FLOOD HAZARD AND RISK ASSESSMENT THROUGH INCORPORATING GIS WITH HYDRODYNAMIC MODELLING: CASE STUDY OF MUDA RIVER

by

RABIE A. A. HUSSEIN

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LIST OF ABBREVIATION

ARI = Average recurrence interval

CH = Chainage

FCRP = Flood Control Remediation Plan

DID = Department of Irrigation and Drainage

EO = Earth Observation

FFA = Flood frequency analysis

FEQ = Full Equations Model

GIS = Geographic information system

GPS = Global positioning system

HEC = Hydrologic Engineering Centre

ICT = Information communication technology

JICA = Japan international cooperation agency

KEDA = Kedah Regional Development Authority

LIDAR = Light Detection and Ranging

RDBSM = Relational database system management

RS = Remote sensing

SCADA = supervisory control and data acquisition systems

SID = Satellite image database

QdF = Flow duration frequency

UNET = A one-dimensional unsteady state hydraulic model

WSPRO = A computer model for Water-Surface PROfile computations

LIST OF SYMBOLS

Symbol	Definition
A	cross sectional area of flow (m^2)
B	stream top width (m)
g	Gravitational acceleration
V	cross-sectional average velocity (m/s)
k_n	1.486 for English units and kn = 1.0 for SI units
n	Manning coefficient of roughness
R	hydraulic radius (m)
S	slope (m/m)
S	Sinuosity
L	channel length (m)
l	straight-line valley length (m)
y	stage (m)
Q	Discharge (m^3/sec)
q	Lateral flow into the channel per unit length of channel
x	Distance along the channel(m)
t	time
S_f	Friction slope
K	conveyance
R	hydraulic radius
T	The return period

BAHAYA DAN PENILAIAN RISIKO BANJIR BERDASARKAN GABUNGAN GIS DENGAN PEMODELAN HIDRODINAMIK: KAJIAN KES DARIPADA SUNGAI MUDA

ABSTRAK

Sungai Muda telah menghadapi banjir bermusim dan mengakibatkan kerosakan yang serius dan menjejas tahap ekonomi dengan memusnah penempatan penduduk dan harta benda di kawasan tadahan Sungai Muda. Banjir pada tahun 2003 merupakan peristiwa yang paling membinasa berlaku dalam sejarah kawasan tadahan Sungai Muda. Perubahan dari segi geomorfolgi, kelakuan banjir dan impak kepada Sungai Muda telah dikaji dalam kajian ini dengan pengintegrasian antara pakej perisisian khusus dan teknik permodelan komputer untuk menjangka perubahan langsung terhadap kelakuan sungai dan membantu dalam meramal dan menghubungkan dengan risiko banjir. Kekasaran permukaan tanah telah dibangunkan melalui beberapa lawatan tapak di kawasan kajian. Kekasaran permukaan ini merupakan satu input yang amat penting bagi permodelan hidraulik. Keputusan daripada penyelakuan model hidrodinamik satu dimensi menunjukkan kawasan yang luas telah ditenggelami banjir di sekitar dataran banjir dan juga kerosakan teruk pada kawasan yang berciri-ciri penempatan penduduk dan kegunaan tanah pertanian. Penilaian bencana dan analisis risiko pada dua jenis gunaan tanah menunjukkan bahawa kerugian ekonomi pada banjir tahun 2003 (RM 27.6 juta) adalah setinggi lima kali ganda berbanding dengan banjir yang sebelum ini (1982) bagi tempoh 20 tahun (RM 3.87 juta). Kerugian yang besar ini boleh dihubungkan dengan perubahan-perubahan dramatik pada sistem sungai yang mempunyai sejarah dan kontemporari eksploitasi manusia yang tidak mapan di kawasan tadahan Sungai Muda ini, iaitu dengan peningkatan kerentanan terhadap bencana hakisan dan penurunan kekasaran permukaan tanah. Model bagi peristiwa banjir kala ulangan 100 tahun juga telah dibina untuk menilai keberkesanan pembinaan ban bagi menampung kenaikan paras banjir semasa berlakunya banjir besar. Penyelakuan model telah menunjukkan bahawa reka bentuk ban yang dicadangkan mempunyai kapasiti yang cukup untuk menampung air banjir dengan kapasiti tambahan setinggi 1.5 m. Hasil keputusan permodelan menunjukkan pembinaan ban dapat mengurangkan risiko banjir ke status sifar, dan seterusnya akan melindungi kegiatan manusia yang berada di dataran banjir. Pada jangka panjang, sungai ini mungkin mengalami penyesuaian geomorfik tanpa dipengaruh oleh bencana banjir; akan tetapi di masa hadapan latidakstabilan luar biasa saluran dan penyesuaian geomorfik mungkin bertambah besar dan dengan demikian berlakunya peristiwa banjir di kawasan kajian. Pemodelan komputer yang dilakukan dalam kajian ini dapat meningkatkan lagi pemahaman tentang perilaku jangka panjang dan perilaku banjir di Sungai Muda.

FLOOD HAZARD AND RISK ASSESSMENT THROUGH INCORPORATING GIS WITH HYDRODYNAMIC MODELLING: CASE STUDY OF MUDA RIVER

ABSTRACT

Muda River has been for many years experiencing seasonal floods and causing serious damage and economical loss to human settlements and property in the Muda basin. The 2003 flood was the most devastating event throughout the history of the river. The geomorphological changes, flood behavior and impacts of the Muda River have been investigated in this study using integration of specialized software packages and computer modeling techniques to envisage the consequent changes projected on the river, and assisting in predicting and communicating the flooding risk. Ground surface roughness was delineated through several field visits to the study area. This ground roughness acts as a significant input data for hydraulic modeling purpose. The results of one-dimensional hydrodynamic modeling showed a wide spatial extension of flooding inundation in the vicinity of the floodplain, and indicated damage severity on households and agricultural land use features located in these highly inundated areas. Hazard assessment and risk analysis on these two land use types revealed that the economical damage of the 2003 flood (RM 27.6 million) was five times than that of the last flood (1982) in a 20-year-period (RM 3.87 million). This enormous loss can be attributed to the dramatic changes imposed on the riverine system by much historical and contemporary unsustainable human exploitation of the Muda basin land assets, increasing its vulnerability to erosion hazards and decreased ground surface roughness. The 100-year flood event model was also reconstructed in order to

investigate the effectiveness of the proposed bund in controlling the increase in water depth during extreme flooding conditions. The modeling indicated that the proposed bund has enough capacity to contain safely the flood water, with an additional capacity of containing extra 1.5 m of flooding water without exceeding the breaching point. The modeling result also suggests the effectiveness of the proposed bund structure in reducing the flooding risk, protecting thereby the human activities in the floodplain. On the long run, the engineered river may experience localized geomorphic adjustments without initiating flood hazard; but under futuristic extensive and extraordinary channel instabilities, geomorphic adjustments may become magnified, initiating thereby flooding event in the study area. The computer modeling performed in this study improved the understanding of the long-term behavior of Muda River and its flooding behavior.

CHAPTER ONE
INTRODUCTION

1.0 Background

Natural hazards, as one of the elements of global ecodynamics, are caused by natural processes independent from the existence of the humans. Natural disasters can arise from weather patterns (e.g. tornadoes, storms, floods, and hurricanes.), changes in Earth's crust (e.g., earthquakes, volcanoes, and landslides) and climatic conditions (e.g. droughts, bush fires, cold snaps, etc.). Natural risks result from natural hazards when humans are exposed to them (Proske, 2008; Kondratyev et al., 2006). Since the earliest emergence of civilization on Earth, the humans have described natural disasters, such as the Noah's flooding in The Holy Quran. Flood disasters, either driven by natural or man-made forces, account for about a third of all natural disasters by number and economic losses and are responsible for over half the deaths on a global scale. In the poor and heavily populated Asia, flood disasters continue to cause the largest number of deaths. The global factors that might govern the future prospects for flooding are related to population growth, pressure on land use, climate change and insurance market response. Unfortunately, flood disasters' share in insured losses is relatively small, with an average of fewer than 10% (Knight, 2006). As the fast developing Asian countries face pressures of urban expansion and demand for more floodplain to be developed, they are expected to continue setting up flood management for the sake of community safety, sustainable development and resource management.

Flood hazard is the only significant natural hazard that affects Peninsular Malaysia (Chan, 1993). Flooding is a byproduct of the interaction between a natural events system and a human use system. Continuous changes in land use and climate affect the geomorphology of river systems (Toy et al., 2002; Houben et al., 2006). Aside from natural causes, the rapid development of modern Malaysia is causing changes in the natural hydrological regime which could have very serious consequences if not foreseen and allowed for in the design of development (Toebes and Seng, 1975). Flooding is a serious problem in Malaysia where drainage systems are poor and there exists a relatively high water table and flat topography. Many anthropogenic land use patterns (e.g. agriculture, industrialization, commercial, residential) are concentrated along rivers and in the vicinity of floodplains and submergible areas throughout Malaysia; thus are seriously subjected to the flooding catastrophes over the time. In the light of Malaysia's 2020 vision to be an industrial nation, more and more floodplain areas are expected to be developed, thereby exposing even more people and property to flood risk. This necessitates the need to set up efficient and effective flood management schemes and initiate engineering projects on national scale to alleviate the imposed risk to an acceptable level.

Dealing with flood management necessitates dealing with a huge amount of datasets; be they environmental, technical, economic, or social. Experience shows that increasing complicated problems in flood management entails the need for an integrated view, multidisciplinary methodology and smart solutions that are no longer simple to generate or implement. The complexity in flood management needs, therefore, to be uncovered, comprehended and its behavior to be simulated, analyzed and predicted to make flood decision-making/management feasible, efficient and effective. Fortunately, the modern, revolutionized digital technologies and the advent of computer-based hydro-modeling come to fulfill this requirement – hydroinformatics as emerging technology. The application of this technology becomes important in hydraulics studies and provides value as it relies on physical sciences, natural sciences, ICT and social awareness (i.e., sociotechnology) (Price, 2006; Abbott et al., 2005).

1.1 Flooding and Flood Management in Muda River

Floods are extreme natural phenomena that develop slowly and affect gradually on the environment. With increased in global warming, large-scale floods are possible in wider territories (Kondratyev et al., 2006). Flood hazard has been and will continue to be a threat for Malaysians, especially when humans choose to occupy floodplains, ignore the dangers of such hazard zones, over-develop land and deplete natural resources at rates that natural system can neither cope with nor adapt to. The damages for an annual flood, a 10-year flood and a 40-year flood are estimated to be RM 3 million, RM 18 million and RM 44 million respectively (Chan, 1993).

Stream channels are complex systems in space, time and causality (Lane and Richards, 1997). A change often triggers another, causing multiple responses to a single influence (Schumm, 1977). In fluvial systems, variability in the river's behavior and response to natural and anthropogenic activities is subject to three types of controls (Schumm, 2005): upstream, downstream and local, as illustrated in Figure 1.1.

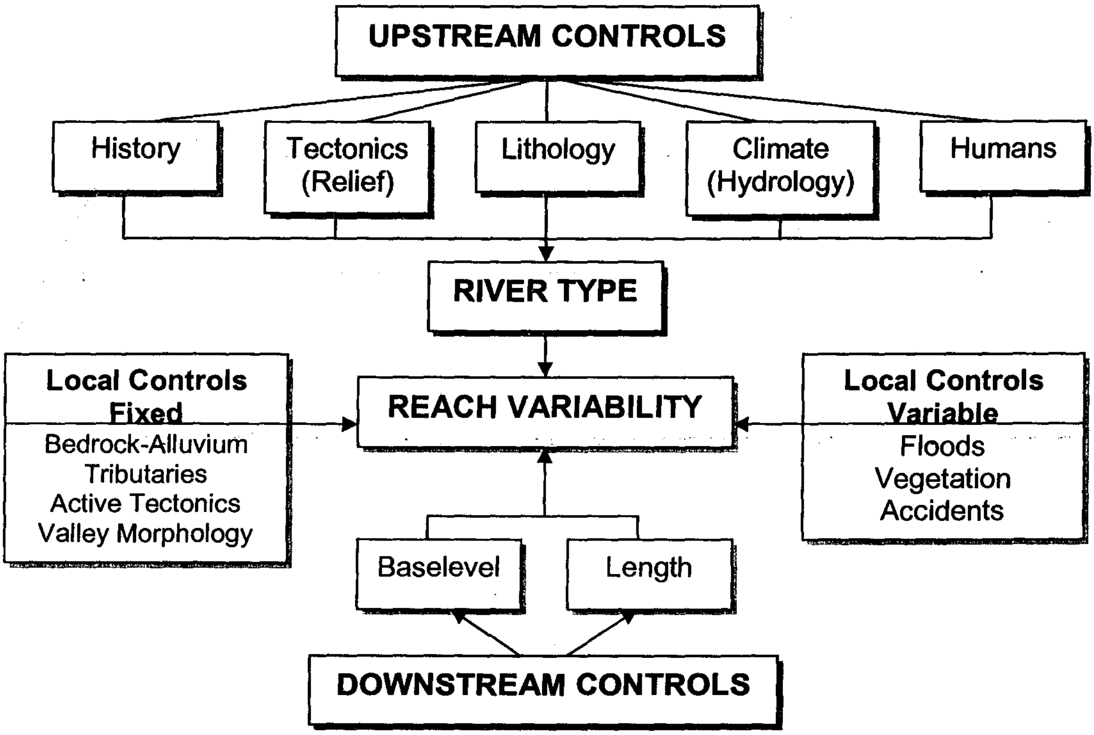

Figure 1.1 Three Controls of River Morphology and Behavior: Upstream, Downstream and Local (Schumm, 2005)

According to Figure 1.1, river response to human impacts will vary depending upon sediment characteristics, climate and the type of river, which results in uncertainty and unpredictability concerning the effect of controls (Phillips, 2002). Generally, for important land use changes, deforestation, afforestation and urbanization, experimental data interpreted for use under

Malaysian conditions indicated to the following observations (Toebes and Seng, 1975):

I. Land use changes have at least as great an effect on the hydrology as in temperate zones
II. water yield increases upon deforestation and decreases upon afforestation
III. peak flows and flood volumes increase (for smaller catchments) upon deforestation and urbanization
IV. Low flows and high water table due to high infiltration rate increase upon deforestation but tend to do the reverse upon urbanization

Muda River is a major source for water supply and sand mining for the northern states of Malaysia. It has been affected dramatically by unsustainable human activities that sacrificed environmental values for the sake of national development. The land draining into this river has been rapidly changing and cleared for agriculture, industrial and urban development. Forested areas are reduced. This has been caused by the growth of population size. These activities contribute to the increase in the amount of runoff entering the river and thereby exposing the population to the risk of flooding. Considering these disturbances and the complexity and variability can a river reach over the time and space, as perceived earlier in Figure 1.1, one can stereotype the dramatic scenario of the consequences in changing Muda River's flooding behavior as a result of its natural response to the changing controls.

Significant damages and losses of property, life and money had been associated with flood disasters in Malaysia. Muda River experiences floods almost every year (recurrent event), each differing only in their magnitude. The October 2003 flood saw 45,000 people affected with catastrophic damages. Many problems were associated with catastrophic flood of Muda River including riverbank erosion, river pollution and reduction of water resources. (JICA, 1995).

The appearance of conditions of danger to Muda River community is mainly connected with the probability of the flooding catastrophe as a result of poor landscape management. The catastrophe threatens human life and therefore their prevention through formalized prediction is a necessary element of safe and sustainable development of Muda basin in future.

The importance of sustainable development of the valuable riverine systems of the nation must be recognized. The Malaysian government initiated and generously allocated resources for a new "Flood Control Remediation Plan (FCRP)" devoted to study, design and implement flood mitigation projects in the Muda River district. The plan aims at better understanding of the dynamics of Muda River's flooding, defining options for flood loss prevention, design criteria for proposed mitigation measures and plot a strategy for flood management for Kedah State's vulnerable resources. The proposed mitigation works were structural and nonstructural, and ranged from changing river geometry, design discharge and bund height, channel realignment, flood diversion to constructing piers and bridges. (JICA, 1995)

Given that the current proposed FCRP flood mitigation (control) projects in Muda River are expected to change the flooding behavior of the river in future (in reference to the conceptual view shown in Figure 1.1), it is important to investigate and predict these behavioral changes and their spatio-temporal consequences in terms of project investment, feasibility and impact assessment.

Knowing the character and predicting the behavior of meandering rivers is also important for sound management and planning, especially as rates of down-valley migration and lateral channel shifts occur, both on spatial and temporal dimensions (Richards *et al.*, 2005). As development of infrastructure in developing Asian countries is the most damaged by natural disasters such as flooding, the problem of risk reduction due to infrastructure transformation turns very important. The solution to this problem is connected with optimizing processes of the use of land resources and working out ecological strategies. Furthermore, quantitative and qualitative dynamism in urban development leads to an overproportional increase in the vulnerability of such territories to flooding risk. This situation is provoked by either the economic interests or socio-political factors, when a large number of people are concentrated in a small area, which drastically increases the risk to human life (Krapivin and Varotsos, 2007).

Therefore, the problem of regional infrastructure optimization is becoming with the passage of time more urgent (Gurjar and Leliveld, 2005).

Risk as a measure of danger can serve as a guideline to resolve the problem of controlling a set of circumstances that can disturb human habitats and change conditions for the functioning of society. This includes getting estimates of the levels of adversity for many different aspects. At the same time, risk also has a subjective constituent which can be measured with the help of formal methods of decision-making that take into account intuitive assessment of the situation and psychological norms of perception of the environment. Furthermore, optimizing the risk to insurance industry from natural disasters becomes every year an ever more urgent problem, since economic losses are on the increase and are almost unpredictable. Evaluation of the risk and subsequent damage requires interdisciplinary analysis of a vast amount of information (Krapivin and Varotsos, 2007). This requires the flood expert to deal with a huge, complex computer databases relating to the many physical, natural, technical, economical, social and environmental aspects of flood risk.

Many types of flood controlling approach are being practiced in different flood-prone river basins. One of these is using hydroinformatics as an integrated flood management system to assist decision makers in encountering the issues of complexity in watershed hydrology, river hydraulics and environmental aspects. Computer modeling used in hydroinformatics can greatly improve the understanding of the long-term behavior of Muda River and its flooding behavior in the pre- and post Flood Control Remediation Plan (FCRP) phases. This will assist the concerned parties on perceiving the level of insurance might be prescribed for a successful flood management project and, therefore, resolving urgent or potential problems that might arise on the long run, and/or earlier in the project cycle.

The current thesis, therefore, comes to explore and address these challenges and investigate the use of hydroinformatics in studying the natural-anthropogenic interactions and their influence on the flooding behavior of Muda River and the subsequent impacts upon implementing flood management strategies. This research's interest comes in line with the global trend of investigating the importance of the interconnection of human living standards and natural process of flooding in the eye of digital technology. The state-of-the-art developments of hydroinformatics have significantly enhanced the ease with which computer model predictions can be computed and communicated. Its tools aim at solving the problems of water engineering issues as a single entity with available geospatial dataset collected, stored and processed by means of Geographic Information System (GIS), Global Positioning System (GPS), remote sensing and ground surveys. With the aid of hydroinformatics techniques in simulating and predicting the consequences and assessing the impacts, the outputs of this thesis will hopefully assist in optimizing the process of flood characterization, in improving the flood management practices, in playing as a feedback for these practices, in stereotyping negative-change consequences, and in defining suitable alternatives to mitigate the negative effects in a sustained manner.

1.2 Problem Statement

The flood event of 2003 of Muda River in Kedah State is considered as the most damaging flood event within the last 50 year. Since that time natural and land use changes have been affecting on flood behavior of the river. The new implementation of the FCRP plan will have an impact on the flooding behavior; therefore there is a need to assess the flooding behavior before and after implementing the FCRP plan. The flooding behavior before applying mitigation/prevention works will also differ than in the post (FCRP) phase. The assessment need to be qualitatively and quantitatively described to predict future impact, recommend control measures or correct the existing, and to communicate the risk to different concerned parties on the track towards reducing the risk to an acceptable level.

1.3 Research Objectives

The present study is directed to employ the state-of-the-art techniques of hydroinformatics in accomplishing the following objectives:

I. To determine the ground surface roughness of the study area based on field visits.

II. To assess of flood behavior pattern and its risk against a variety of site input variables.

III. To assess of flood risk on proposed structural control works and recommend new alternatives to manage possible hazard.

1.4 Research scopes

The scope and limitation of the present study are as follows

I. The modeling reach is limited from Ladang Victoria to the river mouth of Muda River.

II. The ground surface roughness is based on field visit during the years of 2007, 2008, and 2009. It's expected that the ground surface roughness needs to be reevaluated after 5 years from 2010.

III. The flood risk map developed in this study should be reevaluated every 5 years.

1.5 Organization of the Thesis

Chapter 2 in this thesis addresses the concept of hazard assessment and risk management and the old and new developments of hydroinformatics in water-based civil engineering works. The discussion is elaborated on those issues concerning the concepts and approaches of risk mapping and modeling with view of ICT role, scope, tools, methodologies and applications in flood investigations. Specific focus is given to discuss how hydrological modeling avails of the potential of geospatial technologies of remote sensing, GIS, computer graphics and artificial intelligence, and in which they strengthen hydrology as a science and as a profession. The chapter also outlines a literature review of the previous works and recent developments pertaining to river flood modeling and forecasting that lie within the interests of this thesis. The discussion highlights the importance and value of coupling and linking a GIS with other computing and modeling software packages to act in union towards disseminating new intensive data of multiple nature, dimension and use. A comparison in terms of capabilities, advantages and applications is drawn on between the most common commercial software products used in flood investigations by the experts.

Chapter 3 provides a description of the study area, Muda River, Kedah State. The description deals with the natural, physical, environmental and historical site use of Muda basin, supported with desk study maps, space imagery and ground photographs.

Chapter 4 deals with the general research methodology adopted to achieve the ultimate objectives of this study. Details on methods, techniques and procedure of data collection, data management, data treatment, data processing and visualization employed in the study are elaborated.

Chapter 5 represents the findings of flood simulation modeling and analysis computationally and graphically. Synthesized results and assessment of the simulated flood behavior change and its impacts on spatial and temporal bases are discussed and verified with statistical and thematic information. The outcome is directed to support the decision making process regarding current and future flood management practices.

Chapter 6 highlights the conclusion and recommendations this study comes up with. Future work and proposed developments regarding Muda River basin and flood management are also projected for further investigation and study by prospective researchers and interested personnel.

CHAPTER TWO
HYDROINFORMATICS IN FLOOD RISK MANAGEMENT

2.0 Background

The advancement in Information Communication Technology (ICT) in general and Geographic Information Systems (GIS) in particular has created countless opportunities for developing decision support for flood studies. Consequently, the decision-making process to manage the hazard of flood events has become more feasible, time- and cost-effective using computer aids and mapping tools found in GIS. In general, the procedures of data collection, data management, data processing, data representation and data communication of flooding risk have benefited widely from computer development and GIS. These tasks are now becoming operationally optimized in a new branch of computer-based hydrological studies, called "hydroinformatics" which will be defined later in this chapter.

This chapter addresses the aspects of flood risk management in the era of digital technology. It highlights the framework of flood risk management and the power, practicality and the revenue gained from applying hydroinformatics tools in this framework through reviewing the recent developments and previous works published in the scientific literature. The chapter paves a space for the mapping-based flood hazard assessment and elaborates on the various types, configuration and usefulness of flood risk mapping and modeling systems to ultimately disseminate a proper decision for flood risk management endeavor.

2.1 Hazard, Risk and Flood Risk Management

Hazard is a naturally occurring or human-induced process, or event, with the potential to create loss. Risk is the actual exposure to a hazard (Smith, 2001). De Bruijn and Klijn, (2009) indicated that flood risks can be defined as '*the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event*'. Therefore, flood risk has two components (Samuels, 2006b; Helm, 1996):

I. The probability of a flooding event occurred, and

II. The consequence of the flood event's impact which may be desirable or undesirable

So that the objective measurement of risk can be formulated by the following equation:

$$\text{Risk} = \text{Probability} \times \text{Consequence}$$

And to establish flood risks, both flood probabilities and consequences must be considered or – alternatively – flood hazard and the vulnerability of the flood-prone area (Gouldby & Samuels, 2005).

River channel hazards can arise naturally from geomorphologic processes, from activities of land use, or from a response to channel management actions (Downs and Gregory, 2004). These hazards are subject to a host of changing variables, such as time, discharge, sediment load and base level. Types of river channel hazard (Table 2.1) can be categorized into the following (Schumm, 1988):

I. abrupt, producing a catastrophic event, such as dramatic channel widening in response to a large storm event;

II. progressive change that leads to rapid change, such as meander's growt leading to a meander cut-off;

III. progressive change that has slow but progressive results such as bank erosio

Table 2.1 Types of River Channel Hazards (Downs and Gregory, 2004)

Erosion	**Deposition**	**Pattern Change**	**Metamorphosi**
• Incision • Knickpoint formation and migration • Bank erosion	• Aggradation • Back and downfilling • Formation of berms	• Meander growth and shift • Island and bar formation and shift • Meander cut-offs • Avulsion	• Straight to meandering • Straight to braide • Braided to meandering • Braided to straig • Meandering to straight • Meandering to braided

Flood hazards are characterised in terms of flood probability, flood depth flow velocity, water level rise rate, and other factors. Hazard dimensions can be characterized in terms of *where, when, how long-lived* and *how much* adjustmen occurs. Flood managers dealing with such dimensions should understand the location, likelihood, persistence and magnitude of prospective hazards Management options then can be evaluated besides predictions on the dimensions adjustments resulted from applying these options (Downs an Gregory, 2004). Flood impacts comprise both direct and indirect impacts, or tangibles (usually property and economy) and intangibles, such as people (fatalities, injuries, psychological damage, etc.) and ecosystems. Generally, i flood impact assessments, flood damage and fatalities are considered first (De Bruijn and Klijn, 2009).

Recent research in flood studies has recognized that adopting risk-base approach in flood management has proven to be better over the traditional flood protection strategies (De Moel et al., 2009). This is because risk has many dimensions in management practice in terms of safety, economy, environmental and social issues; thus the process of decision-making will cover multiple issues and go in accordance to the risk manager's needs. Risk also has been the main focus of mitigation procedures of integrated flood management projects (Green et al., 2000). Since risk is typically concerned with the likelihood of undesirable consequences that would harm society, property or the environment, hence; the practice is directed towards preventing or managing possible impacts of a flooding event. Therefore, risk should form the framework for managing and communicating the effects of flooding (Samuels, 2006a). Both spatial and temporal scales of flooding consequences must be taken to avoid inadequate, biased decision-making process (Samuels, 2006b). Aven and Kristensen (2005) discussed that risk can be considered both as a way of expressing uncertainty, and as a collection of perceptions. This means that risk should be considered to be a judgement rather than a fact. The 'probability' approach is an expression for the state of knowledge, that depends on the information and the knowledge of the individual who assigns it. Hence, no universal and true probability exists (Raaijmakers et al., 2008).

In order to take effective and efficient decisions in flooding events, a consistent, systematic and integral risk management approach has to be designed (Plate, 2002). Ammann (2006) proposed the concept of the integral risk management of a natural hazard (Figure 2.1) where the process is composed of a complete set of risk identification, risk analysis, risk assessment and planning of mitigation measures. The general framework of this concept (Figure 2.2) involves a strategic and systematic process of controlling the risk and a comprehensive risk dialogue between all stakeholders. The cornerstone of this framework is t information of people at risk and of the authorities and agencies responsible f flood management. Only if the people and decision makers are aware of the flo risk, and only if they are able to evaluate the risk, they can be expected adequately respond to this thread.

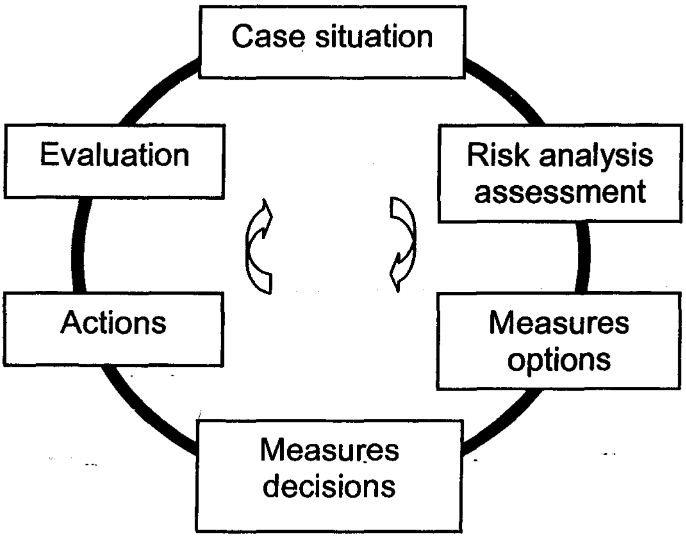

Figure 2.1 Elements of an Integral Risk Management as Proposed by Ammann (2006)

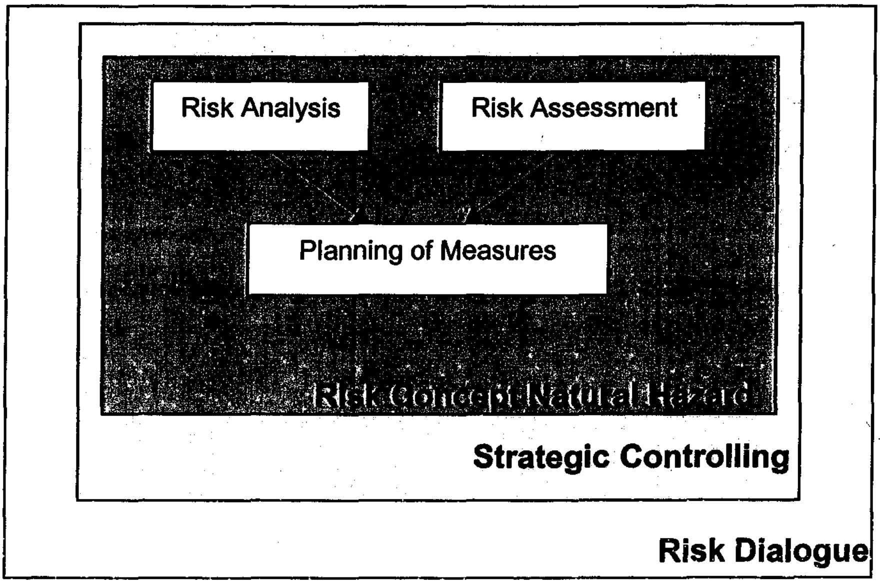

Figure 2.2 Framework for the Integral Risk Management as Proposed by Ammann (2006

2.1.1 Risk Analysis

Risk analysis is the first phase and considered central in risk management framework (Plate, 2002). In this phase, aspects of hazard analysis (i.e. source, pathway, receptor and consequence), exposure analysis, impact analysis, risk estimation and visualization are assessed. In terms of flooding, this phase is trying to answer the following questions (Samuels, 2006b):

I. Can the flood happen in the land?
II. What area is affected?
III. What causes the flood?
IV. How often does flood occur?
V. How deep is the flood?
VI. How rapidly does the flood rise?
VII. How long does the flood last?
VIII. Can any warning be given?

2.1.2 Risk Assessment

Flood risk assessment has gained increasing attention due to its importance in flood management. In this phase, consideration is given to the protection goals of lives and assets, the risk categories and risk aversion, trying to answer the question of "what extent of flood is acceptable to happen?". This require understanding the behavior of a flooding system, i.e. its physical, man-made defense, economic, social, environmental aspects, statutory responsibility, insurers, and stakeholders. Once the behaviour of the system is understood, many dependent and independent issues could be identified, and a system failure probability can be estimated and combined with knowledge of the consequences

(Samuels, 2006b). All in all, the assessment context has to do with complexity, uncertainty and ambiguity of the risk.

Risk perception is vital to the assessment phase. Raaijmakers et al. (2008) discussed a standard approach that integrates the conventional risk methodology (technical expertise) with societal risk perception. This combination helps to explain the influence of flood risk perception on risk-benefit trade-offs. Four types of risk characteristics need to be considered in flood risk perception: (1) Ignorance; (2) Safety; (3) Risk reduction; and (4) Control. Raaijmakers et al. (2008) believed that "worry" is the characteristic that links risk perception to the risk-benefit trade-off. If levels of worry are high, there will either be a demand for risk reduction in terms of lower probabilities of damage or a demand for reduced effects/consequences. If levels of worry are low, the individual believes that society is in control, feels safe or is completely ignorant of the situation. In the latter case, risk communication becomes important.

2.1.3 Risk Planning

In risk planning phase, relationships of risk-costs and marginal costs, and integration of possible measures that are required to reach the protection goals are assessed. These measures must be planned and checked for effectiveness and undertaken to play valid management solutions that fulfill prevention, intervention and reconstruction through risk cycle (Figure 2.3), and also meet sustainability, acceptability, feasibility, and reliability criteria (Ammann, 2006).

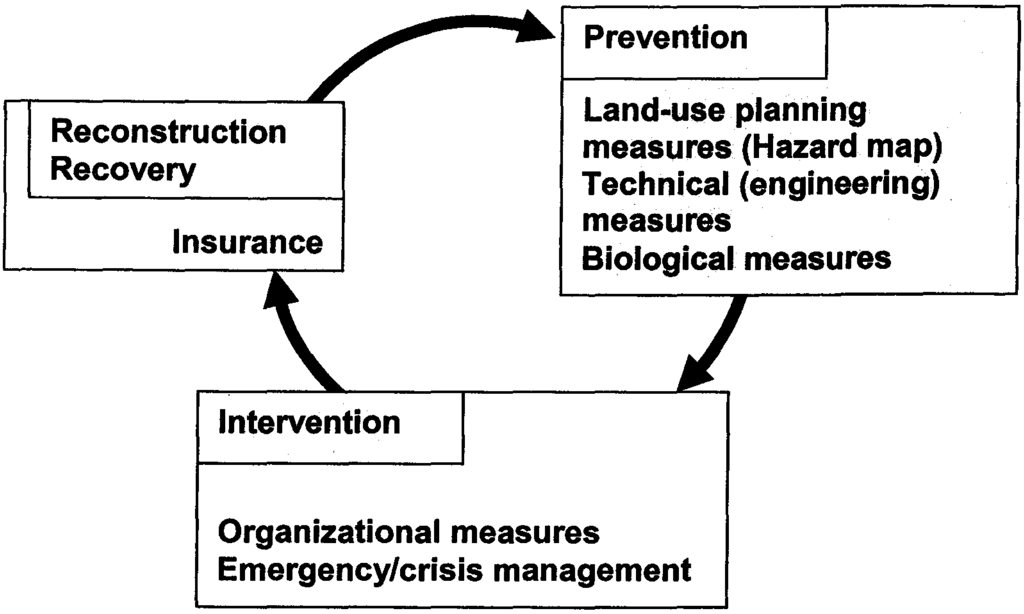

Figure 2.3 Risk Cycle and Possible Measures for Risk Reduction and Mitigation (Ammann, 2006)

Flood risk reduction and management have generic options aiming at controlling the source, the pathway, the exposure and the vulnerability (Samuels, 2006b). In this case, risk can be controlled by addressing both the probability through structural defenses and the consequences of flooding through non-structural measures. As the actual provision of flood defenses requires economic justification through cost-benefit analysis on a project-by-project basis, risk assessment comes here to determine whether the current provision is sufficient to mitigate the flood risk and/or identify new protection measures towards controlling the risk to acceptable levels (Samuels, 2006a). Therefore, to obtain insight into the appropriateness of proposed measures, risk assessment is essential.

Mitigation approaches to deal with flood risk have changed over the past and present time, between primitive approaches such as building houses on a higher level or using boats to escape danger areas (White and Haas, 1975), to engineering approaches such as the construction of dams and levees (Monroe e al., 2007; Downs and Gregory, 2004). Advanced approaches included also floo risk mitigation for the public by providing forecasting and warning systems, whic allow appropriate emergency response to flooding in marginal areas and th potential failure of flood defenses (Samuels, 2006a). However, such mitigatio tasks function at different spatial and temporal scales, and is often still lacking i flood assessment studies.

Land use planning combined with risk mapping contributes effectively i limiting the consequences of flooding. This has made floodplain mapping a common practice in most countries (Samuels, 2006a). New developments i computer visualization have also brought the attention to modeling and mappin issues of flooding hazard and river complexity, and allowed for quantifying the prediction of uncertainty of the end-product at higher level (Savic and Khu, 2005).

2.2 Modern Approaches of Flood Risk Assessment

The basis of effective and efficient risk management is risk analysis an assessment (Merz et al., 2007). Huang (2005) pointed out that in the past, floo risk assessment used to be based on statistical risk-analysis approaches which focus on the study of flood defence systems using probabilistic design. Such methods provide risk assessment to support long-term planning such as dike construction which is usually applied for large spatial scales. This approach does not usually involve complex hydraulic computations beyond 1-D. In recent times, a collection of flood risk assessment methodologies have been developed by simulating the consequence using physically-based numerical simulation models for inundation modelling, which calculates the damage caused by individual flood events. This method provides the consequence of the impact associated with a particular flood event, and involve computations in 1-D and beyond. Often such a method is used for short-term operation such as the operation of a retention basin during flooding.

Gilard (2002) proposed the "inondabilité" method to assess the flood risk based on estimating the two components of risk – vulnerability and hazard - from synthetic hydrological model called flow-duration-frequency (QdF). This method was applied in several basins in France of areas from 20 up to 1,000 km square. Gilard (2002) found that the method has helped decision makers in designing better policies for flood management. Furthermore, a new trend in modern risk-based analyses in integrated flood management systems shows an increasing relyianc on the tools and capabilities of computing machines and mathematical modeling (i.e. algorithms). This was a natural consequent of the global trend in employing evolutionary computing in wide range of applications in hydrological sciences and by which a new thrust of discipline has emerged – hydroinformatics (Savic and Khu, 2005). Digital mapping is one successful endeavor used in hydroinformatics for flood forecasting and communicating flood risk to different concerned parties (Albaneseb et al., 2008). Since maps give a more direct and stronger impression of the spatial distribution of the flood risk than other forms of presentation (verbal description, diagrams), they are valuable for presenting and assessing the local flood situation, and they provide information for many applications in flood defense and disaster management (Merz et al., 2007; De Bruijn and Klijn, 2009).

Today, various flood damage estimation methods are in use in several countries around the world. However, there is no standardization of such methodology, and different organizations are using various methods without any national consensus. To date Malaysia does not have a standard procedure or methodology to assess damages caused by flood that comes yearly as a mere repetition (Neging, 2004). Therefore, there is a need for adopt different flood risk assessment approaches to achieve sustainable river management for the sake of effective planning on short- and long-term bases.

2.3 Hydroinformatics

Abbott et al. (2005) defined hydroinformatics as "*the application of information, computation and communication technologies in the various fields of hydroscience and engineering*". They argued that the term per se rooted on the recent developments in computer-based applications in the field of hydrology. Hydroinformatics has recently developed from computation to communication and soon become able to interconnect the communication-enhancing technologies with the social aspects of development (decision-makers, stakeholders, public, etc.) – thus it increasingly becomes a sociotechnology. According to Savic and Khu (2005), the tools and algorithms emerged by the evolutionary computing techniques of hydroinformatics have allowed for the following features:

I. Utilizing multiple solutions instead of a single solution;
II. Synthesizing new solutions from previous ones, and
III. Modifying previous solutions to accommodate changes