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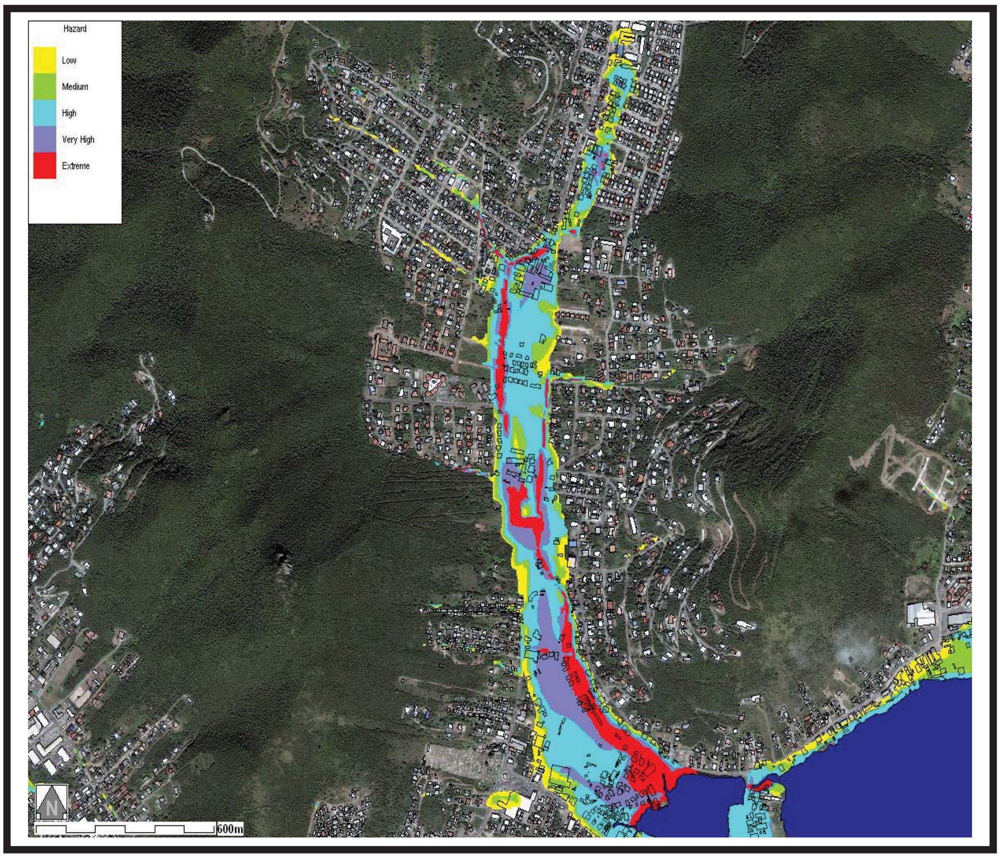

A GIS-based framework for urban flood modelling and disaster management

J.C.W. Ediriweera

MSc Thesis (WSE-HI. 07.02)
April 2007

UNESCO-IHE
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SWITCH

A GIS – based framework for urban flood modelling and disaster management

Master of Science Thesis
by

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"The work in this report received funding from the EU 6th Framework SWITCH project (no.018530)"

This research is done for the partial fulfilment of requirements for the Master of Science degree at the UNESCO-IHE Institute for Water Education, Delft, the Netherlands

Delft
April 2007

Abstract

Floods can be generally considered in two categories, flash floods and general floods. Flash floods occur within a minutes after heavy rainfall. This situation generates an urban flood. Flood disaster is recorded to cause about the third of all natural disasters in the world. For the purpose of flood disaster management planning, computer based flood modelling studies are carried out to understand the physical system of the flood plane, as a general practice. At the same time the concept of flood hazard mapping is becoming a more and more important to the society to better understand floods and on such basis minimize the interaction with the flood event and to minimize the flood damages. Flood hazard zones are usually generated based on the basis of flood depths and velocities. However, the computer based flood modelling result does not give any integration of velocity and depth to produce flood hazard maps. Therefore, this research study is aimed to develop a GIS based framework to produce hazard zones. At the same time this study approaches to asses and visualise the tangible and intangible flood damages by manipulating thousands of data with different formats such as polygons, poly line, point, raster, etc, on one GIS based platform. Further to that, this research demonstrates the capabilities of traffic planning and evacuation strategies, with the help of network analysis tool on the same GIS based framework to minimize the flood damages in future.

Keywords:

Flash Flood, Computer based flood modelling, GIS, Hazard map, Flood damages, Tangible, Intangible, Disaster, Planning, Decision making

Acknowledgements

My research study is an approach to “A GIS based framework for urban flood modelling and disaster management”. This research is done for the partial fulfilment of requirements for the Master Science degree at the UNESCO-IHE Institute for Water Education, Delft, The Netherlands, 2007.

I acknowledge my deepest sense of gratitude to my supervisor Dr. Zoran Vojinovic for his patient guidance, excellent advice, comments and criticism, and constant encouragement on each step from inception up to the end this study.

It is also my pleasure to express my sincere gratitude to Ahamad Fikri Abdullah,Msc for his support , encouragement he gave me throughout this study.

I would also like to deeply acknowledge the Government of Sri Lanka and National Water Supply and Drainage Board, for my nomination with study leave to this master study programme.

I would like to take this opportunity to express my sincere gratitude to the Joint, Japan/World Bank Graduate scholarship programme (JJ/WBGSP) for financing my studies at UNESCO-IHE in Netherlands.

My appreciation specially goes to all department staff members and UNESCO-IHE community who helped me directly or indirectly during my stay in Delft, The Netherlands.

Finally I like to express my deep appreciation to my parents and wife, Ajantha as well as my two daughters, Yashodha, Thedini and my son Tharusha for their patience and moral support during my studies and long stay in the Netherlands.

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List of Symbols

1D	One dimensional models
2D	Two dimensional models
AEP	Annual Exceedence Probability
ALK	Automated Real Estate Map
API	Anxiety Productivity and Income interrelationship Approach
CMS	Cubic Meter per Second
IMS	Arc Internet Map Server
ARI	Average Recurrence Interval
DEM	Digital Elevation Models
DSS	Decision support System
DTM	Digital Terrain Models
FDC	Flood Damage Curve
GIS	Geographical Information system
NSO	National Statistical office
TIN	Triangulated Irregular Network

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1. INTRODUCTION

1.1 Background

Urban floods

Floods can be generally considered in two categories, flash floods and general floods. Flash floods occur within a few minutes or hours after heavy rainfall. Most flash flooding is caused by tropical storms, slow-moving thunderstorms, repeated thunderstorms in a local area, or by heavy rains from hurricanes.

Rapid developments of the cities change the land cover from fields and forests to residential and commercial areas. The change of land covers lead to changes of the hydraulic system of the basin. Impervious concrete and asphalt surfaces that cover most of the urban area decrease the ground infiltration and increase the surface runoff. This situation generates an urban flood. Urban flooding is one of the biggest problems in most of the city around the world.

Why Flood modelling is required

However, the phenomenon of flood is natural part of the hydrological cycle. Flood disaster is recorded to cause about the third of all natural disasters in the world. But most important factor is that, there is a trend of increasing loss of lives and properties on flood disasters, year by year.

The proper flood management is becoming more and more significant to the society to minimize the flood disasters. The better understanding of the physical system, and it's interaction with the environment is an essential condition for effective flood planning and management. In this regard, computer-based flood modelling studies are very important to identify the flood mitigation measures and flood forecasting as an integral part of flood management planning.

1.2 Importance of the research

The need for understanding as a prerequisite for judgement and decision making

With the view on scientific development and the breath of applications the discipline called computational hydraulics has trained into a new discipline named hydro informatics (Abbott, 1991).With the development of hydroinfomatics, the knowledge (beliefs, facts) encapsulated in numerical models and combined with stakeholder preferences have been used as a platform for decision making. Today this concept has been further extended to focus on human understanding process and finally it is encapsulated as a socio technical tool.

Abbot (2004) equated the following set of actions to improve the judgement and decision making process.

$$Modelresults \Leftrightarrow Information \Leftrightarrow Unders\tan ding \Leftrightarrow Knowladge \qquad \text{.....................................} (1)$$

There is a need to turn model results, data, measurements (i.e. facts) into meaningful messages that can be used in urban flood management.

As explained in Vojinovic and van Teeffelen (2007), effective communication of information and knowledge is a key to ensure that each phase of flood mitigation is understood by all concerned and implemented. Consequently, effective decision-making is inextricably linked with an effective communication process. For effective communication to take place between all stakeholders it is important to translate the data and technical information into the form of knowledge and understanding that can be assimilated by non-technical population if they are to be able to intervene meaningfully and responsibly in the decision-making process. To provide the right means that will enable such effective communication process to take place is yet another challenge facing hydroinformaticians.

In this respect, GIS and other visualization tools play a critical role in order to enable environment where stake holders can be included in the decision making process concerning flood and disaster management.

Why is GIS important

A 2D map provides flood extent and depth information, which can be used for catchment planning , risk analysis and also for public education and awarenesess.3D views are of great benefit to the catchments planners because different perspectives of the flooded area can be observed, providing a better understanding of the interested area, including the appreciation of the topography. Features of interest can also be superimposed on such maps, allowing improved interpretation, which is particularly useful for man made features that are not represented in Digital Elevation Models (DEMs).

GIS has been recognized as powerful means to integrate and analyze data from various sources in the context of comprehensive flood plain management. As part of this comprehensive approach to flood plain management, it is very important to be able to predict the consequences of different scenarios in terms of flooded areas and associated risk. So, the results of the 1D, 2D flood models; digital elevation models and other GIS data sets for hydraulic modelling and flood plain mapping are integrated to predict areas at risk of flooding.

GIS can play a major role to transform knowledge (beliefs, facts) to attitudes, judgements, and decisions, to complete the stream of understanding which has been explained by Mike Abbort(2004) and Vojinovic and van Teeffelen (2007). .All knowledge and information which are acquired by hydrodynamic models can process to understanding and making judgements with the use of GIS tool.

As a summary, GIS can use as a good data base which can handle thousands of data in different features such as poly line, point, polygon, etc. Apart from that, GIS can use as an information transformation tool, communication tool and decision making supporting tool. For example, the information of flood depth and flood velocity can integrate and transform to new information of flood hazard, and that can visualize and communicate for decision making process. Further to that the recent update of GIS provides optimisation capabilities to find the best route in networks too.

What are the models used in flood damage assessment
At present there are number of models available for flood damage assessment .Out of that three well known models are Flood Damage Analysis Package (FDAP), ANUFLOOD and ESTDAM.FDAP was developed at the Hydrological engineering centre (HEC) of the US Army Corps of Engineers at Davis, California to compute flood losses (USACE, 1994).In addition to that MOUSE, MIKE-11, MIKE-21, Infoworks models are also available for flood damage assessment.

What kind of flood damages can be incurred?
The first systematic attempt to assess both tangible and intangible damages was introduced by Lekuthai.A and Vonvisessomjai.S in 2001.Intheir research, new proposal of "Anxiety – Productivity and Income Interrelationship Approach (API)"has been introduced to quantify the intangible damages into monitory terms.

In 2004 Van Der Veen .A and Logtmerjer .C come out with broaden damage estimation to the concept of vulnerability, which is the indirect economic effects from urban flooding. Vulnerability is defined as a function of dependence, Transferability, susceptibility

What is the GIS based framework for flood management?
Visualization of flood damage result is extremely important to communicate flood costs to decision makers, in order to give the information to publics and decision makers, the results should be visualized in an understandable way. It is often the case that the end users who are decision makers do not have sufficient technical background to understand complex calculation and or graphs.

On the other hand, still further research is required to evaluate and display the velocity impact, structural impact and traffic disruptions, during flash flood situation. Therefore, this present study explores the use of different GIS techniques for presentation of model results, urban flood mapping, adjust the different flood damage assessment methods to quantify and visualize the urban flash flood, and preparation of emergency flood response planning. In order to, achieve the goals of this research the case study of St Maarten was used. The St Maarten Island is located in Caribbean Sea and has a tropical climate. It is a subject to tropical storms, floods and flash floods.

1.3 Motivation

It is very important to enable visualisation of flood damage results to decision makers, policy planners, designers and to the general public in understandable way. This is important because most of the times decision makers and general public are not competent enough to understand the complex format of tables to make more appropriate decisions to minimize the flood damages in future.

Hydrodynamic model of a drainage system consists of streams, open channels, pipes manholes, weirs and pumps in study area. The model results such as depths, velocities and dimensions of channel section are usually displayed with numerical values and graphs. However, unless used by modellers, such information does not mean much to a general public as well as to the decision makers. Therefore the research area is explored to visualize model results in understandable way on GIS based framework.

The concept of flood hazard mapping is becoming a more and more valuable aspect to the society to minimize the interaction with the flood event and then to minimize the flood damage. Flood hazard zones are generated based on the impact of both depths and velocities. The knowledge of GIS is essential to produce hazard zones, on the basis of numerical model results, because, numerical models does not give any integration of velocity and depth to produce flood hazard maps.

The knowledge of flood damage assessment is a predominant factor to implement structural or non-structural flood prevention measures at preparedness or recovery and rehabilitation stages. In order to assess flood damages, a large amount of data with different formats polygons, poly line, point, raster, etc, has to be manipulated on one platform. The GIS has unique power of handling thousands of data in different formats. Therefore flood damage assessment can only be done within a GIS framework. Further to that traffic planning and evacuation strategies can also be planned within a GIS framework, using network analysis functions.

Finally a Decision Support System can be developed where GIS plays a central role as shown in Figure1.

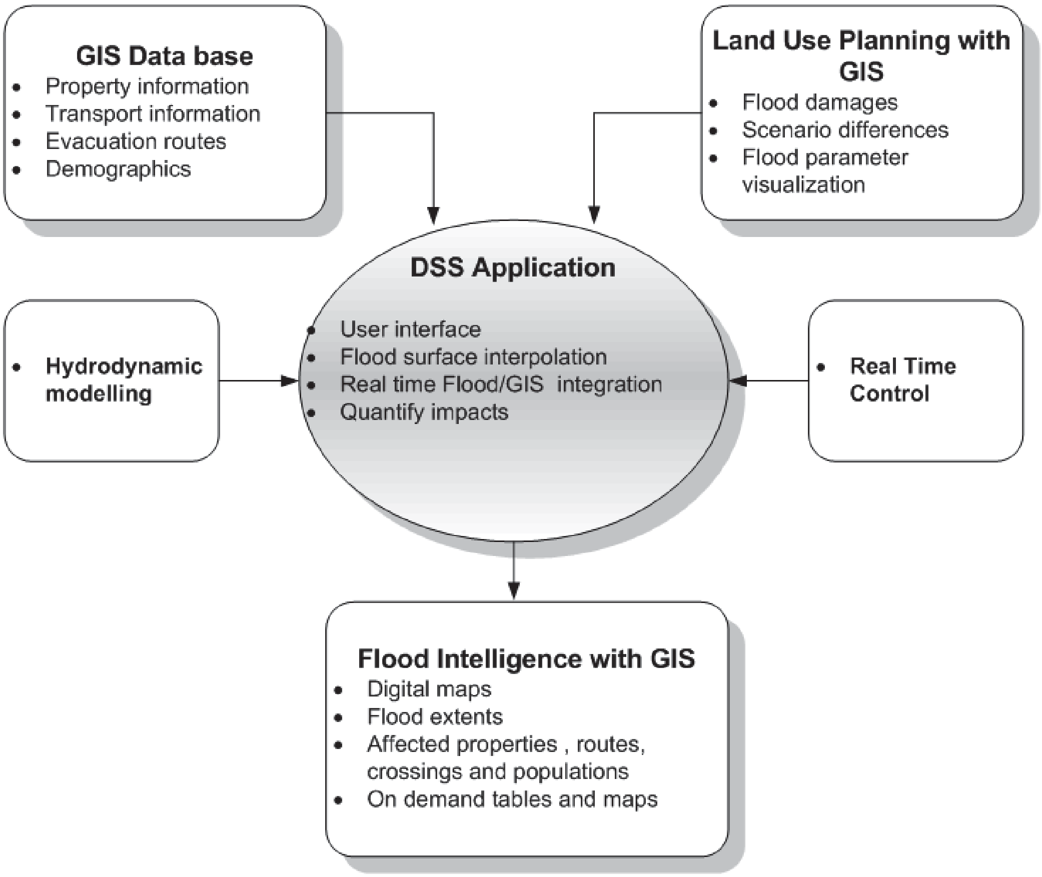


Figure 1: Flood Emergency Decision Support System
Adopted from McConnell .D.D[1], Druery .B.M[1] and Rahman.K [2] (2006)

2. OBJECTIVE OF THE STUDY

2.1 Scope of work

The main objective of the present study is to develop a GIS – based framework for urban flood modelling and disaster management planning. In order to achieve this higher level objective, the following specific objectives were identified.

1. To explore the use of different GIS techniques for presentation of numerical model results, urban flood mapping, and visualization.
2. To explore different methods to quantify and visualize the extent of urban flood damages.
3. To explore the benefits of using GIS in flood disaster management planning.

2.2 Research Questions

To reflect the above stated objectives, the following research questions can be posed.

How to present the extent of flood risk?
How to asses the direct flood damage of study area?
How to asses the intangible flood damage?
How to do the disaster management planning?

3. LITERATURE REVIEW

3.1 Urban Flooding

As a result of uncontrolled human activities, urbanization and unpredictable tropical weather conditions, most of tropical developing countries are facing a risk of urban flood. This is becoming a catastrophic during tropical cyclone and flash flood situations. Such events cause loss of lives, damage properties, road and drainage systems, and whole environment.

There are many studies which emphasize that, with the threat of climate change; such natural disasters are likely to amplify this trend in years to come. In many situations it is the population living in low lying urban areas that are most prone to these disasters. From this it follows that the scientific and professional communities have responsibility to constantly evolve with better stormwater management approaches to minimize hazard risks of urban flooding while addressing different climate conditions.

The water management practices can vary based on climate conditions, geographic location, availability of resources and culture. Especially for tropical islands the sudden and heavy rainfall can unexpectedly occur. Since typically they have mountainous geographical character, low lands and basins are suddenly flooded with high flows. Therefore in order to minimize the frequent urban flash flood damages in tropical Island, the structural measures ,effective non-structural measures such as better hazard mitigation and prevention, improved preparedness and warning systems, well organized pre-emptive action and emergency response have to be effectively integrated. Therefore, the management of urban flooding is a multi- disciplinary process. The urban planners, economists; lawyers, emergency services and other professionals should be involved along with the engineers in this multi- disciplinary process to develop strategic plans for hazard reduction.

Parkinson and Mark (2005), have presented the short, medium and long term objectives of storm water management strategies. In the short-term, the priorities are runoff control flood protection and pollution mitigation strategies, which in many developing countries have yet to be addressed effectively. The medium term objectives focus on the development and implementation of water quality improvement, water conservation and strategies to preserve the hydrology and natural catchments. The long-term objectives place greater emphasis on preservation of natural resources and the amenity value of water in the urban environment for recreational activities and to promote an increased awareness of environmental issues. Although these objectives may initially appear to be somewhat idealistic goals especially considering the existing situation in many developing countries, it is important that planners and designers of urban drainage systems aim to satisfy the need of future generations while keeping with the objectives of sustainable development as defined by World Commission on Environment and Development in 1987.

3.2 Urban Flood Models

Flooding is a natural and variable phenomenon, it can occur on any land surface either in rural or urban. Flooding results in damage to lives, property, crops and negative impacts on human welfare. Flood Plain Management aims to minimize damages and reduce the threat to human life and welfare when major flood events occur. Numerical simulation provides good information of physical process. Expansion process and the distribution of the water depth by numerical simulation results are helpful for discussion and consideration comparing with field survey.

From the review of application concerning modelling of urban flooding it can be concluded that it is important to have a hydrodynamic model based on full dynamic equations in order to describe the flood sufficiently. In this section, a model such specification has been reviewed. The one-dimensional numerical models are based on the cross-sectional averaged Saint-Venant equations, describing the development of the water dept *h* and the discharge *Q* or the mean flow speed *U*. These can be written for the continuity equation

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = F_S \qquad \textbf{(2)}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial(\alpha Q^2 / A)}{\partial x} + gA\frac{\partial}{\partial x}h + \frac{gQ|Q|}{C^2 AR} = 0 \qquad \textbf{(3)}$$

where *h* is the water depth, *Q* is the discharge, α is a velocity distribution coefficient, *x* is the distance between chainage, *t* is time, F_S is a source term, *g* is gravitational acceleration, *C* is the Chezy number, *A=f (h)* is the area of wet cross-section, which depends on the water depth and *R=A/P* is the hydraulic radius with *P=g (h)* being the wet perimeter.
There are 4-point and 6- point numerical schemes. Examples of such model can be found in commercial software such as MIKE-11, MOUSE, SOBEK, Infoworks, SWMM, MIKE-21, etc. Briefly, the numerical solution is obtained from a finite difference formulation of the equations, using a scheme, which is based on alternating *Q* and *h* points (Abbott and Ionescu, 1967).

MIKE 11
Jesper T. Kjelds and Henrik Giørtz Müller(2005), presented, MIKE 11 as a fully dynamic, one-dimensional modelling tool for the detailed design, management and operation of both simple and Complex River and channel systems. This hydraulic numerical modelling tool provides a complete and effective design environment for engineering, water resources, water quality management and planning applications. They developed MIKE 11 GIS interface by linking the MIKE 11 hydraulic model with the Arc View GIS technologies within a DSS Framework as shown in figure-4. The MIKE 11 GIS interface allows for presentation of flood inundation maps, flood impact maps and related statistics. It has the potential to assist in clarifying and disseminating information through enhanced mapping of impacts on flood levels, communities, agriculture, fisheries and the environment.

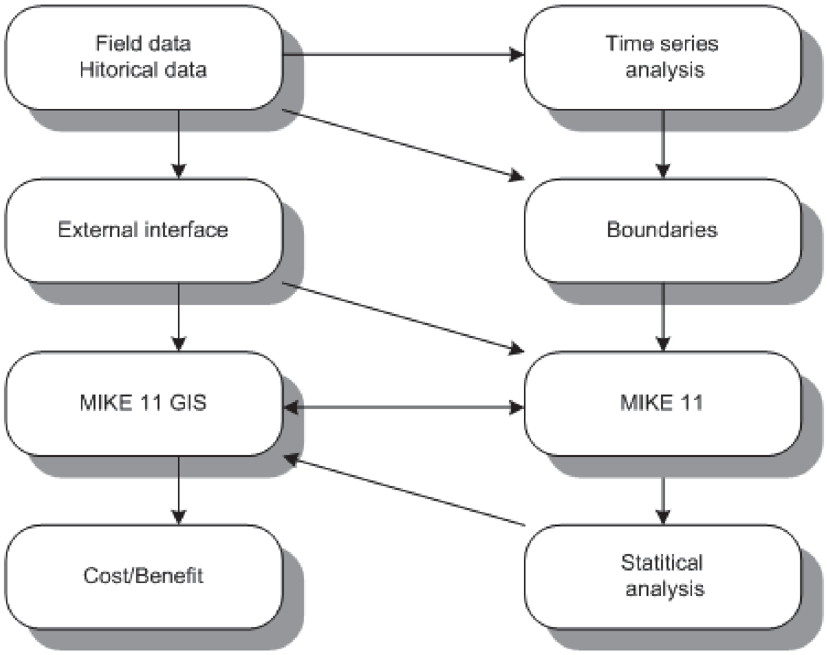


Figure 2: Disaster Management using the MIKE 11 Decision Support System
Adopted from, Kjelds.J.T and Müller.H.G (2005)

During their studies they explored that the main data inputs to MIKE 11 GIS were MIKE 11 model networks and MIKE 11 simulation results, GIS themes, one or more Digital Elevation Model's (DEM), and, if available, imagery from satellites or aerial photography. Data output from MIKE 11 GIS were flood maps, graphs of flood levels, terrain and flood level profiles, flood inundation statistics and flood plain topographic data. Flood plain cross-section profiles were extracted and exported to a MIKE 11 database. The profiles were also merged with MIKE 11 river profiles. Then Flooded area versus elevation curves were computed to quantify the storage capacity of sections of the flood plain, and were also exported to a MIKE 11 cross-section database.

The MIKE 11 GIS main outputs are flood maps, an ideal media for visualizing and understanding flooding, and for analyzing flood impacts on other sectors because of interference. Flood depth maps and duration depth maps were generated. Comparison maps, which compared two flood maps of the same type, presented the impact from flood interference or the change in flooding over time. Flood maps and comparison maps can be used by other sectors for flood damage mapping

Flood level time-series and Terrain/Flood level profiles were also output to supplement the flood and comparison maps. The Duration of flooding also incorporated using Duration Depth maps. These maps are particularly useful for assessing crop damage based on resistance to Inundation and growth rate. Impacts caused by flood interventions or the changes over time were displayed using Comparison maps. Two Flood Maps were compared and the visualized the change in flood depths or Duration Depth.

MOUSE

MOUSE offers comprehensive and advance modelling tools for urban drainage systems, storm water sewers and sanitary sewers. The MOUSE surface runoff modules have three types of surface runoff computation:

- Time-area model
- Kinematics wave model
- Linear reservoir model

The pipe flow (hydrodynamics) model is based on computation of unsteady flows in pipe network. The computation is an implicit finite different numerical solution, which is based on 1D Saint Venant Equation. Both sub critical and supercritical flows are treated by means of the same numerical scheme, which adapts to the local flow conditions. This system can also model flow phenomena such as backwater effect and surcharge. MOUSE also has modules that can simulate Real Time Control features. It permits description of various controllable devices and makes the definition of complex operational logic for interdependent regulators fully transparent and time efficient. The devices may be specified as settings- or PID-controlled, with control function selection based on a global system analysis. It has GIS add-on modules and animation for result presentation .The MOUSE system is organized in several modules:

- MOUSE Runoff
- MOUSE Pipe (Hydrodynamics)
- MOUSE Real Time

SOBEK-Urban

SOBEK-Urban is a comprehensive tool for a simple and complex urban drainage system. It consists of sewers and open channels. It can model the rainfall runoff process for various types of paved and unpaved areas. This model can also model street flow .For hydrodynamic module, SOBEK-Urban used the complete Saint Venant equation including backwater and transient flow phenomena. Hydraulics structure can be specified virtually in the model to see its performance so that the urban drainage can be improved. The Real Time Control module allows the system to react optimally to water level, discharges and rainfall anywhere in the sewer system or its environment. The output can be superimpose over a GIS or Aerial Photo map of the area so sewer pipes, man holes, canals weirs and pumping stations can be seen at a glance. It also has animation option. This software is conforms to strict Dutch guideline for sewerage calculation .SOBEK-Urban consists of three modules:

- Hydrology
- Hydrodynamics
- Real Time Control

SWMM (Storm Water Management Model)

XP SWMM is a link-node based model for simulation of the full hydrologic cycle from storm water and wastewater. It gives fast solution for analyzing the design of the most complex hydraulics networks including loops, tidal inflows, hydraulic structures ,regulators, multiple time varying boundary conditions and distributed storage structures .But it is North American based technology for their local use, not popular in other areas .

XP SWMM is typically used in combined sewer overflows, Sanitary Sewer overflows, interconnected pond analysis, open and closed conduit flow analysis, major/minor flow analysis, design of new developments, Pollutant Routing and Sewage Treatment Plant Analysis. It has three layers:

- Storm water layer for hydrology and water quality generation.
- Wastewater layer for generation of wastewater flows.
- Hydrodynamic hydraulics layer for the hydraulic simulation of open and closed conduit wastewater or storm water system.

It utilizes self-modifying dynamic wave solution algorithm using implicit solution for unlimited time step. It is not courant number limited, but uses courant time step as guide to prevent numerical attenuation that may occurs for large time steps. Flow routing is computed by modified pulse method in sanitary layer and St. Venant equation in open channel layer. Water quality routing is performed by the solution of Advection equation.

MIKE 21

MIKE 21 is a professional engineering software package for the simulation of flows, waves, sediments and ecology in rivers, lakes, estuaries, bays, coastal areas and seas. Recently MIKE 21 model has been improved to meet the specification of urban flood modelling. MIKE 21 provides the design engineer with a unique and flexible modelling environment using techniques, which have set the standard in two-dimensional modelling. MIKE 21 solved the vertically integrated equations of continuity and conservation of momentum in two horizontal directions. The equations are solved by implicit finite different technique.

Delft-FLS

Delft-FLS is specially suited to simulate the two dimensional dynamic behaviour of overland flow over initially dry land, the influence of existing or future infrastructure on the flow pattern, as well as flooding and drying processes on every kind of geometry, in lowland and mountain areas. Delft-FLS is based on the finite differences method applied to a rectangular grid. It used very robust numerical scheme, known as the Delft or Stelling scheme which makes possible the simulation of both supercritical and sub critical flow, as well as flooding and drying without the use special procedures.

In conclusion there are lots of flood modelling soft wears available in the market, but according to the budget and the objectives, any of these models can be used. In this study, MIKE 11 and MIKE21 are principally preferred because both models can be integrated with Arc GIS to visualize the results and do the damage calculation.

3.3 Use of GIS in Urban Flood Modelling

As a result of rapid urbanization and climate changes urban flooding has become an increasing and continuous threat all over the world. Therefore, better analytical understanding and visualization of this disaster is essential to develop strategies that will minimize the risk of urban flooding. At present, 1D River models, digital elevation models and other GIS data sets for hydraulic modelling and floodplain mapping are often collectively used to predict areas at risk of flooding. Hydraulic and hydrological modelling are an obvious choice for predicting those areas of the floodplain most at risk to flooding and for providing information for use in the evaluation of the associated economic damage.

Geographic Information System (GIS) has evolved over the last couple of decades into a powerful tool for storing, managing, analyzing and displaying spatial data (Burrough and McDonnell, 1998). Generally, the integration of hydraulic models and GIS for floodplain mapping aims to provide

1. Functions to extract information describing the channel system from a terrain model to provide a network description (e.g. topographic data of channel network and adjacent area)

2. Tools that are capable of manipulation results from hydraulic models and displaying and automating mapping of floodplain in GIS (e.g. water surface profiles) (Jones et al, 1998).

Approaches for integrating hydraulic model to GIS have resulted in many different tools for flood prediction and floodplain mapping, e.g. ARC/HEC2 (Beavers, 1994), MIKE 11 GIS (Muller and Rungoe, 1995), HECGeoRAS (Ackerman et al., 2000).

Hydraulic Modelling Data Requirements

Hydraulic models are complex tools, requiring large amounts of input data for their specification to a particular application and produce a vast amount of output data. The data requirements for distributed hydraulic models are grouped into topographic and hydrologic data (Cunge et al., 1980).

Topographic data: describing the channel geometry of the river system and adjacent areas (channel widths, cross-sectional areas) and elevations of the flood plain.

Hydrologic data: model boundary conditions (e.g. inflow hydrographs) and discharge and water level data for the calibration of model parameters (e.g. bed roughness and weir coefficients).

Hydraulic Modelling Simulation Results

1D hydraulic models give ‘point’ results (i.e. point locations along cross-sections or channel with associated water levels), which provide a limited representation of the floodplain. To view the results in a more realistic (real world) representation, a floodplain inundated map is needed, which requires spatially distributed data. This requires the interpolation of point data to give a fully 3D data set, which can then be used perform the flood depth calculation and determine the flood extent.

1D River Model and Geographic Information System (GIS)

Thaveevouthti and Kutija (2007) integrated the hydroinformatics (NOAH) 1D modelling System with Arc view GIS and developed the NOAH-GIS tool to generate 2D and 3D flood plain maps.

NOAH GIS is divided into two parts: Pre _NOAH-GIS and Post _NOAH-GIS tools. Pre _NOAH GIS provides an approach for extracting topographic information from digital spatial data and preparing text files from these data to feed into NOAH 1D. Post NOAH GIS allows the results from the simulation to be imported back to Arc View GIS to perform floodplain mapping. The methodology is explained as shown in Figure 3.

Extracting geometric data

NOAH-GIS provide facilities to create and edit a given river system through interactive digitizing. Along each centreline a series of cross sections, representing the topography of that river channel and the adjacent floodplain area, are specified. During this pre - processing stage, this system allows the topographic attributes of selected cross-sections to be extracted from DEM data sets.

Once the channel centrelines and cross sections have been selected, a TIN DEM is required to provide the necessary elevation. Where the vectors representing the channel and floodplain cross-section configurations intersect with the surface of the DEM, the spatial location (x and y coordinates) and the elevation (z coordinate) are extracted. These geometric data can be exported to text files (ASCII Generate file format), which contain only the basic geometry (i.e. a series of lateral and elevation coordinates) and features descriptions (e.g. identifiers, length) that are required for the hydraulic model.

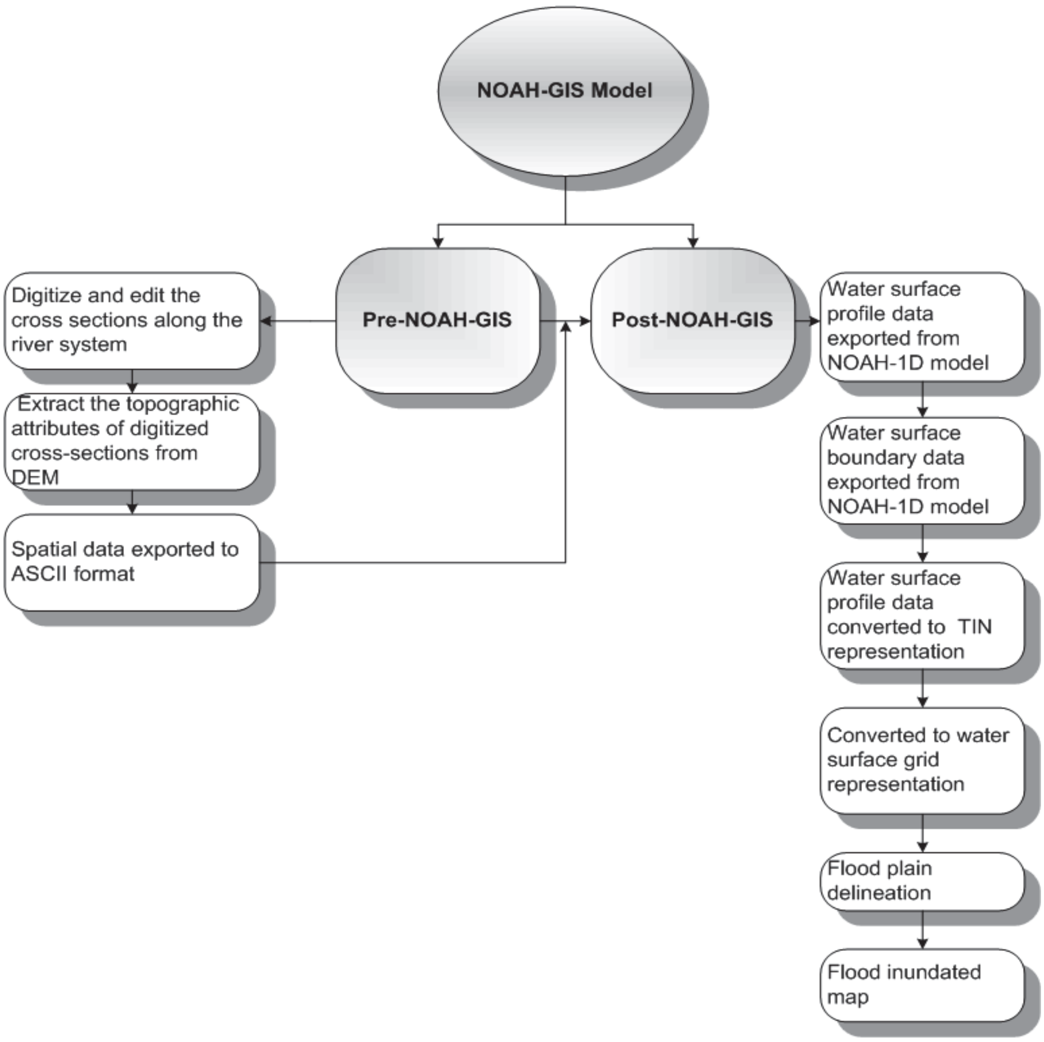


Figure 3: Hydroinformatics (NOAH) 1D modeling System with Arc view GIS
Adopted from Thaveevouthti and Kutija (2006)

Importing physical model (NOAH 1D) results

Water surface boundary data and water surface profile data are required to be exported from NOAH 1D, to develop a floodplain inundation map, with flood extent and depth during the post processing of NOAH-GIS.

The water surface boundary data represent the maximum extent of floodplain area (assumed to coincide with the end of the cross sections) and are used to limit the edge of the water surface when interpolating. Water surface profiles are time series data and can be exported from NOAH 1D as a set of x and y coordinate pairs along each cross-section, with the associated water surface elevation (z coordinate).

Then the water surface profile data are converted to a TIN representation of water level, the extent of which is limited by the surface boundary data. (The water surface profiles are assigned as break lines to force the formation of triangle edges during triangulation.)

Water surface grid

The water surface TIN is converted to a water surface grid and the heights (water surface elevation) data in the input water surface TIN are interpolated to the centre-cell position of all cells. The calculated water surface elevation at each centre-cell is used as a representative for each cell. Therefore, the water surface grid contains representative of water level for each grid cell. Finally, the land elevation is deducted from the water surface grid which is carrying information of flood water level, and produces the floodplain inundated map.

3.4 Urban Flood Damage Assessment

The assessment of monetary damage value for future urban floods is essential to preparing for a disaster and facilitating good decision making at the local, regional, state, and national levels of government. Flood damage assessment can be used to evaluate the cost – benefit analysis of alternative approaches to strengthening flood control measures. Planning and zoning activities, development of regulations and policies can also be implemented to reduce the flood risk based on flood damage assessment.

Existing methodologies for estimating different categories of damages due to floods differ from country to country. In general, flood damages can be mainly discussed under the Tangible, Direct and Indirect damages and Intangible damages as shown in Figure 4.

There are basically two methods in carrying out flood damage estimations. One is to carry out a thorough questionnaire survey of affected population and properties to estimate the incurred loss. The other method is to use stage-damage functions, which describe the damage extent to different types of property for a given inundation depth and inundation duration. Using such stage-damage functions, economic damage to different property categories is estimated and the summation provides the total flood damage. Stage-damage functions are derived either from past flood data analysis, or through analytical descriptions of flood damage to various properties considering the possible damage ratio to a given flood depth and duration. A number of studies are reported in literature that describes stage-damage functions derived from post flood damage analysis (Parker et. al., 1987; Smith, 1994; NTIS, 1996; etc.).

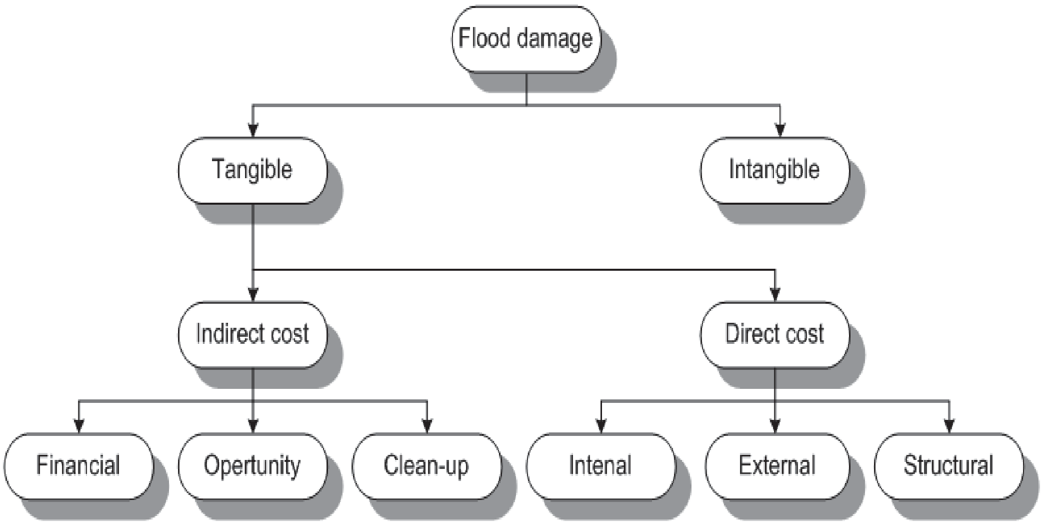


Figure 4: Flood damage classification
(Adopted from "Guidance on the Assessment of Tangible Flood Damages"-2002, Queensland Government)

Type of flood damages
Urban flood damages can be broadly classified into Tangible damages and Intangible damages. The damages which can be estimated directly in terms of money are called Tangible damages. Damages to buildings and contents are considered tangible, because it can be quantified in terms of replacement or restoration cost. The damages which cannot be estimated directly in monetary values are called Intangible damages, such loss of life, anxiety (flood stress) are considered as Intangible and cannot be readily expressed in monetary terms.

Tangible damages are further classified to Direct damages and Indirect damages. Damages that are occurred immediately as a direct interaction with the flood like community infrastructure and private property, called Direct damages. Indirect damages occur as a consequence of direct flood impacts. They include reduced economic activity and individual financial hardship, as well as adverse impacts on the social comfort of a community, and take in disruptive impacts, including lost trading time and loss of market demand for products.

3.4.1 Tangible Damage

In order to estimate the Tangible direct damages, the physical damages to the building structure and its contents should be assessed based on two main flood characters, flood depth and duration. Kanchanarat (1989) developed the flood damage curves to calculate the flood damage per establishment by explaining the two main flood characteristics of depth and duration on that establishment. In the same time, flood damage changes with type of land use for the same depth. Lands can be classified and valued as residential, commercial, Industrial and agricultural based on their usages. He derived the damage curve for four different land use types namely residential, commercial, industrial and agricultural in Bangkok and vicinity.

These four damage curves are originally based on data from 1983 Bangkok flood event, and then processed by using the following equations.

$$DPE = a0 + a1H + a2L,$$

Where

DPE = Damage per establishment (baht);

H = Maximum flood depth (cm);
L = Flood duration (day);

*a*0, *a*1, *a*2 = Parameters

According to the results of case study in Bangkok, Kanchanalak introduced following values for a_0, a_1, a_2 parameters based on the type of land use, as describe in Table 1.

Table 1: Parameters of damage curve equations

Type of Land use	a_0	a_1	a_2
Residential	-300.5	45.4	33.8
Commercial	-2.2	88.1	0
Industrial	-1740	522.8	180.5
Agricultural	-1047.2	553.5	0

Source: Kanchanarat, 1989.

Having estimated the direct damage per every land use, total amount of direct damage for all land use types and cells were calculated using following formula.

$$DFD = \sum_{j=1}^{3}\{\frac{DPE(j,H,L)}{APE(j)} * PC(j) * AREA\} \quad \text{..} \quad \textbf{(4)}$$

Where

DFD = Direct Flood Damage
DPE (j, H , L) = Direct flood damage establishment of j at H,L
APE (j) = Average area per establishment of j
PC (j) = Percentage of land use type j in cell
AREA = Area of cell
J = 1, 2, 3 (Residential, Commercial, Industrial)
H = Maximum flood depth (cm)
L = Flood duration (day)

Indirect damages can be considered as a fixed percentage of the direct damage. This assumption is accepted for practical reasons, as the time required for a detailed analysis of indirect analysis is too great to be justified in an individual flood study (James and Lee, 1971).

How ever in residential sector, flood damage is related, among other factors than the flood depth, duration and velocity. The factors of quality of the building, location state of the building and its contents. Based on all these factors, four different levels of High, normal, low, and labouring building standards are also associated in flood damage curve function. In this manner commercial sector buildings are also classified based on income criteria. (Nilo Nacimento.2006).

3.4.2 Intangible Damages

An intangible damage assessment is very complicated and difficult to quantify due to its subjectivity. However, it is also very interesting to develop a new approach to quantify or convert the intangible damage into monetary terms. Unfortunately, so far there has not been any research that investigates this possibility. In 2001 Lekuthai and Vongvisessomjai started a research on Intangible damage quantification and developed the "anxiety –productivity and income interrelationship approach" (API) to quantify the intangible damage in monetary terms.

This new API multidisciplinary approach assumes that flood depth and duration are the two main variables that determine anxiety damage, which is, in this way, similar to tangible damage. Furthermore, the land-use patterns are also integrated in this model for determining anxiety damage as well. In effect, anxiety damage can be indirectly measured in terms of the decrease in productivity that affects the national product or national income.

The relationship between flood depth and anxiety, are generally assumed to be directly related. The depth scale, which varies from 0.1 to 1.0 m, is taken from a study on the 'Socio-economic Evaluation of the Integrated Flood Relief Plan of the West Bank' published by the Institute of Environment Research at Chulalongkorn University (1986). The socioeconomic data in this study, which was collected after the 1983 flood in Bangkok, indicates that over 80% of people feel that they will not be affected by a flood depth of less than 0.1 m. On the other hand, over 80% of people feel that they will be greatly affected by floodwaters higher than 1.0 m. The study measures anxiety on a scale from 0 to 100 units, as there is no standard anxiety scale currently available. In general, normal people should not have 0-level anxiety because, even when there is not any flood, people normally possess some degree of anxiety. It is therefore assumed that the minimum level of anxiety is 20, while the maximum anxiety level is set at 80, as anything above 80 is considered intolerable for a human being. Despite the fact that the same flood depth may cause different levels of anxiety in different people, it remains undeniable that flood depth and anxiety are directly related. A non-linear function involving a polynomial equation is applied to describe this relationship and its associated behaviour.

The scale of productivity is assumed to vary from 50 to 80% of total production capacity. Productivity is the ability to produce output from a combination of inputs. Again, different people have different levels of productivity while operating at the same anxiety level, but the act remains that anxiety and productivity are inversely related and may be characterized by a polynomial equation. The upper productivity limit is assumed to be 80% of maximum capacity for the simple reason that nobody works at 100% of his or her maximum productivity. A similar explanation can be given insofar as machine efficiency is concerned. Conversely, nobody works at 0% of his or her maximum productivity and still gets paid. It is assumed that people have to maintain their productivity at least above the 50% level in order to meet an employer's minimum requirements for the payment of wages.

The relationship between productivity and income is considered to be the return on production. People contribute their productivity and in return earn their income, and, in principle, their income should reflect their productivity. At the national or macro level, the anxiety damage will create a tremendous decrease in national product or national income, as productivity and income are directly related and as the relationship is assumed to be linear. There is, however, a lower limit on the income scale, which is 80% of the normal rate. In practice, a part of income is spent on necessary consumption, and the remainder is saved. Income cannot be zero because a human being must consume to survive. According to an NSO Report, people in Bangkok area are required to spend 80% of their income on consumption. As a result, anxiety damage exists in terms of income reduction on a scale varying over from 0 (normal income) to 20 (lower income limit), which is derived from the income reduction linear scale form 80 to 100.This methodology is described in Figure 5.

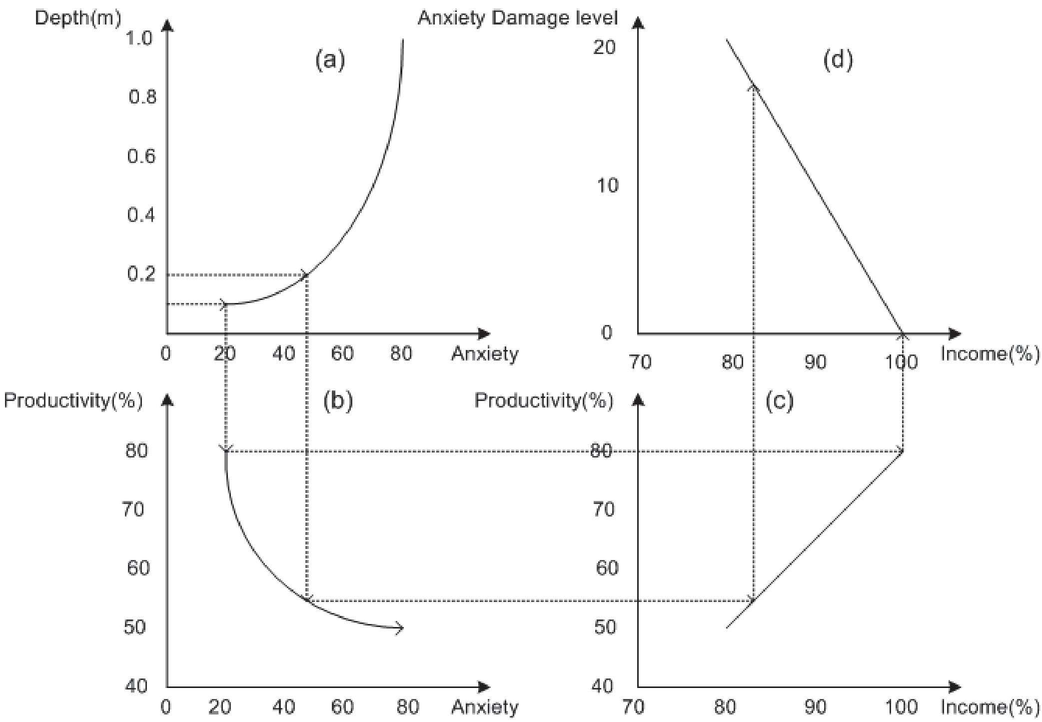


Figure 5: Flood depth-anxiety-productivity and income relationship
Adopted from Lekuthai and Vongvisessomjai (2001)

3.4.3 Expected Annual Flood damages

Penning-Rowsell and Chatterton (1977) developed a methodology and derived following four inter relationships:

a) Flood levels and extents: stage-discharge data,
b) Return period of different flows: probability-discharge data,
c) Losses caused by various levels of flooding: stage-damage data
d) Damage probability to determine the expected annual flood damage.

The total flood damage can be calculated by summation of tangible and intangible damages as discussed in early chapters. The total flood damage can furthermore be simulated under different magnitudes of floods.

The probability-discharge relationship is the relationship between river discharge and recurrence interval (flood return period). The flood frequency analysis e.g. Log-Pearson Type III, Gumbel, and Log –Normal distribution, is applied. Therefore, the interval between recurrent flood events (the flood return period) is obtained on the basis of the discharge from a given river according to the method presented in Figure 6/graph-B. This flood return period (exceedance probability) is needed in order to develop the probability-damage relationship, which is needed to calculate the expected annual flood damage.

Then, the recorded river discharge data is converted into a stage value by means of the rating-curve (flood stage-discharge relationship). This rating-curve is the relationship between discharge and flood stage, which can be determined on the basis of data collected in the field. The measured river discharge and its water level data are collected in order to produce this rating-curve, which is illustrated in Figure 6/graph-A. In this way, the water level of the river corresponding to the occurrence of a certain flood event is determined. This is used as a boundary condition for hydrodynamic mathematical model simulation, which can generate values for the water level in the research area throughout a certain period. The simulated water levels over the given time Constitute the required input data for calculating both the tangible and intangible flood damage by means of the procedures that have already been described.

The stage-damage relationship can be determined from the data on the total flood damage corresponding to the relevant flood stage, as shown in Figure 6/graph-C. The total damages caused by periods of recurrent flooding (flood return periods) are utilized to determine the probability-damage relationship, as presented in Figure 6/graph-D. At the same time, this curve presents the flood damages incurred for different intervals of recurrent flooding (flood return periods). The expected annual flood damage can be determined from the above probability-damage curve. The benefit calculation determines the value of the expected annual benefit from an alleviating procedure, constituting a factor by which all damage data are proportionately reduced. This is achieved by calculating the contribution each successive flood event makes to the annual average flood damage.

Thus, the mean damage expected from two flood events of similar magnitudes is multiplied by the probable interval between the two occurrences (Parker *et al*., 1987). In other words, the expected annual flood damage is
the damage divided by its return period, or the damage multiplied by its exceedance probability. Furthermore, in practice, the area under the curve describing the probability-damage relationship is equivalent to the expected annual flood damage. Then, the expected annual benefit can be calculated by means of the differences in the expected annual damage forecasts provided by two flood mitigation scenarios, as demonstrated in Figure 6/graph-D.

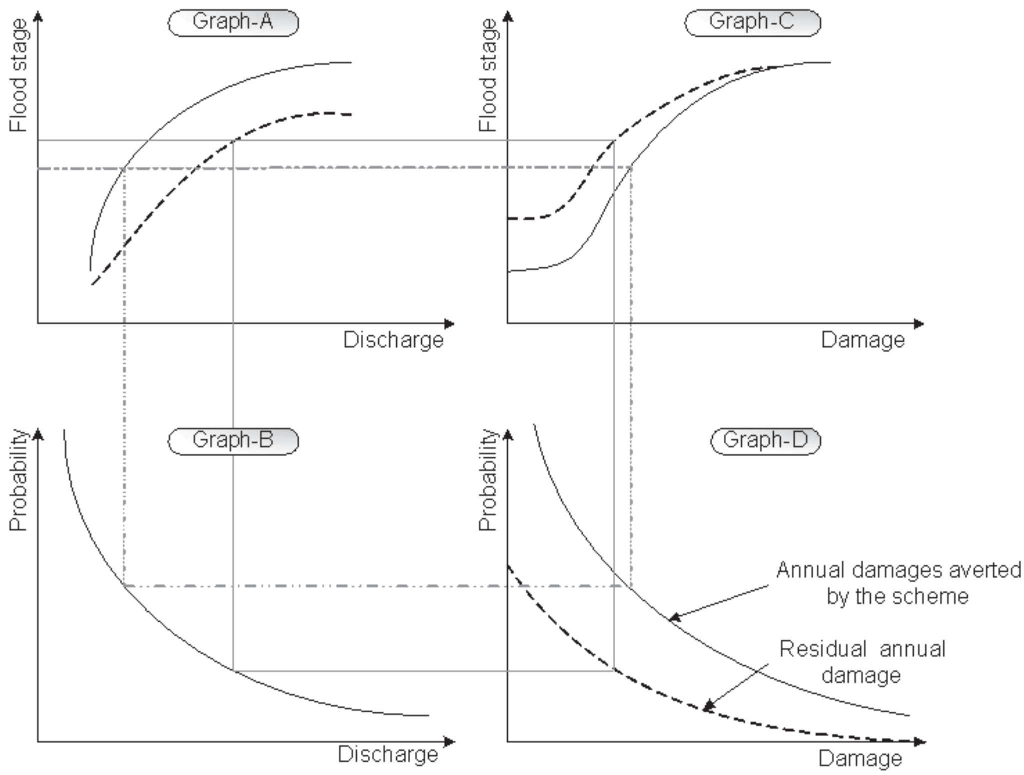


Figure 6: Annual flood damage assessment
(Adopted from Penning-Rowsell and Chatterton-1977)

Observation form the previous research found that there are a lot of models available for direct damage estimation. Besides conventional way of damages estimation, there are also some positive movements in research to incorporate other available tools and technology such as GIS with the existing models. This evolution is very helpful and will give the better future in flood damage estimation. The capability that can be adopted from the new technologies with this incorporating model hopefully can serve more accurate and reliable result. As for indirect and intangible damages, very few models have been established. A lot of them still in research and only a few of indirect and intangible damage have been discovered. It is worth to discover further aspect of damage such as traffic disruption in future research. In this present research, Flood Analysts tools were used to perform the urban flood damage estimation for St –Maarten Island.

3.4.4 Presentation of Damages

The GIS methodology that quickly provides detailed information for planning, implementing, and reporting was integral to the overall success of assessment methodology following a disaster. S. Waring et al (2005) in his research "The utility of GIS in rapid epidemiological assessment following weather-related disaster" reported that the entire process was completed within 1 week and provided timely reports to city officials, health departments, and other agencies assisting with flood recovery efforts. These results provided an expedient assessment of health-related problems and damage, underscoring the utility of rapid needs assessment to identify actual health threats and ensure delivery of resources to those with the greatest and most immediate need.

In 2001, Zerger has been examining GIS decision utility for natural hazard risk modelling. The output provided by his model is a probability of over floor flooding for each building in the range 0–100% for each inundation scenario. Continuous risk probability maps are then re-classified into binary maps of risk by selecting a threshold value below which flooding is not likely.

Der Veen et al.A.V. (2005) tried to visualize vulnerability to flooding. In their research, they want to detect the intensity of economic production in space measured by the economic concept of value added. Grids in space with high value added are labelled as hotspots.

Massachusetts Department of Environmental Management (1997) report that in City of West Covina, Natural Hazard Mitigation Plan has introduced localized flood hazard maps. One method that has been introduced is by using high water mark from flood event or aerial photo in conjunction with the existing maps to better reflect the true flood risk. GIS analysis of flood hazard area has been used to update FRIM (Flood Insurance Flood Map). Using GIS technology and flow velocity models, it is possible to map the damage that can be expected from flood events over time. It is also possible to pinpoint the effects of certain flood events on individual properties. Flood hazard areas are than overlay on tax assessment parcel maps to evaluate the flood hazard risk for a specific parcel during review of a development request.

In conclusion, the previous research suggests that GIS is the most popular method used to visualize the result of flood damage estimation. Many of the research use raster grid approach to represent the flood damages result. From observation flood inundation map is the most popular subject to be visualized to represent the flood damages. It is understood that from flood inundation map, only location of the flood can be easily determined but the damages itself cannot be seen directly from the map. In previous way, the calculation and presentation of damages is presented in graph and tables. Very few of them tried to visualize it in term of maps. From the observation it is seen that recently, more and more research appears to fulfil the lack of damages visualization. This present study tried to focus on the methods in GIS that can be used to visualize flood damage analysis result. The attention is paid on the visualization of the damages itself and not only the flood.

3.5 Flood Disasters and Emergency Management with GIS

Emergency response refers to actions taken immediately before, during, and after the onset of a major disaster or large-scale emergency to minimize the loss of life and harm to people and their property and enhance the effectiveness of recovery. Examples of emergency response activities include hazard detection and warning, evacuation of threatened populations, shelter for victims, emergency medical care, search and rescue operations, security and protection of property, and family assistance. Other examples include the construction of temporary levees, closure of roads or bridges, provision of emergency water or power supplies, and response to secondary hazards such as fire or the release of hazardous materials. The quality and timeliness of disaster response are typically functions of the planning and training done during pre-disaster preparedness.
Therefore flood Disaster management and emergency response planning is required to minimize the damages and re-establishes the essential services as illustrated in Figure 7.

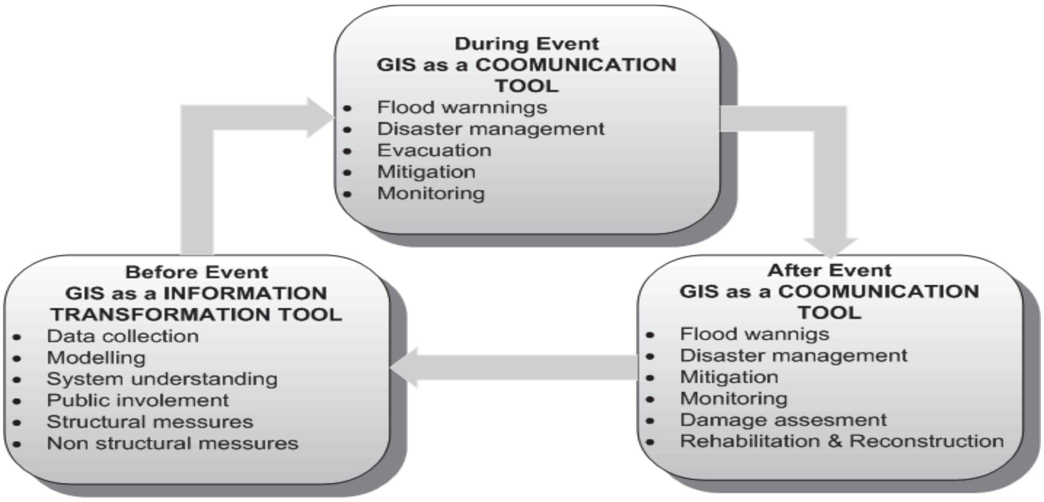


Figure 7: Disaster Management Plan
Adopted from Vojinovic and van Teeffelen (2007)

Vojinovic and van Teeffelen (2007) focused the flash flood situation in St Maarten Island, which is a tropical Island in Caribbean Sea. Since this Island is frequently affected by the flash flood, it is very important to formulate an emergency response plan to minimize the damage and maximize the effectiveness of the integrated actions and measures against the disaster.

The better understanding of behaviour of the existing system, during any disaster is, a key role in emergency response planning. The distribution of peak velocity and depth of flooding throughout the flood plain are usually determined by mathematical models. Mathematical models are an approximation of the real flow conditions and the degree of approximation varies between models. In order to identify the hazard zones, the distribution of velocity and depth profiles, based on mathematical model results are integrated in a GIS framework. Hazard assessment identifies the probable location and severity of disaster and the possibility of their occurring within a specific time period in a given area.

Geographical Information system (GIS) is identified as a very useful data base as well as a tool for hazard assessment, since all these studies are completely based on available scientific information, including geologic, geomorphic, and soil maps; climate and hydrological data; and topographic maps, population data, aerial photographs, and satellite images. Historical information from long-term residents also helps characterize potential hazardous events. To be most successful, hazard assessment requires data and scientific teams trained to evaluate the data and finally to develop global and regional hazard maps on a GIS based platform.

This hazard visualization explores the avenues to identify and evaluate the structural and non-structural measures against the hazard, under the “Before Event’’ in Emergency response planning process.

3.5.1 Non-structural Mitigation Measures

Capacity building
Non-structural mitigation measures are non-engineered activities that reduce the intensity of hazards or vulnerability to hazards. Examples of non-structural mitigation measures include, capacity building and professional training, flood warning system, land use and management, zoning ordinances and building codes, public education and training, and reforestation in coastal, upstream, and mountain areas. Non-structural mitigation measures are particularly appropriate for developing countries because they usually require fewer financial resources. Capacity building and professional training is very important to design and maintain reliable mathematical models with time.

Flood warning
Subsequently very important non-structural measure is establishing a real-time flood warning and information system. The main advantage of this kind of system is to minimize the public interaction with the flood and prevent disasters. In such, real time warning systems can substantially enhance the actions and decisions on safety measures. Especially this warning can be incorporated with traffic controlling, emergency services, (fire brigade, and rescue forces) and evacuation of children from schools, etc.

Awareness
Awareness involves building an emergency response and management capability before a disaster occurs. Key disaster preparedness activities include training programs for response personnel, exercises and drills of emergency plans, education programs to inform citizens, hazard detection and warning systems, identification of evacuation routes and shelters, maintenance of emergency supplies and communications systems, establishment of procedures for notifying and mobilizing key personnel, and individual household measures such as clearing attic space to make room for belongings in case of a flood. Many programs can be used to increase public disaster awareness. Broadcasting agencies can contribute to increasing public awareness by designing announcements and disaster-related programs. Inclusion of disaster awareness in school programs is a particularly efficient and economical strategy. Other successful practices include advertising at popular sporting events, on shopping bags, or during community programs; hosting workshops; and organizing national disaster preparedness days.

Vulnerability

Vulnerability studies show which are the most sensible and helpless locations to be addressed at any disaster .Producing the vulnerability map based on GIS platform helps to make safety measures and keep continuous monitoring on this matters. Physical vulnerability studies analyze impacts on buildings, infrastructure, and agriculture.

Social vulnerability studies estimate the impacts of especially vulnerable groups, such as the poor, single parent families, pregnant or lactating women, the mentally or physically handicapped, children, and the elderly. Social vulnerability studies take into account the public awareness of risk, the ability of groups to self-cope with catastrophes, and the institutional structures in place to help them cope (Coburn, Spence, and Pomonis, 1991).

Economic vulnerability studies estimate the potential impacts of hazards on economic assets and processes. These studies include indirect losses (such as business interruption) and secondary effects (such as accentuated poverty, higher unemployment, or increases in levels of external debt).

Risk analysis

The risk analysis stage of risk identification integrates information from the hazard assessment and the vulnerability studies in the form of an estimate of the probabilities of expected loss for a given hazardous event. Identification of risk leads to the development of insurance markets.

Formal risk analyses are time-consuming and costly, but risk modelling comes from the private sector, and that give adequate results for project evaluation (Bender, 1991).

Risk transfer is a critical component of a comprehensive program for most developing countries. Japan, France, Spain, the United Kingdom, and the United States all use risk transfer to link the various components of their natural disaster risk strategy. Insurance is a major component of the risk management strategy of wealthier countries. In the higher-income countries, 30 percent of the loss from natural hazards is insured. In the poorer countries, insurance covers 1 percent of the losses from natural hazards.

3.5.2 Structural Mitigation Measures

Structural mitigation reduces the impact of hazards on people and buildings via engineering measures. Examples include designing infrastructure, such as electrical power and transportation systems, to withstand damage. Underground transmission lines, for example, are protected from hurricane damage. Levees, dams, and channel diversions are all examples of structural flood mitigation.

The structural mitigation projects have the potential to provide short-term protection at the cost of long-term problems but in areas in Vietnam, flood control systems have exacerbated rather than reduced the extent of flooding; sediment deposit in river channels has raised the height of river channels and strained dike systems. Now when floods occur, they tend to be of greater depth and more damaging than in the past (Benson, 1997).

Vojinovic and van Teeffelen (2007) identified structural measures for different design storms on a case study of St Maarten. Detention storage in upstream of problem area was identified to pond the channel overflows. This action is considered as a short term measure until the critical channels are up graded. Upgrading of stormwater outlets, improvement of channel network, draining of areas with high groundwater table are identified as long term measures. On the other hand onsite detentions, removal of culverts are identified as short tem measures.

As a summery, structural flood mitigation works are usually expensive, besides creating other social disruption and inconvenience during the construction period. Hence, in most cases, the optimal strategy for flood control is one which combines structural measures with non-structural measures developed on the basis of a comprehensive master plan study that takes into account the future potential for development or land use. There should be a wider application of planning and legal instruments through appropriate laws and administrative procedures; this would ensure that future development would take place with the least burden or impact on existing drainage systems, particularly in the highly built-up areas where land acquisition, construction and utilities reallocation costs are high or prohibitive. The problem of urban drainage and flooding is a real concern and must be dealt with properly since it has a direct impact on the quality of life and the living environment, besides supporting and sustaining urban growth.

Non-structural flood mitigation strategies rely upon action and support from household and local organization working collectively and require the participation from the inhabitants of flood-risk areas. In addition, flood warning need to be issued so that communities can prepare for the onset of a large flood event and for urban authorities to prepare for an emergency situation. These response strategies can minimize potential damage, but there will also be a need to develop appropriate strategies for flood recovery and rehabilitation for affected communities.

Reconstruction and Rehabilitation

Reconstruction and rehabilitation refer to programs that provide longer-term assistance for people who have suffered injuries or incurred losses due to a major disaster. The objective is to facilitate the return of these communities to their pre-disaster condition. Rehabilitation encompasses repairing and reconstructing houses, commercial establishments, public buildings, lifelines, and infrastructure; restoring and coordinating vital community services; expediting permit procedures; and coordinating activities among governments. Recovery can take a few weeks or several years, depending on the disaster’s magnitude and the reconstruction resources available.

4. METHODOLOGY

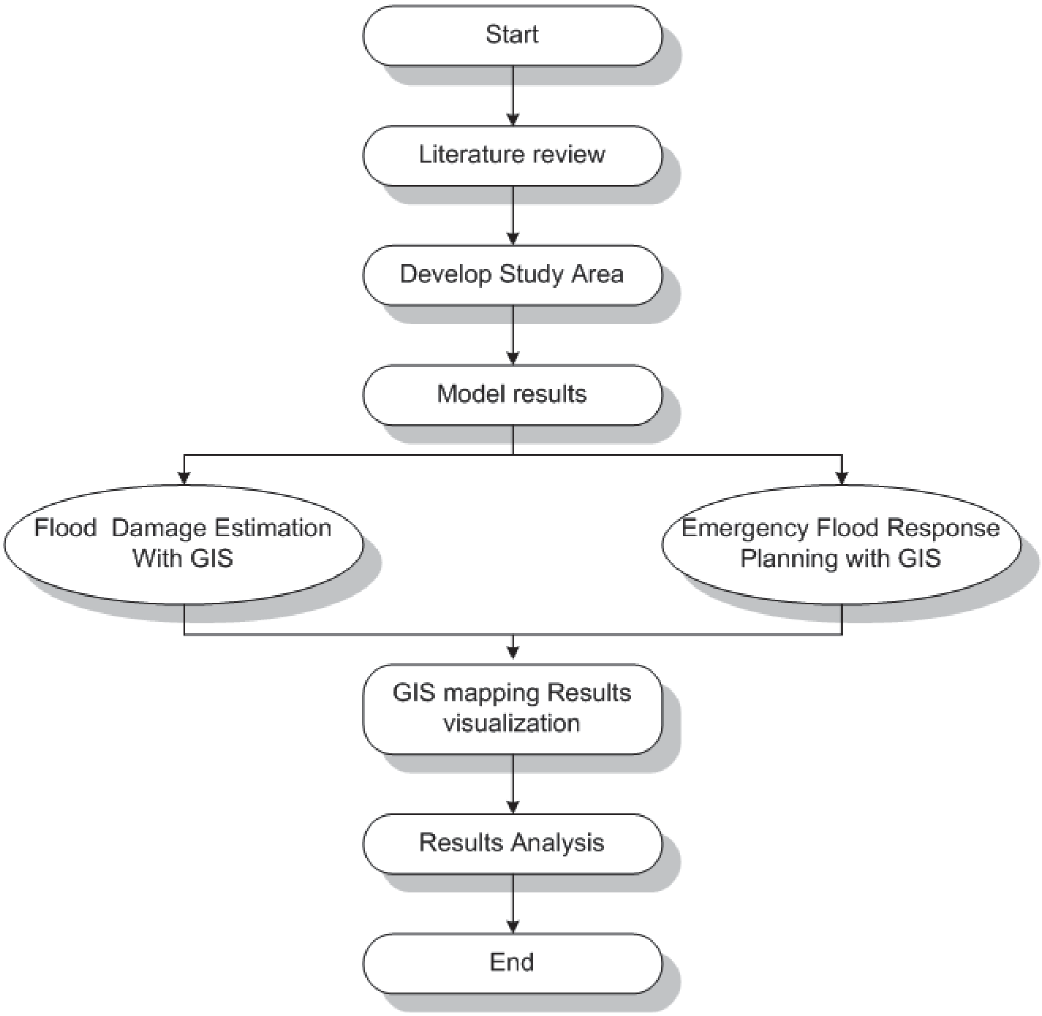


Figure 8: Methodology flow chart of this Research study.

The overall methodology of this research study is shown in Figure 8, and discussed in this chapter. At the beginning of the research, the relevant literature on urban floods, Flood modelling, Flood hazard mapping, and tangible and intangible damage assessments was reviewed to acquire the knowledge about, conventional and current methodologies.

In order to achieve the research objectives the flash flood situation on St Maarten Island was used as a case study. The tropical climate condition and topography are the significant features which contribute to the flood disaster in this area.

Hydrodynamic model was simulated to understand the physical phenomena of this disaster. The all stormewater drainage network in this study area was modelled with MIKE-11 hydrodynamic model. This is a 1D model, which provides the depth and velocity variation along the branches.

In order to visualize to 1D model results in a 2D spatial interface, the 1D, MIKE-11 model results were interpolated to create a surface and intersect with the Digital Terrain Model (DTM). DTM stored elevation value in as such used to regularly spaced 10m intervals. Each value represents the elevation value of that cell. But along the channel section there are no regular spaced intervals. To overcome this problem Triangulated Irregular Network (TIN) approach was used. A TIN is a vector-based topological data model used to represent terrain. As indicated by the name, TINs contain a network of irregularly spaced triangles. Areas of high-relief will contain a higher density of small triangles while areas of low-relief will be represented by larger triangles. TINs can store a higher amount of topographical detail in a smaller sized dataset. The binary MIKE-11 model results files were converted to the readable text file format and then used as input to a GIS. The triangulation as well as the file conversion was carried out in "waterRIDE" software. waterRIDE package is a product by Patterson Britton and Partners developed for flood modelling, flood plane management and planning, flood emergency management, custom application and spatial data management.

Depth and Velocity result were mapped in Arc –GIS 9.1, to define the flood hazard zones. With the functionalities of Arc GIS, new flood hazard zones are developed for this study area, based on velocity and depths. Disaster management planning, including evacuation strategies and traffic planning was done based on the flood hazard zone maps.

In order to calculate the total flood damage, direct damages, indirect damages and intangible damages were estimated separately. In this research, methodology is developed and improved to estimate direct damages, using Arc GIS. At the same time, methodology has been revised to estimate the intangible flood damages, according to the study area. Indirect damages are estimated on a percentage basis .Within the scope of this research, there was no intention to deal with indirect damages and therefore most analysis concern the derivation of direct damages.

5. CASE STUDY

5.1 Study Area

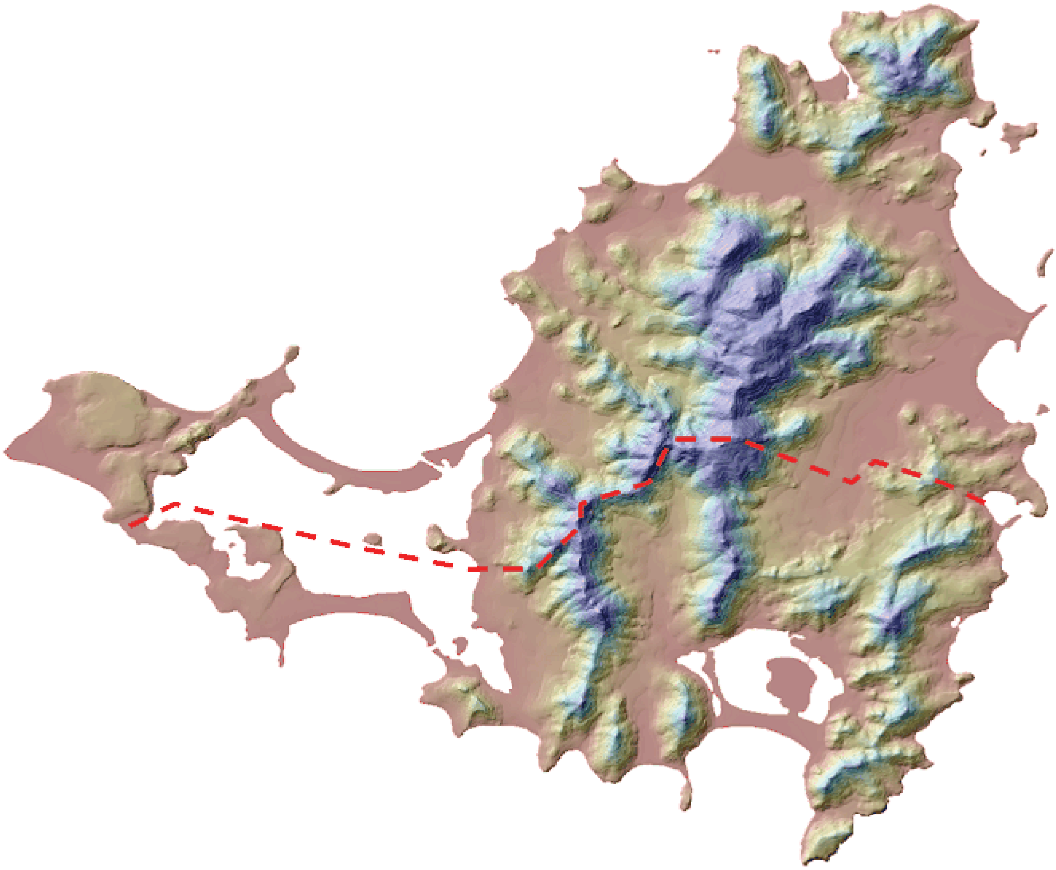


Figure 9: Study Area

(The red dashed line depicts the borderline between the Dutch side and the French side of the Island Territory)

St Maarten is located at the South-East of the Bahamas and Florida, in the middle of numerous English, American and Dutch islands. The southern part of the island which is illustrated in Figure 9 ,belongs to the Dutch government, and is named St Maarten, and occupies the southern 44 square kilometres of this 95-square-kilometer island; St. Martin, a French dependency, occupies the northern half.

5.2 Problem Statement

The climate on St Maarten is tropical and as such subject to tropical storms and hurricanes. It has an average, 27-30 degrees of centigrade, all year round with gentle trade winds which keep the humidity low. The winds blow a fairly regular 28 km/hr from mid-November to mid-April. Occasional showers in late summer and early fall, with average annual rainfall of 1125mm. As in all tropical environments, sudden rain showers are to be expected. They can be intense due to the unexpected cloud burst from tropical wave systems, but are typically brief. St Maarten has been badly affected frequently by the flash-floods, due to the tropical rain showers.

The rapid development of St Maarten, over the past 10 years has led to expansion of both residential and commercial infrastructure. The total population has grown from 13,156 in 1980 to nearly 41,000 in year 2000.Government is presently in the process of a major road enhancement project, which includes the construction of new roads, the re-paving of existing roads, the implementation of roundabouts and traffic lights.

However all these development activities pave and improve the soil surface increasing the impermeability of soil to reduce the infiltration, as well as decreasing the surface roughness to increase the surface runoff velocities.

On the other hand, large areas of the island are steep, with relatively little vegetation coverage, since any rain fall causes, a high level of erosion which carries a large volume of silt and debris clogging the drainage system in flat terrains.

Consequently, a large quantity of surface runoff at high velocity accumulates to the drainage system within very short period during the tropical rain showers, which can not be accommodated by the existing drainage system and generates a flash urban flood. Then all stormwater channels are flooded causing damage to the adjoining roads, properties and loss of lives too.

6. AN APPROACH FOR TANGIBLE DAMAGE ASSESMENT

6.1 Conventional methods

The present study of direct damage estimation is limited to estimate the direct monetary flood damage to buildings and contents of private households. The flood-damage estimation can be undertaken on different levels of spatial differentiation:

On local scale, the damages can be estimated based on spatial data and stage-damage-functions for individual buildings or land parcels. . In Germany, commonly the Automated Real Estate Map (ALK) is used for these assessments. The ALK data show the base-area of the single buildings and give their specific use (e.g. residential building, commercial building, stable, garage).

On a more aggregated level, the approach can be based on statistical information about population, added values, business statistics or capital assets for land-use units. These values are published yearly by responsible state authorities (statistical offices). Commonly data from the Authoritative Topographic-Cartographic Information System (ATKIS) is used for this approach in Germany. The ATKIS data differentiate more than 100 types of land-use (e.g. residential area, power plant, sports facilities).

Large-scale analyses may be carried out for larger land use units, like communities or ZIP-code areas, considering that they may be only partially flooded. These analyses are often based on the CORINE land cover data (Coordinated Information on the European Environment). The CORINE data differentiates 45 different types of land-use (e.g. continuous urban fabric, industrial or commercial units, agro-forestry areas).

6.2 Proposed approach for direct damage assessment

This study is focused on flood damage assessment on St Maarten Island. Damage assessment is every much required for this study area, since rapid development activities are being implemented on tourism against the flood hazard. In order to make quick decisions, the monetary value of damage is required. This is mainly required for cost-benefit analyses, for local protection measures and rating of risks for insurance purposes.

In view of these practical requirements, a GIS-based tool for damage estimation was developed for this study area and the following basic procedures were followed:

- Selection of flood affected zones.
- Extraction of ground elevation from DTM to the buildings
- Estimation of the lowest damaging water level.
- Categorization of each building, based on their utility and area.
- Estimation of unit cost per area or per unit for buildings, based on their fixed and mobile inventory.
- Estimation of the stage-damage-functions, differentiated for different types of buildings, cellar/floor, buildings, structure/contents.
- Estimation of the damages to buildings and contents for different water-levels based upon the type and use of each building.

6.2.1 Classification of properties

Selection of flood affected zones

In order to identify flood affected zones, mathematical model results expressed in flood depth were overlaid on study area; on GIS based platform. Then delineation of six major flood affected zones, based on flood depths and functionality of community was carried out. These interested areas were selected either from tables or as graphical selection in GIS. Finally calculated flood damages for each zone were compared in "after rehabilitation" and "before rehabilitation" scenarios as shown in Figure 10.

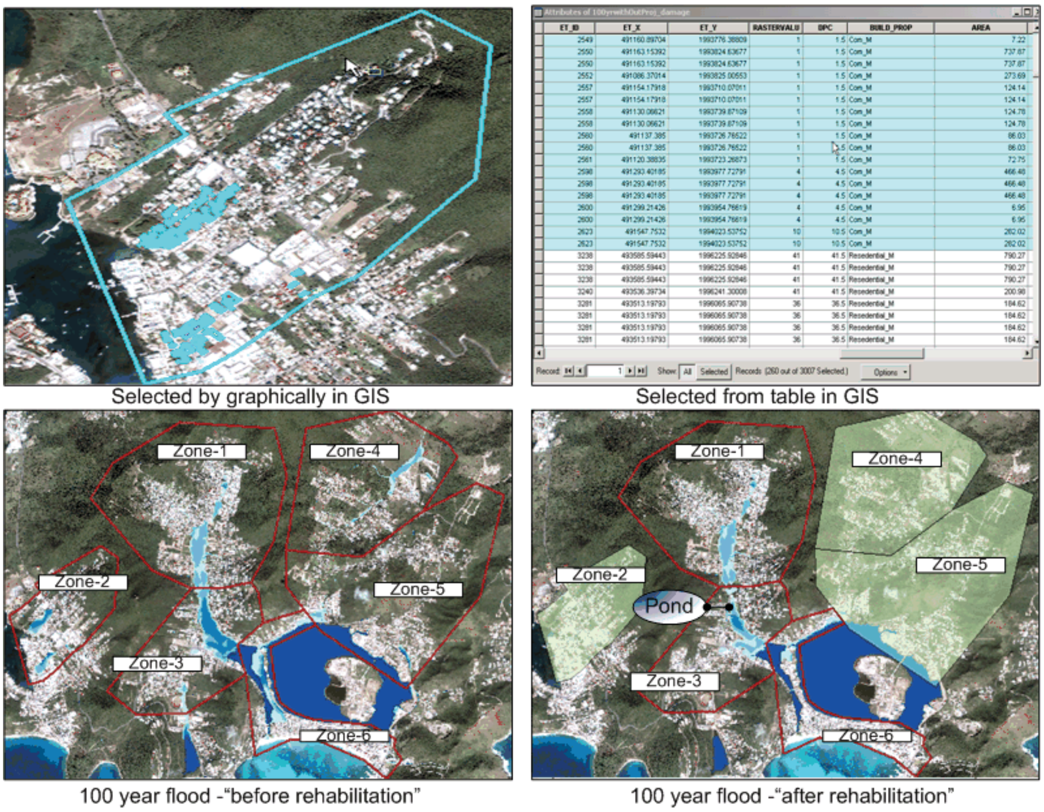


Figure 10: Selection of flood affected zones

Extraction of ground elevation from DTM

For the damage estimation, the water depth close to or inside the building is the determining factor .In this case ground elevations were extracted from DTM to each building, But then each building polygon was given a number of elevation points. Therefore those elevation points have to be averaged to a single point for each and every building.

Data management tool in ET Geo wizard 9.6, was used to convert the building polygon shape file into a point feature shape file, then the elevation values were extracted from DTM to points and averaged them into a single point as described in Figure 11.

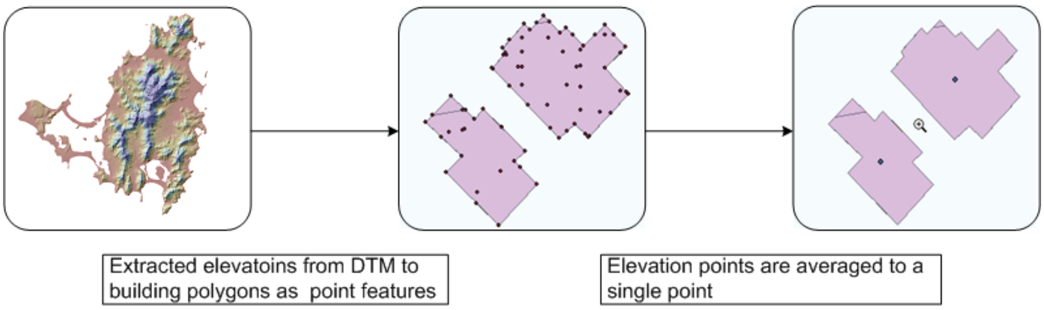


Figure 11: Extraction of ground elevation from DTM

Estimation of the lowest damaging water level

The lowest damaging water level to any building property is not exactly the ground level (GL) of that location because there is a foundation height which can protect the building floor from flood .Therefore 0.5m height was assumed as foundation height for all buildings as shown in Figure 12.This new elevation of flood levels can be calculated by adding new fields to GIS data base.

Elevation of flood water level = WL (flood depth of model results) – (GL+ 0.5m)

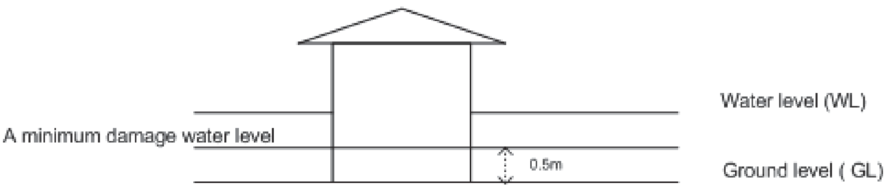


Figure 12: Lowest damaging water level

A minimum damage water level is used here to account for an actual habitable floor level which is on St Maarten usually found to be elevated by few steps.

Categorization of buildings

All buildings in this study area were categorized as Residential, Commercial and Industrial based on their functionality. The areas of each building polygons were calculated with the use of GIS.

Then, all residential buildings were sorted out by selecting attributes and re-classified, as Residential small and Residential large with the use of GIS. Subsequently other buildings were also reclassified as Commercial low, Commercial medium, Commercial high, Industrial low and Industrial medium, based on their area. The criteria used is given in Table 2 and shown in Figure 13.

Table 2: Classification of buildings

Building Type	Classification criteria
Residential small	Area < 50 m^2
Residential large	Area > 50 m^2
Commercial low	Area < 100 m^2
Commercial medium	100 m^2 < Area < 1000 m^2
Commercial high	Area > 1000 m^2
Industrial low	Area < 100 m^2
Industrial medium	Area > 100 m^2

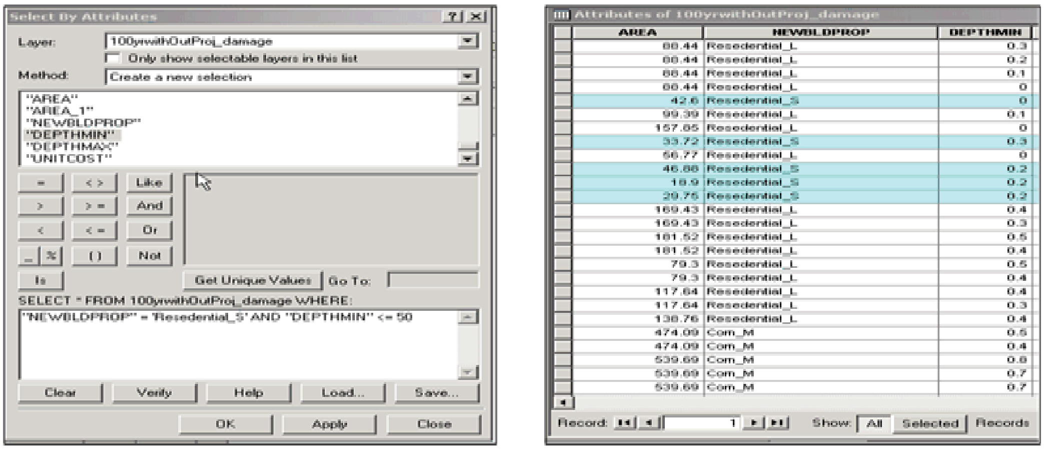


Figure 13: Data base is sorted by attribute fields**.**

6.2.2 Estimation of flood damage curves

The damage estimation is based on the general assumption that the monetary damage depends on the type and use of the building. One of the basic studies was performed by Penning-Rowsell and Chatterton (1977). In the manual, stage-damage functions for residential buildings in the UK were derived for age and type of the buildings, the duration of the flood event and the social class of the inhabitants. The damages are differentiated for building fabric and contents. Other similar international studies were done by Wind et al. (1999); Smith (1994); Parker et al. (1987).

Flood damage estimation is mainly based on the flood stage damage function. That means, the flood stage has only been considered as predominant factor for the damage calculation, while, the velocity factor also has significant impact especially on flash flood events. The peak velocities and peak flood depths were not coincided at a given location as shown in Figure 14. Generally, peak flood depth is taken place sometimes after the peak velocity has occurred. It can be observed that the value of velocity component is very low when flood depth reaches its maximum value. In addition, it is not feasible to measure the flood velocities, but peak flood depths can be recorded at the affected buildings. Therefore, flood depth has been considered as a predominant factor for flood damage estimation.

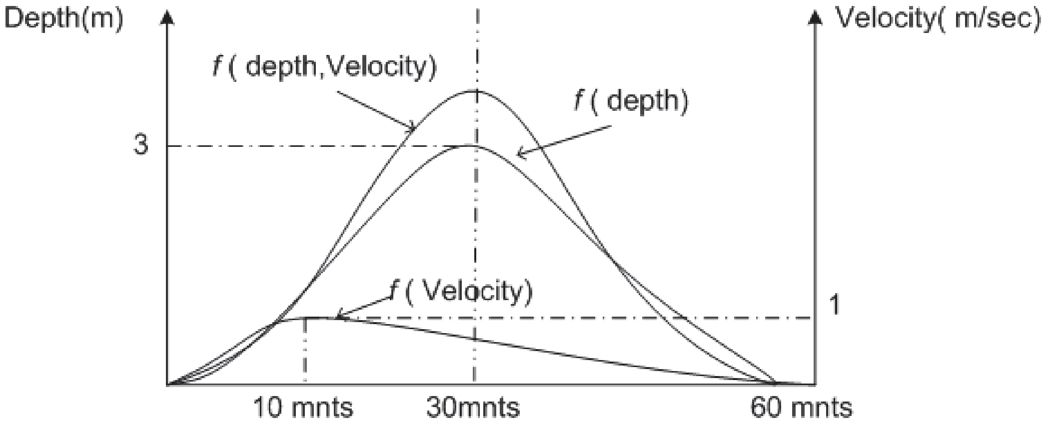
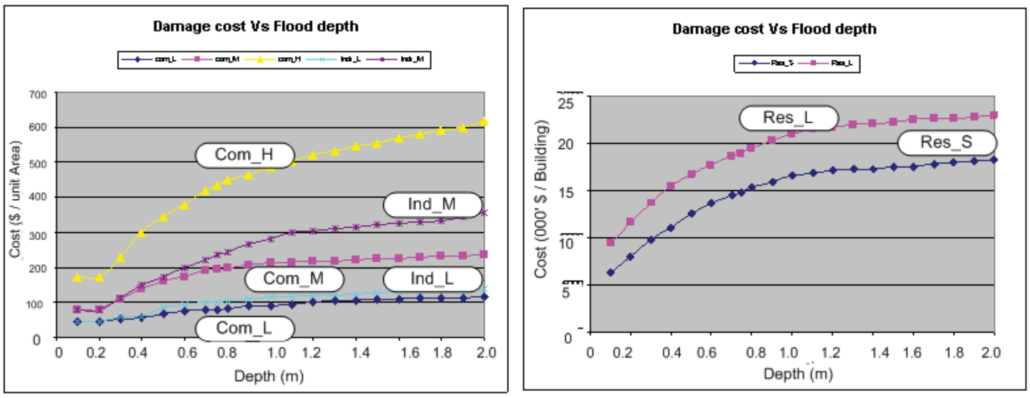


Figure 14: Impact of flood depth and velocity

Based on historical data, flood stage damage curves have been developed for each category of buildings. By considering the types of industry, machinery, turnover and national benefits, the damage values per unit area are assigned with depths, for industrial buildings. In the same manner flood damage values have been assigned for commercial buildings per unit area, based on their turnover and trade.

However a different methodology was used to establish the damage stage curve for residential buildings. Based on area of residential units, the commodity, value of belongings and social class of the in habitants are changed. Therefore single values have been assigned for each building in different classes.

In conclusion seven flood stage damage curves have been established for the study area. All damage curves give damage values per unit area except for residential buildings. In residential buildings, unit values have been assigned for each building, based on residential category as shown in Figure 15.

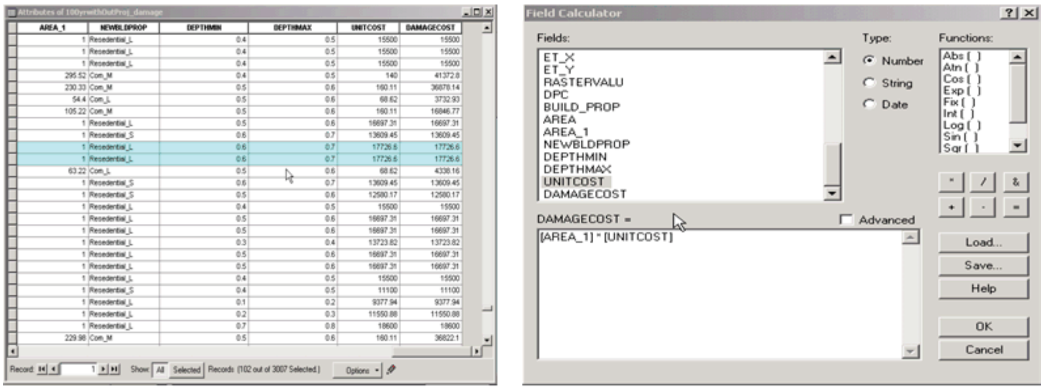


Other buildings   Residential buildings

Figure 15: Flood damage curves

Estimation of damages for different water-levels

Having finalized the unit costs for each building type, GIS model was established to calculate direct damages. Damage cost can be obtained by multiplying the building area with unit cost at each flood depth stages. However before doing this calculation, new data field within the GIS data base file was calculated for building area, by fixing value "1" for residential building areas. It is because, for residential buildings, unit cost has been derived per unit building, but for other buildings, it's defined per unit area. Then damage calculation was done for each building category at different flood depths. Flood depths of up to 0.5m were not considered for damage calculation, since that flood depth is assumed to be below the habitable floor level. GIS database was incorporated to do the damage calculation as shown in Figure 16.



Selection building catogory & flood stage   Caculation of damage cost

Figure 16: Flood damage calculation in Arc GIS

6.2.3 Visualization and Analysis of Direct Damage

After completion of calculation, damage values were displayed on a GIS platform as shown in Figure 17.Damage values were classified into five main damage groups. This classification has been done as damage incurred 0 to 25,000$ -Low, 25,000$ to 50,000$- Medium, 50,000$ to 100,000$ -High, 100,000$ to 200,000$- Very high, above 200,000$- Extreme.

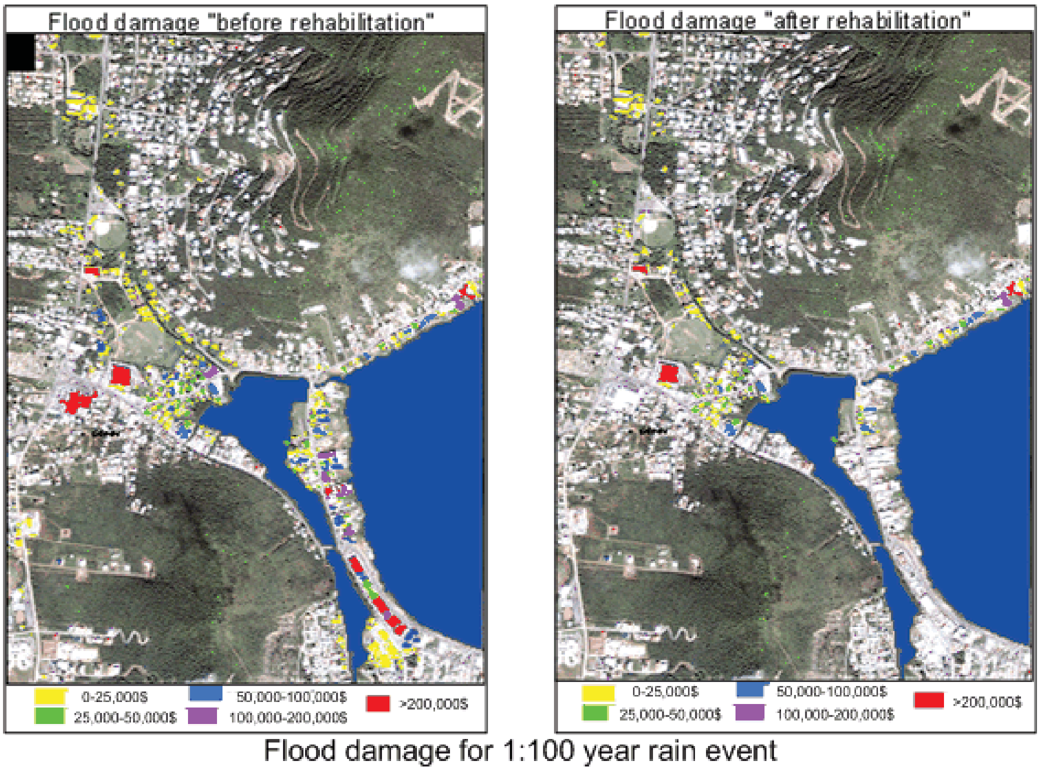


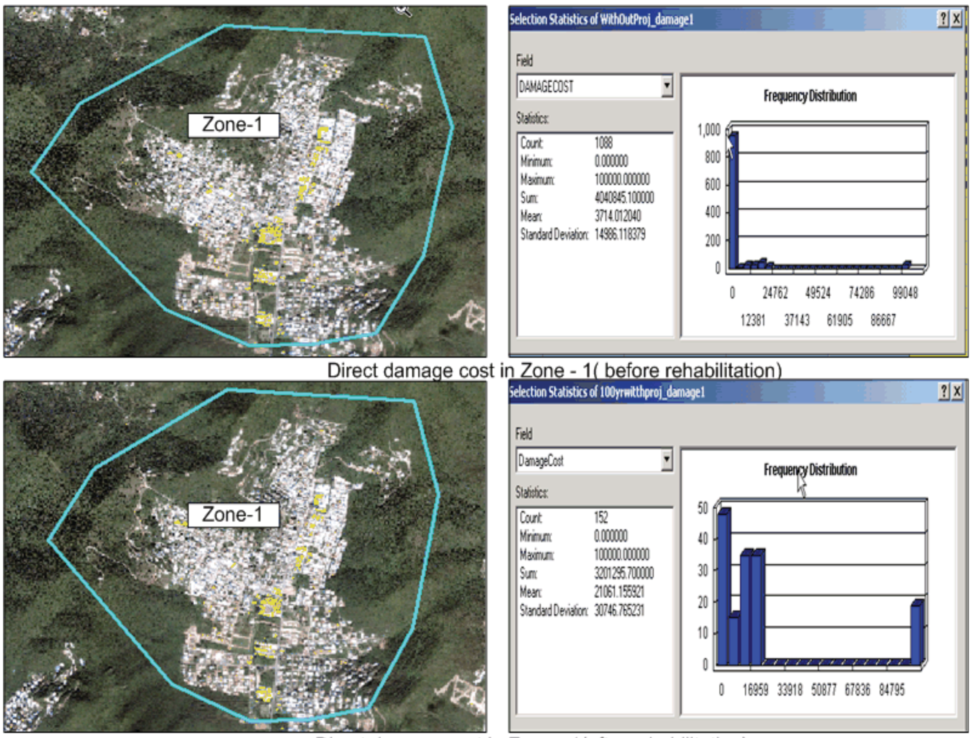
Figure 17: Visualization of damage values on GIS map

Damage analysis

Damage calculation was carried out for "after rehabilitation" and "before rehabilitation" scenarios for six major rain events. For the planning and design purposes**,** 100 year (ARI) rain event was assumed to be reasonable design criteria. Therefore, 100 year (ARI) rain event was considered as a design event for the study area.

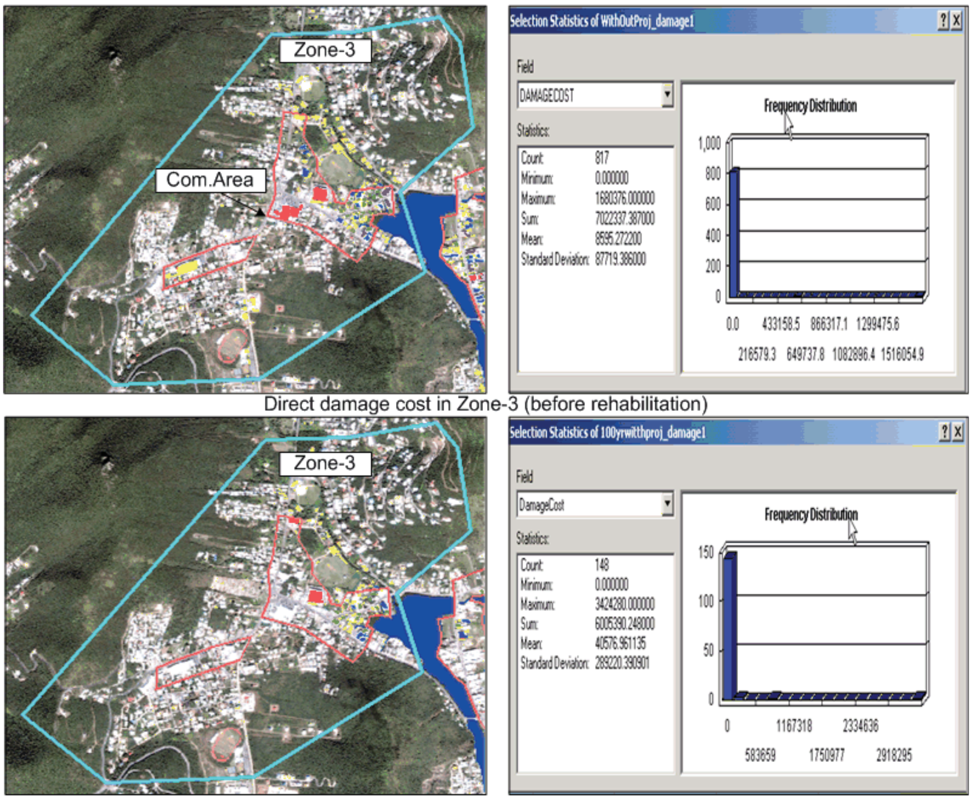
By simulating the 100 year rain event, six flood-affected zones were identified, in Figure10. .It can be observed that, three zones (zone-2, 4 and 5) are completely recovered as flood free zones, after introducing detention storage pond.

It was found that, 1088 residential buildings were damaged in zone-1 (refer Figure 18) .The estimated cost for this damage is 4.0 mill $, but after implementation of rehabilitation project this cost is reduced to 3.2 mill $.as shown in Figure 18.



Direct damage cost in Zone - 1(after rehabilitation)

Figure 18: Damage comparison in zone-1

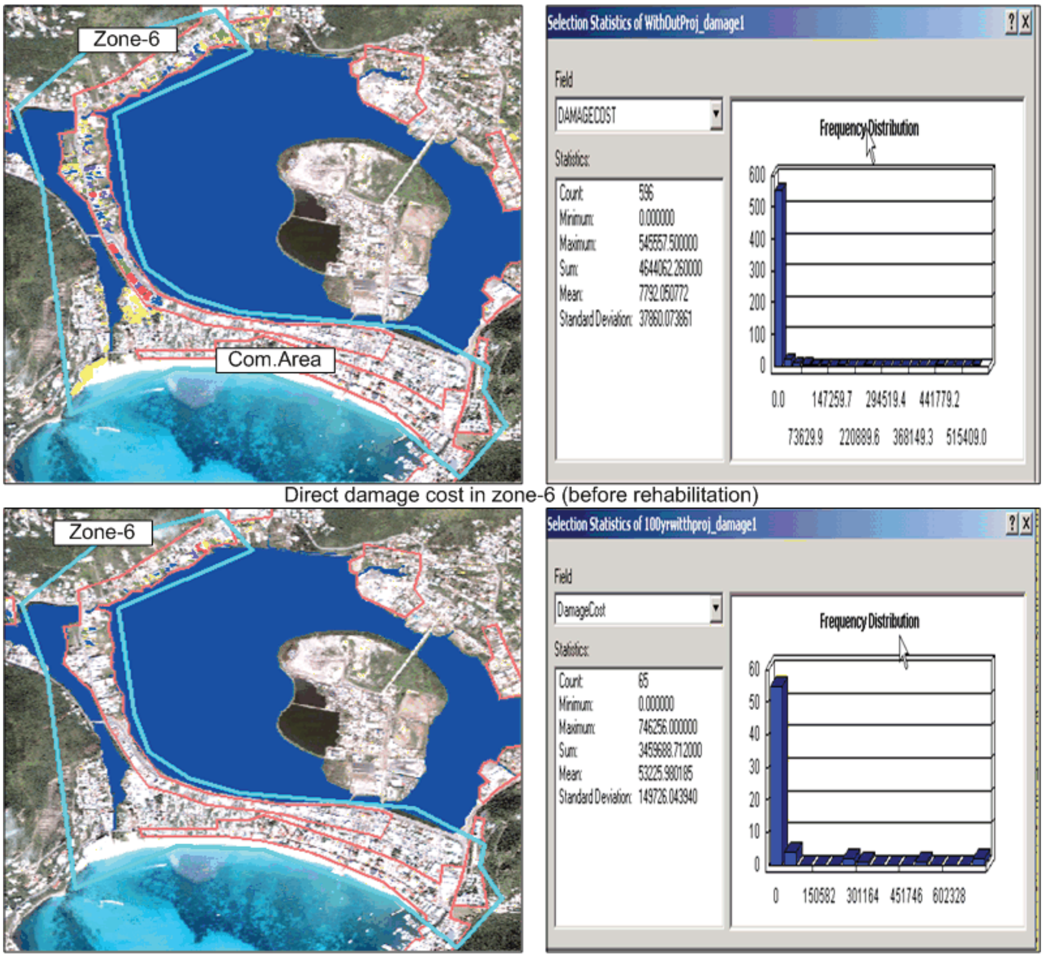


Direct damage cost in Zone-3 (after rehabilitation)

Figure 19: Damage comparison in zone-3

Zone -3 consist of both commercial and residential buildings, as described in Figure 19.There are significantly damaged commercial buildings which can costs more than 200,000$.The total damage cost of this zone has been estimated 7.0mil$.However after introducing a storage pond to this zone, the damage cost of this zone drop down to 6.0 mill $.

Only the commercial buildings have been damaged in zone-6.From the analysis of buildings it was found that many tourism and commercial activities being carried out in this zone. It appears that significantly damaged buildings are available in this zone. After the flood alleviation project, this zone also be improved, and the total damage is reduced from 4.6mill $ to 3.5 mill $ as illustrate in Figure 20.



Direct damage cost in zone-6 (after rehabilitation)

Figure 20: Damage comparison in zone-6

In conclusion, flood damage can be estimated for all five rain events, for “after rehabilitation” and “before rehabilitation” scenarios. It can be graphically represented as shown in Figure 21.

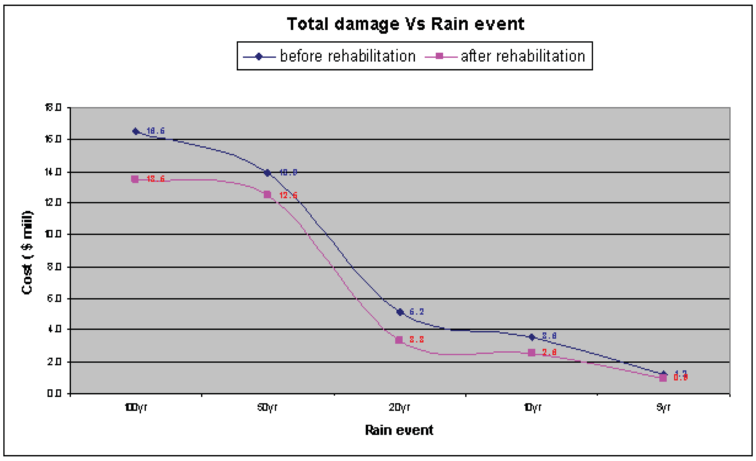


Figure 21: Flood damage assessment for different scenarios.

6.3 Indirect flood damage assessment

Once total direct flood damage for the whole study area is obtained by means of GIS based methodology, indirect damage can be determined, as it is usually considered to amount to a fixed percentage of the direct damage. This assumption is accepted for practical reasons, as the time required to incorporate a detailed analysis of indirect damage is too great to be justified in an individual flood study (James and Lee, 1971). This research follows the same principle and applies the same figures as those proposed by Kates (1965), who analyzed a number of studies by the Corps of Engineers to determine the following values for indirect damage (formulated as a percentage of direct damage): 15% for residential land, 35% for commercial, and 45% for industrial . These above- mentioned methodologies are all used to quantify the tangible damage studied in this research project. Then the total tangible damage can tabulated as shown in Table 3.

Table 3: Estimation of indirect damages-*before rehabilitation*

Rain Event	Direct damage			Indirect damage			Tangible damage
	Res	Com	Ind	Res(15%)	Com(35%)	Ind(45%)	
1:5 year	0.9	0.3	0.0	0.1	0.1	0.0	1.4
1:10 year	1.8	1.8	0.0	0.3	0.6	0.0	4.5
1:20 year	2.4	2.7	0.0	0.4	0.9	0.0	6.5
1:50 year	4.0	9.2	0.7	0.6	3.2	0.3	18.0
1:100 year	4.7	10.9	0.8	0.7	3.8	0.4	21.4

Table 4: Estimation of indirect damages –*after rehabilitation*

Rain Event	Direct damage			Indirect damage			Tangible damage
	Res	Com	Ind	Res(15%)	Com(35%)	Ind(45%)	
1:5 year	0.7	0.2	0.0	0.1	0.1	0.0	1.1
1:10 year	1.5	1.1	0.0	0.2	0.4	0.0	3.2
1:20 year	2.0	1.4	0.0	0.3	0.5	0.0	4.2
1:50 year	3.9	7.9	0.7	0.5	2.8	0.3	15.8
1:100 year	4.1	8.6	0.8	0.6	3.0	0.4	17.5

7. AN APPROACH FOR INTANGIBLE DAMAGE ASSESSMENT

In year 2005, it was reported that, the 150mm flood event occurred in St. Maarten Island. This was the greatest flood event ever occurred, over the past history. The flood damage was enormous, lost of lives, destroyed the properties ,buildings, infrastructures like water supply, sewer network, roads, electricity and etc .Not only that , but lost their productivity and economy too. The total damage to this island was thousands millions of dollars in words, but how to quantify this damage in to monetary values?

In previous chapter, It has been explained how GIS integrates to do the damage calculation on tangible damages. But most challengeable area is how to convert intangible damages due to flood anxiety into monetary value. Second part of this research study is directed to quantification of intangible damages into monetary values.

An intangible damage assessment is very complicated and difficult to quantify due to its subjectivity. However, it is also very interesting to develop a new approach to quantify or convert the intangible damage into monetary terms. Unfortunately, so far there has not been any research that investigates this possibility. To evaluate the role of the intangible damage component, this present research adopts and emphasizes an intangible damage assessment approach. However, considering only engineering factors is not sufficient for this type of damage appraisal. A multidisciplinary approach is utilized to obtain a more complete picture of total flood damage by integrating engineering, social science and economic knowledge. This research focuses, to find the intangible damage in St – maarteen Island by determining the Anxiety Productivity and Income relationship using the (API) methodology which was proposed by A. Lekuthai and S. Vongvisessomjai (2001).

In order to find the relationship between anxiety, productivity and income, directly affected following predominant factors were identified.

Anxiety = f (Flood depth, Land use)

Productivity =f (Anxiety, Income)

7.1 Identification of the extent of Intangible Impact

With the help of GIS Arc view, and the numerical model results, flood inundation map was generated to identify the flood affected areas in St – maarteen Island The tangible damage occurred only within the flooded areas, but. It was found that the people who are living in six regions, where it is shown in Figure 22 were critically affected by flood. For example the all people in region -1 are emotionally affected by the flood, because they are not in position to attend to their jobs safely, as Figure 23 shows that the only available road to access this region is flooded with the depth of 1.7m at point- A. This circumstance badly affects to the productivity.

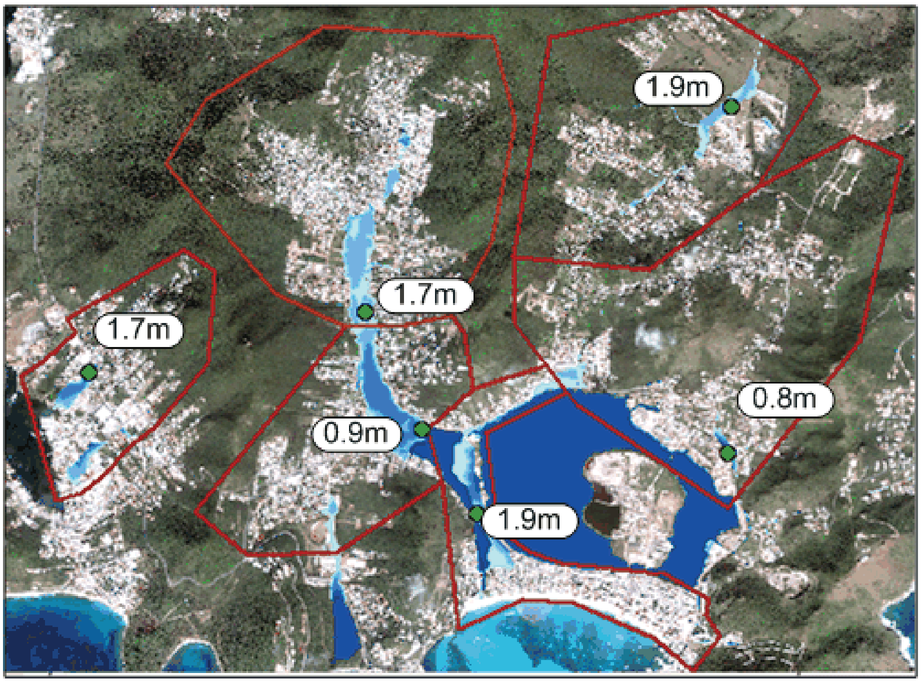


Figure 22: Distribution of flood depth**.**

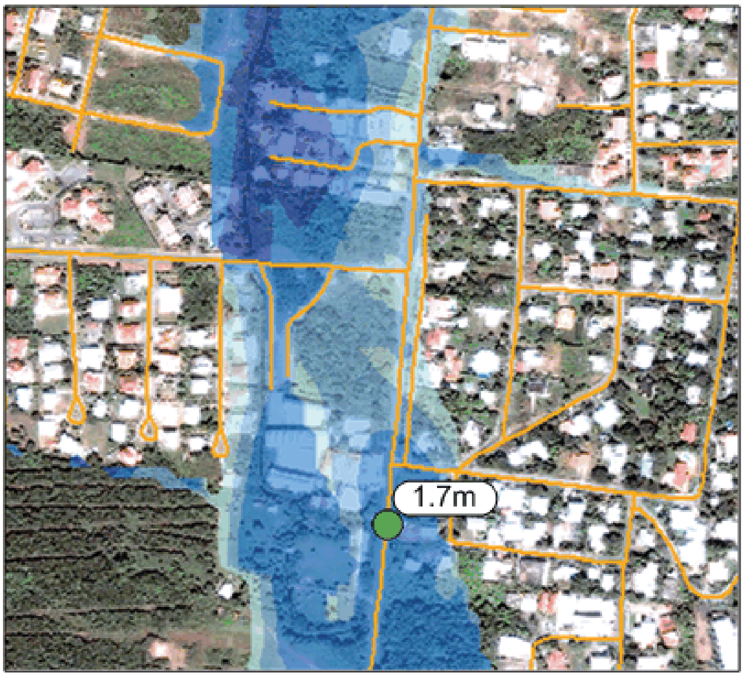


Figure 23: Flood depth at the main entrance to the zone-1

To find out how people in St – maarteen are affected by the flood in the scene of their attitudes of attending to the jobs, work efficiency and fluctuation of productivity and income with anxiety a sociological survey was carried out based on results of "Socio-economic Evaluation of the Integrated Flood Relief Plan of the West Bank" published by the Institute of Environment Research, at Chulalongkorn University (1986).

The previous study measures anxiety on a scale from 0 to 100 units, as there is no standard anxiety scale currently available. In general, normal people should not have 0-level anxiety because, even when there is not any flood, people normally possess some degree of anxiety. It is therefore assumed that the minimum level of anxiety is 20, while the maximum anxiety level is set at 80, as anything above 80 is considered intolerable for a human being.

From the sociological survey on St – Maarten Island, it was found that, Over 80% of people feel that they will not be affected by a flood depth of less than 0.1 m. On the other hand, over 80% of people feel that they will be greatly affected by floodwaters higher than 0.9m.Since flash flood is a threat to this island situation with high velocities can cause enormous damage even when there are small depths. Therefore, they have very high anxiety even over the small flood depths. The Table 5 shows the findings of the sociological study, and it shows that even for 0.3m water depth, they have anxiety level at 50, that is almost 63% of the tolerable anxiety level of 80 for human being. In the same time, the maximum tolerable flood depth for this area was found as 0.9m. Finally anxiety against flood depth relationship was approximated to non linear exponential function shown in Eq. (4) and illustrated in Figure 24.

Table 5: Relationship of flood depth and Anxiety

Flood depth (m)	Anxiety
0.10	20
0.20	40
0.30	50
0.40	55
0.45	60
0.50	65
0.60	70
0.75	75
0.90	80

$$Y = 0.05e^{0.0361x} \quad \text{......} \quad \textbf{\textit{(5)}}$$

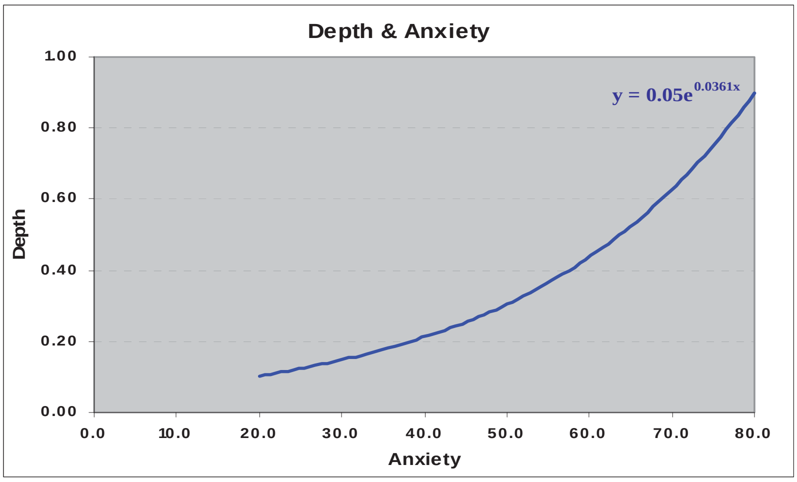


Figure 24: Depth and Anxiety relationship

In conclusion, anxiety levels on St Maarten for people who live in the six regions is given in Figure 22 and summarized in Table 6. In this research, it was assumed that, at least two people from each family unit are involved in income generating activities. Based on this assumption, a number of affected people have been calculated. The number of family units was sorted in GIS database under the Residential classification. It is important to mention that, without this feature of GIS data base it is impossible to find out this information as well as critical depth information relevant to each region. The critical depths on the available access roads to each region are considered as affected flood depths for those who live in these six regions.

Table 6: Flood affected people due to anxiety

Region	No of flood affected people	Affected flood depth (m)	Anxiety level
1	4630	1.1	80 *(above the tolerable limit of 0.9m)*
2	1154	1.4	80 *(above the tolerable limit of 0.9m)*
3	2616	1.6	80 *(above the tolerable limit of 0.9m)*
4	3620	0.5	65
5	4050	1.4	80 *(above the tolerable limit of 0.9m)*
6	1866	0.5	65

7.2 Conversion of Intangible impact into monetary values

The relationship between anxiety and productivity has been build up with the basic assumptions that the Productivity varies from 50% to 80% of total production capacity within the anxiety level range from 20 to 80 respectively. That explains that maximum productivity of 80% of the total production can be expected until the value of anxiety level not exceeding 20. At the same time, minimum production is restricted to 50% of the total production, at the maximum anxiety level of 80, in order to meet employer's minimum requirements for the payment of salaries. With theses assumptions, following field survey results are tabulated in Table 7.

Table 7: Productivity and anxiety relationship

Anxiety	Productivity
20	80
30	60
40	55
50	52
80	50

Then, the field survey outputs were extrapolated to establish the production capacities relevant to the anxiety levels and depths. The results are tabulated in Table 8 and illustrated in Figure 25. This relationship of productivity and anxiety can be approximated to a 4^{th} order polynomial equation as shown in Eq (6). It can be observed that there is a rapid drop in productivity from 80% to 51 %, with in the flood depth from 0.1m to 0.45m. There is a trend to cross this flood depth in normal situations, but on St. Maarten Island, it is very risky attempt since there can be an unpredictable high velocities, which can cause a serious damage to people and properties.

Therefore, even at lower depth of flood situation the productivity remains within the minimum capacity range of 50% of the total capacity.

$$Y = 7x^4 * 10^{-6} - 19x^3 * 10^{-4} + 178x^2 * 10^{-3} - 7.5624x + 173.84 \text{ .... } \textbf{\textit{(6)}}$$

Table 8: Flood depth and Productivity

Flood depth (m)	Anxiety	Productivity
0.10	20	80.0
0.20	40	55.0
0.30	50	52.0
0.40	55	58.0
0.45	60	51.0
0.50	65	50.8
0.60	70	50.6
0.75	75	50.3
0.90	80	50.0

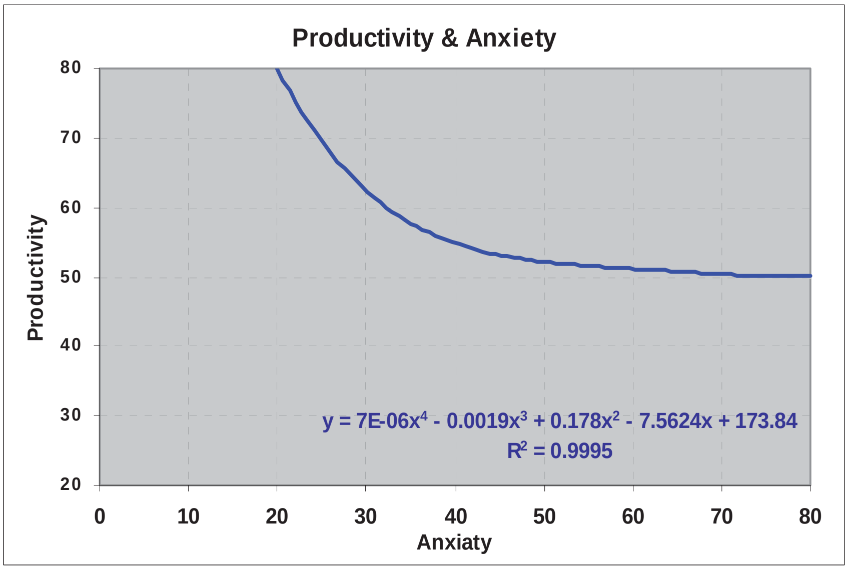


Figure 25: Productivity vs. Anxiety

It is assumed that income level fluctuates within 100% to 80% range .The maximum income of 100% is recorded when productivity is 80% or above and the minimum income value of 20% is recorded when productivity is at its lowest value of 50%. Based on these assumptions, following linear relationship was established as shown in Eq (7). Then income fluctuation was extrapolated with flood depths as shown in Table 9 and Figure 26.This analysis shows that the maximum loss of income of 20 % of the total income will occur when flood depth is at 0.6m.

$$Y = 1.4956x - 69.627 \text{ .... } \textbf{\textit{(7)}}$$

Table 9: Productivity and Income fluctuation with flood depth

Flood depth (m)	Anxiety	Productivity %	Income %
0.10	20	80.0	100.0
0.20	40	55.0	83.5
0.30	50	52.0	81.5
0.40	55	58.0	81.0
0.45	60	51.0	81.0
0.50	65	50.8	80.5
0.60	70	50.6	80.5
0.75	75	50.3	80.0
0.90	80	50.0	80.0

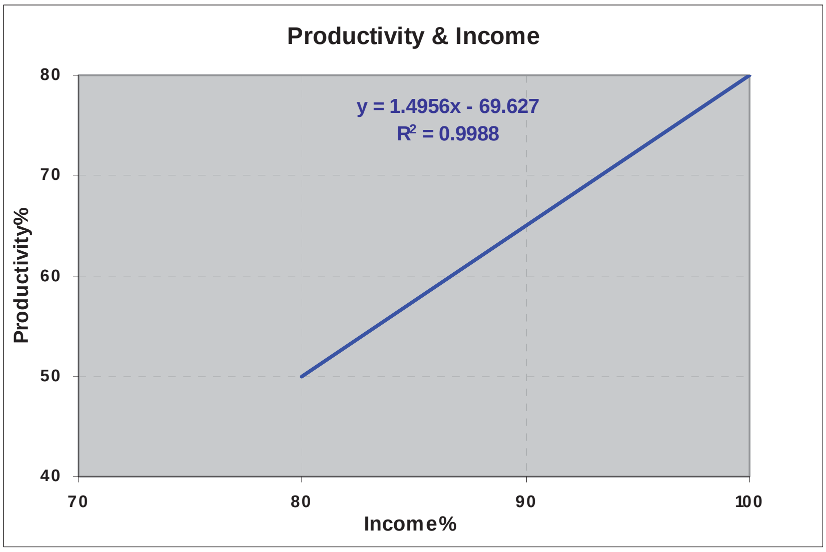


Figure 26: Income Vs Productivity

The income reduction has been defined as anxiety damage level. This indicator can illustrate the percentage of income reduction against the flood depth. The maximum income reduction is 20% of the total income and the minimum reduction is 0%.This relationship can be shown in Figure 27. Then the Income reduction factor can be projected from flood depths as shown in Table 10.

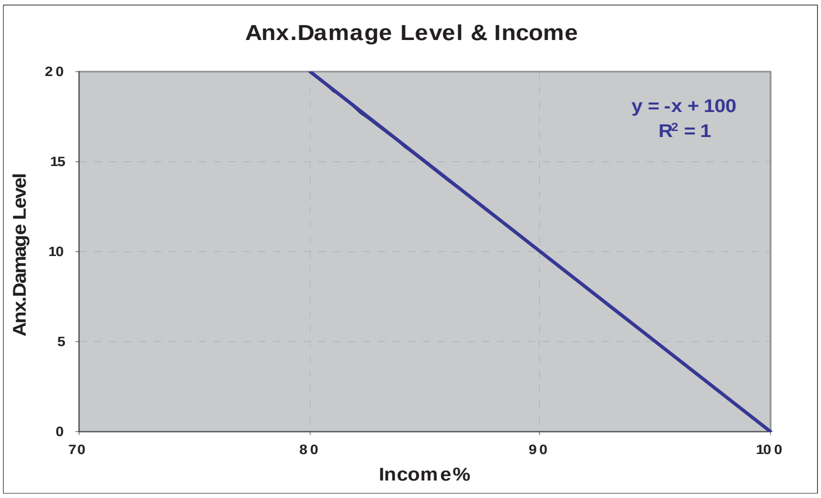


Figure 27: Anxiety damage level vs. income

Table 10: Relationship between Flood depth and anxiety damage level

Flood depth (m)	Anxiety	Productivity %	Income %	Anxiety damage level %
0.10	20	80.0	100.0	0.0
0.20	40	55.0	83.5	17.0
0.30	50	52.0	81.5	19.0
0.40	55	58.0	81.0	19.0
0.45	60	51.0	81.0	19.0
0.50	65	50.8	80.5	19.5
0.60	70	50.6	80.5	19.5
0.75	75	50.3	80.0	20.0
0.90	80	50.0	80.0	20.0

Finally nonlinear relationship of depth against anxiety damage level can be derived for St Maarten, as a 6th order polynomial function in Figure 28.

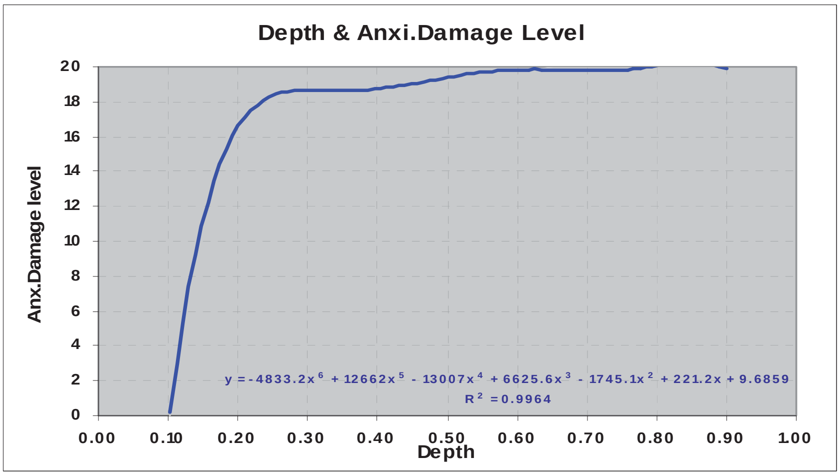


Figure 28: Flood depth vs. Anxiety damage level

On St. Maarten, six major flood events of 5 year, 10 year, 20year, 50year, 100year and an event of 150mm/ hour which occurred recently(equating to an event which is between 200 and 500 year ARI) were simulated by MIKE -11 hydrodynamic model and results were integrated in a GIS platform. Then, flood affected regions, number of flood affected people and critical depths for each region were identified as described at the beginning of this chapter in Figure 22, Figure 23 and Table 6.The predominant factors for the Intangible damage are anxiety and flood duration. The derived relationship between flood depths and the anxiety damage levels on St,.Maarten (Figure28) was used to calculate the intangible damage for each and every scenario. Here, it is assumed that anxiety damage remains constant throughout the flood duration.

In conclusion, the Intangible damage on St. Maarten, for each scenario is converted to the monetary values using the methodology summarized in Figure 29 and the results are tabulated in Table 11, Table 12 and illustrated in Figure 30 for six major flood events.

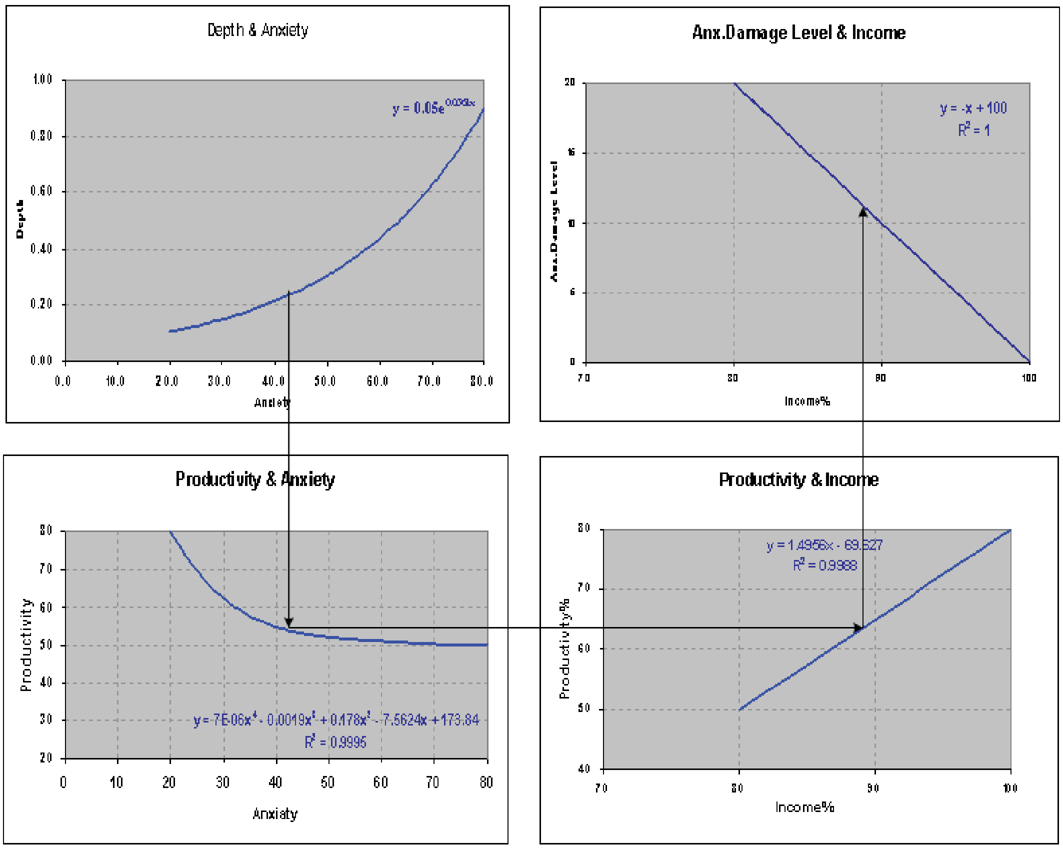


Figure 29: Proposed approach to estimate Intangible damages.

Table 11: Affected flood depths in each rain event

Flood Event	Affected flood depths (m) in each regions					
	Zone-1	**Zone-2**	**Zone-3**	**Zone-4**	**Zone-5**	**Zone-6**
1:5 year	0.0	0.0	0.1	0.0	0.5	0.0
1:10 year	0.3	0.0	0.3	0.0	1.1	0.0
1:20 year	0.6	0.0	1.1	0.2	1.2	0.0
1:50 year	0.8	1.1	1.4	0.4	1.3	0.3
1:100 year	1.1	1.4	1.6	0.5	1.4	0.5
150mm/hr	1.8	1.6	1.9	0.8	2.1	0.9
Average income per person per month($)	500	500	500	500	500	500
Flood affected people	4630	1154	2616	3620	4050	1866

Table 12: Flood anxiety in each region in each rain event

Flood Event	Anxiety damage level						Total Damage 000'$/day
	Zone-1	**Zone-2**	**Zone-3**	**Zone-4**	**Zone-5**	**Zone-6**	
Before rehabilitation							
1:5 year	0.00	0.00	0.00	0.00	0.20	0.00	14
1:10 year	0.19	0.00	0.19	0.00	0.20	0.00	37
1:20 year	0.20	0.00	0.20	0.17	0.20	0.00	48
1:50 year	0.20	0.20	0.20	0.19	0.20	0.19	58
1:100 year	0.20	0.20	0.20	0.19	0.20	0.20	59
150mm/hr	0.20	0.20	0.20	0.20	0.20	0.20	60
After rehabilitation							
1:100 year	0.20	0.00	0.20	0.00	0.00	0.00	24

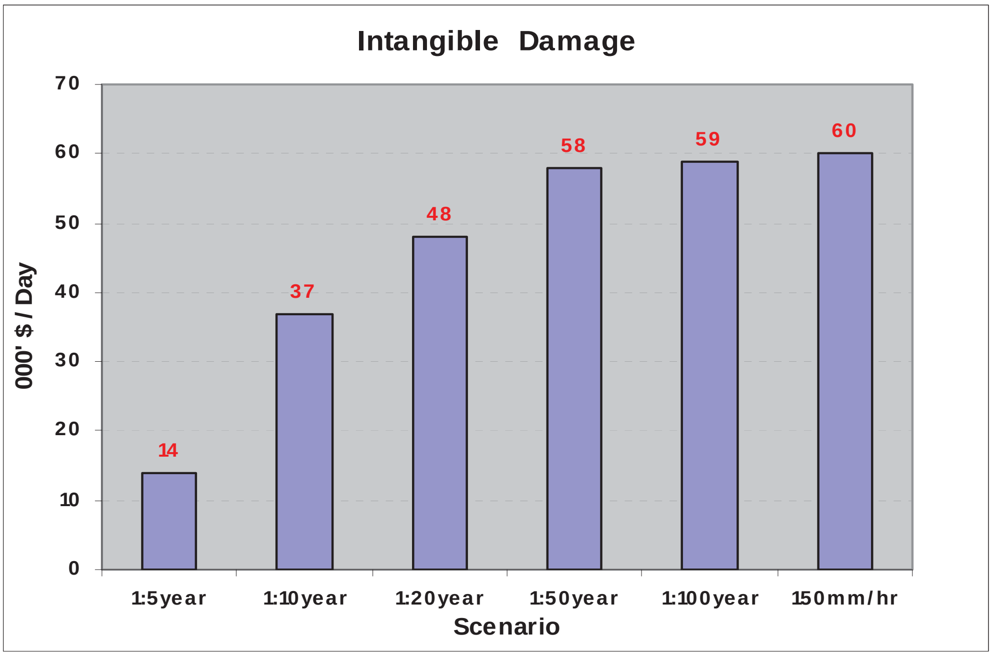


Figure 30: Estimated Intangible damages

8. AN APPROACH FOR ANNUAL BENEFIT CALCULATION

Direct, indirect and intangible flood damages have been estimated and described based on the simulated water levels and within the GIS based framework, in early chapters. Table 13 summarizes the estimated total damages for 100year rain event.

Table 13: Total flood damages

Average Recurrence Interval (ARI)	Annual Exceedence Probability (AEP)	Project	Flood damage(mill$)				Total (mill$)
			Direct	Indirect	Tangible	Intangible	
1:100 year	1%	Without	16.4	5.0	21.4	0.1	21.5
		With	13.5	4.0	17.5	0.1	17.6

The total damages caused by periods of recurrent flooding (flood return periods) are utilized to determine the probability-damage relationship, as presented in Figure 31/Graph-C. At the same time, this curve presents the flood damages incurred for different intervals of recurrent flooding (flood return periods). The expected annual flood damage can be determined from the following probability-damage curve. The benefit calculation determines the value of the expected annual benefit from an alleviating procedure, constituting a factor by which all damage data are proportionately reduced. This is achieved by calculating the contribution each successive flood event makes to the annual average flood damage. Thus, the mean damage expected from two flood events of similar magnitudes is multiplied by the probable interval between the two occurrences (Parker et al., 1987). In other words, the expected annual flood damage is the damage divided by its return period, or the damage multiplied by its exceedance probability. Furthermore, in practice, the area under the curve describing the probability-damage relationship is equivalent to the expected annual flood damage.

Then, the expected annual benefit can be calculated by means of the differences in the expected annual damage forecasts provided by two flood mitigation scenarios, as demonstrated in Figure 31/Graph-C. Atthanan Lekuthai and Suphat Vongvisessomjai (2001).

This flood damage assessment model is designed for 1: 100 year rain event (or 100 year ARI) that is 1% of annual exceedence probability (or 1% AEP). Therefore a hydrodynamic model was simulated with 1:100 year rain event and peak discharge and flood depths were estimated accordingly (Figure 31/Graph-A).The Peak discharge and flood depth were recorded as 68 cms and 7.2m respectively.

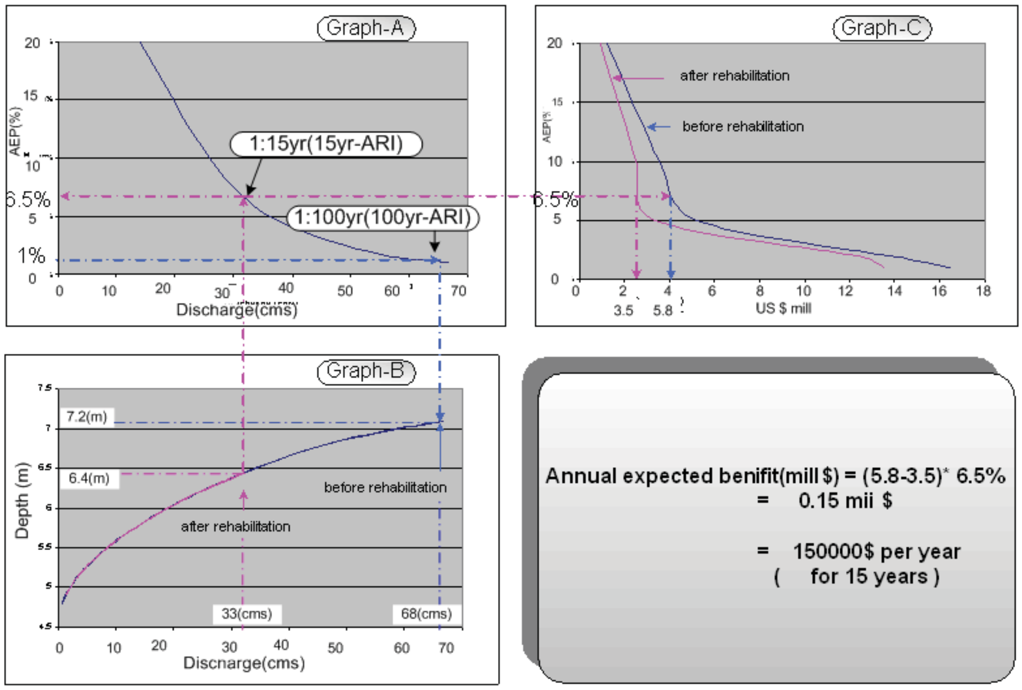


Figure 31: Results from Annual benefit calculation

Then the flood detention storage pond was introduced to the system to curtail the peak flood flow as well the flood depth. Figure 31/Graph-B illustrates that peak discharge and flood depth reduces to 32 cms and 6.4m correspondingly. Having introducing flood protection reservoir, the impact of 1: 100 year flood event (1% AEP) is reduced to 1: 15 year (6.5%AEP) flood event as shown in (Figure 31/Graph-A).Further to that, this explains that there is a 6.5% probability of getting a flood with peak flow of 32 cms and depth of 6.4m in each year.

Flood damages have been estimated for five flood events and evaluate for both “before rehabilitation” and “after rehabilitation” scenarios, as shown in Figure 31/Graph-C. Therefore, project benefit can be estimated as follows.

Flood damage without project	=	5.2 mill$
Flood damage with project	=	2.9 mill $
Project benefit for 6.5% AEP	=	2.3 mill$
Annual expected benefit	=	2.3 * 6.5%
	=	0.15 mill $/ Annum

This can be explained as, if this project is implemented, society will get 0.15mill $ benefit for each year. But it’s limited for 15 year (6.5%), because there is a chance of getting this flood 1: 15 year time.

9. AN APPROACH FOR DISASTER MANAGEMENT PLANNING

Subsequently this research is extended to prepare a disaster management plan. The main objective of disaster management planning is to identify the set of measures and actions to minimize the risk of disaster and maximize the effectiveness of the actions and measures against the disaster. This study is mainly focused to identify disaster management activities and describe how GIS technology plays a critically important role in disaster management planning process on St.Maarten Island. The GIS-based framework for this study can be formulated as shown in Figure 32.

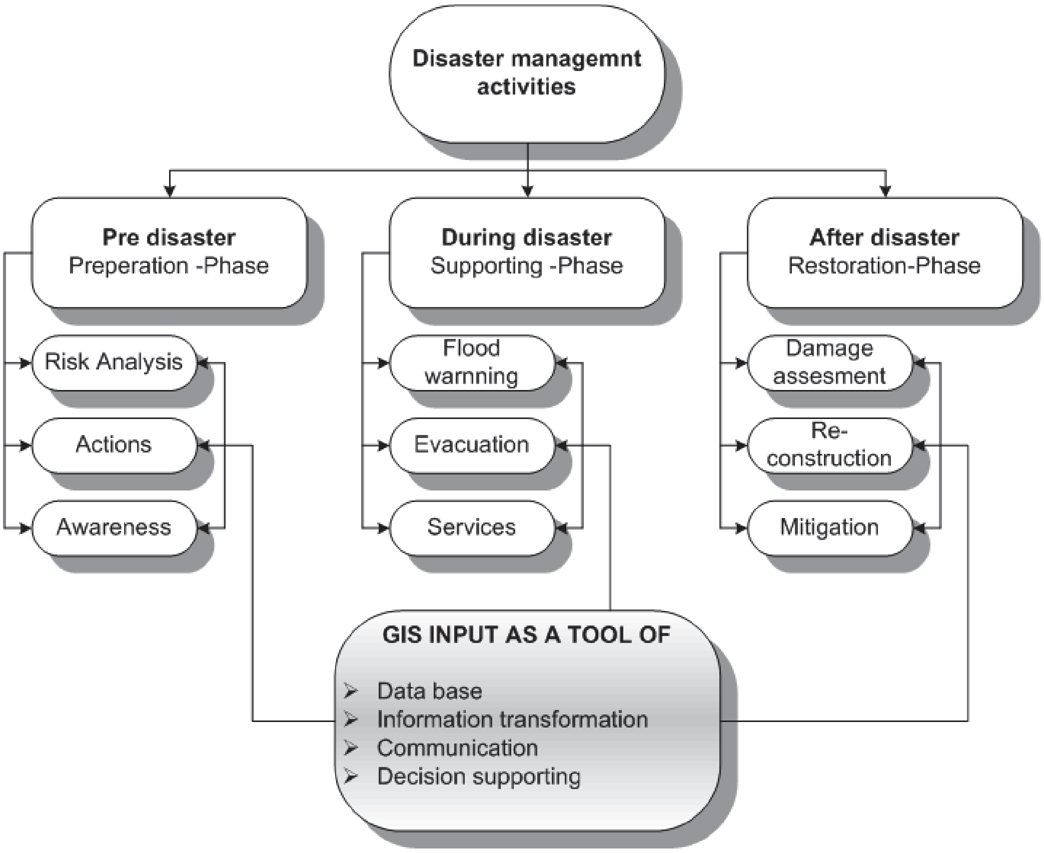


Figure 32: Proposed approach for disaster management with GIS

Disaster management planning activities were studied under following three major stages.

1) Pre disaster - (Preparation phase)
2) During disaster - (Supportive phase)
3) Post disaster - (Restoration phase)

9.1 Pre-disaster - (Preparation phase)

At this stage, vast range of planning has to be done to Identify the risk and its extents, preventive measures and actions, and awareness.

Risk Analysis

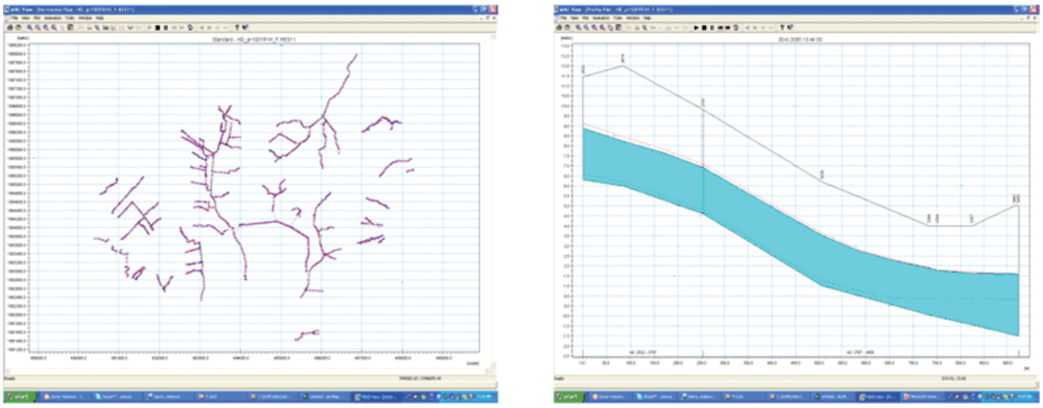
Risk = (Probability) * (Consequences), and also

Risk =f (hazard, vulnerability)

Risk can be defined as a function of hazard and vulnerability. That means that risk can be identified in terms of hazard and vulnerability.

9.1.1 Proposed approach to prepare flood hazard maps

The extent of hazard is identified from flood hazard mapping. In this study, six major flood events, that is for 5 year, 10 year, 20 year, 50 year, 100year and 150mm per hour which occurred recently were considered. Each and every flood events was simulated with MKE-11 numerical model to study and identify physical process. The numerical model results are usually presented in a very technical form (Figure 33).Such results gives detail about flow and depths for a given rain event, at any cross-section of the scheme in MIKE-VIEW as shown in Figure 33, but it does not convey much to less technical users such as planners, decision makers and to general public. However, this information should transfer or convey message to wider audience, during the pre disaster management phase, for better planning and decision making and awareness.



MIKE-11 results MIKE-VIEW results

Figure 33: Hydrodynamic model results

At this stage, GIS performs as an information transformation tool as well as a database, to transfer the information of numerical model results into understandable format as stipulated steps in Figure 34.

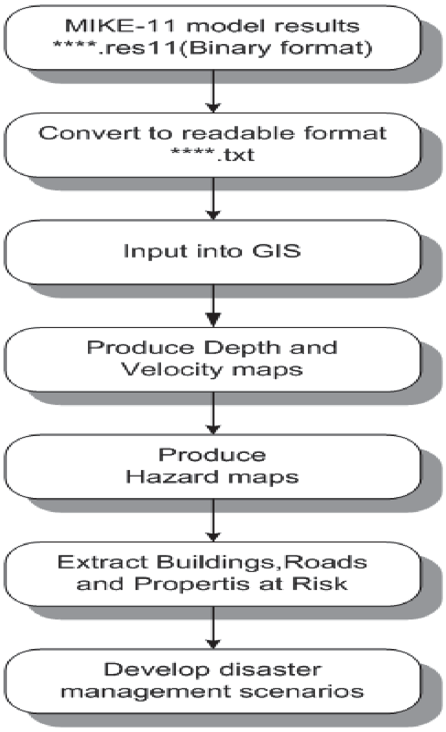


Figure 34 : Methodology of Conversion of Model results into GIS plat form

The model results are usually stored in a "binary format" that is in a case of MIKE11 as a X.res11 file. Then, such files need to be converted into readable ***.txt file format and assessed by a GIS system, as shown in Figure 35.

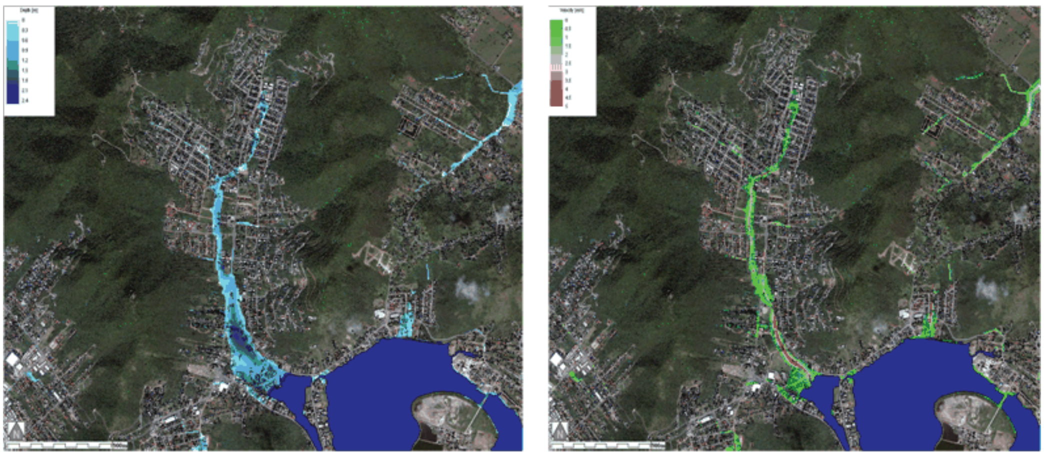


Figure 35: Model results of Depth and Velocities on GIS platform.

Also, since images are have no geo reference system as oppose to a DTM data used in this study area. Therefore, it is essential to bring these images into common projections. Using "Data management" and "Warp" tools in GIS, this unique reference plane was created as presented in Figure 36.

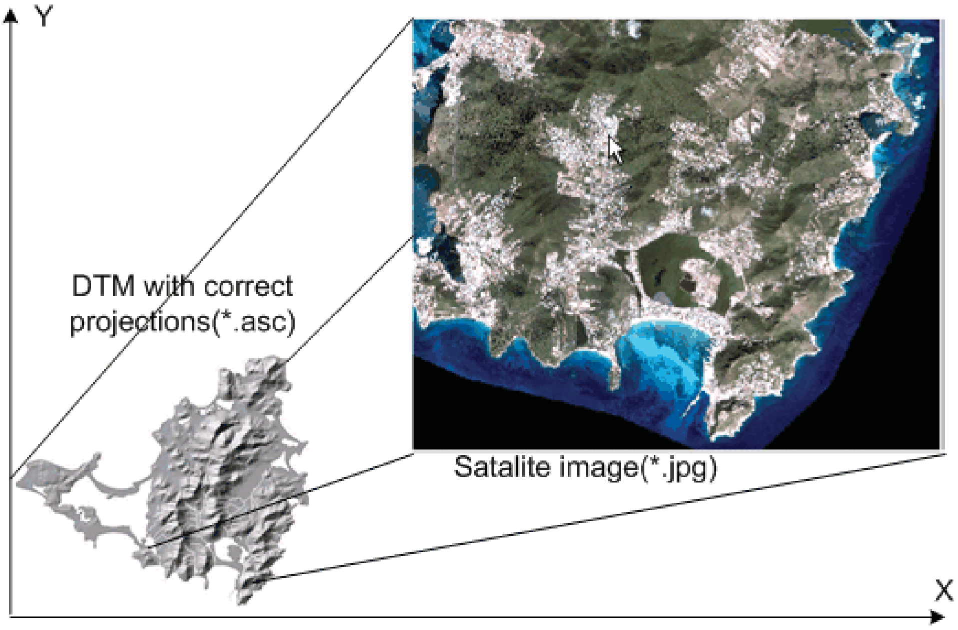


Figure 36: Preparation of unique geo reference plane

After creating a surface of depth and velocity data in a GIS system (where, waterRIDE software was used) the hazard areas were identified. However, hazard represents not only the impact of depth but it has a great contribute of velocity. For instance, the flood depth of 0.3m does not give any life threat unless the velocity is less than 2m.per sec., but if velocity is grater than two, then even at 0.3m depth flood will have an extreme damage.

Then a hazard zoning criteria was developed, based on the previous study of McConnell and Low (2000).Five main hazard zones were identified, as low, medium, high, very high and extreme. The hazard criteria are described in Table 14 and Figure 37.

Table 14: Criteria for flood hazard

	Low	**Medium**	**High**	**Very High**	**Extreme**
Velocity(ms^{-1})	<0.5	<2	<3	<4 and >0.5	>0.5
Depth (m)	<0.4	<0.8	<1.8	>0.2	>0.2
Velocity*Depth	<0.2	<0.5	<1.5	<2.5	>2.5
Safe for	cars	heavy vehicles and wading for adults	Light constructions	Heavy constructions	Nothing

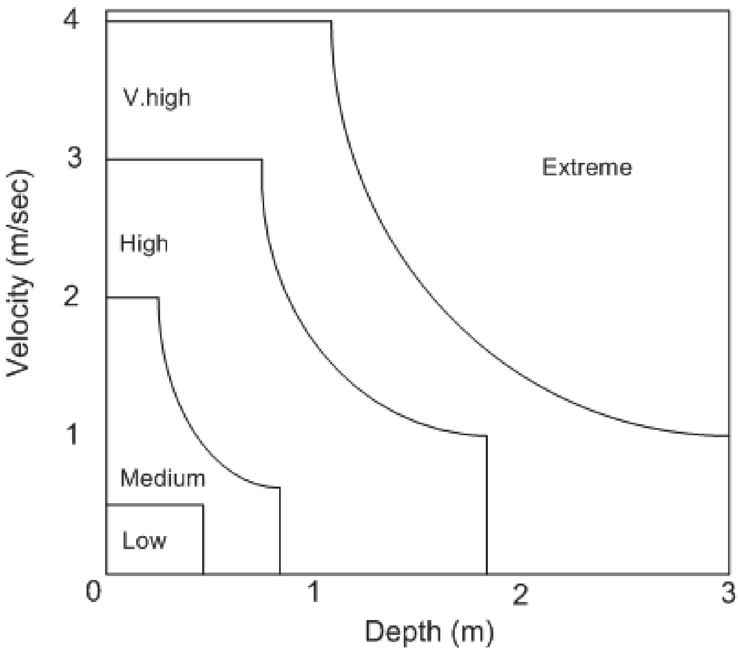


Figure 37: Flood hazard zones

In order to create the hazed zone maps, GIS is used as an information transformation tool. Based on the information about depth and velocities new, hazard zones were generated as specified criteria in Table 14. In this process Arc GIS provides "map algebra" tool to establish different constraints or relationship between depth and velocity shape file.

But before applying constraints, velocity and depth files should be converted to raster files. In this case following constraints were given to generate the "Medium hazard zone"

[Depth 150mm existing. raster] ***** [Velocity 150mm existing. raster] <0.5 and
[Depth 150mm existing .raster]<0.4 and
[Velocity 150mm existing. raster]<0.5

Then it has produced a raster file with Boolean expression. This file indicates '0' and '1'.The '0' shows area, where the given constrains are not satisfied and '1'shows the satisfied region. .This raster file converted to polygon as a shape file. Then medium hazard shape file can be generated by selecting and deleting '0' in attribute of "Grid ID" of this shape file as illustrate in Figure 38.

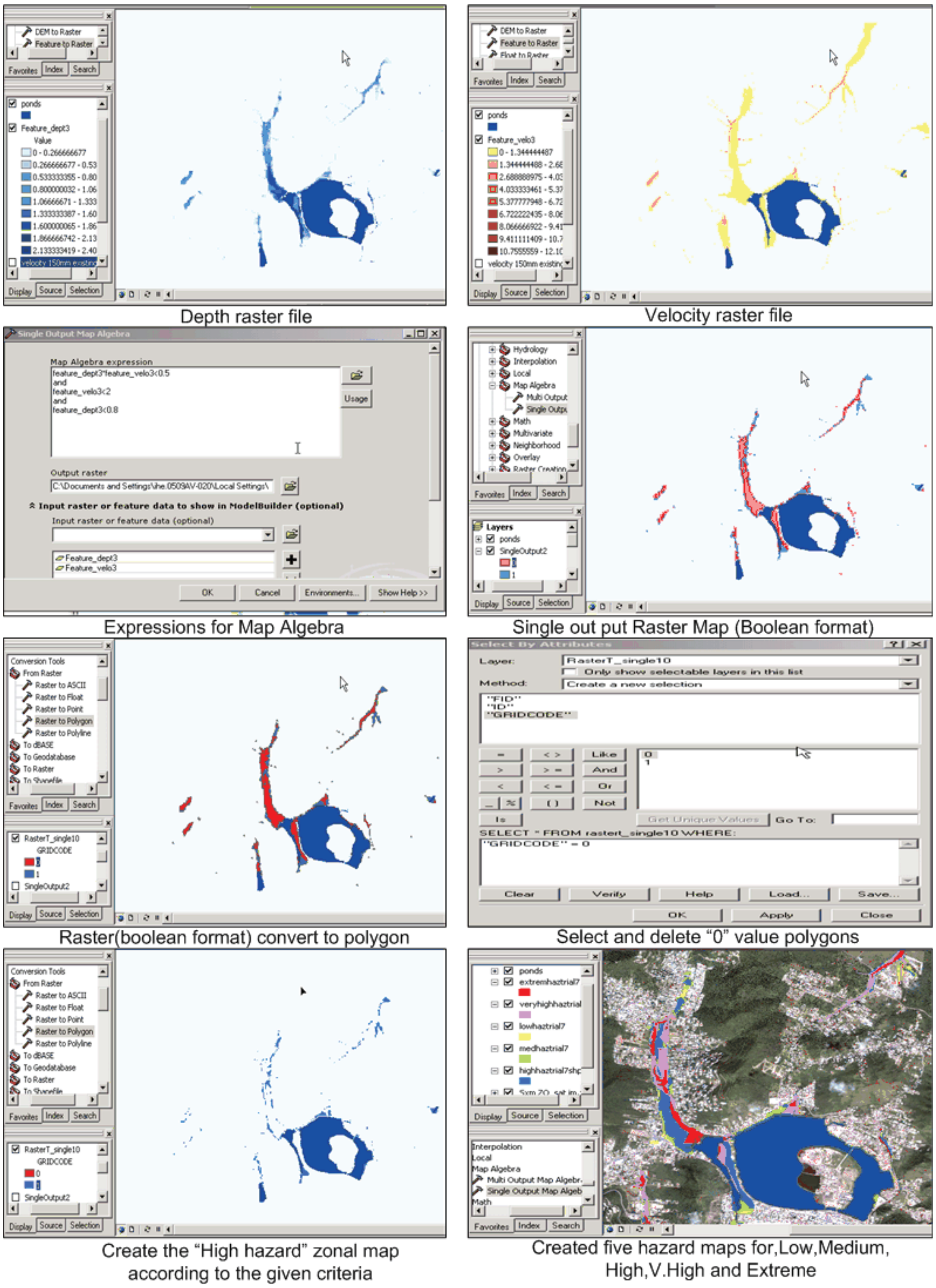


Figure 38: Calculation for flood hazard zones

Six separate hazard maps that illustrate hazard zones for each and every rain events were generated. Now it can be easily understood the location of the hazard as well a magnitude of the hazard. But, especially planners, designers and decision makers require further classification, quantification and dimensions of flood affected properties, infrastructure, lands and roads, etc.

At this stage GIS plays a unique role for classification, quantification, dimensioning and providing additional information to the data base. In order to identify the flood affected buildings and roads in a hazard form , building and road shape files were overlaid and intersected with 150mm Hazard map as shown in Figure 39.

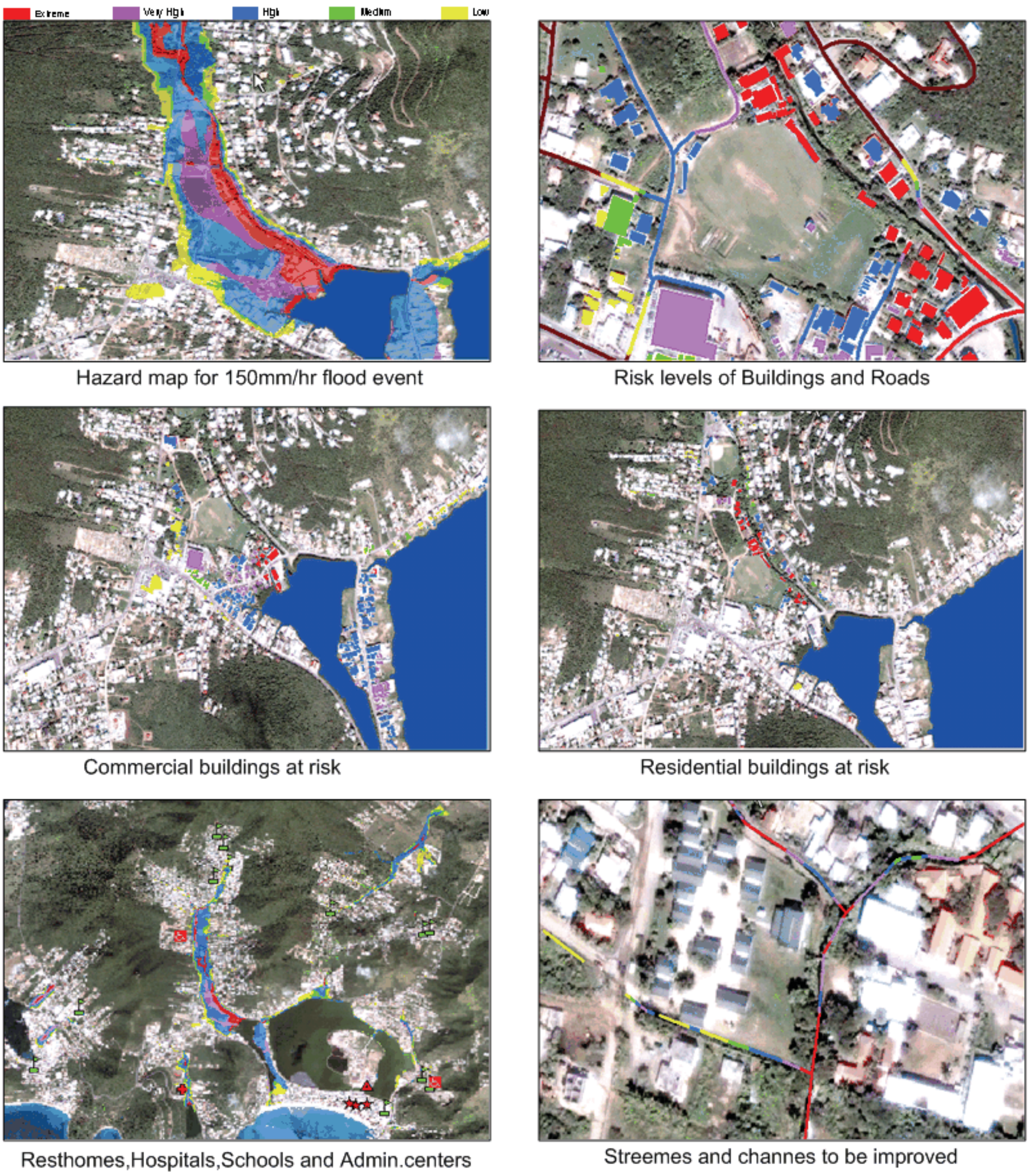
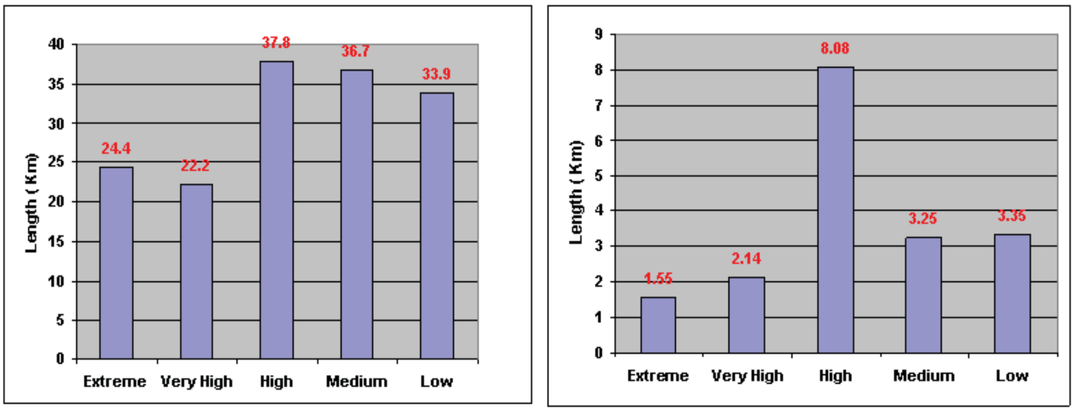


Figure 39: Risk identification and quantification

Elevations were extracted from DTM to relevant properties. Further to that, any additional data could be added to the data base. Finally any required information was able to summarize as in Figure 39, or statistically analyzed with the use of GIS.



Flooded Roads   Flooded Streames

Figure 40: Quantification of Flooded Roads and Streams

This risk analysis is extended by further classification of buildings, based on their functionality and the area. In previous chapter, all buildings were mainly classified as Commercial, Industrial and Residential buildings and subsequently reclassified them as Residential small, Residential large, Commercial low, Commercial medium, Commercial high, Industrial low and Industrial medium based on their area, for the purpose of direct damage assessment. Detailed re-classification was done in Table 2 using GIS tools.

During the risk identification stage it is very important to identify the flooded roads and their level of risk, because flood interaction can be minimized by introducing alternative roads when flood happens. At the same time road raising plans can also be implemented to reduce the level of risk. This planning process should be associated with improvement of drainage network. Significantly flooded stream sections either can be widen or culverts have to be introduced. With this information, planning and design can be done in accordingly.

9.1.2 Vulnerability

The risk analysis stage of risk identification integrates information from the hazard assessment and the vulnerability studies in the form of an estimate of the probabilities of expected loss for a given hazardous event. Formal risk analyses are time-consuming and costly, but with the help of GIS this analysis can be done within short period as well as at cheap rate. In other words, vulnerability is defined as identification of communities, properties, and social aspects where high need of disaster-related mitigation and preparedness projects are required.

Physical Vulnerability

GIS can help to identify and visualize the flood impact on the most important buildings, infrastructure, and lands (see example in Figure 39). During the heavy rainfall events the storm water runoff gets mixed with the waste water system and such flows overland, causing pollution and the potential for a wide range of problems associated with waterborne diseases. Consequently planner's designers and decision makers can implement projects on channel improvement and providing extra storages to the system, to minimize this physical vulnerability.

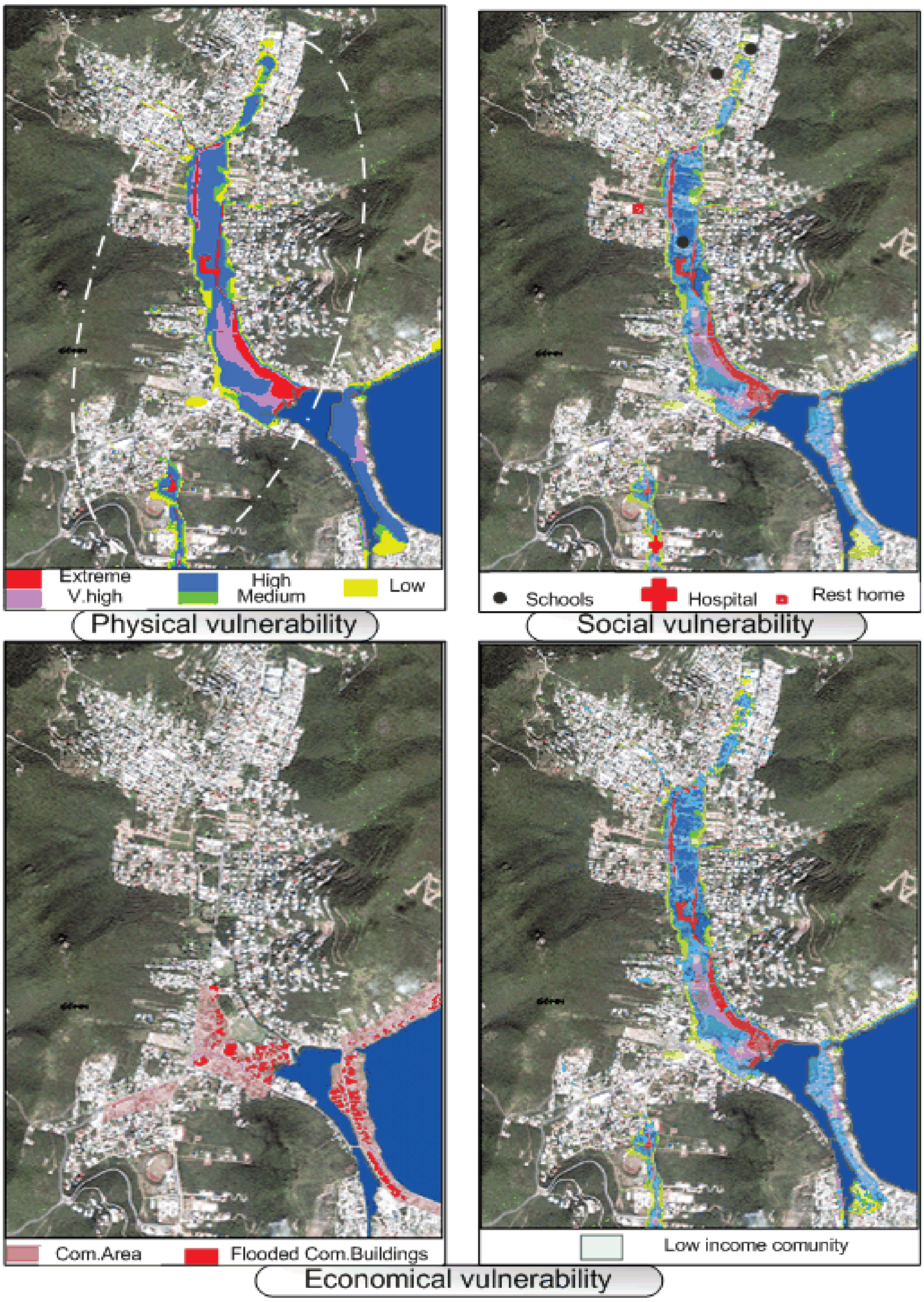


Figure 41: Presentation of different vulnerability.

Social vulnerability

In social aspects, the most helpless or disable communities where they can find in rest homes, hospitals and schools should be given higher priority to prevent any interaction with flood. These locations can identified in a GIS platform and relocation or shifting of these places can be done as a mitigation measure, during the preparedness stage, to minimize this social vulnerability.

Economic vulnerability (EV)

EV represents studies of estimating the potential impacts of hazards on economic assets and processes. Such studies include indirect losses (such as business interruption) and secondary effects (such as accentuated poverty, higher unemployment, or increases in levels of external debt).

In this aspect GIS can help to screen the commercial areas, industrial areas, and residential areas. Further to that, with the power of the GIS and its data base, it is easy to provide a cross-section of poverty and low income group within this flood plain. To address the economic vulnerability, by implementing mitigation measures during the preparedness stage is also very important to minimize the entire disaster. Finally, physically, socially, and economically most vulnerable places were identified on St Maarten as shown in Figure 41.

8.1.3 Actions and measures

After the risk and vulnerability identification, a set of actins and measures should be identified to minimize the disaster. In this study area, risk and vulnerability were analyzed for five different storms (i.e. 1:5 year,1:10 year, 1:20 year, 1:50 year, 1:100 year, and 150mm per hours).Then following structural and non-structural measures and actions can be proposed to planners , design engineers and decision makers for further evaluation with more field data.

Structural system improvement measures

Detention storage pond can be proposed to reduce flood risk in most vulnerable catchments (Figure 28).This system would cut off the peak flow by 50 % , that is from 70cumecs to 35cumecs in 1:100 year storm event. This improvement gives 150,000 $ annual benefit to the society as discussed in Figure 18. However, this improvement could be introduced only as a short term proposal, until the storm water channel system are upgraded to accommodate the design flows. This short term proposal is not sustainable for ever, because it may create environmental and health hazard with the future developments. Therefore upgrading of channel network, and upgrading of storm water outlets are proposed as long term sustainable development plan.

In addition, reduction of groundwater table is to improve the drainage system. Therefore groundwater drainage or dewatering is proposed to eliminate or reduce problems initiated by ground water seepage.

Non-Structural system improvement measures

Non-structural measures can be implemented to minimize the public interaction with flood and minimize the disaster .In this aspect, preparation of emergency response plan based on stormwater model results, study of hazard maps, plays a key role to manage the disaster. Emergency response plan consists of activities of prevention, preparedness and recovery during the flood event. In order to maximize the effectiveness of these measures it will be necessary to communicate some of the stormwater modelling results to the public and then raise an awareness of flood hazard areas and flood hazard emergency mitigation measures.

The simulation of a computer model is very important to study and understand the physical process in this area. The expertise of this knowledge should be established within the study area especially to upgrade and maintain the system with the time. In this sense, capacity building and professional training is essential to introduce at the pre disaster management phase.

Under the flash flood situations, flood warning system can minimize the public interaction with flood. At this stage GIS performs as an integration tool for communication and dissemination. This flood warning system should be integrated with the real-time flood forecasting system. In order to do that, radar image downloaded from the website. This data does not have any geographical projection. ArcGIS software is used to re-project all radar images. Since the radar images is needed to place coordinates to the raster image so that it can fit with other GIS data. In order to rectify this issue, the transformation tools in the Projections and Transformations toolset provided by ArcGIS can be used. This toolset is used to transform the earth three-dimensional surface and create a flat map sheet. This mathematical transformation is commonly referred to as a map projection In ArcGIS, there are seven options to make a map projection. The options include flip, mirror, project raster, rescale, rotate, shift and wrap. After the projection and transformation process, the radar image is now can be overlay to other GIS data. In addition to that GIS helps to calculate the accumulate rainfall. This process is done using spatial analysis tool plus function provided by ArcGIS. These web based information are transformed to the GIS platform and produce the hazard maps. Then Arc Internet Map Server (ArcIMS) can assists to produce hazard maps based on radar data. This system has been further improved to generate flood warning system based on this radar data. Such warning system would need to be able to release flood warnings in advance of the storms. Such in advance warning would bring significant improvement in decision making on preparedness, mitigation and planning measures.

Awareness and training

The concept of awareness is very important to minimize the disaster by eliminating public interaction with flood. In order to minimize the disaster or damage to the society and property, people should become aware to face the flood hazard.Therefore, workshops and training programs can be conducted to keep people aware of approaching storm, keep their door open, and use the evacuation paths and places during the e flood warning., etc.

Public awareness is very important for land acquisition, and to get the public consent to implement some structural measures of upgrading channel system, construction of detention storage, and non-structural measures such as implementation of laws and regulations against flood. Therefore, GIS can help as a communication as well as information transformation tool to present hazard maps, evacuation paths and centres, development plans, impact of with and without project scenarios, etc, to aware the general public as well as decision makers.

9.2 During the disaster- (Supporting phase)

At this stage GIS can play a role as an optimization tool to find the best possible evacuation paths according to the prevailing situation. Especially in this study area, the administrative complex is isolated from the most vulnerable places like, schools, hospitals, rest homes, etc. Therefore, an emergency service and essential services should be provided to those places to recover the disaster. In the case of St Maarten, it was found that, six regions are isolated during the 150mm per hour rain event as shown in Figure 9. Therefore it is recommended to establish six separate emergency response units in each region because it is not possible to access these regions during this flood event.

9.2.1 Proposed approach for evacuation routes

In order to provide emergency services from emergency controlling centre to evacuation places, the best optimum routes have to be found, to enhance the level of service. The GIS provides facility for network analysis to find the best route, for services and evacuations. Further to the St Maarten case study, having done the network analysis, the emergency services can be provided with two evacuation centres using the best optimum route as shown in Figure 42. At the same, time people can avoid the flood and find best paths for their transportation. For example, children in two schools have to be evacuated immediately before the flood circumstances. Therefore, best route was found to vacate the schools, as described in Figure 42.

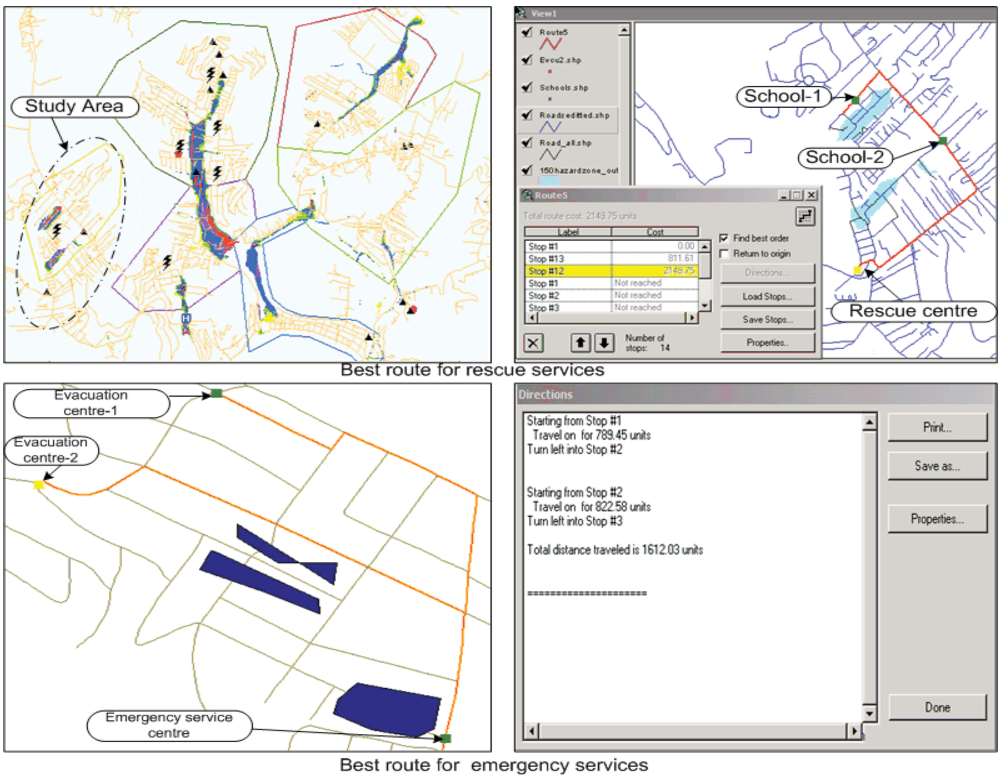


Figure 42: Best route for Evacuation centers.

The flood warning system can give a large coverage of protection against the disaster, by adopting proper measures towards disaster preparedness, mitigation, control, planning and management. Based on the warnings issued by the flood warning system following set of specific actions can be implemented during the disaster time.

- Evacuation of children from schools
- Control or diversion of traffic
- Establishing the rescue services at great risk areas

All above actions can are predetermined within a GIS based framework at the pre-disaster management stage. Therefore, these measures can be executed effectively to minimize the disaster.

9.3 After disaster (Re –construction phase)

The main objective of the re –construction phase is to facilitate flood affected communities, properties and services back to their pre-disaster condition. Rehabilitation covers repairing and reconstructing houses, commercial establishments, public buildings, lifelines, and infrastructure; restoring and coordinating vital community services etc. Recovery can take a few weeks or several years, depending on the disaster's magnitude and the availability of reconstruction resources. The most important recommendation for reconstruction and rehabilitation projects is that they should reduce future vulnerability and avoid recreating prior vulnerable conditions.

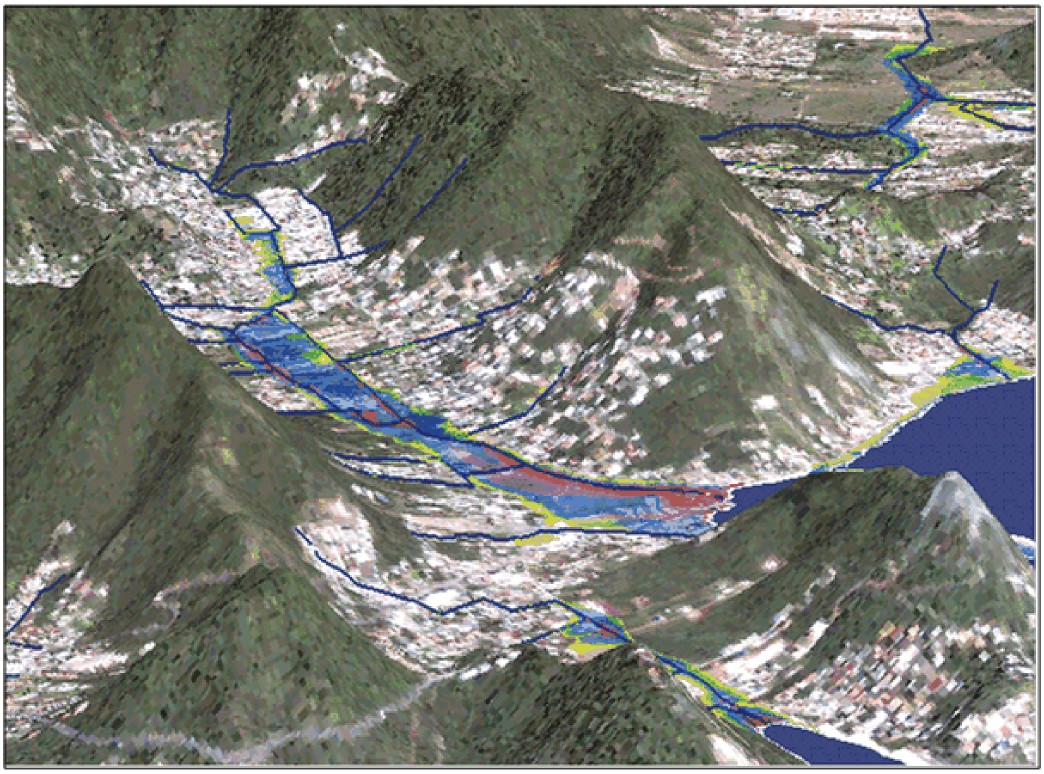


Figure 43: Three Dimensional View of Hazard situation

At this stage GIS is used to assess the damage cost of each rain event in each zone. Any flood alleviation projects can be evaluated by its benefits and priority, based on this damage estimation. In order to identify proper flood alleviation strategies, GIS plays a key role to estimate the damages, unless otherwise there is no way to estimate damages immediate after the disaster .At the same time, GIS can provide three dimensional view as shown in Figure 43, for better understanding of the overall condition of study area. Especially planners and decision makers can easily comprehend the overall situation effectively and design and make decisions better.

A detention pond is proposed as a short term flood alleviation project in St –Maarten Island. Planners and design engineers can easily describe the proposed location for decision makers and general public using 3D maps. The most sensitive and crucial issues of flood diversion and stormwater detention pond projects can be discussed effectively with general public and decision makers with the help of overall three dimensional geographic visualisation. At the same time the relocations of public services, residential areas can also be identified in most practicable way with the use of 3D maps.

The flood damage assessment for both tangible and intangible has been done on GIS based framework. Finally, the total flood damage in 150mm per hour event was assed as 16.5 mill US$ in “before rehabilitation” scenario. Subsequently the system was evaluated for “after rehabilitation” scenario, and found that the annual benefit is 150000US$ per annum for 15 years time. This helps decision makers to make decision to implement this mitigation measures.

10. CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusion

This research study is an attempt to incorporate the GIS technology with computer-based flood modelling results for flood damage assessment and disaster planning. St.Maarten was chosen as a case study for this research, because of its unique topography and tropical storm weather conditions which generate frequent flash floods and as such impose a continuous threat to residents. Further more, availability of appropriate data made St Maarten all necessary to be a good case study.

From the analysis of numerical model results, irrespective to the modelling system used, it can be concluded that the results of those models do not provide sufficiently clear message to non-technical users. For instance, this study area was modelled with MIKE-11 1D model, and if the results are presented in MIKE VIEW tool, still the real application of flood plain against the DTM cannot be derived. In that respect, separate software called waterRIDE was used to translate the binary data into the format that can be used to present the model results on a GIS platform.

The Hazard zones can not be defined reliably enough by considering the impact of flood depths only. The velocity component also has a significant impact on hazard zones, especially due to flash flood situation in this study area and therefore it must be considered. The simulated model results give thousands of data on flood depths and velocities at each time steps which needs integration and transferring in GIS user friendly environment.

Therefore, this research is directed to find an approach to integrate both impact of flood depth and velocities within a GIS platform. The GIS has a power of manipulating thousands of data, using different features of point, polyline, polygon or raster. The data of flood depths and velocities which were in polygon feature classes were integrated with pre formulated hazard criteria on a GIS-based platform. The algebraic criteria for Low, Medium, and High, Very high and Extreme hazards was formulated based on the past data of this study area as well as from the knowledge of previous studies. All those algebraic criteria for each hazard zones were evaluated with the use of function “MAP ALGEBRA” in ARC GIS, as specified to produce the hazard maps accordingly. These algebraic criteria can further be improved with the assistant of sound sociological survey.

Flood damages have been estimated as tangible and intangible damages. Even though flood damage is influenced by both flood depth and velocities, it was assumed that, flood depth was the predominant factor which causes the flood damages, due to the following reasons:

1. Since the velocities across the flood plane can not be reliably measured where as the maximum flood depth can still be recorded any assumption without the field correction in this respect was assessed to be inappropriate.

2. Peak velocity occurs when flood depth is increasing, but at its lower values, that is at the beginning of the time series, but peak flood depth is at place following the recession part of the time series, that is when velocity is decreasing and at its lower values. This is to say that the velocity and depth peaks are not coinciding at the same point simultaneously. Therefore, flood damages are estimated on flood depths for this study.

All buildings were classified according to their functionality and then flood damage curves (FDC's) have been developed for each classification. These FDC's were developed based on the results of field valuation survey. FDC's were defined as unit cost per unit area at each flood stages for commercial and industrial properties .However, for residential buildings , the costs were defined as unit costs for each building or property at each flood stage.

Flood depths are extracted from MIKE -11 results and averaged into a single value for each building. The maximum submerged depth was considered as flood depth for that building. Then direct flood damages were estimated by multiplying flood depth and unit cost.

All of the above operations were possible to be carried out within a GIS system, especially, when there is no other way to handle thousands of data as efficiently as it is with a GIS. Therefore, this approach was found to be efficient and accurate to estimate direct damages than any of conventional approaches.

Indirect damages were determined as a percentage of the direct damage. This was done according to the approaches as proposed by Kates (1965).

One of the objectives of this research is to find a methodology to estimate intangible damages in this study area, Therefore, the so-called API methodology was modified according to the field data. Following this, the new relationships were established to estimate intangible damages for St Maarten Island:

1. Relationship of flood depth and anxiety was derived as $FloodDepth = 0.05e^{0.0361Anxiety}$

2. Relationship between the flood depth and loss of income was derived as 6th order polynomial function.

This methodology was associated with GIS to abstract flood depths and to identify the extent of damage.

With respect to disaster planning, it is very important aspect to undertake the traffic planning and find the best routes to provide essential and rescue services during the disaster. Therefore, network analysis tool in ARC GIS was used to analyse the road network in flood condition to find the best routes.

Further to the use of this functionality the analysis were not fully successful due to the discontinuities in the road network. Therefore, in order to make such analysis successful it is critical that the road network is accurately digitised prior to the network analysis.

Output of this research produces flood hazard maps, an approach to estimate Tangible and Intangible damages, damage visualizations and preparation of disaster management plan with GIS.

Finally, the flood damage assessment for both tangible and intangible have been done in a GIS-based framework. Then the total flood damage from the largest event used in this study was assed to be 16.5 mill US$ in the "before rehabilitation" scenario. Subsequently, the system was also evaluated for the "after rehabilitation" scenario, and found that the annual benefit is 150,000US$ per annum for 15 years time. Such analysis can certainly help decision makers to make better decisions to implement mitigation measures.

10.2 Recommendations

The following recommendations can be proposed to overcome shortcoming of this research:

1. To study the ways of measuring more reliably depths and velocities across the flood plain.

2. To establish a best practice concerning calibration for flood plan areas.

3. Detailed field survey should be arranged for more detailed hazard classification.

4. A study to integrate the velocity component for flood damage estimation.

5. In this research, FDC was developed only for building properties. But other infrastructure and land should be also valued for more precise damage estimation.

6. FDC was established best possible given the limitation in data. This can be certainly done more accurately with a more detailed field survey. Therefore, it is recommended to undertake a detailed property valuation survey to establish more reliable FDC.

7. Damage roads should be also valued.

8. Relationship between flood depth and loss of income is 6th order polynomial function. Therefore, a sound sociological survey should be undertaken to simplify this complicated relationship.

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