GIS-Based Management System in Floods

(Final Term Paper Report)

By

Jaafar Bu-Saad
ID # 906098

For

CRP 514: Introduction to GIS
Term 051 – 12th Offer

Instructor:
Dr. Baqer Al-Ramadan

Date: January 21st, 2006

TABLE OF CONTENTS

Page number

ABSTRACT

Floods are the major disaster affecting many countries in the world year after year. In 1988, floods have resulted with an estimated 45 million people were directly

affected and killed about 2000 to 3000 people throughout Bangladesh (References: 2 and 3).

The unit of this study is Bangladesh. Bangladesh is a flood prone country. Structural methods of flood protection are neither economically viable nor these are environment friendly. Therefore, non-structural methods are becoming popular in mitigating flood disaster. The study selects the new flood forecasting system, MIKE 11, which has been integrated in a GIS environment and provides a very powerful tool for real-time flood forecasting and flood warning. The advance warning dissemination is important to reduce loss of life and property and assist in disaster preparedness.

1. INTRODUCTION

Water covers about 70% of Earth's surface and is critical to supporting life on the planet. However, water can also cause a significant hazard to human life and property in certain situations such as a flood. Flooding is the most universally experienced natural hazard.

Flooding occurs when abnormally high stream flow overtops the natural or artificial banks of a watercourse. Floods can be deadly - particularly when they arrive without warning. On an annual basis, flooding causes the most damage in many places of the World.

Figure.1: Flood-a disaster of catastrophic dimension in Bangladesh
(Reference: 8)

Most communities experience some kind of flooding after spring rains, heavy thunderstorms or winter snow thaw (Figure 1). Dam failures can also produce flooding. Flash floods result from intense storms dropping large amounts of rain within a brief period with little or no warning. In industrialized countries loss of life because of flooding is typically much lower than in developing countries, but the amount of damage and disruption can be staggering.

Floods have been viewed as extreme acts of Nature, which could be combated by building structures such as dams, levees, and bank reinforcements to contain, redirect, and otherwise control floodwaters. Dams, levees, channels and other protective works are designed to provide protection against some specific level of flooding. The "level of protection" is selected based on cost, desire of the community, potential damage, environmental impact, and other factors. Engineers can design and construct levees, dams and other measures providing a very high level of protection. Communities tend to choose lower levels of protection because of the initial financial cost rather than overall costs and benefits.

Bangladesh is a poor country and floods make human suffering tragedies and economic losses. The early and timely flood forecasts and warnings will help in saving people life and properties.

2. PROBLEM OVERVIEW

Many organizations study flooding, work toward preventing floods, and recommend adjustments to reduce flood hazards. Mitigation is the basis of emergency management. The loss of human life and property could be reduced considerably by giving reliable advance information about the oncoming floods. Development of Decision Support System for flood risk assessment is vital in flood forecasting and warning for administrative machinery involved in rescue and emigration work. The importance of the flood forecasting and warning is a fundamental non-structural measures to aid mitigating- the loss of life, crops and property caused by the annual flood occurrence. Preparedness provides leadership, training, readiness and exercise support, and technical and financial assistance to strengthen citizens, communities, State, local and Tribal governments, and professional emergency workers as they prepare for disasters, mitigate the effects of disasters, respond to community needs after a disaster, and launch effective recovery efforts.

Organized response to flood hazards takes two main forms: (1) structural and engineering approaches aimed at controlling flooding and (2) regulations, emergency response programs, and compensation packages aimed at decreasing vulnerability and adjusting to the hazards.

3. PAPER OBJECTIVE

This paper presents a study implies the application of Geographic Information Systems technologies in forecasting floods rather than flood mapping for flood risk assessment in flood prone countries. The importance of the flood forecasting and warning is widely recognized as an essential non-structural measures to aid mitigating the loss of life, crops and property caused by the annual flood occurrence. For standardizing different approaches in implementing a flood forecasting and warning systems, the paper will restrict itself to a literature evaluation to the project of the Danish Hydrodynamic Model MIKE 11 and GIS in Bangladesh. It may not be practical to avoid floods but it is a worthy target to move toward minimal flood disaster damages from severity.

4. PAPER METHODOLOGY

The paper aims to standardize a global user-friendly system in flood forecasting and early warning systems. The searching domain is limited to Bangladesh country and it constitutes a tool of utilizing both flood modeling and GIS technologies. This study concludes the future success of using GIS for flood forecasting is reliant upon developing enlarged interfaces between GIS and the numerical flood models (MIKE 11). The summary of the selected case study (Development of flood warning system) is supplemented by additional text for the purpose to achieve this paper objective.

5. REVIEW OF LITERATURE

Different studies have been published to monitoring and forecast of floods (disasters) in Bangladesh using remote sensing technology, the National Oceanographic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) and GIS in developing Flood Hazard Assessments and Maps, the Remote Sensing and the Digital Elevation Model (DEM), ESRI development of a HEC-RAS (Hydrologic Engineering Center - River Analysis System) pre-processing and post-processing ArcView extension called AVRAS, Hydrodynamic and GIS to predict the effects of future events from events occurred or potentially expected and the Hydrodynamic model MIKE 11 (A generalized river modeling package) and GIS to flood (disaster) mitigations in Bangladesh (References: 2, 4, 7, 8 and 9). In general, there are two basic types of floods. In a regular river flood, water slowly climbs over the edges of a river. The more dangerous type, a flash flood, occurs when a wall of water quickly sweeps over an area. The precipitation leads in flooding either upstream or downstream:

1. Upstream Flooding: intense, infrequent and short duration of raining storm. Such floods typically have a short lag time and can be very hazardous. Floods in which the lag time is short duration are called *Flash Floods*.
2. Downstream Flooding: continue raining, long duration and extend over an entire region.

A number of different aspects affect flow response and flooding:

1. Removal of vegetation or conversion to plants with lower annual evapotranspiration and interception increase runoff volumes. After rainfall, the antecedent soil moisture content and water tables tend to be higher for the next event. Consequently, less storage is available to hold the precipitation of the next event.
2. Activities that further reduce the infiltration capacity of soils are intensive grazing, deforestation and urbanization. As the proportion of precipitation for surface runoff increases due to human interference, the river responds more quickly to precipitation events.
3. Increased erosion and sedimentation reduces the capacity of stream channels at both upstream and downstream locations. Flows that would have remained within the streambanks previously may now flood.
4. Alterations of the stream channel (canalization, dikes, dams, bridges) change the overall conveyance system of a catchments area.

Many studies have discussed and explained the approach of integrating GIS with the Flood Management software system; a common reliable product is MIKE 11 system. This integration between GIS and the MIKE 11 modules offers new opportunities to develop and implement a user-friendly, interactive decision support system for flood forecasting and identifying the affected areas using dynamic spatial modeling (Reference: 9)

Further Readings are available in the list of references section.

6. **CASE STUDY:** Development of Flood Warning System

6.1 Description of Study Area

The profile of case study area is Sundarganj Thana of Gaibandha district in Bangladesh. The area is subjected to flood almost every year. There are two major rivers bound Sunderganj: Brahmaputra (Mansoon Flood) in the eastern and Teesta (Flash Flood) in the northern part of Bangladesh. The size of urban area of Sunderganj Thana is 5.0 Sq. Km, whose population is 9, 940. Area of household in Tarapur union is 6.42 Sq. Km; population is 25,796 (Reference: 13).

Bangladesh is located in the Bay of Bengal and surrounded by India. Water enters in Bangladesh through three major channels (draining the Himalayan mountains through India and other neighboring countries into the bay of Bengal): Ganges, Brahmaputra and Meghna Rivers. Bangladesh is a flood prone country with a high number of population (about 800 persons per square kilometer) having area of 144, 000 sq km and a population of about 110 million. Major factors responsible for disasters in Bangladesh are flat topography, rapid run-off and drainage congestion, low relief of the floods, plains, low river gradients, heavy monsoon rainfall, enormous discharge of sediments, funnel shapes and shallow Bay of Bengal, etc (References: 2 and 4). Bangladesh suffered damage on account of the most catastrophic floods of 1987, 1988 and 1998, resulting in untold suffering of the people. About one fifth of the country is flooded every year, more than half of the country can be flooded. The primary cause of flood in Bangladesh is rainfall in the catchment areas of the rivers of Bangladesh. The annual rainfall varies from about, 60 inches in the western part of the country to about 200 inches in the northeastern part. The average rainfall in Bangladesh generates annually only 100 million-acre feet of water whereas 1100 million acre feet of water comes from outside Bangladesh. Thus about 90 percent of the water carried by the river system. Whenever the inflow of water is greater than the carrying capacity of the rivers (and this happens very often) flood results. The magnitude of the flood depends on the magnitude of excess water that is generated. Besides the primary cause, namely rainfall in the catchment area, there are other factors that may aggravate the floods in Bangladesh. (References: 6 and 8) They are:

1. Snow melting in the Himalayas.
2. Hydrographic changes in the Brahmaputra basin.
3. 2.4 billion tons of sediments carried by the river system of Bangladesh every year reduce the water carrying capacity of the rivers, which worsens the flood.
4. Deforestation in the catchment area tends to aggravate the flood.
5. Construction of unplanned roads, railways, barrages, embankments etc. also create obstacles to the flow of water and aggravate the flood.

6.2 Objective of Case Study

The study attempted to develop a flood warning system by integration between GIS and hydrologic models and emergency response plans (Figure 2). Flood forecasting can be divided into two categories:

1. Flood forecasting in the rivers caused by upstream rise of river stage as well as rainfall in the basin; Overland flow from upstream.
2. Flash flood forecasting in small basins generally induced by heavy localized rainfall and characterized by sharp rise and fall.

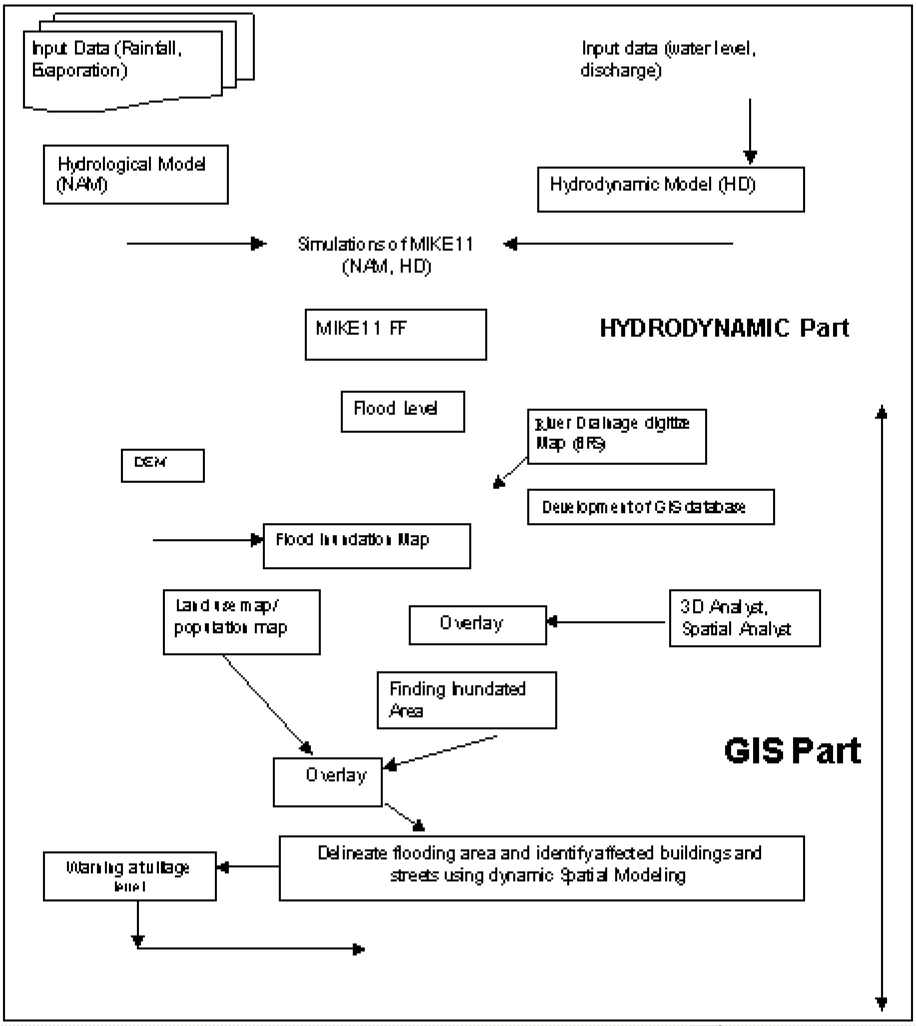

Figure 2: Development of flood warning system (Reference: 8)

6.3 Methodology of Case Study

In the current study the issue of flood hazard mapping has been addressed low priority, and considered an integrated approach in a GIS environment of a new model for warning of floods for flood risk assessment or early notifications in flood prone countries (Bangladesh) for regular monitoring of damages.

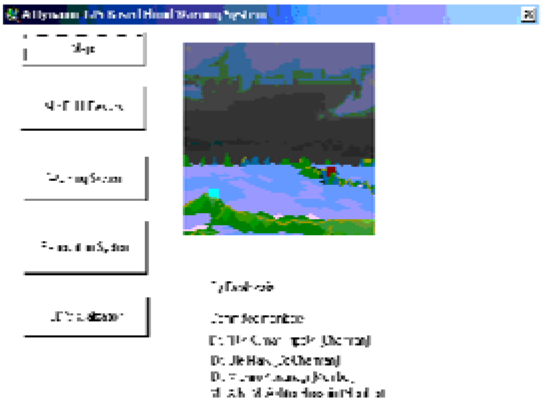

Figure 3: Customized Dynamic GIS based flood-warning system (Reference: 8)

MIKE 11 is a project that was initiated by the Danish Hydraulic Institute (DHI) in 1995, to enhance the flood forecasting and warning system in Bangladesh. The project was bridged in close collaboration with the Bangladesh Water Development Board (BWDB) and carried out for a 3-years implementation period. Flood Forecasting Warning Center issues the forecast using the MIKE 11 and Flood Watch Model Systems. MIKE 11 is a comprehensive, one-dimensional modeling system for simulations of flows, sediment transport and water quality in estuaries, rivers, irrigation systems and other water bodies (Reference: 17). The MIKE 11 is structured on a great flexibility of basic modules for Hydrology, Hydrodynamics, Advection-dispersion and cohesive sediment transport and Water quality and non-cohesive sediment transport.

Hydrodynamic model MIKE 11 Flood Forecasting system (MIKE 11 FF) was successfully integrated with GIS in the ArcView GIS environment. The GIS has been used intensively to create watershed models from digital elevation (DEM) data to trace flow-paths to get a complete surface for identifying the actual flood flow.

The MIKE 11 FF flood forecasting system is a part of the modeling integrated in the MIKE 11 Flood Watch system. The MIKE 11 Flood Watch also works in an ArcView GIS environment and consists of three main modules: 1. a database management module; 2. a map-oriented data editing and presentation module; and 3. simulation and post processing of results. The daily procedures to handle flood forecasting and warning services are being carried out from the MIKE 11 Watch System that is outline in Figure 4. (References: 7 and 9)

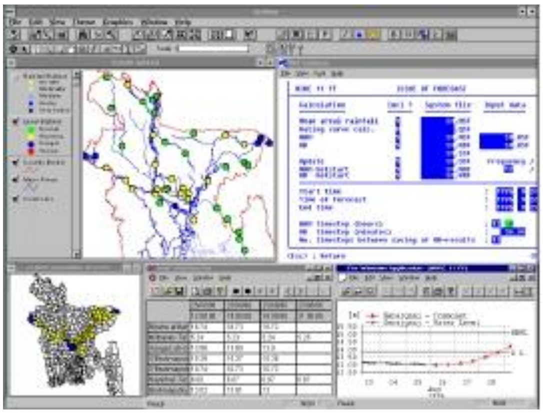

Figure 4. The MIKE 11 Flood Watch system (Reference: 9)

The MIKE 11 FF is designed to perform the calculations required to predict the variations in discharge and water level in a river system as a result of catchment rainfall and inflow/outflow through boundaries in the river system. All the model calculations required for issuing a forecast are done automatically by utilizing a number of individual modules (Reference: 9). The MIKE 11 NAM is a precipitation-runoff model that simulates the rainfall-runoff process in catchments. The MIKE 11 hydrodynamic module, HD, is for the computation of unsteady flows in rivers and estuaries. Flood Forecasting, FF, performs the calculations required to predict the variation in discharges and water levels in a river system as a result of catchment rainfall and inflow/outflow through boundaries in the river system. From the MIKE 11 FF module, the hydrodynamic model HD and the rainfall-runoff model NAM are controlled. All necessary input data and runtime parameters can be specified from MIKE 11 FF. (Reference: 7)

MIKE 11 software package is a versatile and modular engineering tool for modeling conditions in rivers, lakes/reservoirs, irrigation canals and other inland water systems. It is designed for: (Reference: 7 & 9)

- flood risk analysis and mapping
- design of flood alleviation systems
- real-time flood forecasting
- real-time water quality forecasting and pollutant tracking
- hydraulic analysis/design of structures including bridges
- drainage and irrigation studies
- optimization of river and reservoir operations
- dam break analysis
- water quality issues
- integrated groundwater and surface water analysis
- *…….reliable results*

The MIKE 11 FF flood-forecasting techniques are used to predict local flood levels and river discharges. The forecasts can be used to set up control strategies for reservoir operation, which will prevent or reduce flooding in the downstream reaches and avoid unnecessary waste of water resources. In addition, the forecasts form the basis for the dissemination of warnings to local authorities and the public. The forecasts provide information on the time scale and the extent of the flood inundation expected locally. Consequently, flood-forecasting techniques constitute a viable and important tool within flood management.

Method of development the warning system is summarized in Figures 2 and 5.

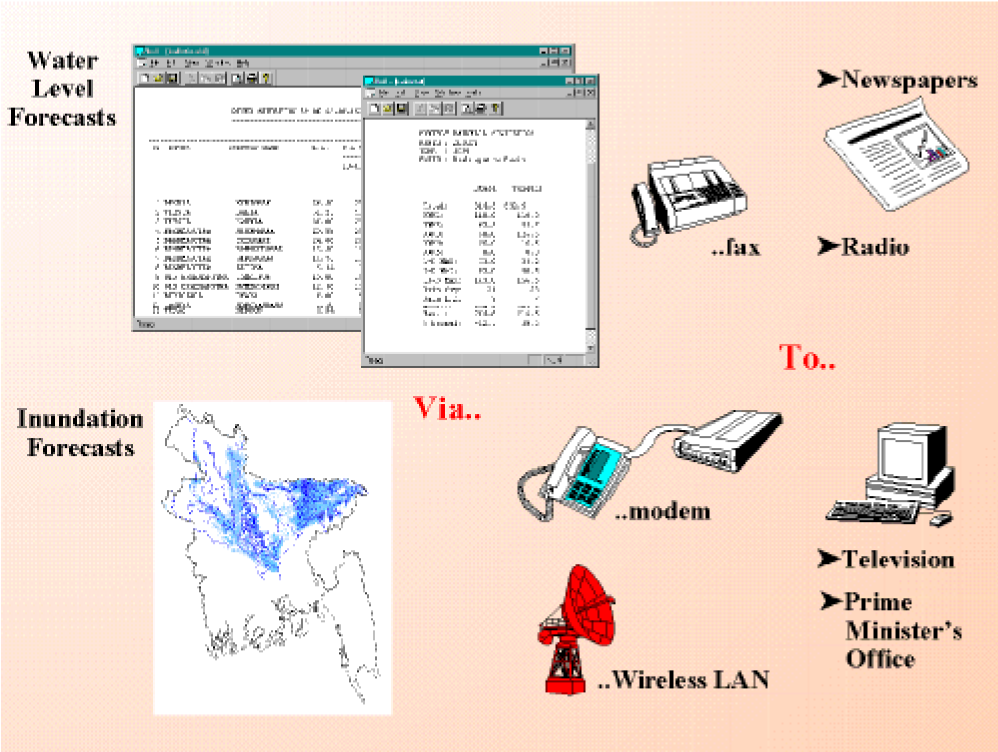

Figure 5: MIKE 11 FF provides flood warnings (Reference: 7)

MIKE 11 and GIS are successfully integrated in ArcView GIS environment for instantaneous flood level information. The analysis demonstrates that an efficient warning system can release cautions in advance. This would change the current standpoint of flood disaster management and make available information for planning and emergencies decision making to which reduce deaths of people. This includes finding alternate routes in different situations: quickest route to the hospital or to the flood shelter and the direction of travel are very important at that moment.

The methodology and database has been customized in ArcView GIS for user-friendly interface and easy implementation.

7. CONCLUSION AND RECOMMENDATIONS

“We cannot avoid flood, but by implementing effective flood prevention schemes, we can reduce damages from severity”. The MIKE 11 “Flood Watch” dynamic model can be automated fully to be accomplished with the existing flood warning system to provide warning for the people without the knowledge of GIS to identify the possible inundated areas to take initiative to evacuate people to the safe places in time.

The MIKE 11 system results provide helpful information about flood risk management and should be useful in assigning priority for the development of very high-risk areas for flood control planning, and the construction and development of flood countermeasures.

Five requirements for further improvements:

1) Regional cooperation among neighboring countries to get access to all types of required data on a continuous basis for the entire catchments.
2) Automated data recording and collection system can improve data quality.
3) A close monitoring and feedback from the users and updating using the feedback data.
4) Rainfall estimation using weather radar in conjunction with satellites for measuring rainfall over catchments.
5) DEM with higher resolution to produce quality inundation maps. The map has to be updated with new field data.

Damages from severe flooding can be reduced if effective flood prevention scheme is implemented. This can be achieved if the sufficient information for flood forecasting is acquired both in time and in quality. Hydrologic applications of GIS range from synthesis and characterization of hydrologic tendencies to the prediction of response to hydrologic events. The payoff comes from the multiple ways in which the data can be used once it is made to be digitally accessible in a GIS (Tawatchai, 1999).

Use of GIS will provide supplementary data in Hydrology for such analysis and will lead to easier interpretation and understanding of flood phenomena and characteristics. The use of Digital Elevation Model (DEM) can be effectively used for simulation to get a complete model of the study area.

ACKNOWLEDGMENTS

The author would like to acknowledge the course offerings (Introduction to Geographic Information Systems) of King Fahd University of Petroleum and Minerals and particular express thanks to Dr. Baqer Al-Ramadan for the excellent course teaching materials and support in writing this paper.

REFERENCES

1. Lawrence W. Lundgren, 1992, 2^{nd} Edition, Environmental Geology
2. Md. Monirul Islam, and Kimiteru Sado, 2002, Flood Hazard Assessment for the Construction of Flood Hazard Map and Land Development Priority Map Using NOAA/AVHRR Data and GIS – A Case Study in Bangladesh.

3. Partha Pratim Sarker, May 2003, Floods Fail to Dampen Spirit of Bangladesh: http://www.centerdigitalgov.com/international/story.php?docid=53250
4. J. A. M. de Brouder, 1994, Flood Study in the Meghna – Dhonagoda Polder, Bangladesh, International Institute for Aerospace Survey and Earth Sciences, The Netherlands.
5. ABM Faruquzzaman Bhuiyan, 1998, Flood Alleviation Schemes, School of Environmental Sciences, University of East Anglia, Norwich, UK.
6. A. M. Choudhury, 1994, Monitoring and Forecast of disasters in Bangladesh using remote sensing technology, Bangladesh Space Research and Remote Sensing Organization (SPARRSO), Agargaon, Sher-e-Bangla Nagar, Dhaka-1207.
7. Kjelds, J. T. and Jorgensen, G. H., 1997, *FLOOD WATCH: GIS Based Management System for Flood Forecast Applications*, Danish Hydraulic Institute, Agern Alle 5, DK-2970 Horsholm, Denmark.
8. Farah Aziz, 2001, Dynamic flood warning system: An integrated approach to disaster mitigation in Bangladesh, Asian Center for Research on Remote Sensing (ACRoRS), School of Advanced Technologies.
9. Gregers H. Jorgensen, and Jacob Host-Madsen, 1997, Development of a Flood Forecasting System in Bangladesh, Danish Hydraulic Institute, Denmark, Flood Management Department.
10. Journal of the Japan Society of Photogrammetry and Remote Sensing, Vol.30, No.6, 1991, P34.
11. Meijerink, A.M.J., C.R. Valenzuela & A. Stewart (eds.) 1988. ILWIS, the Integrated Land and Watershed Management Information System. ITC Publication No 7, Enschede, The Netherlands.

12. BPC, 1994, Bangladesh Population Census, 1994, Zila: Gaibandha: 1994, Bandladesh Bureau of Statistics
13. EGIS, 1998, Microwave Remote Sensing Applications for Flood Monitoring. Environmental and GIS Support Project for Water Sector Planning, Dhaka.
14. Tawatchai, T. 1999, Use of Geographic Information Systems and Remote Sengin in Hydrological modeling. A Publication of the School of Civlil Engineering, Asian Institute of technology, Vol. 1, No. 1.pp.7
15. FLOOD WATCH: GIS Based Management System for Flood Forecast Applications - http://gis.esri.com/library/userconf/proc97/proc97/to500/pap486/p486.htm
16. MIKE 11 (2003), A brief introduction to MIKE 11 and its capabilities, http://www.dhisoftware.com/mike11/Description/What_is_MIKE_11.htm. Accessed Jan 15, 2004.
17. Havn˝ K,Madsen MN, Dŕge J. MIKE 11—a generalized river modelling package. In: Singh VP,editor. Computer models of watershed hydrology. Colorado: Water Resources Publications; 1995. p. 733–82.
18. Dartmouth College Flood Remote Sensing – http://www.dartmouth.edu/artsci/geog/floods/
19. FEMA National Flood Insurance Program – http://www.fema.gov/nfip

APPENDIX - 1

Definitions

- **Flood**: water overflow above its natural or artificial confines and submerges land in the surrounding area due to rise in the level of a water body.
- **Flash Floods:** are floods in which the lag time is exceptionally short duration.
- **Stream**: a body of water that flows downslop along clearly defined natural passageway, transporting particles and dissolved substances.
- **River**: a stream of considerable volume with a well-defined passageway.
- **Channel**: the passageway of a river.
- **Load**: the particles of sediment and dissolved matter.
- **Discharge**: quantity of water passing by a given point on the bank within a given interval of time.

- **Stream Gradient**: a measure of the vertical distance between two points along a channel course.
- **Drainage Basin**: an area of land surrounded by divides that funnels all its water into network of streams draining the area.
- **Divide**: a ridge of high ground along which all rainfall is shed as funoff down one side of the rise or the other.
- **Precipitation**: the change of atmospheric water vapor to liquid (rain) or solid (snow).
- **Evaporation**: the exchange of water from a liquid to a vapor.
- **Transpiration**: the release of water into the atmosphere by plants and animal cells.
- **Infiltration**: the movement of liquid water downward from the surface into and through the soil and rock.
- **Infiltration Capacity**: the max rate at which water can be absorbed is exceeded.
- **Rundoff**: The total amount of water flowing in a stream.
- **Stream Capacity**: ability of a stream to carry large volumes of sediment

APPENDIX - 2

(Print out of Case Study)

Development of Flood Warning System