Journal of River Engineering
Volume 1, Issue 1, 2013
http://www.scijour.com
SCIJOUE

Importance of Flood Severity Estimation for Flood Plain Management in a River Valley

Saqib Ehsan[1,*], Walter Marx[2] and Silke Wieprecht[3]

[1]Head Civil Engineering Department, NFC- Institute of Engineering & Fertilizer Research (IEFR), Faisalabad, Pakistan
[2]Ex-Deputy Director, Department of Hydraulic Engineering and Water Resources Management, Institute for Modeling Hydraulic and Environmental Systems, Universitaet Stuttgart, Stuttgart, Germany.
[3]Head (Department of Hydraulic Engineering and Water Resources Management), Institute for Modeling Hydraulic and Environmental Systems, Universitaet Stuttgart, Stuttgart, Germany.

ABSTRACT

Climate changes strongly affect the occurrence of floods. Extreme flooding can occur due to dam failure but sometimes high outflows that exceed the downstream safe channel capacity can also cause significant flooding. This paper emphasizes the importance of flood severity estimation in a river valley for long-term flood plain management. For hydraulic analysis, about 329 km long, the Jhelum river valley downstream of Mangla dam in Pakistan has been considered. The project reach has been modeled for unsteady flow conditions with MIKE 11 (1D). The flood severity has been computed downstream of the dam for different flooding scenarios by various flood severity criteria and the results have also been compared. The information about flood severity at downstream river locations plays a very important role in dealing with flood risk assessment and damage estimation. This study is intended to provide useful guidelines for the realistic estimation of flood severity in a river valley.

KEYWORDS

Extreme flooding, flood severity, Jhelum river valley, Flood plain management, MIKE 11

INTRODUCTION

The risk of flooding has always been a crucial issue in flood control projects. Especially in a river valley downstream of a dam, the flooding risk is seen more and more critical for safe flood plain management. Severe weather changes with extreme rainfall can cause catastrophic flooding downstream of a dam as a result of dam failure or very high outflows even with the dam remaining intact. In this study, the flooding risk for the Jhelum river valley downstream of Mangla dam in Pakistan has been analyzed. With a height of about 125 m above riverbed, Mangla dam is one of the largest earth and rock-fill dams in the world. The crest length of the main dam is about 2561 m [11]. The original catchment area of the reservoir is about 33360 km^2 and the water surface area (at normal operating conditions) is about 253 km^2 [10]. The project reach downstream of Mangla dam is about 329 km long with different hydraulic structures as shown in Fig. 1. Based on GIS and other official data, one dimensional modeling for unsteady flow conditions has been carried out by using MIKE 11 (1D). Different available flood severity criteria following the specific flood severity definitions have been discussed. The results of flood severity downstream of Mangla dam by various available criteria have been compared for different flooding scenarios (with and without dam failure).

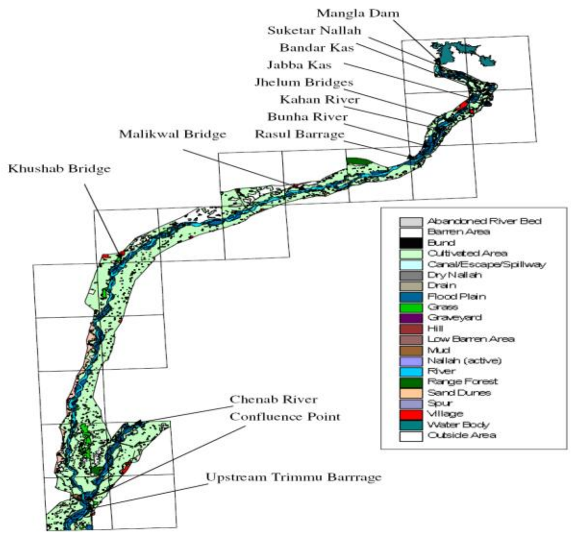


Fig. 1. Jhelum river valley downstream of Mangla dam

*Corresponding Author: Dr. Saqib Ehsan
E-mail: Saqib.Ehsan@gmail.com
Telephone Number: +92-41-9220355 Fax. Number : +92-41-9220360

Flood severity does not depend only on one parameter. Different important parameters such as flood discharge, flood velocity, flood depth, flood width and safe channel capacity directly influence the flood severity computation [3].

FLOOD SEVERITY DEFINITIONS

There are different criteria available for flood severity computation depending mainly on maximum discharge, safe channel capacity, flood width, flood depth and flood velocity. They are based on specific flood severity definitions depending on the expected damage to buildings and life loss. There are mainly two flood severity definitions available in the literature following the specific criteria. In the following, these two flood severity definitions have been discussed. (Tab. 1) [2], [4], [7]

Tab. 1: Flood Severity Definitions

Definition 1	Definition 2
High severity: total or major damage to buildings	High severity: clean sweep of area and little or no evidence of prior human and habitation remaining (rare type of flooding like e.g. Vajont dam, Italy)
Medium severity: partial or moderate structural damage, little damage to the major elements of buildings	Medium severity: destruction of houses but still trees and mangled homes remain for refuge
Low severity: inundation and no damage to structures	Low severity: no buildings are washed off their foundations

FLOOD SEVERITY CRITERIA

There are different criteria available for flood severity computation with respect to the flood severity definitions. In the following, different flood severity criteria have been mentioned.

A) vh- criterion for flood severity (definition 1)

This criterion is based on the definition 1 of flood severity (Tab. 1). Its thresholds for different categories of flood severity are given by (Eqs. 1 and 2). [2], [5], [7], [8], [9]

If $vh \geq 7$ (m^2/s) then high flood severity, (1)

where,
v = Average flow velocity of the flood water (m/s)
h = flood depth (structures are exposed to) (m)

if $7 > vh \geq 3$ (m^2/s) then medium flood severity, (2)
otherwise low severity.

The above mentioned *vh*- thresholds are applicable to materials that are mostly used in buildings such as concrete, brick and masonry.

B) DV- criterion for flood severity (definition 2)

This criterion follows the definition 2 (Tab. 1). The available thresholds are incomplete. They are defined in the literature only for medium and low flood severity [4]. There is no threshold available for high flood severity. As no specific building type is mentioned in the literature [4], the following criteria are assumed to be applicable to all common types of buildings.

if $DV > 4.6$ (m^2/s) then medium flood severity, (3)
otherwise low severity.
where,

$$DV = \frac{(Q_{df} - Q_{safe})}{W_{df}} \text{ (m}^2\text{/s)} \qquad (4)$$

where
Q_{df} = discharge at a particular site caused by dam failure (m^3/s)
Q_{safe} = mean annual discharge or safe channel capacity at the same site (m^3/s)
W_{df} = maximum width of flooding caused by dam failure at the same site (m)

C) h-criterion for flood severity (definition 2)

There is also another criterion for definition 2 (Tab. 1) depending on flood depth (h). This criterion is also incomplete as it gives thresholds only for medium and low flood severity. [4]

if $h \geq 10$ ft then medium flood severity, (5)
otherwise low severity.

D) An improved criterion (GA) for flood severity (definition 1)

It is quite obvious that the available criteria by the definition 2 (Tab. 1) are incomplete as they provide thresholds for only medium and low severity categories. The definition 1 is very common in literature and mostly used for flood severity computation. For having more reliable and realistic results, an improved criterion (*GA*) for flood severity computation with respect to the definition 1 has been developed by the main author with thorough consideration of the other available criteria and it includes necessary parameters responsible for flood severity at a river location. This new criterion has been developed by the geometric aggregation of *vh* and DV'', where *vh*-thresholds are the same as mentioned above for different categories (definition 1) and new *DV*-thresholds have been derived for the definition 1 in terms of DV'' for different flood severity categories. The general form of the geometric aggregate (*GA*) in this case is given by (Eq. 6), [3]

Journal of River Engineering
Volume 1, Issue 1, 2013
http://www.scijour.com
SCIJOUE

$$GA\ (\mathrm{m^2/s}) = vh^{w_1}DV^{w_2} \text{ with } \sum w = 1 \quad (6)$$

Collectively, the thresholds of geometric aggregate (*GA*) for different flood severity categories with respect to the definition 1 (Tab. 1) can be shown as under, [3]

$$GA\ (\mathrm{m^2/s}) = 7^{0.65} \times 4.6^{0.35} \quad \text{for high/medium flood severity} \quad (7)$$

$$GA\ (\mathrm{m^2/s}) = 3^{0.65} \times 1.97^{0.35} \quad \text{for medium/low flood severity} \quad (8)$$

It should be noted that these suggested weights are not fixed for the future. They might change for different cases depending on specific data/information available by that time. Above thresholds are considered to be applicable to commonly used materials such as concrete, brick and masonry.

FLOOD SEVERITY COMPUTATION DOWNSTREAM OF MANGLA DAM

A) 1D-Hydrodynamic Modeling

According to available GIS and other official data, one dimensional modeling for unsteady flow conditions has been carried out by using the model MIKE 11 (1D). For all modeling scenarios, the upstream and downstream boundary conditions are an outflow hydrograph at Mangla dam and respectively the water levels upstream of Trimmu barrage as shown in Fig. 1. One dimensional flood routing in MIKE 11 is based on an implicit finite difference scheme developed by [1]. The basic equations are derived considering the conservation of mass and conservation of momentum [6]. After calibration and validation, the model has been run for different flooding scenarios with and without dam failure.

Regarding the hydraulic situation in the valley downstream of Mangla dam, two cases of bridges have been considered for the unsteady flow simulation of all flooding scenarios. In the first case, the model has been run with the existing bridges at different locations downstream of the dam, whereas in the second case model runs were made without bridges assuming that the bridges might have been washed off due to extreme flooding.

Fig. 2 shows maximum discharges at downstream locations after dam break flood routing (with and without bridges). The maximum outflow for the worst case of dam failure is more than 300,000 m^3/s which could be the highest possible discharge after the failure of Mangla dam. In all scenarios the maximum discharge decreases along the reach due to retention of upstream hydrograph with respect to the shape of cross-sections. The overall flooding downstream of the dam is more in the case of no bridges. In the first case (with bridges), there is local impoundment upstream of bridges which reduces the maximum discharge for the whole downstream reach. But in the other case (without bridges) water flows down faster and spreads more over the flood plains in order to increase the overall flooding.

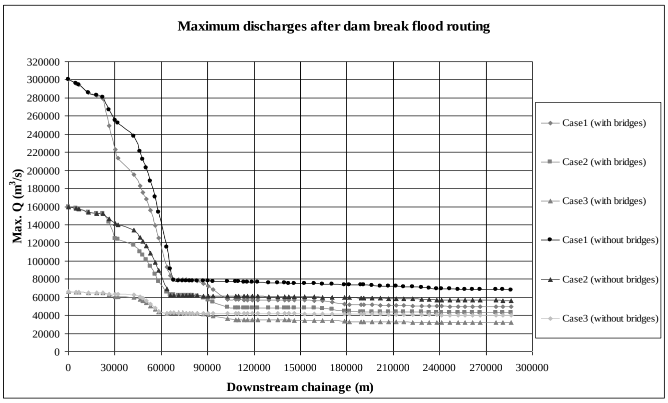


Fig. 2. Maximum discharges after dam break flood routing

The results of maximum water levels after dam break flood routing are shown in Fig. 3. In all cases, the water levels upstream of Rasul barrage are higher than the water levels downstream of Rasul barrage due to possible impoundment upstream of Rasul barrage. For the case of bridges, the maximum water level are higher than the water levels computed in the other case (without bridges) only for the locations upstream of bridges due to local impoundment. For all other river locations the maximum water levels are higher in the case of no bridges due to more inundation.

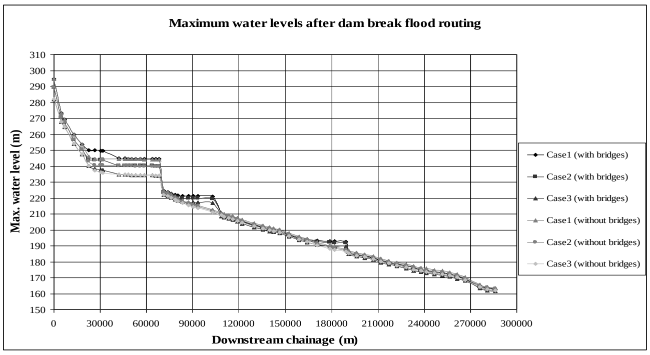


Fig. 3. Maximum water levels after dam break flood routing

The flood severity downstream of Mangla dam has been computed for different flooding scenarios (with and without dam failure) by using the respective flood routing results of unsteady flow simulations.

B) Safe discharge and Safe water level

For flood severity estimation, the safe discharge capacity and safe water level for Jhelum river downstream of Mangla dam have also been computed as shown in Figs. 4 and 5. It has been done by running several steady flow simulations and analyzing the change in water levels at downstream cross-sections with respect to the location of flood plains and establishments shown in the available GIS maps. The parameters can also be referred to as bank full discharge and bank full water level (related to bank full depth).

Journal of River Engineering
Volume 1, Issue 1, 2013
http://www.scijour.com
SCIJOUE

Safe discharge capacity of a river cross-section is related to its size and shape and it shows the ability of a cross-section to carry a specific amount of discharge without overbank flooding. For this study, the safe discharge capacity has been estimated at each downstream cross-section. As shown in Fig. 4, there are significant changes in the safe discharge capacity at some downstream locations. According to the available cross-section data, this is due to the change in the bank full area of respective cross-sections with respect to the change in their overall shape and hydraulic conditions. For all flooding scenarios, the safe water levels (Fig. 5) have been used for the calculation of flood depth (*h*) with respect the computed water levels.

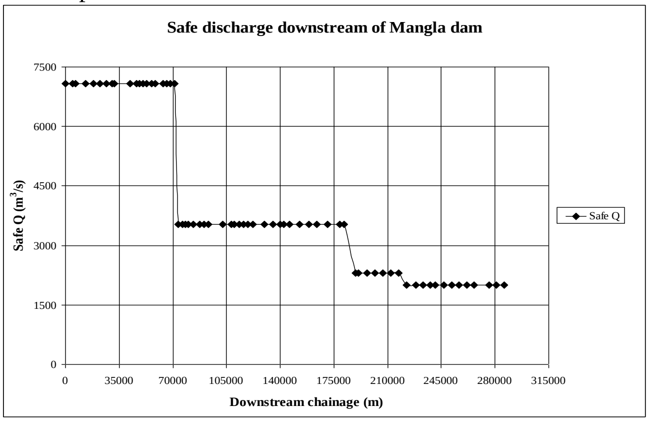


Fig. 4. Safe discharge downstream of Mangla dam

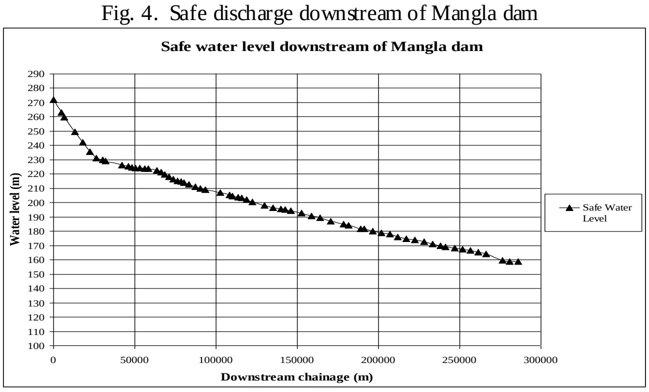


Fig. 5. Safe water level downstream of Mangla dam

RESULTS OF FLOOD SEVERITY

By analyzing the flood routing results, the flood severity has been computed at locations downstream of Mangla dam for different flooding scenarios according to the above mentioned criteria. The results of flood severity have been illustrated as points representing the downstream locations (cross-sections) with different colours for different flood severity categories (high, medium & low). The flood severity at a downstream river location depends on hydraulic conditions (*Q*, *v*, *h* etc.) as well as the cross-sectional shape. In Fig. 6, the results of flood severity have been shown for different flooding scenarios (with & without dam failure) according to the *vh*-criterion.

The *vh*-criterion (definition 1) describes all flood severity categories (high, medium and low) (Fig. 6). It is obvious that overall flood severity increases with the increase in flooding. For dam break scenarios, the overall flood severity is quite higher as compared to other scenarios (without dam break) and there is no low severity at any location downstream of the dam. In all scenarios, the flood severity is higher in the upper part of the downstream reach and then it decreases. But at few locations in the lower part of the downstream reach the flood severity increases due to change in typical cross-sectional shape. Fig. 7 shows the flood severity according to the *DV*-criterion (definition 2) at different downstream locations. The flood severity criteria (definition 2) are incomplete because they give flood severity only for medium and low categories. The results of flood severity by both criteria (*DV* and *vh*) are quite different from each other.

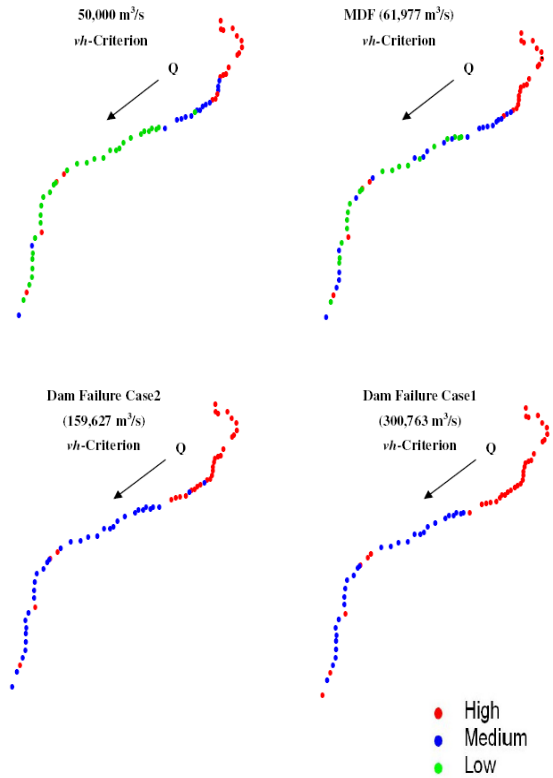
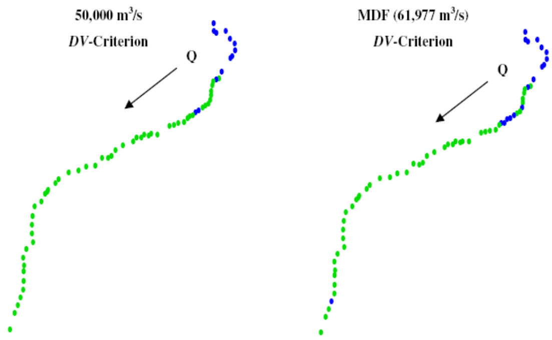


Fig. 6. Flood severity downstream of Mangla dam
(*vh*-criterion: with bridges)



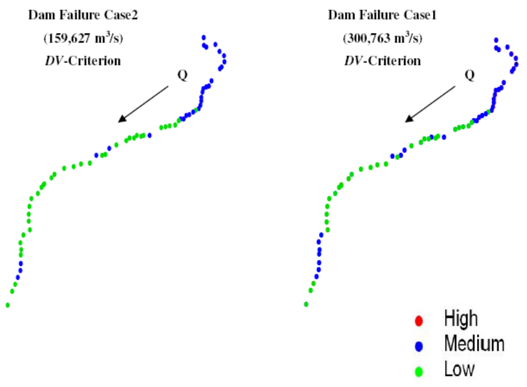


Fig. 7. Flood severity downstream of Mangla dam
(*DV*-criterion: with bridges)

As discussed earlier, the involvement of all necessary parameters (flood discharge, flood velocity, flood depth, flood width and safe channel capacity) in flood severity computation is very important for having more realistic results. For this purpose, the flood severity at downstream locations has also been computed for different flooding scenarios according to the recently developed *GA*-criterion (definition 1) as shown in Fig. 8. The results of flood severity have been computed for all severity categories (high, medium & low) as in the case of *vh*-criterion (definition 1) (Fig. 6).

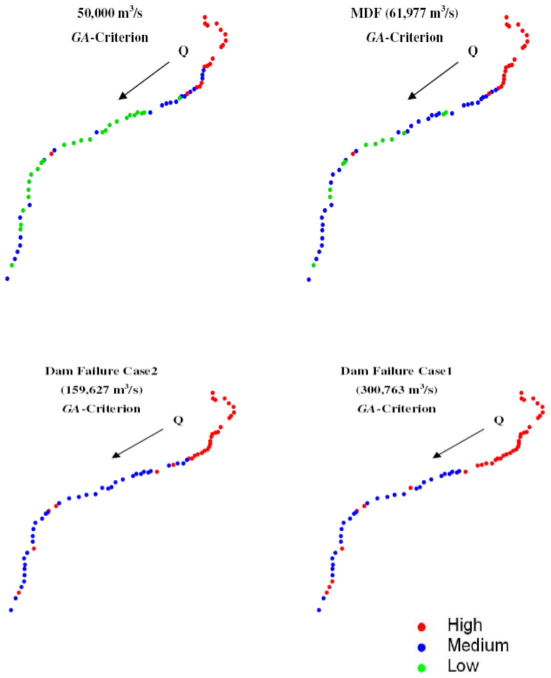


Fig. 8. Flood severity downstream of Mangla dam
(GA-criterion: with bridges)

The flood severity results by the *GA*-criterion (definition 1) are not comparable to the results by the *DV*-criterion (definition 2). As the *DV*-criterion gives the flood severity only for medium and low severity categories (Fig. 7). On the other hand, the results by the *vh*-criterion (Fig. 6) can be compared with the flood severity results by the *GA*-criterion (Fig. 8). For flooding scenarios (without dam break), there are differences in the flood severity results by both criteria (*GA* and *vh*) mainly in the lower part of the downstream reach. Further for dam break scenarios, there are also few differences. As the *GA*-criterion includes all key parameters and shows the flood severity with their combined effect. So the results of flood severity by the *GA*-criterion (Fig. 8) for downstream river locations are considered to be more reliable as compared to the results by other criteria.

CONCLUSIONS

The computation of flood severity in a river valley plays a very important role in flood safety management. The meaningful and realistic estimation of flood severity requires the involvement of all necessary parameters such as flood depth, flood velocity, flood discharge, flood width and safe channel capacity etc. Flood severity does not depend only on one parameter. Different available criteria of flood severity with respect to the specific flood severity definitions have been considered. It was found that some criteria do not include all important parameters in flood severity computation. The available criteria by the definition 2 are incomplete as they provide no threshold for high severity. Moreover, the definition 2 seems to be more extreme in terms of flood severity categorization in comparison to the definition 1. The definition 1 is very common in literature and mostly used for flood severity computation. The flood severity for the Jhelum river valley downstream of Mangla dam has been computed according to the available criteria by both definitions for different flooding scenarios (with & without dam break). By comparing the results, it was found that overall flood severity increases with the increase in flooding. Further, the overall flood severity is significantly higher for dam break scenarios as compared to the flood severity in other scenarios. The GA-criterion (definition 1) includes all essential parameters in flood severity computation and shows their combined effect in the results. So the results of flood severity according to the GA-criterion (definition 1) for different flooding scenarios of the Jhelum river valley are considered to be more realistic and reliable. Finally, it is concluded that the GA-criterion (definition 1) should be used for the flood risk assessment of other river valleys in the world.

ACKNOWLEDGEMENTS

Authors would like to acknowledge the support of respective authorities in Pakistan, mainly Water and Power Development Authority (WAPDA) and National Engineering Services Pakistan (Pvt.) Ltd. (NESPAK) for providing the necessary data of Mangla dam and Jhelum river valley. Further, the continuous technical support provided by the Institute for Modeling Hydraulic and Environmental Systems, Universitaet Stuttgart, Germany is also highly appreciated.

REFERENCES

[1] ***Abbott, M.B. and Ionescu, F***. *On the numerical computation of nearly-horizontal flows, Journal of Hydraulic Research, 1967, Vol. 5, PP. 97-117.*

[2] ***Clausen, L. and Clark, P.B.*** *The development of criteria for predicting dam-break flood damages using modeling of historical dam failures, International Conference on River Flood Hydraulics, edited by W. R. White. 17. - 20. September, 1990, John Wiley and Sons Ltd. Hydraulics Research Limited,1990, PP. 369-380.*

[3] ***Ehsan S.*** *Evaluation of Life Safety Risks Related to Severe Flooding; Institute of Hydraulic Engineering, Universität Stuttgart, Germany: 2009, Vol. 180, ISBN: 978-3-933761-84-2.*

[4] ***Graham, W.J.*** *A procedure for estimating loss of life caused by dam failure (DSO-99-06), U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado, 1999.*

[5] ***Kelman, I.*** *Physical flood vulnerability of residential properties in coastal Eastern England., Ph.D. Dissertation, University of Cambridge, U.K. 2002.*

[6] ***Reference Manual MIKE 11***. *A modeling system for rivers and channels; 2004.*

[7] ***RESCDAM***. *The use of physical models in dam break flood analysis, Final report of Helsinki University of Technology, 2000.*

[8] ***Reiter, P.*** *Loss of life caused by dam failure, the RESCDAM LOL Method and its application to Kyrkösjärvi dam in Seinäjoki, Summary of the final report by PR Vesisuunnittelu Oy PR Water Consulting Ltd., 2001.*

[9] ***Reiter, P.*** *International methods of risk analysis, damage evaluation and social impact studies concerning dam-break accidents, International Seminar on the RESCDAM project, Seinäjoki, PR Vesisuunnittelu Oy PR Water Consulting Ltd., 2000.*

[10] ***WAPDA*** *Mangla Dam Raising Project, Feasibility Study Report Volume I: Main Report; Pakistan: 2001.*

[11] ***WAPDA*** *Mangla Dam Raising Project, Tender design Report Volume I: Section 3, Embankment Dams; Pakistan: 2004.*