Flood loss asssessment of the 2003 Muda River flood

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ABSTRACT
Muda River in Malaysia has been for many years experiencing seasonal floods and causing serious damage and economical loss to human settlements and property in the Muda basin. The 2003 flood was the most devastating event throughout the history of the river with a peak discharge of 1,340 m^3/s. It caused one of the most devastating losses to the national economy and necessitated hazard assessment studies to support decision-making policies in the future development of the Muda basin. Assessment of the extent of flooding, flood losses and resultant needs of the affected communities is essential for flood relief coordination. Estimated by economical loss in Malaysian Ringgits, the damage of the 2003 flood (RM 27.6 million) was seven times than that of the last flood (1982) in a 20-year-period (RM 3.87 million).

Keywords: Flood hazard; Flood loss; GIS; Flood risk; Muda River.

1 Introduction

In the Muda River, Kedah State, Peninsular Malaysia, the appearance of hazardous conditions to the community is mainly connected to the probability of the flooding catastrophe as a result of poor land use management decisions that were made earlier. Flooding in Muda River is a recurrent event. The catastrophic floods threatens human life, thus its prevention through formalized prediction is a necessary element of safe and sustainable development of the Muda basin in the future. In addition, the historical floods of the Muda River need to be qualitatively characterized and quantitatively described in terms of spatial and temporal contexts to predict future consequences, assess flood risk and support decision-making to reduce the risk to an acceptable level up to the design return period of 50 years as required by the Malaysian Department of Irrigation and Drainage Malaysia (DID)'s River Management Manual (DID, 2009).

The spatial extension of recent flood events can now be accurately determined by remote sensing imagery. When flood extents are calculated for specific return periods, flood depths can also easily be calculated based on the digital elevation model (DEM) of the study area. Then a water depth layer can be visualized on a separate map.

In areas where flooding is not a result of overtopping but rather of failing structures (e.g. polder areas), a different type of water depth layer can be created. For the assessment of flood hazard, the integration of these layers can be combined into a single map showing the maximum (or average) flood depth per pixel (de Moel et al., 2009).

The physical damage to property in urban areas is considered the major cause of tangible loss in flood areas. There are also secondary losses associated with a decline in property values after the event. Such decline in property prices can have either temporary or continuous effects with a single event or a repeatedly flooding behavior, respectively (Montz, 1992; Tobin and Montz, 1997). Furthermore, damage to crops, livestock and agricultural infrastructure may also be high in intensively cultivated rural areas (Smith, 2001). In this paper, we intend to assess the flooding behavior of Muda River and its hazard potential on property end-points by mapping the flood depth, and exploiting the huge collected spatial data over a 20-year study period from field and archived reports. The water-depth based mapping will be used as input for a more advanced level of flood modeling and simulation in order to be later used in supporting decision-making and providing suggestions on flood risk management in the Muda basin.

2 Study Area

Muda River is the longest river in Kedah State, northern Peninsular Malaysia, with its upstream lying in the northern mountainous area of the state. The river flows down toward the south of the state, with a stream's length of 180 km and a catchment area of 4,210 km^2. Figure 1 shows the lower end of the Muda River (41.2 km in length) that is used in this study.

A review of the hydrographic history of Muda River for the last 44 years indicated that three major floods occurred, once each in 1988, 1998 and 2003. An examination of the floods over a 44-year period indicates that the 2003 flood event has the highest peak discharge, 1340 m^3/s, measured at Ladang Victoria station, which was considered to be slightly larger than the 50-year peak discharge (Julien et al., 2010).

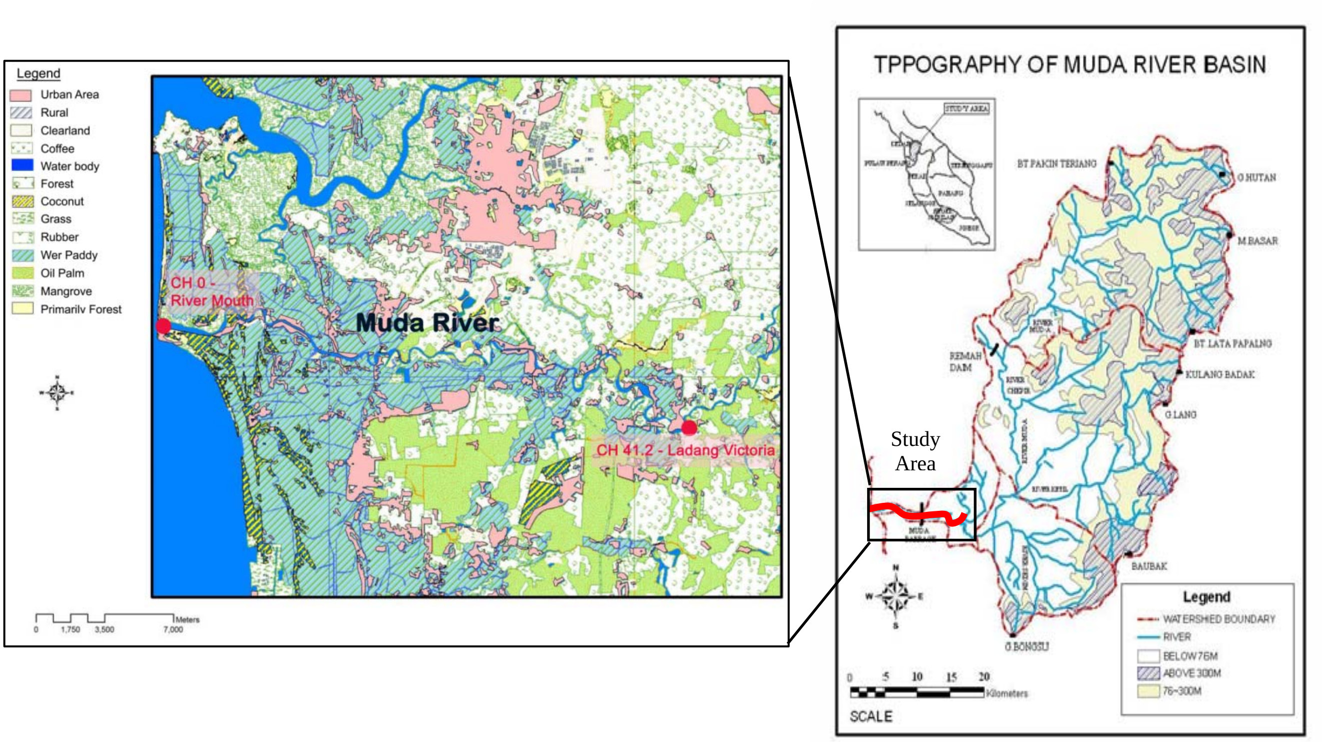

Figure 1 Land Use Map of the Lower End of Muda River (Ali, 2009)

3 Methodology

3.1 Data & GIS Database Development

Figure 2 illustrates the general methodology used in this study. Initially, a comprehensive GIS database based on land cover/land use categories and ground roughness values was developed to support the flood risk analysis study in Muda basin. Spatial and non-spatial data derived from field survey measurements, previous reports and remote sensing image analysis were input in the InfoWork RS software to generate vector-based layers. InfoWorks RS is a combined 1D hydrodynamic ISIS Flow simulation engine with GIS function and database storage that can perform one dimensional hydraulic modeling for a full network, and provide input and output information in tabular and graphical formats (Wallingford Software, 2007). This system is capable of performing steady and unsteady flow water surface profile calculations.

A total length of 41.2 km (Figure 1) between the river mouth at CH 0 and Ladang Victoria at CH 41.2 was used to cover the river cross-sections taken in this study with an area extension of 40.7 km^2. The numbers of houses included within this spatial extension were estimated to be 2617. The 2003 hydrograph (Figure 3) of Muda River was used as temporal data input in the database. The digital terrain model (DTM) was used to extract accurate elevation data with spatial resolution of 20 cm. Georeferencing was performed during the process to make the data compatible and collate well with the ones available in the master geodatabase. Once the database was developed, the InfoWork RS was used in modeling the surface extension of the river water. The model was then calibrated with observed data to ensure the best representation of surface water extension before the whole database was exported into GIS environment for further spatial analysis.

3.2 GIS Analysis and Risk Mapping

To characterize the site into hazardous classes, the inundation water depth classes used by the Malaysian Department of Irrigation and Drainage after the standards of the Japan International Corporation Agency (JICA) was adopted in this study to generate flood hazard maps. These water depth classes (Table 1) were based on human characteristics as suggested by the Japanese municipalities in conformance with the Japanese Flood Fighting Act established in 2001 (DID, 2003).

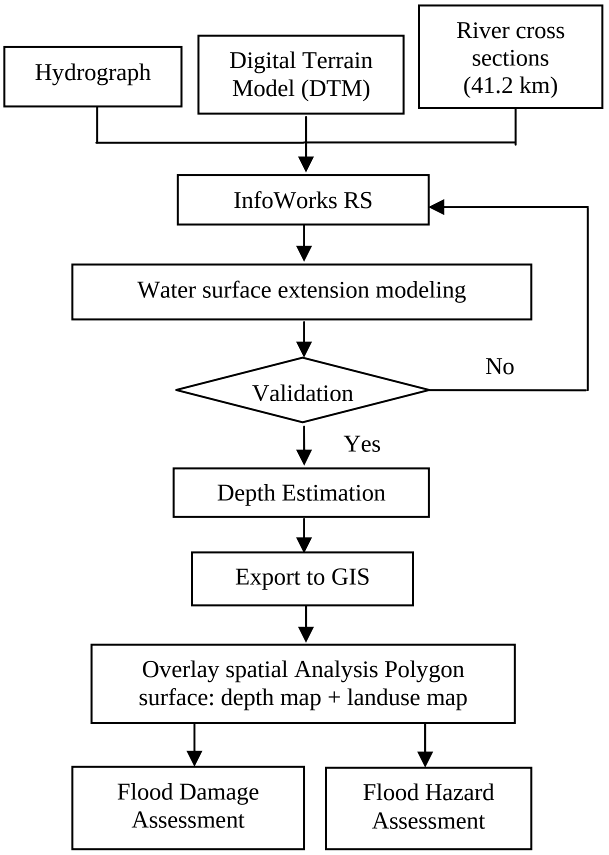

Figure 2 Flowchart of database development, management and geoprocessing adopted in the study

Each classified land use category was analyzed in GIS by layering them with the water depth map to estimate and compare the inundated areas and establish risk maps. This was necessary to assess the damages posed on human settlements/activities and agricultural sites, and also to estimate on the hazard probability and magnitude of the 2003 Muda River flooding event in the study area to support the decision-making.

The risk mapping concept adopted in our methodology is based on the flood damage, which is associated with both water depth and flood duration. Therefore, we need to define damage factors to quantify the levels of flood damages for land use types of human settlement and agriculture (four types of crops i.e. paddy, rubber (mortality of young trees), oil palm and coconut palm), due to the depth and duration of flooding (> 7 days).

If the depth and duration of the flood is very severe, the flood damage factor can be 100% which implies total loss for a given category of flood damage. The flood damage factors adopted in this study are based on the 1999 and 2000 studies conducted by JICA (DID, 2003) carried out on some mega riverine systems in Malaysia of similar conditions to Muda River system. Table 2 represents the reference damage factors used in this study for estimating the loss in Malaysian Ringgits (RM) per unit value of households and crops in Muda area.

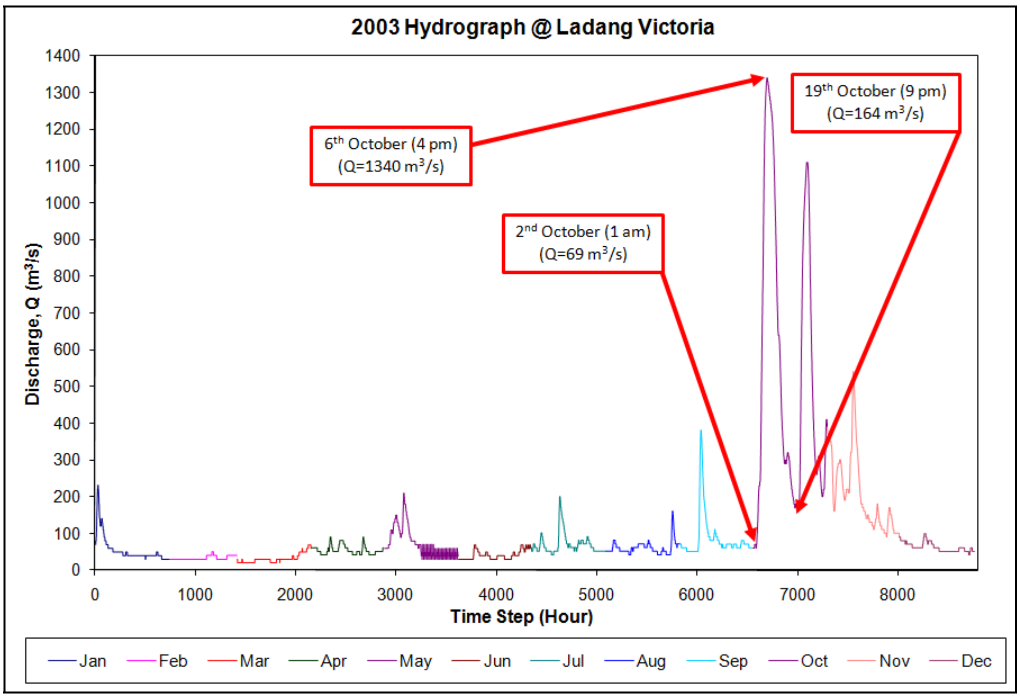

Figure 3 Input Hydrograph @ Ladang Victoria for 2003 Flood

Table 1 Water Depth Classes Suggested by the Japanese Flood Fighting Act 2001

Water Depth (m)	Hazard Indication
0 – 0.5	most houses will stay dry and it is still possible to walk through the water
0.5-1.0	there will be at least 0.5 m of water on the ground floor and electricity will have failed by now
1.0-2.0	the ground floor of the houses will be flooded and the inhabitants have either to move to the first floor or evacuate
2.0-5.0	both the first floor and often also the roof will be covered by water. Consequently evacuation is the logic choice of action now. The same applies, evidently, for the depth class > 5 m

To estimate the damages in RM for each classified land use category, the amount of damage sustained is estimated by multiplying the unit value of the damageable asset (Table 3) by an appropriate damage factor in Table 2. For agriculture land use type, Equation 1 was used for estimating the damage on each classified crop and houses category in reference to Table 2; while from the damage estimates on human settlements, we derived extended damage estimates (Equations 2, 3, 4 and 5) of another anthropogenic-based activity category, such as livestock; public utilities; and industrial facilities. At the end, the indirect damage estimate of the total loss in RM due to the 2003 flood event in the study area was calculated by Equation 6.

Crop Damage: Unit value of production loss x Damage factor x Flooded area (1)
Damage to houses: Unit value x Damage factor x No. of houses affected (2)
Public Utilities: 30% of damages to Houses (3)
Industrial Facilities: 10% of damages to Urban Houses (4)
Livestock Loss: RM25 x No. of rural households affected (5)
Indirect Damages: 30% of total direct damages (total of items 1 to 5) (6)

The output flood risk maps were then visualized in vector shape files in which hazardous and non-hazardous zones are spatially presented.

4 Result and Discussion

Figure 4 represents the simulated water depth map of the 2003 flood event resulting from the developed database processed in InfoWorks RS environment. The map shows that high hazardous sites are located within the inundation water depth zones of >3 meters (red color codes); while low hazardous urban sites are located within the inundation water depth zones of less than 1 meter (green color codes). The high hazardous sites are distributed around the most inundated areas due to the meandering nature of the river. Ab Ghani et al. (2010) had calculated the sinuosity indicator, S of Muda River to be 1.561 which clearly indicates that the river is an ‘actively meandering’ channel. Sinuosity is the ratio of channel length to valley length, typically ranges from 1.0 (straight) to 3.0 (tortuous).
Figure 5 shows the risk map of flood-prone urban areas in the 2003 flooding event of the Muda River. In the map, the site is categorized into damaged and non-damaged areas considering the flood’s spatial extension. It indicates that most flood-prone urban and agricultural areas are concentrated more in the downstream terrains of the Muda basin, while the urban and agricultural areas concentrated in the upstream terrains are considered less subjected to flood hazards. Therefore, engineering controls are necessary to be applied in these flood-prone areas in the Muda floodplain. The damage severity on agriculture and urban land use categories is estimated by the economical loss in RM as summarized in Table 4.

Table 2 The reference damage factors for each land use classification category used for risk mapping in Muda River based on JICA 1999, 2000 (DID, 2003)

Agriculture damage factors

Land use categories	Area (ha)	Flood Depth	Flood Duration	Damage Factor (%)
Paddy	1,319.5678	More Than 1m	More than 7 days	96
Rubber (Mortality of young trees)	778.9793	More than 0.25m	More than 7 days	15
Oil Palm	270.8445	More than 0.25m	More than 7 days	20
Coconut Palm	78.5616	More than 0.25m	More than 7 days	20

Household damage factors

Inundation Depth (m)	Inundated Area (x 1000 m^2)	No. of Inundated Houses	No. of People Affected	Damage Factor (%)
0 - 0.5	712	183	805	5.7
0.5 - 1	1,374	444	1,954	9.6
1 - 1.5	1,687	523	2,301	11.9
1.5 - 2	1,934	680	2,992	13.5
2 - 3	1,804	473	2,081	33.6
>3	1,185	314	1,382	68.7

*Note: Average household density (Persons/household) urban = 4.4 (JICA, 1995).

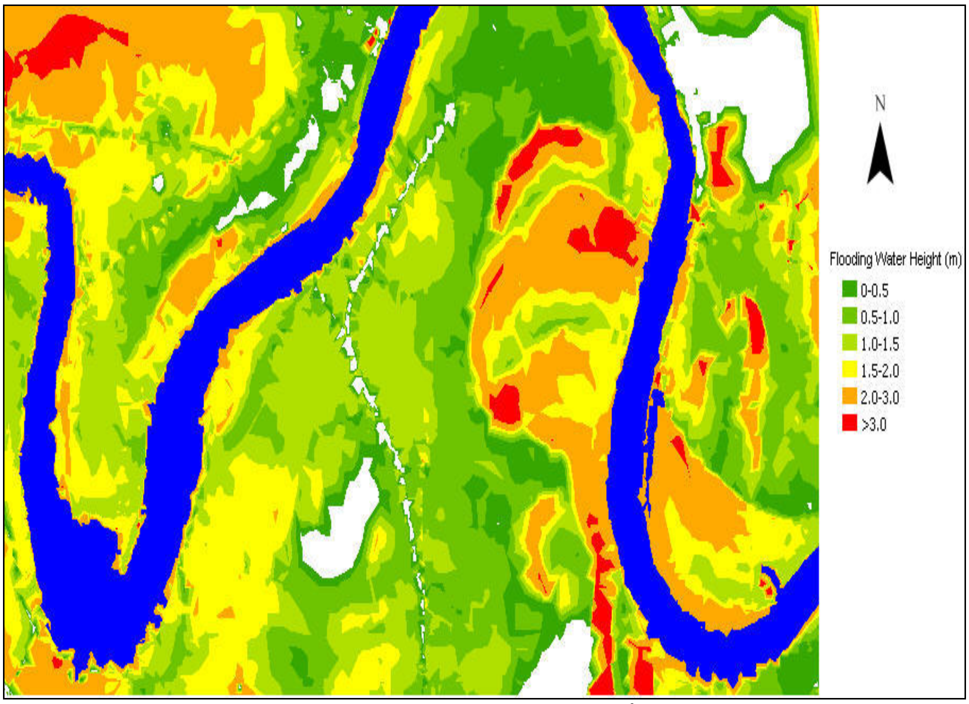

Figure 4 Simulated Inundation Depth Map during 6th October 2003 Flood

Figure 5 Risk Map of Flood-Prone Urban Areas for the 2003 Flood event

Table 3 The unit value in Malaysian Ringgits (RM) of each classification land use category in the study area (DID, 2003)

Property/crop	**Value (RM)**
Urban house	22,000/ household
Paddy yield	1,857/ha
Rubber	5,200/ ha
Oil palm	3,500/ ha
Coconut tree	6,200/ ha

Based on Equations 3, 4, 5 and 6, economical loss estimates for other land use sub-categories that are reliant on the urban land use category are summarized in Table 5. The estimated total damage in urban areas was above RM 27.6 million

The estimated economical loss of the 2003 flood event was RM 27.6 million, which is considered higher than previous flooding events of 2002 (RM15.36 million) and 1982 (RM 3.87 million) (DID, 2003). This is attributable to the extensive human activities within a time frame of 20 years that have changed many features of this river system.

Table 4 Summary Estimates of Flood Damage on Agriculture and Urban Land Use Categories

Agriculture damage estimates	
Land use categories	**Economic loss (RM)**
Paddy	2,352,420.00
Rubber	607,604.00
Oil Palm	189,591.00
Coconut Palm	97,416.00
Total loss	3,247,031.00
Urban damage estimates	
Inundation Depth (m)	**Damage (RM) per house numbers**
0 - 0.5	229,482.00
0.5 - 1.0	937,728.00
1.0 - 1.5	1,369,214.00
1.5 - 2.0	2,019,600.00
2.0 - 3.0	3,496,416.00
>3.0	4,745,796.00
Total loss	12,798,236.00

Table 5 Economical Damage estimates of Urban Land Use Sub-categories

Categories	**Estimated Damage (RM)**
Livestock Loss	65,425.00
Damage to houses	12,798,236.00
Public Utilities	3,839,470.80
Industrial Facilities	1,279,823.60
Indirect Damages	6,368,995.92
Total Damage Estimated	27.6 million

5 Conclusions

Based on hazard mapping of the flood event of 2003, it can be stated that the flood hazard of the Muda River is high and impose severe damage on urban and agricultural land use types, as well as other sub-category land uses. The flood damage estimates of the 2003 flood event were seven times those of the 1982 flood event. The risk is expected to increase in the coming future as more lands in the floodplain are under human development and exploitation.

References

1. Ab. Ghani, A., Ali, R., Zakaria, N.A., Abu Hasan, Z., Chang, C.K. and Ahamad, M.S.S (2010). *A Temporal Change Study of the Muda River System over 22 Years*, International Journal of River Basin Management, Vol. 8, No. 1, pp. 25-37
2. Ali, R. (2009). Flood Hazard and Risk Assessment through Integration of GIS with Hydrodynamic Modelling: Case Study of Muda River. *PhD. Thesis*. Penang: Universiti Sains Malaysia.
3. Ationg, M. (2005) Road towards effective flood hazard mapping in Malaysia. report for *JICA Region-Focused Training Course on Flood Hazard Mapping JFY 2005*, Nov., Department of Irrigation and Drainage, State of Sabah, Malaysia
4. de Moel, H., van Alphen, J. and Aerts, J.C.J.H. (2009). *Flood maps in Europe-Methods, availability and use, Nat.* Hazards Earth Syst. Sci.,9, 289–301.
5. Department of Irrigation and Drainage Malaysia Or DID. (2000). *Urban Stormwater Management Manual for Malaysia or MSMA.* DID, Kuala Lumpur, Malaysia
6. Department of Irrigation and Drainage Malaysia or DID. (2003). *National Registry of River Basins*, Volume No. 2, Updating of Condition of Flooding in Malaysia.
7. Department of Irrigation and Drainage Malaysia or DID. (2009). DID Manual, Volume 2 – River Management. DID, Kuala Lumpur, Malaysia.
8. Genovese, G. (2006) A Methodological approach to land use-based flood damage assessment in urban areas: Prague case study. *European Commission*. Report No. EUR 22497 EN.
9. Japan International Cooperation Argency. (1995). *Comprehensive Management Plan Of Muda River Basin*, Final Report.
10. Julien, P.Y., Ab. Ghani, A., Zakaria, N.A., Abdullah, R. & Chang, C.K. (2010). *Case Study: Flood Mitigation of the Muda River, Malaysia*. Journal of Hydraulic Engineering, ASCE. Vol. 136, No. 4, pp. 251-261.
11. Moglen, G. E. and Maidment, D. R. (2005) *Digital elevation model analysis and geographic information systems*. Encyclopedia of Hydrological Science. Anderson, M. G. (ed). pp. 239-255
12. Montz, B. E. (1992) The effects of flooding on residential property values in three New Zealand communities. *Disasters*, 16, 283-298
13. Noson, L. (1998), Risk Based Mitigation Planning Report, Colombo 12 -13 June 1998
14. Plattner, Th. (2006) Evaluation of risks due to natural hazards: *A Conceptual Approach. RISK 21-Coping With Risks Due to Natural Hazards in the 21st Century*, Ammann, W. J., Dannenmann, S. and Vulliet, L., (eds) p. 67-76
15. Samuels, P.G. (2006) Risk and uncertainty in flood management. In *River Basin Modelling for flood Risk mitigation* (Knight, D. W. and Shamseldin, A. Y., eds) p. 481-517
16. Smith, K. (2001) Environmental Hazards: Assessing Risk and Reducing Disaster, 3rd ed., Routledge, London.
17. Tobin, G. A. and Montz, B. E. (1997) The impacts of a second catastrophic flood on property value in Linda and Olivehurst, California. *Quick Response Report*. No. 95. Natural Hazards Research and Applications Information Center, Boulder, CO
18. Townsend, A.P. and Walsh. S. J. (1997) *modeling floodplain inundation using an integrated GIS with rader and optical remote sensing.* Journal of Geomorphology. p. 295-312.