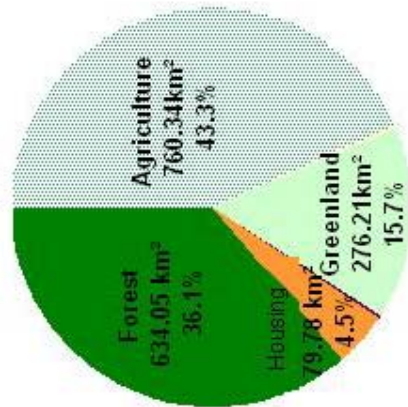
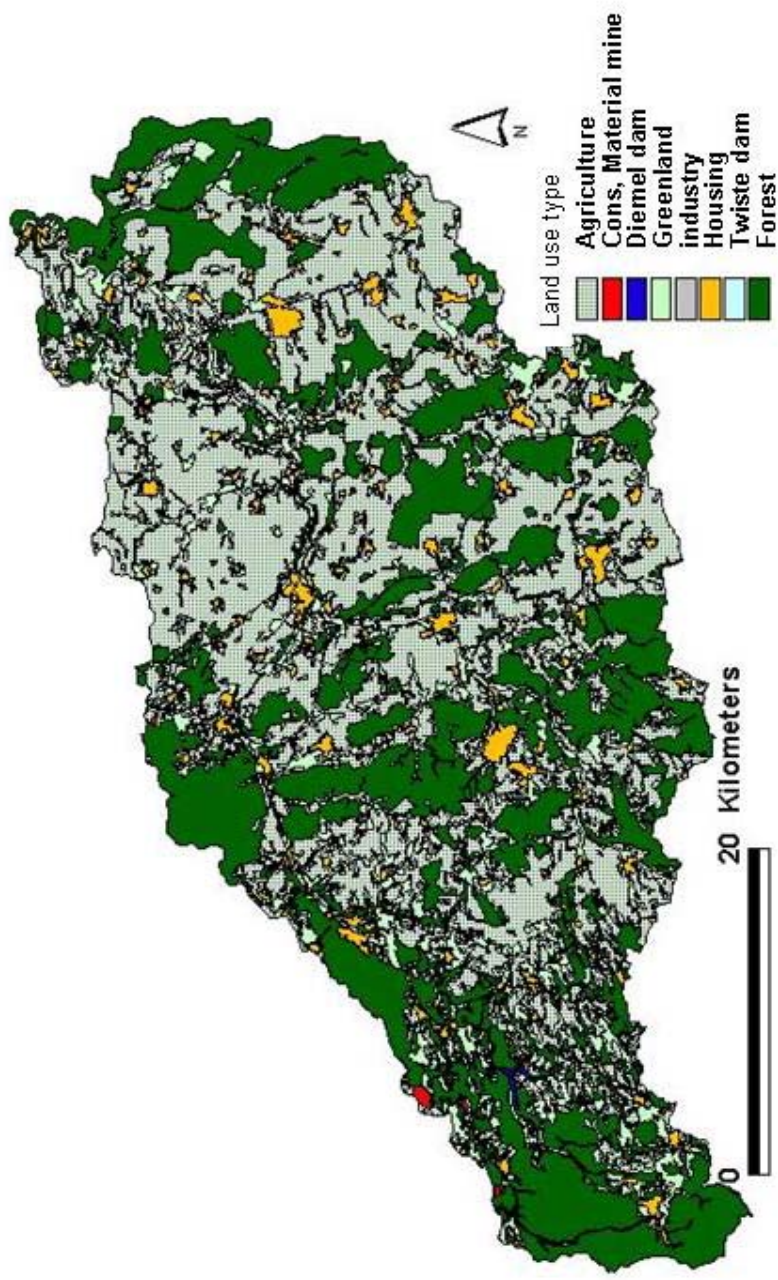


Figure 6-4 Diemel land use map

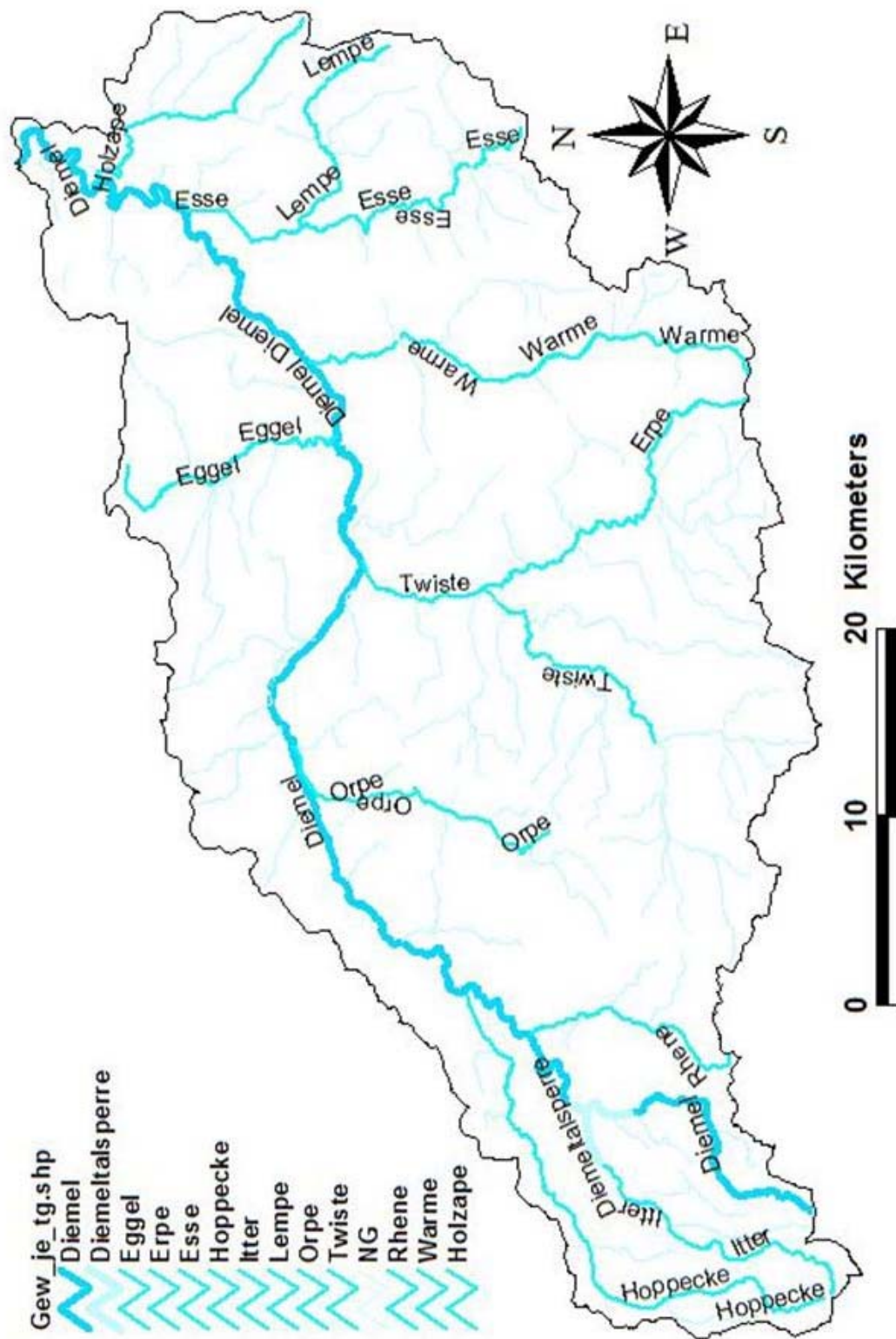
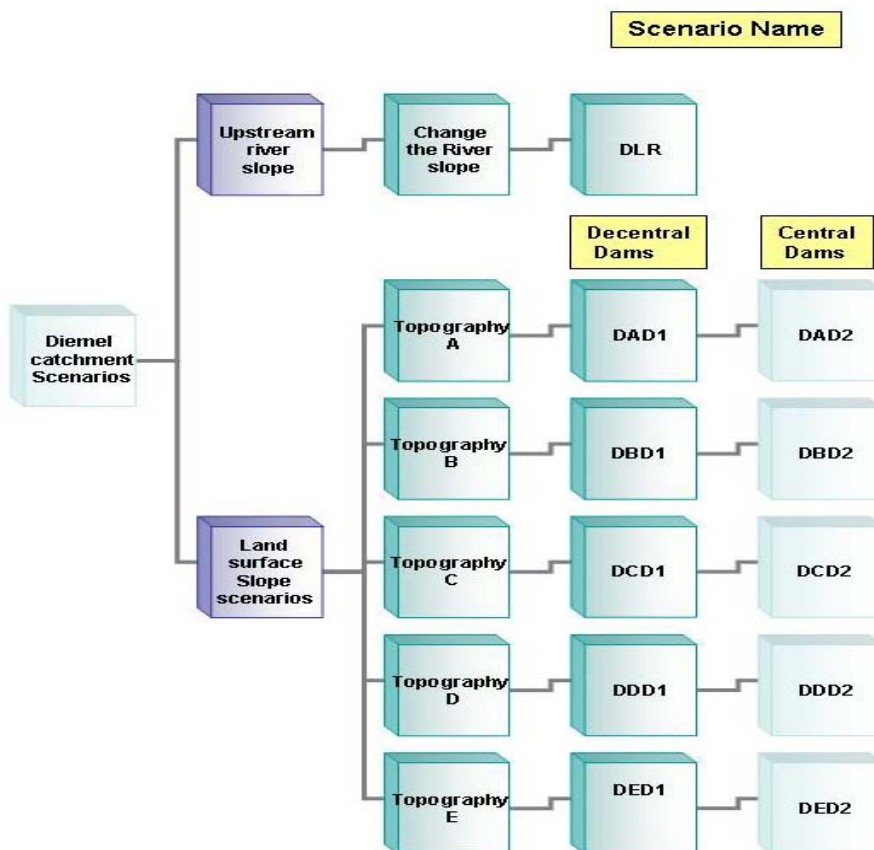


Figure 6-5 Diemel river and its tributaries

## 7 Rainfall runoff simulation of Diemel catchment scenarios

### 7.1 Introduction

In the previous sections, effects of topography on flood wave parameters, such as maximum discharge and time to peak, was considered for the Erpe catchment as a pilot. In addition, to consider the effectiveness of different flood defense measures the application of the rainfall runoff model (NASIM) was employed. According to the results, some flood defense measures are selected to examine for the whole Diemel catchment. First, the effects of upstream river network slope on flood parameters and second, the central and decentral dam construction were examined. The sensitivity of the Diemel catchment response parameters to each measure are investigated in this section. Figure 7-1 shows the different scenarios of the Diemel catchment. Effects of upstream river slope (scenario DLR) are examined on the base catchment. In other words, we used the existing catchment for this scenario. Central and decentral dams are used for five topography scenarios (existing topography and artificial topographies).



**Figure 7-1 Diemel catchment scenarios**

The method of creation of artificial catchments was described earlier. In addition, the selected land surface scenarios for the Diemel catchment are similar to the Erpe catchment.

Floods will be simulated for these scenarios and then the effectiveness of each flood defense measure will be considered.

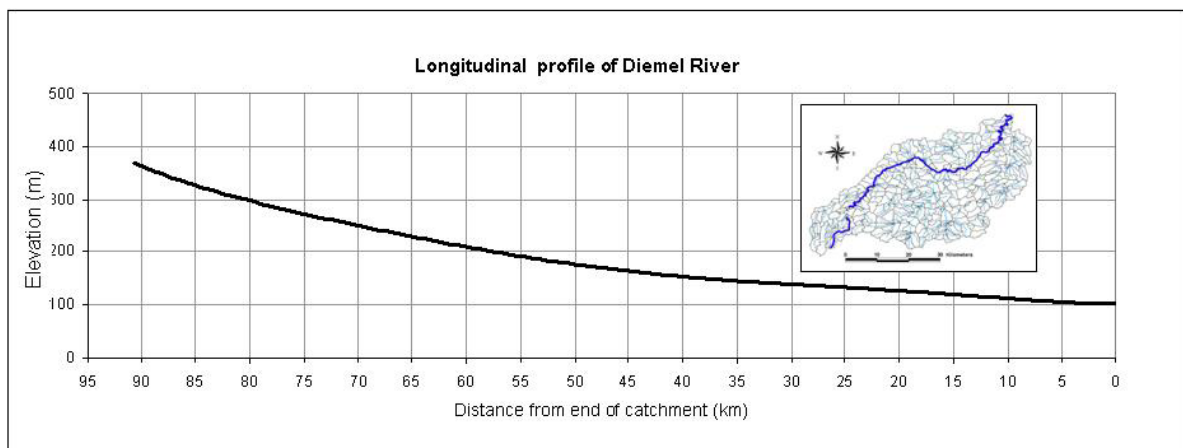
## 7.2 Influence of upstream main river slope on flood

Effects of changing river slope on flood parameters, especially maximum flood discharge, are considered in this section. Figure 7-2 shows the longitudinal profile of the Diemel main river from downstream of the Diemel reservoir dam to the Diemel mouth (Bad Karlshafen), more than 90 km long. The river bed slopes vary from 0.011 to 1.03 percent in this span. The weighting average of the river slopes ( $S_e$ ) for this span of the Diemel river is calculated by the following equations:

$$\text{Equation 7-1} \quad S_e = \frac{\sum L_i \cdot S_i}{L}$$

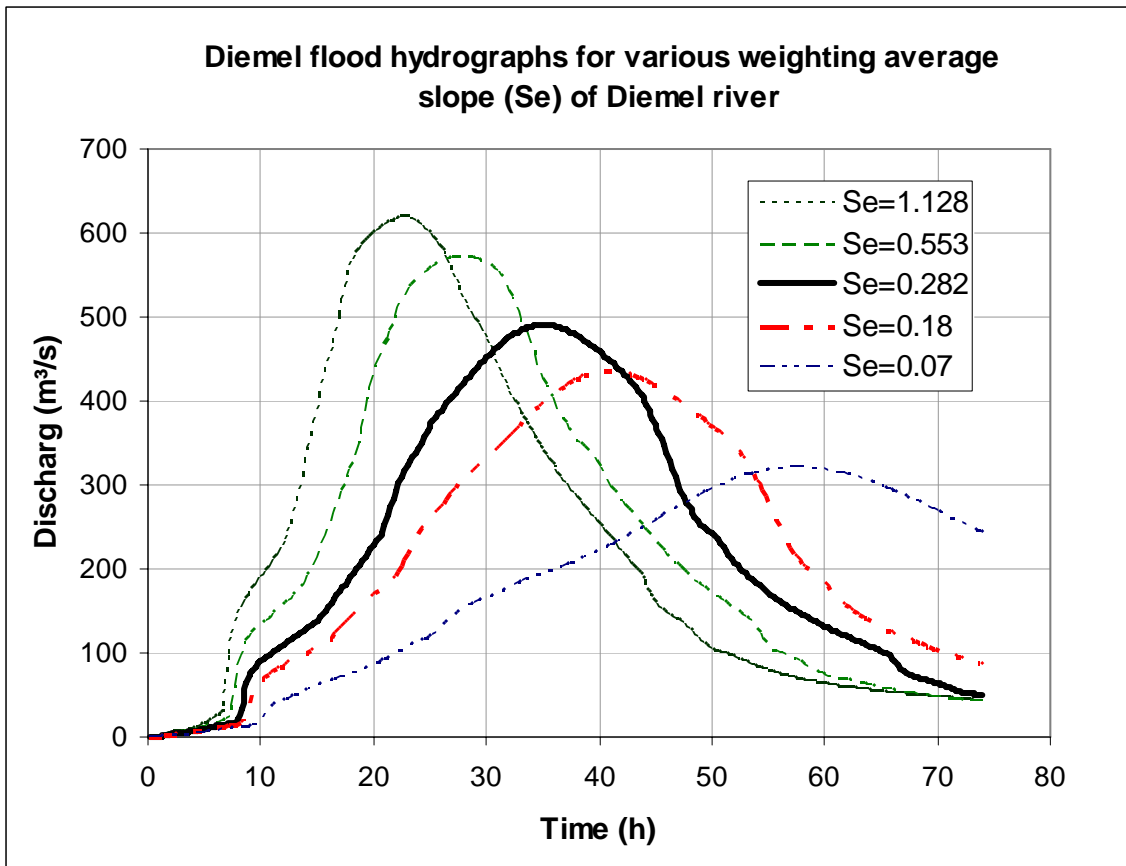
$$L = \sum L_i$$

The weighting average of the Diemel river slope is  $S_e=0.282\%$ . This parameter ( $S_e$ ) is selected as the base parameter to look over the flood parameters.

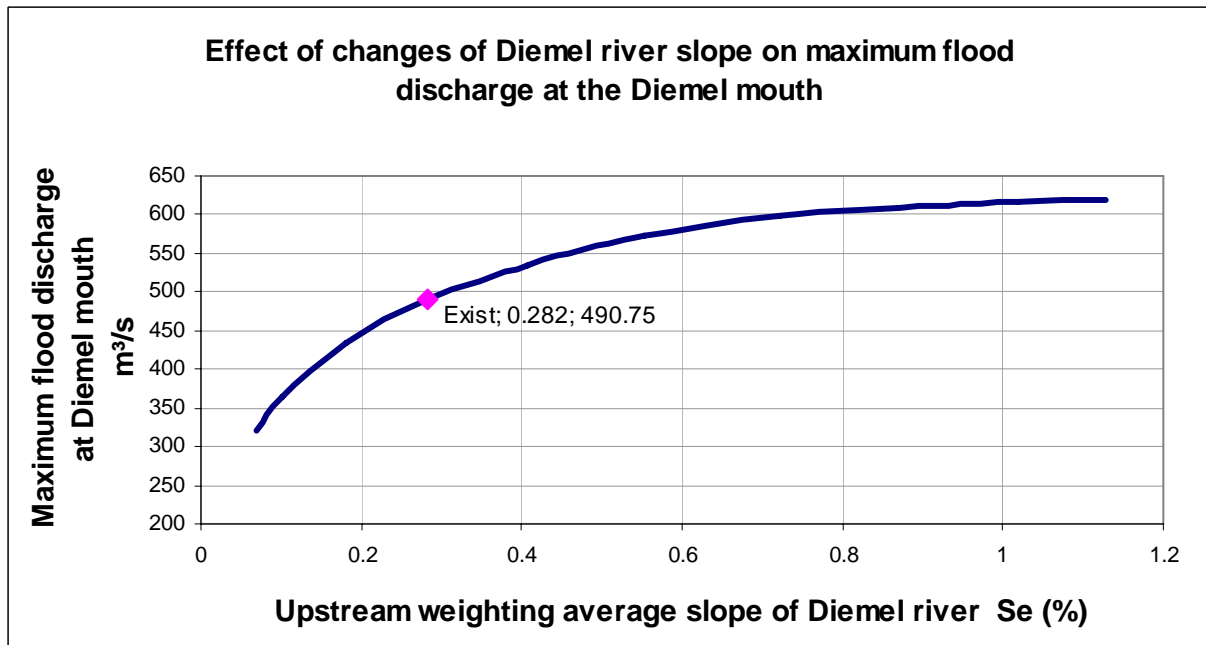


**Figure 7-2 Longitudinal bed profile of Diemel river from Bad Karlshafen to Diemel dam**

Figure 7-3 shows the flood hydrographs for various weighting river slopes. The river slope has direct relation with river mean velocity. When the river slope increases, consequently the river means velocity increases and the flood hydrograph moves left and up. In other words, the maximum flood discharge increases and time to peak decreases. The increase in river slope is executed by straightening the river and decreasing the length of meanders. In addition, an increase in the river slope raises the channel capacity and decreases the flow depth; as a result we observe a decrease in the inundated area. River slope deduction makes the flood hydrograph flatter and causes a decrease in the maximum flood discharge and an increase in the time to peak. It is important to take into consideration that a decrease in the river slope causes deduction in channel capacity and increases the flow depth and inundated areas. Maximum flood discharge reduces about 35% (from 490 to 320 m<sup>3</sup>/s) when the weighting average slope of Diemel river changes from 0.282% to 0.07%. Figure 7-4 shows the variation of flood discharge in the mouth of the Diemel catchment versus weighting average of river slope. In this curve, the rate of changes in low river slopes is high. In other words, the gradient of the curve decreases by increasing the river slope. It is clear that the maximum flood discharge in rivers with longitudinal slope less than 0.6 is more sensitive to changes in the river slope.



**Figure 7-3 Flood hydrographs at the mouth of Diemel catchment**



**Figure 7-4 Variation of maximum flood discharge against Diemel river slope**

Changes of maximum flood discharge from downstream of the Diemel reservoir dam to the Diemel mouth (Bad Karlshafen) along the river are shown in figure 7-5. According to this graph, the river slope change in short span does not have a sensible effect on maximum flood discharge. However, the restored river distance increases so that the changes in flood

discharge increase as well. The last span of Diemel river (from 0 to 20 km) has low slope (less than 0.07%), so by decreasing the river slope the flow velocity goes down and depth of water goes up, as a result the flood plain operate as a retarding reservoir and retains the flood water, so the maximum flood discharge in this span of river goes down.

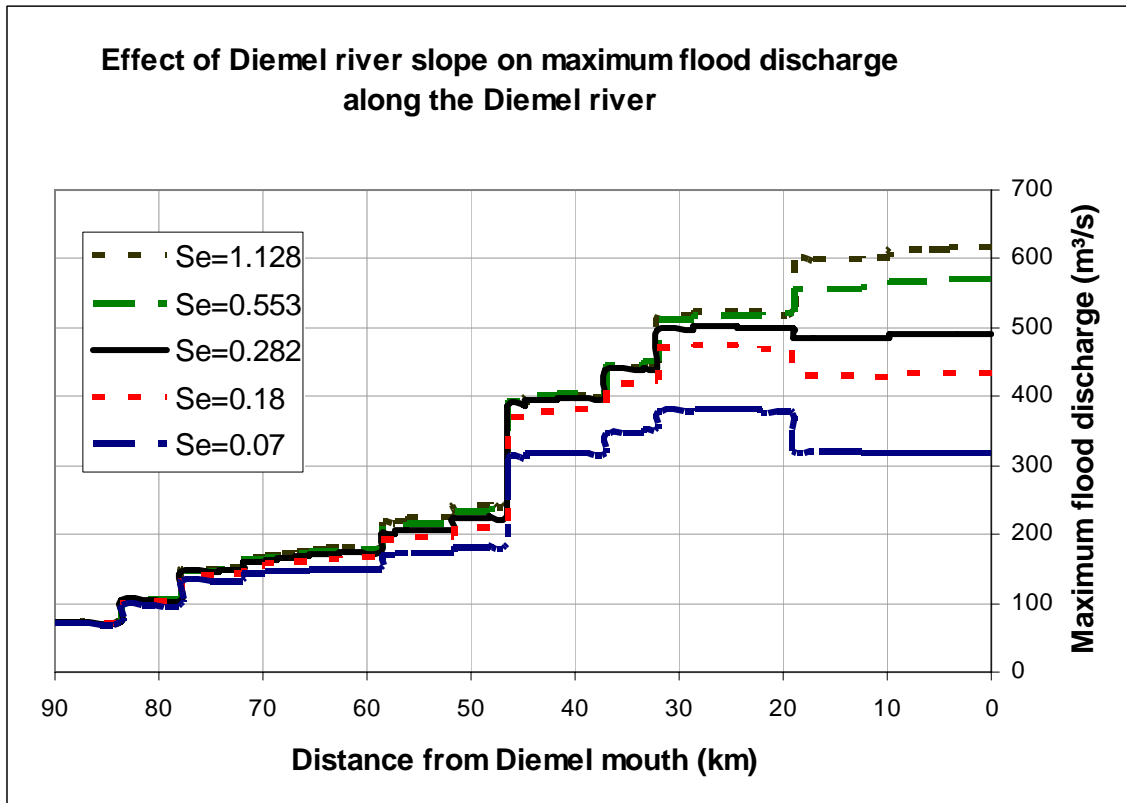


Figure 7-5 Maximum flood discharge along the Diemel main river

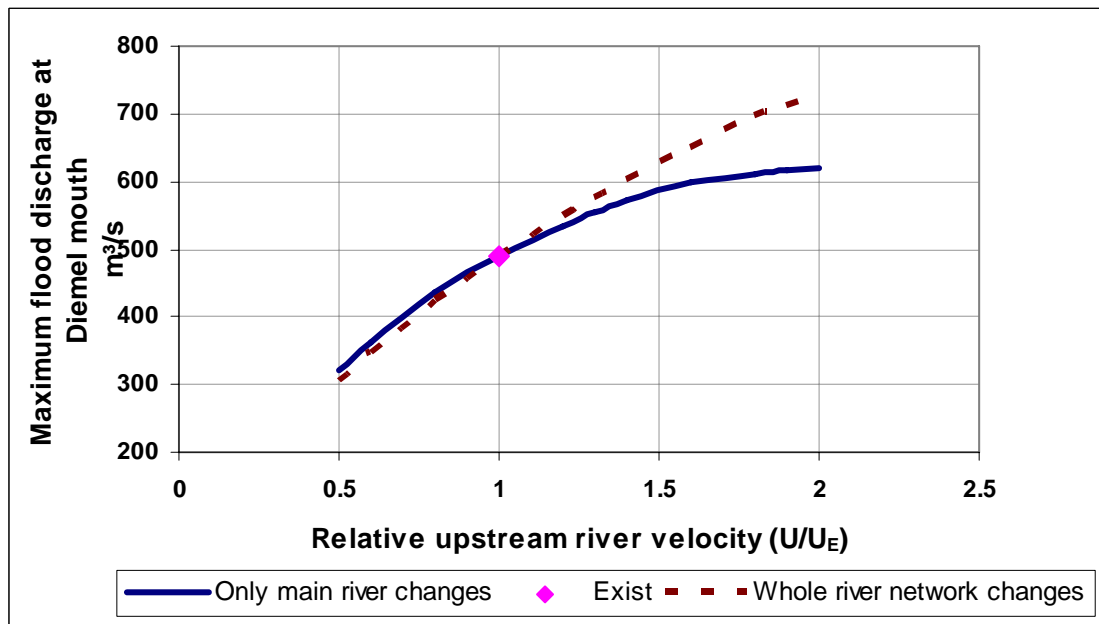


Figure 7-6 Comparing flow velocity changes in the Diemel river and in whole rivers network,  $U$  and  $U_E$  are the flow velocity in the river and existing situation respectively.

Figure 7-6 shows the variation of maximum flood discharge in two situations: first changes on the Diemel river slope and second the changes on rivers slope of complete drainage network of Diemel catchment (include the Diemel river and all its tributaries). According to the graph, in low river slopes both curves are close to each other but in high river slope or high upstream river velocity the curves move away from each other. By attention, it is clear that in rivers with low slope, changes on main river slope have similar results with changes on river slope of complete drainage network. In other words, it is preferred to make river restoration in main river. It could be done by meandering in catchments with low river slope.

### 7.3 Land surface slope scenarios

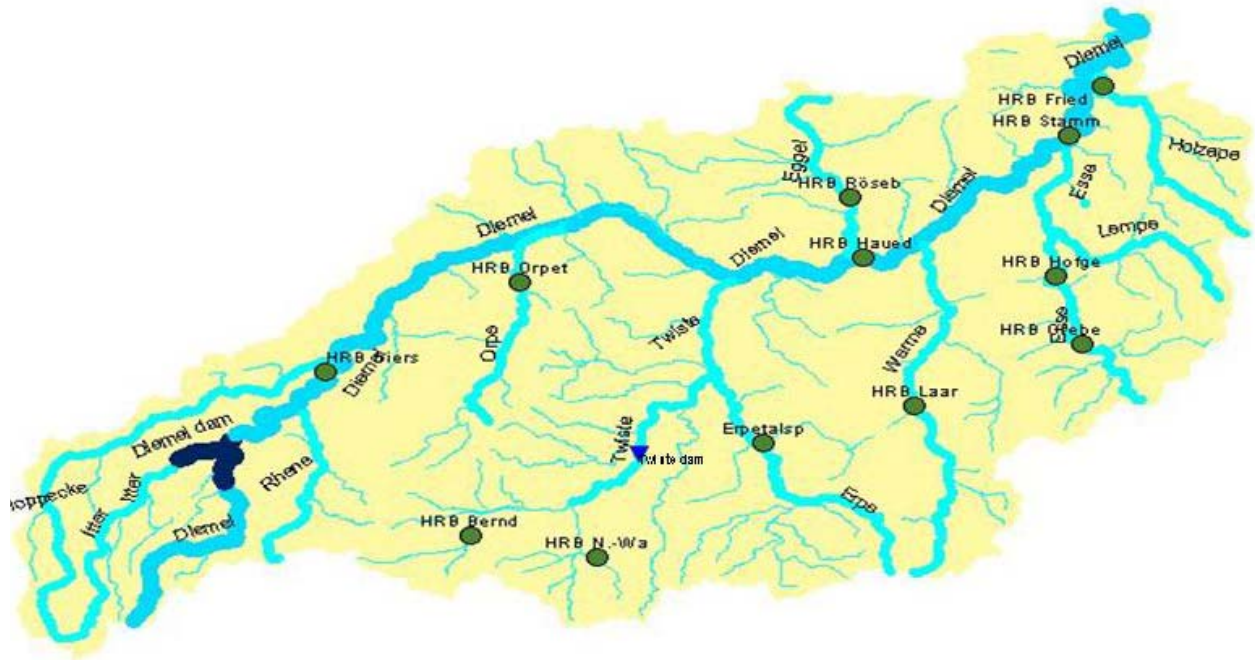
According to the results of the previous chapters, four artificial topographies from the Diemel catchment will be considered. Two of them are steeper (A and B) and the rest (D and E) flatter than the existing situation. In this section, four artificial scenarios and existing topography will be considered to consider the central and decentral dams and to find out their effects on flood.

#### 7.3.1 Retarding decentral and central dams

There are two dams in the Diemel catchment which are now in use (the Diemel reservoir dam and the Twiste dam). The Diemel dam is located in the west of the catchment. It was constructed during the years 1912-1923. It is 43 meters high, 143 meters in crest length and its reservoir capacity is  $20 \cdot 10^6 \text{ m}^3$ . The Twiste dam is a small dam, 23 meters high with an reservoir capacity of  $9.1 \cdot 10^6 \text{ m}^3$ . It lies on the Twiste River.



Figure 7-7 Reservoir of Diemel dam (Google earth)



**Figure 7-8 Location of decentral dams on the Diemel catchment**

**Table 7-1 Information of decentral dams on Diemel catchment**

No.	Name of dam	River	Location	Max. H.	State	Reference
1	HRB Giershagen	Diemel	Land kreis Waldeck-Frankenberg	15	NRW	A. D. **
2	HRB Orpethal	Orpe	Landkreis Waldeck-Frankenberg	13	HE	A. D.
3	HRB Berndorf	Twiste	Landkreis Waldeck-Frankenberg	-	HE	A. D.
4	HRB N.Waroldern	Bicke	Landkreis Wolfhagen-	-	HE	A. D.
5	Erpetalsperre	Erpe	Landkreis Kassel	12	HE	A. D.
6	HRB Roesebeck	Eggel	Landkreis Kassel	4	NRW	A. D.
7	HRB Hauda	Diemel	Landkreis Kassel	7	HE	A. D.
8	HRB Laar	Warme	Landkreis Kassel	9	HE	A. D.
9	HRB Hofgeismar	Esse	Landkreis Kassel	8	HE	A. D.
10	HRB Grebenstein	Esse	Landkreis Kassel	8	HE	A. D.
11*	HRB Stammen	Diemel	Landkreis Kassel	4	HE	A. D.
12	HRB Friedrichsfe	Holzape	Landkreis Kassel	15	HE	A. D.

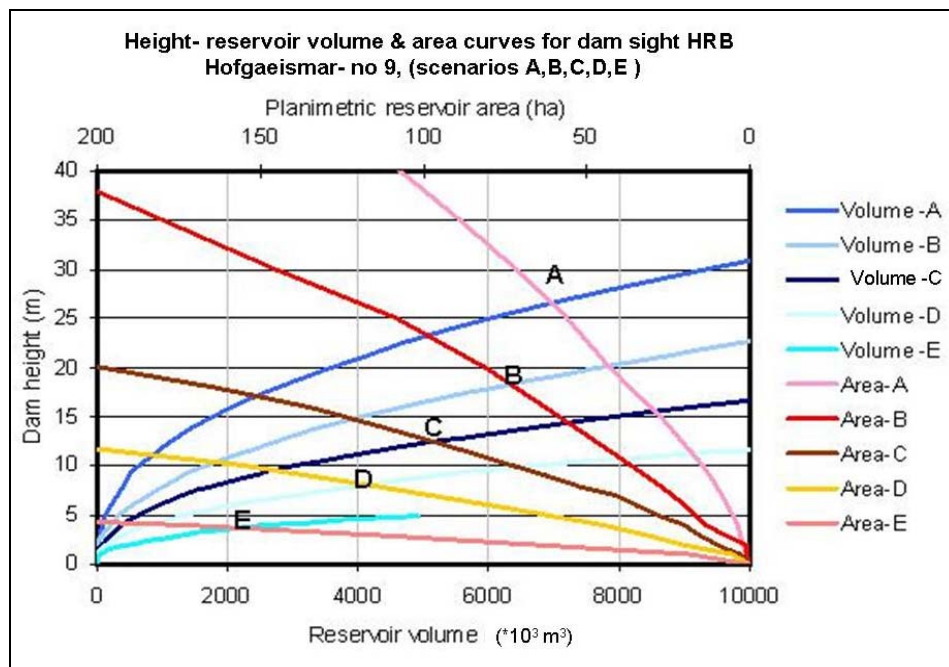
\* Site of central dam      \*\* A. D. : Ausbau der Diemel [21]

According to the “Ausbau der Diemel, Regelung der Abflußverhältnisse im Niederschlagsgebiet” report [21], there are twelve appropriate sites to build flood retainer reservoirs that are compatible with environmental and topographical parameters. The sites mentioned in this study are considered to build decentral dams. Figure 7-8 and table 7-1 show the location of these sites on the catchment [21]. Sites of HRB Bernd and HRB N-WA are rejected from simulations because of small catchments area. There are three sites on the main Diemel River. The first one is located in the downstream of the existing Diemel dam, the second one is situated just downstream of the Eggel joint point to the main river and the last

one is positioned on the downstream of the Esse. Other sites are located on the Diemel tributaries. The HRB Stamm site is also selected as a central dam.

The following conditions are taken into account for all topographical scenarios:

- The site of dams are constant in the all topographical scenarios.
- The height of dams is selected according to the site plan and land use in the existing situation.
- The maximum height is either 15 m for decentral dams or reservoir volume less or equal to  $10 \cdot 10^6 \text{ m}^3$ .
- The heights of dams are constant in all scenarios.
- The operation rule for outlet of dams is “constant discharge method” which is described in chapter four.
- The maximum height of each dam is determined in view of the land use as well as the site plan.

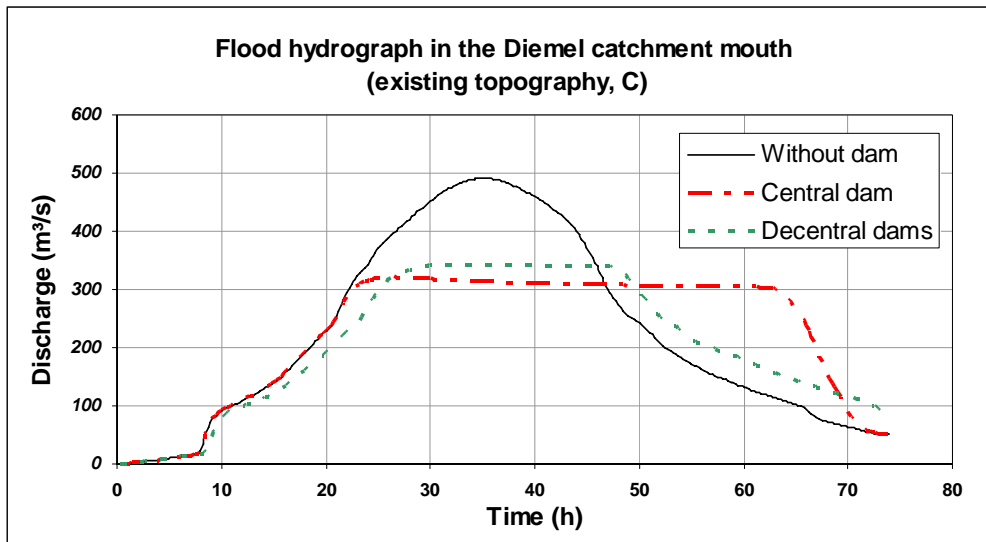


**Figure 7-9 Dam volume and area curves**

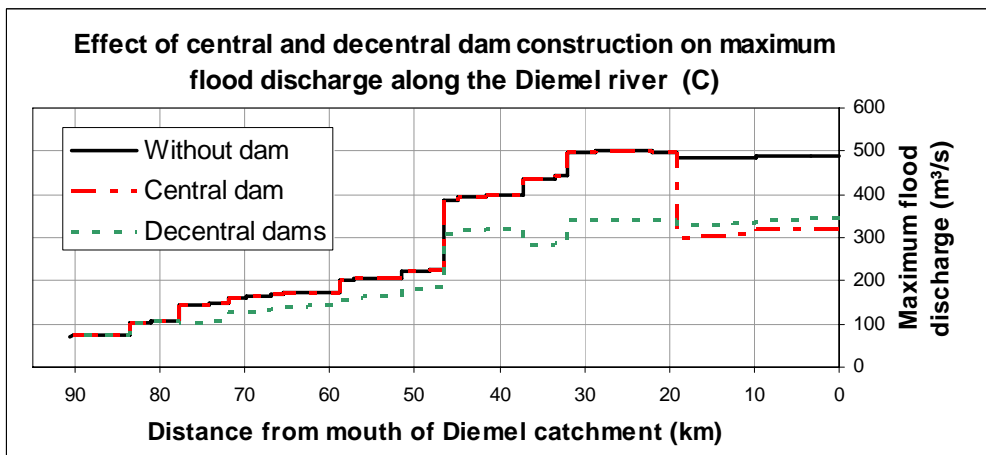
The height-reservoir volume and height-reservoir area curves are calculated for every topographical map and every site. Figure 7-9 shows these curves for site No. 9 (HRB Hofgaeismar) which is located on the Esse River. In addition, the similar curves are also calculated for other sites. According to the curves while the catchment will be flatter then the reservoir area and volume increase. In other words, by decreasing the land surface slope the curves gradient decrease too.

### 7.3.1.1 The existing topography (topography C)

The existing topography of the Diemel catchment was described in chapter six. Three conditions for this catchment are considered: first; the existing situation, second; the catchment with new decentral retarding dams construction (table 7-1 introduces the sites of dams) and last; the catchment including only one retarding dam in the function of a central dam. The flood hydrographs have been determined for the three conditions.



**Figure 7-10 Effect of central and decentral dams on flood hydrograph, topography C**



**Figure 7-11 Maximum flood discharge along the Diemel river topography C**

Figure 7-10 shows three hydrographs at the end of Diemel catchment (Bad Karlshafen) for existing topography, first denotes the flood of catchment without any new dams, second denotes flood after the construction of ten decentral dams on the catchments and the last one shows effect of a central dam. The site of the central dam is HRB Stammen on the Diemel River which is located in a place near the city of Trendelburg. The maximum flood discharge of the real situation is  $490 \text{ m}^3/\text{s}$ , it decreases to  $343 \text{ m}^3/\text{s}$  by means of constructing ten decentral dams. This deduction is due to ten decentral dams with different heights and reservoir capacities. The sum of the reservoir volume of decentral dams is about  $9.9 \cdot 10^6 \text{ m}^3$ . When a central dam is replaced with decentral dams, the catchment outflow shows 320 cubic meters per second. This is the maximum flood discharge and in this situation the reservoir volume is about  $10 \cdot 10^6 \text{ m}^3$ . By attention on maximum flood discharge along the Diemel river (Figure 7-11); the discharge in the downstream of central dam decrease to safe value in the central dam scenario while it is reduced in the upstream in the decentral scenario. So this is one of advantages of the decentral scenario.

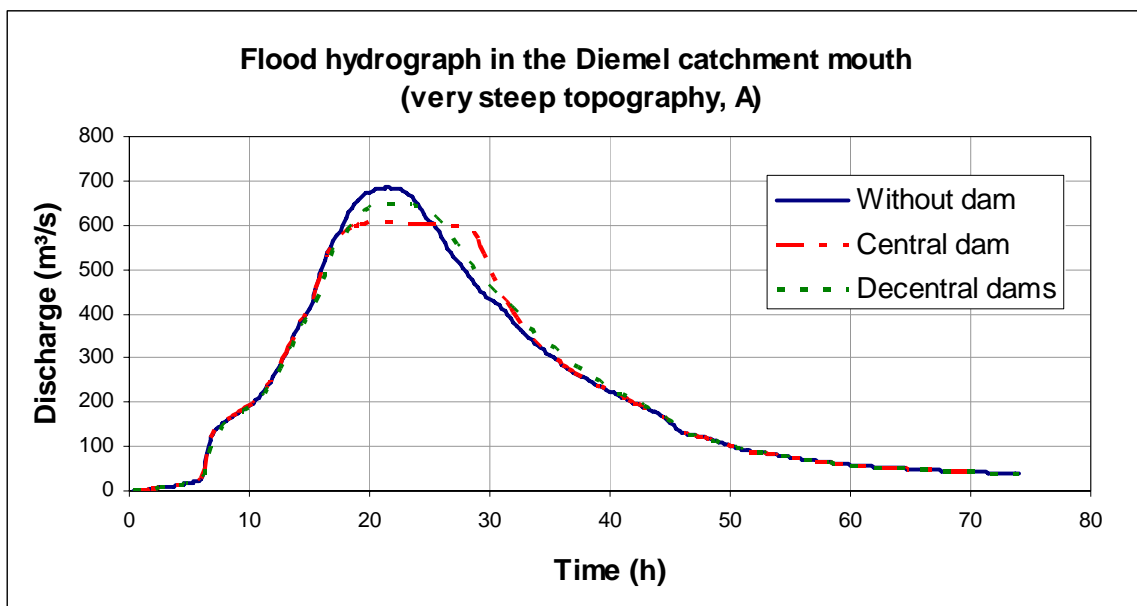
### 7.3.1.2 Very steep topography (topography A)

In this scenario the land surface slope is increased in such a manner that the elevation of every point increases two times that of base level. Consequently, the land surface slope is tripled.

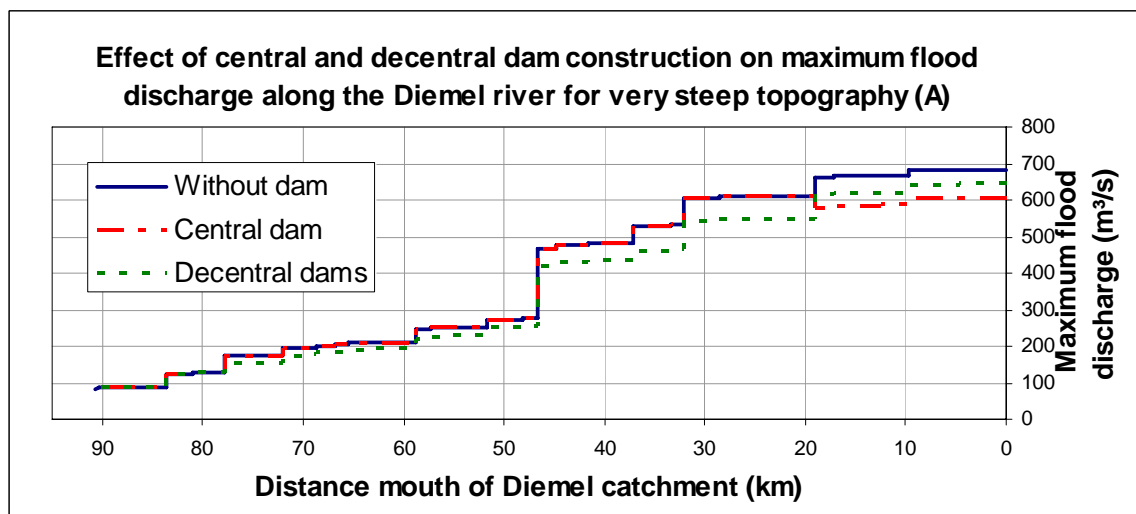
**Equation 7-2**

$$Z' = Z + 2(Z - Z_0)$$

In addition, the longitudinal river slope increases and as a result the mean flow velocity also increases. An increase in the river slope causes an increase in the river flow velocity and a decrease in dam retarding volume. Figures 7-12 and 7-13 show the flood hydrographs and the variation of maximum flood discharge along the Diemel river respectively. In this scenario, the retarding reservoir of each dam is very small because of high longitudinal river and bank slopes. Therefore, the small dams can not have a significant influence on flood discharge. To reach a safe discharge in downstream we need to increase the height of dams in this scenario. The maximum flood discharge is 684 m<sup>3</sup>/s without flood retarding dams and It decreases to 644 m<sup>3</sup>/s and 607 m<sup>3</sup>/s by employ decentral and central dams respectively. So the differences between amounts of maximum flood discharge in central and decentral dams and without dam is small in this scenario because of steep topography. As a result, the small flood retarding reservoirs are not so effective in very steep catchments.



**Figure 7-12 Effect of central and decentral dams on flood hydrograph, topography A**



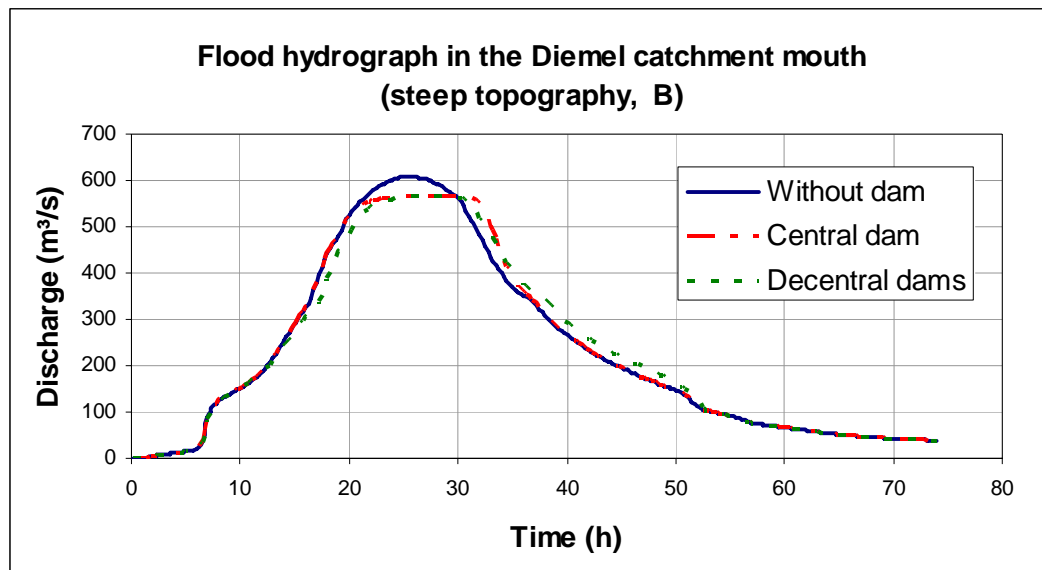
**Figure 7-13 Maximum flood discharge along the Diemel river for topography A**

### 7.3.1.3 Steep topography (topography B)

In this scenario, the land surface slope increases 100% of the existing land surface slope. The following formula is used to create new topography:

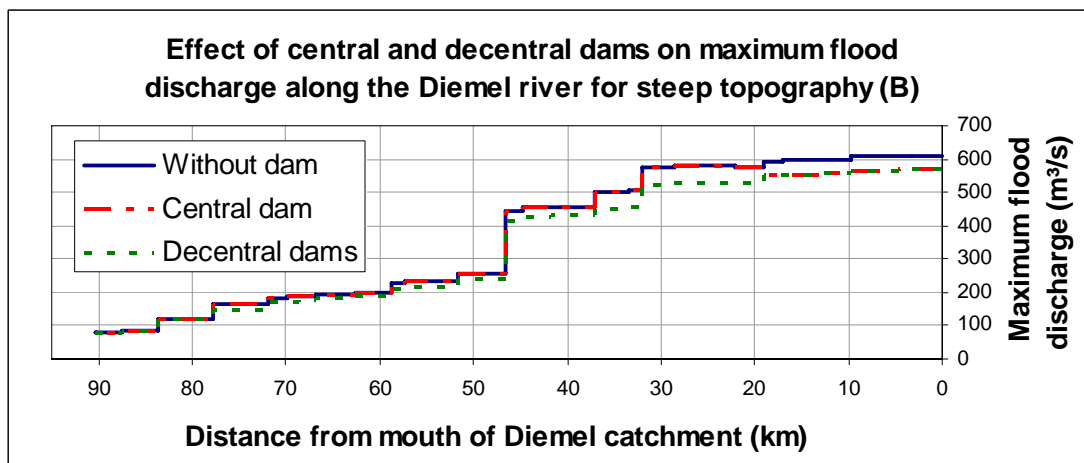
**Equation 7-3** 
$$Z' = Z + (Z - Z_0)$$

In addition, the longitudinal river slopes increase and double. Figures 7-14 and 7-15 show the flood hydrographs and variation of maximum flood discharge along the Diemel river respectively. In this scenario, retarding reservoirs are small because of the river longitudinal and bank slope become steep. However, they are bigger than the one in scenario A.



**Figure 7-14 Effect of central and decentral dams on flood hydrograph, topography B**

The maximum flood discharge is about 608 m<sup>3</sup>/s in the mouth of catchment, whereas it decreases to 565 m<sup>3</sup>/s through the use of decentral dams with total capacity volume of about 3.5·10<sup>6</sup> m<sup>3</sup>). Also, the central dam with 1.5·10<sup>6</sup> m<sup>3</sup> reservoir capacity has same effect on maximum flood discharge. In this scenario maximum flood reduction is small by using central and decentral dams. The shape of river valley make small reservoir in low height of dam in steep catchments; so flood reduction by use of small dams not so effective.

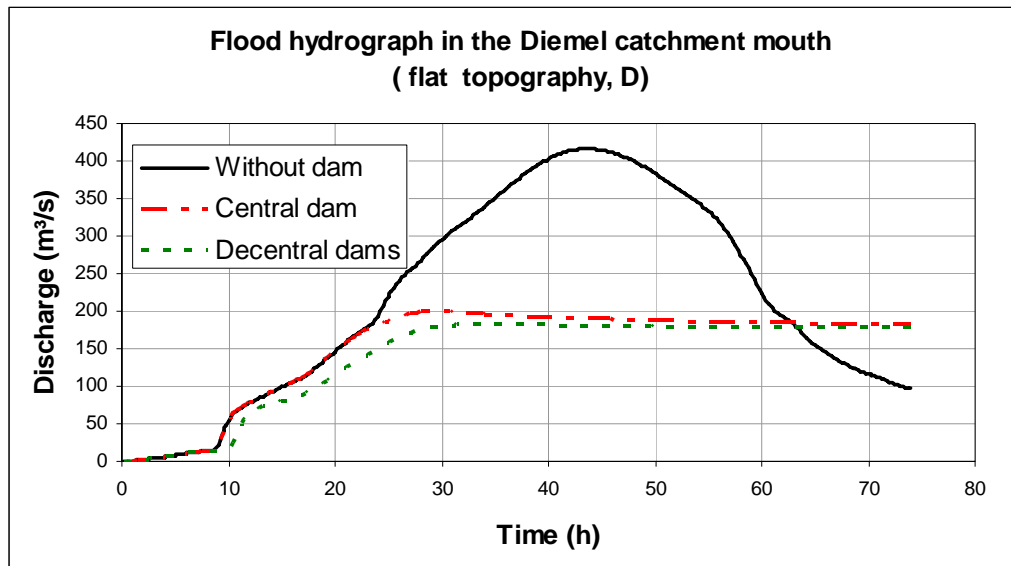


**Figure 7-15 Maximum flood discharge along the Diemel river for topography B**

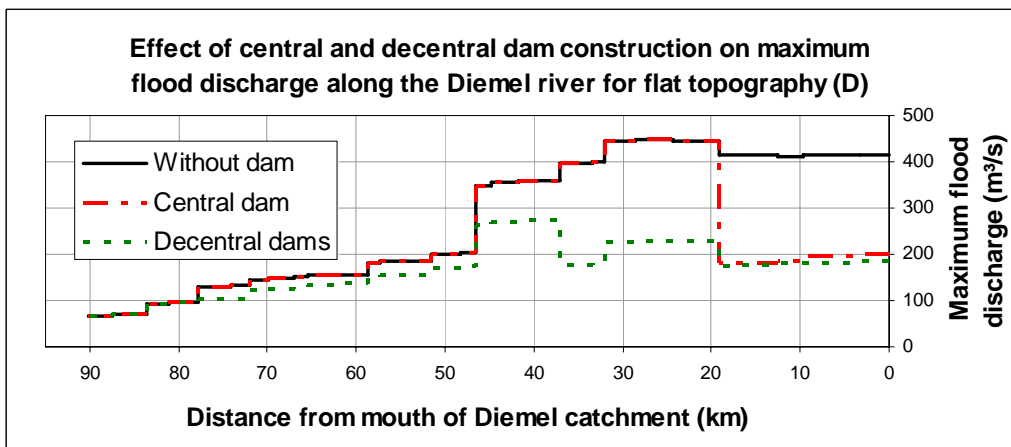
### 7.3.1.4 Flat topography (topography D)

The catchment topography of scenario D is flatter than the existing topography in such a manner that the land surface slope decreases. The following formula is used to create the topography:

$$\text{Equation 7-4} \quad Z' = Z - 0.4(Z - Z_0)$$



**Figure 7-16 Effect of central and decentral dams on flood hydrograph, topography D**



**Figure 7-17 Maximum flood discharge along the Diemel river for topography D**

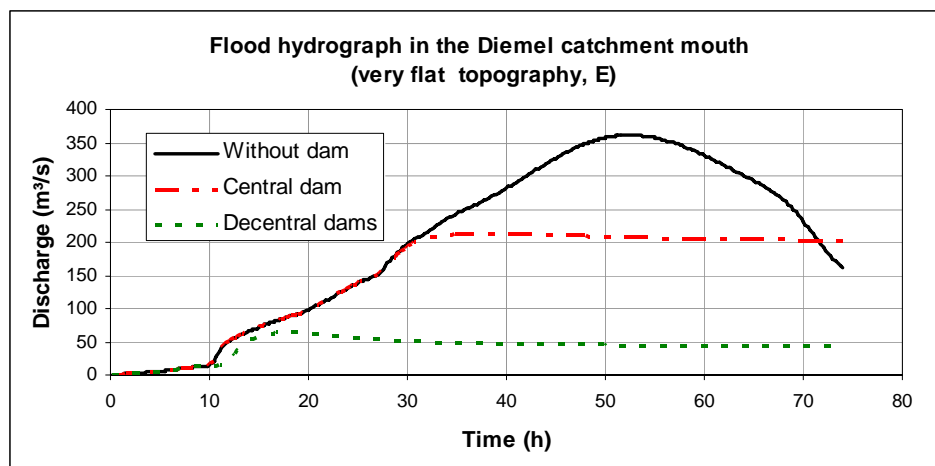
The elevation of every point reduces in the catchment, so that the height of the mountains and hills becomes small and the longitudinal river slopes decrease. Figures 7-16 and 7-17 show the flood hydrographs and variation of maximum flood discharge along the Diemel river respectively. In this scenario, retarding reservoirs are bigger than the existing situation because of low river longitudinal slope as well as bank slope. So the central and decentral dams are more effective on flood than steep catchments. The maximum flood discharge is 415 m<sup>3</sup>/s in the normal situation of catchment. However, by using decentral dams with 34.7 · 10<sup>6</sup> m<sup>3</sup> total reservoir volumes it decreases to 180 m<sup>3</sup>/s. Differences of central and decentral dams is understandable by comparing the maximum flood discharge along the river. The flood discharge decreased about 50% in the more than 25 kilometers of Diemel river from upstream of dam site No 11 (starting 20 to 47 in figure 7-17).

### 7.3.1.5 Very flat topography (topography E)

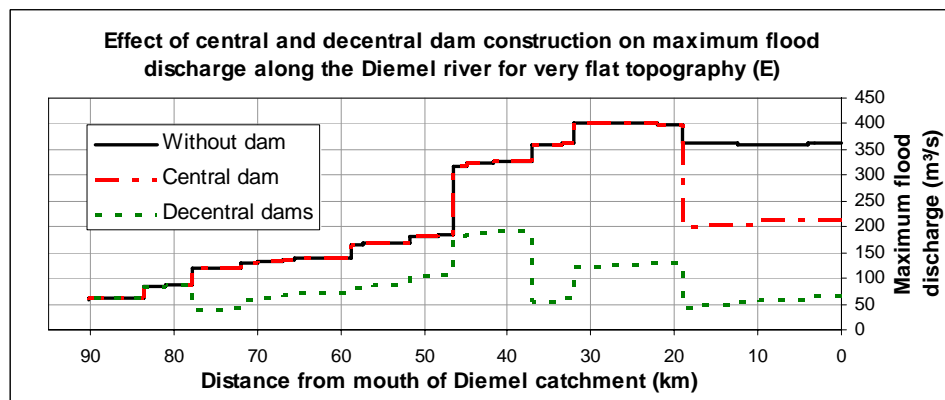
Catchment topography of scenario E is flatter than the catchment in existing topography and scenario D in such a manner that the land surface slope decreases. The following formula is used to create the topography:

$$\text{Equation 7-5} \quad Z' = Z - 0.8(Z - Z_0)$$

In this scenario, the elevation of every point in the catchment also decreases, so that the height of the mountains and hills height becomes very small and the land surface slope becomes too small. Figures 7-18 and 7-19 show the flood hydrographs and variations of maximum flood discharge along the Diemel river respectively. In this scenario, retarding reservoirs are much bigger than the existing situation because of low longitudinal slope of river and river bank slope. So the small dam height makes big flood retarding reservoir. It causes an increase in effectiveness of flood retarding dams. The maximum flood discharge is about 360 m<sup>3</sup>/s in the normal situation. The safe flood discharge in downstream is about 200 m<sup>3</sup>/s which is accessible by central dam easily. The flood discharge arrives to 60 m<sup>3</sup>/s by use of low height decentral dams which is less than safe discharge. So it is possible to reject some of decentral dams. Also the differences between maximum flood discharges are sizable along the river in central and decentral scenarios. The flood discharge along the river will decrease sizably by use of decentral dams.



**Figure 7-18** Effect of central and decentral dams on flood hydrograph, topography E



**Figure 7-19** Maximum flood discharge along the Diemel river for topography E

### 7.3.2 Comparison of results

Five systems of the Diemel catchment containing four artificial catchments and the existing catchment were modeled by way of the described conditions. Scenarios DAD and DBD have steeper topographies than the existing catchment (DCD). Scenarios DDD and DED have flatter topography than the existing catchment. Table 7-2 shows decentral dams' volumes, topographical site index and the total volume of reservoirs in each scenario. The heights of dams for each scenario were taken as a constant value. So if land surface slope increases then dam reservoir volume decreases.

Figure 7-20 shows the variation of H-f curves as an example, for different topography scenarios in dam HRB Giershagen (No. 1). According to the curves, the value of topographical site index decreases with a reduction of land surface slope; in other words, flood defense cost of one cubic meter of flood in steep topography is more expensive than flatter topography. If the dam height is kept constant for all scenarios, the  $f$  value decreases because of the reservoir volume increases. The other dams in the catchment behave similarly. The values of topographical site index show in figure 7-21, for all decentral dams and various topographies. So it is easy to compare dam sites and also different topographies. An increase in the land surface slope causes to grow in the topographical site index and also increasing the cost of flood defense measure. The sites No. 1, 2, 5 and 12 have high value of  $f$  which indicate the flood control in these sites are more expensive than others (like 6, 7, 8, 9, 10 and 11).

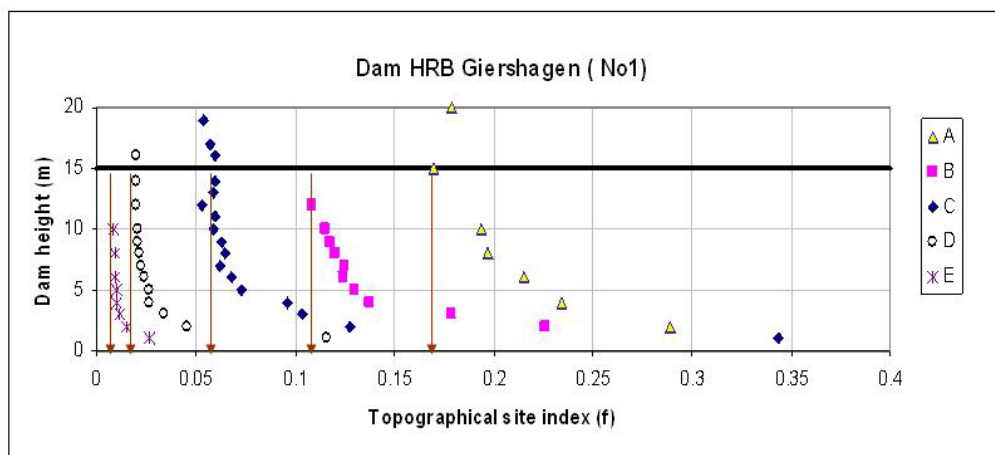


Figure 7-20 The variation of H-f curves for different scenarios in dam No 1

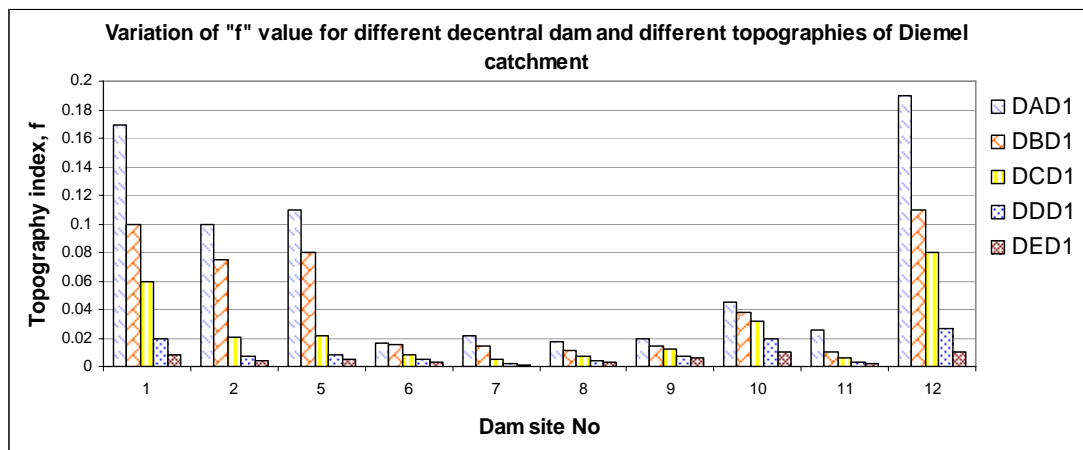
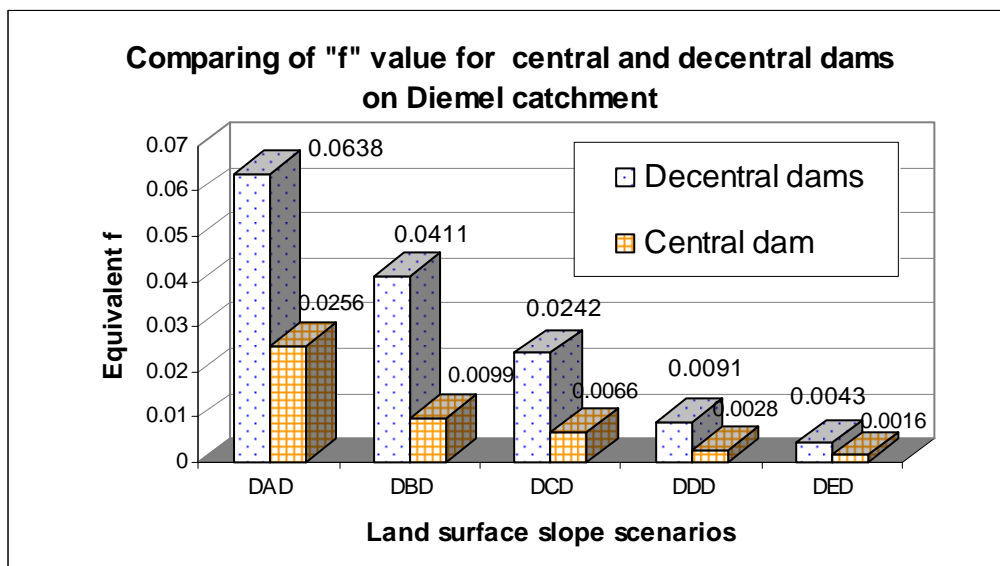


Figure 7-21 The variation of  $f$  for different scenarios of land surface slope

Therefore, according to the flood hydrographs of decentral and central dams in different topography scenarios, the volumes of dam reservoirs increase as a result of the flattening of the catchment. Thus, the effectiveness of flood retarding dams will be higher.

Figure 7-22 shows the comparison of central and decentral dams by using the topographical site index. The equivalent topographical site index used for decentral dams (such as Erpe catchment). The figure shows that flood control in the central dams has less value of topographical site index than decentral dams in all scenarios. It is clear that in this research used the same conditions for all decentral and central dams without any optimization.

Figure 7-23 shows the variation of H-f curves for different sites as well as different topographies. The curves in steep topography are far from each other whereas in flat topography they are close together. This means that in steep catchments the topography has more influence on flood defense cost than flat catchments. Also site selection is also more important in steep topography than in flat topography.



**Figure 7-22** The comparison of equivalent f for decentral dams and central dams

## 7.4 Conclusion

Figure 7-4 shows the sensitivity of maximum flood discharge to the main river slope of the Diemel. The maximum flood discharge reduces about 35% (from 490 to 320 m<sup>3</sup>/s) when the weighting average slope of the Diemel river changes from 0.282% to 0.07%. While the Diemel river slope increases, the curve gradient increases. In other words, it decreases 8 m<sup>3</sup>/s for each percent reduction on weighting average of river network slope. According to figure 7-5, the changes of river slope in short span does not have an important effect on maximum flood discharge. More increase in the length of rehabilitated span of river would result in more changes in flood discharge.

Changes in maximum flood discharge are investigated in two situations: first, the changes slope of Diemel river and second, the slope changes of river network in the whole catchment. According to the results, in low river slopes both curves are close to each other while in high river slopes or high upstream river velocity the curves move away from each other.

Central and decentral dams are used to control the flood for the Diemel catchment. Ten sites mentioned in this study are considered to build decentral dams (Figure 7-8 and also table

7-1). There are three sites on the main Diemel river: the first one is located in the downstream of the Diemel dam, the second one is situated just downstream of the Eggel joint point to main river and last one is placed on downstream of Esse. Other sites are located on the Diemel tributaries. The HRB Stamm site is also selected as a central dam. The topography of the selected sites was studied and topographical site index was used to evaluate and compare them. The results show that the H-f curves are scattered on the sheet area in very steep catchments; conversely flat catchments and h-f curves are close together. In other words, the differences of dam sites are more important in steep catchments than in flat catchments. Thus, the H-f curves are close together in flat catchments.

Five systems of the Diemel catchment containing four artificial catchments and the existing catchment were modeled by way of the described conditions. Ten appropriate sites are selected to build flood retainer reservoirs that are compatible with environmental and topographical parameters. The value of topographical site index considered for all dams and scenarios. According to the curves, the flood defense cost of one cubic meter of flood in steep catchment is more expensive than flatter topographies. Also the flood hydrographs considered for decentral and central dams on the various topographies. Comparison of central and decentral dams was described by using the topographical site index.

**Table 7-2 Reservoir volume and f value for decentral dam's scenarios**

D N	Name of dam	River	Location	Max. H.	Topographical site index Reservoir volume (Tm <sup>3</sup> )					
						DAD1	DBD1	DCD1	DDD1	DED1
1	HRB Giershagen	Diemel	Landkreis Waldeck- Frankenberg	15	f	0.1697	0.10	0.06	0.02	0.0085
					V	120	273	975	4500	9000
2	HRB Orpethal	Orpe	Landkreis Waldeck- Frankenberg	13	f	.1	0.075	0.021	0.0075	0.0045
					V	279	428	946	4200	8000
5	Erpe talsperre	Erpe	Landkreis Kassel	12	f	0.11	0.08	0.022	0.008	0.005
					V	200	573	1000	3500	8636
6	HRB Rosebeck	Eggel	Landkreis Kassel	4	f	0.016	0.015	0.008	0.005	0.003
					V	57	265	1000	2700	7306
7	HRB Haueda	Diemel	Landkreis Kassel	7	f	0.022	0.014	0.0056	0.0022	0.0009
					V	197	230	1060	3700	9797
8	HRB Laar	Warme	Landkreis Kassel	9	F	0.0173	0.0117	0.007	0.004	0.003
					V	300	480	960	3000	9760
9	HRB Hofgeismar	Esse	Landkreis Kassel	8	F	0.02	0.014	0.0012	0.0075	0.006
					V	390	819	1000	3900	4899
10	HRB Greibenstein	Esse	Landkreis Kassel	8	f	0.03	0.11	0.035	0.02	0.01
					V	43	220	1000	1500	4153
11	HRB Stammen	Diemel	Landkreis Kassel	4	f	0.0256	0.0099	0.0065	0.0028	0.0016
					V	150	530	1000	5630	13466
12	HRB Friedrichsfe	Holzape	Landkreis Kassel	15	f	0.19	0.11	0.08	0.027	0.01
					V	130	200	800	2090	3138
Total volume for decentral dams reservoirs (Tm <sup>3</sup> )						3066	4018	9741	34720	78155

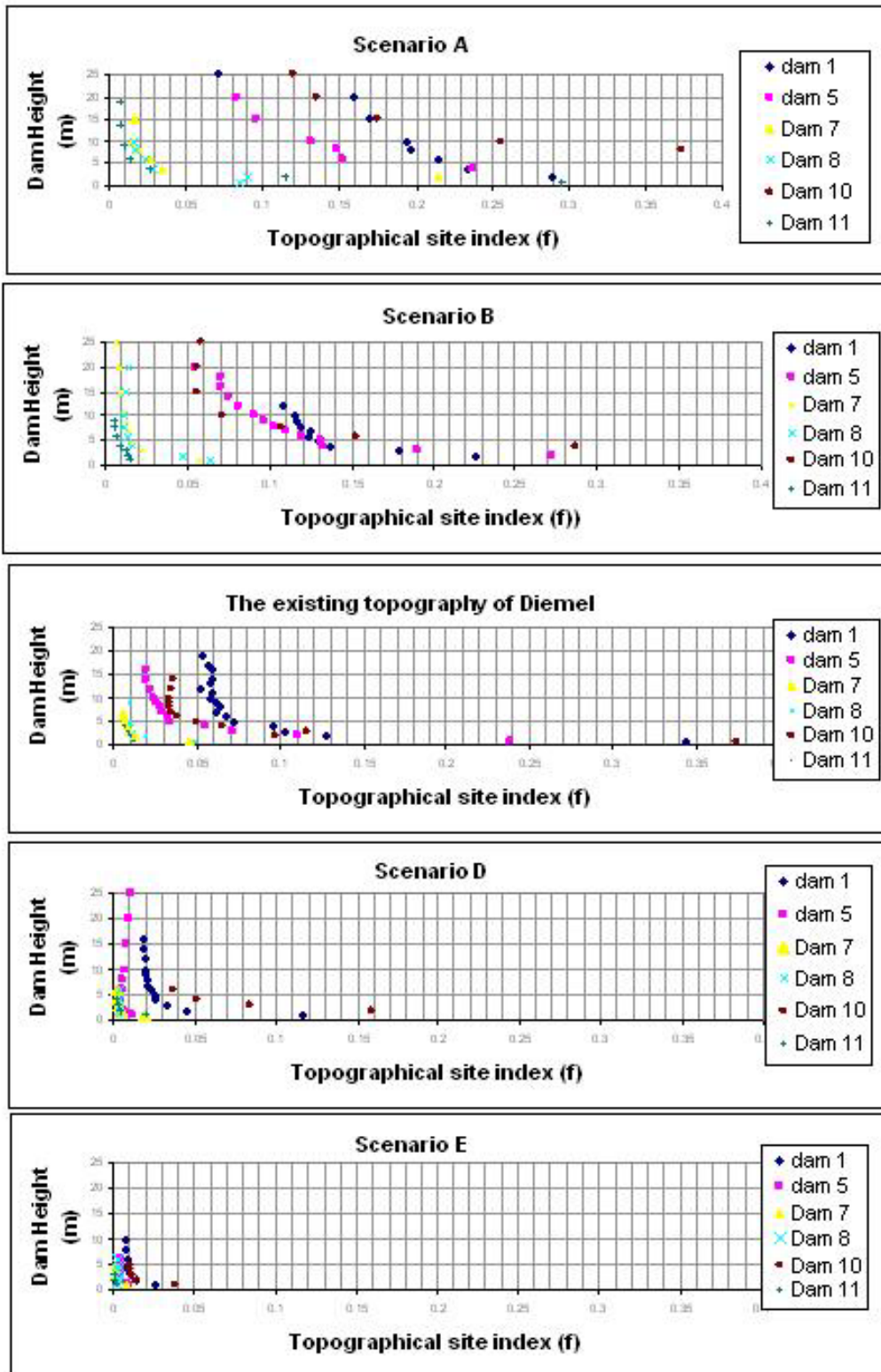


Figure 7-23 H-f curves for selected dams on Diemel catchment with different topographies

## **8 Discussion of results and conclusion**

### **8.1 Introduction**

Flood defense measures, topographical parameters, a combination of flood defense concept and topography parameters are all topics that were described to find out the effects of topography changes on flood parameters. Finally, the relationships between parameters of topography, floods and flood defense measures were examined for the Diemel catchment with different topographies. Floods are measured by height, area inundated, peak discharge, volume of flow and other important parameters (such as time to peak discharge, flood duration and flood return period). Flood defense measures are classified by different views such as structural and non-structural methods, water control measures, settlement measures and social measures.

The flood defense measures were described in mountain and low land areas via some experiences for the reason that encounters with floods in these areas are different. To mention in brief, there are five effective elements in natural floods (figure 1-2): first, meteorological elements (temperature, rainfall, evaporation, sunshine, wind, etc.); second, soil information (soil type, hydraulic conductivity, field capacity, etc.); third, topographical elements; fourth, the land use; and fifth, river network elements. The topographical elements influence land use and drainage elements. For example, the farm land and settlement areas are located on the low land surface slopes. In addition, mountain catchments have a more condense drainage network than low land catchments. Erpe and Diemel catchments have been considered as the base catchments and their topographies have been changed synthetically. The effect of catchment topography on floods was considered in previous chapters by using the NASIM rainfall-runoff model. Flood hydrographs were considered for all real and synthetic topographies of Erpe and Diemel catchments. The general outcomes of this research are described in this chapter briefly.

### **8.2 Influence of land surface slope on floods**

According to the catchment area, the results of the Erpe catchment are classified in two categories: subcatchments with areas less than 15 km<sup>2</sup> (10 subcatchments) and the area more than 15 km<sup>2</sup> (6 subcatchments). The results were described in chapter five. In a case in which the land surface slope increases, the maximum of the flood hydrograph goes up and left therefore the rising limb will be steeper. It would be reverse in cases where the land surface slope decreases. The sensitivity of falling limb to changes of topography is less than rising limb for all scenarios. Consequently, when the catchment becomes flatter, the flood hydrograph will be flatter too. In other words, the concentration time increases because of reduction of land surface velocity.

According to the results, catchments are divided to four categories. The first category is catchments with a mean land surface slope less than 3.5% (2 Deg). In this category the flood parameters are very sensitive to topography.

The second category has a mean land surface slope from 3.5% to 10 % (6 Deg) called medium land surface slope. The flood parameters in this group are sensitive to topography but less than in the first category.

The third category is called steep land. The mean land surface slope in this category is more than 10 % and less than 28.6 % (16 Deg).

The fourth category is very high or very steep lands with a mean land surface slope more than 28.6%. It is possible that there are very small catchments in this category. The important point here is that the topography changes are not important and do not affect flood parameters.

**Table 8-1 Sensitivity of flood parameters according to land surface**

Land surface category	description	Mean land surface slope %	Mean land surface slope DEG	$Q_{max}/(Q_{max})_E$
I	low lands	$S_m < 3.5$	$S_m < 2$	Very sensitive
II	medium lands	$3.5 < S_m < 10$	$2 < S_m < 6$	sensitive
III	Steep lands	$10 < S_m < 28.6$	$6 < S_m < 16$	Low sensitive
IV	Very Steep lands	$28.6 < S_m$	$16 < S_m$	Not important

The results show that the catchment topography does not affect maximum flood discharge for very steep catchments (a mean land surface slope more than 20 degree or 36 %). On the other hand, the catchment topography is very important for low land surface slope (a mean land surface slope less than 3.5%). In other words, very steep catchments are not overly sensitive to land surface slope. The above results are used to select some limited topographies to study the flood defense measures and topography.

### **8.3 Topographical parameters and flood defense measures**

The general relationship between topographical parameters and flood defense measures was described in chapter three. The catchment topography is comprised of catchment land surface and flood plain. Flood defense measures which are done in land surface area are called catchment area planning and management. These methods reduce the runoff volume and make a reduction on maximum of flood discharge and increase time to peak. These methods have been based on the decreasing of runoff; therefore, they concentrate to increase infiltration, interception and surface storage. The efficiency of flood defense measures which lead to reduction in runoff volume and velocity has been increased by decreasing the land surface slope (figure 8-1). In this way, land use has an effect on interception and runoff velocity. Some part of floods could be controlled by catchment land use management especially when using a suitable plant and agricultural operation on agricultural land. Figure 3-5 recommends the combination of land surface slope and agricultural plants. So make use of plants with more interception and also root depth is recommended by increasing the land surface slope to control erosion and decrease flood.

The measures, which are done on flood plain area, aim to delay the flood wave and affect flood parameters such as maximum discharge and time to peak.

Increases of infiltration rate in agricultural lands were considered for Erpe catchment. Results show if the infiltration rate in the agricultural land of the Erpe catchment increases only 10 mm/h then the maximum flood discharge decreases about 12%.

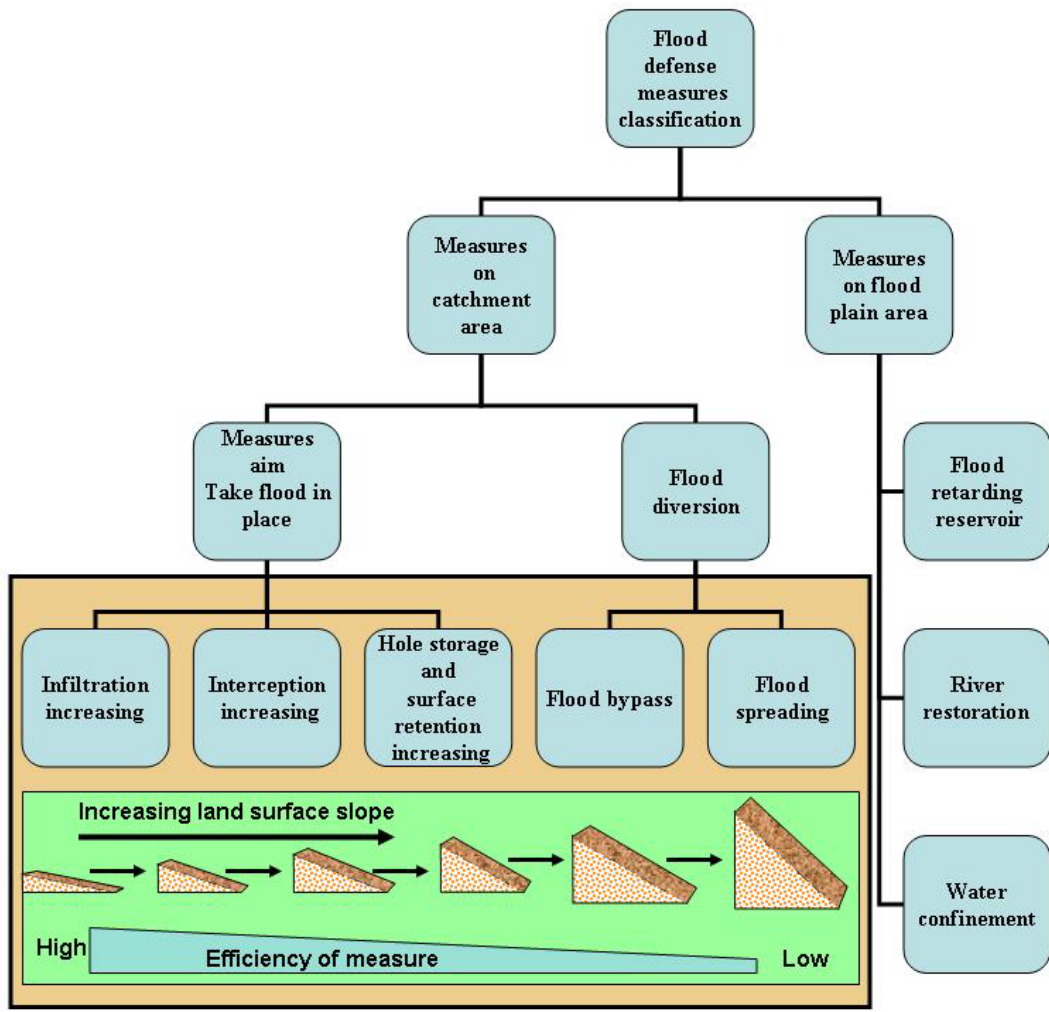


Figure 8-1 Flood defense measures on catchment area and topography

### 8.4 Rivers restoration

The influence of river network slope and river flow velocity on flood hydrographs were considered in this research in the function of flood defense measure via the river restoration. The relationship between flood hydrograph parameters and river slopes was considered by using the NASIM model for Erpe and Diemel catchments. The output flood hydrographs was calculated by the model for each subcatchment. Three important parameters (maximum discharge, flood volume and time to peak) are considered in the flood hydrographs of Erpe and Diemel catchments. The results presented in chapters five and seven at length.

When river slope increases then the flow velocity in the river also will increase, so the concentration time of catchment reduces and the maximum flood discharge is added. The curves of Erpe catchments show that the gradients, or rate of changes of maximum discharge, depend on the catchment size. If the upstream river slope increases only 1% then the maximum flood discharge will add about 12.5% to the whole Erpe catchment.

Two conditions have been investigated for the Diemel catchment: changes of longitudinal slope of the Diemel river (from Diemel dam to Karlshafen) and change of river slope of the entire upstream rivers network on whole Diemel catchment. The river bed slopes vary in Diemel river span from 0.011 to 1.03 percent. The weighting average of the river slopes is  $S_e = 0.282\%$  for this span of the Diemel river. When the river slope increases, consequently

the mean flow velocity increases as well and the flood hydrograph is moved to the left and up. In other words, the maximum floods discharge increases and the time to peak decreases. Increasing the river slope is done by straightening the river and decreasing the length of meanders. Increasing the river slope would also cause a raise in the channel capacity and a decrease in the flow depth; therefore it decreases the inundated area. River slope deduction makes the flood hydrograph flatter and causes a decrease of the maximum flood discharge and an increase in time to peak. It is important to take into consideration the fact that decreasing the river slope causes a deduction of channel flow velocity and an increase in the flow depth and inundated areas.

Maximum flood discharge reduces about 35% (from 490 to 320 m<sup>3</sup>/s) when the weighting average of Diemel river slope changes from 0.282% to 0.07%. Figure 7-4 shows the variation of flood discharge in the mouth of the Diemel catchment versus weighting average of river slope. In this curve the rate of changes in low river slope is high (weighting average of river slope less than 0.2). In other words, the gradient of the curve decreases by increasing the river slope. It is clear that the maximum flood discharge in rivers with longitudinal slope more than 0.6 has a lesser amount of sensitivity to changes in the river bed slope.

In short, any increase or decrease in the river slope have a small effect on the maximum discharge of flood and time to peak in small catchments. Increase in the area of the catchment results in an increase of the influence of the upstream river slope.

Comparing the changes of main river slope with changes of river slope of whole catchment network, been considered for Diemel catchment, so the variations of maximum flood discharge are shown in figure 7-6 for the following conditions: According to the graph, in low river slope the two curves are close together while in high river slope, or high upstream river velocity, the curves go away from each other. So it is clear that reduction of maximum flood discharge by reducing the river slope of whole catchment is more than a reduction on main river slope in steep catchments

According to above results three points can be directly comprehended:

- Maximum flood discharge and flood time to peak have an exponential relationship with catchment river network slope.
- Whenever the catchment area has been bigger, the flood retention in the rivers is more valuable. In other words, in big catchments river restoration is so efficient to reduce the flood wave parameters such as maximum discharge. The measure efficiency decreases too by decreasing the catchment area.
- Main river slope in big catchments such as Diemel plays an important role in retaining water in low slope range.

## 8.5 Central and decentral dams

According to the equations 4-17 the topographical site index (f) defines as an arithmetical ratio of dam body volume to reservoir volume. It is a function of dam height. Here it is supposed that the flood control dams are earth dam. Thus, the dam body volume is:

$$\text{Equation 8-1} \quad V_d = a \cdot b \cdot H + (a \cdot n + b \cdot m)H^2 + \frac{2}{3}n \cdot m \cdot H^3$$

It is a polynomial function (the parameters have defined in figure 4-11). In general, the geometry of embankments dams make an example function of increasing the dam cost by

dam height. The reservoir volume is determined by the ArcView program from the catchment topography. As follows, the topographical site index (f) is the ratio of dam volume to reservoir volume (figure 8-2).

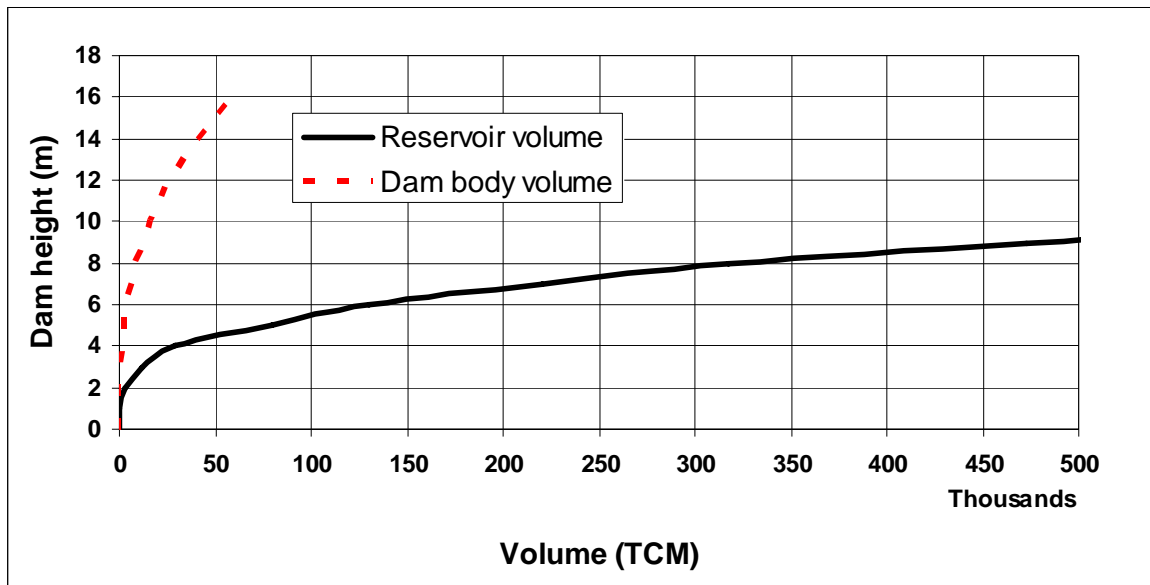


Figure 8-2 An example of dam body and reservoir volumes curves

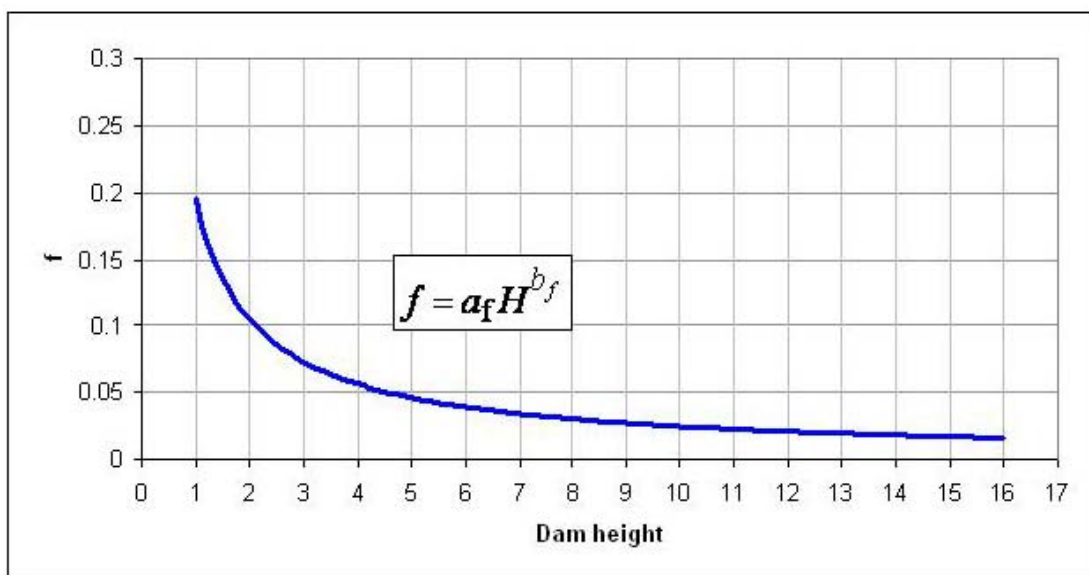


Figure 8-3 An example of the topographical site index curve

The topographical site index has a power function with dam height (figure 8-3). It is:

**Equation 8-2** 
$$f = a_f \cdot H^{b_f}$$

**Equation 8-3** 
$$C_u = f \cdot \lambda \cdot \varphi = a_f \cdot H^{b_f} \cdot \lambda \cdot \varphi$$

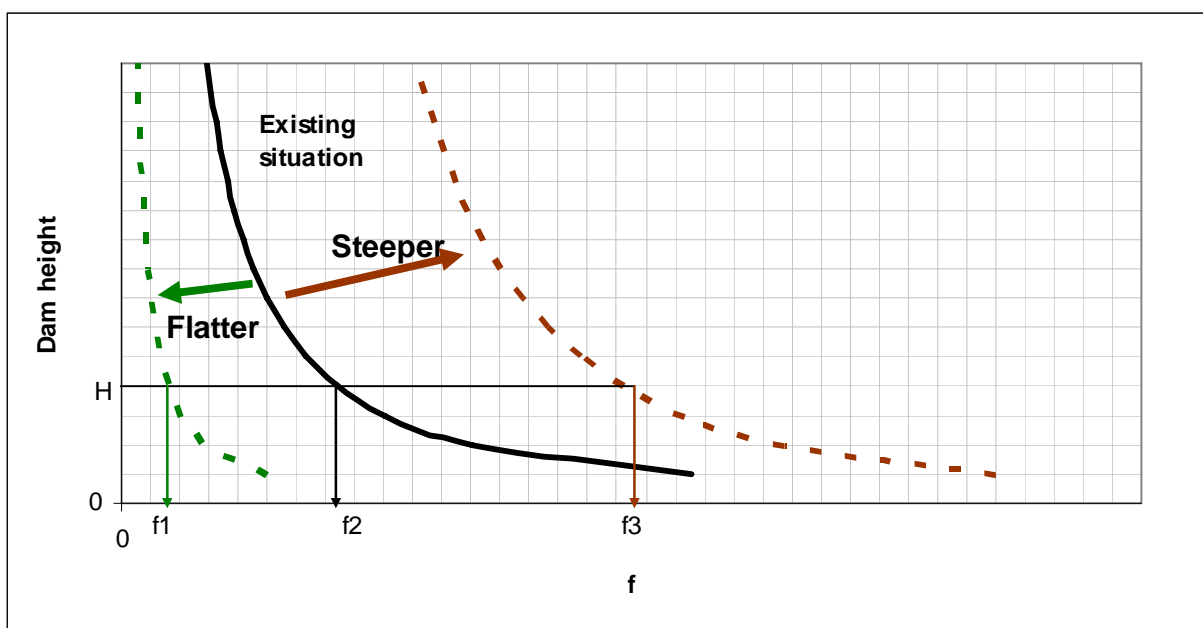
In addition, the followings points are clear:

- Topographical site index is an indicator which shows the topographical identification of dam sites according to flood defense measure.

- The gradient of H-f curves is negative that demonstrates the value of  $f$  decreases while dam height increases.
- The curve gradient is small in low dam height and  $f$  value changes rapidly. In higher height of dams,  $f$  value changes slowly and it can be said that the curve has one asymptote line.

The above theory was used to compare the different dam sites and flood control for the Erpe (153 km<sup>2</sup>) and Diemel (1800 km<sup>2</sup>) catchments. Four artificial topographies (named A, B, D and E) were selected by the study of flood parameter changes for the Erpe catchment (see section 5-6). These four topographies and the existing topography (called C) were examined to study the flood defense measures for the Erpe and Diemel catchments.

Figure 8-4 schematically shows the variation of H-f curve with topography for a dam site. The curve goes to right when the topography increases and it is inverse when the topography goes flat.



**Figure 8-4** Variation of topographical site index with topography changes

Six place were considered for decentral retarding dam on the Erpe catchment. The topographical site index was calculated for all sites and all five scenarios of topography. Safe flood discharge in the catchment mouth was fixed by HQ<sub>5</sub> in the Erpe scenarios. Therefore, the dams' height is changed to attain a safe discharge in downstream. The reservoir volume curves show that  $\frac{dH}{dV_r}$  (rate of changes of dam height to reservoir volume) is high in the low dam heights and it decreases by raising the height. Whenever the catchment is converted into flatter surface slopes, the curve lies and  $\frac{dH}{dV_r}$  decreases because of a decrease in river bank and longitudinal slopes. The curves of the topographical site index show the variation of flood retainer cost. In other words, the total cost of flood retarding dam become equal to the scalar product of  $f \cdot \phi \cdot \lambda \cdot V_r$ . The graphs show the variations of different sites according to their effects on the flood. An investigation on the information of sites in the Erpe catchment shows that an increase in the land surface slope causes a shift in the H-f curve to the right and as a result, the  $f$  value is raised. Thus, the dam's height rises to achieve full flood control. It is

converse for the decreasing land surface slope. This means that the f curve moves to the left by a decrease in the land surface slope, therefore f value is decreased, as well as dam height (figure 5-23). This also applies to decentral dams (figure 5-24). Central and decentral dams were compared by means of the topographical site index for all topographical scenarios of the Erpe catchment. The equivalent topographical site index was calculated for decentral dams and then compared with the central dam in each scenario (figure 5-26). As a result, the central dams are appropriate for all scenarios.

Ten sites have been selected on the Diemel catchment and were examined to build decentral dams (Figure 7-8 and also table 7-1). Five systems of the Diemel catchment containing four artificial catchments and the existing catchment were modeled by way of the described conditions. H-f curves were determined and investigated to compare decentral dams and central dam. The heights of the dams were taken as constant values in the different scenarios. Therefore, the catchment has been modeled. The value of topographical site index considered for all dams and scenarios (figure 7-21). So the comparisons of different sites are showing us the cost of flood retaining in every dam. For Diemel catchment sites No. 1, 2, 5, 12 are more expansive than others. According to the results, the flood defense cost by using the central and decentral dams in catchments with steep topographies is more expensive than flatter topographies (figure 7-22). The results showed that the maximum decreases of flood in cases in which the land surface slope increases. By close look at the curves, it can be understood that the cost of retarded flood varies in different sites.

The results show that the H-f curves are scattered on the sheet area in very steep catchments; conversely flat catchments and h-f curves are close together. In other words, the differences of dam sites are more important in steep catchments than in flat catchments.

## **8.6 Final Conclusion**

Catchment topography forms the flood wave shape and flood defense measures influence it. This research investigated the interaction between topography and flood parameters, as well as flood defense measures. The logical relation between catchment topography and flood defense measures have considered by using the contexts and also a sample catchment which modeled by the rainfall runoff model. The following outcomes are mentioned from this research:

- 1- Catchment area planning and management have been based on decreasing of runoff by means of increasing the infiltration, interception and surface storage. The effectiveness of flood defense measures, which lead to a reduction of runoff volume and velocity, has been increased by decreasing the land surface slope. In this way, land use has an effect on interception and also runoff water velocity. It is easy to manage them in agricultural land by using a suitable plants and agricultural operation.

- 2- The river parameters were considered which influence flow velocity (such as longitudinal river slope and river roughness), are more and more efficient in large catchments than small catchments. Maximum flood discharge and flood time to peak have an exponential relationship with catchment river network slope. The less slopes, the more effectiveness of flood retention in the river per unit slope changes. Whenever the catchment area is bigger, the flood retention in the rivers is more efficient. In other words, efficiency of river restoration methods which aims to reduce maximum flood discharge increases by an increase in catchment area. Main river slope in big catchments plays an important role to retaining water in low slope range.

3-The topographical site index has been presented in this research to evaluate the central and decentral flood retarding dams. It is the ratio of volume of dam body to reservoir volume. Topographical site index is an indicator which shows the topographical identification of dam which aims flood defense measure. The  $f$  value is only a function of topography. it has a power function with dam height. The H-f curves in steep topography are distant from each other whereas in flat topography they are close to each other. This means that according to the topography, site selection has more influence on flood defense cost in steep catchments than in flat catchments. So it shows that the site selection in mountainous catchments is very important.

H-f curves show us the topographical characteristics of flood retarding dams which creates an easy way for comparing and evaluating different scenarios.

## **8.7 Recommendations**

Recommendation for future steps of the relevant project could be:

- The ArcView program could utilize to calculate the topographical site index. So, an extension is defined in this program which calculates the index along the river or selected sites. So it is easy to compare different flood retarding sites.
- Optimization is important when there are more than one retarding dams in a catchment. The equivalent topographical site index could define as a target function for optimization. It shows the topography situations.
- The efficiency of catchments planning and management measures in different land surface slope can examined to observe the real experiences.
- The reservoir area could be considered with other parameters of retarding dams in future studies.

## References

1. Andjelkovic, Ivan, "Guidelines on non-structural measures in urban flood management", Technical Documents in Hydrology No. 50, UNESCO, Paris, 2001
2. Bauer, Christian, 2004, "Bestimmung der Retentionspotenziale naturnaher Massnahmen in Gewässer und Aue mit hydraulischen Methode", Kasseler Wasserbau Mitteilungen
3. Bauer, Christian, Frank Toensmann, 2000, "Retention increasing measures in the flood plains of the Lahn river", Proceeding of International Symposium on River Flood Defense, Kassel, Germany, 2000, pp. H-91-H-115
4. Bauer, Christian, Klaus Roettcher, Frank Toensmann, 2005, "The impact of near natural flood protection measures on the peak discharge in great catchment areas- example Lahn/Germany", "Floods, from Defense to management" Symposium Proceeding of the 3<sup>rd</sup> International Symposium on Flood defense, Taylor and Francis Group, London, p 753-761
5. Brath, A., A. Montanari, 2003, "sensitivity of the peak flows to the spatial variability of the soil infiltration capacity for different climatic scenarios", physics and chemistry of the earth, Elsevier Science Ltd,
6. Brilly, Mitja, 1992, "Flood protection on headwater streams, In Floods and floods management", edited by A. J. Saul, Kluwer Academic Publishers, Dordrecht, Netherland
7. Britanica encyclopedia, <http://www.britanica.com>
8. Bridge, John, 2003, "River and flood plains, form, processes and sedimentary record"; Blackwell Science Publishing, UK
9. Brooks andrew; F. Douglas Shields JR, 1996, "River channel restoration, Guiding principles for sustainable projects"; Edited by Andrew Brooks and F. Douglas Shields JR, John Willy & Sons, NewYork
10. Chow, Ven Te, 1959, "Open channel hydraulics, Mc Graw Hill Civil Engineering Series", Mc Graw Hill book company, New York
11. Chow Ven Te, 1966, Handbook of applied hydrology, Mc Graw Hill Civil Engineering Series, Mc Graw Hill book company, New York
12. Clark, Michael J., 1998, "Putting water in its place: a perspective on GIS in hydrology and water management", Hydrological processes, Vol 12, P 823-834
13. De Roo, A., et al, 2003, "The influence of historic land use changes and future planned land use scenarios on floods in the Oder catchment", physics and chemistry of the earth, Elsevier Science Ltd,
14. DIN (Deutsches Institut für Normung), 19700, Teil 12 , 2004-07, „Hochwasserrückhaltebecken“, Berlin und Köln
15. DVWK (Deutscher Verband für Wasserwirtschaft und Kulturbau), 1999, „Einflüsse Land- und forstwirtschaftlicher Massnahmen auf den Hochwasserabfluß- Wissensstand“, Skalenprobleme, Modellansätze, Materialien 7/1999, Bonn
16. DTLR (Department of Transport Local Government Region); Feb. 2002, "Preparing for floods", Department of transport local government region, London
17. Environmental Agency, "Audit of flood risk management and spatial planning institutional framework", Report of Environmental Agency of UK, March 2004, London

18. Falkenhagen, Bettina, 2005 „Zürs das Zonierungssystem der deutschen Versicherungswirtschaft zur Einschätzung der Überschwemmungsgefährdung“, Hans-B. Kleeberg (Herausgeber), Forum für Hydrologie und Wasserbewirtschaftung, Heft 08.05, Hennef
19. Fergusen, Bruce K.,1994, “Storm water infiltration”, CRC press, USA, pages 269
20. Hessisches Landesamt für Umwelt und Geologie, 1999, Umweltatlas Hessen, <http://atlas.umwelt.hessen.de>
21. Hessische Minister für Landwirtschaft und Umwelt Wiesbaden, 1972, „Ausbau der Diemel, Regelung der Abflußverhältnisse im Niederschlagsgebiet“, Hessischer Minister für Landwirtschaft und Umwelt Wiesbaden und Wasserwirtschaftamt Kassel.
22. Hessischer Wasserverband Diemel, 2004, „Studie Zum Hochwasserschutz an Warme und Erpe“, Hessischer Wasserverband Diemel, Oktober 2004, Kassel
23. Hydrotec, 2002, „Niederschlag-Abfluss-Modell NASIM“, Version 3.1.0, Hydrotec Gesellschaft für Wasser und Umwelt mbH, Aachen
24. ICOLD (International Commission on Large Dams), 2003, “Dams and floods”, Bulletin 125. ICOLD, Paris
25. ICOLD (International Commission On Large Dams), 1983, “Operation of hydraulic structures of dams”, Bulletin 49, ICOLD, Paris
26. Informationsbroschüre zur Hochwassergefahr der Fulda in Rotenburg, Rotenburg a. d. Fulda, März 2003
27. Issar, Arie, Sol D. Resnick,1996, “Runoff, infiltration and subsurface flow of water in arid and semi-arid regions”, Kluwer Academic Publishers, pages 181
28. Kraijenhof, D.A., J.R. Moll, “River flow modeling and forecasting”, 1986, Reidel Publishing Company , Dordrecht, Holland
29. LAWA (Länderarbeitsgemeinschaft Wasser), “Guidelines for forward-looking flood protection”, German Working Group on Water Issues of the Federal State of Germany, Environmental Ministry , Baden-Württemberg, 1995
30. LAWA (Länderarbeitsgemeinschaft Wasser), „Instrumente und Handlungsempfehlungen zur Umsetzung der Leitlinien für einen zukunftsweisenden Hochwasserschutz“, Länderarbeitsgemeinschaft Wasser, Düsseldorf, 2004
31. Linsley, R. K., Joseph B. Franzini, David L. Freyberg, George Tchobanoglous, “Water resources engineering , fourth edition”, Mc Graw-Hill, 1992, New York
32. Mendiondo, E. Mario, Robin T Clarke, Frank Toensmann, 2000, “River restoration discharge uncertainties and floods”, Proceeding of International Symposium on River Flood Defence, Kassel, Germany, 2000, pp. G-179 – G-188
33. Oosthoek, Jan, 2008, “Dutch river defences in historical perspective”, Environmental History Resources, <http://www.eh-resources.org>
34. Philip J.R., 1991, “Hill slope infiltration: planar slopes”, Water Resources Research, 27, 1035-1040
35. Planen und Bauen von Gebäuden in hochwassergefährdeten Gebieten Hochwasserschutzfibel, 2002

36. Plessis LA du, MF Viljoen, “Determining the benefits of flood mitigation measures in the lower Orange River: A GIS application”, *Water SA*, Vol 25, No 2, April 1999, pp. 205-241
37. RBC, “River Basin Commission Weser”, <http://www.weserflus.de>
38. Roettcher, Klaus, 2001, „Hochwasserschutz für kleine Einzugsgebiete im Mittelgebirge am Beispiel der Bauna“, *Kasseler Wasserbau Mitteilungen*, Heft 11/2001
39. Roettcher, Klaus, Frank Toensmann, 2000, “Highlighting the potentialities and limitations of decentralize a flood defense approach by the example of the case study Bauna”, *Proceeding of the International Symposium on River Flood Defence*, Kassel, Germany, 2000, pp. I-31-I-41
40. Roettcher, Klaus, Frank Toensmann, 2005, “Environmental friendly flood protection for the catchment areas of the Diemel and Diemel Rivers”, *Symposium Proceeding of the 3<sup>rd</sup> International Symposium on Flood defense*, Taylor and Francis Group, London, p 929-933
41. Rosgen, Dave, 1996, “Applied river morphology”; Hillton Lee Silvey, United State of America
42. Schmidt, Martin, “Flood and flood protection in Germany 850-1850”, *Proceeding of International River Flood Defence Conference*, Kassel, Germany, 2000, pp B37 – B42
43. Singh, Vijay P, Donald K, 2006, “Frevert Watershed models”, Taylor and Francis Group
44. Smith, Keith, Roy Ward, 1998, “Flood physical processes and human impacts”, John Wiley and Sons, England
45. Sobirey, Axel, Frank Toensmann, 2000, “The influence of river morphology on water level computations of low mountain range brooks during flood events”, *Proceeding of the International Symposium on River Flood Defense*, Kassel, Germany, 2000, pp. F-201-F-212
46. Toensmann, Frank, 2000, “The Kassel concept for river flood defense”, *Proceeding of the International Symposium on River Flood Defense*, Kassel, Germany, 2000, pp. G-245 – G-260
47. Toensmann, Frank, Bernhard Kuehne, Klaus Roettcher, 2000, “Environmentally sound flood defense in Northern Hesse: A worldwide project of the World Exhibition in Hannover (Expo 2000)”, *Proceeding of the International Symposium on River Flood Defense*, Kassel, Germany, 2000, pp. I-1-I-16
48. United Nations, “Guidelines for reducing flood losses”, United Nation, Second edition April 2004
49. Vis, M., F. Klijn, M. van Buuren, “Living with floods, resilience strategies for flood risk management and multiple land use in the lower Rhine river basin”, NCR publication, 2001
50. Wikipedia, the free encyclopedia, “online encyclopedia”, <http://wikipedia.org>
51. Stokkom, H.T.C van, A.J.M Smits, 2002, “Flood defense in the Netherlands: a new era, a new approach”, *Proceeding of Flood Defence Conference 2002*
52. Weingartner, R.; M. Barben, M. Spreafico; 2003; “Floods in Mountain areas – an overview based on examples from Switzerland”; *Journal of hydrology*, 282, p 10-24

## Publikationen des Fachgebietes Wasserbau und Wasserwirtschaft

### Reihe: Kasseler Wasserbau - Mitteilungen

Heft 1/1993 Tönsmann, F. (Hg.)	Wasserkraftnutzung mit Niederdruck- anlagen	vergriffen
Heft 2/1995 Tönsmann, F. (Hg.)	Hochwasserschutz	vergriffen
Heft 3/1995 Hoffmann, A. (Hg.)	Antike und mittelalterliche Wasserver- sorgung in Mitteleuropa	
Heft 4/1995 Tönsmann, F. (Hg.)	Zur Geschichte der Wasserstraßen insbesondere in Nordhessen	vergriffen
Heft 5/2005 Hoffmann, A.	Hessische Lebensbilder zur Kulturgeschichte des Wassers – Ein biografisches Handbuch 1350 - 1950	
Heft 6/1996 Tönsmann, F. (Hg.)	Sanierung und Renaturierung von Fließ- gewässern - Grundlagen und Praxis	
Heft 7/1996 Tönsmann, F. (Hg.)	Geschichte der Wasserkraftnutzung	vergriffen
Heft 8/1999 Marburger, M.	Entwicklung eines tiefengemittelten morpho- dynamischen Fließgewässermodells – ein Beitrag zur zweidimensionalen numerischen Simulation bettbildender Prozesse	
Heft 9/2000 Tönsmann, F. und M. Koch (Hg.)	River Flood Defence	
Heft 10/2000 Rösch, T.	Modell zur Regulierung des Sauerstoffhaus- haltes in Fließgewässern durch Wasserkraft- anlagen	

Heft 11/2001 Röttcher, K.	Hochwasserschutz für kleine Einzugsgebiete im Mittelgebirge am Beispiel der Bauna
Heft 12/2001 Hoffmann, A. (Hg.)	Wasserwirtschaft im Wandel Festschrift zum 60. Geburtstag von Frank Tönsmann
Heft 13/2002 Flörke, M	Bestimmung effektiver hydraulischer Parameter in heterogenen porösen Medien
Heft 14/2004 Tönsmann, F. und Kasimierz Banasik	Integrierte Wasserbewirtschaftung
Heft 15/2004 Hoffmann A., und Achim Richter	Wasser für Kassel – zur Geschichte der Wasser- versorgung der Stadt und ihrer Region
Heft 16/2004 Bauer C.	Bestimmung der Retentionspotenziale naturnaher Maßnahmen in Gewässer und Aue mit hydraulischen Methoden
Heft 17/2009 Weiß, A.	Beitrag unterschiedlicher Bodenbearbeitungsverfahren und Bewirtschaftungsformen der Landwirtschaft zur Re- duzierung des Hochwasserabflusses

## Reihe: Forschungsberichte und Materialien

(ab 2005 nicht mehr fortgeführt)

Band 1/1993 Tönsmann, F. (Hg.)	Hochwasserschutz im Lossetal - Vergleichende Umweltverträglichkeits- untersuchung (Kurzfassung)	vergriffen
Band 2/1994 Scheffler, M.	Sauerstoffeintrag in Wasserkraftanlagen am Beispiel der Twistesee-Anlage	vergriffen
Band 3/1995 Tönsmann, F. (Hg.)	Studie zum Hochwasserschutz an der Bauna (Kurzfassung)	vergriffen
Band 4/1995 Röttcher, K.	Der Kanal des Landgrafen Karl in topo- graphischen Karten	vergriffen
Band 5/1996 Schmidt, Th. und F. Tönsmann	Rahmenplan eines gebietsbezogenen Re- naturierungskonzeptes für die Losse (Kurzfassung)	vergriffen
Band 6/1997 Rösch, Th. und F. Tönsmann	Sauerstoffanreicherung in Wasserkraftan- lagen unter ökologischen und ökonomischen Gesichtspunkten – Verfahrensweise und Empfehlungen (inkl. Diskette mit Meßdaten)	
Band 7/2000 Röttcher, K., J. Tondera und F. Tönsmann	Der Kanal des Landgrafen Karl	vergriffen
Band 8/1999 Röttcher, K. und F. Tönsmann	Umsetzung dezentraler Hochwasserschutz- maßnahmen am Beispiel der Bauna (incl. CD mit Klimadaten)	vergriffen
Band 9/1999 Lang, T., F. Tönsmann	Vorbeugender Hochwasserschutz im Einzugs- Gebiet der hessischen Lahn	
Band 10/2000 Sauerwein, B. und F. Tönsmann	Umweltgerechte Reaktivierung der Wasserkraft- kaskade an der Mahlgera	vergriffen
Band 11/2000 F. Tönsmann (Hg.)	Vorbeugender Hochwasserschutz im Einzugs- gebiet der hessischen Lahn, Lahnkonferenz am 20.09.2000	

Band 12/2000 Tönsmann, F. und M. Koch (Hg.)	Internationales Symposium Hochwasserschutz, Beiträge des Fachgebietes Wasserbau und Wasserwirtschaft der Universität Gh Kassel	vergriffen
Band 13/2000 Tönsmann, F. and M. Koch (Eds.)	International Symposium on Flood Defence, Papers of the Department of Hydraulic and Water-Resources Engineering, University of Kassel, in English language	
Band 14/2001 Sobirey, Axel	Schwebstoffmessungen zur Prognose morpho- logischer Änderungen in einem Mittelgebirgs- fliessgewässer	
Band 15/2002 Hoffmann, A.	Wasser zum Waschen und Baden, die sanitäre Bedeutung des Wassers im Wandel der Zeit, Tagungsband zum 9. Kasseler Technikgeschicht- lichen Kolloquium im Juli 2001	
Band 17/2002 Lang, T. und F. Tönsmann	Vorbeugender Hochwasserschutz im Einzugs- gebiet der hessischen Lahn, Handbuch *)	
Band 18/2003 Hoffmann, A.	Gezähmte Flüsse – besiegte Natur, Gewässerkultur in Geschichte und Gegenwart. Tagungsband zum 10. Kasseler Technikgeschichtlichen Kolloquium im Juli 2002	
Bestellungen an:	Kassel University Press Diagonale 10 34127 Kassel Tel.: (0561)804-2159 Fax: (0561)804-3429 E-Mail: <a href="mailto:geschaeftsfuehrung@upress.uni-kassel.de">geschaeftsfuehrung@upress.uni-kassel.de</a>	

\*) der Band 17 wird nicht im Buchhandel vertrieben. Kostenlose Exemplare können beim Regierungspräsidium Gießen, Dezernat II 31.3, Landgraf-Philipp-Platz 3-7, 35390 Gießen, angefordert werden.