# RISK-BASED PLANNING AND OPTIMIZATION OF FLOOD MANAGEMENT MEASURES IN DEVELOPING COUNTRIES

*Case Pakistan*

*Muhammad Atiq Ur Rehman Tariq*

# Risk-based planning and optimization of flood management measures in developing countries: Case Pakistan

Proefschrift

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*To*

*'Munir Akhtar'*

*—may her soul rest in the Heaven (Amin)*

Although circumstances did not allow her to finish her own education, she succeeded to motivate me, her son, to complete mine…

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Muhammad Atiq Ur Rehman Tariq

## Summary

*Problem statement*

Among all the natural hazards, floods claim most lives and highest financial losses. About 95-97% of all deaths and a significant part of economic losses caused by floods occur in developing countries. Despite spending considerable resources, flood management arrangements in developing countries are still unable to deliver satisfactory results. Limited resources, lack of research, and absence of proper planning are the main constraints towards the optimization of flood management in developing countries. Flood management plans are often accomplished with the financial and technical help of developed countries following their design methodologies and safety standards. Such plans are often not suitable for local conditions. Flood safety standards for developed countries may not produce the most efficient results when applied in developing countries.

*Objectives*

The subject of this thesis is flood management in developing countries, focusing on fluvial floods, with special focus on Pakistan. To address this issue, the development of a methodology that can appropriately consider the socio-economic and technical constraints of a country is crucial. This thesis intends to provide guidance for flood managers and land-use planners that develop a floodplain. Their general concerns can be described as: How much should land-use planners curtail developments and how much should the river be regulated to minimize flood risks? For a satisfactory solution of these concerns, a risk-based methodology is introduced and outcomes are compared with locally used and worldwide well-established methods. In other words, the objective of this thesis is to develop a method 'to maximize advantages by minimizing flood deductions in a floodplain, using the available resources'.

*Flood management in Pakistan*

Flood management in Pakistan is a resource-demanding and complex issue. A complete understanding of the problem and the existing setup is important. The nature of the problem of flooding varies extremely over the country depending on the hydrological, topographical, and demographical conditions. Considerable resources have been deployed over time since the country came into being in 1947. Despite deploying major financial resources and institutional support, flood management is still not appropriately optimized at the national level. The recent devastating flood in 2010 raised concerns over the reliability of existing flood management arrangements.

*Risk-based flood management*

Like most countries, Pakistan also uses probability-based flood safety standards (using a 50-years return period) for flood protection structures. To design flood protection measures according to probability-based standards, only flood characteristics need to be considered. Moreover, these standards do not provide guidance for the design of non-structural measures. A risk-based flood management approach provides the logical grounds for the selection and design of flood measures, whether structural or non-structural. It incorporates fairness and uniformity, and provides a firm basis to flood management practices. Risk calculations should not ignore the advantages of floodplain usage for productive purposes, like residential, industrial, and agricultural use. Risk-based analysis provides a systematic methodology to optimize flood management.

*Components of flood risk*

To estimate and minimize the risk of flooding at any location within the floodplain, it is important to know the basic components of risk and understand their role in inducing risk. Although risk mechanics have been defined differently in literature, this research proposes alternative, more appropriate, concept that considers all independent components of risk while avoiding redundancy. In this research, risk is defined as the result of the interaction between 'hazard' and 'vulnerability'. While a hazard can be characterized by its intensity and probability, vulnerability depends on 'susceptibility' and 'exposure'. The understanding of risk mechanics is important to select appropriate flood management measures with optimized design.

*Cost benefit analysis*

Cost benefit analysis (CBA) is a requisite for risk-based assessment. Multi-objective or multi-criteria analysis (MCA) may also be incorporated as a part of CBA for the optimization purposes. Careful valuation of economic, social, and environmental assets is indispensable for the precision of CBA. These analyses are often used to determine the feasibility of projects nowadays. Benefit to cost ratio (BC Ratio), Present Value (PV), Internal Rate of Return (IRR), and Economic Rent (ER) are economic efficiency indicators commonly used for the evaluation of projects. These indicators help to best utilize investments, but do not explicitly correlate the targeted flood management arrangements to the optimal arrangements.

*Expected annual damages*

The proposed risk-based assessment method helps decision-makers to envisage the spatial and temporal distribution of risk over the floodplain. Direct and indirect losses due to floods are related to the occurrence of floods, whereas investments in measures consist of the initial capital investments and the maintenance costs throughout the useful life of the measures. The 'Expected Annual Damages' (EAD) combine both the flood losses and investments in measures and spread (average) these over the lifetime of measures. Damage curves and EAD distribution maps provide a detailed picture of risk distribution.

*Optimal risk point (ORP)*

Nowadays, flood management aims at deriving maximum net-benefits from a floodplain. Starting from this premise, a method to maximize the net benefit is developed. Generally, flood losses decrease as investments on flood measures increase. Marginal costs for measures to reduce losses are initially low. When efforts are made to further decrease flood losses, the ratio between marginal benefits and marginal costs reduces. The point where marginal losses are equal to marginal benefits is known as the 'optimal state'. Different measures can achieve different optimal states. If different measures are considered to reduce flood losses and to increase land-use benefits, then a number of optimal states can be obtained. The optimal state with the lowest risk is called the 'Optimal Risk Point' (ORP). Combined direct, indirect, and induced losses due to floods are at their minimum while maximum benefits from the floodplain can be obtained at this point. Once the ORP is determined, economic indicators can provide guidance for the feasibility of a project.

*Case studies*

Two case study areas were selected. The first study area is the 90km long reach of the Chenab River from Marala Headworks to Qadarabad Headworks in Pakistan. It is densely populated, with valuable economic activities, and it has an almost flat terrain. The second study area is located on the Swan River within Islamabad City (Capital of Pakistan) where land is very expensive and developers have an interest in developing every inch of land.

Risk assessment and flood management optimization of these areas provided valuable information and suggested solutions for land-use developers and floodplain inhabitants. The following measures were analyzed:

- Risk-based design of dike crest levels
- Risk-based flood zoning
- Risk-based flood insurance

*Results*

In the study area of the Chenab River (from Marala to Qadarabad), flood risk was found to be extremely high where the General Trunk (GT) Road crosses the river connecting Gujrat and Wazirabad cities. The reduced width of the floodway causes the inundation of urban areas due to the backwater effect. At present, dikes are provided downstream of the GT Road bridge as the river slope is gradual and the area is almost flat. In those rural areas that experience frequent flooding, people adapt their land-use pattern to cope with this situation by reducing exposure and/or susceptibility. In the study area of the Swan River, risk had increased severely due to recently built residential areas. A number of private dikes divert hazard impacts to the other side of the River. These dikes are designed either with arbitrary design standards or with probability-based flood standards to protect the inner areas. Dikes and dredging were found not to be suitable measures here, due to the

high relief of the area and the steep slope of the riverbed. Flood zoning was demonstrated to be the most effective measure in this study area.

*Conclusions*

Development of effective and efficient flood management addressing the socio-economic conditions of developing countries is important. The concept of zero flood risk as a result of total flood protection is unrealistic in a floodplain. The acceptability of risk is a function of social, economic, and environmental concerns and may vary largely at personal and national levels. Arbitrary or probabilistic standards do not consider this variation and will not lead to an effective and efficient design of measures. Optimization of flood management requires adjustments to reduce the hazard as well as the vulnerability. The ORP-concept may help in developing risk-based standards for flood management.

*Recommendations*

Flood management must be an integral part of land-use development, in this way reducing risk by providing both land-use modifications and flood protection measures. Risk assessment must be accompanied by an intense understanding of social, economic, and technical aspects of a country and floodplain. The national risk management policy should consider the local context and address the issues accordingly. The personal choice of accepting flood risk may be covered by introducing complementary insurance or tax. Providing information indicating the initial risk and the residual risk after taking measures is extremely important. Therefore, the standard method practiced in a country should assure the information generated portrays the entire context. In addition, more reliable and agreed upon approaches must be developed to incorporate social and environmental factors into risk calculations.

*Muhammad Atiq Ur Rehman Tariq*

# Samenvatting

*Probleemstelling*

Overstromingen eisen de meeste levens en veroorzaken de grootste economische schade van alle natuurrampen. Ongeveer 95-97% van de overstromingsslachtoffers valt in ontwikkelingslanden en ook een belangrijk deel van economische schade treedt hier op. Overstromingsbeheer-maatregelen leveren nog steeds geen bevredigend resultaat. De optimalisatie van het overstromingsbeheer wordt beperkt door gebrek aan middelen, onderzoek en goede planning. Overstromingsbeheerplannen worden meestal opgesteld en uitgevoerd met financiële en technische hulp van ontwikkelde landen, op basis van hun ontwerpmethodieken en veiligheidsnormen. Dergelijke plannen passen vaak onvoldoende bij lokale omstandigheden. Hoogwaterveiligheidsnormen ontwikkeld voor ontwikkelde landen leiden vaak niet tot de meest efficiënte resultaten bij gebruik in ontwikkelingslanden.

*Doelstellingen*

Het onderwerp van dit proefschrift is het overstromingsbeheer in ontwikkelingslanden, met een focus op rivieren. Een methodiek die adequaat rekening houdt met de socio-economische en technische beperkingen van een land is hierbij van groot belang. Tevens probeert dit proefschrift richtlijnen te bieden voor waterbeheerders en planologen die overstroombare gebieden langs de rivieren inrichten en beheren. Hun dilemma kan grofweg als volgt worden omschreven: in hoeverre moeten zij enerzijds socio-economische ontwikkelingen in die gebieden beperken en anderzijds de rivier beteugelen om overstromingsrisico's te minimaliseren. Voor goed onderbouwde afwegingen hierover werd een op risico gebaseerde methodiek geïntroduceerd en werden de resultaten vergeleken met de lokale praktijk en wereldwijd gevestigde methoden. Het doel van dit proefschrift kan in het kort omschreven worden als 'de voordelen van overstroombare gebieden maximaliseren en tegelijkertijd de kosten minimaliseren, gebruik makend van beschikbare middelen'.

*Waterveiligheid in Pakistan*

Overstromingsbeheer in Pakistan is complex en vraagt de inzet van veel middelen. Een volledig begrip van het probleem en de huidige aanpak is belangrijk. De aard van het overstromingsprobleem varieert sterk over het land, afhankelijk van de hydrologische, bodemkundige, en demografische omstandigheden. Sinds het land in 1947 onafhankelijk werd, zijn aanzienlijke investeringen gedaan, maar ondanks die inzet en de institutionele ondersteuning, is het beheer van overstromingen op nationaal niveau nog steeds niet geoptimaliseerd. De verwoestende overstroming in 2010 voedde de bezorgdheid over de betrouwbaarheid van de bestaande overstromingsbeheersmaatregelen.

*Overstromingsbeheer op basis van risico*

Net als in de meeste landen van de wereld worden beschermingsmaatregelen in Pakistan ontworpen op basis van hoogwaterveiligheidsnormen die de kans op overstromingen uitdrukken (bijvoorbeeld een herhalingstijd van 50-jaar). Bij het ontwerp van een maatregel op basis van deze normen, worden alleen de overstromingkarakteristieken meegenomen. Deze normen geven daarnaast geen richtlijnen voor het ontwerp van niet-structurele maatregelen. Een op risico gebaseerde aanpak kan de selectie en het ontwerp van alle overstromingbeheermaatregelen ondersteunen, zowel structurele als niet-structurele. Een dergelijk aanpak is in hoge mate betrouwbaar en uniform, en biedt solide grondslagen voor overstromingsbeheer. De risicoberekening moeten niet voorbijgaan aan de voordelen van het gebruik van overstroombaar gebied voor productieve doeleinden, zoals wonen industrie en landbouw. Op risico gebaseerde analyses bieden een systematische methode om overstromingsbeheer te optimaliseren.

*Componenten van overstromingsrisico*

Om het overstromingsrisico op elke overstroombare locatie in te schatten en te minimaliseren, is het belangrijk om de basiscomponenten van de risico's te kennen en te begrijpen wat hun rol is in het induceren van risico's. Hoewel in de literatuur ook andere risicomodellen zijn gedefinieerd, wordt in dit proefschrift een voor dit onderzoek geschikter concept voorgesteld dat alle onafhankelijke componenten van het risico beschouwt terwijl het redundantie vermijdt. In dit onderzoek is risico gedefinieerd als resultaat van de interactie tussen 'gevaar' en 'kwetsbaarheid'. Een gevaar kan worden gekenmerkt door ‘intensiteit’ en ‘waarschijnlijkheid’; kwetsbaarheid door ‘gevoeligheid’ en ‘blootstelling’. Begrip van de mechanismen die risico’s veroorzaken is belangrijk om geschikte overstromingsbeheermaatregelen te selecteren en het ontwerp hiervan te optimaliseren.

*Kosten-batenanalyse*

Een kosten-batenanalyse (KBA) is nodig voor een op risico-gebaseerde beoordeling. Een multi-criteria analyse (MCA) kan ook worden opgenomen als onderdeel van KBA's voor optimalisatiedoeleinden. Een zorgvuldige bepaling van de economische, sociale en ecologische waarde is essentieel voor de precisie van de KBA. Deze analyses worden tegenwoordig veel gebruikt om de haalbaarheid van projecten te beoordelen. De ratio van kosten en baten, de contante waarde, de interne opbrengstvoet en de rentabiliteit zijn economische efficiëntie-indicatoren die gebruikt worden voor de evaluatie van projecten. Deze indicatoren helpen om investeringen zo goed mogelijk in te zetten, maar leiden niet noodzakelijkerwijs tot optimale keuzes vanuit het oogpunt van overstromingsrisicobeheer.

*Verwachte jaarlijkse schade*

De op risico gebaseerde beoordelingsmethode helpt om de ruimtelijke en temporele verdeling van hoogwaterrisico’s in overstroombare gebieden inzichtelijk te maken voor

besluitvormers. Directe en indirecte schade als gevolg van overstromingen treden incidenteel op, terwijl voor het treffen van maatregelen zowel eenmalige initiële investeringen als investeringen in onderhoud gedurende de levensduur nodig zijn. Het concept de 'verwachte jaarlijkse kosten' (VJK) combineert deze twee soorten kosten en spreidt ze uit over de looptijd van de maatregelen. Schadecurven en VJK-verspreidingskaarten geven een gedetailleerd beeld van de spreiding van de risico's.

*Optimaal risico punt (ORP)*

Het huidige overstromingsbeheer heeft als doel overstroombare gebieden maximaal te benutten. Dit is het uitgangspunt voor het ontwikkelen van een methode waarbij de baten worden gemaximaliseerd. In het algemeen neemt de hoogwaterschade af naarmate de investeringen in maatregelen toenemen. De marginale kosten om verliezen te beperken zijn in het begin laag. Wanneer er meer inspanningen worden gedaan om verdere daling van hoogwaterschade te bewerkstelligen, wordt het verschil tussen de marginale baten en marginale kosten kleiner. Het punt waarbij de marginale verliezen gelijk zijn aan marginale baten wordt de 'optimale toestand' genoemd. Verschillende maatregelen kunnen leiden tot verschillende optimale toestanden. Als verschillende maatregelen worden beschouwd om overstromingsverliezen te verminderen en de opbrengst uit landgebruik te verhogen, zijn meerdere optimale toestanden mogelijk. De optimale toestand met het laagste risico staat bekend als het 'optimale risico punt' (ORP). Directe, indirecte en geïnduceerde verliezen als gevolg van overstromingen zijn op dit punt minimaal, terwijl de voordelen van het gebruik van deze gebieden maximaal zijn. Na het bepalen van het ORP kunnen economische indicatoren toegepast worden om de haalbaarheid van de projecten te beoordelen en een prioriteitsvolgorde te bepalen.

*Case studies*

In twee gebieden zijn case-studies uitgevoerd. Het eerste studiegebied is de rivier de Chenab over een lengte van 80 kilometer tussen Marala Headworks en Qadarabad Headworks in Pakistan. Dit is een dichtbevolkt gebied met veel economische activiteit en een bijna vlak terrein. Het tweede studiegebied is gelegen aan de Swan River in Islamabad (hoofdstad van Pakistan), waar het land erg duur is en ontwikkelaars elke centimeter grond willen ontwikkelen. Risicobeoordeling en optimalisatie van overstromingsbeheer in deze gebieden biedt waardevolle informatie en oplossingen voor planologen en inwoners van overstroombare gebieden. De volgende maatregelen zijn geanalyseerd:

- Risico-gebaseerd ontwerp van dijken
- Risicozonering
- Risico-gebaseerd overstromingsverzekeringsstelsel

*Resultaten*

In het studiegebied van de Chenab River (van Marala tot Qadarabad), werd vastgesteld dat het overstromingsrisico extreem hoog is op de plek waar de General Trunk (GT)

Road, die de steden Gujrat en Wazirabad verbindt, de rivier kruist. De verminderde breedte van het rivierbed op dit punt veroorzaakt opstuwing en daardoor worden stedelijke gebieden voor de brug overstroomt. In plattelandsgebieden die frequent overstromen, passen de mensen hun landgebruik zodanig aan dat de kwetsbaarheid en de blootstelling wordt verminderd.

In het studiegebied van de Swan River bleek dat het risico sterk is toegenomen als gevolg van recent gebouwde woonwijken. Door enkele private dijken wordt het gevaar verplaatst naar de andere zijde van de rivier. Deze dijken zijn ontworpen op basis van willekeurige ontwerpnormen of op kansberekening gebaseerde hoogwaterstanden om de achterliggende gebieden te beschermen. Dijken aanleggen en baggeren zijn hier geen geschikte maatregelen vanwege het grote reliëf van het gebied en de steile helling van de rivierbedding. Overstromingsrisicozonering bleek de meest effectieve maatregel in dit onderzoeksgebied.

*Conclusies*

De ontwikkeling van een effectieve en efficiënte aanpak van overstromingsbeheer die past bij de sociaal-economische omstandigheden van de ontwikkelingslanden is belangrijk. Het concept van verwaarloosbare overstromingsrisico's en volledige bescherming tegen overstromingen is niet realistisch. De aanvaardbaarheid van risico is een functie van sociale, economische en omgevingsfactoren, en kan sterk variëren op persoonlijk en nationaal niveau. Willekeurige of probabilistische normen houden geen rekening met deze variatie en leiden niet tot een effectieve en efficiënte vormgeving van maatregelen. Optimalisatie van het overstromingsbeheer vraagt om aanpassingen gericht op zowel het gevaar als de kwetsbaarheid. Het ORP concept kan helpen bij de ontwikkeling van op risico gebaseerde normen voor het overstromingsbeheer.

*Aanbevelingen*

Het overstromingsbeheer moet een integraal onderdeel van de ruimtelijke ordening zijn om risico's te verminderen door middel van aanpassingen in landgebruik zowel als beschermingsmaatregelen. De risicobeoordeling moet gebaseerd zijn op goed begrip van sociale, economische en technische aspecten van een land en het overstroombare gebied. Nationaal risicobeheer beleid moet passen bij de lokale context en de lokale problemen. De persoonlijke keuze van het aanvaarden van overstromingsrisico kan gedekt worden door de invoering van een aanvullende verzekering. Het leveren van goede informatie is uiterst belangrijk, de standaard in een land gebruikte methode moet informatie leveren die een compleet beeld van de situatie geeft. Betrouwbaardere en maatschappelijk meer gedragen benaderingen moeten worden ontwikkeld om sociale en ecologische factoren te integreren in risicoberekeningen.

*Translated by*

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# 1 Introduction

## 1.1 Floods

Among all the natural catastrophes, floods have claimed most lives and have caused the highest economic losses than any other single natural hazard in the world. Based on data of floods and all other natural hazards used in long-term analysis (1988-1997)[1], the following facts about floods shows the severity of problem (Loster, 1999):

- Floods count 1/3 of all natural catastrophes (largest counts)
- Floods claim 10% of all the fatalities due to natural catastrophes
- Floods cause about 1/3 of the overall economic loss
- Floods have caused approximately $250 billion loss worldwide within last 10 years

Floods occur throughout the world with large variations in their impacts. There are areas, for example, the Nile, the Mekong, and the lower Indus floodplains, where regular flooding is a source of agricultural activities. However, with growing population and industrial activities in floodplains, floods are not accepted anymore in majority of floodplains. As a result, flood management and flood control measures are introduced in many places to control floods and their negative consequences (Duivendijk, 1999).

Actually, floodplains have been the sources of food, livelihood, and economic activities. Consequently, these floodplains have always been centers for human settlements, especially in early ages of human civilization. Since then, society is taking advantages associated with floodplains while trying to avoid flood losses. Due to high densities of masses and economic activities in floodplains, the impacts of floods are felt severely. The Netherlands and Bangladesh are examples of floodplains that exhibit high population densities (APFM, 2009a).

[1] Although these analyses (by Munich-RE) are quite old, these provide comprehensive comparisons. Some of newly conducted analyses support the same trends e.g., EM-DAT http://www.emdat.be/.

Losses due to natural disasters have greater impacts on developing countries comparatively. The largest casualties due to floods occur in developing countries and Asia (Douben, 2006). About 95-97% of all deaths and major part of economic losses caused by disasters occur in developing countries (Tung, 2002; WMO, 2003; UN-WATER, 2005; Kelly and Garvin, 2007). Naturally, such damages are higher proportions of national income in developing countries (Dilley et al., 2005). Flooding events do not affect only developing nations, but often affect and devastate the economically advanced and industrialized nations. Recent tsunami in Japan in March 2011 is an example. In the USA, 90% of all natural disasters involve flooding (Collins and Simpson, 2007) and costs approaching $6 billion annually (ASFPM, 2003, 2004).

Due to demography, life-style, and climatic trends, flood damages are likely to become more frequent, prevalent and serious as time passes (Borrows and Bruin, 2006). These higher flood losses demand an effective system for flood management and present growing trends in flood losses emphasize a revision of existing strategies on priority. An understanding of floods, their impacts, and flooding mechanics is necessary to propose improvements in flood management.

## 1.2 Flood management practices

Intensive use of floodplain triggered ever-growing flood losses. Structural measures are considered as conventional and effective measures. The first interaction with river can be the one when human settlements started maintaining a minimum safe distance from the rivers. Hence, the flood zoning (in an informal way) can be considered as the first step towards flood management (Cuny, 1991). The use of structural measures for flood protection dates back to the civilization of the Nile and the Romans. Structural measures remained the only option for a long time, but it was realized then that embankments are not suitable for all situations.

As mentioned, first action of man against floods was non-structural consisting of living at higher and safer areas, it was in the late 1950's, when non-structural measures were introduced as engineered measures. In addition, it was realized that the cost of protecting an area liable to flooding with structural measures is sometimes higher than for non-structural measures (Duivendijk, 1999; Tucci, 2007). Non-structural measures, such as warning systems, floodplain zoning, flood proofing, and flood insurance programs started to receive more attention. Further improvements were brought into the field of flood management with recent concepts of flood management. Integrated, sustainable, risk-based, holistic, and balanced concepts of flood management as well as the concepts of floodplain conservation are examples. Now these concepts are conjointly applied in the field of flood management. Sustainable and effective flood management requires an integration of policies, plans, projects, strategies, and measures (Petry, 2002).

## 1.3 Problem statement

Unfortunately, establishment of effective and optimized strategies are still important issues in developing countries (Petry, 2002). Limited resources, lack of research, and absence of proper planning are often considered main restraints towards the optimization of flood management in developing countries. Flood management plans are sometimes accomplished with the financial and technical help of developed countries along with their design methodologies and safety standards. Such plans do not suit to the local conditions appropriately. High safety standards (500-1000 years return period) proposed by donor countries for Dhaka after floods in 1988 are a good example that failed to provide desired results during floods in 1998 (Stalenberg and Vrijling, 2009). Flood management standards devised for developed countries do not efficiently produce desired results in developing countries. In this perspective, development of a methodology that considers the socio-economic and technical constraints of developing countries is crucial.

Nevertheless, the flood losses in developing countries are expected to increase in future due to their increasing vulnerabilities and absence of flood management strategies. In recent decades, developing countries have increased their vulnerabilities against floods due to their rapid development (ADPC, 2005). If no serious step is taken now, the risk will continue to increase in the future. Unfortunately, with the existing setups, it seems that "disasters will continue to take people, communities, and governments by surprise in developing countries" (White et al., 2001).

### *1.3.1 Major factors*

Before handling the flood problem in developing countries, understanding the flooding characteristics is very important. The flooding situation is worsening due to typical unplanned land-use development style and ad-hoc flood management practices. Most of new settlements are taking place with 'unplanned and organic' pattern (APFM, 2009a). Economic activities are usually concentrated in big cities. The poor populations, which earn their livelihood from big cities, have to acquire these outskirts of metropolises that are particularly at risk (WMO, 2003). Mostly, there is no insurance coverage to such settlements or people do not have the capacity to buy one. In addition, the ratio of economic loss to the total economy tends to be higher in future (WMO, 2003).

As mentioned earlier, most of flood management programs are accomplished with the financial help of international donors. The fact is that governments and NGOs put the interests of their national companies and members ahead of those of the recipients who live in floodplains (Green et al., 2000). These lopsided arrangements cannot assure a successful solution, instead, will develop mismatched adjustments.

Another important factor is that developed nations of the world produce the majority of greenhouse gases. The impacts will be more severe on developing countries who have larger vulnerable populations, national economies dependent on agricultural production

and are not fully equipped to deal with extreme flooding (Pelling et al., 2004). As those losses are uninsured, affected communities take a long time to recover. Sometimes, floods revisit these communities before they are fully recovered from the previous episode.

### *1.3.2 Possible way forward*

The developing countries must progress in the field of disaster mitigation and vulnerability reduction (White et al., 2001), because, without such reforms, developing countries will have little chance of generating higher economic growth. One hurdle in the way of sustainable flood management setup in developing countries is their dependency on post disaster aid, which can be considered as a problem of moral hazard (Benson and Clay, 2004). Developing countries should learn from the experiences of the developed countries rather than to replicate their policies and strategies (Green et al., 2000). Due to increasing trends in flood losses, even developed countries must revise their flood management practices. There are no 'off the shelf' management solutions that are invariably more appropriate than the others. As every climate and hydrological situation (rain, river, and sea proximity etc) is different from others, every floodplain needs to be treated individually. A general assessment method applicable to all floodplains, however, can be established. In addition, some common characteristics for a successful strategy can be defined there to evaluate the suitability of an approach. A genuine and logical approach must be proposed, rather than simply transposing the approaches of developed countries.

## 1.4 Objectives

The motive behind this research is to improve the flood management in developing countries that are characterized by their limited resources, dense population, and unplanned urbanization. The initial idea was to take advantage from the experiences of developed countries. Although, developed countries that experience comparatively less damages, are not an exception from flood damages. It was planned to see how these experiences could be used for developing countries. Due to the scope of work, this thesis focuses flood management in general, and fluvial floods in developing countries, in particular. It will help in developing a balanced, affordable, and effective approach at the national level.

This thesis intends to assist flood managers and land-use planners in the process of floodplain development and maintenance. The general concerns of both sides can be described as such: How much the developments are to be restrained and how much river should be trained to ensure a harmonious coexistence with floods? For the satisfactory solution of these concerns, risk-based methodology is introduced and outcomes are compared. In other words, the purpose of this thesis is to facilitate maximizing the advantages and minimize damages in floodplain within societal capacity. The focus is set to establish a criterion that can help to evaluate the suitability of flood measures for developing countries. The objective of research can be defined as "to develop a standard

flood management assessment approach that aims at optimizing the land-use net-benefits by reducing flood deductions in a floodplain suitable to socio-economic conditions of a country and the local society". This assessment may help to choose an appropriate flood management strategy suitable to any country whether it is a developed or developing country. That criterion may also help in choosing the most efficient measure or combination of measures to produce maximum benefits of floodplain.

Flood management is a technical problem, which has to address many aspects of legal, institutional, communication, emergency management, environmental, monitoring, and land development issues as well. It has to address all the components of flood risks. It must allow freedom to consider diverse measures. Assessment of measures, in our case, will be done within a probabilistic framework through risk-based criteria. A comparison with existing and presently practiced methods will also be performed. As mentioned, the flood management experiences in developed countries will also be utilized to achieve our objectives.

## 1.5 Study areas

For our case studies, two floodplains in Pakistan are selected. The Chenab River and the Swan River were selected. The river reach from Marala Headworks to Qadarabad was selected on The Chenab River whereas the reach between Islamabad Highway and GT Road was selected on the Swan River. Figure 1-1 shows the locations of study areas.

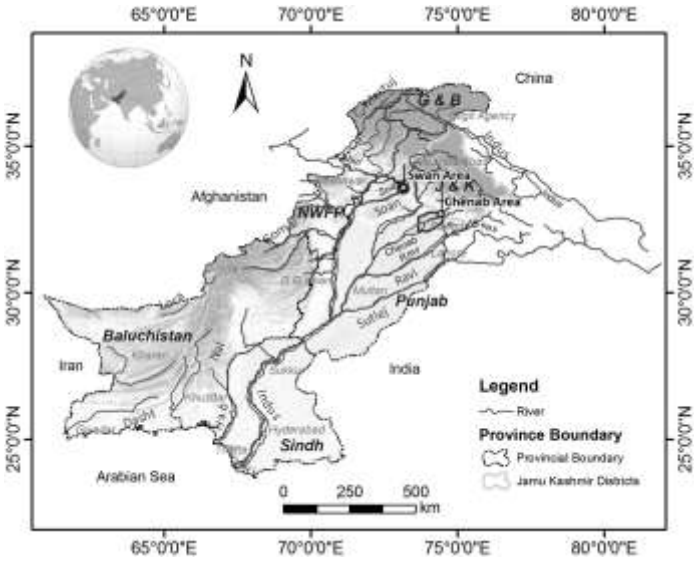


*Figure 1-1: Map of Pakistan indicating the Swan River at General Trunk Road, Rawalpindi and Chenab River floodplain from Marala Headworks to Qadarabad Headworks.*

The selection of the study areas is based on three reasons

- Pakistan represents a good example of a developing country where floods are common and efforts are made to establish an appropriate flood management strategy at the national level;
- Data was easily available and accessible due to the cooperation of government and private departments;
- The research is funded by the Higher Education Commission of Pakistan. Although there was no such demand by the Commission, Pakistani rivers were selected as goodwill to honor its financial support;
- The Author is familiar with the river system and floodplain characteristics of the study areas.

### *1.5.1 The Swan River*

The Swan River flows through Islamabad city. Due to intense pressure of extending population areas, developers are developing its floodplain. In the absence of a standard evaluations procedure, this development is going unchecked. In some areas of floodplain, development of residential areas might be extremely risky. Few dikes are presented in area that shift flooding to other side of river causing increase in risk across the river. These dikes may shift risk upstream or downstream as well. These are designed either with arbitrary design standards or against a certain flood design. People interested in buying property in protected areas never know that these developments might be safe against some design flood but not safe against all floods. Whereas, the standards adopted are also highly debatable.

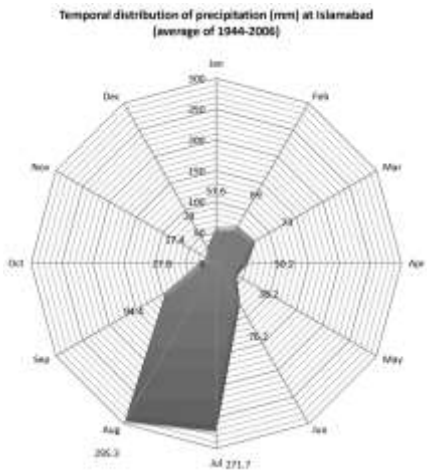


*Figure 1-2: Temporal distribution of precipitation at the Swan River basin*

### *1.5.2 The Chenab River*

The Chenab River is selected for this study as being the major source of fluvial floods in Pakistan. Having no suitable site for major storage reservoir in Pakistan, the Chenab River flows as an uncontrolled river. Whilst, Baghlayar and Salal hydropower dams in India (run of the river projects) have little effect on flood alleviation because of their limited storage capacities and mismated reservoir operation practices. Due to continuous deforestation in upstream hilly catchment areas, even higher floods are expected in future. The Chenab River is 1,240 km long and drains a basin of 67,500 $km^2$ excluding of its major tributaries Jhelum, Ravi, and Sutlej and joins the Indus River (NESPak, 2008). As mentioned, 90 km long river reach between Marala Headworks and Qadarabad Headworks has been selected. The selected reach is situated after the River just crosses international boundary and flood-warning system for this initial reach is not very effective.

## 1.6 Structure of thesis

This dissertation provides a conceptual approach for the assessment of flood management strategies based on risk process and its spatial distribution, equipped with interactive flood management. Figure 1-3 describes the schematic layout of this thesis.

Chapter 2 describes flood characteristics and the implemented flood management system in Pakistan. Basic concept of risk and risk-based flood management is proposed in Chapter 3. Chapter 4 provides the complete framework for the assessment of any measure, plan, or strategy. From Chapter 5 to Chapter 7, are the case studies and implementation demonstrations of proposed assessment method. Chapter 5 deals with the impacts of hazard adjustment. Chapter 6 presents the impacts of reducing community vulnerability. Whereas, Chapter 7 gives a brief description of impacts of flood insurance and indicates its importance to achieve desired vulnerability adjustments. Chapter 8 contains the main conclusions of this work and recommendations for future work.

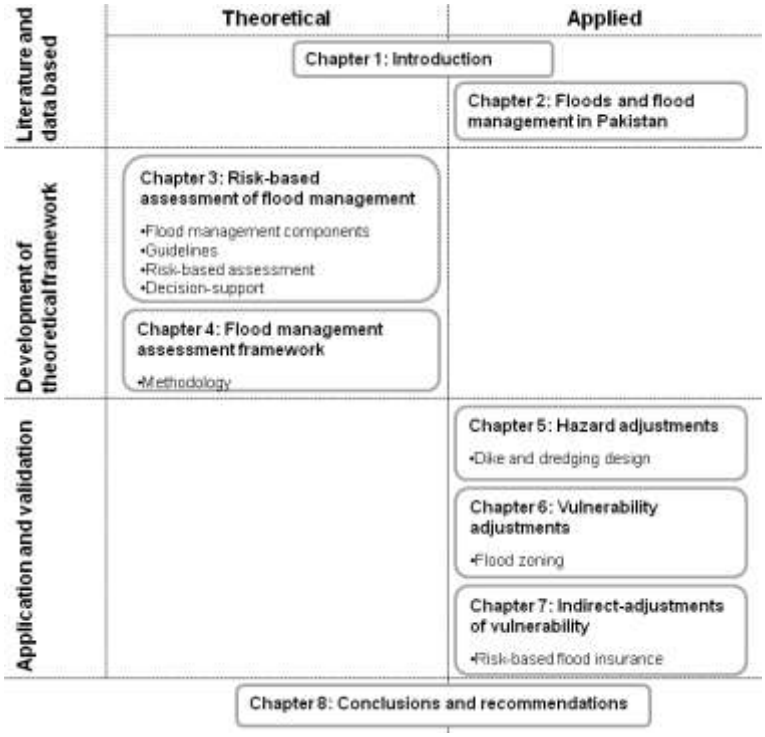


*Figure 1-3: Outline of this thesis*

# 2 Floods and flood management in Pakistan

## 2.1 Introduction[1]

In August 2010, Pakistan suffered one of the most severe floods in its history. Floods are the most frequently occurring and damaging natural hazards in the country. Of all population who are affected by natural hazards, 90% are subjected to flooding (Haider, 2006). In the recent flooding, almost 1800 persons died and financial damages were in range of tens of billions US dollars. According to available official statistics, about 8,000 people lost their lives and economic losses amounted to approximately $10 billion between independence in 1947 and the 2010 flooding (Baig, 2008). These estimates are carried out at the local administration level and uncertainty in these values is unknown. Although no major flood had occurred since 1995, the devastating flooding in 2010 demonstrated the continuous presence of flood risks.

The nature of flooding varies according to geography. Fluvial floods in the Indus plain prove most devastating, as the terrain is flat, densely populated, and economically developed. High discharges in rivers coming from upstream are the main cause of floods. Hill torrents (flash flooding) are the second most destructive type of flood. Hill torrents threaten large areas of the country (Figure 2-1) and claim human lives most frequently. Floods due to cyclones and intensive localized rain are dominant at other locations. Exceptionally high floods have also occurred due to the breaching of some of the small dams, e.g. the Shadi Kor dam in Pasni, which breached on February 11, 2005, washing away more than 135 people (IFRC, 2005; Javed and Baig, 2005). The hydrology of floods is linked to weather and climate as well as to physiographic features (Shah and Gabriel, 2002). A brief overview of related geographical features is provided to interpret the flooding characteristics. The country can be divided into three physiographical regions (Framji and Mahajan, 1969):

- Mountains in the north and north-west 241,647 km$^2$
- Plateau of Baluchistan in the south-west 242,683 km$^2$
- Indus River plains 311,766 km$^2$

[1] This Chapter is reproduced from the author's article published in Journal of Physics and Chemistry of the Earth with DOI 10.1016/j.pce.2011.08.014

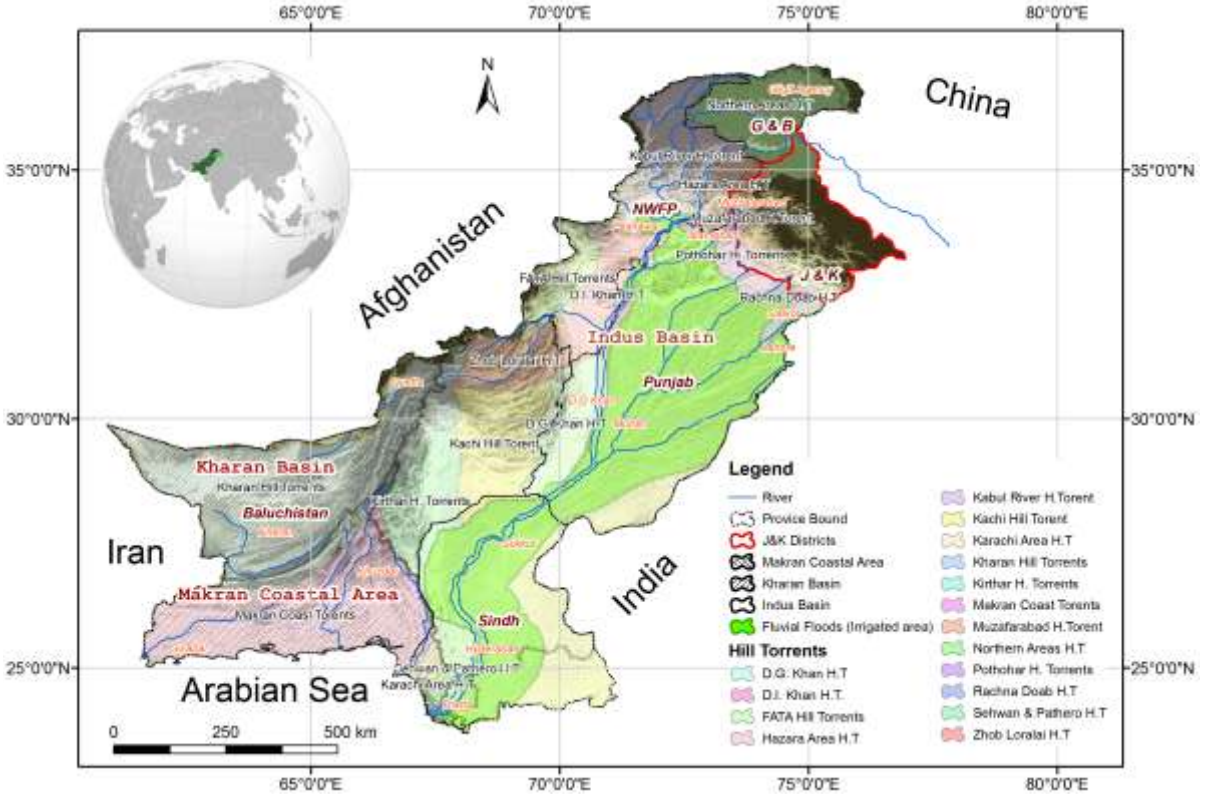


*Figure 2-1: Map of Pakistan rendering the important hydrological and geopolitical features*

The spatial variability of rainfall throughout the country is high. Of the total area, 59.3% can be classified as rangeland, which receives less than 200 mm annual rainfall (Umrani, 2001; ISDR, 2005). In the north of the country, the Himalaya Range receives annual rainfall between 760 mm and 1270 mm (ISDR, 2005) and contributes almost 72% of the mean annual flow in the Indus River System (WWF, 2010). These rainfall data are based on the national meteorological network. The spatial distribution of stations over the country is not uniform. Stations in developed areas and meteorologically important locations generally comply with World Meteorological Organization (WMO) standards. Southern Punjab, Baluchistan, and northern Sindh receive the lowest amounts of rain. Rainfall increases again towards the coast. Three types of weather systems influence the precipitation in catchments, which produce floods in Pakistan. These weather systems are

- Monsoon depressions originating from the Bay of Bengal (the most important system)
- Westerly waves coming from the Mediterranean Sea (Winter rains)
- Seasonal lows from the Arabian Sea (Cyclones)

The country has four distinct climate seasons. April, May, and June are extremely hot and dry months. July, August, and September are hot and humid with intense heat and heavy but scattered rainfall (monsoon). The cool and dry period starts in October and continues through November. December, January, and February are the coldest months of the year.

Hydrologically, the country can be divided into three major units: Indus basin, Kharan basin, and Makran coastal drainage area. Flooding characteristics of these basins vary greatly and require in-depth understanding.

## 2.2 Fluvial floods in the Indus basin

The total watershed area of the Indus is 944,000 $km^2$, 60% of which lies in Pakistan (MoE, 2003). The Indus, with its major tributaries Jhelum, Chenab, Sutlej, and Ravi, has an average annual flow of 175 $km^3/yr$. Table 2-1 presents a brief overview of the major rivers in the Indus Basin.

Seasonally, flows fluctuate from 3,000 $m^3/s$ to 34,000 $m^3/s$ (FFC, 2009). Annual river flows at rim stations (first gauging station after a river enters into Pakistan) fluctuate between 120 $km^3/yr$ and 230 $km^3/yr$ (MoWP, 2002b). Rainfall in the Indus Basin occurs during the monsoon and cold weather seasons, but severe floods only occur in the monsoon season. High flows are experienced in the summer due to the increased rate of snowmelts and monsoon rainfalls. About 82% of the annual water flows during the summer months (MoWP, 2002c). In this period, heavy rainfall in the upper catchments located across the border in Kashmir (Indian) often causes floods. Sometimes heavy showers occur in areas just within Pakistan. As a consequence, the rivers expand into their entire floodplains. The flooding behavior of the major rivers differs according to catchment characteristics and the types of installed river training facilities. In low elevation catchments (Sutlej, Ravi, and Jhelum), maximum snowmelt occurs in April

through June and does not coincide with the monsoon rains (July through September). In high altitude catchments (Indus and Chenab), snowmelt contributes significantly to flood flows. Maximum snowmelt in the Indus and Chenab basins is experienced in July and floods of high magnitude are generated due to monsoon rainfalls. The flood peaks of the different rivers usually do not coincide. However, when they do coincide, widespread flooding occurs.

*Table 2-1: Main features of the Indus River System*

| | **Sutlej** | **Ravi** | **Chenab** | **Jhelum** | **Indus** |
|---|---|---|---|---|---|
| **Origin** | Tibet | H.P.* | H.P.* | Kashmir | Tibet |
| **Discharge to** | Chenab | Chenab | Indus | Chenab | Arabian Sea |
| **Length (km)** | 1,500 | 900 | 1,240 | 820 | 3,200 |
| **Basin Area (km²)** | 122,000 | 40,000 | 67,500 | 63,500 | 727,000 |
| **Avg. Annual Flow (km³/yr)** | 3.05 | 4.46 | 25.17 | 24.33 | 83.15 |
| **Dams in India** | Bhakra, Pong^ | Thein | Salal, Baglihar | - | - |
| **Dams in Pakistan** | - | - | - | Mangla | Tarbela |
| **No. of Barrages** | 2 | 2 | 5 | 1 | 6 |

Sources: WAPDA annual report 2000, FPSP-II/C report 2008, and FFC annual report 2008
* Himachal Pradesh, India
^ Pong Dam on the Beas River (Major tributary of the Sutlej River)

Floods in the Indus and Jhelum basins are largely controlled by the Tarbela and Mangla dams. There is almost no control (in Pakistan) over the Chenab, Ravi, and Sutlej rivers, which results in flooding problems in the monsoon season. The Chenab has historically given rise to the most devastating floods because of the lack of any controlling structures and large flows induced by the combination of rain and snowmelt. India owns the exclusive water rights of the Ravi and Sutlej rivers under the Indus Water Treaty (1960). Because of that, there is practically very little flow in these rivers (Haq and Nasir, 2003). Average annual flows observed at the rim stations are about 3.15 km³/yr in the Ravi River and 0.02 km³/yr in the Sutlej River (Mir et al., 2010). Floods of higher intensity are observed on the Ravi River after the Treaty. According to annual peak flows data at the Balloki Barrage, of the seven most severe floods on the Ravi River (1922-2004), six floods occurred after effectuation of this treaty in 1973 (Figure 2-2). The decreasing width of these rivers and vanishing flows encourage encroachments for residential and industrial purposes, but an episode of severe flood may wipe out these developments.

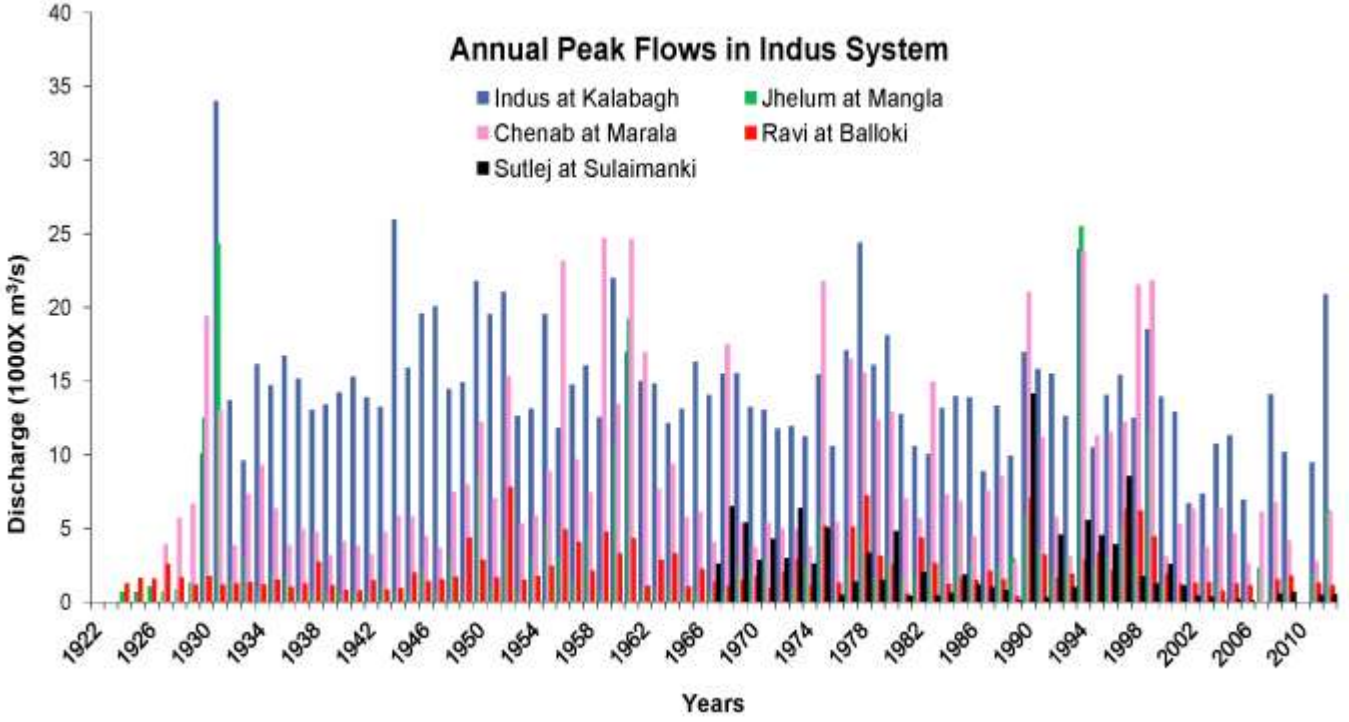


*Figure 2-2: Historical flood flows in main rivers (1921-2010), Source: NESPak*

In the upper and mid reaches of the Indus Basin, it is generally the tributaries like the Jhelum and the Chenab rivers that cause flooding rather than the Indus River itself. Since these rivers are also snow-fed, an early monsoon may combine with peak snowmelt runoff to exacerbate flooding. Generally, heavy rainfalls are limited to the Chenab, Jhelum, Ravi, and Sutlej River catchments. Occasionally, low atmospheric pressure crosses further north into the Indus River catchment like in the recent case of flooding. Intense rainfall produced exceptionally high flood peaks, which resulted in flash flooding in North West Frontier Province (NWFP, now Khyber-Pakhtunkhwa) and fluvial flooding in Punjab and Sindh provinces. Fluvial flooding caused losses by inundating large agricultural and residential areas, by damaging lifelines and powerhouses, and by eroding land along the riverbanks.

The nature of fluvial floods in the upper Indus Plain differs from that of the lower Indus Plain. In the upper Indus, the bed level is lower than the adjoining lands. When a flood occurs, floodwater spilling over the riverbanks generally returns to the rivers in the upper part of the Indus Basin. However, in the lower part of the Indus in Sindh province, where the riverbed is higher than the floodplain (suspended river), spills do not return to the river. This lack of return flow extends the duration of inundation, resulting in larger damages. Although flood protection by embankments has been provided along almost the entire length in Sindh province and at many locations in the upper areas, bund breaches can still occur (Haq and Nasir, 2003; Khan, 2007b; FFC, 2009). Such breaches often cause greater damage than would have occurred without dikes because of their unexpected nature and intensification of land-use following the provision of flood protection.

## 2.3 Flash floods in the Indus and Kharan basins

Flash floods typically hit the hilly areas of NWFP, Baluchistan, Kashmir, and Punjab. Kashmir and NWFP receive high average annual rainfall, whereas the steep and barren terrain of Baluchistan and Dera Ghazi Khan (D.G. Khan) watersheds typically produce severe flash floods, causing damage to infrastructure, settlements, and loss of human and animal lives. Flash flooding in the Indus Basin, is confined to the tributaries of the Indus, Jhelum, and Chenab rivers. Most areas in NWFP, Kashmir, and Baluchistan and some areas in Punjab endure flash floods. Flash floods are relatively lethal, e.g., more than 230 people died due to flash floods in the Pothohar Plateau (Islamabad, Rawalpindi, and NWFP areas) in 2001 (IFRC, 2002). According to flood loss data of the Federal Flood Commission (FFC), about 60% of the casualties were reported in NWFP during the 2010 flood due to flash flooding. Consolidated economic loss and casualty data has not been compiled nationwide and very little flood discharge data for hill torrents is available. It is extremely difficult to measure such peak flows with conventional methods due to their short duration and their unpredictability.

Floods in the NWFP are mainly hill torrents due to steep bed slopes, which greatly increase flood velocity and severely erode the banks. To save the areas from erosion, spurs have been constructed by the provincial government with the funds provided by the

federal government. Fluvial floods in NWFP are limited to Nowshera and some parts of Charsadda, Peshawar (by the Kabul River), and Dera Ismail Khan (by the Indus River). In the rest of NWFP, flash flooding is a common disaster along with landslides and torrential rains (PMD, 2009). Some dikes have been provided for flood diversion or abatement as well as to minimize the effects of torrential rains and consequent floods. Other severe flash flooding occurs in Dera Ismail Khan along the Indus. These hill torrents have an average annual flow of about 1 $km^3$/yr (MoWP, 2002a). A battery of spurs has been constructed on the right bank of the Indus River (FFC, 2009). Large numbers of spurs and a few embankments have been constructed along the Swat, Kurrum, and Kabul rivers and their tributaries.

The area of the Pothohar plateau (in north Punjab) often experiences flash flooding. Islamabad and Rawalpindi have endured flash floods from the Nullah Lai, which nearly flows through the centers of both cities. The low-lying areas in Rawalpindi along the Nullah Lai are even affected by small floods. Extreme floods in Nullah Lai were observed in 1981, 1988, 1997, and 2001 (Kamal, 2004). The hill torrents generated in Suleiman Ranges (Baluchistan and Afghanistan) hit the districts of D.G. Khan, Layyah, and Rajanpur in Punjab province. As the catchment area that generates torrents is quite far away from the above-mentioned districts, sometimes, weather conditions in the catchment area and affected areas are very different. In such cases, these torrents appear without any weather symptom or warning sign. D.G. Khan hill torrents have an average annual flow of 1 $km^3$/yr (MoWP, 2002a). These floods have destroyed bridges, settlements, and agricultural land along riverbanks and have deposited huge amounts of debris into the rivers.

All of Baluchistan Province, with its barren and steep land, is subject to hill torrents. The Nari, Kaha, and Gaj rivers are part of the Indus drainage system located in the northeastern edges of the province. Contrary to the rest of Baluchistan, the Kachi area is highly fertile and needs floods for irrigation (Jarrige, 1997).

Kharan Basin (within Pakistan) covers an area of 121,860 $km^2$ and includes part of the Kharan Desert and Pishin Basin in west Baluchistan. Average annual rainfall throughout the desert is less than 100 mm (Khosa, 2000) and average inland drainage is about 1 $km^3$/yr (Shah and Gabriel, 2002; UNITAR, 2004). The flow regime in the rivers is typified by spring runoff and occasional flash floods caused by Westerly waves during the winter months. The riverbeds are dry for most of the year. Intense flash floods do occur but are infrequent. Some bunds have been constructed to serve as flood diversion or abatement measures. During a severe flood, most of the embankments and floodwalls constructed to protect orchards or abadies (residential areas) are washed away. As flash floods of high intensity that disturb the settlements are quite rare, people are not prepared for disaster responses, which results in relatively large destruction and losses.

Pishin Lora Basin is a major river basin in Baluchistan (16,928 $km^2$ with 10 sub-basins) spread over five districts with a total population of about 1.2 million (ADB, 2008). As this basin covers the area with Baluchistan's main economic activities and high population concentration, the disturbance due to floods is high.

## 2.4 Floods due to cyclones in Makran coastal area

The coastal area of Pakistan stretches over a length of 1,046 km between 62°E and 68°E (Rehman and Bhattarai, 2005). Makran in the south of Baluchistan is a semi-desert coastal strip with an area of 123,025 $km^2$ and a length of 750 km along the Arabian Sea (Shah and Gabriel, 2002). The region is sparsely populated, with much of the population being concentrated in small ports and fishing villages. Away from the coast, the narrow coastal plain rises very rapidly into several mountain ranges. The entire length of the coastline is subjected to tropical cyclones. The Makran Coastal Basin includes the Dasht, Hingol, and Porali rivers, which discharge individually into the Arabian Sea (MoWP, 2002a) with an average annual flow of 3.5 $km^3$/yr. The climate is dry with very little rainfall and can be classified as arid with warm summers and mild winters. The monsoon rainfall increases with the increase in longitude along the coastline, whereas winter rainfall decreases with the increase in longitude. The average annual rainfall is approximately 150 mm or even less along the Makran Coast.

Floods in coastal areas are associated with cyclones and high tides. The Makran Coastal Areas have occasionally been hit by severe cyclones. Cyclones generated in the Arabian Sea produce torrential rains throughout the region. One cyclone is expected per year in the Arabian Sea. About 75% of these cyclones end up at the Omani coast on the western Arabian Sea and the remaining 25% curve clockwise and cross the coast near the Rann of Kutch (MoE, 2003). No severe tidal floods have been recorded so far. The coastal areas of Sindh are the most vulnerable and most exposed to cyclones. The period from 1971-2001 saw 14 cyclones (ISDR, 2005). One severe cyclone in 1997 affected Makran (Gawadar and Kech) and then crossed into the Kharan Basin up to the Chaghai and Dalbadin districts. The Nihang and Kech rivers caused widespread flooding in a region approximating 8,000 $km^2$ (PMD, 2009). The floods due to heavy showers of two consecutive cyclones caused tremendous damage. Cyclone Gonu struck the coast on June 4, 2007 and inflicted damage in the Sur Bandar area of Gawadar (Khan, 2007a). Cyclone Yemyin on June 26, 2007 is among the worst recorded so far. It affected 2.5 million people and made 250,000 homeless (UNESCO, 2007). The cyclone hit the catchment area of the Mirani Dam (Dasht River). Substantial rainfall occurred during the storm, causing serious flooding in the Dasht River. The Pakistan Meteorological Department data showed rainfall of 172 mm over the storm period (two days) at Turbat Airport in Baluchistan. The rainfall event was the highest rainfall recorded in the last 90 years (NDMA, 2007). The storm moved from east to west, moving from the Kech River's catchment to the Nihing River's catchment, the two main tributaries of Dasht River. As mentioned earlier, intense cyclones do not occur often, but they can cause large-scale damage and cyclone Yemyin was one such example. This cyclone caused flash flooding in various districts of the Baluchistan and Sindh provinces.

## 2.5 Flood management arrangements

After independence, devastating floods occurred in 1950, 1956, and 1957. Due to limited resources and institutional arrangements, no comprehensive flood management plan was initiated at the national level. Until 1976, flood protection and management was the sole responsibility of provincial governments. This changed after the annihilating floods of 1973, which claimed 474 lives and caused damages of 160 billion Pakistani Rupees (PKR) (approximately $2 billion) (FFC, 2009). A unified countrywide approach was initiated to manage the flood problem. As a result, a long-term principal plan was prepared in 1978 at the national level. The present flood management arrangements can be discussed under three aspects:

- Flood management measures
- Legislative framework
- Institutional setup

## 2.6 Flood management measures

The flood management measures in Pakistan are mainly comprised of flood protection embankments, spurs, studs, and advanced flood-forecasting techniques. Various flood protection structures were built by the provincial governments to solve local flood problems (Baig, 2008). Since the establishment of FFC in 1977, flood management has been practiced according to an integrated approach at the national level. A long-term National Flood Protection Plan (NFPP) was prepared in 1978. The NFPP contained phased implementation in the form of sub-plans known as the 'ten-years National Flood Protection Plans' (NFPPs). An estimated expenditure of over PKR 17.8 billion (approximately $220 million) has been spent on flood works, rescue and relief not included, under different programs since 1977 (FFC, 2009). A number of flood protection works have been completed and some are still in the implementation phase. The provinces receive financial and technical support provided by the FFC to address the flooding problem.

So far, three NFPPs have been executed covering periods from 1978-1987 (NFPP-I), 1988-1997 (NFPP-II), and 1998-2007 (NFPP-III). Under NFPP-I, 350 flood protection schemes (individual structure repaired or constructed) were implemented at a cost of PKR 1.73 billion (approximately $22 million) (Shaikh, 2008). NFPP-II was carried out under two sub-projects, namely, the Normal Annual Development Plan (NADP) and the Flood Protection Sector Project-I (FPSP-I). Under FPSP-I, 170 schemes (costing PKR 2,541 million, approximately $32 million) have been completed under the NADP and 257 schemes (costing PKR 4,860 million, approximately $61 million) have been executed. Three sub-projects were carried out under NFPP-III (1998-2007). 101 schemes (costing PKR 4,165 million, approximately $52 million) under FPSP-II, 362 schemes (costing PKR 3,415 million, approximately $43 million) under the NADP and development of a flood forecasting and warning system for Lai Nullah in Islamabad/ Rawalpindi (PKR 348

million, approximately $4.5 million) have been completed for this plan (FFC, 2009). These plans have been financed by the government and some donor agencies. The execution of the flood protection works is the responsibility of the provincial agencies, while decision-making and control of funds lie with the federal government. The approving authority for each single sub-project is also the federal government. About PKR 17.8 billion (unadjusted, approximately $222 million) has been spent on flood management measures since 1977 and about PKR 30 billion (approximately $375 million) is planned for NFPP-IV (2008-2017) (Shaikh, 2008; FFC, 2009). Financial resources, employed in rescue, relief, and rehabilitation process are used in addition to the above-mentioned expenditures.

According to the planning and approval criteria of the FFC, new flood projects are executed under two categories: either need-based measures to address local flood problems or integrated measures under the NFPP. Priorities are given to those measures, which serve areas of high economic losses, human suffering, and socially and economically vulnerable groups. Since the NFPP plans are mostly financed through loans from the Asian Development Bank, the measures are not sanctioned unless they have an economic internal rate of return (EIRR) of at least 12% (FFC, 2009) in compliance with bank criteria. The EIRR of a project can be defined as the average annual effective compounded return rate of investments. EIRR serves to enable a direct comparison of investments and benefits, which typically have a different temporal distribution. EIRR is very common indicator in a cost-benefit analysis. Protection standards adopted in Pakistan are 50-years for flood protection structures and 100-years for vital river training structures and bridges (Halcrow et al., 2001). The planning and approval criteria are the same throughout the country, but there are different practices locally in design, construction, and maintenance of bunds, studs, and spurs.

### *2.6.1 Structural measures*

Numerous efforts have been made in the past to train rivers and protect the adjoining areas from river erosion and flood damages, but large-scale variations in river discharge and sediment concentrations have led to eroding river plains. Flood management plans initiated at the government level have relied heavily on the provision of structural measures for flood containment. Structural measures are employed on a large-scale and include construction of embankments, spurs, dikes, gabion walls, floodwalls, dispersions, diversion structures, delay action dams, bypass-structures, and channelization of floodwaters. River training has mainly been executed with the help of embankments and spurs. Embankments are constructed wherever over-bank flooding is the major problem and spurs are constructed to counter land erosion and regulate the river's main course. About 6,719 km of embankments have been constructed along major rivers and their tributaries. In addition, more than 1,375 spurs have been constructed to protect these embankments (FFC, 2009). Details of embankments and spurs at provincial and national levels are provided in Table 2-2. Economical and efficient measures have been implemented based on their suitability for local conditions. For the most part, earthen dikes have been constructed along the main rivers.

*Table 2-2: Details of embankments and spurs at the provincial and national levels*

| Province | Embankments (km) | Spurs (no.) |
|---|---|---|
| **Punjab** | 3,334 | 494 |
| **Sindh** | 2,422 | 46 |
| **NWFP** | 361 | 185 |
| **Baluchistan** | 602 | 650 |
| **Total in Pakistan** | **6,719** | **1,375** |

Source: FFC annual report 2008

Flood protection bunds have generally been constructed either to protect headworks, irrigation structures, or certain towns and villages. Controlled breaching of embankments is also practiced to avoid unwanted breach. In the upper Indus Basin, the main rivers flow in a south-west direction. The general slope is southwards, meaning that most of the canals stem from the left banks of the rivers. Breaching is usually produced on the right banks to avoid devastation, as most of the development is also on the left side where the canal irrigation system is located. A double line of flood embankments have been constructed along (almost) both banks of the Indus in Sindh province stretching from the Guddu Barrage to a few kilometers before the river forms its delta. The embankments have been further compartmentalized to contain inundation.

Floods in the upper reaches of the Indus and Jhelum rivers have been attenuated since the construction of the Mangla and Tarbela dams in 1967 and 1974, respectively. Though the storage capacities of these dams are decreasing due to sedimentation, they still play an important role in flood management. The useful lives of these dams are expected to expire in 2050 and 2060 for Mangla and Tarbela dams respectively (MoWP, 2002c; Izhar-ul-Haq and Abbas, 2008; Hashmi et al., 2009). Their effectiveness in flood control is subject to their storage capacities, adopted reservoir operation practices, and intensities of floods. Although these dams are multipurpose, their prime function is to store water for irrigation and power generation. The operation planning of these dams has not yet been optimized to control floods downstream.

The Mirani Dam was constructed in 2006 on the Dasht River for the storage of hill torrent water for irrigation purposes in Baluchistan. It enabled irrigation supplies on both sides of the river and minimized flood damages in the floodplain (Majeed and Khan, 2008). About 12 sub-projects of protecting bunds and delay action dams were constructed in Baluchistan under FPSP-II (Contijoch, 2008). The harnessing of hill torrents in D.G. Khan has also been studied by the National Engineering Services Pakistan (NESPak) in 1984 and by the Japan International Cooperation Agency in 1992 (MoWP, 2002b). NESPak accomplished another countrywide feasibility study on hill torrents in 1998. The study area was divided into 14 hill torrent zones in the Federal Areas, NWFP, Punjab, Sindh, and Baluchistan (Figure 2-1). Structural work has been completed in a few sub-zones of D.G. Khan (e.g., Kaha and Mithawan).

### *2.6.2 Non-structural measures*

All the major rivers in Pakistan are transboundary and flow through India. The shape of a flood wave mainly depends upon water management practices in the watershed and upstream operations. Being a low riparian country, flood management options are limited and flood prediction is complicated in Pakistan. Therefore, main emphases have been put on precise flood forecasting and an early warning system. Flood warning is mainly the responsibility of the Flood Forecasting Division of Pakistan Meteorological Department but the Water and Power Development Authority (WAPDA) also contributes to improve the ability to forecast. The flood early warning system was initiated in 1975 when a real-time VHF telemetry system was introduced for hydrological data collection from 16 river gauges and 24 rain gauges (Figure 2-3) (NESPak, 2008). A total of about 40 stations were established at all rim stations and within the Mangla Dam catchment area. The number was gradually reduced to about 20 due to maintenance problems. The Flood Early Warning System (FEWS) was updated under FPSP-II in 1998 in cooperation with the NESPak-Deltares Consortium. FEWS is a physically-based hydrodynamic model using real-time data. The meteor-burst based communication system was integrated into the FEWS through the WAPDA's "Surface Water Hydrology Project" in 1998. About 22 high frequency radio sets were installed to serve as a double support for automatic gauging and the telemetry system (ADB, 2008). The high frequency radio system works as a backup for telemetry and the meteor burst system.

Currently, flood-zoning considerations do not exist in Pakistan. Development of flood risk mapping for the main rivers was initiated under FPSP-II. So far, hazard maps for 5-years and 50-years return periods have been compiled. Calibration and risk assessment of these maps is planned in the forthcoming NPFP. Interpretation and legislation regarding flood zoning will be carried out afterwards.

The larger and more productive part of the flood-producing upper catchments of the Sutlej, Ravi, and Chenab rivers lies across the border in Kashmir (Indian) (Figure 2-3). Precise and timely measurement of precipitation in those areas is critical for effective functioning of FEWS. A weather radar unit at Sialkot was installed with the ability to detect the position of clouds and precipitation within a radius of 230 km. This radar covers catchment areas of about 17 tributaries. A 10 cm S-band Doppler Weather Surveillance Radar unit, installed in 1997 at Lahore, provides rainfall data about the Sutlej, Beas, Ravi, and Chenab catchments from across the border (NESPak, 2008). Floods in the Jhelum River occur mainly due to heavy rainfall with very short lead-time. Therefore, a weather radar unit at Mangla was put up during FPSP II to provide quantitative rainfall forecasts. More radar units have been planned to cover the hill torrent generating catchments of D.G. Khan, NWFP, and Baluchistan.

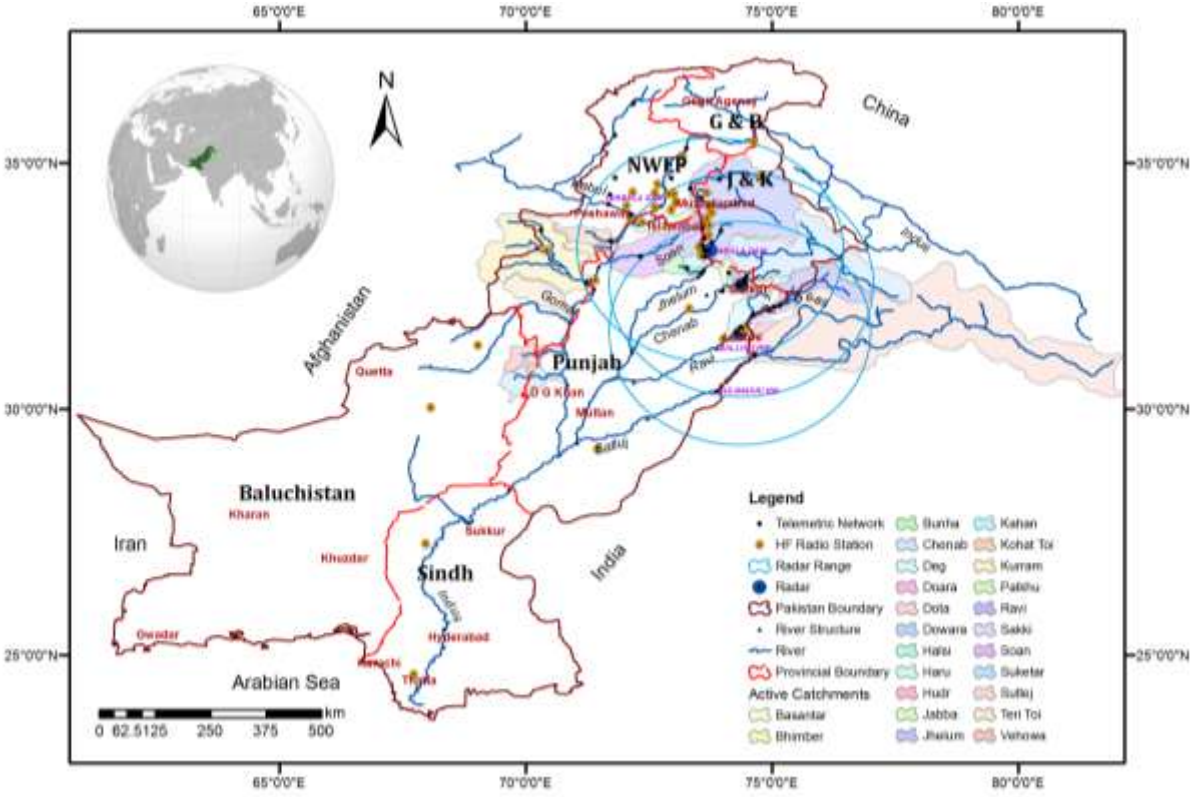


*Figure 2-3: Locations of telemetric gages, HF radios, weather radars, and river structures*

The Mangla and Tarbela dams were constructed for irrigation and power generation operations. Current reservoir operation practices do not play any substantial role in flood management. The clear example is the recent flooding 2010, in which the Tarbela dam did not play any significant role in reducing flooding downstream. Improved reservoir operation of the Mangla dam to facilitate flood management was included in FPSP-II, but now has been postponed due to a Mangla dam raising project. Pre-flood releases on the basis of the flood forecasts can create required flood storage capacity. Improved planning of reservoir operations for the Mangla and Tarbela dams is included in the next NFPP to enhance their role in flood management.

The Pakistan Meteorological Department issues daily satellite cloud pictures from the polar orbiting meteorological satellites on its website to inform the general public. In case of cyclones, warnings are issued quickly. Cyclone detection radar is used for tropical cyclone monitoring. Japan has donated radar equipment to the WMO regional center for Bangladesh and Pakistan. This radar had contributed substantially to the detection, monitoring, and forecasting of tropical cyclones in the country. Pakistan is a member of the WMO and the ESCAP (Economic and Social Commission for Asia and the Pacific) Panel on Tropical Cyclones, which aims to promote measures to improve tropical cyclone warning systems in the Bay of Bengal and the Arabian Sea. A technical plan aimed at the development and improvement of the cyclone warning system in the region has been drawn up by the panel (WMO, 2008).

In addition, a number of control structures have been constructed in India, making the operation of rainfall or runoff models more complicated. An agreement was signed in 1989 between the two countries to share river flow and rainfall data for flood forecasting (Awan, 2003). The 'zero flood warning' manual was also accomplished to homogenize the flood warning procedures and emergency action plans under FPSP II (Awan, 2003; FFC, 2007). Tackling the flood problem within flood managing bodies seems to become a smoother and better-organized process. The setting up of standard operating procedures may produce better interagency cooperation and coordination.

## 2.7 Legal framework

According to the Constitution of Pakistan, water is a provincial government responsibility, but the federal government also performs a number of tasks and responsibilities in the water sector, mostly relating to international and inter-provincial matters. The federal government, through the WAPDA, the Indus River System Authority (IRSA), and the FFC performs coordinated planning, development, and management of water and hydropower resources. The legal framework for carrying out these tasks is provided by the WAPDA Act (1958), the Environmental Protection Act (1997), the Indus River System Authority Act (1992), and by the Constitution under various articles on inter-provincial coordination and resolution of conflicts through the Council of Common Interests.

Recent policies dealing with crises are the Emergency Services Ordinance (2002) and National Disaster Management Ordinance (2006), which provide the national strategy for

dealing with emergencies. A Draft National Water Policy by the Ministry of Water and Power (MoWP) in 2002 was prepared to address most of the water-related issues in the country, including flooding. This policy emphasizes all necessary structural and non-structural measures for flood management and the need for stakeholder participation in the flood management process, as well as enhanced flood awareness in the community. It also recommends replacement of various water-related acts with a simple unified law that enables clearer understanding and subsequent application of the law (Rehman and Kamal, 2005). A number of strategies, visions, initiatives, and plans have also been prepared, including the Ten Year Perspective Plan (by the Planning Commission in 2001) and Vision 2025 (by the WAPDA in 2001) etc.

Pakistan has a very important agreement with neighboring India. The partition of the subcontinent created a conflict over the water distribution rights of the Indus Basin. This trans-boundary water issue between Pakistan and India was addressed with a temporary 'Standstill agreement 1947', the 'Inter-Dominion Accord 1948', and eventually the 'Indus Water Treaty', which was signed with the help of the World Bank in 1960. Six main rivers, the Indus, Jhelum, Chenab, Ravi, Beas, and Sutlej, along with their tributaries, are covered in this agreement. According to this treaty, the exclusive rights of water use for the three western rivers (Indus, Jhelum, and Chenab) were given to Pakistan and rights for three eastern rivers (Ravi, Bias, and Sutlej) were awarded to India. Compensation to the eastern rivers was managed with a number of link canals.

## 2.8 Institutional arrangements

Many federal and provincial institutes are involved (directly or indirectly) in flood management activities. Based on the nature of services and support provided, these institutes can be grouped under risk-managing and crisis-managing institutes. Risk-managing institutes deal with prevention and relief, whereas crisis-managing institutes are concerned with rescue, relief, and rehabilitation operations.

### *2.8.1 Hazard managing institutes*

The ***Federal Flood Commission*** was established in 1977 and assigned the task of preparing the NFPPs on a countrywide basis. Their specific jobs are to construct flood protection and river training works, improve the weather radar data collection system, and create awareness and adaptability among the local population. The FFC has played the main role in the country's flood management since 1977. Normally, flood protection schemes are prepared by provincial governments (Provincial Irrigation and Drainage Authorities) or concerned federal agencies. These schemes are then reviewed and approved by the FFC, either on an emergency basis or in the context of a group of projects. Flood protection plans in Pakistan are prepared on a countrywide basis by consultants under the supervision of the FFC. Funding is provided by the FFC and execution of these projects is carried out by provincial agencies. The FFC monitor and evaluate these works.

These projects can be executed as an individual independent project or as a subproject of the NFPP.

The approach followed by the FFC encompasses both structural and non-structural measures. Non-structural measures mainly pertain to the establishment of modern flood forecasting and warning systems to provide timely and reliable flood information to the flood mitigation agencies and to the public.

The ***Provincial Irrigation and Drainage Authorities*** (1997) are an upgraded form of the Provincial Irrigation Departments with the extended scope of irrigation and drainage management. The Provincial Irrigation and Drainage Authorities play an important role in flood mitigation by performing design, construction, and complete maintenance of river training and flood protection works. These also provide the flow measurement of rivers, canals, and drains for flood forecasting. In addition, their role in crisis management is to prepare flood emergency plans before, during, and after the floods.

The ***Water and Power Development Authority*** is involved in the flood forecasting process by providing river and rain data from its telemetric gauge sites within the upper catchments of Indus and Jhelum rivers. The safety of the Mangla and Tarbela dams are the top priority for this data collection. It is also involved in providing inflow and outflow data from the Mangla and Tarbela dams and the Chashma barrage.

The ***Flood Forecasting Division*** of the Pakistan Meteorological Department collects hydro-meteorological data from various national and international sources and then processes data to produce flood forecasts and warnings. Flood warning dissemination is solely the responsibility of the chief meteorologist to avoid rumors and misinformation about floods.

### *2.8.2 Crisis managing institutes*

Crisis management is mainly performed through a set of administrative entities. Therefore, it will be convenient for international readers if administrative divisions in Pakistan are described before discussing the existing institutional setup. The country is divided into 5 provinces each having their own political government. These Provinces are further divided into Divisions that, in turn, consist of Districts. Both Divisions and Districts are only administrative levels headed by Commissioners and Deputy Coordination Officers without political representation. Each district is further divided into Tehsils and Tehsils into Unions that are represented by elected Councilors.

The ***Provincial Relief Departments*** are responsible for flood preparedness as well as rescue and relief plans. The department arranges surveys to ensure that all flood protection bunds are satisfactorily maintained before the flood season. It sets up flood warning centers and flood centers at district and union levels. In fact, the Relief Department functions through control and coordination of the personnel and resources of other government departments generally organized in form of committees.

The ***Emergency Relief Cell*** works at the federal level and mainly deals with the planning and assessment of relief requirements for major disasters. The scope of their activities covers stock piling of necessities needed during an emergency, establishing emergency funds, and assisting international donors in their relief efforts. The provincial governments and local administrations provide relief for disasters. The National Disaster Plan from 1974 covers procedures, organizational set-up, and standard procedures for the monitoring of disaster operations.

The ***Army*** provides necessary help to civil authorities to carry out rescue and relief operations during and after floods. The Army also takes part in pre-flood season surveys and inspections of the flood protection works. It is the responsibility of the provincial government to provide all support equipment (boats, life jackets, vehicles, tents, etc.) to the Army for these operations. During the flood season, the Army sets up flood emergency cells at each corps headquarters. In the case of major floods, the Army is responsible for actuating controlled breaching of pre- defined flood dikes to divert the peak away from the cities. Although, there exists no standard procedure, the breaching is decided on the basis of existing and forecasted flood stages with the mutual consultation of local officials of civil administration, irrigation department, and army. The Army has been playing a vital role in flood relief activities in 2010 flood since the start of this disaster. Their relief activities demands intense cooperation with organizations that provide flooding information. There are also a number of departments, which are assigned special tasks during floods.

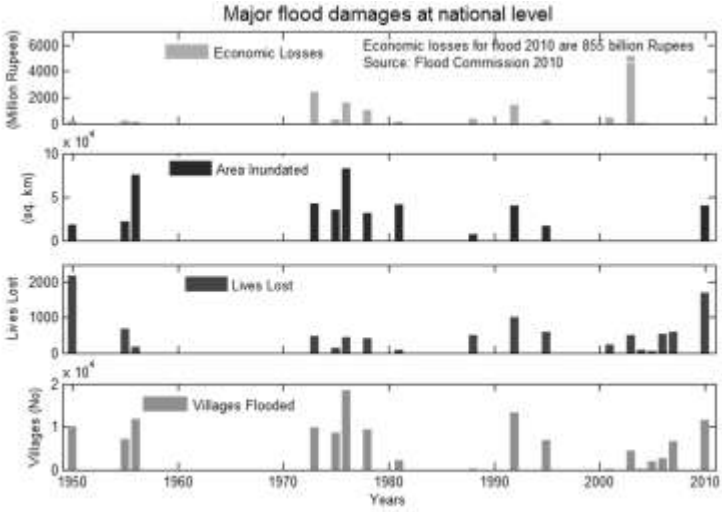


*Figure 2-4: Flood losses details at national level against severe flooding years, Sources: FFC annual report 2008 and National Disaster Management Authority*

## 2.9 Analysis and discussion

The overall data of lives lost and villages flooded (Figure 2-4) shows a decreasing trend from 1950 to 2009, which may be due to improvements in flood management. According to the Centre for Research on the Epidemiology of Disasters - International Disaster Database EM-DAT (1980–2000), the ratio between the number of deaths and population exposed to floods in Pakistan is lower than Afghanistan, Bangladesh, India, and China (Pelling et al., 2004). Whereas flood losses at the worldwide level demonstrate an increasing trend (Pielke, 2006), flood losses in Pakistan showed a decreasing trend due to improved defense until the recent flood. The sense of safety induced by the decrease in floods resulted in increased vulnerability of society. As a result, life losses and financial losses were exceptional during the 2010 flood, given the flood levels, which were the same as in 1978 at Kalabagh gauging station (Figure 2-2 and Figure 2-4). Main factor was poor maintenance of dikes.

Flood loss data at district level show that historic fluvial floods of the major rivers seldom claim lives, whereas regular annual losses are mainly agricultural. Total areas flooded and flooded cropped areas can be used as good indictors to assess the impacts of flood management at district level. Therefore, flooded areas and crop areas flooded at district level have been charted for major rivers upstream from the river confluence (Figure 2-5) to evaluate trends in flood losses. Some reductions in the flooded areas have been noticed, overall. Historical trends show that the country observes alternate flood rich and flood poor periods. It is also worth noting that there has been no major flood since 1995 and that the flood in 2010 occurred after a prolonged dry spell.

Though both structural and non-structural measures have been implemented to reduce flood losses, available statistics show that flood management in Pakistan basically revolves around structural measures with a primary focus on flood prevention (MoWP, 2002c). Crisis management strategies are mainly comprised of rescue and relief actions. However, no solid strategy has been developed to enhance the flood fighting abilities of individual communities. Flood mapping has been initiated but still no final and authentic product has been produced to integrate flood mapping into existing flood management. New initiatives for structural and non-structural measures are taken continuously but lack of continuity and maintenance mostly results in failure. Poor maintenance of telemetric system, dikes, and FEWS are among the examples. Dike failures and malfunctioning of FEWS for flood warning due to poor maintenance and negligence have been observed during 2010 flooding (Tariq and van de Giesen, 2010). The lack of social support for technical designs also plays an important role.

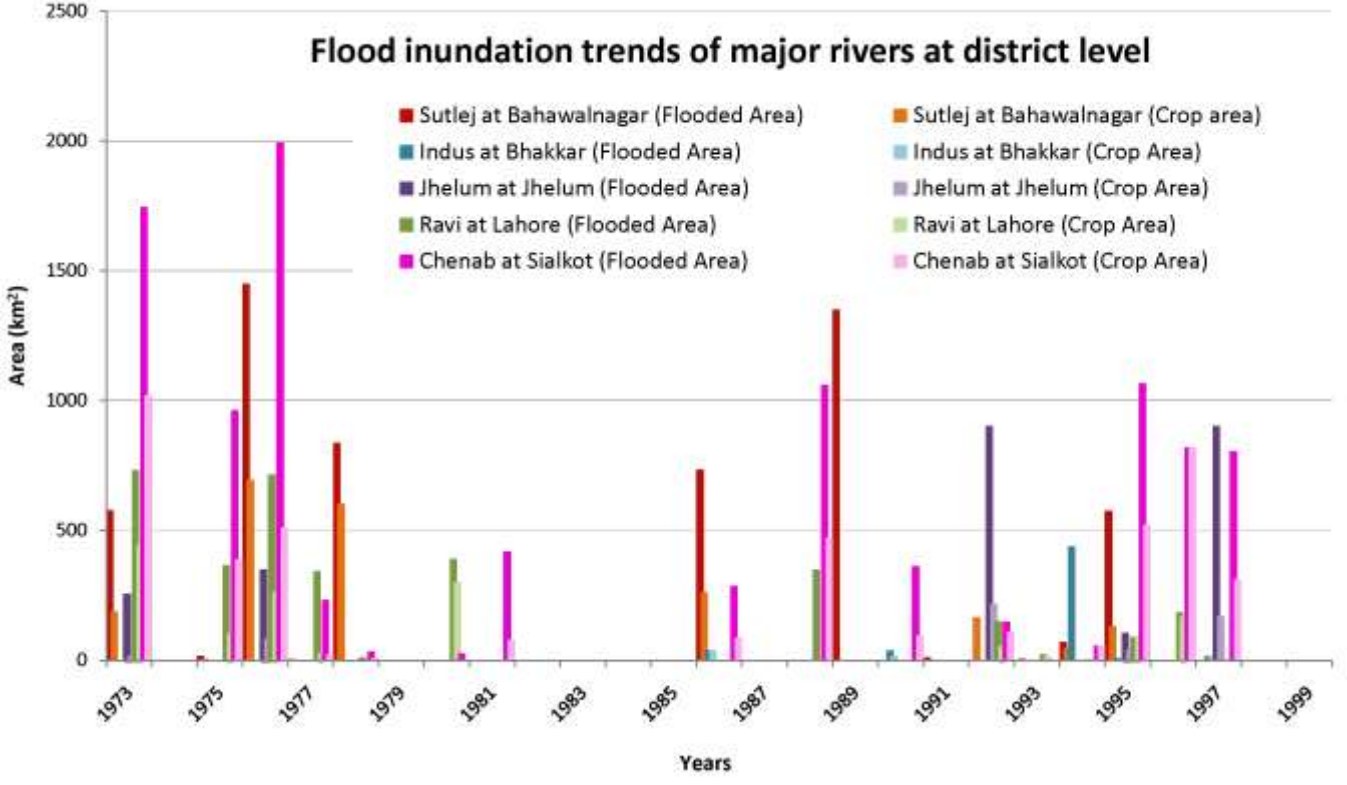


*Figure 2-5: Area flooded and crop area flooded at district level for major rivers, Sources: District governments and Punjab Irrigation department*

Funds are controlled and provided by the federal government through FFC and there is no consideration in terms of 'who pays and who benefits'. On the other hand, the project approval guidelines set by FFC (FFC, 2009) carry strategic biases that are aimed at protecting locations and infrastructure of greater economic, political, and strategic significance, at the cost of areas and communities with lesser influence and importance. For a project to qualify the acceptance criteria, it must have an EIRR above a threshold, usually set by donor agencies. Self-reliance and risk-based approaches are not yet part of project acceptance criteria.

The social and economic infrastructure of Pakistan depends on the waters of Indus Basin. Alarming records of historical flood losses (Figure 2-4) show the seriousness of the flood problem. Measures have been taken for flood management, but there is no serious effort to increase the system's ability to cope with the fluctuations in annual and seasonal flows in the Indus River System. Pakistan's current water storage capacity is around 12% of annual availability. No major dam has been constructed since the completion of Tarbela Dam in 1974. Construction of new dams and reservoirs has been hindered by inter-provincial disputes. The country was suffering severe draught and water shortage shortly before it was hit by the devastating flood in 2010.

## 2.10 Discussion

Flood management in Pakistan is a task that requires both the resources and comprehensive understanding of the flood problem. The nature of floods varies drastically throughout the country due to contrasting physiographic, climatic, hydrologic, demographic, and socio-economic factors. The present approach for flood management incorporates both structural and non-structural measures, yet their inter-linkage and combined efficiency still need to be optimized. The efficiency of any proposed measure should be evaluated for its integration into existing measures to achieve efficient and economically viable solutions.

Change in flow regime due to low flows in eastern rivers after the Indus Water Treaty and enhanced flood protection measures have attracted economic activities and settlements in floodplains. Flood management arrangements are concentrated around the Chenab and Jhelum rivers because of the frequent and devastating nature of flooding. Those floodplains that have not faced flooding over a considerable time are under extremely high risk. Vulnerability on such locations has increased due to a false sense of safety. The 2010 flood in the upper Indus was due to exceptional intensive rainfall in the catchments of the Kabul and Swat rivers, which was not covered by Doppler Weather Surveillance Radar units. The Doppler Weather Surveillance Radar network should be extended to cover northwestern areas of the Indus Basin to enhance the capability and reliability of FEWS and the same system should be established for the hill torrent areas of the Kharan Basin after carrying out feasibility analysis.

Currently, there exists no well-defined criterion to initiate new measures. Political processes and influence shape flood management planning. The situation worsens, as

funding is not a responsibility of floodplain inhabitants. A race to secure more measures is unavoidable. In addition, the protection of high value areas at the cost of low priority areas promotes unlawful breechings of dikes, which was also observed during the flood in 2010. To overcome the problem, the risk-based approach must be incorporated to handle flood problems within available resources. Resources required for flood management must be generated from water users and floodplain inhabitants and dependency on donors must be avoided. Comprehensive standard operating procedures must be formulated based on risk and self-reliance.

Expansion of structural and non-structural measures is extremely important to enhance the efficiency of the flood management system. Flood zoning and flood mapping projects must be completed on priority basis. Necessary legal and institutional support must be provided to flood mapping and flood zoning. New dams are necessary for improvement in water management in general and for effective flood management in particular.

Unfortunately, maintenance and functioning of flood measures have been neglected. High priorities must be assigned for the proper functioning of measures. FEWS is a state of the art model. Its proper functioning and full utilization must be assured. Comprehensive flood management plans must be prepared and executed without waiting for another devastating flood.

Concluding, a risk-based pro-active approach is required to achieve sustainable flood management.

# 3 Risk-based assessment of flood management

Neither the problem, nor its solutions, is new, yet with ever-growing environmental awareness, standards of life, and expertise in technology, the demand for more effective and efficient flood management is quite natural. In addition, flood management is a slow dynamic process and should be updated on a regular basis, roughly 30-50 years (Plate, 2002). New approaches, ideas, and measures have been introduced accordingly. With growing numbers of new terminology and concepts, three major concerns are raised:

- Are there any new concepts with new terms, or just old concepts with new terms? Do these new concepts replace old practices, or do these need to be implemented alongside?
- What are the characteristics of good approaches for flood management?
- How can we come up with efficient and effective flood management practices?

These questions are addressed in this chapter. Basic components of flood management are also defined for the understanding of important flood management concepts, practices, and ideas. General guidelines for an ideal flood management strategy are described. Basics of risk-based assessment are defined. It is elaborated how risk-based assessment ensures a strategy that will meet the standards described in guidelines (See 3.3).

## 3.1 Flood impacts

The nature of flood impacts determines the shape of flood management strategies. Floods can have both adverse and beneficial impacts (Ref. Table 3-1). Flood impacts can be summarized as all the effects that floods have on their environment including the drowning, wetting, erosion, deposition, disturbances, rehabilitation, insurance, management, etc. There is a wide variety of positive and negative flood impacts (De Bruijn, 2005). In eastern Spain, for instance, large floods are very important for the recharge of groundwater aquifers used for agriculture and for tourism, and for the

maintenance of coastal wetlands (EEA, 2003). Different flood impacts can be categorized based on the following criteria:

- Whether the impact is positive or negative
- The connection/ relation with the flood
  - *Direct:* Impacts due to physical contact with flood itself (Dutta et al., 2001; Merz et al., 2004; Nascimento et al., 2006)
  - *Indirect:* caused by the direct impacts through interruption and disruption of economic and social activities and may occur in space or time outside the flood event (Merz et al., 2004; Veerbeek, 2007)
    - Primary: Indirect impact within floodplain
    - Secondary: Indirect impact outside floodplain
  - *Induced:* Impacts related to efforts in context with flood management
- The conventional expression of impacts in monetary values
  - *Tangible:* The impacts can be expressed in monetary terms using conventional methods (Smith and Ward, 1998; Dutta et al., 2001)
  - *Intangible:* The impacts cannot be expressed in monetary terms using conventional methods. They have an effect equivalent to 50% to 100% of the direct financial losses (ANFAS, 2003).

Damage categorization determines which damage types are most relevant in a specific situation. For the optimization of flood management, it is of utmost importance to consider the types of damages and effective measures to take into account.

In developing countries, mostly the poor population lives in floodplains (Dilley et al., 2005). On the other hand, it is also true that the people living in floodplains might become poor as they are frequently flooded (APFM, 2009a). The benefits relating to agricultural, ecological, environmental, groundwater recharge, and business activities about flood management can be considered as positive impacts of floods. Based on these criteria, examples for flood impacts are given in Table 3-1.

## 3.2 Components of flood management practices

Flood management practices vary by time and location. Present day practices differ across countries and have evolved over time. These practices depend on the severity of the flood problem, available resources, economic growth, and the social apprehension of flooding and water resources. Recently researched policy documents new ideas, approaches, and visions are often expressed by 'concepts that seem to have turned into buzzwords' (De Bruijn, 2005). However, there remains a need to understand this terminology and the basic structure of flood management. Following are the basic components of flood management practices and conceptual composition are shown in Figure 3-1 and discussed in more details in the following sub-sections.

- Approaches
- Measures

- Assessment/ Design criteria
- Plans/ Projects/ Strategies

*Table 3-1: Classification of flood impacts (river floods)*

| | | Tangible | | Intangible | |
|---|---|---|---|---|---|
| | | **Positive** | **Negative** | **Positive** | **Negative** |
| **Direct** | | High nutrient water to crops reducing water and fertilizer costs | Capital loss (houses, crops, cars, factory buildings), deposition of pollution and debris or salts | Increased biodiversity. Archaeological discoveries. Flushing of salt from land surface | Victims, ecosystems, pollution, monuments, culture loss |
| **Indirect** | **Primary** | Increased business & production for relief & rehabilitation industry | Production losses, income loss, theft and robbery during evacuation | Replenishing lakes and ponds for fishing production. Groundwater recharging | Social disruption, emotional damage |
| | **Secondary** | Increase in production and sales of competitors outside floodplain | Production losses for supplier from outside the flooded area, unemployment, inflation | Occlusion of seawater intrusion in estuaries and coastal areas. Aquifer recharging of outside areas | Transmission of vector-borne diseases to outside area, migration |
| | **Induced** | Opportunities for flood protection & insurance business | Costs for relief aid, flood protection measures and all management costs | Raised patriotism & regional cooperation in relief and rehabilitation | Evacuation stress. Land-use restrictions/ regulations |

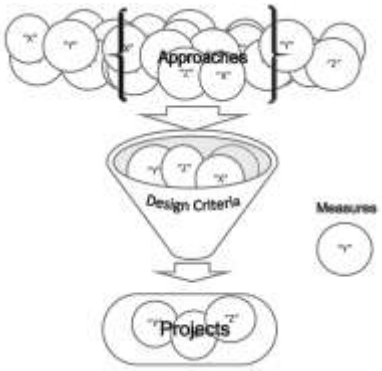


*Figure 3-1: Schematic concept of Measures, Approaches, Design Criteria, and Projects*

### *3.2.1 Measures*

Flood management measures are the measures taken to reduce the flood problems. This way, flood management can be considered as coordination and management of these measures (ADPC, 2005). New measures become available with the advancement in science and technology. The suitability of a measure to any specific flooding problem is subject to flooding behavior, available resources, and technical limitations at hand. The selection of flood management measures is carried out in two steps. In the first step, measures are shortlisted based on adopted flood management approaches (Ref. 3.2.2), available resources, and technical suitability. In the second step, positive and negative effects are evaluated according to assessment method or 'design criteria' (Ref. 3.2.3), and the technical design is carried out.

There exists no single solution that can be applied everywhere. Consequently, it is not logical to argue for or against any measure but a measure can be most suitable depending upon the local situation (APFM, 2009a). That is, the suitability of a measure depends upon both the socioeconomic conditions of the country and the behavior of the floods (Green et al., 2000). Following are some common examples of flood management measures with a brief description of their functionality:

- *Reservoirs* reduce flooding by holding or attenuating flood wave peaks.
- *Rain harvesting* stores part of the runoff for agriculture or domestic use and reduce flood volumes.
- *Dikes, levees, floodwalls, and other barriers* are erected between a river (source of flooding) and the settlements thereby to avoid floods.
- *Channel improvements* increase the flow capacity of a stream/ channel by making it wider, deeper, smoother, or straighter.
- A *diversion (or by-pass)* is a channel that is used to divert part of the peak flow and may return it back at downstream.
- *Insurance and relief* are traditionally considered as tools for recovery after flood occurrence but may also play an indirect role in flood risk control.
- *Flood warning, rescue, and pre-emptive evacuation* help by timely moving lives and goods out of the floodplain.
- *Public awareness* is highly flexible and extremely effective measure. Providing people with a basic understanding about floods, flood management, and emergency responses can reduce their vulnerability significantly.
- *Flood zoning, encroachment control, and implementing building codes* in floodplains reduce vulnerability and hence reduce flood losses.

Details showing the role of some important flood management measures and their classification have been described in Table 3-3.

### *3.2.2 Approaches*

Flood management approaches can be defined as the way to deal with flood problems. It can also be considered as a long-term planning exercise (Halcrow, 2004). Similar to measures, the appropriateness of a flood management approach depends on the context of the floodplain and country (Green et al., 2000). No flood risk management approach is superior in all aspects and in all conditions (Middelkoop et al., 2004). The development of a suitable approach needs to consider the socioeconomic and environmental conditions as well as the severity of flood problems at national level. Unfortunately, when developing an approach, a simple 'copy-paste' function that is being practiced in developing countries, will not work. Green et al. (2000) describe such practice as "Simply proposing to adopt the approach that is appropriate in one area to another area is parochial at best and neo-colonialist at worst". Flood management approaches of a country represent the priorities of social, environmental, and economic assets.

- *Flood control and flood mitigation* approaches tend to confine flood spread through structural measures.
- *Adaptation* is another concept that describes the adjustment or modification of human activities to minimize flood losses.
- *Resilience-based flood management* is an approach that emphasizes to structure floodplain activities such that the system can recover after flood occurs.
- *Integrated flood management* emphasizes connecting flood management and other river functions and floodplain activities appropriately. Multidisciplinary expertises are involved.
- *Sustainable flood management* ensures the selection of such measures that do not cause grave complications in the future. This approach demands a fair valuation of social, economic, and environmental assets.
- *No adverse impact approach* claims the formation of such plans that do not shift or increase problems in adjacent areas.
- *Floodplain restoration* is based on the understanding that a natural floodplain has better capabilities to handle floods.

Although, some approaches are widely appreciated and practiced, few failed to attain worldwide attention. Setting fascinating targets and using appealing terminologies to obtain acceptance without considering ground realities is one of the reasons that made few approaches unpractical. Selecting a suitable approach is subjected to thorough assessment for its suitability at national level.

### *3.2.3 Assessment/ approval criteria*

'Assessment' can be defined as the set of minimum required standards or specifications that must be met in order for a specific measure to be selected. Alternatively, it can be defined as the procedural evaluation of positive and negative impacts of any measure or plan. Measures that are short-listed on the basis of the adopted approach are further

analyzed for their suitability, along with their design specifications. Measures provide safety but cost money. Some measures have environmental and social consequences in addition to economic expenses. Thus flood risk assessment is a tradeoff between risk and financial investments (Middelkoop et al., 2004).

Assessment criteria should be clear, transparent, and objective oriented. These may include social appraisal, economic evaluation, and environmental assessment. In addition to assessment criteria, every individual measure is designed on its technical grounds. Non-structural measures need detailed assessment of their impacts under institutional planning. Measures that involve engineering structures are designed under hydrologic, hydraulic, and structural prospects.

The development of assessment methods has been a continuous process. At present, a number of assessment methods are used in practice. Following is a brief introduction of these assessment methods:

- Element-design standards
- Probability-based designs
- Risk-based assessment

The purpose of all the standards, developed so far, is weighing benefits and costs of measures (Hoes and Schuurmans, 2006). The improvements that are made in assessment approaches are due to the better understanding of flood management.

*Element-design standards*

Element-design standards can be considered as the very first type of standards brought into practices. The purpose of incorporating such standards was to establish a common understanding, and to set the minimum quality that must be ensured. These standards are derived from experiments or (successful) past experiences. According to this approach, the design of flood protection structures must follow in-practice minimum standards. Heights of flood protection structures are designed against historical flood experienced (Andjelkovic, 2001; ASFPM, 2004) or, alternatively, design heights are set as multiples of a rounded figure, say 5ft.

These standards require fewer efforts for analysis. However, they are not optimized in terms of the costs to benefits ratio. These standards are still used in practice in those cases where high accuracy is not strictly required (Nathwani et al., 1997). One form of such standards remained in practice by the Connecticut Resources Commission in the USA, that used 5-7 times the mean annual flood as a standard as late as the 1960's (ASFPM, 2004). Until 1953, dikes in the Netherlands were constructed to withhold the highest known water level without being overtopped (Roos and Jonkman, 2006).

*Probability-based standards*

In the field of hazard and disaster management, safety is given prime importance. With the advancement of the knowledge of disaster management, probabilistic safety standards are developed and implemented worldwide. In the probability-based approach, the

degree of flood-control is expressed by the return period of flood (N-years) (Duivendijk, 1999). The probabilistic approach tends to assume that events in the future can be predicted based on the extrapolation of past observations (Pistrika and Tsakiris, 2007). At present, these safety standards are the most widely practiced assessment methods to design flood management plans.

By the early 1960's, a uniform standard (100-years probability) for the design of flood protection structures was recognized in the USA (ASFPM, 2004). Currently, this standard is still used to identify, map, and manage flood hazards (Carter, 2005; Kron, 2007). In many other countries, such as United Kingdom, Germany, Italy, Spain, France, Canada and New Zealand, a 100-years flood plays an essential role in flood mitigation strategies (Apel et al., 2009). Similar standards are followed practically worldwide. For example, the Netherlands have standards as high as 10,000-years against sea floods for the province of Holland (J.K, 2001), whereas Bangladesh follows a design standards of 20-years (Duivendijk, 1999). Pakistan adopts 50-years for designing flood protection structures and 100-years for vital river training structures and bridges (Halcrow et al., 2001).

Establishing a design probability and defining an acceptable risk always remained a matter for debate. Unfortunately, instead of defining the safety standards on the basis of the acceptable risk, in practice, it is most often the reverse. For example, Hunter and Fewtrell (2001) relate the acceptable risk and the probability standard as "a risk becomes acceptable when it falls below an arbitrary defined probability". However, such standards target only floods of the designed probability. These standards lack the ability to deal with severe floods, and the response would typically be an ad-hoc reaction in case a severe flood occurs (APFM, 2009a). Another shortcoming of this method is that only the hazard probability is considered irrespective of consequences, while the advantages of a measure depends on the damage prevented (Hoes and Schuurmans, 2006).

The probability-based approach delivers more information than Element-design standards that may develop a false sense of complete security. The probability-based standards come up with the indication that there is always residual probability of failure of a measure. On the other hand, just like the Element-design standards, this approach may lead to inefficient use of precious resources or insufficient protection due to ignoring the exposure (Chetty and Smithers, 2005) and susceptibility of the society. Optimization of the flood management measures is not possible using these standards.

Probability standards and acceptable risk are related to location characteristics and cannot be the same everywhere (Hunter and Fewtrell, 2001). Most developing countries follow the probability standards adopted by developed countries due to the lack of research, knowledge, and/ or the fact that most of such projects are designed and executed with foreign help. These assessment criteria seldom fit to their socio-economic setting.

*Risk-based assessment*

Until recently, flood control and protection have been engineering-centered and based on probability. Little or no attention was given to the social, cultural and environmental effects of any specific strategy (APFM, 2006a). In the field of flood management, risk-based assessment methods were introduced during the 1990's. The main characteristic that distinguishes this method from the previous two methods is its clear focus on flood impacts, instead of floods. The risk-based assessment tries to reduce all possible flood-related risks rather to consider the impacts of a specific discharge (Duivendijk, 1999). In the risk-based design, the design return period is a decision variable and not a pre-selected design parameter value, as with the probability-based design method (Tung, 2002). The flood-risk at a location can be defined as the potential damages due to all possible floods. These damages can be economic, social, and/ or environmental. Here, tangible losses are comparatively easy to handle while advanced methods are needed to evaluate intangible losses in monetary terms. A cost-benefit analysis forms a core component of the risk-based assessment. In case of floods, there are many benefits involved. This method involves extensive data analysis and computer processing, but has the ability to optimize the flood management.

Design of a flood measure contains a number of uncertainties. Assessment methods are means by which to judge whether a measure should be selected to achieve a specific goal. All of the above-mentioned assessment methods have uncertainties at different levels, e.g., in data processing and target orientations. Even though the uncertainties remain there, decisions are made based on expected outcomes (Nathwani et al., 1997). In this thesis, the risk-based assessment method has been applied with an improved assessment model (Figure 3-2) for the optimization of flood management measures. This improved model may significantly enhance the overall efficiency of flood management.

### *3.2.4 Plans/ projects*

Plans or projects are the outcomes of a flood management strategy. A plan consists of one or more measures. A project is a practical form of (part of) a plan. Depending on the severity of the flood problem, plans are prepared. The availability of required resources transforms plans into projects. It is possible that a combination of measures for flood risk management can be implemented throughout the lifetime of a strategy (Halcrow, 2004).

The worldwide practice of flood management is mostly reactive rather than proactive. After each severe episode of flood, governments incur considerable expenditures directed at the plans for flood management. Practical examples are the establishment of the Afsluitdijk as a result of the Zuiderzee flood in 1916, the Delta Commission after the 1953 flooding in the Netherlands, and the Federal Flood Commission of Pakistan (Ref. 2.8.1) in 1977. Both Commissions were established for long-term comprehensive flood management plans for their respective countries. 'Room for the River' and 'Delta Plan' in the Netherlands and 'National Flood Protection Plan' in Pakistan are the examples of large-scale long-term plans.

## 3.3 Guidelines for flood management approach

As mentioned at the start of this chapter, new strategies and measures are both needed and become available over time. New measures and approaches must be considered, assessed, and compared with measures adopted in the past. Before choosing flood management options, the policy makers must envisage the consequences thoroughly. Different countries have a different nature of flood problem and different capabilities, therefore the solution should be different (Ref. 3.2.2). Just creating flood storages, protecting dikes, or abutments in floodplains are not economically feasible measures everywhere. The developing countries usually lack research, and continue to replicate the flood management practices in developed countries. In addition, the act of imitating the flood management practices of rich countries while having insufficient resources creates problems. Every country must develop its own indigenous strategy according to the flood behavior and available resources. In following sections, important guiding principles are described to shape the national flood management strategy of a country.

### *3.3.1 Enhancement in flood management*

The most important guideline is that a strategy can only be adopted if it enhances the flood management. The word 'enhancement' means reducing the flood risk without compromising social, economic, and environmental aspects of overall progress. Trends in national flood losses need not necessarily provide any guidance to the success or failure of the adopted strategy (Green et al., 2000). Reduction in risk due to better flood management attracts more economic activities to the floodplain. In such situations, though a rise in both the losses and the costs of flood management can be observed, yet the economic gains might be higher even after compensating these costs. In other words, the damages with the project should be less than the damages without it, or simply, the net benefits must be positive (Medina, 2006). Therefore, the enhancement in flood management must be assessed by the relative increase or decrease in the overall risk. Nathwani et al. (1997) emphasize incorporating the overall impacts: "it is foolish to seek maximum benefit without considering the risks involved, but it is just as foolish to pursue minimum risk without regards for the cost".

The desire of full protection prevailing a few decades ago, has now shifted to a concept of risk-based sustainable floodplain management, as it has been realized that risk cannot be entirely eliminated in many cases (Pilon et al., 2003). The majority of flood management options redistribute the risk spatially and temporally. This redistribution can be considered an enhancement when the overall risk is reduced, which is described by the 'Kaldor-Hicks Compensation Principle' stating, "A redistribution of risk is efficient if it enables the gainers to compensate the losers, whether or not they actually do so" (Ref. 3.6.1). In sum, a risk redistribution that results in risk reduction is an enhancement in flood management.

### *3.3.2 Identification of problem*

Floods should not be seen as the problem; it is the impacts of the flood that should be considered as the actual problem. Floods can be beneficial in many cases where floodplains are less occupied. Actual estimation of total losses is operose as flood damages are both tangible (direct and indirect) and intangible (Andjelkovic, 2001). The initial response against flooding was to prevent floods. Later on, it was realized that there is a need to minimize the flood losses and increase the flood benefits. Therefore, a systematic approach is required to identify the nature of the problem and those measures that can reduce the severity of the problem more effectively.

### *3.3.3 Holistic considerations*

Whether designing an individual measure or a strategy, both should consider all possible impacts of all possible floods. Although a probability-based design possesses more holistic approach as compared to element-design assessment is done against a specific return period only. However, flood management can be more effective if it considers and addresses all probable floods (Green et al., 2000; APFM, 2009a). Therefore, the whole range of possible floods must be considered and addressed accordingly. A design according to a specified probability standard, without carrying out detailed assessment of all possible floods, is not technically sound and acceptable.

### *3.3.4 Integrated approach*

Flood management is not an isolated process that is disconnected from the functions of the river and society. An integrated approach is essential in order to find and evaluate alternative strategies (De Bruijn, 2005). The International Commission on Large Dams (ICOLD), defines four distinct successive periods in the approach development (Duivendijk, 2006). From the time when people were not capable of doing much against floods, to implementing structural measures, to incorporating non-structural measures, and finally, adopting an integrated approach. Integration of flood management can be defined by the following aspects

- Integration with river processes
- Integration with societal functions
- Profit-loss sharing

*Integration with river processes*

To establish an implementable floodplain management policy to address the flooding problem, in all cases, solutions must consider the whole functionality of the river. Rivers perform multiple functions to sustain social, economic, environmental, and ecological prospects of floodplain activities. Basin-wide consistency of flood management is recommended for such integration (Duivendijk, 1999).

*Integration with societal functions*

Flood management will only be successful if it works with, rather than against, community goals and priorities (Montz and Gruntfest, 2002). It is extremely important to consider the behavior of society while designing the flood management strategy. After all, not the river but the functioning of the (local) society is at stake (De Bruijn, 2005). Therefore, it directly follows to consider societal functions and behavior, as well as river processes.

*Profit-loss sharing*

The majority of flood management measures reduce flood losses by redistributing these risks. While redistributing these risks, the policy makers should not ignore the distribution of the benefits. Issues of 'who benefits and who pays' often hamper source control efforts (Andjelkovic, 2001). Strengthening the society to cope with floods, profit-loss sharing relies on fairness and social justice in society. The decision-makers must envisage whether the redistribution of risks in time and space is viable (APFM, 2009b).

### *3.3.5 Incorporation of diverse measures*

Optimum flood management may incorporate many structural and non-structural flood management measures with certain priorities and combinations. Introducing non-structural measures along with structural measures is vital to reduce damage (Duivendijk, 1999). Not all measures can be applied to all locations, as their efficiency is subject to flood characteristics, societal responses, interaction with other measures and their technical designs. Every measure possesses specific characteristics and attenuates risk in specific aspects. Understanding these characteristics of any measure makes it easier to choose the appropriate flood management option fulfilling the local constraints. These constraints could be economic, social, and environmental in nature.

As mentioned, the impact of a measure is not independent of flood conditions and other in-situ measures. In addition, the technical design and planning of a measure has a large influence on the efficiency of that and any other measures. Given the potential for synergy in effectiveness, where possible, structural measures should be backed up with non-structural measures. Non-structural measures need extreme care in planning; otherwise, their efficiency may reduce severely and may even increase the risk instead. For example, the new-for-old insurance policies have increased flood losses (Messner et al., 2007). Utmost care is required while incorporating non-structural measures. The ultimate impacts of non-structural measures depend upon a number of factors (Yoe, 1994). The careful coupling of non-structural measures to structural measures may prove beneficial and limit flood damage (Duivendijk, 1999).

### *3.3.6 Balanced approach*

Flood management requires an adequate balance between the river processes and the societal activities in the floodplain. Furthermore, flood management must establish a

social, economic and environmental balance using quantitative analytical tools (Duivendijk, 1999; Young et al., 2000). Flood management should not be a practice merely to suppress the floods, or the human activities. Traditionally, all risk was attributed to the floods; this is the reason why the measures adopted for flood management in the past (and are in use in most of developing countries and to some extent in many developed countries) extremely suppress river functioning. Growing environmental awareness changed the approach and points at the responsibility of human activities. Eq. 3-2 shows the involvement of both sides.

### *3.3.7 Uniformity and fairness*

In most cases, flood management is a government task. Establishment of a common framework is necessary to guide decision-makers to prioritize flood management uniformly over the entire country (Nathwani et al., 1997). An unbiased, uniform, fair, and clear approach is required to implement flood management nationwide. Duivendijk (1999) recommends the implementation of a uniform policy at basin level suiting the current economic, social and environmental values. However, economic, social, and environmental values may not be equal at basin level. Therefore, uniformity of approach at national level and planning at basin level can be considered as appropriate.

Another common source of inequity is assigning temporal priorities to environmental assets or to life-saving, while designing individual projects. Priorities to environmental assets and life-savings must clearly defined be forehand at national level considering social and economic constraints, and should be the same for all areas and all projects.

### *3.3.8 Long-term considerations*

Policymakers must envisage the short-term and long-term impacts of a selected measure. Every measure that is taken is an intervention, and may thus disturb the dynamic equilibrium of the system by introducing some adverse impacts. Therefore, these impacts must be envisaged by performing prior analysis. Experience has shown that structural measures can cause severe impacts on the floodplain ecology. This results in increasing flood losses, environmental degradation, and an inability to incorporate climatic changes (Lyle, 2001). For sustainable flood management, it is important to choose an option that does not compromise the future. The flood management should be flexible, adaptive, and future-oriented both in short and long-term. We should have a preference for options that involve resilient natural systems with enhanced but adjustable coping capacity of individuals and communities (Green et al., 2000).

## 3.4 Risk-based assessment

Risk-based assessment relates to the evaluation of flood management measures based on their potential impacts. These potential impacts are comprised of probable social, environmental, and economic consequences, and are typically referred to as risk.

Consequently, flood management can be considered effective only when it reduces net negative impacts of floods. On the other hand, risk-based analyses are the only systematic procedure to achieve flood management optimization, due to their orientation towards risk instead of flood. Recent research therefore suggests to follow this risk-based approach in flood management (Hooijer et al., 2002; Hoes, 2006; Moel et al., 2009).

The concept of risk-based design has been around for some time, yet there still exists reluctance and resistance in accepting practical problems (Tung, 2002). A risk-based flood management approach provides the logical grounds for selection and design of flood measures. It incorporates fairness, uniformity, and firm logical bases for flood management practices. Based on risk, the proposed assessment method provides a systematic approach that allows decision-makers to balance losses and benefits properly.

Before going into details on flood management, it is important first to understand the mechanism how floods affect human developments. In order to accomplish a comprehensive approach to risk-based flood management, it is necessary to make a clear understanding of the risk concept. There is a certain need to elaborate the role of river processes and societal activities in inducing risk. To understand the risk-based assessment better, a detailed explanation is given in coming sections. In addition, basic terms are also defined to allow for clarity and avoid ambiguity. Although there is general agreement on most of these definitions, some scientists define a number of terms slightly different.

### *3.4.1 Risk*

The term risk has been defined and understood somewhat in similar meanings worldwide. Several aspects have been emphasized while being defined by different scientists. In defining risk, some over-simplification or redundancy of terms is often found in literature. The most commonly used and agreed upon definition of risk can be 'the expected losses due to a hazard' (UNDHA, 1992; Smith, 1996; Crichton, 1999; Granger et al., 1999; Kron, 2002; Sayers et al., 2003). Losses may comprise of lives, health, social disruption, environmental impacts, economic losses etc. Others define risk as 'the exposure of something of human value to a hazard' (Smith, 1996).

In pseudo-mathematical terms, 'risk is the product of probability and loss' (Helm, 1996; Smith, 1996; Sayers et al., 2003) (Risk = Probability × Consequences). Kron (2002) defines risk as the product of a hazard and its consequences. Some define it as 'the product of hazard and vulnerability' (UNDHA, 1992) (Risk = Hazard × Vulnerability). While others include the 'hazard impacts, elements (value, exposure) and their vulnerability' (Blong, 1996; Crichton, 1999), Cruz-Reyna (1996) include 'preparedness' as a dividend, Granger et al. (1999) included 'elements at risk' in definition of risk.

It is obvious that risk has been understood in a similar way, yet major differences can be seen when expressing risk mathematically. The main reason is that the terms vulnerability and hazard are defined differently. To come up with consolidated concepts

and an agreed upon understanding of terminology (before explaining the application of risk-based assessment in the next chapters) basic terms and the corresponding expressions have been established here.

There is no doubt that risk is associated with hazard, probability, consequences, preparedness, impact of hazard, value of elements at risk and vulnerability (where these parameters have been defined also differently). Concluding, as a proper definition based on generally agreed concepts, risk can be broadly conceived as 'an estimate of the potential consequences associated to a hazard'.

$$\text{Risk} = \text{Probability (year}^{-1}) \times \text{Consequences (\$)} \qquad \textit{Eq. 3-1}$$

Risk is a function of hazard, vulnerability and their mutual interaction.

$$\text{Risk} = \text{Hazard (m year}^{-1}) \times \text{Vulnerability (\$m}^{-1}) \qquad \textit{Eq. 3-2}$$

The above-mentioned expression shows that hazard alone is not responsible for inducing risk. This is the reason why measures that reduce the vulnerability of a society must also be considered. There is a certain need to elaborate the role of both sides in inducing risk. This understanding will help in optimizing the measures and land-use planning in the floodplain by minimizing the risk for sustainable flood management. The exposure and susceptibility of the vulnerable on one hand, and the intensity and probability of the hazard on other hand, are the main parameters to determine risk in a quantitative way. Everyday hazards and vulnerability form patterns of accumulating risk that can culminate in a disaster due to an extreme natural event (Pelling et al., 2004). Therefore, we can analyze risk from two independent factors: hazard, and vulnerability.

### *3.4.2 Hazard*

The 'hazard' in flood management is defined as the occurrence of a high water level event with a defined exceedance probability (Kron, 2007).

In the context of risk management, the hazard is that which triggers risk once the defense is exceeded. The hazard can be characterized by its probability and intensity. In an area where the probability of a flood is practically zero there is no risk involved, and for an area where a flood occurs, the losses depend on the flooding characteristics i.e., the lead-time, water quality, depth, speed, duration of inundation, etc. The hazard is characterized by its probability and intensity

$$\text{Hazard (m year}^{-1}) = \text{Probability (P) (year}^{-1}) \times \text{Intensity (I) (m)} \qquad \textit{Eq. 3-3}$$

Where

Probability is the chance with which a hazard occurs in unit time, which is typically measured in years in case of floods.

Intensity is the particular characteristic of the hazard that has disastrous consequences.

Floods are distinguished with their exceedance frequency and the probability or average period that the same intensity flood is expected to reoccur, called the return period (ADPC, 2005). Generally, frequency analyses are carried out to calculate all potential flood discharges against their probabilities (Vrijling and Meijer, 1992). The Gumbel distribution and Log-Pearson type-III distribution are most commonly used frequency curve fitting methods to estimate river peak discharges. Three types of areas can be marked. One with frequent flooding where people are highly adapted to floods. In such areas, floods are welcomed every year, as the livelihood of floodplain inhabitants is mostly associated with these floods. Second, are the areas that may suffer with only exceptional floods. Such floods are unexpected and not prepared against, and therefore produce destruction at mega level. Third, are those areas that suffer flooding after a considerable time. These are the areas where flood risk is high because of both high probability and exposure. Such areas must receive most of the flood management considerations.

The intensity can be represented by (a combination of) independent properties of the hazard. In case of floods, these properties usually are, for instance, water depth, duration, product of water depth and velocity, etc. For example, the depth and speed are important to calculate the chances of drowning. A strong current of water (only 60 cm deep) can carry off most passenger automobiles (APFM, 2007b). The flood depth is mostly considered an appropriate indicator of flood intensity but other properties are also considered for many studies. In most cases, the effect of water depth dominates the effect of other variables (Penning-Rowsell and Fordham, 1994; Wind et al., 1999; Merz et al., 2007) and thus for the sake of simplicity, most analyses have focused on the relationship between damages and the stage of flood waters (Yoe, 1994). In Switzerland, the product of water velocity and water depth is used as a parameter for the flood risk in steep sloping areas, while water depth alone is used for flat or nearly flat terrains (Meon et al., 2006). Sediments in floodwater will cause more damages to urban areas, but will prove less harmful or even beneficial to cultivated land. Therefore, different properties of a hazard can be used to evaluate risk. The flood intensity at any given location is found by field data, modeling techniques, or relies on expert judgement. Following is a brief description of a number of flood characteristics that may be considered relevant in calculating flood risk:

- *Inundation extent* determines which elements are being affected.
- *Depth* is the most prevalent indicator.
- *Duration of inundation* affects crops and determine long-term damages to buildings.
- *Velocity* may turn down structures and increases drowning.
- *Rise rate or warning time lapse* is important for flood warning and evacuation.
- *Time of occurrence* during the year is important for crops, and during the day for rescue and evacuation.
- *Sediments load* or pollutants may increase damages significantly.

### *3.4.3 Vulnerability*

The hazard can damage elements that are vulnerable to that specific hazard. If elements are not vulnerable, there cannot be any risk. For example, if there are no infrastructures or people in a floodplain, then there is no risk. In a similar way, when people and their belongings are ideally prepared and protected against flood-damage, then there will be no risk as well. Thus, the vulnerability is the result of exposure and susceptibility.

$$\text{Vulnerability } (\$m^{-1}) = \text{Susceptibility (S) } (m^{-1}) \times \text{Exposure (E) } (\$) \qquad \textit{Eq. 3-4}$$

Where

Exposure is the value and life that is present within the area under threat (Kron, 2002).

Susceptibility is usually described by relative damage functions (Merz et al., 2007; Messner et al., 2007).

Exposure is generally related to land-use practices. Land-use maps can be developed by physical surveys or by consulting GIS maps. These maps show the spatial distribution of financial, social, and environmental assets. Population distribution, infrastructures, public services, lifelines, and industrial installations can be identified as important exposures to be considered while estimating risk.

Susceptibility is the ability to accept the damages from the hazard. The degree of damage depends upon the susceptibility of vulnerable items and people as well as the intensity of hazard. This intensity-response relationship (also called damage function) can be represented using tables, graphs, and equations. Stage-damage (type of intensity-damage) curves are the essential building blocks upon which flood damage assessments are based (Smith, 1994). Appropriate damage functions can be derived either from collecting field data (Genovese, 2006) or synthetic data obtained by lab experiments. Real flood damage data is collected in many countries directly after a flood has occurred, whereas damage functions can also be derived from proto-type lab experiments or correlating types of construction and inventory with different flood properties. The intensity damage functions behave differently for different land-uses. As mentioned earlier, susceptibility is the ability to accept the impacts or percentage loss or reduction in value caused by the immersion by floodwater (Messner et al., 2007). When a flood occurs, it damages buildings and households, causes drowning of a percentage of the human and animal life in the inundated area. The extent a building will be damaged, and drowning rates vary with the capability of buildings and people to withstand these floods. Infrastructures in floodplains can be built such that these are immune or less vulnerable to flood waters.

### *3.4.4 Calculation of direct damages*

Traditionally, the risk has been defined as the probability times the damage. This definition is good for calculating risk, but the role of the river and the societal activities, which cause this risk, remain unclear. In order to understand the role of both sides, it is

necessary to express risk in terms of hazard and vulnerability, as shown in Eq. 3-2. Now, substituting hazard and vulnerability by their components in Eq. 3-2 we get Eq. 3-5. Expressing probability separately will result in Eq. 3-6.

$$\text{Risk} = [\underline{P \times I}]\ (\text{m year}^{-1}) \times [\underline{S \times E}]\ (\$\text{m}^{-1}) \qquad \textit{Eq. 3-5}$$

$$\text{Risk} = P \times [\underline{I \times S \times E}]\ (\$\ \text{year}^{-1}) \qquad \textit{Eq. 3-6}$$

The probability is associated with a hazard that has a specific return period while intensity, exposure, and susceptibility pertain to the resulting consequences. Hence, Eq. 3-6 represents the elaborated form of Eq. 3-2. This model can be used to the estimate direct losses. The exposure sets the worst possible damage, while the intensity and susceptibility determine the extent of this damage, and the probability converts this damage to the notion of risk.

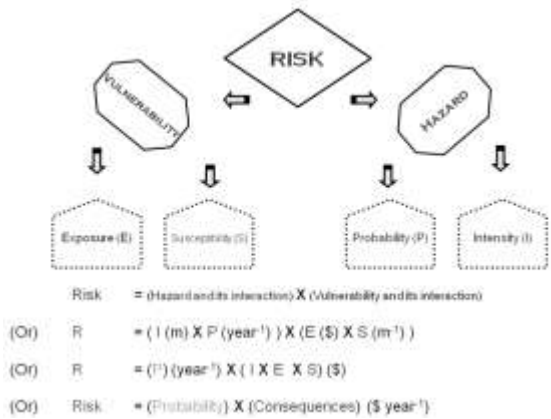


*Figure 3-2: Risk mechanics explained in terms of hazard, vulnerability, probability, intensity, exposure, susceptibility, and consequences*

The purpose of explaining risk in terms of its components is to facilitate the quantitative analysis of flooding scenarios, while applying different measures. Risk is dependent of all four parameters. This decomposition of risk into its components is a first simplification or conceptualization of the more complex reality, which may allow for a better comprehension and precise analysis of the problem.

Rescinding any of the parameters will nullify the total risk. Numbers of hazards go unnoticed in everyday life, because of their low risk. There are such examples of hazards that would disrupt life completely were it not that one of the risk factors makes the risk

negligible. The importance of risk parameters can be illustrated by a number of examples shown in Table 3-2.

*Table 3-2: Daily life hazards with negligible risk*

| Hazard | Rescinding Factor | Explanation |
|---|---|---|
| Ultraviolet rays from the sun | Intensity | Ultraviolet rays may cause sunburn inflammation erythema, and nonmelanoma skin cancer, but due to the low intensity, these are negligible. |
| Meteoroids | Probability | Meteoroids may prove lethal to life, but the probability of hitting human very low. |
| Allergy | Susceptibility | Dust or pollens are harmful to only those who are susceptible to them. |
| Volcano | Exposure | Volcano eruptions can be extremely deadly, but many of such areas do not have close by settlements. |

To estimate and minimize the risk of flooding at any location within a floodplain, it is important to understand the role of basic parameters in inducing risk. The intensity and probability of hazard, and the susceptibility and exposure relating to the vulnerability are the basic components that determine the risk. With the understanding of their role in inducing risk, effective and optimal flood management measures can be selected.

## 3.5 Risk-based flood management practices

Conventionally, flood management practices can be classified as flood abatement, flood control, flood alleviation, and recovery measures. These practices comprise of structural and non-structural measures or relate to reducing the activities in a floodplain. Risk-based assessment also influences the flood management approaches and measures. This section describes the risk-based assessment of various approaches, plans, and measures, and highlights the importance of adopting risk-based flood management practices.

### *3.5.1 Risk-based classification of measures*

Selecting effective and most-suitable measures is the most important task in flood management. Bruijn et al. (2007) has divided direct measures into three types: preventing flood wave generation (flood abatement); managing the inundation (flood control) and minimizing the negative impacts (flood alleviation). Sometimes it is important to see whether the measures involve any structural work that may modify the flow of the river. Non-structural approaches to flood management comprise those activities which aim to eliminate or mitigate adverse effects of flooding without the construction of flow-modifying structures (Duivendijk, 1999). Some measures tend to increase the capacity of society to recover after flooding has occurred. Flood insurance, relief, compensation, and community support are examples and can be classified as indirect measures, as these do

not reduce losses directly. Relief measures do little to reduce the impact of future flood losses (Andjelkovic, 2001), and compensation may even increase the risk.

Knowledge of the effectiveness of various measures is essential for designing an effective strategy. Some measures reduce the hazard by reducing the probability and/or intensity, where some measures aim at reducing the vulnerability by reducing susceptibility and/or exposure. Based on risk-mechanics, measures can be classified into two major types; i.e., direct measures and indirect measures. While selecting a measure, it is important to note which target parameter a flood management measure aims at. Different flood management measures, options and the corresponding risk parameters have been discussed in Table 3-3. Dividing flood management options based on classification, structural involvement, and risk-mechanics with target parameters is important to obtain desirable results for a flood management project.

*Table 3-3: Flood management measures and target risk parameters*

| Class | Measure | Target Parameter | |
|---|---|---|---|
| Abatement | Rain harvesting | Hazard | Probability |
| | Reforestation | Hazard | Probability |
| | Soil conservation | Hazard | Intensity |
| | Groundwater recharging | Hazard | Probability |
| | Storage and retention | Hazard | Probability |
| Control | Dikes, Floodwalls | Hazard | Intensity |
| | Flow diversion | Hazard | Probability |
| | River re-profiling | Hazard | Intensity |
| | River conveyance | Hazard | Intensity |
| | Encroachment control | Vulnerability | Exposure |
| Alleviation | Building codes | Vulnerability | Exposure, Susceptibility |
| | Rescue | Vulnerability | Exposure |
| | Evacuation | Vulnerability | Exposure |
| | Land-use adaptation | Vulnerability | Susceptibility |
| | Flood proofing | Vulnerability | Susceptibility |
| | Public awareness | Vulnerability | Susceptibility*, Exposure* |
| Indirect | Flood insurance | Vulnerability | Exposure, Susceptibility |
| | Relief efforts | Vulnerability | Exposure°, Susceptibility |
| | Compensation | Vulnerability | Exposure°, Susceptibility° |

* Public awareness plays an indirect role
° Play negative role instead, or at least no direct role in reducing risk

### *3.5.2 Risk-based classification of approaches*

Section 3.2.2 describes how a strategy or approach consists of inspirations and priorities that drive the selection of appropriate measures. The most appropriate strategy will vary according to the specific geographical, hydrological, social, environmental, and economic conditions (Green et al., 2000). Risk-based analysis helps to, not only assess and design a

measure (Ref. 3.5.1), but also, choose the most appropriate flood management strategy for the particular local conditions. Based on the flooding risk-mechanics, flood management approaches can be divided into two categories

- Direct approaches
  - Hazard management approaches
  - Vulnerability management approaches
- Indirect approaches
  - Resilience-based approaches

Direct approaches tend to minimize the losses, where indirect approaches target the prompt recovery from these losses. Direct approaches can be further distinguished as to those approaches that reduce the hazard and those that reduce the vulnerability of floodplain inhabitants (Green et al., 2000).

Hazard management approaches follow the principle 'to keep flood away from people'. Flood control and flood mitigation are important examples. The approach aims at reducing the flood event itself by using structural measures. These measures can be extensive in nature, installed in upper catchments (Tucci, 2007), and tend to reduce the probability for a flood to occur. Otherwise, these can be intensive measures that are applied locally (Tucci, 2007) to reduce intensity the flood inundates the area.

Adaptation is an example of vulnerability management (Genovese, 2006) that follows the principle of 'living with floods'. The elements of adaptation (societal adjustment) and preparedness (event-based response (Genovese, 2006)) reduce the susceptibility. In highly adapted societies, the annual floods are expected and anticipated although the extreme floods still may cause casualties and damages (Green et al., 2000). Flood zoning controls the vulnerability by reducing both the exposure (encroachment control) and susceptibility (flood proofing). Encroachment control is a measure that works on the principle of 'keeping people away from the flood' by reducing the exposure within a floodplain.

Flood insurance, relief, rehabilitation, and compensation are a number of measures belonging to an indirect approach. Resilience-based flood management is typical associated with indirect approaches. The working principles here are to 'accept floods and recover afterwards'. De Bruijn (2005) defines resilience as "the ability of a system to return to its equilibrium after a reaction to a disturbance". For this, a system must be designed to aid quick recovery after a flood subsides. Indirect methods reduce the indirect losses significantly, and indirectly influence the direct losses.

In addition to the above-mentioned strategies, there exist other concepts, like 'integrated flood management', 'sustainable flood management', 'no adverse impact approach', 'floodplain restoration', etc. These approaches are not mutually exclusive and can be adopted in combination with other approaches. For example, an integrated flood management prevents isolated perspectives of flood management measures (APFM, 2009a) and does not restrict or exclude any specific measure. Typically, the most

appropriate management strategy will involve a combination of measures and approaches (Green et al., 2000), and involves complementary options (APFM, 2007d).

### *3.5.3 Risk-based explanation of plans/ projects*

A risk-based assessment enables policy-makers to target risk, and thus results in selecting the most suitable measures. Risk-based management is geared to the evaluation of schemes for reducing, but not necessarily eliminating, the flood risk (Pilon et al., 2003). As mentioned in Section 3.2.4, the severity of a problem and the availability of resources trigger projects. Furthermore, the type of hazard is also an important factor to set measures. The response to a hazard depends on the nature of the hazard, i.e., whether it is natural or man-made and whether the occurrence of the hazard is common. For example, Nathwani (1997) explained: "Currently, fear of cancer and the risks associated with low-level exposures to carcinogenic substances drives much of the regulatory efforts aimed at minimizing health risks. Diet and smoking, however, cause an estimated two out of three cancer deaths. They are major causes of cardiovascular disease and deaths".

The impact of probability on the vulnerability is inversely proportional. Generally speaking, floods that occur more frequently, are responded to more appropriately and, hence, cause less damage. Very rare (extreme) floods can produce high damages. These losses mainly occur in areas that are situated away from the river. The vulnerability increases, due to more exposure and higher susceptibility as people living at larger distances from the river, do not expect flooding. The probability of occurrence predominantly determines the extent of safety measures initiated in a floodplain. The areas that suffer floods frequently incorporate the measures in infrastructures, like flood proofing etc. The effectiveness and suitability of flood measures very much depend upon risk factors as well as technical, financial, and social constraints.

## 3.6 Development of decision-support system

The ultimate purpose of risk analysis is to envisage risk reduction after a proposed project is implemented and to facilitate decision-makers in selecting the best available option. Risk evaluation has already been discussed in detail (Ref. 3.4 and 3.5), whereas communication of results in convenient, elaborated, and guiding shape is discussed in next sub-sections. A number of different techniques exist to aid in the appraisal process (e.g. cost-benefit analysis, multi-criteria analysis) (Green et al., 2000). Some basic concepts, techniques, and terms are discussed here.

### *3.6.1 Guiding principle for decision-support system*

Flood management involves redistribution of risk over temporal and spatial frames. In our case studies, 'The Kaldor-Hicks Compensation Principle' is considered as the prima facie rule for the decision-support system. The principle states, "A redistribution of risk is efficient if it enables the gainers to compensate the losers, whether or not they actually do

so". Flood management measures involve noticeable costs and many of them just divert floods to less valuable areas. Estimation of benefits while ignoring such losses/ costs are illusive in nature. Kaldor-Hicks compensation principle emphasizes holistic considerations of all impacts. The compensation principle establishes the governing rule that benefits (gains in human well-being) should exceed costs (losses in human well-being) for policies and projects to be sanctioned (Pearce et al., 2006).

Structural measures change flood patterns. Such reshaping of the flow regime is associated with a redistribution of flood risk. As this redistribution reduces risk in highly populated and industrialized areas, it may cause over-flooding to rural and agricultural lands at the same time. Net reduction in risk is equal to the combined effects of both areas. Nevertheless, the protected urban area is still subjected to severe, catastrophic, and less frequent floods. Structural solutions to deal with this residual risk could be extremely cost inefficient. Such residual risk could be manageable via insurance at a much lower costs (Erdlenbruch et al., 2009).

### *3.6.2 Cost benefit analysis (CBA)*

Cost benefit analysis (CBA) is commonly applied to determine the adequacy of a project to meet its goals. Furthermore, it helps to define the best composition of a project and compare among competing alternatives (Medina, 2006). The costs include both maintenance and investment costs of measures. Whereas, in case of floodplain abandonment, depriving the community from the benefits otherwise it might have by utilizing floodplain are also considered as costs. Costs are calculated using discounted rates (Ref. 0) assuming a certain lifetime for the measures. Benefits are damages avoided. Therefore, the benefits of a project are equal to the difference in damages with and without project conditions (Medina, 2006).

Cost benefit calculations become difficult if intangible losses and benefits are to be involved (Kron, 2002). Advanced methods are required to evaluate intangible losses. Alternatively, CBA can be expanded using multi-criteria framework to consider intangible along with tangible factors (Tung, 2002) as multi-criteria analysis (MCA) are efficient tools for the optimization. MCA consider a number of factors to facilitate optimization. Generally, weights are assigned to different criteria to conclude results of MCA but these always remain highly controversial and debatable. This approach gives better picture of the problem (Tung, 2002) but at the same time is unable to compare between different choices. Therefore, CBA has been selected for our analysis to facilitate decision-makers in making a choice under the principle of 'like is compared to like'.

At the same time, summarizing intangible values into a scalar-valued ranking function or alternatively into monetary terms for the comparison purposes remains debatable until now (Gilard and Givone, 1997). Establishing a generic valuation of intangible assets, that might be usable for all types of project at the national level, is highly recommended. Alternatively, a flexible and elaborated valuation approach to enhance consensus, reconciliation, and an agreement on valuation of intangibles by separately evaluating

social and environmental losses before combining them into a single EAD value (monetary terms) can also be used. The general idea of the approach is that the decision-makers must evaluate intangible losses on fair and uniform basis. A careful valuation of economic, social, and environmental assets is indispensable to achieve reliable results.

The benefits in CBA are evaluated by comparing damages with and without project conditions. When damages are compared against different projects, CBA provides a comparative risk assessment. Comparative risk assessment (CRA) is used to single out the most effective flood management scheme in context of appropriate flood management options. The plan with the lowest risk is considered the most appropriate one. CRA involves analyzing risks for several alternative projects or policies (Pearce et al., 2006). CRA is used to obtain ORP for designing the master plan for flood measures and for most suitable land-use planning in floodplain (Figure 3-3). Use of CRA for individual projects might not produce satisfactory results. Therefore, isolated evaluation of projects without considering the optimum risk state of the complete strategy might be misleading.

In our case studies, damages due to floods and costs related to measures as well as benefits are expressed in terms of expected annual damages (EAD) (See 4.3.4). For the optimization of flood management, multiple reiterations of analysis are carried out under a number of scenarios in both study areas. Comparing EADs with different measures helped us to determine ORP in our case studies. In the planning phase, economic and financial efficiencies of measures may be reassessed to assign priorities to individual projects under the situational constraints and preferences. Results of this analysis may be presented in the terms of EAD, IRR, BC ratio, economic rent (ER), and net present value (NPV) to facilitate investors, decision-makers, and stakeholders to understand the advantages and limitations of proposed measures.

### *3.6.3 Economic efficiency indicators*

The results of CBA are expressed in terms of economic efficiency indicators. These indicators help to select the most suitable and the most efficient measure. When several alternative options are available, the project with the highest economic efficiency could be the optimal choice. Sometimes, a number of derived indicators are also used for the decision support system. A brief introduction of some of basic terms is described here.

*Benefit-cost ratio (BC ratio)*

Benefit-cost ratio expresses the proportion between what is spent and what is achieved. It is one of the CBA products most commonly used for decision appraisal and is a very effective indicator of the confidence which can be placed in the decision (Messner et al., 2007).

*Internal rate of return (IRR)*

Another important term to evaluate the feasibility of a project is the 'internal rate of return' (IRR). IRR provides the interest rate of return of a project through its lifetime of

cash flows. If the NPV is equal to zero, then the IRR is equal to the discount rate. IRR means the discount rate at which the costs of the project lead to the benefits of the project (Yi et al., 2010). The World Bank uses IRR as a qualifying indicator for funding the projects.

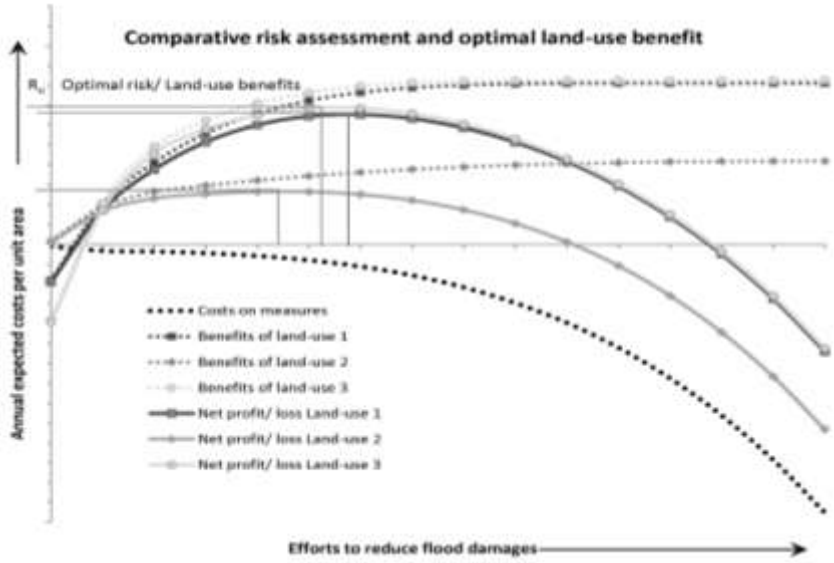


*Figure 3-3: Comparative risk analysis of different strategies and calculation of optimal risk against different land-use schemes in floodplain*

*Economic rent (ER)*

Reduction in flood losses to existing land-use can also be expressed in terms of increase in land-use efficiency. Economic rent (ER) helps in assessing the land-use efficiency. Economic rent is commonly defined as the net annual income associated with a resource (Weisz and Day, 1975). ER of a land-use may be computed as the average of the annual net returns discounted to their present value. If '$R_n$' is the annual net return from unit land area in year 'n', assuming a constant discount rate 'r', then the economic rent 'ER' over the time 't' will be the average of discounted annual net returns. This relationship can be expressed in the following way (Eq. 3-7):

$$ER = \sum_{n=0}^{n=t} \frac{R_n}{t(1+r)^n} \qquad \textit{Eq. 3-7}$$

The net annual return to unit land can also be defined as the gross annual return minus the annual total non-land costs and is synonymous with economic efficiency returns (Weisz and Day, 1975). In case of floodplain, annual costs on measures and remaining expected damages reduce economic rent. This combined reduction may be terms as 'combined deductions' (Figure 3-4). In terms of economic rent, ORP can also be defined as a state of flood management at which risk deductions to economic rent are minimal.

Economic rent might be the most suitable index to be used to evaluate the combined effectiveness of more alternative means of attaining floodplain management objectives. It has two components, namely, 'location benefits' ($R_{loc}$) and 'intensification benefits' ($R_{int}$). Location benefits can be defined as the value of making floodplain land available for new economic uses, such as shifting from agricultural to industrial use (USACE, 1996). Intensification benefits are the value of intensifying use of the land, such as shifting from lower to higher-value or higher-yield crops (USACE, 1996).

$$\Delta R_n = \Delta R_{loc} + \Delta R_{int} \qquad \textit{Eq. 3-8}$$

As flood management is improved, both components rise with higher flow of investments due to reductions in negative impacts of floods. Although increase in location benefits and intensification benefits depend on a number of factors, availability of investments play a main role. Precise evaluation of economic rent is subject to the planning of investment projects in the floodplain. Location benefits are considered while implementing the flood zoning in our case studies (See 6.5).

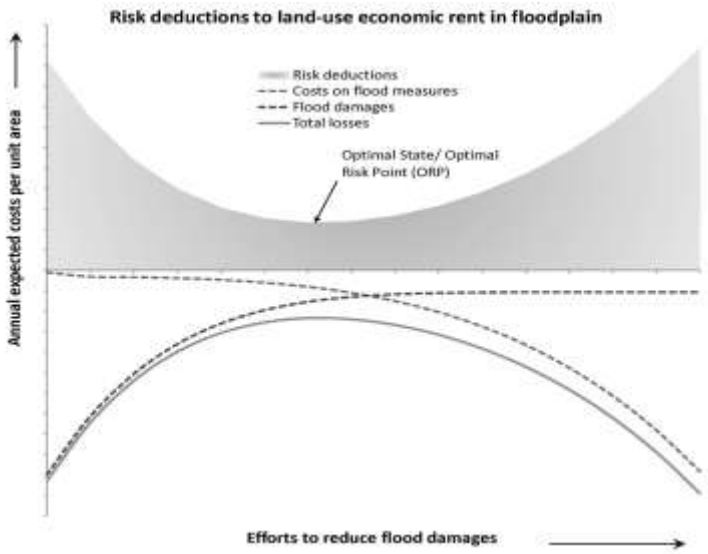


*Figure 3-4: Combined deductions and minimum required net-benefit of land-use*

### *3.6.4 Discounting procedures*

Although floods cause damages to life and infrastructures, flood measures also need heavy investments to reduce these damages. Investments in flood measures are ideally low and are paid in advance whereas flood damages are high and might occur in the future with some probability. Flood measures provide benefits throughout their useful life by reducing the losses, equal to difference in EAD, every year. Flood measures need capital investment in the start and some maintenance costs annually. This capital investments may produce some annual return (equal to compound interest or discount rate 'i') if these were deposited in a bank. Therefore, future returns from flood measures cannot be considered equal if these were obtained at present time. The concept of present value (PV) handles these two series of unevenly distributed benefits and costs.

PV is a basic concept of economics that accounts for the time value of money. Discount rate is considered in all analysis that compares investments and outcomes. The discount rate used is typically set by the federal government and is much higher in developing countries when compared to developed countries. Present value 'PV' of investment 'P' with 'i' interest rate over time 't' (in years) can be found using Eq. 3-9.

$$PV = {}^{P}/_{(1+i)^t} \qquad \textit{Eq. 3-9}$$

In our case studies, interest rate was kept uniform at 12%. In a CBA, it is usually preferable to present the costs and benefits difference in terms of present values to be able to compare costs and benefits from different (future) timestamps. Once the PVs of benefits and costs have been estimated, the BC ratio and net benefit (NB) of the project can be computed using the formula Eq. 3-10 and Eq. 3-11 (Pearce et al., 2006):

$$BC\ ratio = {}^{PV_b}/_{PV_c} \qquad \textit{Eq. 3-10}$$

$$NB = PV_b - PV_c \qquad \textit{Eq. 3-11}$$

If the net benefits are positive, then the project is cost-efficient and the BC ratio is greater than one. The necessary condition for the adoption of a project is that discounted benefits '$PV_b$' should exceed discounted costs '$PV_c$' (Eq. 3-12) or if net present value 'NPV' is greater than zero (Eq. 3-13).

$$PV_b > PV_c \qquad \textit{Eq. 3-12}$$

$$NPV > 0 \qquad \textit{Eq. 3-13}$$

As mentioned, any project for which benefits exceed costs can be accepted, however, if resources are limited, then not all 'acceptable' projects can be undertaken. In this case, projects must be ranked or ordered in terms of the objective function and available resources. Priority ranking of projects is always based on BC ratios. On the other hand, when adequate resources are available (and ideally should be available according to the stipulations behind the risk-based approach), the project with the highest net benefits

(not the highest BC ratio) is the optimal choice (Medina, 2006). Same is recommended for both the proposed flood management standards and flood management optimization in our case-studies. A modern concept that is still evolving in many countries points at maximizing the net-benefits from floodplains, rather than aiming solely at minimizing flood damages (APFM, 2007b). This idea is further pursued in case studies (See 6.5) and a concept of 'floodplain management' has been recommended (See 8.3).

### *3.6.5 Optimal risk point (ORP)*

As mentioned in sub-section 3.3.1, the purpose of flood management must be reducing risk. Risk cannot entirely be nullified in such situations. It is also mentioned that, flood measures reduce flood damages but involve high initial investments and operative maintenance costs. Therefore, the risk in a floodplain cannot be lowered beyond a certain threshold. At this threshold, the combined annual expected losses due to flood damages and costs of measures are at the minimum.

In a floodplain, measures taken in the initial stages usually have high BC ratios. BC ratio then decrease for measures taken afterwards, and may become one or even less for subsequent measures. The stage where marginal costs on measures and marginal benefits are equal, expresses the 'optimum state' (Figure 3-5) (Park, 1999; Jonkman et al., 2009). Different measures may demonstrate different optimum states. The optimum state with lowest risk under all favorable combinations of flood measures is known as 'optimal risk point' (ORP). Figure 3-6 explains the concept of ORP when different strategies (consisting of suitable measures) are compared. It also compares the feasibility of a proposed land-use practice. It also supports the idea that maximum land-use benefits can only be obtained when ORP is achieved in floodplain.

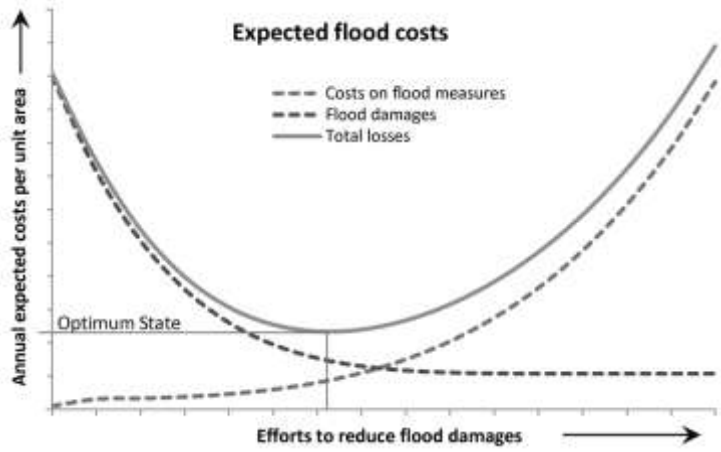


*Figure 3-5: Relationship between increasing costs on measures and reducing flood damages*

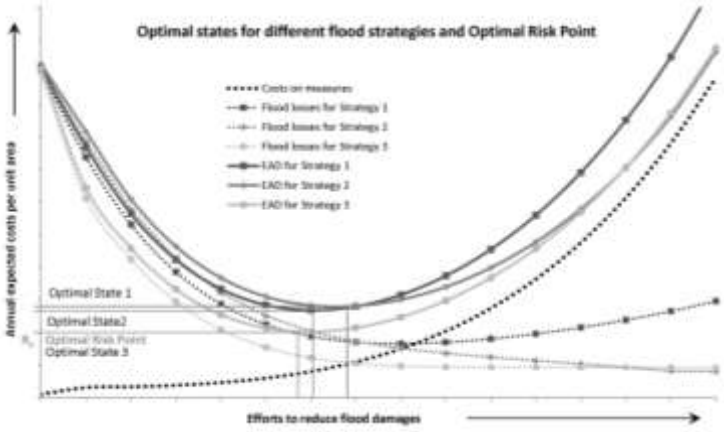


*Figure 3-6: Comparative risk analysis of different strategies and calculation of optimal risk point against a land-use scheme in floodplain*

The strongest point of probability-based approach is that these provide countrywide uniform standards of practices. Risk-based approaches so far fail to provide standards that might uniformly be practiced over a country. With the help of ORP, flood management may be described in terms of risk-based standards. The current or proposed status of flood management might be described as the ratio or percentage of ORP in a floodplain. This ratio may be termed as 'flood management ratio' (FM ratio). FM ratio expresses the ratio between present EAD and EAD at ORP. Ideally, the FM ratio in a floodplain should be unity unless there is temporary shortage of resources and achieving ORP is planned stepwise in phases. Additional information may also be provided by expressing the ratio between the losses due to floods and the investments on the measures for planned EAD.

The commonly practiced economic efficiency indicators need to be used carefully for the assessment of flood management plans. There are two broad categories of these indicators. Some indices compare input-output ratios and the remaining compare input-output differences (Eq. 3-10 and Eq. 3-11). BC ratio is based on input-output ratio. Cost-benefit difference, ER, IRR, NPV, and EAD are based on the difference (or difference rate) of inputs and outputs. These indicators (except EAD) are designed to evaluate the benefits of an investment and can be used for evaluation of flood measures investments as well. Nevertheless, these indices should not be used in a straightforward way for flood management planning. Such practices might be misleading and may derail the planning strategies away from achieving the ORP. The maximum possible ER of a floodplain with available resources is only possible at ORP (Figure 3-4). The most efficient master plan should be decided using proposed ORP standards. For the situations, where there is a budget constraint, the priorities to individual measures within the master plan can be

assigned using established indicators (mostly BC ratio) suitable to the situation and constraints.

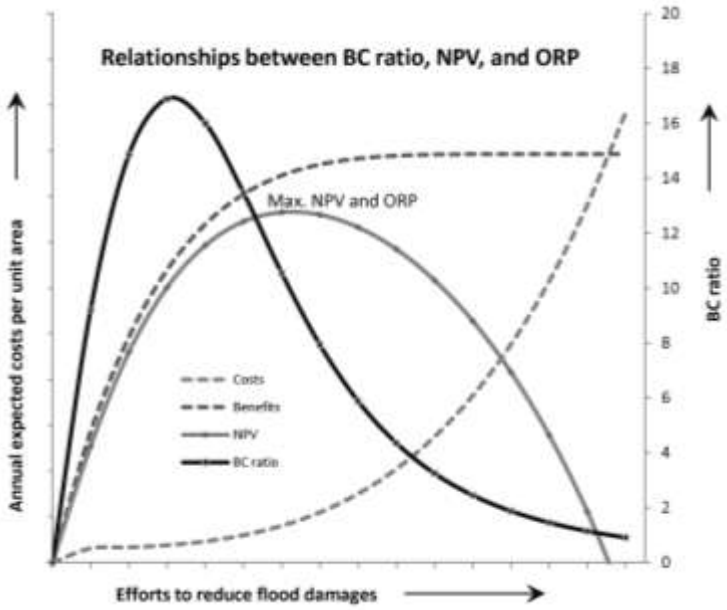


*Figure 3-7: Flood management costs, benefits, BC ratio, NPV, and ORP concepts*

## 3.7 Discussion

Rivers are the source of life and livelihood by enabling fisheries and providing fresh water for domestic, industrial, and agricultural usage. Even floods have numerous advantages along with disadvantages. Risk-based assessment considers these advantages of land-use and river proximity, while accounting for the potential losses. That is why, risk-based assessment is considered a tool to balance river processes and societal activities (Ref. 3.3.6). Risk-based flood management has the ability to handle floodplain dynamics and is inherently capable of achieving an (dynamic) equilibrium between human activities and river processes (Nathwani et al., 1997). In particular, for developing countries, where vulnerability is changing quickly, due to their fast economic transformation (Benson and Clay, 2004).

Another main advantage of risk-based flood management is that it helps to select efficient measures according to the nature of the problem, because of its ability to minimize the disaster impact (Genovese, 2006). In fact, risk-based assessment means to evaluate the impacts instead of controlling the floods. It prioritizes measures that can address the

problem in effective and efficient way. Employing risk-based assessment is therefore the only option to optimize flood management.

A risk-reduction approach for organizing flood management plans likely would produce the desired results given its ability to consider all possible options. With its flexibility to work with almost all major in-practice approaches, it provides a broad canvas to examine various different measures. To conclude, it is agreed that the risk-based approach should be adopted at all levels of flood planning (DCLG, 2006). Thereby, recognizing the necessity to move towards a risk-based approach, the European Parliament has set an example (Moel et al., 2009).

It is evident that establishing ORP is the first step towards designing a flood management strategy. However, FM ratio may be used to plan stepwise planning to achieve ORP at national level. FM ratio also helps by indicating the current departure from achieving ORP. Whereas IRR, NPV, and benefit cost ratio are indicators that describe the feasibility of any measure or project within the master plan. Preliminary optimizations of both the land-use and flood measures have been performed in this thesis.

The maximum land-use benefits in a floodplain are achievable at ORP. Therefore, the first step towards the planning of flood management is to determine ORP of a floodplain. Long term and short term planning may be formulated consisting of only those projects that fit in the strategy that achieves the ORP. Therefore, priorities may be assigned only to those projects using BC ratio (Ref. 3.6.2). However, extensive efforts for data processing and analyses are required to establish the ORP. The proposed risk-based standards, if developed further may replace probability-based standards. ORP once established must be re-evaluated on a periodic basis.

# 4 Flood management assessment framework

This chapter will explain the recommended methodology for implementing the proposed risk-based assessment (Ref. 3.4) in flood management projects. The framework suggested here, essentially comprises of both the evaluation of river processes and societal responses. A flood measure can be considered as an intrusion into the system while such intrusion may have its impacts, both positive and negative. For example, introducing a dike may reduce probability of flood in one area and may increase it in another area. The assessment methodology in such case must cover the impacts on both areas. The method recommended in this chapter, emphasizes the identification of all involved impacts and areas. The recommended framework involves probability-based 2D analysis of flood impacts to describe the temporal and spatial situations due to all possible floods.

The main steps recommended hereby are analyzing the behavior of flood and society, short-listing the feasible flood management options, evaluation of measures individually or in combinations, and finally to recommend the best possible scheme. Schematic layout of these steps is demonstrated in Figure 4-1.

## 4.1 River behavior (Hazard parameters)

Fluvial floods are mostly caused by the fluctuations in river flow. Therefore, their relative intensity, duration, and recurrence pattern play a major role to shape flood impact. Average flow of the river is not that much important. With regular fluctuation patterns, societies are mostly well-adapted and are used to get maximum benefits out of the floods. River behavior perhaps is the most important factor to be considered while analyzing the flooding problem. It is the important factor used for designing measures according to probability-based design.

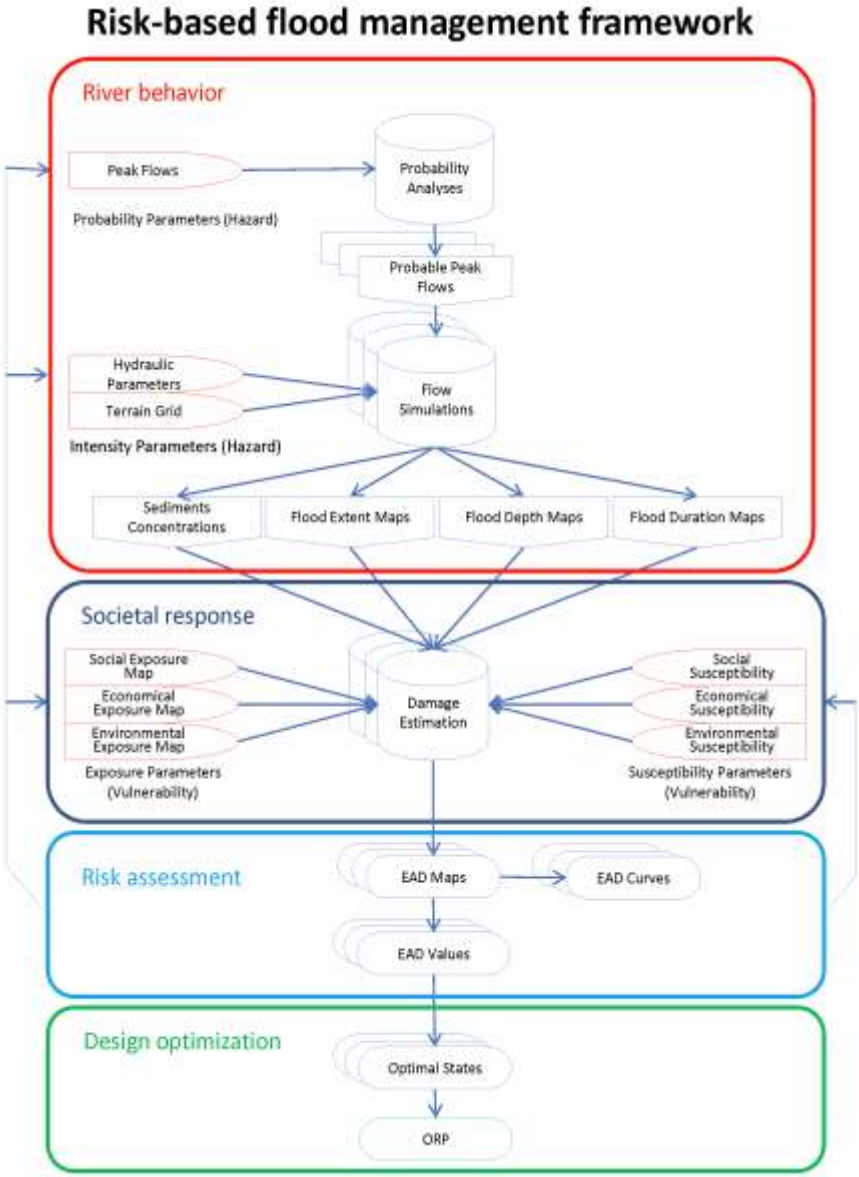


*Figure 4-1: Proposed schematic layout of risk-based assessment*

### *4.1.1 Flood frequency analysis*

Flood risk is a function of damages and their probabilities. The occurrence of flood and resulting losses, both are probabilistic. The probability in occurrence of flood is estimated by frequency analysis, whereas, probability of losses occurrence is generally treated while developing intensity-damage functions (Ref. 3.4.3). Frequency analysis provides a probabilistic approach to design measures assuming that events in the future are predictable based on the experience of the past (Pistrika and Tsakiris, 2007). The purpose of flood frequency analysis is to relate the peak flows to their frequency of occurrence using probability distribution functions (Chow et al., 1988). Fitting the annual peak-flows to the most closely matching cumulative probability distribution function is the most straightforward method for estimating flooding probabilities (Francés and Botero, 2007). Flood frequency analyses are traditionally practiced to deal with flood probabilities. Main limit is that these assume that annual maximum floods are stationary, independent, identically distributed random processes.

Frequency analysis has been carried out to estimate the probability of potential peak discharges for the Swan (at Islamabad Highway Bridge) and Chenab (at Marala Headworks) rivers. In our case studies, preliminary tests for independence and homogeneity as well as tests for outliers are carried out. The best-fit distribution was identified based on Chi square value using the L-moment ratio diagram, best fitting visual inspection, and the Z-dist statistic criteria. 'Design Flood' software developed by Iftikhar Ahmad (Ahmad, 1994) is used to perform frequency analysis and calculations are double cross checked by IH-Flood and Xtremes 4.1 developed by Centre for Ecology & Hydrology and Xtremes Groups, respectively.

Annual peak flow data of 83 years are available in case of the Chenab River study area. Frequency distribution based on collected data follows the Log Pearson Type III distribution, calculated with method of moments. Ranging from 0.0001 to 0.5 probabilities, ten different flood scenarios are estimated. Floods for 0.0001, 0.0002, 0.001, 0.002, 0.01, 0.02, 0.04, 0.1, 0.2, and 0.5 probabilities are calculated. Flow measuring gage of the Swan River is much below the study area and flow data for 41 years and rainfall data for 32 years are available. Rainfall-runoff modeling is performed to estimate peak flows precisely. Frequency analysis results of both rivers are shown in Figure 4-2.

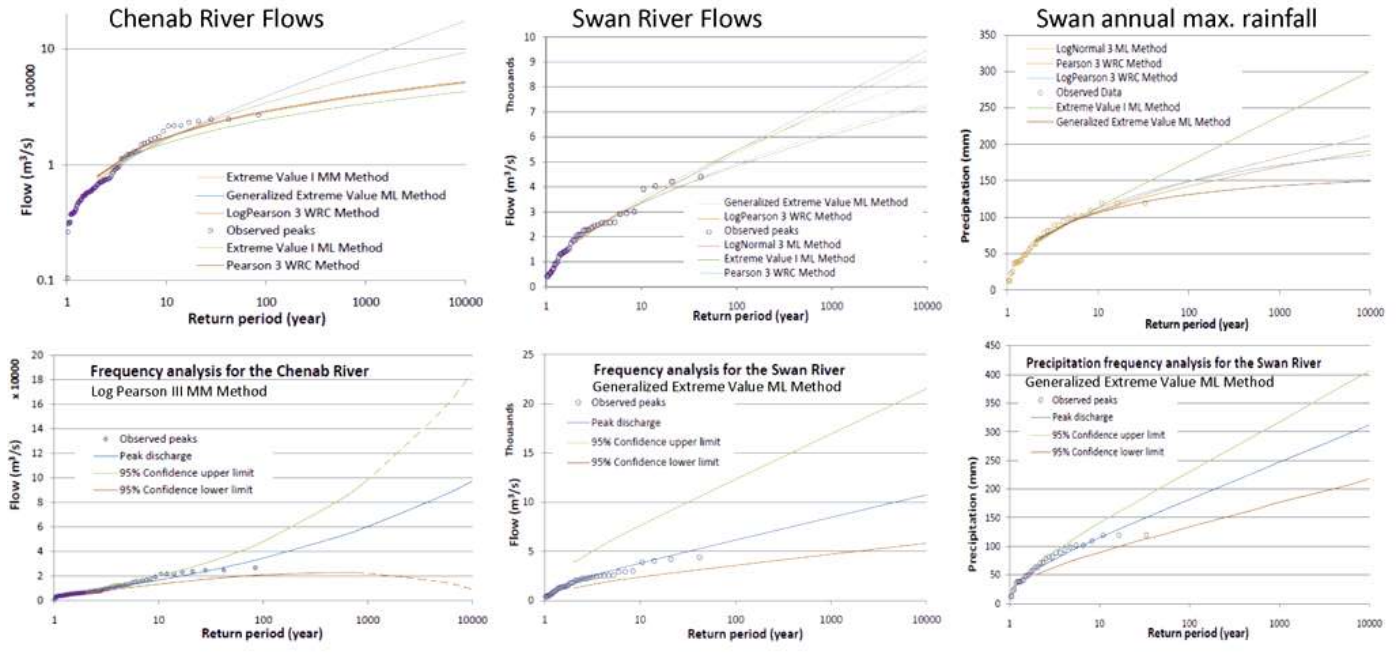


*Figure 4-2: Flood frequency analysis for both study areas: the Chenab River at Marala Headworks using Log Pearson Type-III distribution, [MM method], the Swan River flows at Dhok Pathan and annual maximum rainfall at Islamabad Airport using Generalized Extreme value Distribution, [ML method]*

### *4.1.2 Rainfall-runoff modeling for Swan study area*

The hydrological modeling of the rainfall-runoff process is performed for the Swan River study area using HEC-HMS software developed by US Army Corps of Engineers (Army Corps of Engineers, 2011). The catchment of the study area is subdivided into 39 sub-catchments on the basis of the available geographical information. The minimum area limit for subdivided catchment was kept at 4km$^2$. These cover the whole watershed area and represent drainage units in which the hillslope runoff (surface and subsurface) converge to one point, the drainage point of the each sub-catchment. All sub-catchments are linked by channel sections (Figure 4-3). Their ends match with the drainage point of the sub-catchment and drain into the adjacent channel section. Still in each sub-catchment the vegetation cover, land-use and the hydrogeology might vary. The subdivision of the catchment is based on topography retrieved from a Digital Elevation Model (DEM) of the catchment with 25m resolution (Figure 4-4). DEM data is obtained from ASTER website (ASTER, 2011).

Figure 4-3 shows the schematization of the catchment and illustrates the connections between the sub-catchments. The rainfall-runoff transformation for each sub-catchment was modeled. Losses were deducted and the flood wave was obtained at the mouth of catchment using hydrologic routing along with base-flow. Rainfall to runoff conversion depends on land-use. For our case study, land-use data was obtained by Cheema and Bastiaanssen (2010) (Ref. Figure 4-4). Appropriate methods/ models within the package were chosen depending on the available data and the amount of accuracy required. Processes and methods selected in our case study are described in Table 4-1.

*Table 4-1: Details of methods selected while modeling rainfall-runoff using HEC-HMS*

| **Process** | **Method Selected** |
|---|---|
| Rainfall distribution | Evenly distributed, reduced by 20% |
| Canopy losses | Not incorporated |
| Loss | Initial and constant |
| Transform | Clark unit hydrograph |
| Base-flow | Not incorporated |
| Routing | Lag |

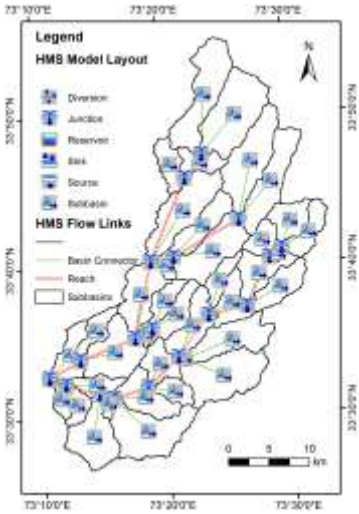


*Figure 4-3: Schematic layout of HEC-HMS rainfall-runoff model of the Swan River catchment*

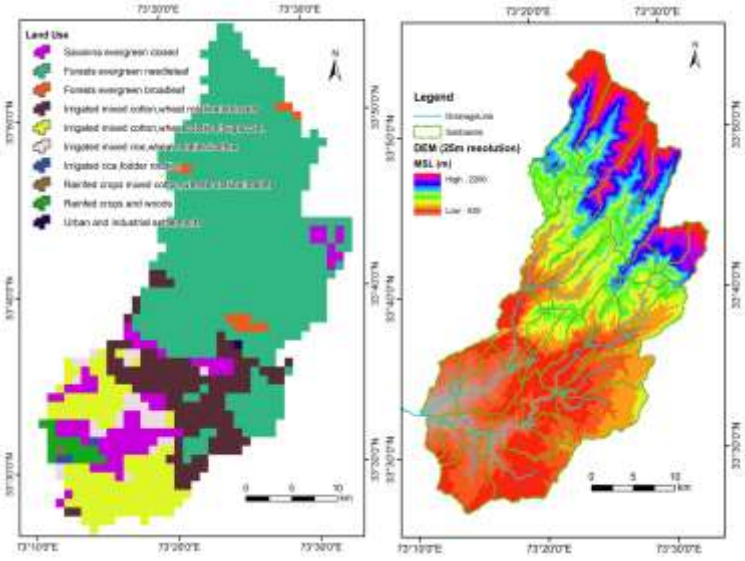


*Figure 4-4: Land-use at 1km resolution on left (Source: (Cheema and Bastiaanssen, 2010)) and right side figure represents the hydro-topographical features of the Swan River study area catchment at 25m resolution.*

### *4.1.3 Flood simulations*

The flood behavior and societal response, both together, determine the extent of consequences. The nature of the flood hazard must be modeled, before designing a flood measure (Green et al., 2000). Nowadays, models of different complexities are applied for the hydrodynamic simulations of floods to analyze flooding characteristics. Remote sensing/ GIS data are becoming more commonly used for simulating floods by modern software packages as these data are cost efficient compared to surveys (Hussain et al., 2009). 'Sobek Rural' developed by 'Deltares' is used for 1D-2D simulation of flood. The Sobek 1D-2D module performs 1D modeling for Channel flow and 2D for the flood-spread over the floodplain. For complex geometries and flow patterns, 2D modeling is recommended (Kron, 2007; Forster, 2008). However, the 2D model approach requires a significantly higher processing effort and longer computation times (Forster, 2008). In our case studies, one-dimensional models of the river coupled with 2D overland flow using 'digital elevation model' (DEM) were used to produce desired results.

The simulation of inundation depths and floodplain extents for the Chenab River area was carried out using 90m resolution DEM obtained from the HydroSHED (Lehner et al., 2008) in Sobek Rural '1D-2D' module. The model has been run against a selected range of floods frequencies (Ref. 4.1.1). Schematic layout and hydraulic simulation was done using HEC RAS, HEC GeoRAS, and Sobek '1D-2D Rural' modules. The model has been run for all calculated floods frequencies. The study area is flat and may exhibit low velocities and longer duration of flooding. Floodwater depth was selected assuming the adequate parameter for loss calculation. The Chenab River model was carefully calibrated and validated against available data of water levels recorded at the Marala Headworks and Qadarabad Headworks. Initial Manning's roughness value 'n' were chosen following the literature and models developed by NESPak Consultants. The Swan River is smaller than the Chenab River. Therefore, the DEM of 25m resolution is used. There is no flow-gauging site in the study area that can be used to validate our model results. Due to lack of calibration data for the Swan River, 'n' values obtained from the literature review were used. This assumption might be acceptable, since there is no other possible method, not even with available GIS data, to calibrate our model.

## 4.2 Societal response (Vulnerability parameters)

A flood of the same intensity may produce different losses in different areas due to the difference in exposure as well as resistance and preparedness of the societies. Flood response of society is often characterized using intensity-damage curves. For this purpose, we used the function developed for areas similar to our study areas after consultation of experts. Inundation of the floodplain was simulated using 2D flood propagation model (Sobek) for a number of inundation scenarios with various measures. These scenarios were developed using dikes of different heights and combinations of land-use practices. Land-use practices and preparedness determine the societal response.

### *4.2.1 Land-use practice (Exposure)*

Land-use maps for the Chenab River floodplain were developed using 'Pakistan survey department' maps and were calibrated with 'google maps' and partial ground-truthing techniques. Land-use maps of the Swan River were prepared by combining the development plans of land-developers currently developing the floodplain in the study area. Figure 4-5 and Figure 4-6 show our study areas of the Chenab and Swan rivers. These maps were used to display spatial distribution of exposure.

### *4.2.2 Flood response (Susceptibility)*

Flood response (Susceptibility) is the property that depends upon the ability of assets or people living in floodplain to withstand against floods (Ref. 3.4.3). As mentioned in subsection 3.4.3, susceptibility of a land-use can be defined using intensity-damage relationships. The stage-damage functions are accepted as the standard approach to assess direct flood damage (Smith, 1994; Middelmann-Fernandes, 2010; Yi et al., 2010) and the same is used in our research. Accurate information on historical flood losses are very rarely available; therefore, estimates are often accompanied by large margins (Douben, 2006). In our case, appropriate damage functions have been developed by consulting literature, different sources, and previous projects on the best-suited basis. Our dominant sources were local authorities, Chen 1999, Wang & Xiang, and ANFAS project (Data Fusion for Flood Analysis and Decision Support). Figure 4-7 shows the stage-damage functions '$F_a$ (d)' used in our case studies. If '$D_{a,max}$' is maximum possible damage for a particular land-use 'a', then damage '$D_{a,i}$' against a flood of probability 'i' can be found using Eq. 4-1.

$$D_{a,i} = F_a(d) \times D_{a,\max} \qquad \textit{Eq. 4-1}$$

## 4.3 Risk assessment

Once the flooding behavior and societal response is determined, the next step is to calculate the risk (potential consequences) with and without project conditions. Choosing a standard procedure, level of details, types of damages, and proper software tools are discussed in next sub-sections. The ultimate outcome of proposed assessment methodology is the detailed estimate of risk. The convenient presentation of the results facilitates decision-makers to choose the best possible option.

Flood damage assessment includes both engineering and economic aspects (Yi et al., 2010) and can be performed with a number of techniques. The choice of an appropriate method depends on too many different factors and not least on the data availability. Almost none of developing countries have any standard methodology for loss estimation (Dutta et al., 2001). However, there exist some generally accepted methods for the loss estimation. Depth-damage functions described in subsection 4.2.2 are used to estimate direct damages.

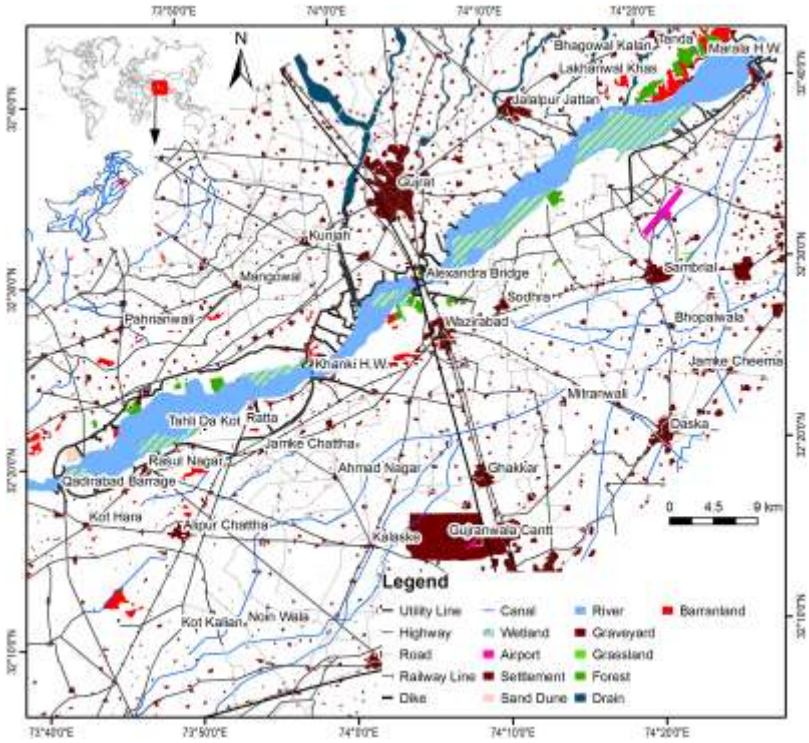


*Figure 4-5: Chenab River floodplain showing the digitized land-use details.*

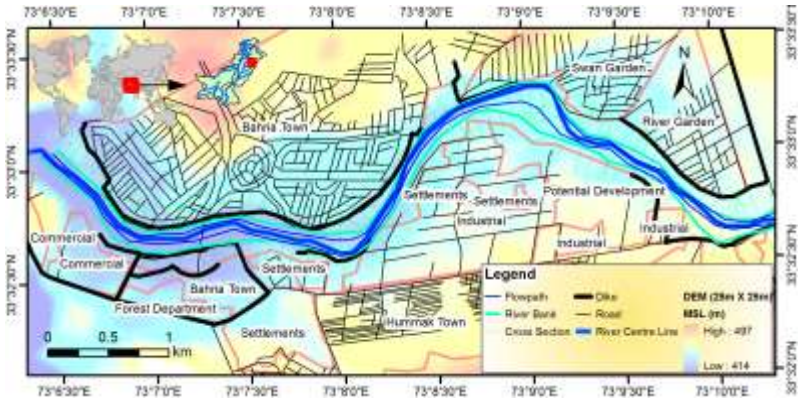


*Figure 4-6: The Swan River floodplain showing the developed areas by different developers.*

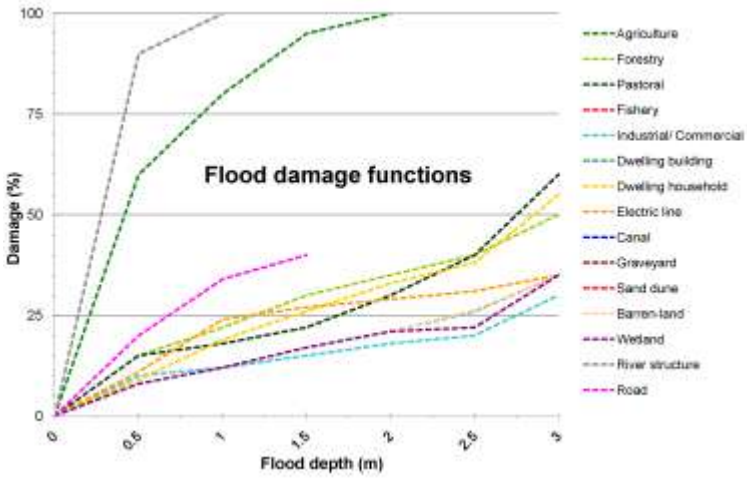


*Figure 4-7: Depth-damage function used for case studies*

To help decision-makers, there is a need as far as possible to devise a common metric for all the consequences of flooding whether tangibles or intangibles (Schanze et al., 2006). Efforts are made to include all possible types of damage categories that include direct, indirect, induced, tangible, and intangible damages to consider the net impact of flooding. Indirect tangible and intangible damages may constitute a significant contribution to total damages. Unlike the estimation of direct losses, the modeling of indirect loss is still in a preliminary phase. Simple, precise, accurate, and standard methods to estimate indirect and intangible losses are still far from maturation (White et al., 2001; Veerbeek, 2007). Current methods of flood loss estimation, either retrospective (i.e. backward analysis based on empirical data) or prospective analysis (i.e. scenario analysis and prediction), mainly focuses on direct losses (Veerbeek, 2007). In this thesis, direct and tangible damages are calculated in detail, whereas, indirect and intangible damages are estimated using generally practiced correlations that can produce fair estimates (Yoe, 1994). In practice, only important damage categories are used in different case studies depending upon their potential role to keep the effort of the analysis reasonable. In addition to losses, floods have many benefits. Flood inhabitants also have interests that are sometimes associated to river flooding. Benefits of floods and living in river proximity are also considered while calculating risk in our case studies.

### *4.3.1 Scale of the study*

Taking a decision about the size of study area is the first step before the execution of a flood damage-evaluation study. The selection of damage evaluation method depends very

much although not entirely on the availability of data as well as on scale and objective of the studies. Scale of the studies is linked with the type and required details of the assessment. The choice of an appropriate type of damage assessment method depends very much on the size of the study area (Messner et al., 2007). If a method of damage evaluation involves more details then it will need consequently more efforts per unit of area. Consequently, the type of 'monetary analysis' is also related to the scale of studies. For small-scale studies, damages to individual household, business plant, or company are considered as 'financial damages', while the macroeconomic effects at country or regional level are covered under 'economic damages' (De Bruijn, 2005). "The 'financial analysis' of a project estimates the profit accruing to the project-operating entity or to the project participants, whereas 'economic analysis' measures the effect of the project on the national economy" (ADB, 1997). The size of study area and detail-level of analysis must be decided based on available resources and objectives of study.

*Table 4-2: Land-use classification used in our case studies for calculation of direst tangible losses*

| Sr. Nö | Land use | Effective Damage Depth (m) | Max. % Damage | Total Damageable | |
|---|---|---|---|---|---|
| | | | | Rs/ft | Rs/ft² |
| 1 | Agriculture | 2 | 100 | | 0.25 |
| 2 | Orchard | 3 | 55 | | 5.50 |
| 3 | Forestry | 3 | 55 | | 0.10 |
| 4 | Pastoral | 3 | 55 | | 0.04 |
| 5 | Dwelling household | 3 | 55 | | 50.00 |
| 6 | Dwelling building | 3 | 35 | | 100.00 |
| 7 | Airport | 3 | 35 | | 50.00 |
| 8 | Electric line | 3 | 35 | 1,000.00 | |
| 9 | Sand dune | 3 | 35 | | -0.05 |
| 10 | Barren land | 3 | 35 | | -0.10 |
| 11 | Wetland | 3 | 35 | | -0.05 |
| 12 | Major road | 1 | 35 | 5,000.00 | |
| 13 | Secondary road | 1 | 35 | 1,500.00 | |
| 14 | Railways | 1 | 35 | 5,000.00 | |
| 15 | Main canal | 1 | 100 | 2,000.00 | |
| 16 | Tributary canal | 1 | 100 | 500.00 | |
| 17 | Structures | 1 | 100 | 2,000.00 | |
| 18 | Graveyard | 1 | 100 | | 5.00 |

### *4.3.2 Tangible losses*

Direct tangible damages are estimated using the damage functions (Figure 4-7). These damage functions estimate losses as percentage of the exposure of each asset type. The percent damage, thus obtained, is then multiplied by the exposure to obtain damages in monetary terms. The depth–damage functions are used to estimate flood damage by using flood inundation depth map and exposure distribution map (Ref. 4.2.2). Intensity-damage function of one asset differs from others. Some assets are movable, may be moved away from flood risk areas, given sufficient warning time, and are not necessarily potentially at

risk. Therefore, a percentage is assumed to be flooded depending upon warning time and immovability of assets. Land-use classification, effective flood depth, and maximum percentage of damageable costs are shown in Table 4-2. Thus, it is obvious that damage functions count the fact that floods do not results in total collapse. In addition, some property can be removed from floodplain at the event of flooding. These functions also consider the probability that a loss will occur each time under same conditions.

*Indirect Losses*

Due to the involved complexity in estimating indirect losses, much less attempts have been done to design such models (Veerbeek, 2007). Indirect losses are mostly correlated to direct losses, or otherwise, treated in a very complicated way. Unit-loss models, input-output models, econometric models and fixed ratio models are used mostly for the estimation of indirect losses. It may be acceptable to use a fixed ratio between direct and indirect flood losses in some studies (Yoe, 1994). The ratio of indirect to direct national losses is 12.7% at 1 meter flood depths (Yoe, 1994) and the same is used in our case studies where needed. Care should be taken while estimating indirect losses to avoid double counting of damages.

### *4.3.3 Intangible losses*

Actual worth of any asset is the sum of its tangible and intangible values. The proportions between both values vary greatly according to type of asset. Intangible values of commercial products are almost negligible, whereas, of historical monuments, religious places, wetlands, habitat of rare species, and graveyards are higher than their tangible values. Households are consisting of some items of sentimental or nostalgic value for which market values that only covers tangible value, may not measure their true worth. Intangible losses can be of either social or environmental in nature. Environmental and social values have been evaluated into monitory terms for our cost-benefit analysis using commonly practiced methods. Because such evaluation presents considerable challenges and difficult choices (Schanze et al., 2006), the framework in our research is kept flexible. Social and environmental can also be described explicitly before concluding a final EAD.

*Estimation of life losses*

Loss of life and affected population comprise the most common and dominant fraction of social losses. Number of persons affected can be estimated by averaging the population over the area while correlating the life losses to the flood parameters. Roos and Jonkman (2006) have distinguished three categories of flood deaths

- Drowning persons due to rapidly rising water
- Drowning persons due to high flow velocities
- Deaths due to other causes, such as hypothermia, heart attacks, shock, failed rescue, etc.

It is expected that especially the combination of water depth and rate of rising cause the danger. A function was developed (Eq. 4-2) that based on the fact that mortality 'K' is a function of water depth 'h'.

$$K = f(h) = 9.18 \times 10^{-4} e^{1.52h} \cdots\cdots\cdots f(h) \leq 1 \qquad \textit{Eq. 4-2}$$

Although potential loss of life is noted in many feasibility reports, there are no well-defined regulations or guidelines for how to incorporate loss of life into the cost-benefit analysis. A more general relationship has been described by Pelling et al. (2004). He described the number of causalities 'K' in terms of exposure 'E', gross domestic product per capita 'G', and local population density 'D'.

$$\ln(K) = 0.78\ \ln(E) + 0.45 \ln(G) - 0.15 \ln(D) - 5.22 \qquad \textit{Eq. 4-3}$$

Eq. 4-3 is used in our case studies. These relationships are not useable for social hot spots like hospitals, schools, old people's homes etc.

### *4.3.4 Expected annual damages (EAD)*

Risk-based methods of evaluation help decision-makers to envisage spatial and temporal distribution of risk over the floodplain. Flood damages are probabilistic events (Yoe, 1994) and flood intensity greatly varies over the floodplain. The spatial distribution of risks as well as of the benefits of flood mitigation measures have been rarely considered so far (Meyer et al., 2009). Expected annual damages (EAD) represent the average damages that might be expected annually due to the probabilistic nature of floods and flood losses. Damage curves and EAD distribution maps provide an expanded illustration of risk distributions. EAD can also be calculated across the flow to see the lateral trends in risk along the river. Therefore, decisions, which are based on EAD, have advantages over conventional approaches. EAD provides the estimation of risk and indicates how far present flood management practice is from achieving the optimal risk point 'ORP'.

In 1990's, US Army Corps of Engineers used the relationships between the damage, frequency, discharge, and stage to develop a hydroeconomic model for EAD estimation (Yoe, 1994). These correlations work well as long as flow conditions and societal vulnerability remain unchanged. Structural measures change the flow regime and flood behavior significantly. Once the flow regime is changed, old developed relationships do not remain applicable. Therefore, a hydroeconomic model cannot be used in such conditions. Detailed analysis using GIS data and 2D hydrodynamic model are needed to handle such changes appropriately. The method supports the calculation of EAD based on actual conditions of the floodplain. The concepts of EAD, damage curve, and EAD distribution map have been introduced along with their possible benefits and proposed uses.

$$\mathrm{EAD} = \sum_{i=0}^{i=\infty} \mathrm{D_i} \times \Delta \mathrm{P_i} \qquad \textit{Eq. 4-4}$$

$$D_i = \frac{D_{P_{i-1}} + D_{P_i}}{2} \qquad \text{Eq. 4-5}$$

The term 'expected' is used rather than 'average' because a frequency curve is used to represent the distribution of future flood events and the expected value of damage is computed by the summation of probability weighted estimates of damage (USACE, 1993).

### *4.3.5 The unit area (Yardstick) approach*

The Yardstick approach is an effective method for small-scale detailed studies. This approach considers individual properties and assesses damage per square meter of the floor space (Messner et al., 2007). The price of any land-use type is determined based on involved materials and labor or otherwise by consulting state agencies, experts, and property brokers to establish market price per unit area. In our case studies, the latter method is used to establish the price of different land-uses and is crosschecked with the first method. Unit loss models require detailed information of land-use. The price of land-use (excluding the price of land) expresses flood damage potential. Flood damage functions calculate losses as percentage of these potential damages. Whereas, the percentage is calculated using the relationship between flood intensity parameter and land-use susceptibility. Generally, depth-damage relationships are used for damage calculations (also in our case studies, Figure 4-7) to find the percentage of land-use value. This method can also be used to calculate the casualties and population at risk (De Bruijn, 2005).

Another advantage of this approach is that it may provide the density distribution of damages over the floodplain. The damage density distribution helps in pointing out the high vulnerability spots. The resulting damage maps are useful for interactive flood management. This method is helpful to translate these damages in terms of risk.

### *4.3.6 Software tools*

A number of software programs have been developed for flood damages calculations. Calculation of flood damages using a complete software package reduces the efforts considerably. At the same time, it limits the freedom of incorporating diverse and new methods for research purposes. These methods can mainly be divided according to their ability to work with GIS data. There seems to be a trend that as GIS has become more common over the last years, it is being integrated in damage evaluation software tools more often (Messner et al., 2007). Software tools also differ in their capabilities and methodologies. Some are capable to calculate flood risk from the basic hydrologic, hydraulic, and topographic inputs while others only calculate flood damages against flood intensity and land-use parameters (Van Mierlo et al., 2003). Table 4-3 demonstrates some popular software tools with their GIS capability and countries of origin.

*Table 4-3: Popular software tools, their compatibility to GIS and their country of origin*

| Software | GIS-based | Country |
|---|---|---|
| ANUFLOOD | No | Australia |
| ESTDAM | No | UK |
| FAT | Yes | Czech Republic |
| FDAM | Yes | Japan |
| FLODSIM | No | South Africa |
| FloodAUS | Yes | Australia |
| HAZUS - MH | Yes | USA |
| HEC-FDA | No | USA |
| HIS-SSM | Yes | Netherlands |
| HWSCalc | No | Germany |
| TEWA | Yes | South Africa |
| MDSF | Yes | UK |

### *4.3.7 Uncertainty and risk analysis*

An important aspect of risk analysis is that the input information for the analysis can never be perfect and methods employed approximate real life. Therefore, outcomes of such analysis can be described as an educated guess of reality and lack certainty. In scientific terms, 'Uncertainty' is the difference between the statistics of the sample and the population of a set of data (Tucci, 2007). Flood-estimation procedures in practice mainly rely on observed discharge data (Buchele et al., 2006) and the quality of source data used in analysis brings major uncertainty. Another key aspect in modeling uncertainty depends upon the availability of actual observed flood events used for the model calibration (ASFPM, 2004). The flood simulations are based on 'clear-water' flooding which happens seldom in reality (Myers, 1995). Debris blockages often create flooding conditions in unexpected areas. The vulnerability of elements at risk is also a source of uncertainty (Merz et al., 2007). Uncertainties may also arise as a result of the land-use data, the value assessment, and mostly in the estimation of susceptibility, i.e. the damage functions (Messner et al., 2007).

Uncertainty plays a major role in the credibility of results. Decision-makers must be aware of the reliability of the risk analysis results while assigning priorities and resources to projects. It is important to consider all the uncertainties to obtain accurate estimate of EAD; otherwise, EAD would be underestimated mostly (Tung, 2002). Mentioning uncertainty in results enhances the understanding of decision-makers. Risk analysis results should, as far as possible, indicate the error range and provide the user with a realistic idea of their accuracy.

All uncertainties cannot be avoided or solved. Choices are, by necessity, made under uncertainty; because they lie in the future, the consequences of all the options are shrouded in uncertainty (Green et al., 2000; De Bruijn, 2005). Most important to consider is to foresee the impacts of such decisions. Decisions under high uncertainty must be

adaptive and flexible and need much effort to minimize the uncertainty. Considerable uncertainties, although being an intrinsic part of extreme value estimations, can be managed by the complementary use of different methods (e.g., flood-frequency analysis and rainfall-runoff models) (Buchele et al., 2006). Schanze et al. (2006) recommend the use of a probability distribution from Monte-Carlo modeling or from more simple representations as 'credible' bounds on some key parameters to represent and communicate the uncertainty in the assessments. To decide whether an uncertainty analysis is required depends upon the extent and reliability of input information available and purpose of the study. On the other hand, a very approximate damage estimate might be sufficient for a high level strategy decision but not for the assessment of concrete protection measures (Messner et al., 2007).

## 4.4 Design optimization

According to the proposed framework (Figure 4-1), the last step is the optimization of the design. Our framework provides the results of risk estimation in shape of EAD values, damage curves, and EAD distribution maps. These values help the designer to modify the proposed measures interactively to further reduce risk.

The EAD distribution map provides the most detailed spatial distribution of risk. This might be helpful to diagnose the high-risk areas in floodplain. These maps provide the combined risk due to all possible floods and cannot show the impacts of individual floods. Damage curves facilitate to see the impacts of any individual flood. If the corresponding damages are weighed according to their (exceedance) probability, these curves represent the EAD curves that demonstrate the contribution of individual flood to risk. The lump sum and net impact of any measure is described by its EAD value.

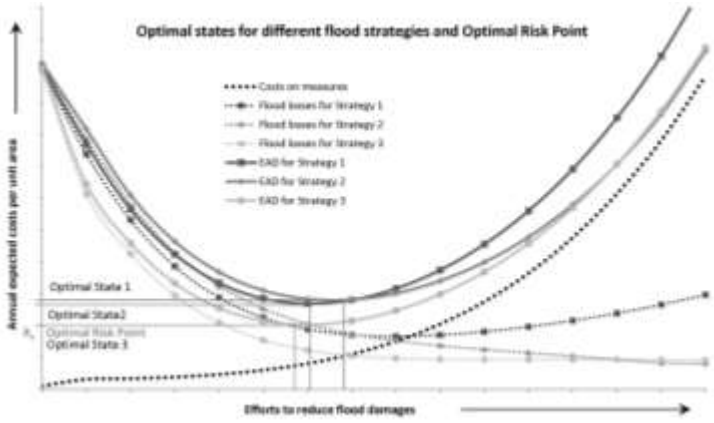


*Figure 4-8: Comparative risk analysis of different strategies and calculation of optimal risk point against a land-use scheme in floodplain (Reproduced).*

Every modification in design of a measure will change the EAD of the floodplain. If this EAD is drawn against the costs required for the measures, a trend line similar to Figure 4-8 can be obtained. Every measure or combination of measures will reduce risk with increasing costs. These 'combined deductions' (Ref. 3.6.3) continue to decrease and then start to increase after reaching an 'optimal state'. A comparison of optimal states against different measures or combination of measures provides the ORP that should have the minimum combined deductions.

We have evaluated the optimal states of dikes, flood zoning, and insurance for our study areas in Chapters 5, 6, and 7. As the flood frequency remains unchanged in all cases, these chapters will cover flood simulations, societal response, risk assessments, and optimal states of proposed measures.

## 4.5 Discussion

The proposed framework defines a risk-based assessment and design approach. This approach is equally applicable for developing and developed countries. The assessment methodology considers the vulnerability of the society in addition to river behavior. To design a risk-based flood measure, important general steps have been described in this chapter. Details for few types of measures (structural or non-structural) are provided in next chapters for example cases.

Although, the development of probability-based standards are supposed to be developed according to the socioeconomic conditions of a country, countries adopt these standards considering standards in other countries (Smith, 2004). Whether a design standard in a country is developed properly or not, probability-based design methodology only covers the hazard behavior, usually done by frequency analysis. The risk-based approach stresses the need to evaluate hazard and vulnerability of society for every single design. This implies that according to the risk-based approach, socioeconomic conditions of floodplains cannot be generalized and must be evaluated on a case-to-case basis. The proposed framework describes the steps that are required for the detailed analysis.

Concluding, this chapter provides the general considerations that are required to address the flood measure design under different conditions. It addresses the necessary steps to define the hazard characteristics and societal response. It also covers the level of detail, types of losses to be considered, damage calculation methods, and an overview of available software packages.

# 5 Hazard adjustments

The first obvious option to reduce hazard risk is to control the hazard itself. In the field of flood management, hazard control has been the most popular and economically feasible option most of the times. For example, fluvial flooding in flat areas inundates wide areas around the rivers. If a literal application of 'natural floodplains' (no man-made activity) prevails, the current vast areas, being used for agricultural and urban settlements, would not be available. In the Indus plains, even though intensive structural measures are in place, flow width of major rivers extends up to 20 km at most of the locations. These widths would have reached many times of the present widths if these were not curtailed by the present dike system. The structural measures facilitate coping with the ever-increasing demographic pressure on the floodplains to meet their residential and food needs by controlling floods (Ref. 3.2.1). So far, flood control has made developments possible in floodplains with a focus on human health, safety and valuable goods and property (White et al., 2001; APFM, 2007d). In addition to some environmental and ecological issues associated with the structural measures, extended protection provided by flood control attracts more investments in floodplains and increases the risk that was reduced by the measures.

Controlling the vulnerability of a society is another way to reduce flood risk. Unfortunately, vulnerability controlling methods are comparatively less developed and sometimes more resource demanding as well as less effective. Measures that reduce vulnerability, manage flood risk either by reducing susceptibility of elements at risk or reducing exposure in floodplain. Reducing susceptibility is not always a cost efficient solution. Whereas exposure control may reduce the substantial economic and societal benefits of floodplain utilization (ASFPM, 2004). Whereas, the population pressure and lack of other farmland emphasize on developing the floodplain (Plate, 2002). Therefore, flood control might be considered as the first choice. Flood control can be performed in the following ways:

- Curtailing flood spread
- Attenuating peak
- Flow diversion etc.

Only those measures that help in curtailing flood spreads will be considered under the scope of this PhD thesis.

Although, fixing rivers to a stable regime often fails and is usually expensive, it is unavoidable in some circumstances (Green et al., 2000). However, the developments in floodplains will continue (ASFPM, 2003) and ever-increasing protection will remain in demand.

## 5.1 Design of structural measures

Present practices of design of structural measures are mostly probability-based (Di Baldassarre et al., 2009). Generally, measures are uniformly designed nationwide to withstand a design flood of specific return period.

### *5.1.1 Residual risk*

Consideration of residual risk at the time of strategy formulation is very important. Floods that result against residual risk are extremely catastrophic due to their intense nature and unexpected occurrence. The residual flood risk behind levees or downstream of dams remains mostly ignored and often is not considered into decision-making of land-use planning. Risk-based assessments provide a better comprehension of these risks (Duivendijk, 1999). There is a growing understanding that total security against floods is impossible (Alkema and Middelkoop, 2007; APFM, 2007d). Absolute protection from flooding is technically not feasible as well as economically and environmentally unviable (APFM, 2009a). Whatever is done to prevent floods from happening, there will always be some residual risk (Genovese, 2006). The residual risk is the portion of the risk that remains even after flood measures have been initiated. Major sources of residual risk are design assumptions and imperfect knowledge. For example, the probability of structural failure against floods lower than the design flood (Carter, 2005), or even the hydrological conditions in the catchment may change in time for various reasons (Duivendijk, 1999). A zero level risk is not a realistic and consistent target as it would involve huge costs (Gilard and Givone, 1997). However, it is important that floodplain inhabitants must be aware of the residual risk (Ref. 5.1.1). Accordingly, floodplain inhabitants may decide to accept or decline that risk against the benefits of the floodplain as a tradeoff.

In other words, deciding the design probability[1] is a compromise, a compromise on safety or a compromise on developments. The proposed ORP standards demonstrate the existence of residual risk that may be termed as 'floodplain land-use rent'. Part of this rent is associated to costs of flood measures[2] (if there is any) and rest is due to flood damages

[1] A common mistake in practice is regarding the design of various types of utility-lines that may pass through the floodplain. Their design probability is usually correlated with the river size. Whereas this must be based on the functional importance of service line and involved costs, instead.

[2] These costs are induced impacts of floods (Ref. 3.1).

(Figure 3-4 and Figure 3-5). Flood planning must consider the consequences of floods that are more severe than the design flood, and must include the management of such floods (APFM, 2009a), which can be performed by non-structural measures.

### *5.1.2 Induced risk*

Structural measures alter the flow regime. Most of the measures just curtail flood spread or divert peak flows. This suppression or diversion induces flood risk for areas on the opposite bank, upstream or even sometimes to downstream areas. This shifting of risk to other areas has often been neglected so far (Collins and Simpson, 2007; Majewski, 2007). The second type of induced risk is due to increased intensity of floods when a structural measure fails (dike, dams, etc.). In addition, the vulnerability of the society increases, as people feel safer when flood protection is provided. High protection standards reduce flood probability resulting in decreased public awareness and willingness to cooperate/take responsibility for flood protection (Alphen and Lodder, 2006). The induced flood risk must properly be modeled and cost-benefit analysis must cover the resulting impacts in all areas involved (Ref. 3.6.1).

### *5.1.3 River dynamics*

Rivers are dynamic systems whose forms vary according to variations in runoff and sediment loads, over time (Green et al., 2000). As mentioned in subsection 5.1.2, the structural measures may cause shifting of flood risk to upstream, downstream, or even across the bank. In addition to shifting of risk, river flow pattern is also disturbed. While designing a structural measure, the modified flow pattern must be considered to envisage future behavior of floods. Commonly, hydrodynamic models are used with the help of geographical data to visualize modified patterns of river. The spatial visualizations help in designing flood measures (Carton, 2002). These visualizations are represented by plotting various hypothetical flood parameters graphically using flood maps (Tariq, 2005). These flood maps are used as the base for the assessment of consequences.

### *5.1.4 Socioeconomic development and flood management*

Socioeconomic development and flood management in floodplains support the development of each other. The theoretical level of risk that would prevail in the absence of any flood measure is represented by the 'baseline' (Erdlenbruch et al., 2009). Most of the floodplains carry economic activities and experience modified flow regimes after having flood measures being incorporated. The purpose of defining a baseline state is to evaluate the economic efficiency of the present state of flood management in a floodplain. The baseline state is also needed as a reference to calculate the deviation of already developed setup from the optimum scheme.

Some common experiences explain the public expectations and demands for the flood management.

- Once floodplains become urbanized, these follow an almost inevitable demand from the local community for flood protection.
- Floods with higher intensities cause catastrophes are followed by public demand for protection from floods (Tucci, 2002).

Interaction between embankment strengthening and socioeconomic developments is explained by the 'diking cycle' (De Bruijn, 2005). The 'diking cycle' represents turn-by-turn increments in safety levels and added exposure on repeated basis. When an area is protected by constructing dikes, floodplain inhabitants feel more secure and raise their investments in the floodplain (Di Baldassarre et al., 2009). This increase in exposure demands higher safety, which is then provided by raising dike heights. Increments on both sides continue turn by turn. Theoretically speaking, this cycles seems to have no end, but very high dikes should be avoided (Tucci, 2007). The ideas of 'Room for the River' (in the Netherlands), and 'Making Space for Water' (in the UK) are good practical examples to overcome this problem. The references of baseline and ORP help in evaluating the best options of achieving ORP at an existing state of flood management setup.

The flood resulting from a dike failure produces more severe impacts than if there were no dike (De Bruijn, 2005; Tucci, 2007), possibly because of sudden and high flow and secondly because the inhabitants are not prepared for the incident. Therefore, it can be concluded that residual and induced risks cannot be avoided, but can be minimized and must be considered while designing flood measures. These standards sometimes lose their economic efficiency in an attempt to make structures withstand against design floods. As a result, high safety factors and large freeboards result in uneconomical designs. These make hydraulic structures more expensive to construct and maintain in good conditions (Majewski, 2007). As a general principle, flood structures in floodplains should be designed to fit within their socioeconomic bounds, and do not detract from the harmony of the floodplain. In addition, flood protection standards must be consistent with the available resources and the requirements for economic efficiency (Handmer, 1990; Duivendijk, 1999).

The risk-based flood management and concept of ORP standards (Ref. 3.6.5) support a proactive approach and facilitate decision-makers to decide the level of protection to be provided. Conventional approaches do not guide in these situations and continue increasing protection levels through 'diking cycles' (Ref. 5.1.4). This increased protection encourages more exposure and reduced susceptibility that results in increased risk.

## 5.2 Risk-based design of dikes and dredging: Case studies

Risk-based design can be defined as the practice to evaluate the schemes for reducing but not necessarily eliminating the overall risk (against affordable costs), as tradeoff between the investment costs and the expected losses in case of failure (Tung, 2002; Pilon et al., 2003). Risk-based design is performed according to the framework developed in Chapter 4.

There are some segmented dikes in both study areas, which protect areas that are more vulnerable. These individual dikes are constructed to prevent flooding at local level. These dikes are built according to the prevailing design standards of 50-years return period flood in Pakistan (Halcrow et al., 2001). In our case studies, the proposed design standards (Ref. 3.6.5) are followed to optimize the design of the dike and dredging. Detailed CBA of the baseline case and proposed designs are analyzed to achieve the optimal state.

### *5.2.1 Dike-crest level design (the Swan River case)*

For study purposes, two types of dikes are evaluated. In the first case, continuous dikes on both sides of the river are introduced. In the second case, fragmented dike sections are introduced to areas that are more vulnerable. Indication of vulnerable area in second case is done based on a baseline EAD distribution map (Figure 5-3). The flood impacts against existing dikes, the baseline case, continuous dikes, and fragmental dikes are evaluated as well as compared against ORP. Dikes are introduced on the natural embankments, as per standard practice (Duivendijk, 1999).

Continuous dikes of five different heights (ranging from 1m to 5m with one-meter increments) were introduced[1]. Figure 5-1 represents the comparison of resulting damage curves of baseline case, existing dike system, and proposed dikes. Damage curves of all cases show complex trends due to the dual role of dikes. Dikes keep floodwater away from the protected areas, unless the floodwater depths exceed the design heights of the dikes. However, once floodwater overtops, dikes prevent floodwater to return to the river, hence exacerbating the losses.

The terrain in the Swan River study area is steep. According to our results, dikes below 4m, did not play any significant role in flood prevention as flow stage rises rapidly up to that level. Higher dikes (4m and 5m dikes) including the existing dikes (4m high) efficiently control flood spreads against floods with 0.2-probability or lower. For further severe (lower probability) floods, these dikes cause increase in flood losses by preventing the return of flood spreads to the river. These dikes even lead this escaped floodwater towards lowlands by driving it in the shape of parallel streams in protected areas. This phenomenon, known as 'shielding effect', causes flood losses to be higher than the baseline situation. The jumps in the damage curve are noticeable when floodwater depths exceed the heights of 4m and 5m dikes (Figure 5-1).

To increase economic efficiency of the proposed dike system, fragmented dikes were introduced to control wider spreads only. The locations of these dikes are decided by inspecting the flood risk spread of the baseline EAD distribution map (Figure 5-3). Fragmental dikes were proposed interactively with heights ranging from 1m to 5m. In the upper reach of the study area, dikes were set farther apart to provide more space for the river flow to facilitate safe passage of high floods. Resulting damage curves show dikes of

[1] Detailed methodology of all involved steps has been described in Chapter 4.

less than 3m do not reduce flood losses (Figure 5-2). Loss reduction trends of these dikes are not complex due to absence of shielding effect. Different heights of dikes control flooding of different probabilities e.g., 3m for 0.2-probability flood, 4m for 0.02-probability flood and 5m for 0.001-probability flood.

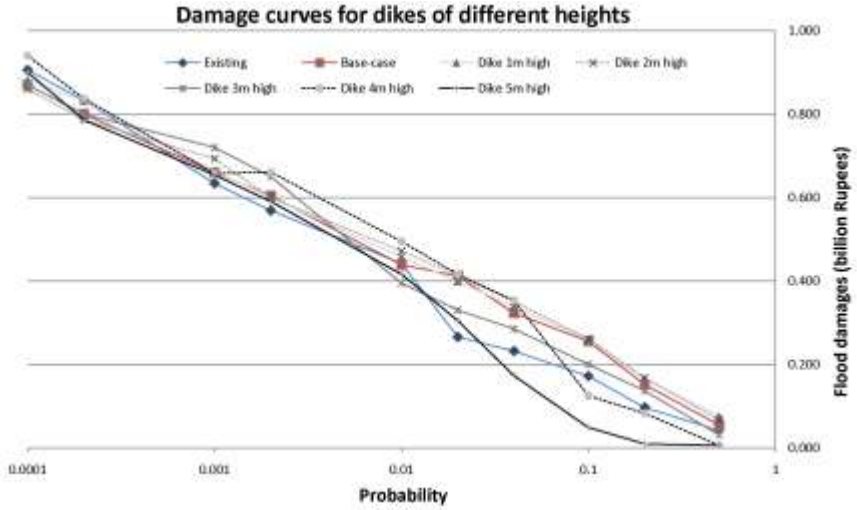


*Figure 5-1: Damage curves of existing, baseline case, and continuous dikes of different heights show the trends in flood losses for the Swan River.*

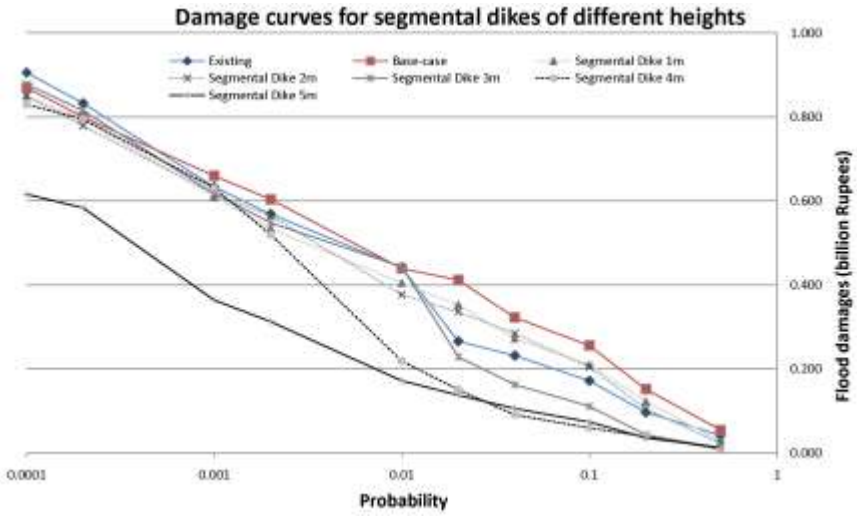


*Figure 5-2: Damage curves of existing, baseline case, and fragmental dikes of different heights show the trends in flood losses for the Swan River.*

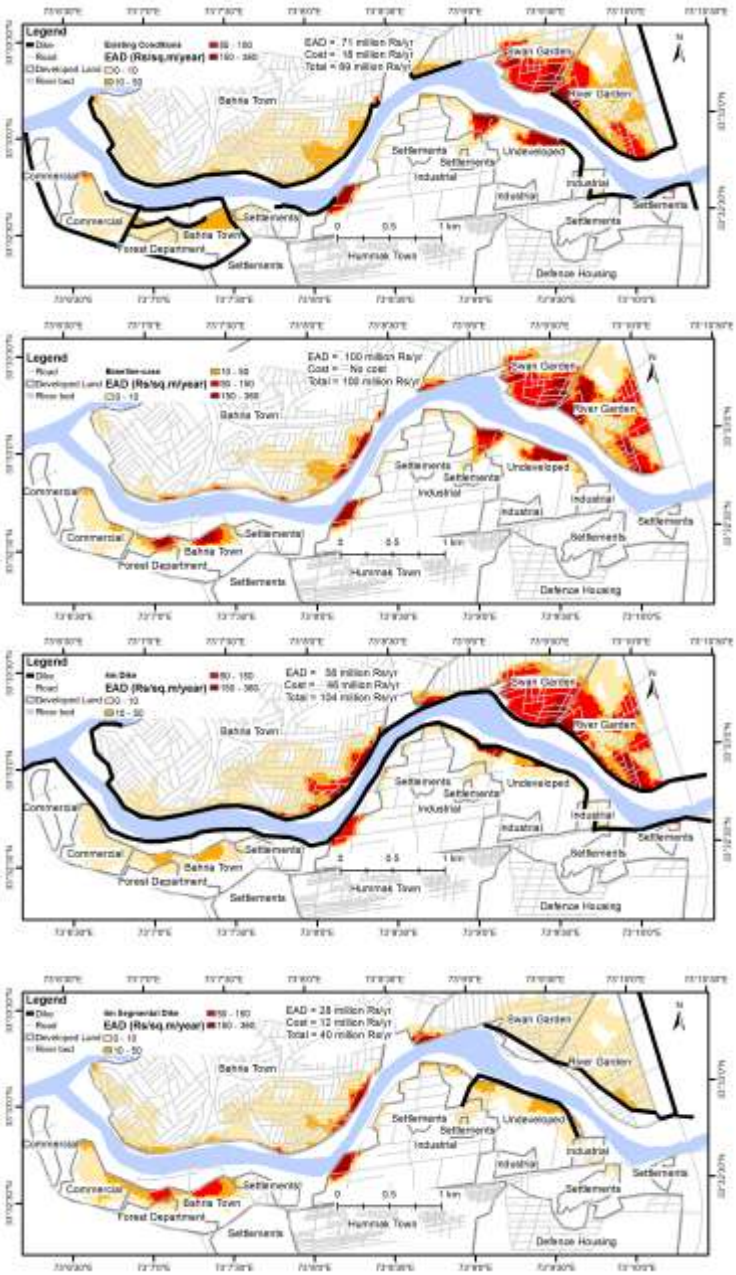


*Figure 5-3: EAD distribution maps of existing, baseline, fragmental dike, and continuous dike (both at 4m heights) for the Swan River.*

Results show that setting fragmental dikes farther apart in the upper reach to widen flow path helps in controlling high floods (Figure 5-3). Flood losses are reduced significantly in protected areas whereas flood losses in unprotected areas remain almost the same. As we found in the continuous dikes case that dikes are not an economically feasible solution for areas that are kept unprotected in this case study, flood zoning might prove helpful.

The case study produced some more interesting results. Having even the same heights of dikes (4m), flood losses of continuous dikes were higher than the fragmental dikes due to the so-called shielding effect (Figure 5-3). In addition, for very severe floods (probability 0.1 and lesser), the low height dikes (up to 3m high) play practically no role.

Results of our simulations may differ slightly as compared to the failure behavior of real earthen dikes. Once floodwater overtops earthen dikes, a breach develops. This phenomenon causes high flow rate of floodwater entering the protected area and facilitates return of floodwater after the flood peak passes. In our simulations, only surplus quantity of water overtops towards the protected areas. Although 'Sobek' can facilitate breach simulations when breach locations are pre-assigned, this was neither the case nor efficient due to the hundreds of simulations in our case studies. Hence, our case studies may provide lower estimates of losses in case of earthen dikes simulations. Therefore, instead of showing jumps, damage curves move upwards gradually after the floodwater depth exceeds the height of dike.

The spatial distribution of EAD for all proposed dikes is shown in Annex A. The floodwater mainly spreads at the upper reach where the terrain is relatively flat. In the lower reach, flood spreads confined to comparatively limited areas. Such limited spreads are due to steep geography of the study area. Flood losses in such areas may be avoided by implementing flood zoning (Chapter 6) in an economically feasible way.

### 5.2.2 *Dike-crest level design (the Chenab River case)*

Continuous dikes are also introduced to the Chenab River study area. The floodplain is flat and dikes may prove an effective solution. Differences in damage curves in Figure 5-4 show the gradual decrease in flood losses as dike height increases. With the increase in dike height, the number of locations where floodwater overtops are reduced, which results in loss reduction. More chances of flood spreads are just upstream of Alexandria Bridge (Figure 5-5 and Figure 5-6) where the very important Grand Trunk road connects Islamabad and Lahore via Gujrat and Wazirabad cities. One reason is that upstream terrain level at the right bank of the river is very low. Secondly, dikes are narrowing at the bridge location and available space for the flow is small. Two important cities (namely, Gujrat at right and Wazirabad at left) are situated at this location. To reduce this flooding, dikes should be set a bit further from the river.

Figure 5-7 demonstrates the reduction in EAD distribution over the floodplain with 5 m high dikes. EAD distribution maps for all proposed dikes in the Chenab River study area are provided in Annex B. As the dike height increases, flood losses decrease. Locations

with high losses may be treated with flood zoning and dikes may be made wider at these locations. Another highly vulnerable location is the Sialkot International Airport. Localized ring dikes may be provided to reduce part of the losses. However, the damages might be still high as indirect losses are high for such facilities.

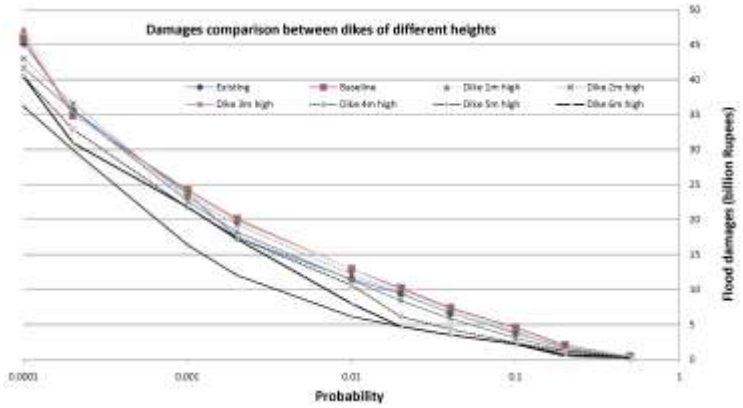


*Figure 5-4: Damage curves of existing, baseline case, and continuous dikes of different heights show the trends in flood losses against floods for the Chenab River.*

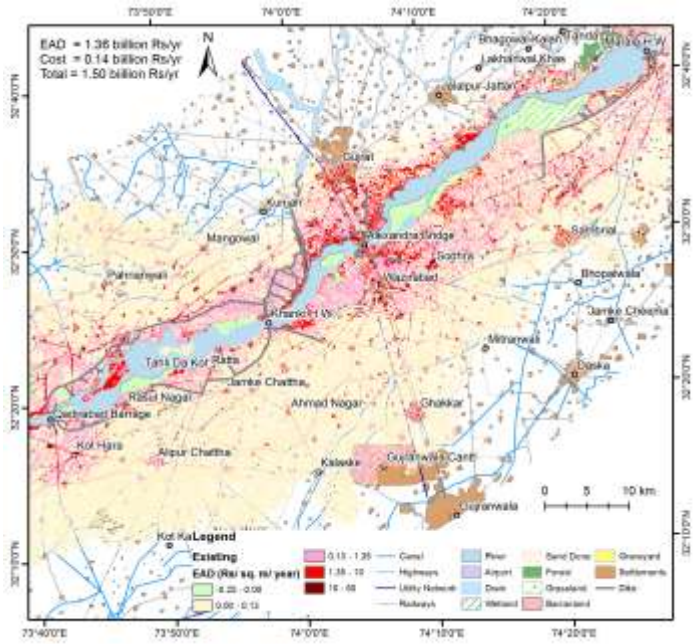


*Figure 5-5: EAD distribution maps of existing case show the spatial distribution of EAD over the Chenab River reach*

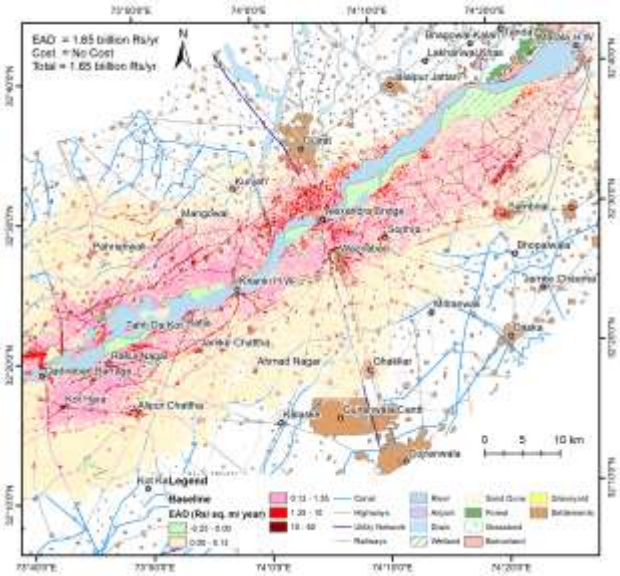


*Figure 5-6: EAD distribution maps of baseline case show the spatial distribution of EAD over the Chenab River reach*

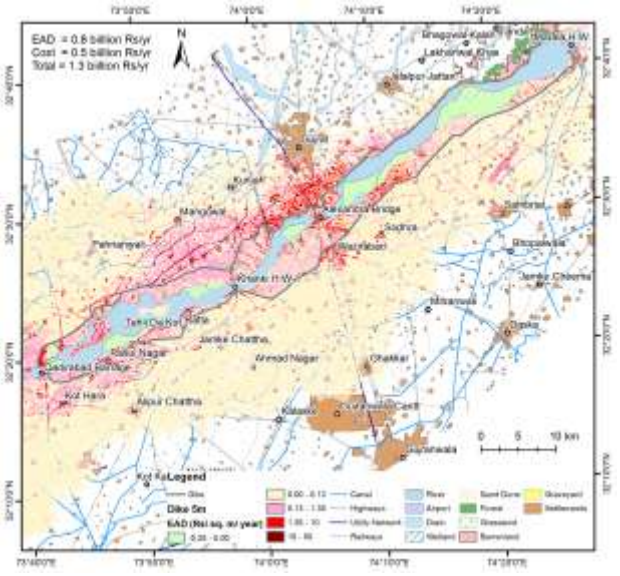


*Figure 5-7: EAD distribution map of proposed dike showing the spatial distribution of EAD against 5m high proposed dikes over the Chenab River reach*

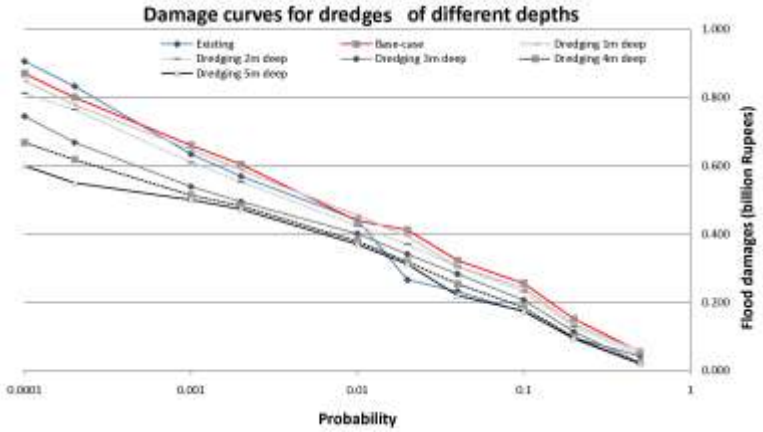


*Figure 5-8: Damages curves of existing, baseline case, and continuous dredging of different depths show the trend in flood losses for the Swan River*

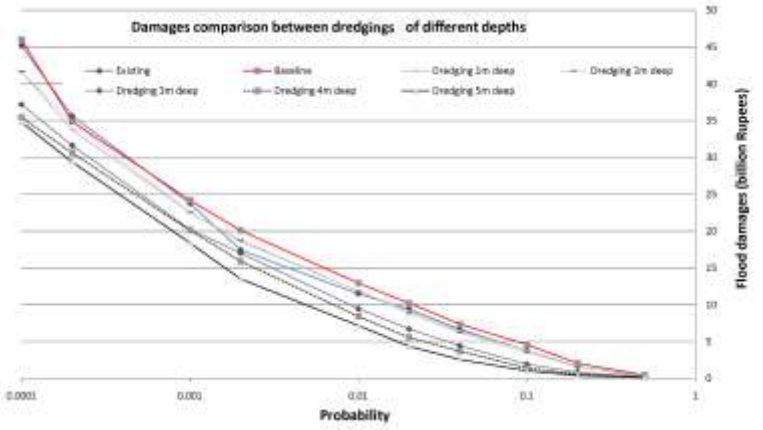


*Figure 5-9: Damages curves of existing, baseline case, and continuous dredging of different depths show the trend in flood losses for the Chenab River*

### *5.2.3 Risk-based river dredging*

Increasing the hydraulic conductivity of channel increases its flow carrying capacity. Therefore, our second type of structural measure, which is applied in our study areas, is dredging. Dredging takes place over widths of 100m (for the Swan River) and 1.5km (for the Chenab River) while depths ranging from 1m to 5m are simulated. Figure 5-8 and Figure 5-9 show the impact of dredging on flood losses in both areas. In both areas, losses are reduced with the increase in depths. Figure 5-10 and Figure 5-11 show the EAD distribution maps of the Swan River area and the Chenab River study area at 5m deep

dredging, respectively. Detailed EAD distribution maps for all cases can be found in Annex C and D.

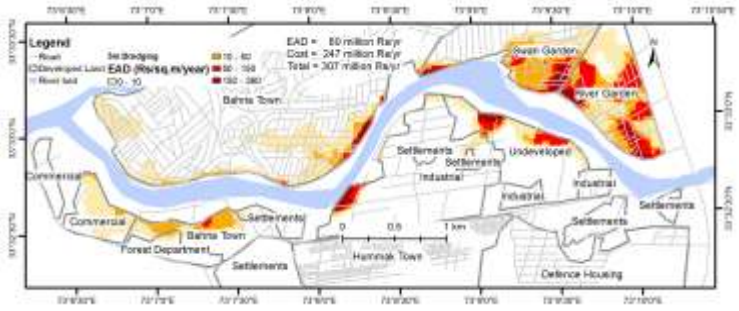


*Figure 5-10: EAD distribution map of 5m deep continuous dredging over the Swan River reach.*

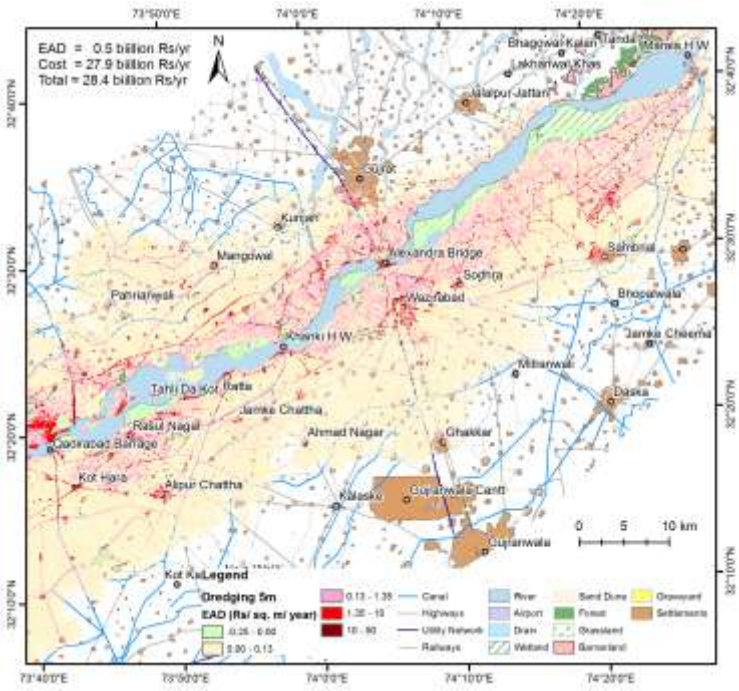


*Figure 5-11: EAD distribution map of proposed 5m deep dredging over the Chenab River reach.*

## 5.3 Discussion

Although both dikes and dredging help in reducing flood damage, dikes proved more economical as compared to dredging as more efforts are involved in dredging. The high dredging costs tremendously increase the total losses (Figure 5-12 and Figure 5-13, crosses graph scale limits). Based on the costs involved in dredging, it is not a recommended solution, but dredging can be achieved economically if the riverbed is used as borrow pit for nearby construction projects.

Neither a continuous dikes nor dredging are feasible for the Swan River. Figure 5-12 demonstrates that a continuous dike of any height is not a feasible solution and cannot achieve ORP. Therefore, it was decided to introduce dikes to only those areas where floods occur often and cause more damages. Providing dikes with more space for high flows results in reduced losses (Figure 5-12). Overtopping of floodwaters across the dikes, mostly accompanying by growing breaches, can exacerbate damage. As a generalized conclusion, increase in dike height reduces overall flood losses but dikes also increase flood losses by blocking the return of floodwaters back to river. Figure 5-12 shows that 4m high fragmental dikes are the most economical efficient solution.

In the Chenab River case study, continuous dikes prove economically efficient in reducing flood losses. High costs of dredging make it unfeasible for the Chenab River. Figure 5-13 shows that 5 m high dikes are the most economical solution. Further accuracy should be achieved by assigning the probability of failure to dikes. Soil or sand excavation from the riverbed for construction and earthworks may prove a cheap but an unorganized dredging type that may be supplemented with organized dredging.

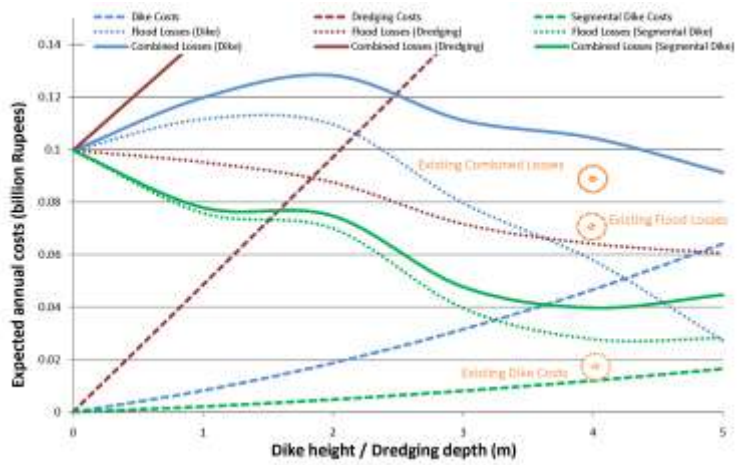


*Figure 5-12: Relationships between the increasing efforts to curtail flood losses and losses due to floods and costs spent on measures to determine ORP for the Swan River.*

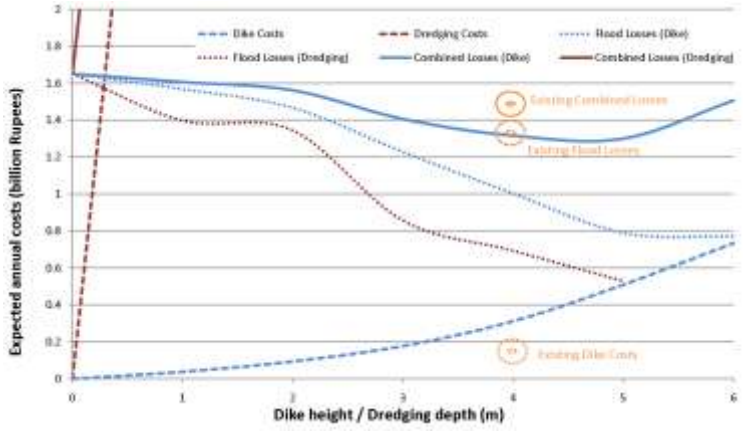


*Figure 5-13: Relationships between the increasing efforts to curtail flood losses and losses due to floods and costs spent on measures to determine ORP for Chenab River.*

# 6 Vulnerability adjustments

Existing flood management strategies in most countries are primarily riveted to the structural measures (dikes), enhancing only the threshold capacity of the community. The importance of non-structural measures was recognized only much later as compared to structural measures. Flood measures between 1850 and 1950 were largely comprised of structural solutions in the USA (Myers, 1995), which changed flow regimes, loss of habitats, biological diversity and productivity. It has been observed worldwide that both flood damage and spending on structural measures are increasing. The structural measures normally cause substantial damages to floodplain ecology and social setup of a floodplain area. Concerns over increasing flood losses and floodplain ecological degradations have been raised by flood managers all over the world and alternatives to structural measures are getting more attention.

In addition to the environmental issues associated with the structural measures, the advantages of non-structural measures should also be considered for flood management strategies. Non-structural measures generally exhibit high economic efficiencies. Their benefit-cost ratio may even be greater for developing countries as compared to structural measures (Handmer, 1990). In addition, flood management by controlling the societal vulnerability (non-structural measures) proves sometimes a potential option.

Another drawback of ignoring non-structural measures is that a unidirectional approach may exhibit limited loss reduction capabilities. Appropriately interlinking of non-structural and structural measures may increase the net benefits (Tariq et al., 2010c). For a 'diversity increasing vulnerability decreasing' strategy, it is necessary to include all components of vulnerability (de Graaf et al., 2007). Coupling non-structural measures with structural measures, increases efficiency and often has proven cost-effective. Flood management planning involves research into the ideal combination of these measures (Tucci, 2007). Initial proposals for the use of non-structural measures to reduce flood damages were made by the mid-1950's (Galloway, 2004). The trends of recently developed policies seem thereby moving away from flood protection towards floodplain adjustments (De Bruijn, 2005).Therefore, the impacts of non-structural measures independently and in combination with structural measures are evaluated in this chapter. The following measures for vulnerability management are evaluated:

- Flood zoning
- Early warning system
- Rescue and relief etc

Only flood mapping/ flood zoning is evaluated for the optimization purposes.

## 6.1 Flood mapping

Structural measures support the growth of economic activities in floodplains and this increased exposure then demands higher levels of flood protection. The high levels of safety thus achieved remain not cost efficient due to the lower ratio of marginal benefits to marginal costs at high safety levels. In addition, these also develop a false sense of security by ignoring the raised residual risk at the same time. Overlooking the residual flood risk (Ref. 5.1.1) is one of the main reasons for growing flood damages. People erroneously or perhaps deliberately conclude that floods were 'freak' events of a pre-modern era, that will not reoccur now on, at least they will not experience in their lives (Pottiera et al., 2005).

Reality is that floods can still occur and can wipe out the economic developments within a floodplain (Pelling et al., 2004). Because total flood control is not possible (Ref. 5.1.1), adjustments in social and economic exposure can be helpful to minimize the flood damages. One solution is to minimize activities in floodplains. However, we must bear in mind that flood-risk areas are also often attractive (APFM, 2007b) and sources of livelihood. A complete abandonment of floodplains will deprive us these benefits. The solution might be to restrain and adapt activities in the floodplains. Flood mapping and flood zoning help to achieve these adjustments.

Flood maps are good tools to illustrate flooding behavior in the floodplains. A flood map is a topographic map where the hypothetical flood characteristics are represented graphically (Tariq, 2005). The purpose of flood maps is to show the areas that are subject to flooding, the expected flood intensities, and, eventually, the different level of risks within the flooded area (ASFPM, 2003). These maps provide guiding information to land-use planners, flood managers, and political decision makers. Governments may plan possible reconstruction and rehabilitation programs based on these maps. These maps may also be used for identifying critical projects that should receive priority in post disaster assistance (Benson and Clay, 2004).

## 6.2 Types of flood maps

Flood maps can be used for a number of purposes. Consequently, their construction techniques and types of parameters that they target to draw are also different. Flood hazard maps contain information about the probability and magnitude of floods whereas flood risk maps additionally provide the information about the consequences (Moel et al., 2009). Flood risk maps are a valuable means of communicating risk to local communities for their awareness, adaptation, and local empowerment (Alphen and Lodder, 2006). In

addition, flood hazard maps are the central instrument to facilitate interagency cooperation for the planning and operational activities (APFM, 2007c). A classification of flood maps is presented here.

*Based on development technique*

*Historic flood maps* are developed based on data collected after a flood has occurred. These data are usually collected by local administration using public interviews or with the help of signs of flooding, which can be seen on walls and trees.

*Simulated flood maps* are also commonly used. Numbers of hydraulic models are available to compute flow in 1D and 2D (Ref. 4.1.3). These hydraulic models can produce quite satisfactory results. These maps may help in probability based flood management standards designs (Ref. 3.2.3).

*Characteristics based classification*

In general, maps may be used to express flood danger, risk, hazard, and vulnerability features.

*Flood danger map*s also known as inundation maps provide the least information. Mostly these are flood extent maps against a predefined frequency or a historical flood event. Sometimes these maps represent extents of multiple floods. These can be supplemented with point information on other flood parameters (e.g. depth or velocity at some points) and important exposed assets (e.g. hospitals, power stations).

*Flood hazard maps* provide flood hazard information in terms of the flood probability and flood intensity being described by one or more parameters (Meon et al., 2006). On such maps, the critical characteristics of a flood hazard, such as the depth and velocity of flooding, should also be indicated (Green et al., 2000). These maps can also be used to represent the flooding scenarios. As in the case of the Netherlands, flood maps are developed on scenarios considering possible breaching at different sections. Flood hazard maps must be produced for the areas where flooding could cause considerable damage (Meon et al., 2006). Flood extents, depths, velocities, durations, propagations, and the rates of water rising are important parameters and may be used depending on the situation and the purpose of the map.

*Flood vulnerability maps* draw the vulnerability of inhabitants or developments in a floodplain. Flood risk management targets information on the consequences of a flood. The consequences of a flood depend broadly on the potential damage and the coping capability (vulnerability) of a region to handle floods. Vulnerability distribution is difficult to represent but a number of indicators can be used. Mostly, health, financial situation, age, preparedness, transport facilities, ecological and social values, as well as early warning mechanisms constitute the vulnerabilities.

*Flood risk maps* combine the hazard and vulnerability information at the same place. Risk maps mostly cover direct damages that are calculated using intensity-damage functions. Intangible damages can also be expressed in a qualitative way. An improved method has

been introduced in our research to express risk spread considering direct damages (Ref. 6.4.2).

In modern flood management, the use of non-structural measures is popular and the use of 'flood risk maps' is attracting more attention. A brief overview of current practices for the comparison and analysis is provided as well as improvements are proposed in subsections 6.3 and 6.4. The conventional approach of flood risk maps mostly generates merely damage maps. These are drawn by combining the hazard maps and vulnerability maps. Such maps fail to incorporate the probability considerations that are essential to convert a damage map into a risk map. Flood risk maps must cover the impacts of all possible floods and not just of one single design flood.

## 6.3 Flood mapping practices

In addition to the variations in development techniques, the regulations and responsibilities associated to flood maps are also different all over the world. Details of procedures and mapping techniques also vary from region to region due to local expertise and concerns. Flood maps have been developed in many countries but with different characteristics. All European Union member states are developing their flood maps following the European Directives (European Commission, 2007). The directives require the development of both of flood hazard and flood risk maps. Many of the EU countries already had developed flood maps but now they are revising them under these directives to meet the standards. Italy, Spain, and Switzerland already have official risk zone maps (RWS and RIKZ, 2007).

### *6.3.1 Flood mapping in the USA*

The Federal Emergency Management Agency (FEMA) is responsible of developing flood maps for the USA. FEMA produces two types of maps, one for flood insurance and another for emergency programs (FEMA, 2008). Flood maps are used for insurance, land-use planning, emergency responses, public awareness and other purposes. Based on these flood maps, evacuation plans have also been prepared (RWS and RIKZ, 2007).

The US Congress created the National Flood Insurance Program (NFIP) in 1969 to regulate land-use management in floodplains by adopting and enforcing floodplain management ordinances to reduce flood damages. They have introduced financial mechanisms which encourage local societies to introduce construction limitations in high-risk areas (APFM, 2007b). NFIP targets controlling development in the floodway and at elevations below the 100-years flood level (Galloway, 2004). The entire 0.01-probability flood hazard area is considered as high-risk floodplain (ASFPM, 2003). Floodplain maps are revised periodically in the USA (Collins and Simpson, 2007).

### 6.3.2 *Flood mapping in the UK*

In England & Wales, the Environment Agency has developed several mapping products to raise awareness of flood risk and support decision-making. Flood maps are prepared for both of river and sea floods. Flooding from rivers or the sea has been mapped for 1% and 0.5% probability floods respectively considering no defenses since defenses can be 'overtopped' or 'fail' if an extreme event flood occurs (EA, 2006). The locations of flood defenses have been marked and the areas benefiting from defenses against the 0.01 and 0.005-probability floods are indicated. Areas being flooded by an extreme flood (0.01% probability) are also shown on the map. The information on the actual (residual) probability of flooding is presented in three categories used by the insurance industry in the UK. Categories are not visible on map but can be perceived by clicking a location on the flood map. Flood intensity and social vulnerability maps are also prepared but these are not available on the internet (RWS and RIKZ, 2007). Flood intensities have been calculated using depth, velocity, and debris concentrations.

### 6.3.3 *Flood mapping in the Netherlands*

In the Netherlands, the long-term project FLORIS (flood risk and safety in the Netherlands) aims at estimating and mapping the probabilities and consequences of flooding for all 53 dike rings in the Netherlands (Merz et al., 2007). Most of natural and man-made risks are available officially on one website[1] for the public and professionals. Province-based single or combined disasters can be viewed on the website. The flood maps show flood prone areas, as defined by more than one meter flooding depth with a frequency larger than 1/4000 per year (RWS and RIKZ, 2007). In land-use planning, a water opportunity map (WOM) is currently being used to outline the relationship between water and land-use. Evacuation plans in relation to flood maps, have also been prepared. Efficient, smooth, and fast evacuation is ensured by blocking the crossings and enabling one-way traffic on evacuation routes.

Flood maps do not carry any associated legislation regarding the land-use planning. Nevertheless, water opportunity map (WOM) and water assessment test (WAT) are currently being used to outline the relationship between water and land-use and consequences of any newly planned land-use development on the water (Voogd, 2006).

### 6.3.4 *Flood mapping in Germany*

The German Parliament adopted in July 2004 the 'Flood Control Act' after the severe flooding in August 2002, (Merz et al., 2007). Federal states (Bundeslander) are responsible for the generation of flood maps along with general flood management (Kron, 2007). Within the country, there are no standardized and uniform nomenclature or agreed practices for the flood mapping (Merz et al., 2007). The flood maps are constructed

[1] http://www.risicokaart.nl/

to represent different return periods (Moel et al., 2009). Flood hazard map guidelines of the German Working Group of the Federal States on Water Issues (LAWA) recommends the plotting of up to 1% probability flood or even less frequent (Meon et al., 2006). Public flood-hazard maps are also available on internet for some states. Some states have also provided the evacuation plans in event of flooding. Some states also show the hazard in a qualitative way using a hazard matrix using intensity and probability of floods. New developments are prohibited in areas with high flood risk outside existing settlements (Wilke, 2004).

### *6.3.5 Flood mapping in France*

In France, all natural disasters risks at any location can be found on a single interactive map website so called cartorisque[1]. Flood maps are based on historical floods, hydrogeomorphology, and flood modeling that is calculated against a single return period. Qualitative risk maps have been created, which are usually classified into three to five risk zones (Moel et al., 2009). Population, urban settlement, and infrastructure are used as indicators for the exposure. There are some other websites, administered by different agencies, showing flood maps developed by different methods (RWS and RIKZ, 2007). Flood risk maps are developed for the insurance purposes, mainly. Legislation exists with respect to restricting or prohibiting developments in flood-prone areas (Moel et al., 2009). Development of new areas and modifications in areas that have already been urbanized are separately treated (APFM, 2007b).

### *6.3.6 Flood mapping in Pakistan*

The Federal Flood Commission of Pakistan started to develop flood mapping under FPSP II in 1998 (Ref. 2.6.2). Initially, flood maps were developed for 5-years and 50-years return period floods for major rivers of Indus basin. Initial maps have been developed, whereas their calibration and validation is still to be done in the near future. The development of maps has not been completed and their planned uses are not yet defined.

Development of official flood maps in most of developing countries either is not initiated or otherwise still in initial stages.

## 6.4 Flood zoning

Flood zoning is the practical step towards implementation of response against floods by adjusting vulnerabilities using the flood maps. Flood zoning consists of a set of rules for the settlements on the floodplain with the aim of minimizing future damages due to floods (Tucci, 2007). Future developments in floodplains must be regulated in order to control risk. This can be achieved by establishing appropriate mechanisms that include legal provisions defining the responsibilities for the damage control and social impacts

[1] http://cartorisque.prim.net/

(Genovese, 2006). Flood zoning is the mechanism that regulates developments by dividing a floodplain into zones and setting development regulations accordingly (ASFPM, 2003). One purpose of zoning is to reduce the susceptibility of communities. Another purpose of the zoning policies is to limit the number of vulnerable persons and assets in risky areas. Governments are particularly interested to control possible expenditure associated with the damage compensation (Erdlenbruch et al., 2009). Flood maps play an essential role for all types of flood mitigation strategies. For example, building laws in Germany demand that the flood risk in flood areas should not rise due to building activities (Wilke, 2004).

Unfortunately, there exists no uniform approach for the development and application of flood risk maps (Smith, 1997; Pottiera et al., 2005; Merz et al., 2007). Flood risk maps are being developed to estimate and alleviate the potential damages. Commonly, these maps are based on hazard maps that show different zones corresponding to flood intensity in different areas against a design flood. Such zones are subjected to different legislative and guiding instruments that restrict or prohibit developments in certain zones. Sometimes these regions are delineated based on floods of different return periods i.e., 25, 50 and 100-years (more common) (Apel et al., 2009) return period floods. This kind of zoning is clearer than other types.

Spatial attributes of flood maps mainly depends on the geographic and hydrological factors whereas 'zoning regulations' must be subject to the economic and social conditions at the national level. Development and implementation of building codes for the construction in floodplain can be an effective tool. Some countries have already reformed their building codes through the flood management legislation (APFM, 2007c) e.g., USA and Australia (NFRAG, 2008).

While establishing zoning regulations, it is important to consider the factors that force or attract the society to live under flood risk. Particularly in developing countries, there are often limited alternatives for economic growth and progress and the livelihoods of millions of people depend directly on these natural resources. For example, in Pakistan, it is the feudalism system that has forced the poor and powerless people into the floodplains (White et al., 2001). In developing countries, population growth and migration towards urban areas, mostly to the unplanned settlements in the floodplains, increase the vulnerability of the poorest sectors of society to flooding (APFM, 2009a). The most common situation, which encourages settlements in floodplain, occurs when a succession of years with low floods takes place.

### *6.4.1 Resistance and reluctance against flood zoning*

Implementation of structural measures is desired by the floodplain inhabitants. Non-structural measures are generally not welcomed. As compared to other non-structural measures, even more opposition is expected in case of land-use restrictions (Forster, 2008). Serious opposition and issues are expected in developing countries due to lack of understanding about flood management, non-availability of alternate suitable land, and expected relief and compensation commonly provided by governments in case of flood

losses (Kunreuther, 1996). Therefore, flood zoning must be introduced in situations where it reduces losses and may efficiently raise land-use benefits.

Techniques associated with flood zoning tend to be less costly in capital expenditures but more so in terms of human commitment (social capital) (Duivendijk, 1999). Rigorous zoning regulations are usually violated at different levels of governments, societies, and individuals (Moel et al., 2009), especially in developing countries. Merely restricting the floodplain development to minimize the flood losses is sub-optimal. Regulation for the urban settlements in floodplain areas must be facilitating and if possible, must be discussed by the community before being implemented (Tucci, 2007). The objective of flood zoning should be to enhance the floodplain land-use benefits. There is a certain need to develop these flood risk maps in connection with the prevailing socioeconomic conditions of society and their implementation should assure the overall advantages in a rational way.

### *6.4.2 Risk-based flood zoning*

Flood zoning based on a specified 'design flood' cannot be justified, as every floodplain possesses unique hydrological, hydraulic, geophysical, environmental, and socio-economic features. Doing so also violates the principle that "all floods must be managed and not just some" (Green et al., 2000). In every floodplain, these properties along with discharge regime must therefore be carefully considered while defining the flood risk zone.

Inappropriately developed flood maps and inconsistent zoning regulations could be more catastrophic and result in an inefficient land-use. Inadequate flood zoning, can restrain the development, and may produce an illusion of intact safety to people living just outside the delineated zone. This sense of security encourages increased exposure with high susceptibility. A flood with intensity higher than the design flood may result in more losses. Therefore, it is important to avoid hard delineation of zones and regulations must be able to provide guidance to common land-use practices. Risk-based flood zoning counts the actual benefits and drawbacks for any land-use.

At present, countries adopt different approaches towards flood zoning. A uniform and universally accepted approach, which is still lacking, would allow comparison between areas and facilitate communication between the regions by providing common bases (Merz et al., 2007).

Flood zoning should be adjusted in a way that society may successfully reduce their losses and remain be aware about the residual risk. As a rule of thumb, flood zoning should consider to maximize the positive aspects of floods (APFM, 2009a). Risk-based flood zoning not only provide a uniform basis but also facilitate to define regulations that suits the socioeconomic conditions of floodplain inhabitants. Therefore, our main objective is to increase net benefits in a floodplain but, strictly speaking, not to reduce flood losses.

## 6.5 Case studies

The risk-based approach was used to develop flood zones in both study areas. Risk calculations were based on risk parameters defined in chapter 3. To cover the impacts of all possible floods, ten scenarios were modeled with their probabilities ranging from 0.5 to 0.0001 (Ref. 4.1.1, 4.1.3, and 4.2). Damage functions developed by different sources have been used in our damage model (Ref. 4.2.2 and Figure 4-7). Land-use maps (Ref. 4.2.1, Figure 4-5, and Figure 4-6) were used to represent the exposure. The risk equation (Eq. 3-6) was used to calculate risk. Preliminary flood zoning for the dwelling (the Swan River) and agricultural land (the Chenab River) were determined. Impacts of flood zoning on the baseline case, existing, and proposed measures cases to achieve ORP, have been studied.

As mentioned earlier, a risk-based approach naturally demands the consideration of impacts due to all possible floods and not just one flood of a specific probability. Figure 6-1 represents annually expected virtual depths of all possible floods whose depths are weighted according to their incremental probabilities of occurrences. Flood losses were calculated against different land-uses. Expected annual damage (EAD) maps (Figure 6-3, Figure 6-4, Figure 6-5, and Figure 6-13) were developed using Eq. 4-4. These EAD distribution maps portray the spatial distribution of risk for different land-uses over the floodplain. About ten land-use classes and six types of service lines were used in our case studies.

### *6.5.1 Flood zoning for agricultural land*

A change in land-use may have impacts on involved risk due to change in exposure (value) and/ or susceptibility (damage function). Depending upon the damage function and exposure of different land-uses, the most suitable land-use can be recommended for any floodplain area. Owing to their significant role in flood damages, agricultural land in the Chenab River area was selected for zoning purposes. Residual values of crop (rice) or alternatively fodder (Figure 6-2) are calculated in the study area for zoning purposes. The objective of zoning is set to increase the economic rent (especially location benefits '$R_{loc}$' (Ref. 3.6.3)) in terms of net profit instead of just loss reduction. Location benefits are obtained by deducting all involved costs of land-use and proportional costs involved on flood management measures from the expected profit.

Figure 6-2 shows the residual net-profit for crop (rice) and fodder against inundation depth. The net-profit for crop is high if there is no flood. Otherwise, impairing losses are expected due to loss of investments involved for crop. On the other hand, pasture and fodder are less profitable in no flood case, yet less impairing in case of flooding. The reason is that less investment is involved for fodder and it is continuously harvested throughout the season. A fraction of land is already harvested before it is flooded, hence shows less flood losses.

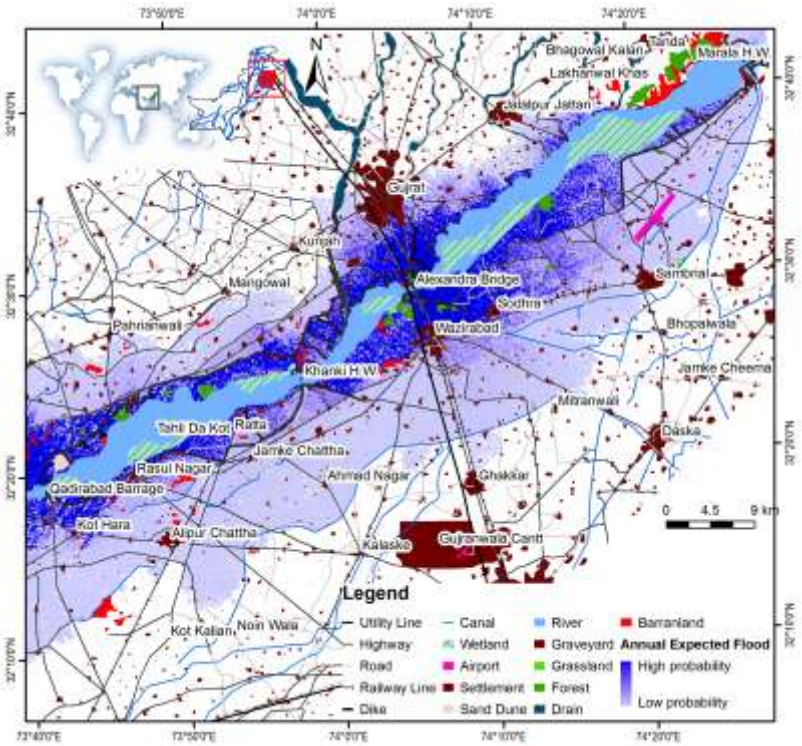


*Figure 6-1: A virtual flooding scenario showing weighted flood spreads based on their probabilities of occurrence in study area, from Marala to Qadarabad, the Chenab River.*

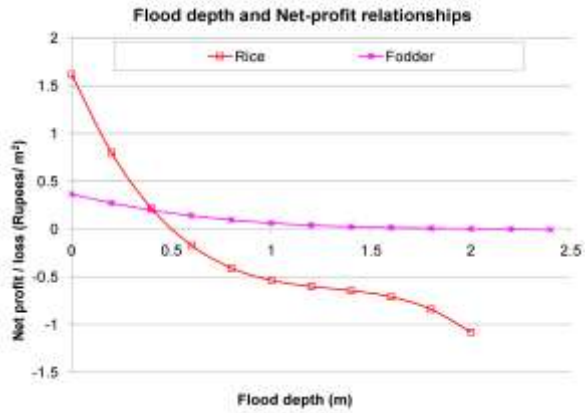


*Figure 6-2: Relationship between flood depth and residual net-profit for agricultural land.*

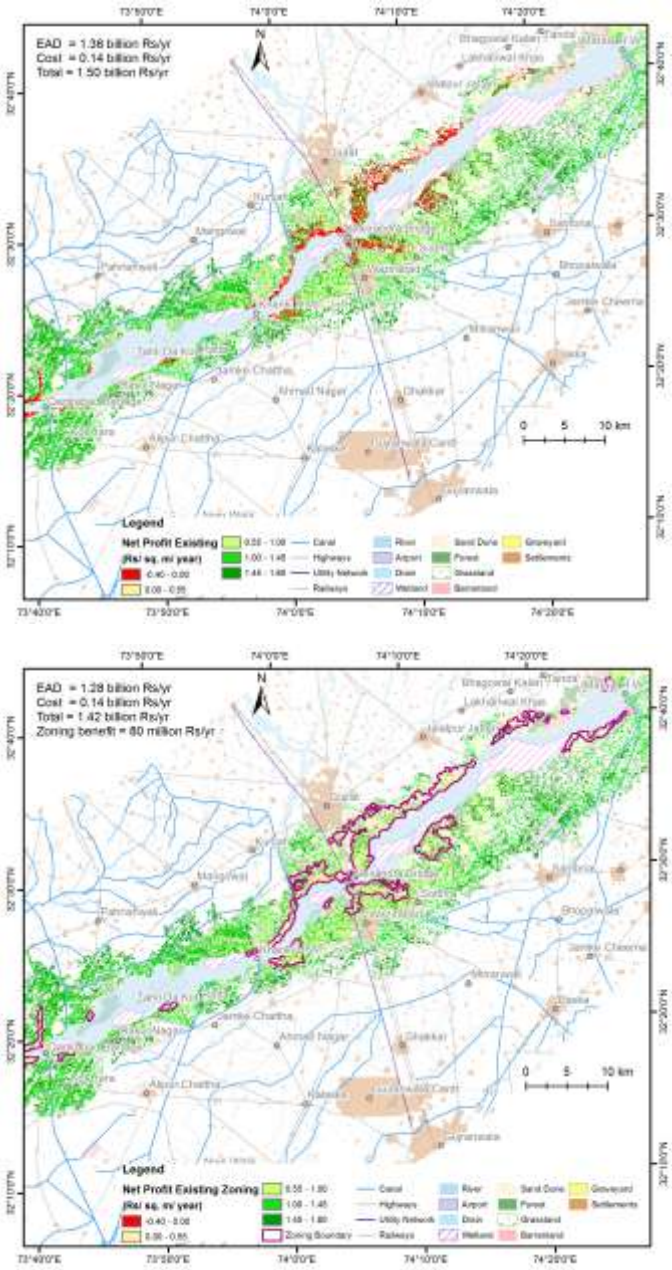


*Figure 6-3: Maps show the distribution of expected annual net-profit of agricultural land for the Chenab River reach against the existing conditions, before and after zoning.*

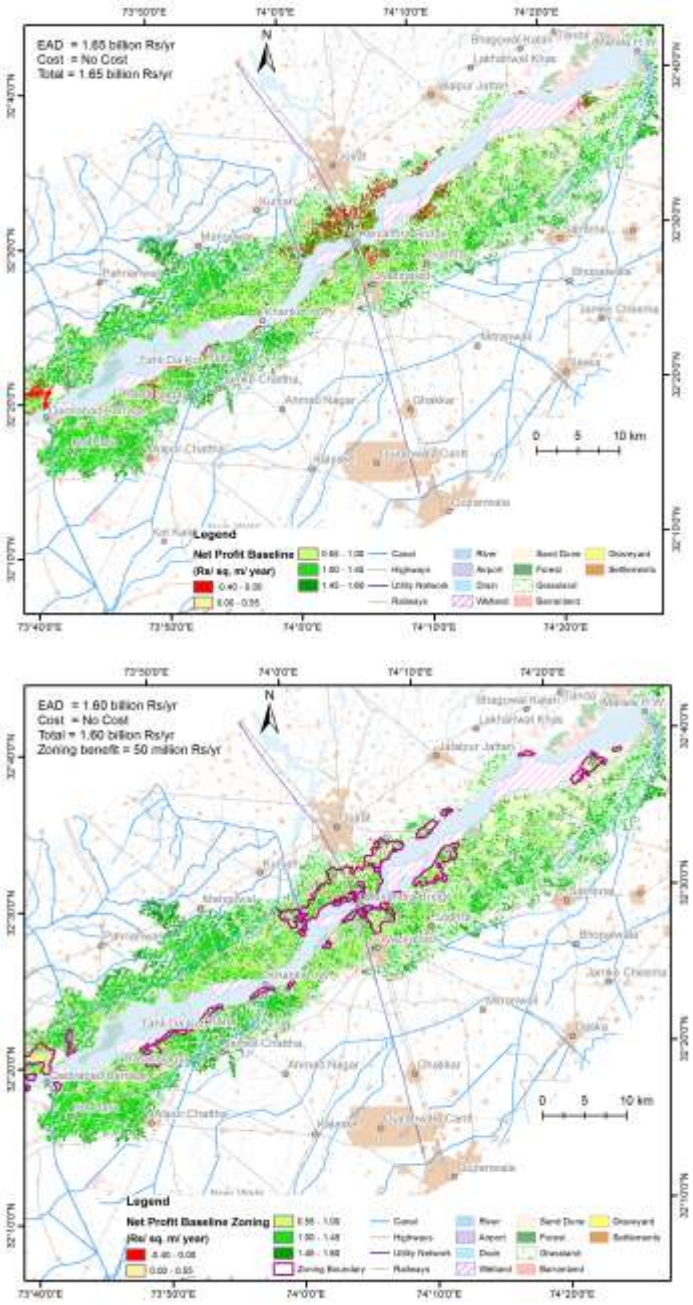


*Figure 6-4: Maps show the distribution of expected annual net-profit of agricultural land for the Chenab River reach against the baseline, before and after zoning.*

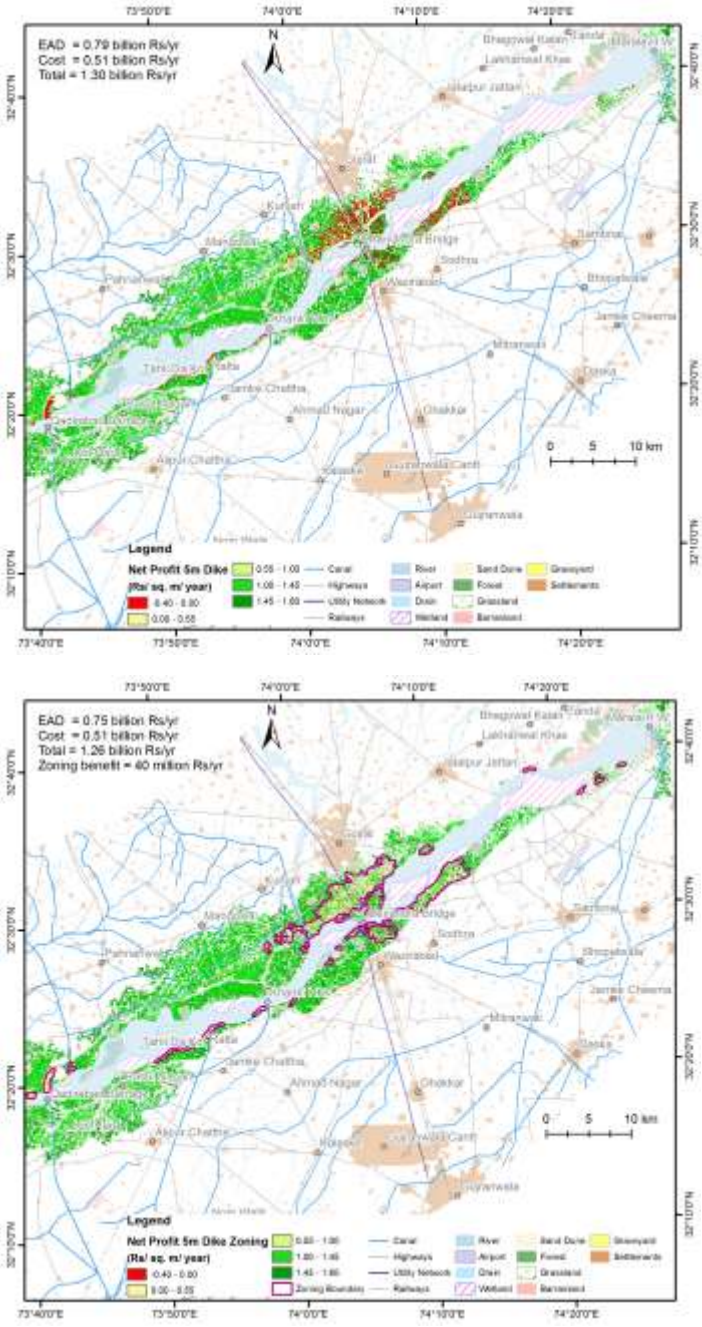


*Figure 6-5: Maps show the distribution of expected annual net-profit of agricultural land for the Chenab River reach against 6m dikes, before and after zoning.*

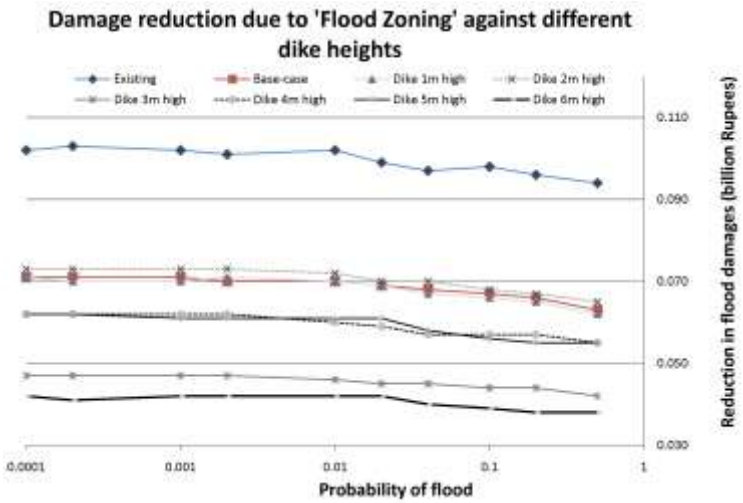


*Figure 6-6: Loss reduction economic effect of risk-based zoning for the Chenab River area.*

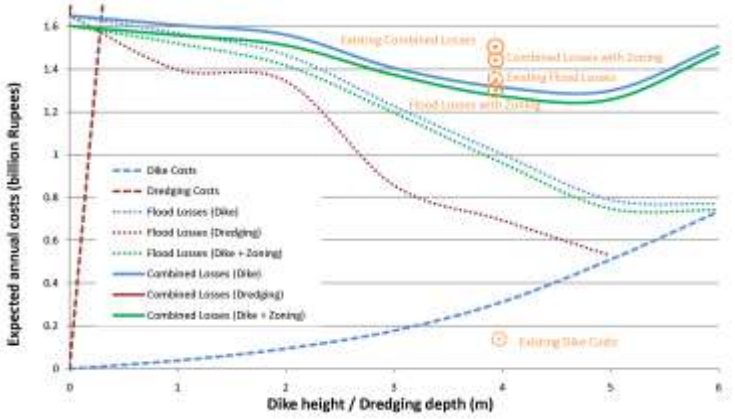


*Figure 6-7: Impacts of agricultural land-use zoning in reducing expected annual damages for the Chenab River area.*

Figure 6-3, Figure 6-4, and Figure 6-5 show residual net-profit of crop and low-profit/ loss fields being replaced by fodder on locations where fodder generates comparatively higher net-profit. Detailed results are presented in Annex E. Based on net profit, land-use changes are proposed for all scenarios developed in subsection 5.2. The impacts on each proposed flood management measure under defined flood zoning have been shown in Figure 6-6.

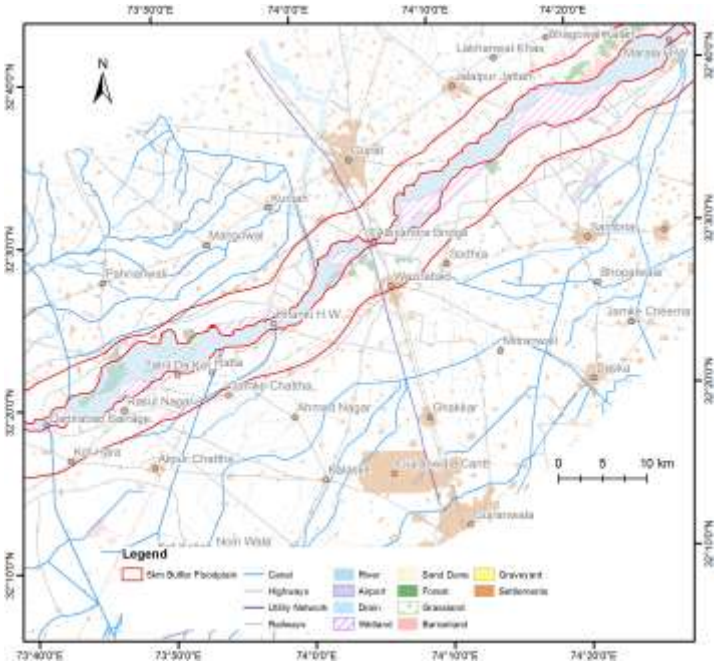


*Figure 6-8: Area selected in the 5km buffer of river centerline to evaluate the increase in net-profit for the Chenab River case.*

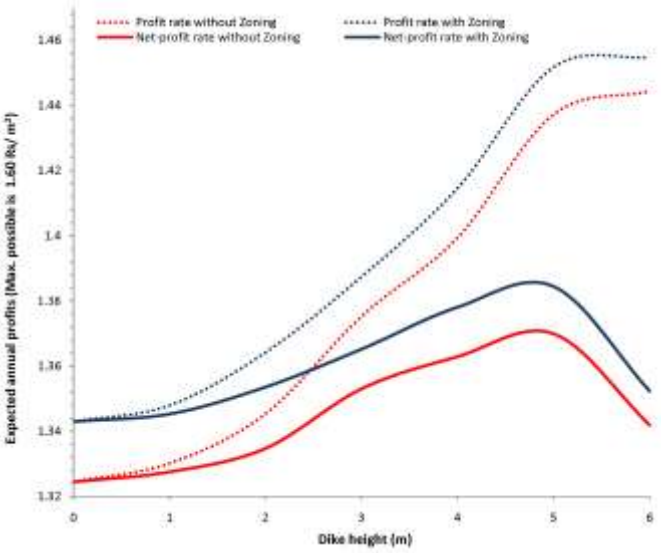


*Figure 6-9: Increase in agricultural land-use net-profit for 5km buffer area around the Chenab River*

Main reduction in flood losses appears at 0.5-probability flood and afterwards this reduction increases slightly for higher floods. It means that the area recommended for land-use change is inundated almost every year. Figure 6-7 shows that the proposed flood zoning contributes in reducing overall flood losses. The lowest point on the curve can be used to achieve ORP after incorporating the impacts of early warning, storage, zoning for more land-use options, and possible flow diversion options etc.

As discussed, the purpose of flood management in our research is to maximize location benefits. The area delineated for flood zoning is in the proximity of the river. Therefore, the impacts of zoning are concentrated in that area. An area within 5km buffer of the river centerline is selected to demonstrate the impacts on net benefits (Figure 6-8). Figure 6-9 depicts the trends of net-benefits for all scenarios. Impacts of flood zoning decrease as dike heights increase. Net-profit is maximum at 5m high dike.

### *6.5.2 Flood zoning for the settlements*

Another important type of land-use is settlements. The Swan River area is selected, as the area is situated in the capital city of Pakistan and is under high pressure for new settlements. The study area is highly valuable and developers are interested to utilize every inch of land. In such situations, proper flood risk evaluation becomes extremely critical. Inappropriate land-use development may waste this land at one end or may lead to high risk to life and dwellings, on the other hand. Utilizing the floodplains for residential purposes in our case seems highly attractive, as the monthly-expected rent from a house is high and the fact that floods do not destroy dwellings and possessions, completely (Figure 4-7). Areas at a distance from the river are safe, as the land is not flat like it was in the Chenab River case study. The areas that are in close proximity of the river are under high risk and need proper evaluation of flood risk.

In our case studies, zoning was proposed to areas where EAD exceeded expected rent of the residential area (Figure 6-13). Detailed results are presented in Annex F. These areas may be used for any other suitable purposes. Alternate use of this land can be less intensive land-uses e.g., park, car parking, picnic spot, or simply open space (as in our case) that may store excessive floodwater, in case of high floods. Figure 6-10 shows a slight decrease in EAD.

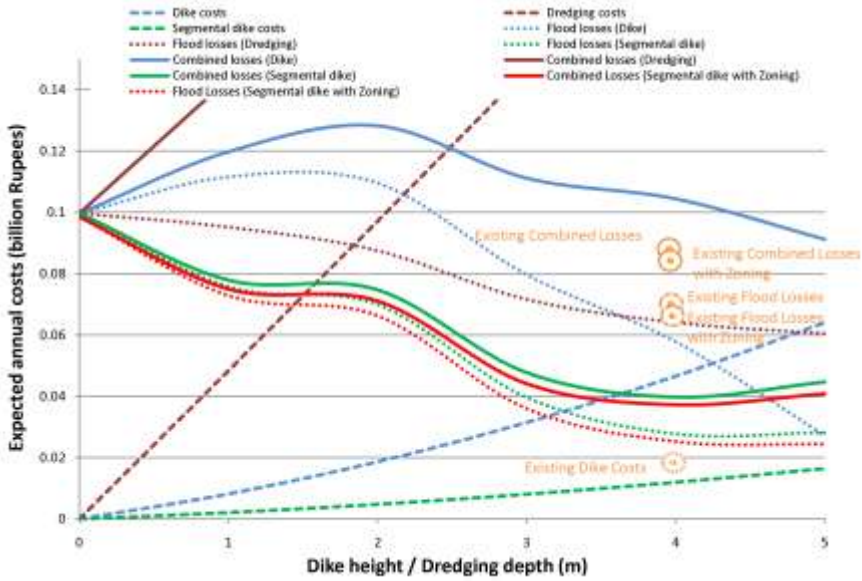


*Figure 6-10: Impacts of dwellings land-use zoning in reducing expected annual damages for the Swan River area*

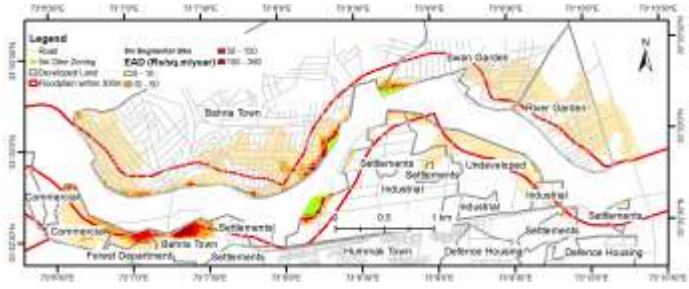


*Figure 6-11: Floodplain area selected within 300m of the river centerline for the Swan River case study.*

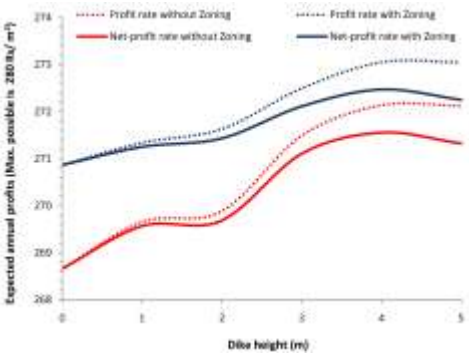


*Figure 6-12: Increase in residential land-use net-profit for 300m buffer area around the Swan River.*

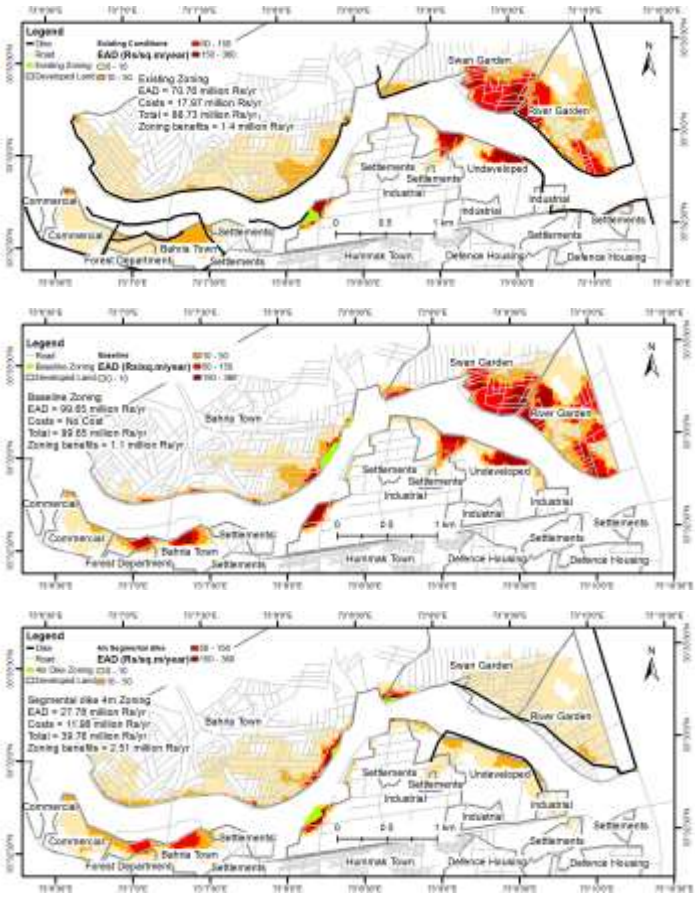


*Figure 6-13: EAD distribution maps of baseline case, existing, and 4m fragmental dikes proposed zoning for the Swan River reach*

To elaborate the increase in net-profit, a narrower strip (300m) of the floodplain is selected (Figure 6-11). Figure 6-12 shows the enhancement in net-profit of land-use after zoning is applied to the Swan River study area.

## 6.6 Concluding remarks

Flood zoning not only helps in reducing the flood losses but also increases the land-use net-benefits. Every flood measure has typical benefits along with some negative characteristics. A synergetic combination is needed in this case. The selection of measures depends on the nature of the flood problem and the target parameters (susceptibility, exposure, intensity, and probability). The results of both case studies support the idea that a combination of flood management measures may prove most efficient, economical, and viable solution.

Detailed inspection of results reveals further significant facts. Land-use practices are already complying with the flood considerations in areas that are situated in close proximity of river. These areas experience floods frequently and flood damages are quite substantial. No settlements or high value crops are cultivated in these areas. Therefore, such areas, in our case studies, are considered as part of the river (Figure 6-3, Figure 6-4, and Figure 6-5). Nevertheless, proposed flood zones are also frequently flooded areas, therefore, more precision and accuracy is required to simulate high probability floods.

Structural measures prevent flood losses against floods up to the design flood. In contrary, flood losses are minimized but not eliminated when flood zoning is implemented. Therefore, it must be understood that the purpose of zoning here in our case is to increase land-use benefits rather to eliminate risk.

As discussed, the zoning criterion in our case is to delineate the areas where present or proposed land-use practice produce net-profits lower than achievable with even lower investments. This does not mean that the area outside the marked zone is safe from floods. Areas outside the marked zone still may suffer substantial flood losses but expected net-profit is still positive and the maximum possible with the available investments. In the Swan River case study, flood zoning delineates areas where dwelling is not profitable.

Flood zoning is sensitive to structural measures and river processes. It may need to be updated as time passes. Structural measures change the flow regime and may greatly influence the design and impacts of non-structural measures. This fact is also supported by our results as the layout of the flood zone changed significantly against different dike heights. In addition, estimates of flow and stage are not static but need to be periodically revised and updated. Simultaneously, vulnerability is also not constant in time due to changes in social setup and economic growth. Therefore, risk maps must be updated periodically to incorporate significant changes in flow and vulnerability.

Although flood zoning is effective to enhance land-use benefits, consideration of intangible losses can enhance the reliability of results. The risk maps may assist

politicians and decision-makers in decision-support process. Although economic losses are not the only type of losses and zoning is not the only option; a more effective and comprehensive optimization can be performed by considering more possible flood mitigation measures and all possible types of economic, social, and environmental impacts. Overall risk reduction must be evaluated by optimizing the combined effects of all suitable measures to define ORP.

Implementation of flood zoning requires an appropriate institutional support to guide and convince inhabitants to adapt zoning recommendations. Farmers, who follow the zoning recommendations, endure lower profit during no-flood periods, while others earn higher profits. The same is true for encroachments for residential and commercial purposes. Such investments in floodplains resemble gambling (Pottiera et al., 2005). That is why, appropriate institutional support is needed that may ensure proper implementation of flood zoning. If the area recommended for the zoning is less frequently flooded, then it becomes even harder to convince the land-users to observe the flood zoning guidelines. For such areas, less restriction or alternative methods should be proposed for effective flood management. Conventional approaches of enforcing flood-zoning requirements are not very effective in developing countries. A more effective setup is essential to implement non-structural measures in general and flood zoning in particular.

# 7 Vulnerability indirect-adjustments

Chapter 6 demonstrated the positive impacts of flood zoning. Unfortunately, flood zoning is not generally accepted by floodplain inhabitants, especially in developing countries. Nevertheless, important benefits associated with flood zoning invoke the demand for its implementation. To ensure appropriate implementation of flood zoning, the resistance to zoning should be overcome by addressing these causes in an effective way. Normally, enforcement of flood zoning is endorsed with legal and institutional arrangements. In addition to all these efforts, tools that are more effective are needed for the achievement of desired results. Risk-based flood insurance has been proposed as a possible way of effective flood zoning enforcement. A risk-based insurance policy not only ensures the enhanced coping ability of floodplain inhabitants but also supports flood zoning in achieving desired land-use practices. Current flood insurance practices are not truly risk-based. With some modifications, conventional flood insurance mechanism can be effectively shaped to support flood zoning.

## 7.1 Flood insurance in practice

Flood insurance is generally separated from the regular insurance. Mostly, all extraordinary natural disasters are excluded from traditional insurance agreements. As a result, property owners need to purchase additional policies in order to insure against natural disasters (Andjelkovic, 2001; Collins and Simpson, 2007). Different countries develop their own insurance objectives, development methodologies, premium calculations, and implementation mechanisms according to their own priorities, technical capabilities, and supporting institutional setups (Duivendijk, 1999).

Correlation between insurance policy and floods remains a debatable issue. In insurance industry, risk assessment models are based either on flood zones (mostly based on a design flood) or on calculation of flood losses for a series of historic events (Mehlhorn et al., 2005). In addition, insurance rates are based on loss experience pooled nationally and divided into properties located within the 100-years floodplain or coastal high-hazard areas (Burby, 2001). The insurance program is expected to be self-supporting (i.e. premiums are set at an actuarially sound level) in an average loss year, as reflected by past experience (Collins and Simpson, 2007).

The implementation of flood insurance is mostly supported by legal provisions, public incentives, and enforcement practices. For example, in the USA, no mortgage lenders that are federally insured or financed can lend money on a property in a floodplain zone unless the property is covered by flood insurance (Collins and Simpson, 2007).

Most significant issues are concerned with the public acceptability of insurance. An admissible insurance rate is essential for the acceptability of insurance policy. Records show that only about one in four homeowners, who live in a floodplains, purchase federal flood insurance in the USA (Collins and Simpson, 2007). According to NFIP records, every fifth policyholder discontinues flood insurance coverage each year (Kunreuther, 1996). Several studies have found that only about 20% of those required to carry insurance actually do so (Burby, 2001). Unfortunately, in developing countries, insurance is not an option for the majority of people (APFM, 2006b).

General hesitation towards purchasing a flood insurance policy is due to the low probability of flood events and response behavior of individuals, societies, and governments. The effectiveness of an insurance approach suffers due to the public's perception that flood will not come again and their expectation for disaster relief. If insurance is available, then it is inequitable if the uninsured (and the grossly underinsured) receive compensation as part of relief payments (Duivendijk, 1999). To establish insurance policy, the social and political hindrances have to be appropriately addressed.

Flood insurance is usually provided to a limited area of a floodplain that is flooded regularly, whereas, most flood losses stem from less frequent flood events (Burby, 2001; Collins and Simpson, 2007). Reluctance to buy insurance is sometimes caused by the fact that investing in insurance appears higher than flood risk itself (Kunreuther, 1996). Improper calculation of premium results either due to lack of understanding, skills, and data availability, or due to oversimplification of the estimated premium. The insurance sector in developing countries is still weak and not in a position to calculate a realistic premium to build up a flood insurance portfolio (Andjelkovic, 2001). Premium rates are made uniform to larger areas in developed countries. For example, in the USA, the entire 1% flood hazard area is considered as high-risk floodplain (ASFPM, 2003). Premium rates in the UK are broken down uniformly by postcode regardless of their exposure to the flood hazard (Arnell, 1990) and these are often high (Collins and Simpson, 2007). A mismatched insurance rate may reduce the acceptability of insurance policy and may even prove counter-productive in overall flood management.

## 7.2 Risk-based flood insurance

In contrast to current practices, insurance premium rates must be proportional to prevailing risk to describe the severity of the flood problem at any location. Flat rates or rates calculated based on a single design flood do not adequately project the actual risk. Risk-based flood insurance has been proposed in our case study to represent existent risk.

The approach, proposed in our research, is also compared with the conventional approach.

Continuous population growth, improved living standards, urbanization, and industrialization in floodplain areas are likely to enhance societal vulnerability to floods. In the present age of science and technology, flooding cannot be regarded as an unforeseeable event (Kron, 2002). The probability of flooding and its impacts can be estimated accurately and precisely. Even today, post-flood management problems can be planned in advance (Andjelkovic, 2001). In order to manage these expected problems associated with floods, establishment of an appropriate setup is essential. The importance of flood insurance increases manifolds in these situations. The flood insurance is a versatile and complementary tool to deal with floods in many respects. Flood insurance differs sharply from the other measures available for managing flood losses. As commonly practiced, measures reduce the cost of damages from each flood, insurance mechanism distributes the losses over time (Duivendijk, 1999).

### *7.2.1 Recovery from flood*

The conventional approach to flood insurance mainly addresses the issue of offering compensation for the losses caused by floods when damages are not avoidable at acceptable costs. The flood insurance mainly spreads the cost of flood damage both in terms of time in order to facilitate the affected society to deal with the aftermath of flood events (Arnell, 1990; Duivendijk, 1999; Andjelkovic, 2001; APFM, 2007a). A flood strike may disrupt economic activities in the affected area. Sometimes, delay in the economic recovery of the affected people can cause extended indirect losses and they become a constant burden on society. Proper insurance can help considerably in mitigating the effects of floods and prevent flooded societies from being ruined (Kron, 2002).

### *7.2.2 Flood risk awareness*

Flood risk awareness has been proved an effective measure in reducing negative impacts of floods. The holding of community-based flood awareness programs may help in raising flood awareness among the people. Unfortunately, flood management is reactive and not proactive worldwide. Before a community experiences a flood, flood risk awareness programs may not be very effective and may not produce the required results. Devastations caused by flood events raise people's attention to the problem. Surprisingly, people often forget their proneness in a short time after a flood they have actually experienced (Kron, 2002). In developing countries, even the public awareness programs are not conducted regularly. Consequently, land-use planning regulations are mostly not followed strictly, despite much efforts undertaken (Kron, 2002). The floodplain inhabitants must be aware of the risk they possess. Flood insurance reminds people on a regular basis about the risk they have accepted. The flood insurance, with rates depending on the degree of the threat, is increasingly used to offset the threat (Majewski, 2007).

### *7.2.3 Reduction in damages*

Insurance premiums act as regular reminders of hazard and produce risk awareness. Ultimately, this risk awareness can be used in risk reduction. Reduction in risk is only possible when insurance premiums are in proportion to actual risk and flood damages are shared by the insured persons as well. If the insurance premiums are based on actual risk then policyholders will avoid activities that may cause increase in premium rates (or risk in other words). To reduce premium rates and to increase net-benefits of land-use, policyholders will devise and adopt those land-use practices that must produce high net-benefits. Within the floodplain, different land-uses may range from highly beneficial to extremely damaging. Sometimes, a complete abandonment is required and the other time a small modification in land-use can produce the desired results. Flood insurance can help to achieve the following goals:

- Discouraging a land-use
- Modifying a land-use
- Promote a certain land-use
- Replace one land-use by another

Higher premiums could be an effective deterrent to uneconomic floodplain encroachment (Arnell, 1990). In the USA, the insurance program aims at limiting development in the floodway (Galloway, 2004).

Insurance may have both advantageous and disadvantageous effects upon flood loss potential (Arnell, 1990). Negative aspect of insurance is that people do not put serious effort into protecting their insured assets. This shortcoming can be overcome by a partial compensation of flood losses as is a usual insurance practice.

Fine-tuning in insurance premiums calculation methodology may lead to a number of advantages. As highlighted earlier in this section, if insurance premium rates are based on intensity of flood risk, above mentioned objectives can be obtained. In other words, risk-based insurance may shape land-user's activities to restrain flood losses and increase economic rent of land.

## 7.3 Advantages of risk-based insurance

In insurance industry, calculation of insurance premium is one of the most critical tasks to accumulate maximum possible number of clients and to avoid adverse selection. Insurers need precise and accurate flood hazard information in order to define realistic premiums for flood damage insurance (Meon et al., 2006). Not all the communities within a floodplain experience the same level of risk. It would be unfair and inexplicable to clients if each member of an insured community had to pay the same premium without taking into account the individual risk his property is exposed to (Kron, 2002). Therefore, the premiums of flood insurance must also be according to the level of exposure.

Risk-based flood insurance can help in overcoming these issues. There is a need to determine risk and collect insurance premium based on actual risk involved. At present, in the absence of risk-based insurance setup, premium is collected on the basis of a flat rate conventional approach. People in high-risk areas are subsidized by people in low-risk areas (Crichton, 2006). Risk-maps can be used for this purpose as these maps portray the actual distribution of risk and facilitate mitigating flood hazard on rational basis.

Insurance premiums based on a single flood event, not only collect disproportional premium rates but also fail to provide insurance to areas under low risk. An effective and appropriate insurance rate should be proportional to involved risk. Non-representative flat rate will cause overcharging in low-risk areas and vice versa. If another insurer offers low insurance rates, clients would obviously prefer to go for low rates. As a result, the insurer will get more clients from high-risked areas where insurance premium rates are lower than the potential damages. The insurer will bear the difference and will make a loss. This phenomenon is known as 'adverse selection', 'negative selection', or 'anti-selection'.

## 7.4 Case study

Following the definition of risk-maps in 6.2, these maps help in determining flood impacts over time and space frames and provide guidance to land-use planners, flood managers, and political decision makers (Tariq et al., 2010b, a). Therefore, flood maps are used in our case study for risk distribution assessment. With the combination of flood simulation and damage modeling, EAD distribution maps are developed to represent the spatial distribution of risk for agricultural areas (Ref. 4.3.4 and Figure 7-1). For the purpose of comparison with the conventional approach, another loss map is also developed against design flood (USA customary design flood with 1% probability, see Figure 7-2). The impacts of both approaches on insurance-providers and insurance-holders have been evaluated. A design flood approach provides the consequences against a specific flood and may ignore the possible losses due to other floods. Damages under design flood were adjusted to the actual EAD calculated considering all possible floods.

## 7.5 Results and conclusions

Results show major differences in spatial distribution of risk when damages of the 100-years design flood are compared with EAD. The obvious difference is that the design flood inundates the floodplain partially (compare Figure 7-1 and Figure 7-2). If flood losses due to all floods are pooled and divided only on this much area, these will estimate insurance premium higher than the actual risk. In addition, due to partial inundation of floodplain by design flood, insurance service cannot be calculated for all areas in a floodplain.

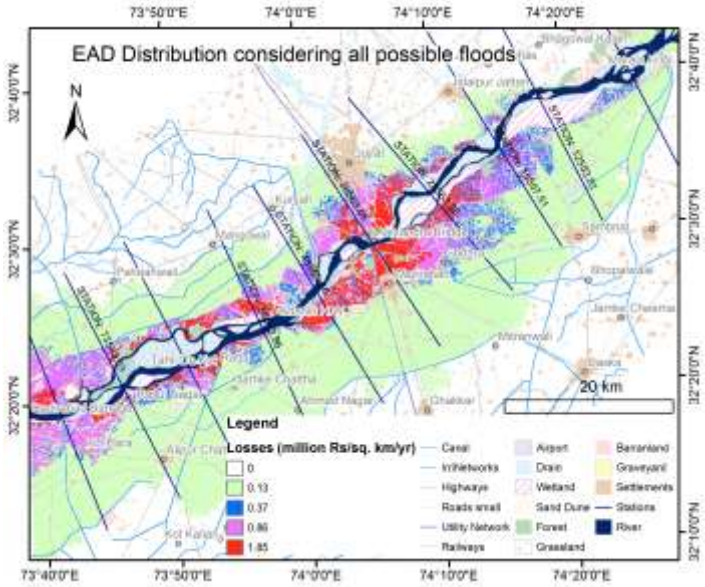


*Figure 7-1: Spatial distribution of flood risk considering all probable floods.*

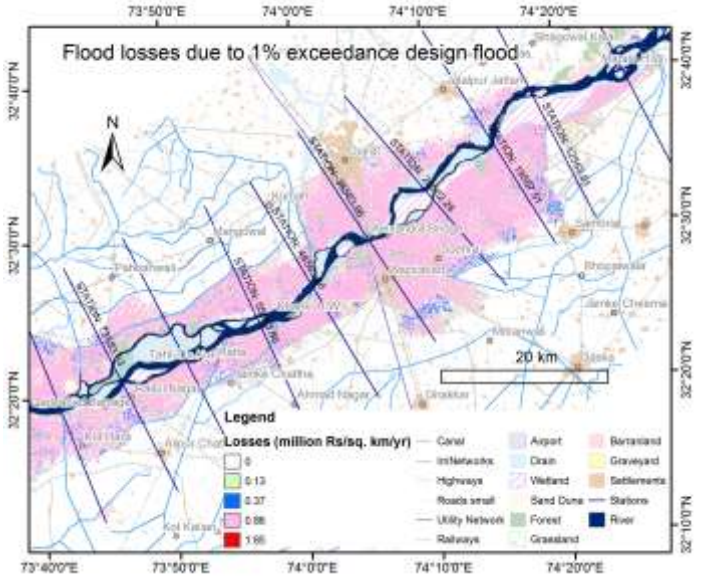


*Figure 7-2: Spatial distribution of flood losses due to 1% exceedance flood.*

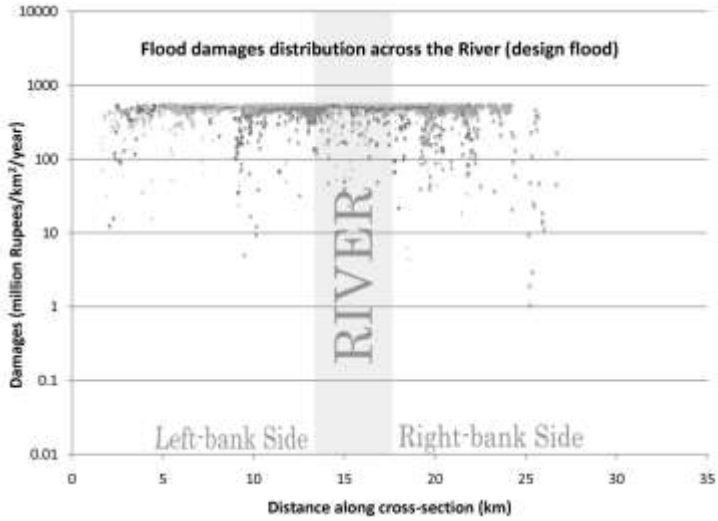


*Figure 7-3: The calculated damage against 1% probability design flood on all stations in study area.*

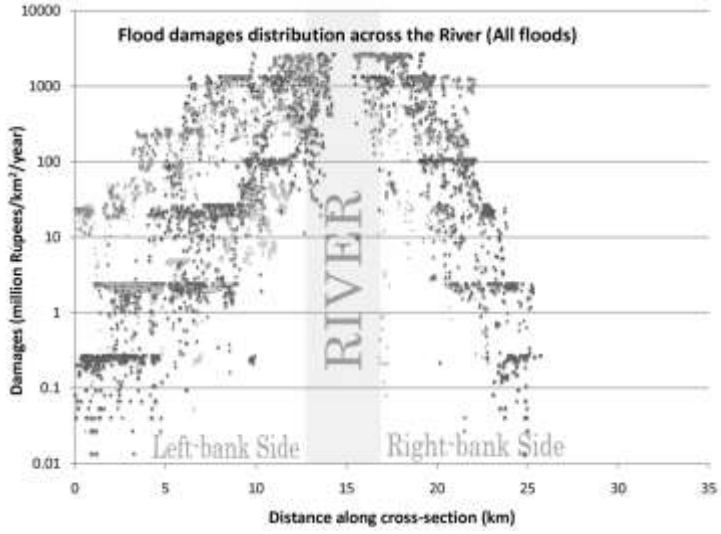


*Figure 7-4: The calculated risk calculated damages considering all probable floods on all stations in study area.*

Another significant observation is that the damage distribution intensity is almost uniform (and maximum) throughout inundated area in case of design flood (Figure 7-3),

whereas, risk intensity varies predominately over the floodplain. Flood risk normally decreases as one move away from the river (Figure 7-4). The reason for this difference is the fact that not all floods inundate the entire floodplain.

To elaborate results further in detail, average damage distributions at ten selected sections along the reach were analyzed. Graphs (Figure 7-5 and Figure 7-6) show that the distribution pattern of damage due to the design flood is different from the actual risk distribution. Average flood damages of design flood are higher than the risk on the left riverbank and lower on the right riverbank. This means that a design flood cannot represent the risk. Furthermore, generally dikes constructed on the left bank shift the risk towards the right bank (Figure 7-7). As dikes are designed in Pakistan to protect a flood of a return period of 50-years, the design flood, which is a 100-years return period in our case study, overtops these dikes and does not account for this shift in flood risk. There are a number of infrastructures, like highways and railways that play an important role in risk distribution. In case of design flood, only the effects of those structures are noticeable that curtail design flood.

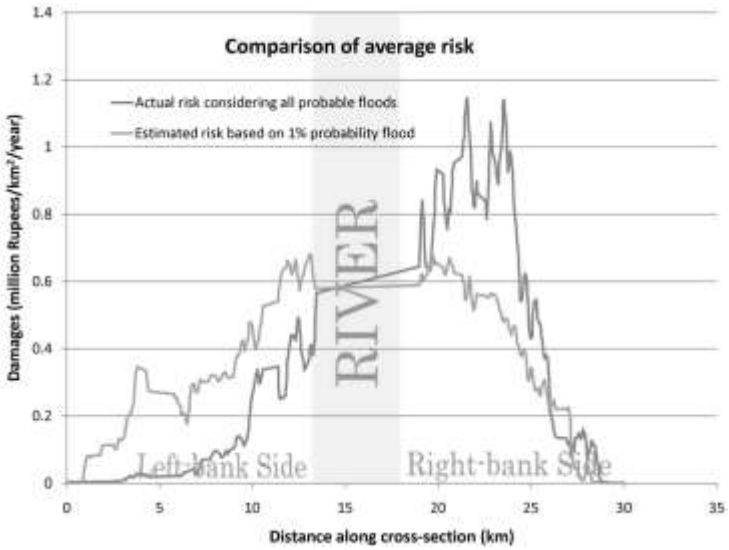


*Figure 7-5: Comparison of estimated average damages based on 1% probability flood with calculated damages considering all probable floods.*

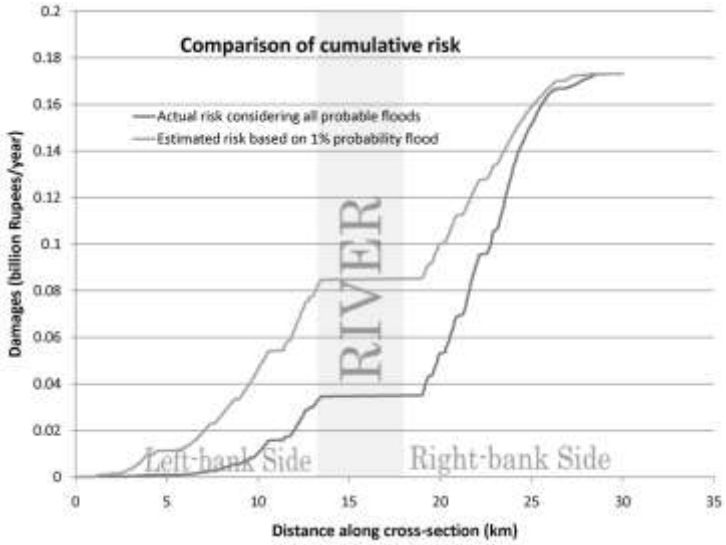


*Figure 7-6: Comparison of estimated cumulative damages based on 1% probability flood with calculated damages considering all probable floods.*

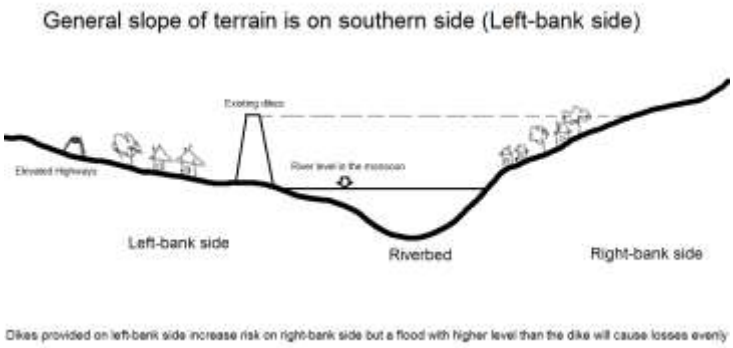


*Figure 7-7: Schematic cross section of the Chenab River elaborating the general slope of ground and shifting of risk due to dikes which are mostly provided on left-bank side of the River.*

## 7.6 Discussion

To promote flood insurance in developing countries, a state sponsored comprehensive program must be initiated. Effective implementation of the program can be achieved through public awareness, attractive incentives, legal support, and strict compliance. Subsidized insurance rates with governmental support must be introduced along with public information campaigns. Assistance provided in case of natural disaster must be denied if flood insurance is not purchased and maintained.

Contrary to the existing practice, calculations of insurance premium should be based on actual risk and must be closely linked to land-use management practice. Insurance rates must be calculated by giving due consideration to the dynamic nature of river flows and land-use practices. Risk reduction by land-use modifications must be appreciated in order to promote zoning. This would also improve the risk pooling efficiency by addressing simultaneously rural and urban sectors.

The basic financial flow conception of flood insurance is based on self-reliance ideology. Normally, the issues relating to 'who reaps the benefits and who pays' often hinder the generation of required resources for flood management (Green et al., 2000; Andjelkovic, 2001). The biggest hurdle on the way to set up effective flood management in developing countries is their unnecessary reliance on others to provide assistance. Therefore, whether on local or on national scale, flood management must be self-supported.

# 8 Conclusions and recommendations

Flood management affects society at a large scale. Society and its functioning are at stake; hence, the socioeconomic aspects of the flood management cannot be ignored. As long as the population, living standards, urbanization, industrialization, and high yielding agriculture continue, the demands for enhanced and effective flood management will also raise. Simultaneously, enormous care, appropriate resources, broad-based multidisciplinary approach, and comprehensive understanding are required to handle the issue. This thesis provides the basic understanding of risk-based flood management. Although, focus of this research lie on developing countries, most results are equally applicable to developed countries.

## 8.1 Discussion and conclusions

By supporting agricultural economies, fertile floodplains in developing countries are vital sources of economic activities and cherished locations for settlements. Flood losses are regular setbacks for their economies. Flood management in Pakistan is a typical example of flood management in a developing country due to the diverse nature of the flooding problem in the country. The study of Pakistan's flood management system supports and urges on the need of the understanding the flooding behavior and societal response before developing a flood management strategy for a country.

Neither a conventional approach of flood control nor a simple replication of modern methods of developed countries can solve the problem. A tailor-made flood management approach is necessary to address local flood problems appropriately. Nevertheless, experiences of developed countries can be employed for the improvement of flood management in developing countries. Simple duplication of strategies, measures, plans, and safety standards of developed countries is rather counterproductive. There cannot be a single generalized solution applicable to every floodplain but there can be a single acceptable approach for the implementation of consistent and uniform design standards. Developing countries must develop flood standards according to their own socio-economic conditions. To shape the most suitable flood management strategy, its impacts and people's response must be envisaged be forehand (Ref. 3.3). This is important to have

an idea about the expected outcomes of flood management, whether positive or negative, as no strategy is perfect and able to eliminate all losses.

Flood events are part of nature. They have existed and will continue to exist. Economic flood management will never preempt all future flooding but the damages by probable future flooding must be brought into account in the design and cost of flood management schemes. Such approach must conform to the local socio-economic context and define the acceptable risk accordingly (Vrijling et al., 1998, 2000). The acceptability of risk is a function of social, economic, and environmental concerns and may vary largely from nation to nation. The commonly stated connection between acceptable risk and probability-based design standards is rather tenuous (Ref. 3.2.3). The risk-based standards are not only based on the acceptable risk but also have the capability to provide the best possible solutions considering the available options and future risks.

In accordance with the proposed risk mechanics (Ref. 3.4), flood management can be categorized into two distinct categories; namely prevention and relief or alternatively hazard adjustments and vulnerability adjustments. Conventional approaches towards flood management mainly comprise of measures that try to adjust only hazard. Our case studies supported the fact that vulnerability adjustments may further reduce the risk. In other words, the optimization of flood management cannot be accomplished without tuning both ends.

It is extremely important to facilitate the decision-support process by providing correct and sufficient information. Therefore, the standard methods should assure that results portray the actual situation in the most convenient way. Flood mapping acts as a visual language and provides support that is readily understood by policymakers. Mapping should be an integral part of flood management evaluation. Moreover, up-to-date flood information that is consistent over the entire territory is required for an effective implementation of flood management strategy.

So far, the main unaddressed issue associated with the risk-based approach is its inability to render uniform flood management standards. Such uniform standards provide fair justifications for the flood management strategies. The probability-based standards have an edge in this regard. Our research attempts to address this problem and the concept of ‘optimal risk point’ (ORP) has been proposed. The flood management standards at national level can be established by correlating to the optimized state of a floodplain. Risk-based uniform standards may facilitate establishing economic, social, and environmental balances.

## 8.2 Limitations

Although, this research provides the guidelines for the practical implementation of a risk-based approach, this exercise itself is an academic activity. Further case studies are required to enhance its practical utilization. Additional case studies consisting of additional measures on more floodplains are required to generalize the findings of this

research. Implementation of this research to practical problems must be supported with adequate social, environmental, and economic expertise. Uncertainty analyses are also required while taking concrete steps.

Although, the research uses the risk-based principle, the 'beneficiary pays the costs'[1] principle is a basic constituent working in the background. Flood management can be optimized to achieve minimum losses, maximum protection, maximum BC ratio, or maximum land-use benefits. The optimization parameter in this research is 'maximum land-use benefits' by reducing 'flood deductions' (Ref. 3.6). Therefore, resources required for flood management can be generated from water users and floodplain inhabitants. Although, redistribution of risk is inevitable to reduce overall risk, suffering stakeholders must be compensated by those who benefit from such redistribution. Ignoring this principle may severely reduce the acceptability and eventually the efficiency of flood management strategy.

## 8.3 Recommendations

Flood management is an integral part of the land-use development. An improvised form of flood management, called 'floodplain management' must be introduced. Floodplain management should cover the river management and promote the coordinated development and management of land-use resources. Just aiming at lowering the damages and ignoring possible land-use benefits is rather counterproductive and must be avoided.

More reliable and consensual approaches must be developed to incorporate social and environmental damages into risk calculations. Valuation of social and environmental assets into monetary terms should not be carried out on individual case basis. Instead, a comprehensive valuation 'one-for-all-purposes' at the national level must be performed to ensure the implementation of fair and consistent standard for any project and any area in a country. The governments need to establish supporting institutional setups for this purpose.

Flood management must be financially self-supporting at all levels of setups. In developing countries, the prominent hurdle in the way of establishing comprehensive and sustainable flood management setup is their reliance and dependency on others to provide assistance at the eve of flooding and flood management projects. The principle of 'beneficiary pays the costs' can be adopted to efficiently generate funds for flood management. Another potential problem in the aftermath of disasters in developing countries is that in the rush to fast-track assistance, new projects are not properly designed or appraised. A proactive approach is highly recommended. Evaluation of ORP

[1] The word 'pays' is to be understood in welfare economic terms, it also covers the sufferings from one's actions. For example, floodplain inhabitants are affected when dikes are raised on the opposite bank, or the general public suffers from the pollution caused by an industry at large scale or by a car at small scale etc. In such situations, these groups must be compensated by those who are getting benefits from these dikes, factory, or car.

for almost all floodplains must be carried out in advance. Emergency responses and measures required afterwards should also be planned.

Freedom of land-use choice of floodplain inhabitants must be honored. Recommendation about suitable land-use is a constructive step but restrictions and compulsions must be avoided as far as possible. Personal choice of accepting risk may be covered by introducing complementary risk-based insurance or flood tax. This can facilitate a harmonious coexistence with floods.

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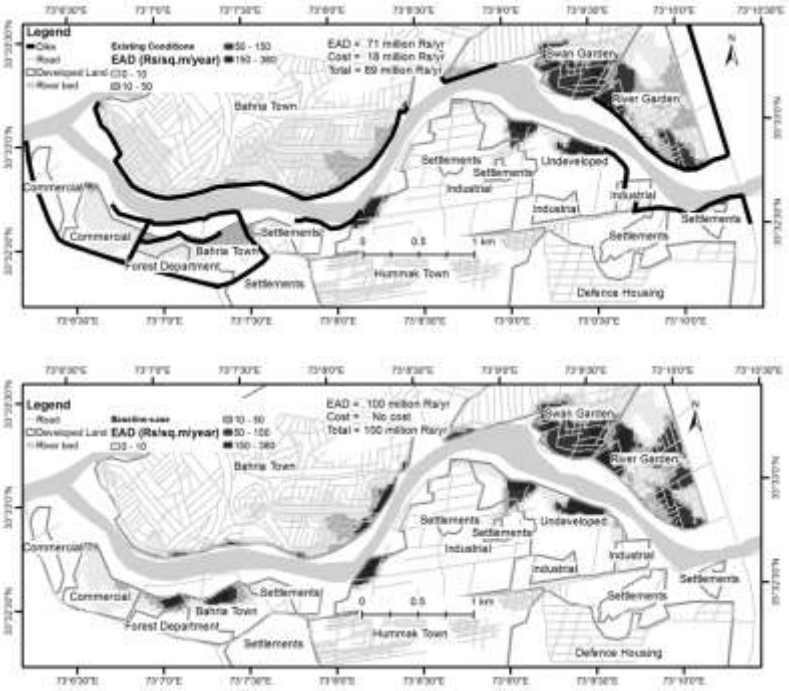
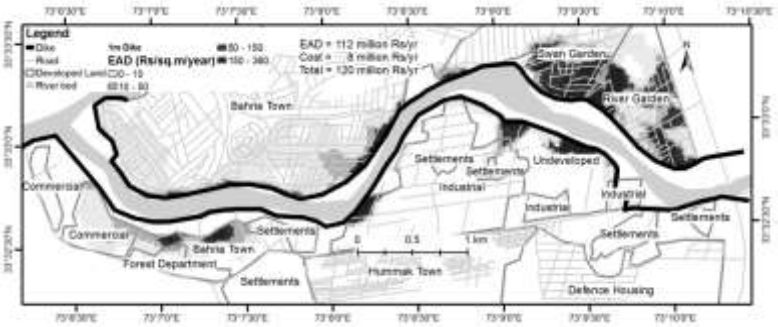
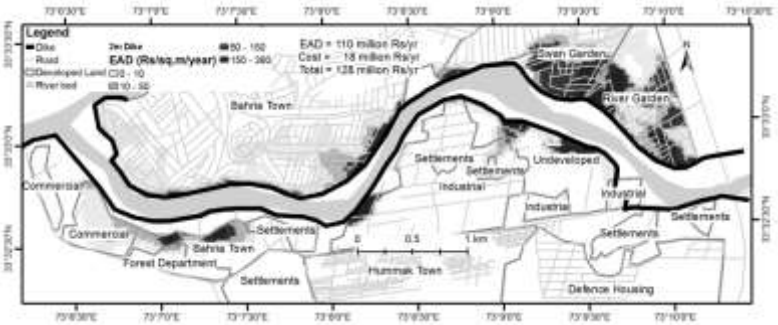
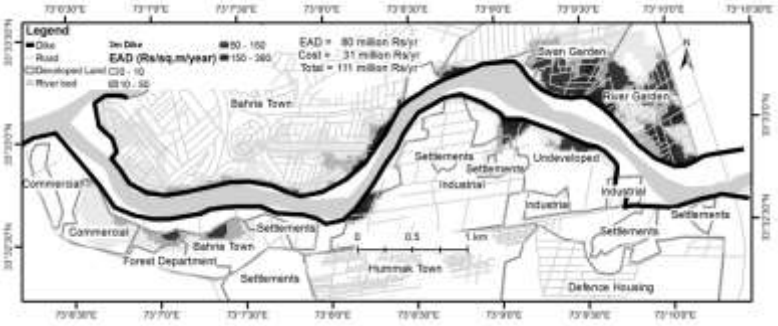
# *Annex A*

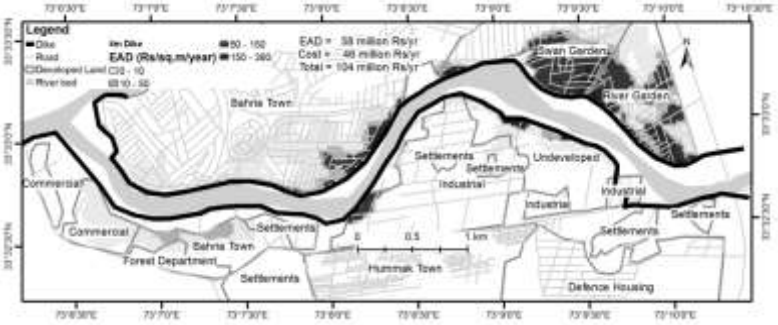
EAD distribution maps of existing, baseline case, fragmental dikes, and continuous dikes (1m to 5m heights) showing the spatial distribution of EAD for the Swan River study area.

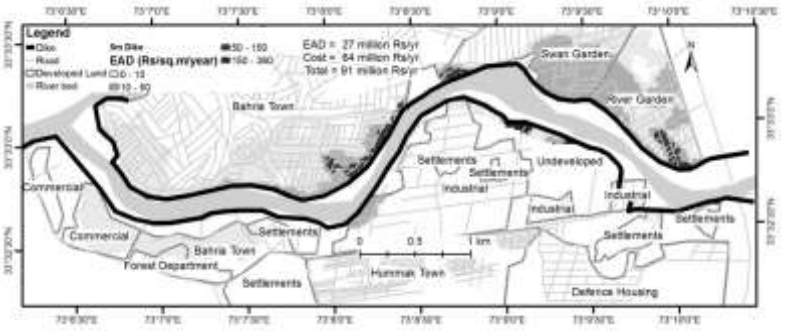



Legend
Dike
Road
Developed Land
River bed
EAD (Rs/sq.m/year)
EAD = 112 million Rs/yr
Cost = 8 million Rs/yr
Total = 120 million Rs/yr
Bahria Town
Swan Garden
River Garden
Settlements
Undeveloped
Industrial
Commercial
Forest Department
Hummak Town
Defence Housing
0
0.5
1 km
N

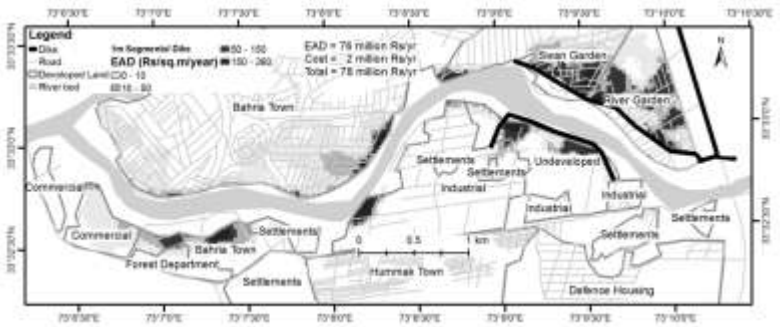

Legend
Dike
Road
Developed Land
River bed
EAD (Rs/sq.m/year)
EAD = 110 million Rs/yr
Cost = 18 million Rs/yr
Total = 128 million Rs/yr
Bahria Town
Swan Garden
River Garden
Settlements
Undeveloped
Industrial
Commercial
Forest Department
Hummak Town
Defence Housing
0
0.5
1 km
N

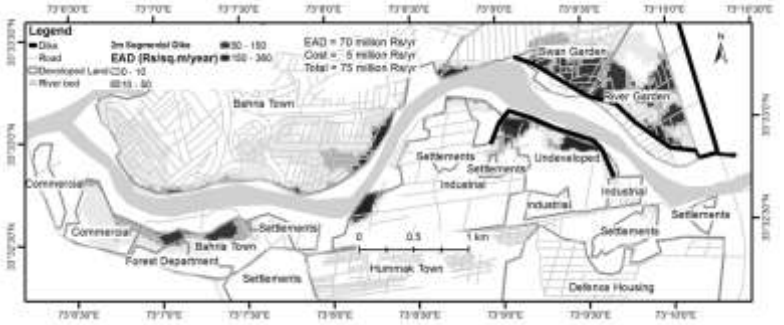

Legend
Dike
Road
Developed Land
River bed
EAD (Rs/sq.m/year)
EAD = 80 million Rs/yr
Cost = 31 million Rs/yr
Total = 111 million Rs/yr
Bahria Town
Swan Garden
River Garden
Settlements
Undeveloped
Industrial
Commercial
Forest Department
Hummak Town
Defence Housing
0
0.5
1 km
N

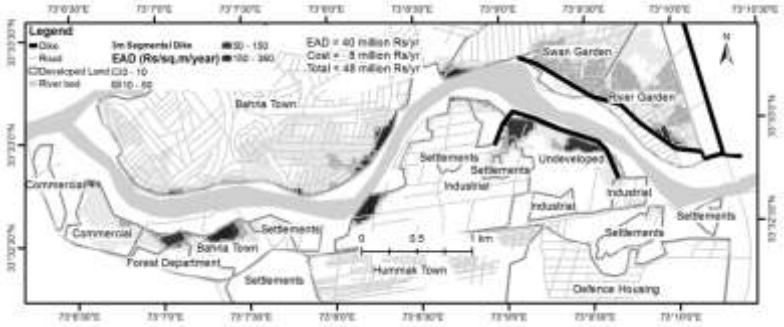

Legend
Dike
Road
Developed Land
River bed
EAD (Rs/sq.m/year)
EAD = 58 million Rs/yr
Cost = 46 million Rs/yr
Total = 104 million Rs/yr
Bahria Town
Swan Garden
River Garden
Settlements
Undeveloped
Industrial
Commercial
Forest Department
Hummak Town
Defence Housing
0
0.5
1 km
N

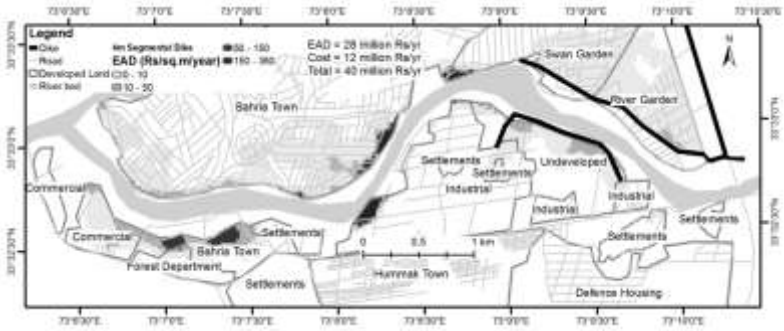

Legend
Dike
Road
Developed Land
River bed
5m Dike
EAD (Rs/sq.m/year)
0 - 10
10 - 50
50 - 150
150 - 360
EAD = 27 million Rs/yr
Cost = 64 million Rs/yr
Total = 91 million Rs/yr
Swan Garden
River Garden
Bahria Town
Settlements
Settlements
Undeveloped
Industrial
Industrial
Industrial
Commercial
Commercial
Settlements
Settlements
Settlements
Bahria Town
Forest Department
Settlements
Hummak Town
Defence Housing
0
0.5
1 km
N

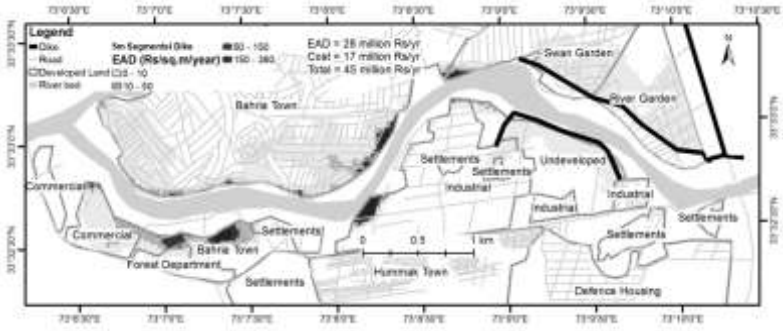
EAD distribution maps of existing, baseline case, and segmental dikes (1m to 5m heights) showing the spatial distribution of EAD for the Swan River study area.



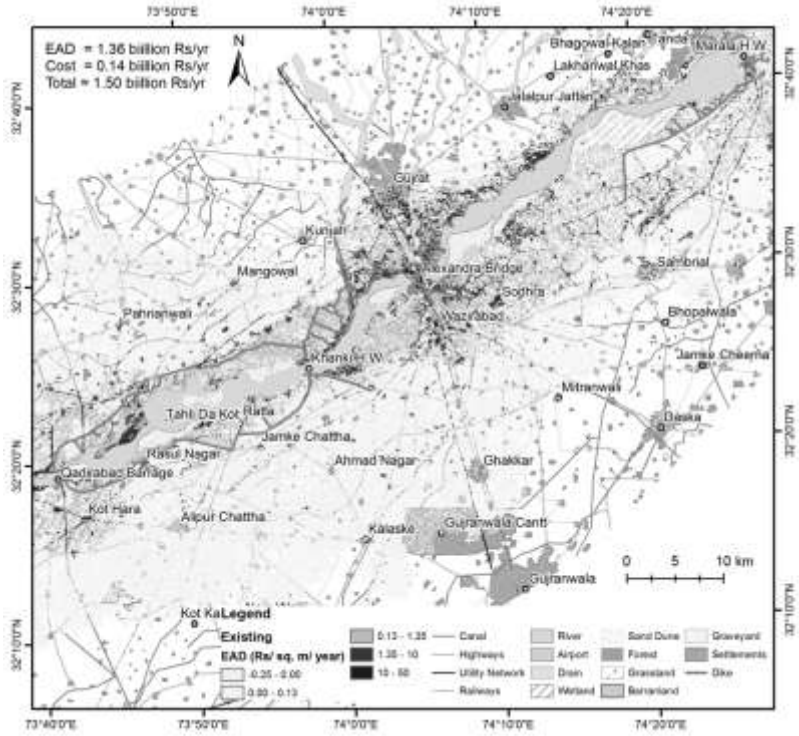



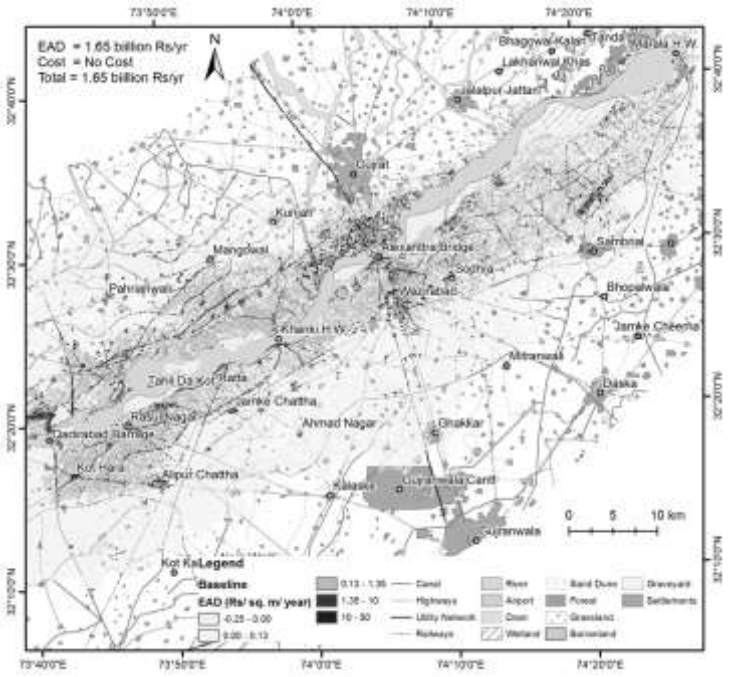



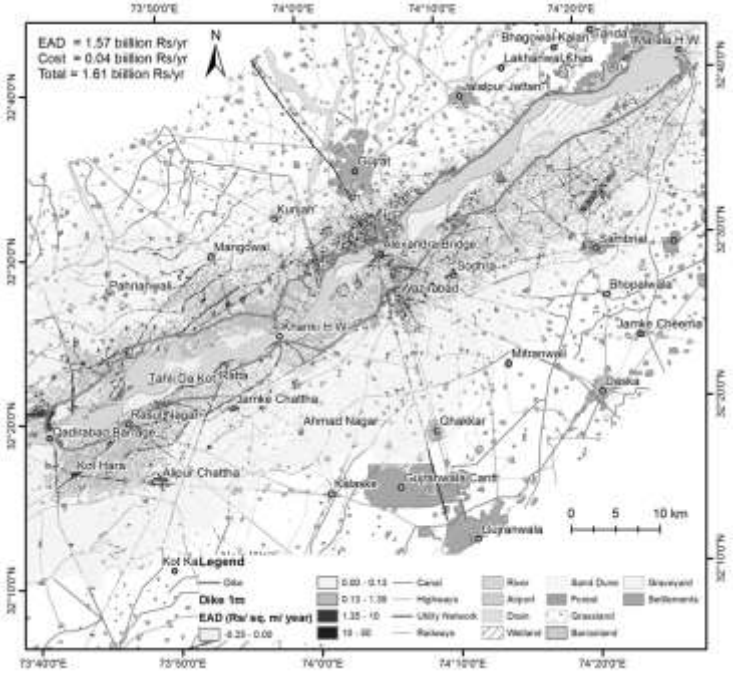

Legend
Dike
Road
Developed Land
River bed
5m Segments Dike
EAD (Rs/sq.m/year)
50 - 100
150 - 360
10 - 50
EAD = 28 million Rs/yr
Cost = 17 million Rs/yr
Total = 45 million Rs/yr
Swan Garden
River Garden
Bahria Town
Settlements
Settlements
Undeveloped
Industrial
Industrial
Industrial
Settlements
Settlements
Commercial
Commercial
Settlements
Bahria Town
Forest Department
Settlements
Hummak Town
Defence Housing
0
0.5
1 km
N

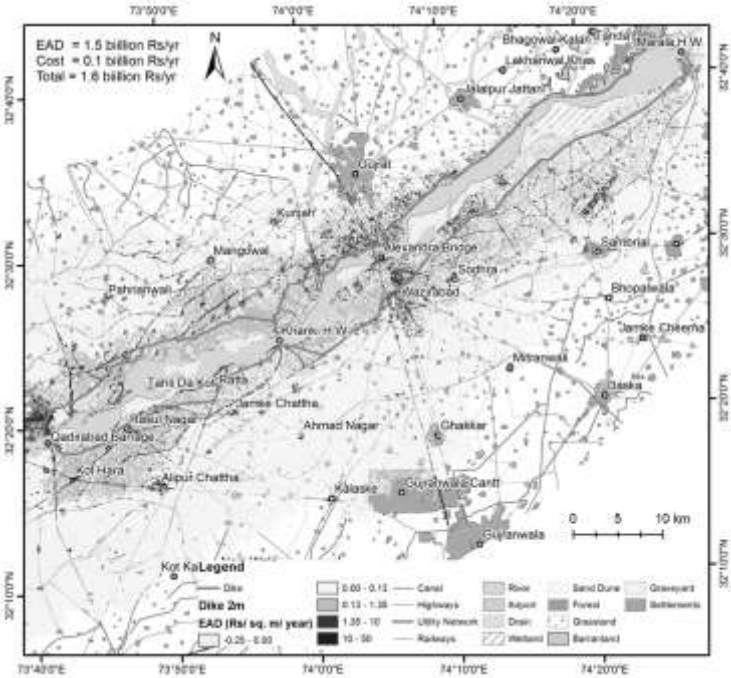
# *Annex B*

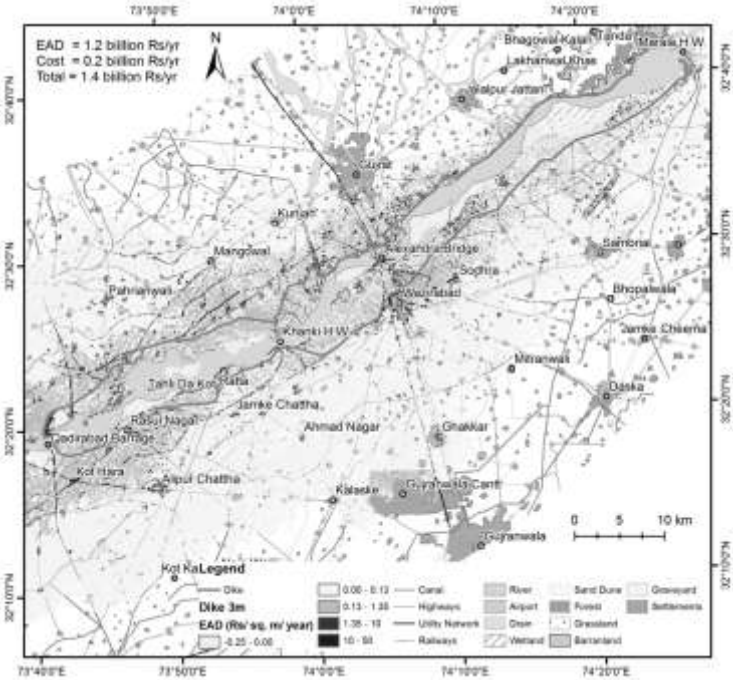
EAD distribution maps of existing, baseline case, and dikes (1m to 6m heights) showing the spatial distribution of EAD for the Chenab River study area.

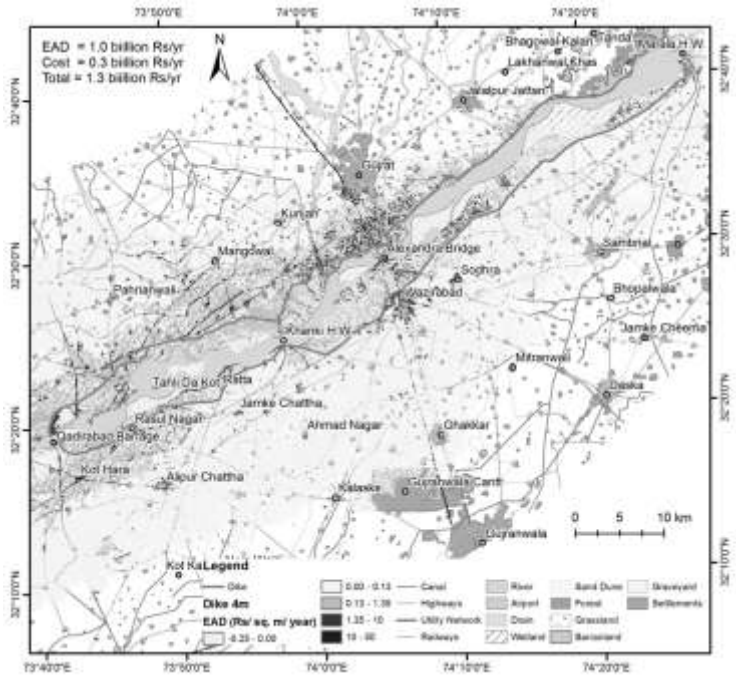


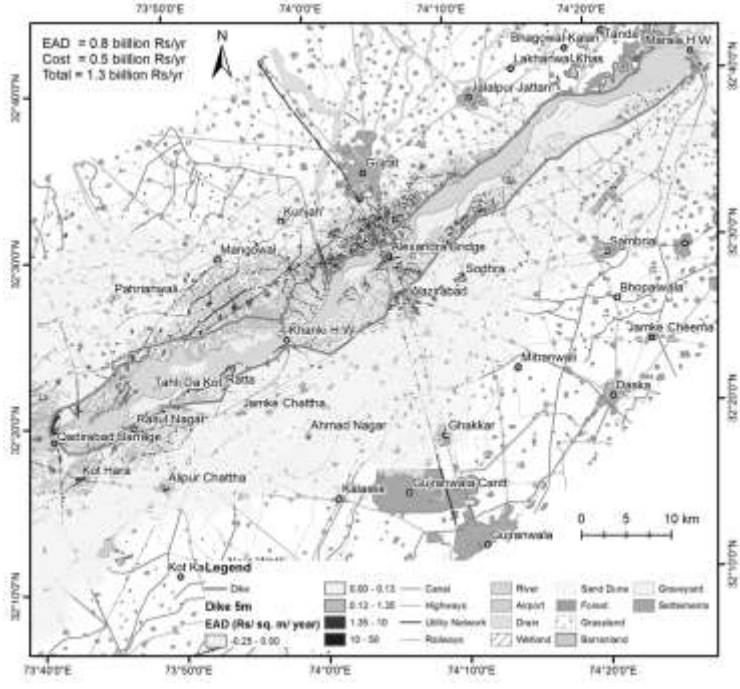

EAD = 1.65 billion Rs/yr
Cost = No Cost
Total = 1.65 billion Rs/yr
N
Bhagowal Kalan
Tanda
Lakhanwal Khas
Jalalpur Jattan
Gujrat
Kunjah
Mangowal
Alexandra Bridge
Sodhra
Wazirabad
Sambrial
Bhopalwala
Pahranwali
Khanki H.W.
Jamke Cheema
Mitranwali
Tahli Da Kot
Ratta
Daska
Jamke Chattha
Rasul Nagar
Ahmad Nagar
Ghakkar
Dadirabad Barrage
Kot Hara
Alipur Chattha
Kalaske
Gujranwala Cantt
Gujranwala
Kot Ka
0 5 10 km
Legend
Baseline
EAD (Rs/ sq. m/ year)
-0.25 - 0.00
0.00 - 0.13
0.13 - 1.35
1.35 - 10
10 - 30
Canal
Highways
Utility Network
Railways
River
Airport
Drain
Wetland
Band Dune
Forest
Grassland
Barrenland
Graveyard
Settlements
73°40'0"E
73°50'0"E
74°0'0"E
74°10'0"E
74°20'0"E
32°40'0"N
32°30'0"N
32°20'0"N
32°10'0"N

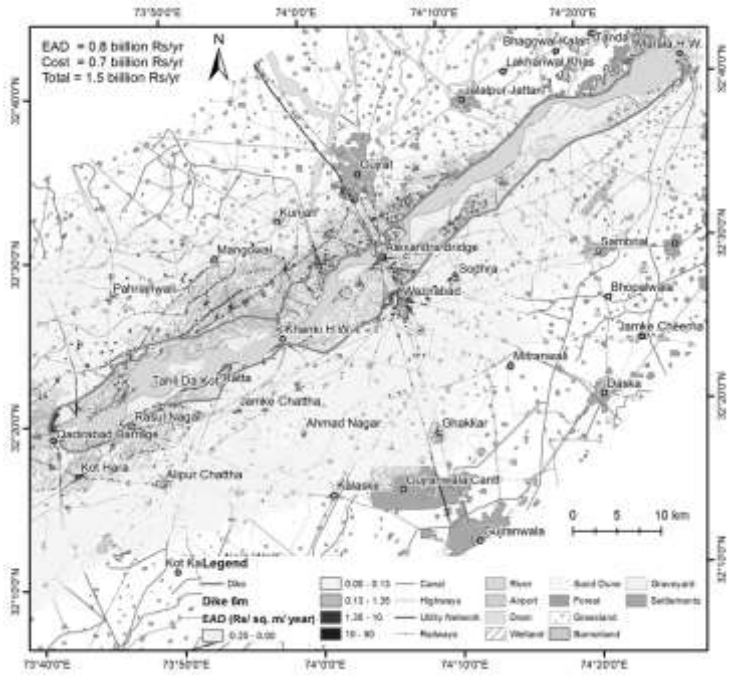

EAD = 1.57 billion Rs/yr
Cost = 0.04 billion Rs/yr
Total = 1.61 billion Rs/yr
N
Bhagowal Kalan
Tanda
Lakhanwal Khas
Jalalpur Jattan
Gujrat
Kunjah
Mangowal
Alexandra Bridge
Sodhra
Wazirabad
Sambrial
Bhopalwala
Pahranwali
Khanki H.W.
Jamke Cheema
Mitranwali
Tahli Da Kot
Ratta
Daska
Jamke Chattha
Rasul Nagar
Ahmad Nagar
Ghakkar
Dadirabad Barrage
Kot Hara
Alipur Chattha
Kalaske
Gujranwala Cantt
Gujranwala
Kot Ka
0 5 10 km
Legend
Dike
Dike 1m
EAD (Rs/ sq. m/ year)
-0.25 - 0.00
0.00 - 0.13
0.13 - 1.35
1.35 - 10
10 - 30
Canal
Highways
Utility Network
Railways
River
Airport
Drain
Wetland
Band Dune
Forest
Grassland
Barrenland
Graveyard
Settlements
73°40'0"E
73°50'0"E
74°0'0"E
74°10'0"E
74°20'0"E
32°40'0"N
32°30'0"N
32°20'0"N
32°10'0"N


EAD = 1.5 billion Rs/yr
Cost = 0.1 billion Rs/yr
Total = 1.6 billion Rs/yr
N
Bhagowal Kalan
Tanda
Marala H.W.
Lakhanwal Khas
Jalalpur Jattan
Gujrat
Kunjah
Mangowal
Alexandra Bridge
Sodhra
Wazirabad
Pahrianwali
Samorial
Bhopalwala
Khanki H.W.
Jamke Cheema
Mitranwali
Daska
Tahli Da Kot
Ratta
Jamke Chattha
Rasul Nagar
Ahmad Nagar
Ghakkar
Qadirabad Barrage
Kot Hara
Alipur Chattha
Kalaske
Gujranwala Cantt
Gujranwala
0 5 10 km
Kot Ka
Legend
Dike
Dike 2m
EAD (Rs/ sq. m/ year)
-0.25 - 0.00
0.00 - 0.13
0.13 - 1.35
1.35 - 10
10 - 50
Canal
Highways
Utility Network
Railways
River
Airport
Drain
Wetland
Sand Dune
Forest
Grassland
Barranland
Graveyard
Settlements
73°40'0"E
73°50'0"E
74°0'0"E
74°10'0"E
74°20'0"E
32°40'0"N
32°30'0"N
32°20'0"N
32°10'0"N


EAD = 1.2 billion Rs/yr
Cost = 0.2 billion Rs/yr
Total = 1.4 billion Rs/yr
N
Bhagowal Kalan
Tanda
Marala H.W.
Lakhanwal Khas
Walpur Jattan
Gujrat
Kunjah
Mangowal
Alexandra Bridge
Sodhra
Wazirabad
Pahrianwali
Samorial
Bhopalwala
Khanki H.W.
Jamke Cheema
Mitranwali
Daska
Tahli Da Kot
Ratta
Jamke Chattha
Rasul Nagar
Ahmad Nagar
Ghakkar
Qadirabad Barrage
Kot Hara
Alipur Chattha
Kalaske
Gujranwala Cantt
Gujranwala
0 5 10 km
Kot Ka
Legend
Dike
Dike 3m
EAD (Rs/ sq. m/ year)
-0.25 - 0.00
0.00 - 0.13
0.13 - 1.35
1.35 - 10
10 - 50
Canal
Highways
Utility Network
Railways
River
Airport
Drain
Wetland
Sand Dune
Forest
Grassland
Barranland
Graveyard
Settlements
73°40'0"E
73°50'0"E
74°0'0"E
74°10'0"E
74°20'0"E
32°40'0"N
32°30'0"N
32°20'0"N
32°10'0"N

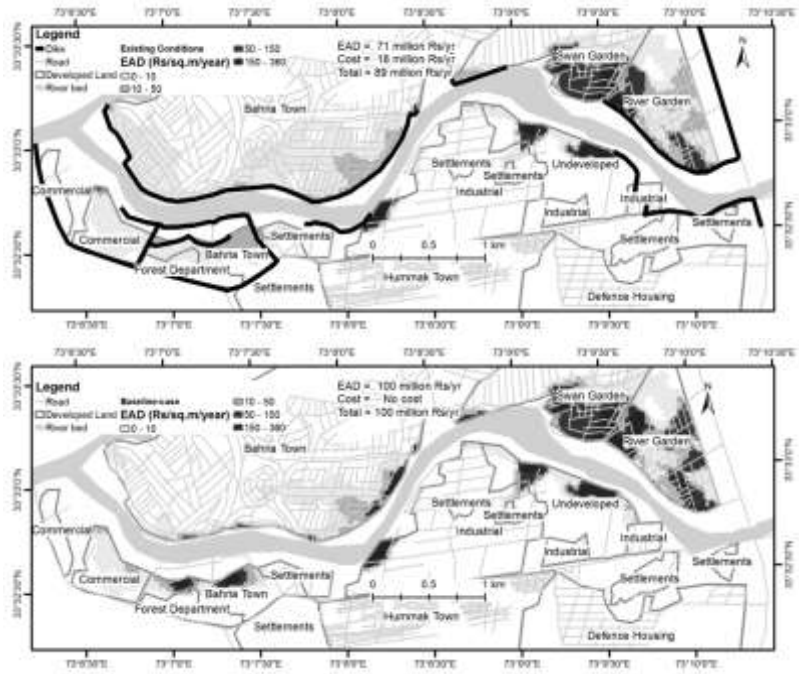

EAD = 1.0 billion Rs/yr
Cost = 0.3 billion Rs/yr
Total = 1.3 billion Rs/yr
N
Bhagowal Kalan
Tanda
Marala H.W.
Lakhanwal Khas
Jalalpur Jattan
Gujrat
Kunjah
Mangowal
Alexandra Bridge
Sambrial
Sodhra
Pahnanwali
Wazirabad
Bhopalwala
Khanki H.W.
Jamke Cheema
Mitranwali
Tahli Da Kot
Ratta
Daska
Jamke Chattha
Rasul Nagar
Ahmad Nagar
Ghakkar
Qadirabad Barrage
Kot Hara
Alipur Chattha
Kalaske
Gujranwala Cantt
Gujranwala
0 5 10 km
Kot Ka
Legend
Dike
Dike 4m
EAD (Rs/ sq. m/ year)
-0.25 - 0.00
0.00 - 0.13
0.13 - 1.35
1.35 - 10
10 - 50
Canal
Highways
Utility Network
Railways
River
Airport
Drain
Wetland
Sand Dune
Forest
Grassland
Barrenland
Graveyard
Settlements
73°40'0"E
73°50'0"E
74°0'0"E
74°10'0"E
74°20'0"E
32°40'0"N
32°30'0"N
32°20'0"N
32°10'0"N

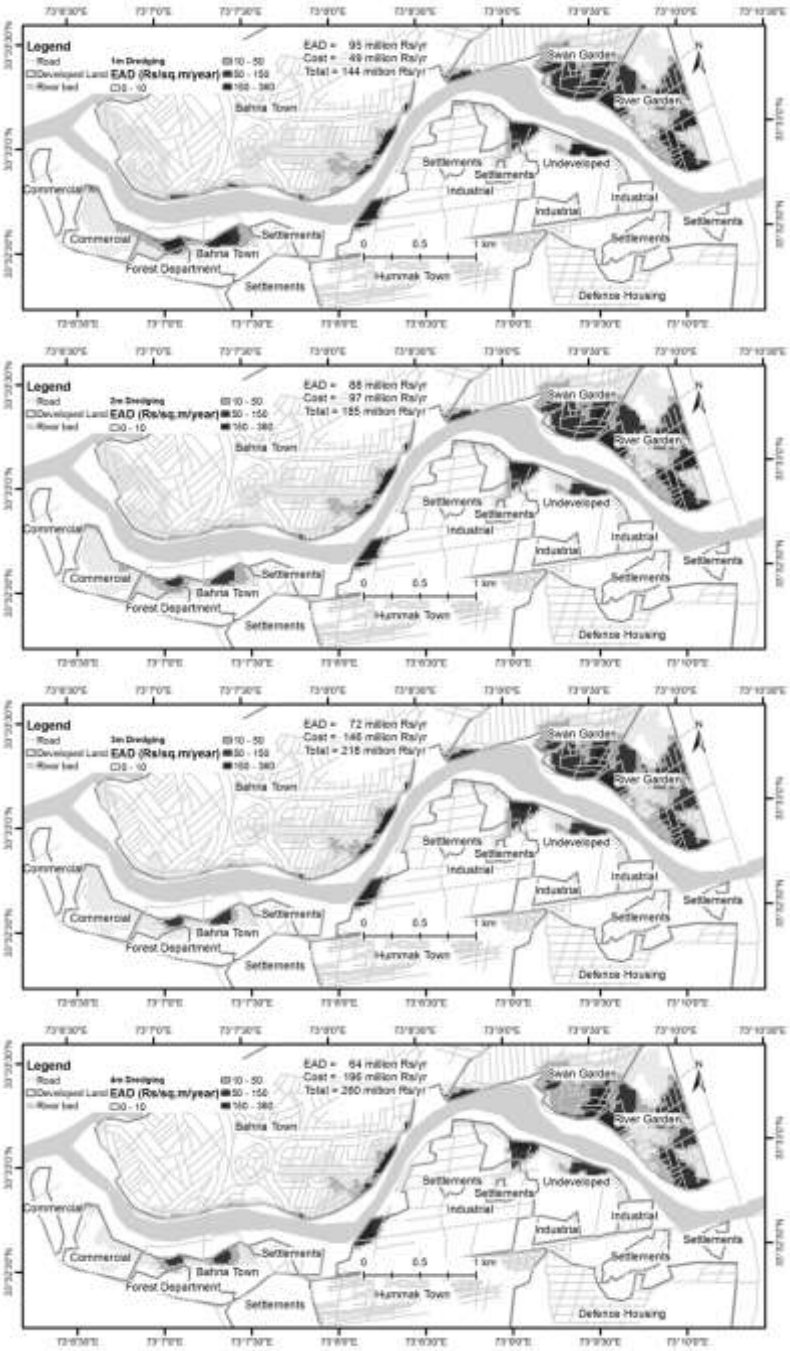

EAD = 0.8 billion Rs/yr
Cost = 0.5 billion Rs/yr
Total = 1.3 billion Rs/yr
N
Bhagowal Kalan
Tanda
Marala H.W.
Lakhanwal Khas
Jalalpur Jattan
Gujrat
Kunjah
Mangowal
Alexandra Bridge
Sambrial
Sodhra
Pahnanwali
Wazirabad
Bhopalwala
Khanki H.W.
Jamke Cheema
Mitranwali
Tahli Da Kot
Ratta
Daska
Jamke Chattha
Rasul Nagar
Ahmad Nagar
Ghakkar
Qadirabad Barrage
Kot Hara
Alipur Chattha
Kalaske
Gujranwala Cantt
Gujranwala
0 5 10 km
Kot Ka
Legend
Dike
Dike 5m
EAD (Rs/ sq. m/ year)
-0.25 - 0.00
0.00 - 0.13
0.13 - 1.35
1.35 - 10
10 - 50
Canal
Highways
Utility Network
Railways
River
Airport
Drain
Wetland
Sand Dune
Forest
Grassland
Barrenland
Graveyard
Settlements
73°40'0"E
73°50'0"E
74°0'0"E
74°10'0"E
74°20'0"E
32°40'0"N
32°30'0"N
32°20'0"N
32°10'0"N

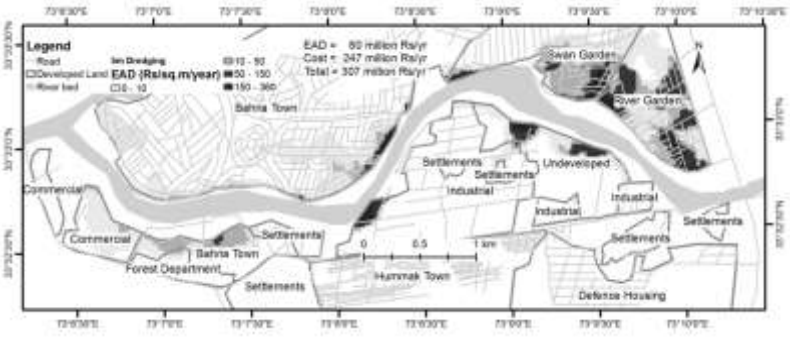

EAD = 0.8 billion Rs/yr
Cost = 0.7 billion Rs/yr
Total = 1.5 billion Rs/yr
N
Bhagowal Kalan
Tanda
Lakhanwal Khas
Jalalpur Jattan
Gujrat
Kunjah
Mangowal
Pahranwali
Sodhra
Wazirabad
Sambhal
Bhopalwala
Jamke Cheema
Khanki H.W.
Mitranwali
Daska
Tahli Da Kot
Jamke Chattha
Rasul Nagar
Ahmad Nagar
Ghakkar
Jadirabad Barrage
Kot Hara
Alipur Chattha
Kalaske
Gujranwala Cantt
Gujranwala
Kot Ka
0 5 10 km
Legend
Dike
Dike 6m
EAD (Rs/ sq. m/ year)
0.00 - 0.13
0.13 - 1.35
1.35 - 10
10 - 80
Canal
Highways
Utility Network
Railways
River
Airport
Drain
Wetland
Sand Dune
Forest
Grassland
Barrenland
Graveyard
Settlements

# *Annex C*

EAD distribution maps of existing, baseline, and proposed dredging, showing the spatial distribution of EAD over the Swan River reach.

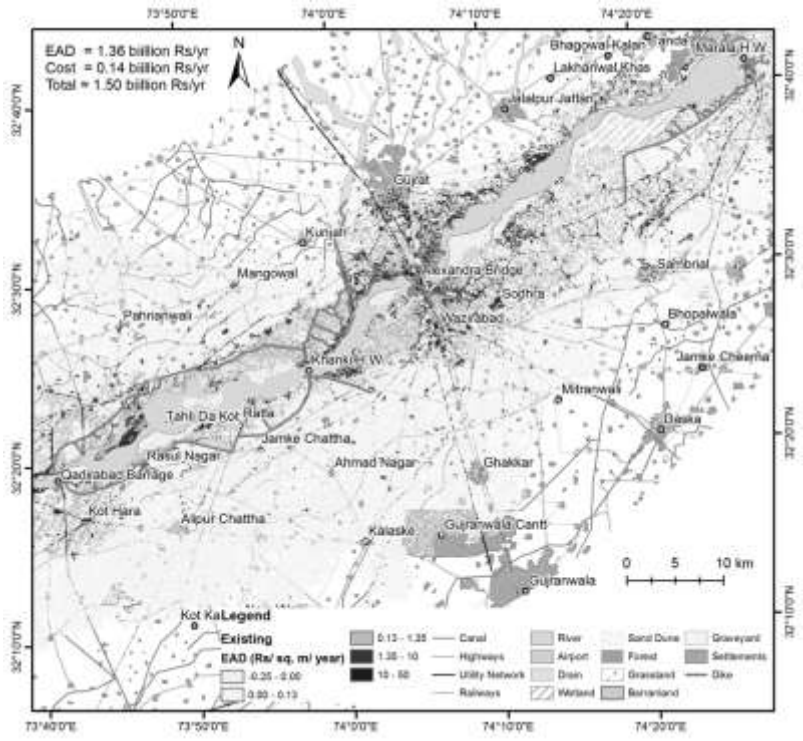


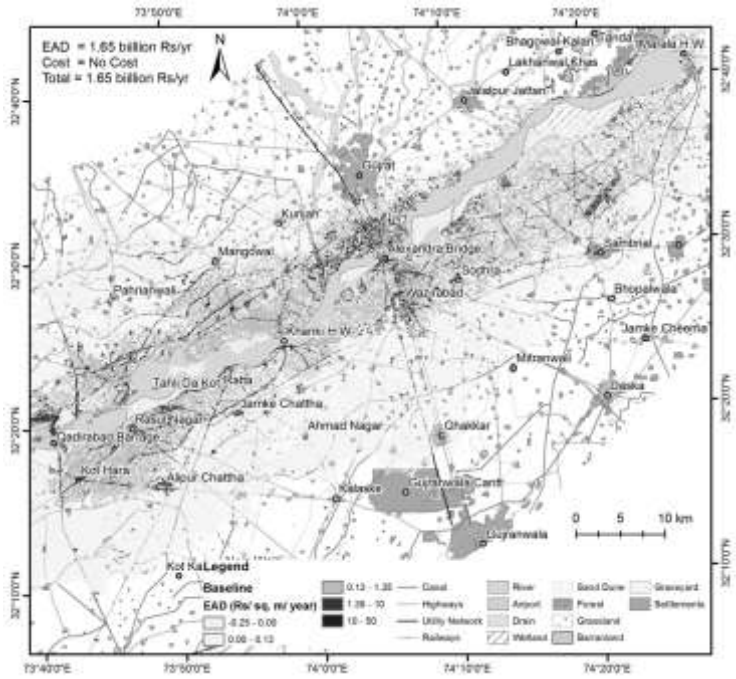

Legend
Road
Developed Land
River bed
1m Dredging
EAD (Rs/sq.m/year)
10 - 50
50 - 150
150 - 360
0 - 10
EAD = 95 million Rs/yr
Cost = 49 million Rs/yr
Total = 144 million Rs/yr
Bahria Town
Swan Garden
River Garden
Settlements
Undeveloped
Industrial
Commercial
Forest Department
Hummak Town
Defense Housing
0
0.5
1 km
N
Legend
Road
Developed Land
River bed
2m Dredging
EAD (Rs/sq.m/year)
10 - 50
50 - 150
150 - 360
0 - 10
EAD = 88 million Rs/yr
Cost = 97 million Rs/yr
Total = 185 million Rs/yr
Bahria Town
Swan Garden
River Garden
Settlements
Undeveloped
Industrial
Commercial
Forest Department
Hummak Town
Defense Housing
0
0.5
1 km
N
Legend
Road
Developed Land
River bed
3m Dredging
EAD (Rs/sq.m/year)
10 - 50
50 - 150
150 - 360
0 - 10
EAD = 72 million Rs/yr
Cost = 146 million Rs/yr
Total = 218 million Rs/yr
Bahria Town
Swan Garden
River Garden
Settlements
Undeveloped
Industrial
Commercial
Forest Department
Hummak Town
Defense Housing
0
0.5
1 km
N
Legend
Road
Developed Land
River bed
4m Dredging
EAD (Rs/sq.m/year)
10 - 50
50 - 150
150 - 360
0 - 10
EAD = 64 million Rs/yr
Cost = 196 million Rs/yr
Total = 260 million Rs/yr
Bahria Town
Swan Garden
River Garden
Settlements
Undeveloped
Industrial
Commercial
Forest Department
Hummak Town
Defense Housing
0
0.5
1 km
N

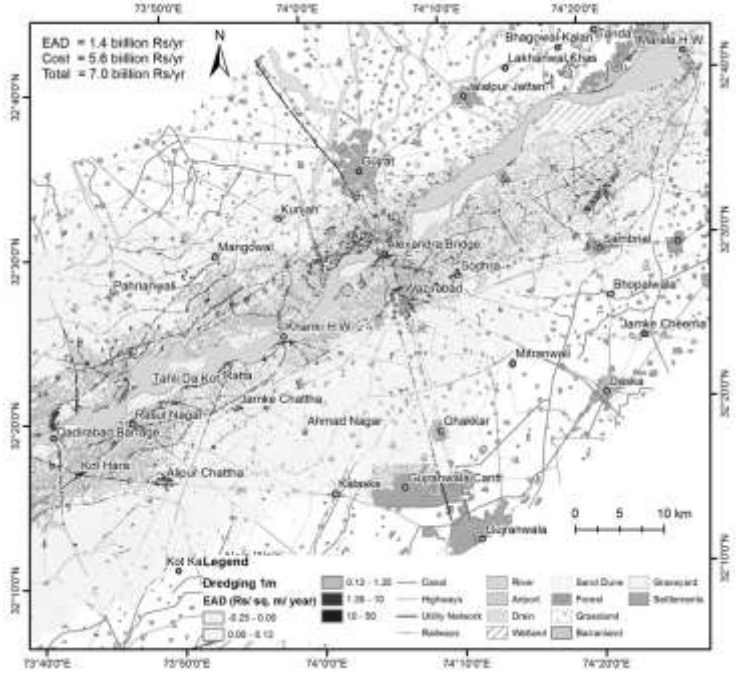

Legend
Road
Developed Land
River bed
1m Dredging
EAD (Rs/sq.m/year)
0 - 10
10 - 50
50 - 150
150 - 360
EAD = 60 million Rs/yr
Cost = 247 million Rs/yr
Total = 307 million Rs/yr
Swan Garden
River Garden
Bahria Town
Settlements
Undeveloped
Industrial
Commercial
Forest Department
Hummak Town
Defense Housing
0
0.5
1 km
N

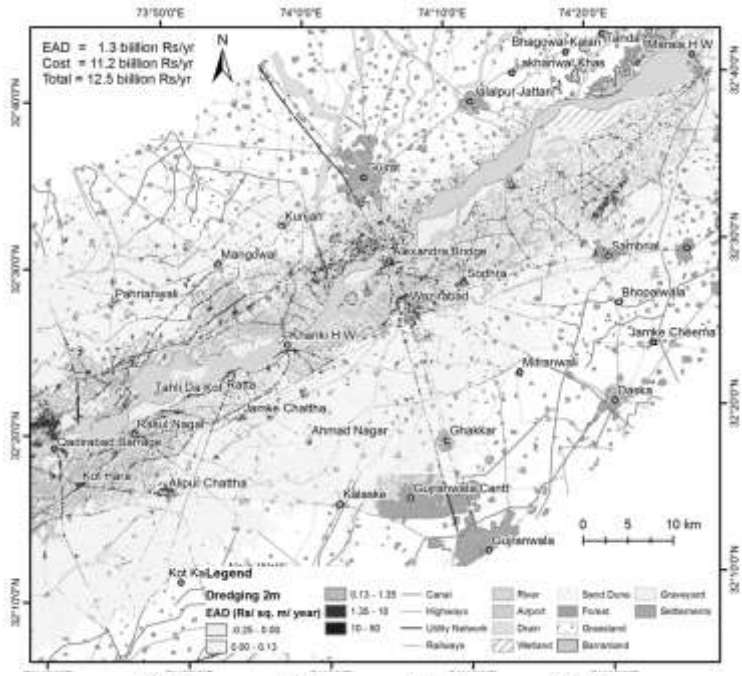
# *Annex D*

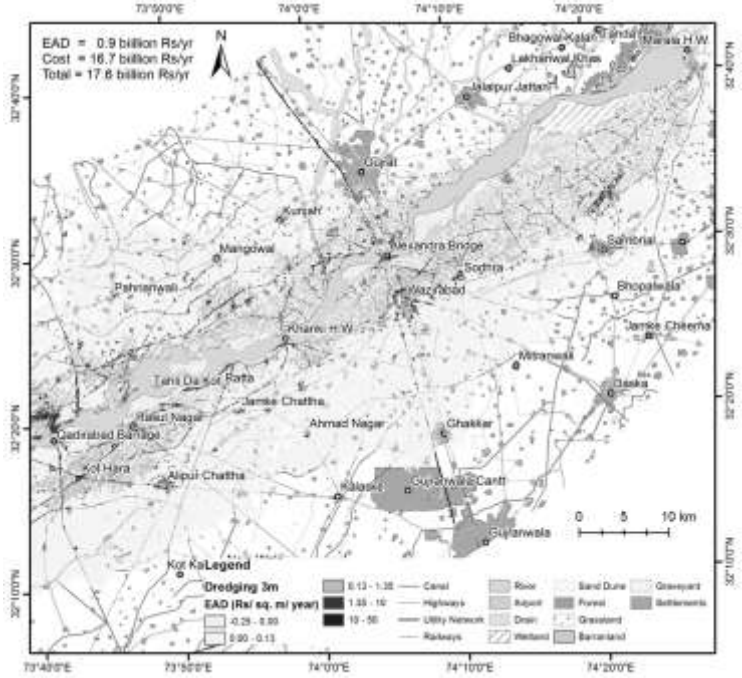
EAD distribution maps of existing, baseline, and proposed dredging, showing the spatial distribution of EAD over the Chenab River reach.

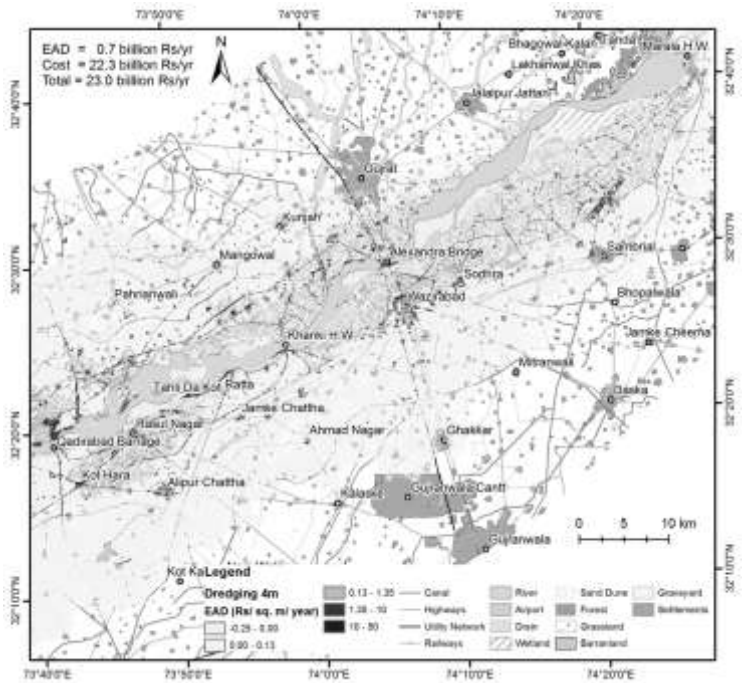


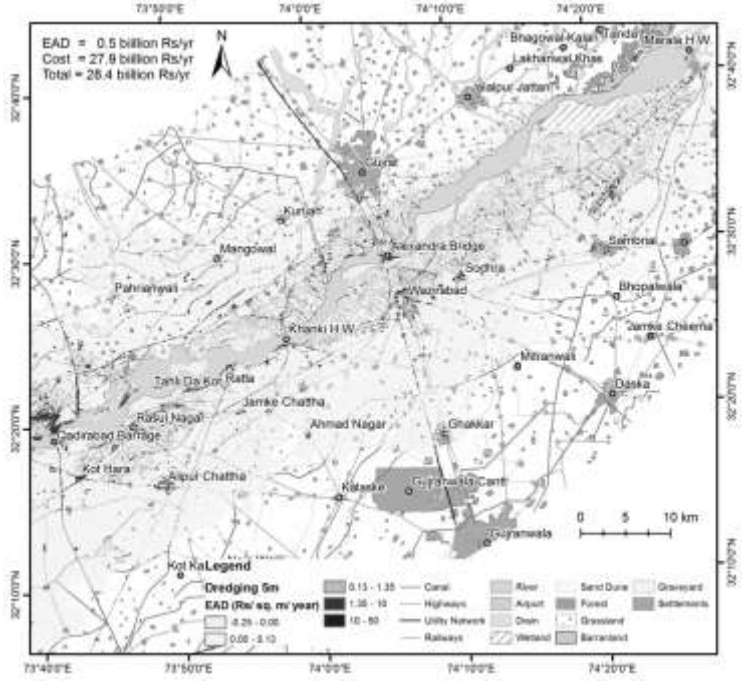

EAD = 1.65 billion Rs/yr
Cost = No Cost
Total = 1.65 billion Rs/yr
N
Legend
Baseline
EAD (Rs/ sq. m/ year)
0 5 10 km


EAD = 1.4 billion Rs/yr
Cost = 5.6 billion Rs/yr
Total = 7.0 billion Rs/yr
N
Legend
Dredging 1m
EAD (Rs/ sq. m/ year)
0 5 10 km

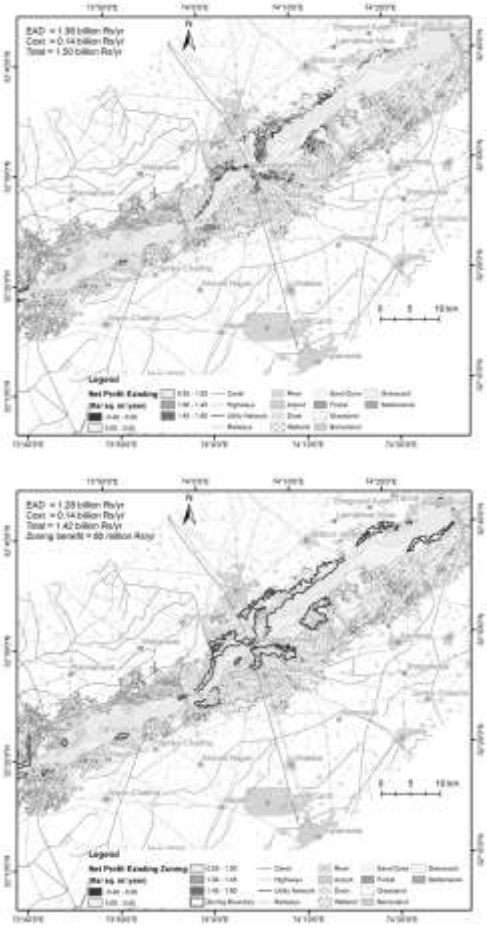

EAD = 1.3 billion Rs/yr
Cost = 11.2 billion Rs/yr
Total = 12.5 billion Rs/yr
N
Bhagowal-Kalan
Lakhanwal Khas
Jalalpur Jattan
Kunjah
Mangowal
Sambrial
Sodhra
Pahrianwali
Bhopalwala
Khanki H W
Jamke Cheema
Mitranwali
Tahli Da Kot
Ratta
Daska
Jamke Chattha
Ahmad Nagar
Ghakkar
Kot Hara
Alipur Chattha
Kalaske
Gujranwala Cantt
Gujranwala
0 5 10 km
Kot Ka
Legend
Dredging 2m
EAD (Rs/ sq. m/ year)
Canal
Highways
Utility Network
Railways
River
Airport
Drain
Wetland
Sand Dune
Forest
Grassland
Barranland
Graveyard
Settlements


EAD = 0.9 billion Rs/yr
Cost = 16.7 billion Rs/yr
Total = 17.6 billion Rs/yr
N
Bhagowal-Kalan
Lakhanwal Khas
Jalalpur Jattan
Kunjah
Mangowal
Sambrial
Sodhra
Pahrianwali
Bhopalwala
Khanki H W
Jamke Cheema
Mitranwali
Tahli Da Kot
Ratta
Daska
Jamke Chattha
Ahmad Nagar
Ghakkar
Kot Hara
Alipur Chattha
Kalaske
Gujranwala Cantt
Gujranwala
0 5 10 km
Kot Ka
Legend
Dredging 3m
EAD (Rs/ sq. m/ year)
Canal
Highways
Utility Network
Railways
River
Airport
Drain
Wetland
Sand Dune
Forest
Grassland
Barranland
Graveyard
Settlements

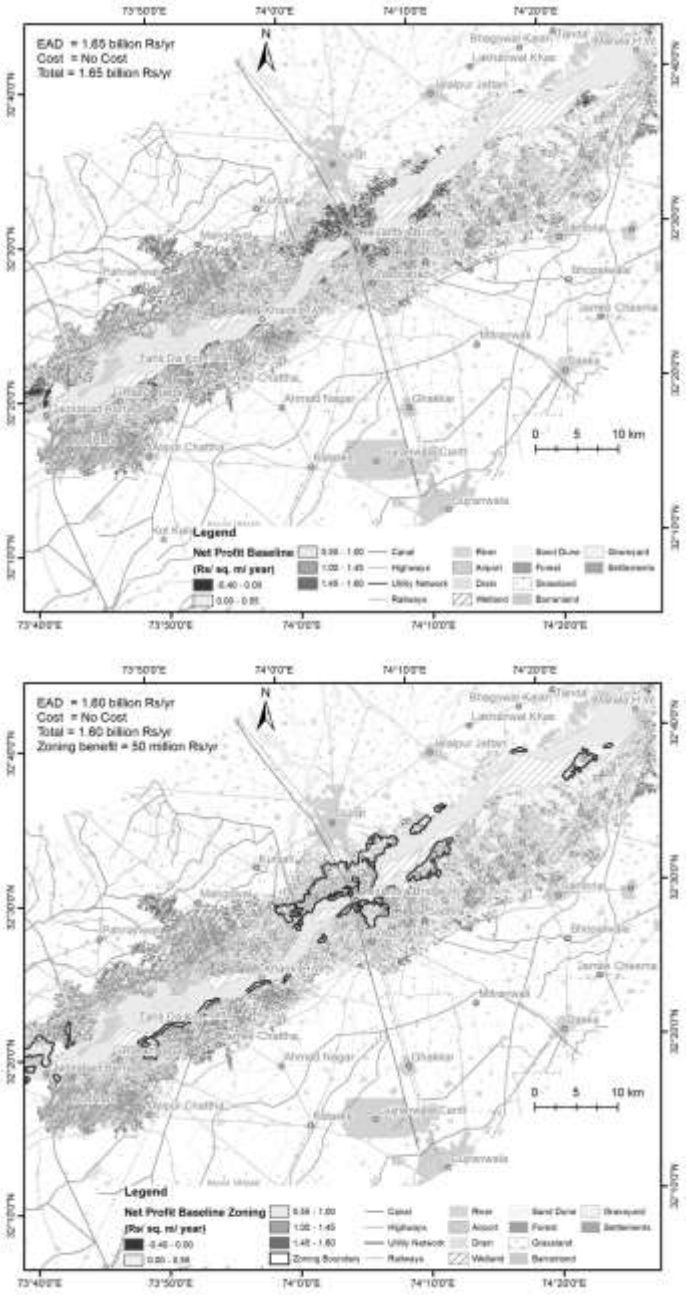

EAD = 0.7 billion Rs/yr
Cost = 22.3 billion Rs/yr
Total = 23.0 billion Rs/yr
N
Bhagowal Kalan
Tanda
Marala H.W.
Lakhanwal Khas
Jalalpur Jattan
Gujrat
Kunjah
Mangowal
Alexandra Bridge
Sodhra
Samonal
Pahnanwali
Wazirabad
Bhopalwala
Khanki H.W.
Jamke Cheema
Mitranwali
Tank Da Kot
Ratta
Daska
Jamke Chattha
Rasul Nagar
Ahmad Nagar
Ghakkar
Jadirabad Barrage
Kot Hara
Alipur Chattha
Kalaske
Gujranwala Cantt
Gujranwala
0 5 10 km
Kot Ka
Legend
Dredging 4m
EAD (Rs/ sq. m/ year)
-0.25 - 0.00
0.00 - 0.13
0.13 - 1.35
1.35 - 10
10 - 50
Canal
Highways
Utility Network
Railways
River
Airport
Drain
Wetland
Sand Dune
Forest
Grassland
Barranland
Graveyard
Settlements
73°40'0"E
73°50'0"E
74°0'0"E
74°10'0"E
74°20'0"E
32°40'0"N
32°30'0"N
32°20'0"N
32°10'0"N


EAD = 0.5 billion Rs/yr
Cost = 27.9 billion Rs/yr
Total = 28.4 billion Rs/yr
N
Bhagowal Kalan
Tanda
Marala H.W.
Lakhanwal Khas
Jalalpur Jattan
Gujrat
Kunjah
Mangowal
Alexandra Bridge
Sodhra
Samonal
Pahnanwali
Wazirabad
Bhopalwala
Khanki H.W.
Jamke Cheema
Mitranwali
Tank Da Kot
Ratta
Daska
Jamke Chattha
Rasul Nagar
Ahmad Nagar
Ghakkar
Jadirabad Barrage
Kot Hara
Alipur Chattha
Kalaske
Gujranwala Cantt
Gujranwala
0 5 10 km
Kot Ka
Legend
Dredging 5m
EAD (Rs/ sq. m/ year)
-0.25 - 0.00
0.00 - 0.13
0.13 - 1.35
1.35 - 10
10 - 50
Canal
Highways
Utility Network
Railways
River
Airport
Drain
Wetland
Sand Dune
Forest
Grassland
Barranland
Graveyard
Settlements
73°40'0"E
73°50'0"E
74°0'0"E
74°10'0"E
74°20'0"E
32°40'0"N
32°30'0"N
32°20'0"N
32°10'0"N

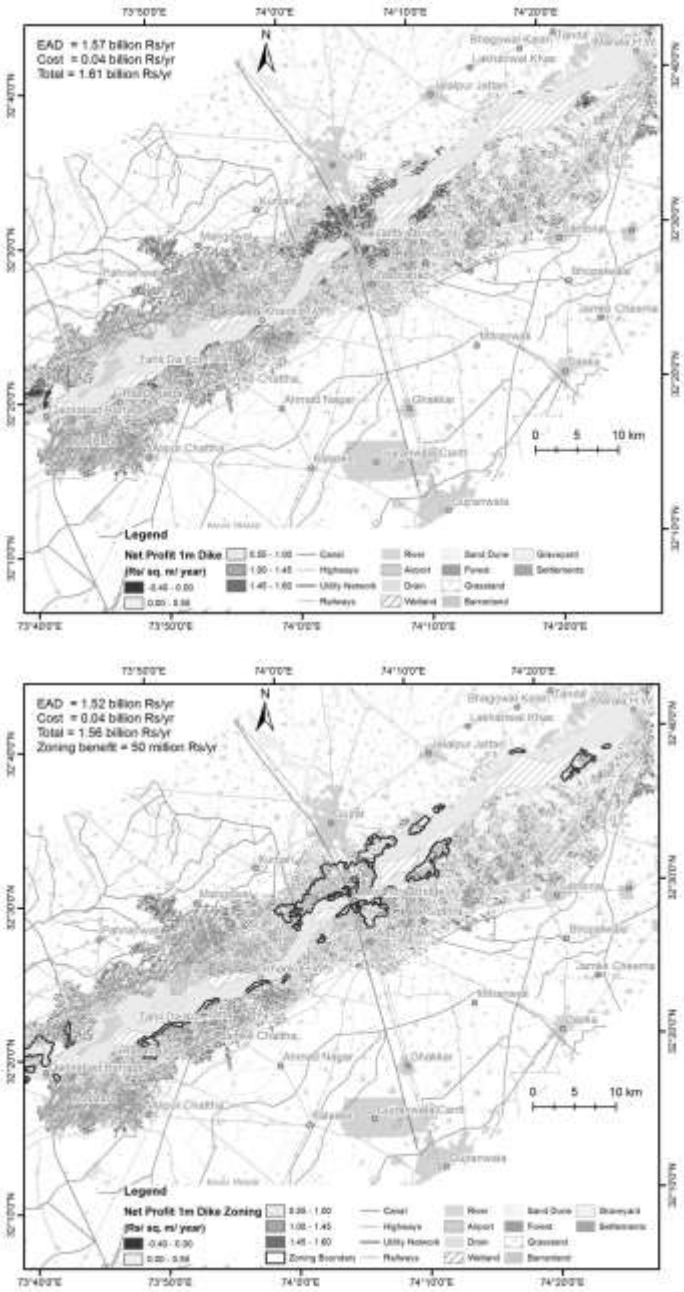
# *Annex E*



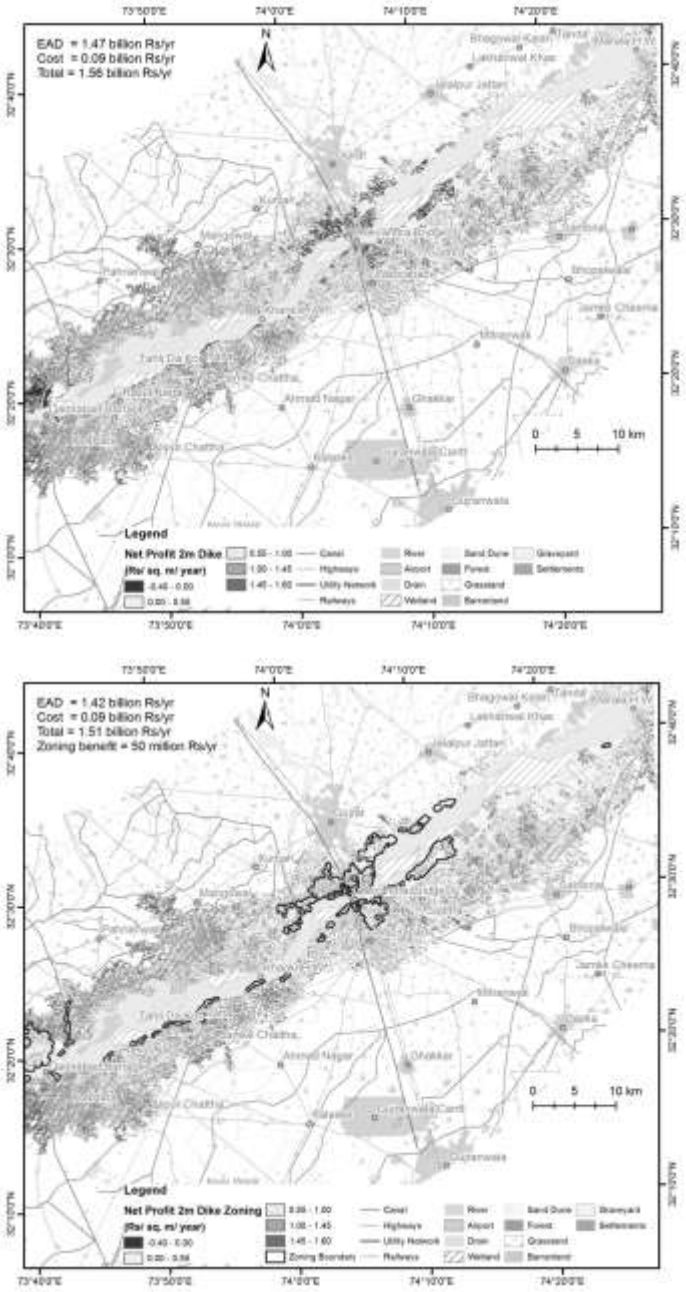
*Annex Figure E1: Maps, showing the expected annual net-profit of agricultural land for the Chenab River reach against existing conditions.*



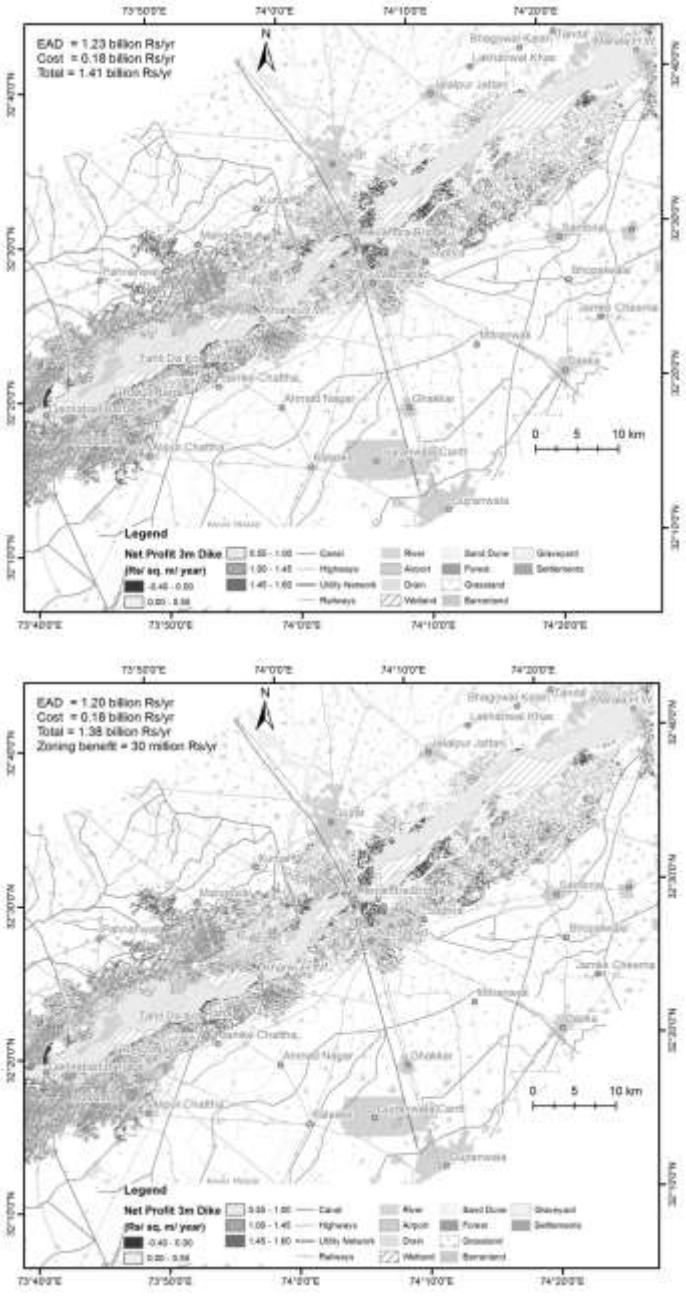

*Annex Figure E2: Maps, showing the expected annual net-profit of agricultural land for the Chenab River reach against baseline case.*



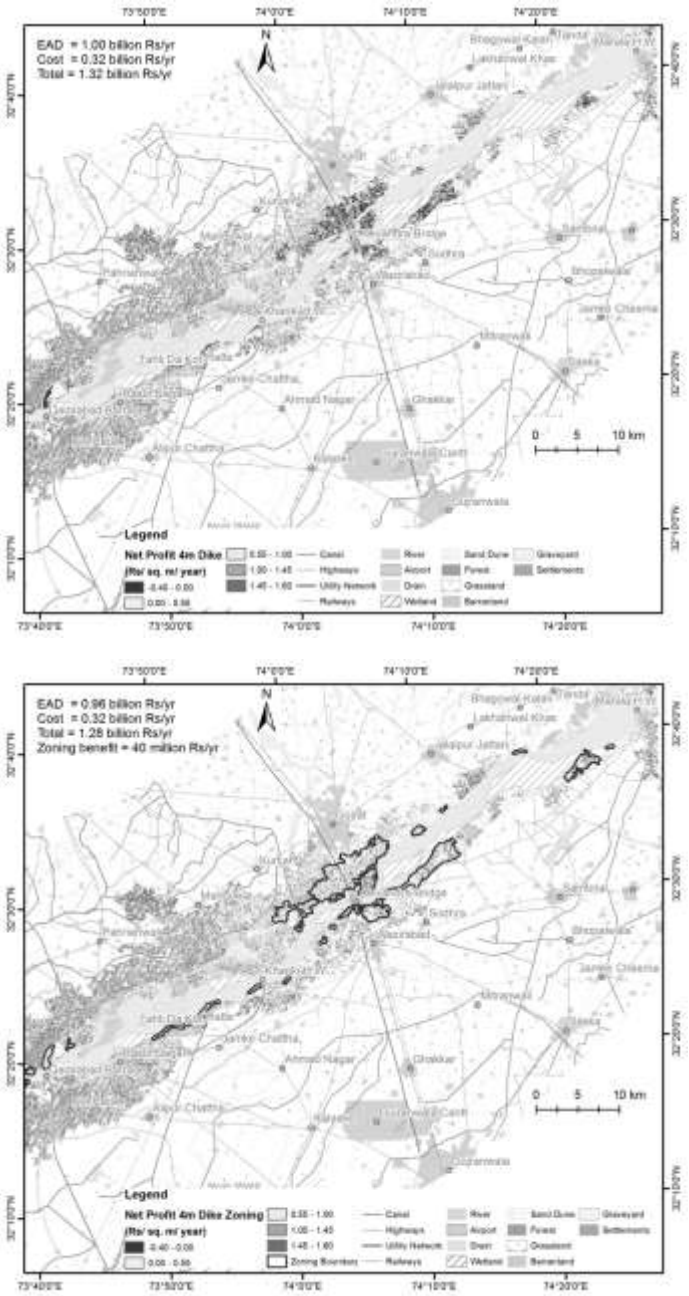

*Annex Figure E3: Maps, showing the expected annual net-profit of agricultural land for the Chenab River reach against 1m dike case.*



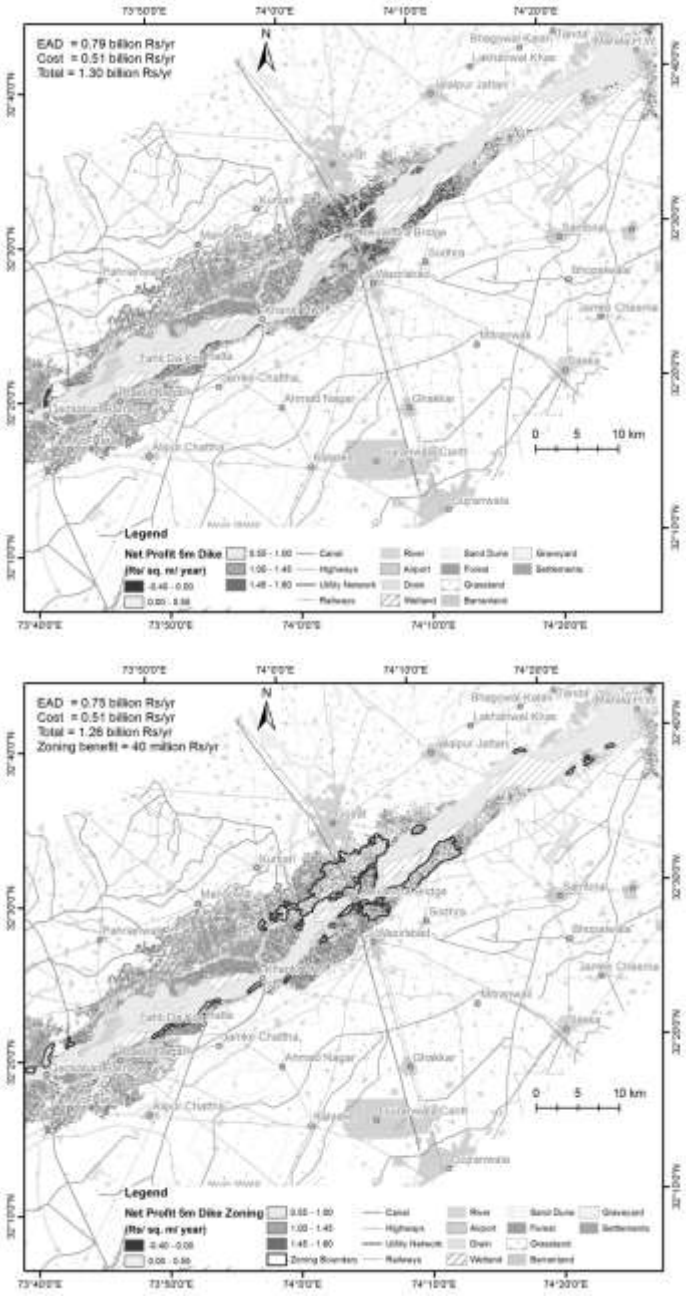

*Annex Figure E4: Maps, showing the expected annual net-profit of agricultural land for the Chenab River reach against 2m dike case.*



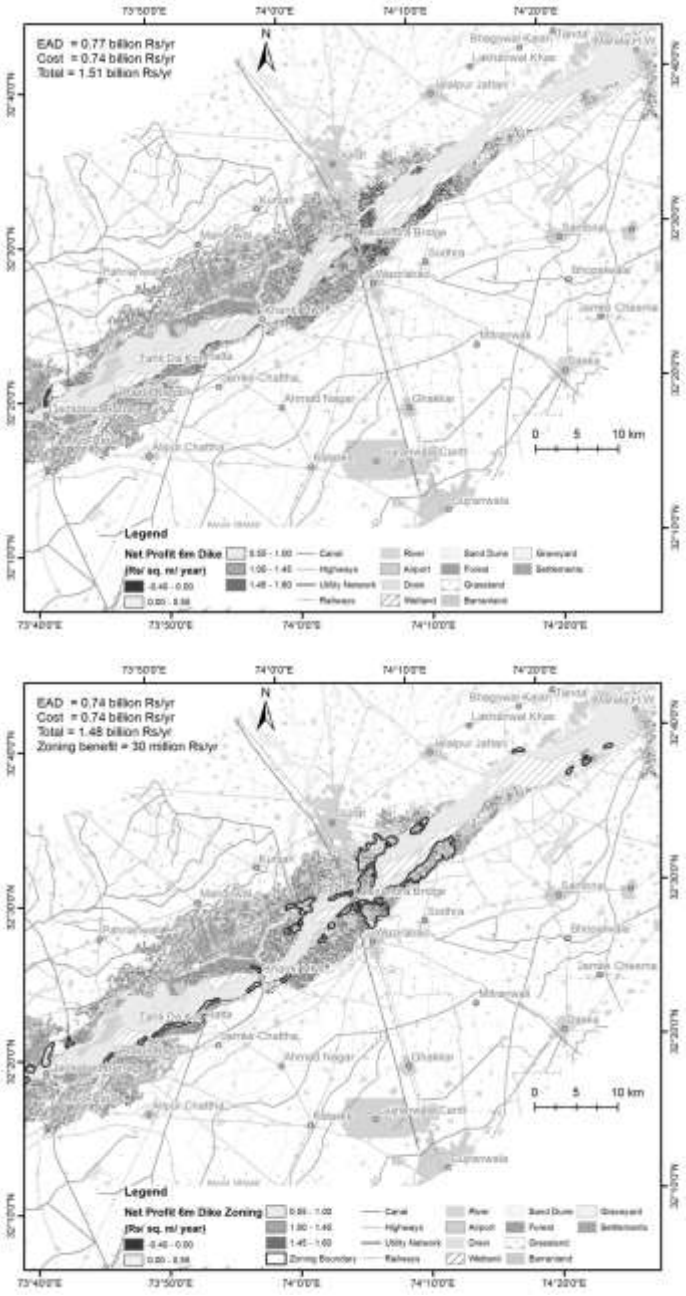

*Annex Figure E5: Maps, showing the expected annual net-profit of agricultural land for the Chenab River reach against 3m dike case.*




*Annex Figure E6: Maps, showing the expected annual net-profit of agricultural land for the Chenab River reach against 4m dike case.*



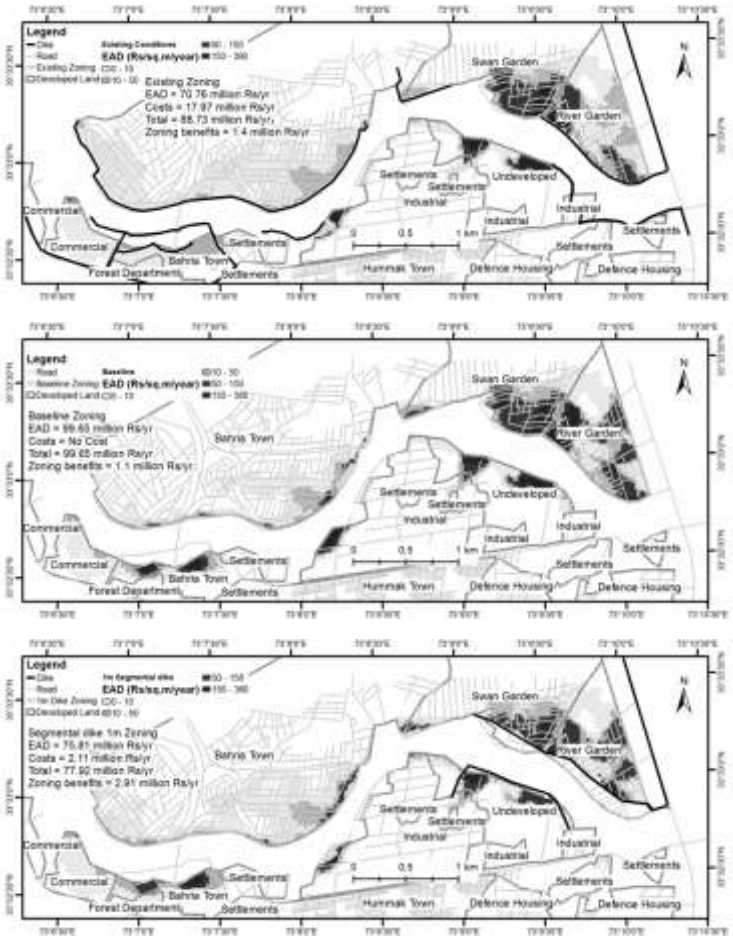

*Annex Figure E7: Maps, showing the expected annual net-profit of agricultural land for the Chenab River reach against 5m dike case.*

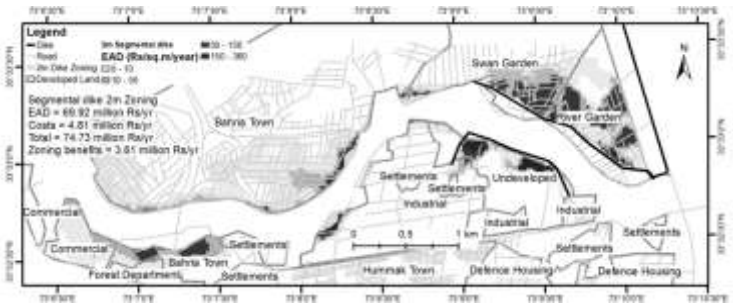


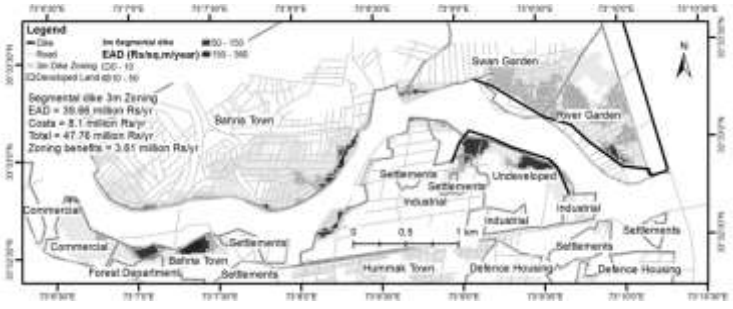

*Annex Figure E8: Maps, showing the expected annual net-profit of agricultural land for the Chenab River reach against 6m dike case.*

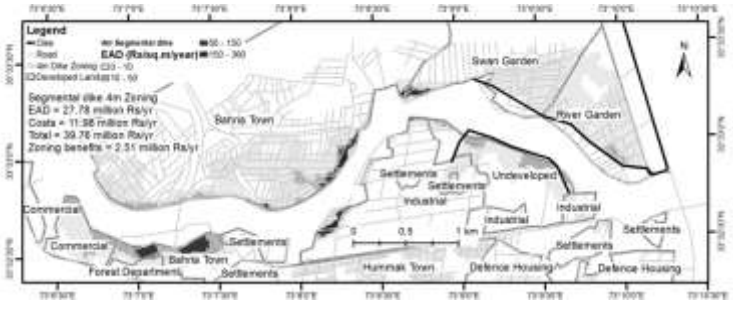
# *Annex F*

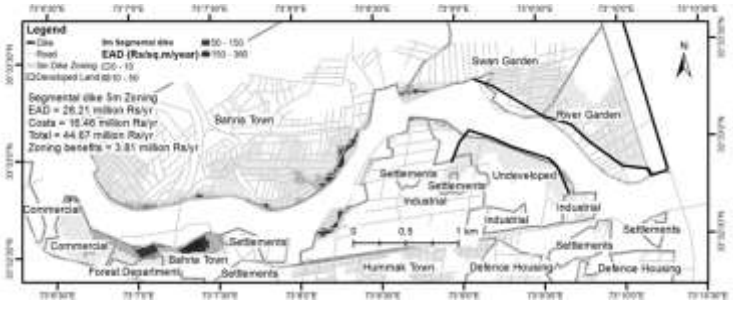
Maps show EAD distribution of settlement areas against proposed zoning for existing, baseline, and all dike heights in the Swan River reach.




Legend
Dike
Road
EAD (Rs/sq.m/year)
Segmental dike 2m Zoning
EAD = 69.92 million Rs/yr
Costs = 4.81 million Rs/yr
Total = 74.73 million Rs/yr
Zoning benefits = 3.61 million Rs/yr
Swan Garden
River Garden
Bahria Town
Settlements
Undeveloped
Industrial
Commercial
Forest Department
Hummak Town
Defence Housing
N
0
0.5
1 km


Legend
Dike
Road
EAD (Rs/sq.m/year)
Segmental dike 3m Zoning
EAD = 39.66 million Rs/yr
Costs = 8.1 million Rs/yr
Total = 47.76 million Rs/yr
Zoning benefits = 3.61 million Rs/yr
Swan Garden
River Garden
Bahria Town
Settlements
Undeveloped
Industrial
Commercial
Forest Department
Hummak Town
Defence Housing
N
0
0.5
1 km


Legend
Dike
Road
EAD (Rs/sq.m/year)
Segmental dike 4m Zoning
EAD = 27.78 million Rs/yr
Costs = 11.98 million Rs/yr
Total = 39.76 million Rs/yr
Zoning benefits = 2.31 million Rs/yr
Swan Garden
River Garden
Bahria Town
Settlements
Undeveloped
Industrial
Commercial
Forest Department
Hummak Town
Defence Housing
N
0
0.5
1 km


Legend
Dike
Road
EAD (Rs/sq.m/year)
Segmental dike 5m Zoning
EAD = 26.21 million Rs/yr
Costs = 18.46 million Rs/yr
Total = 44.67 million Rs/yr
Zoning benefits = 3.61 million Rs/yr
Swan Garden
River Garden
Bahria Town
Settlements
Undeveloped
Industrial
Commercial
Forest Department
Hummak Town
Defence Housing
N
0
0.5
1 km

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Muhammad Atiq Ur Rehman Tariq started his first job as hydrological engineer in Republic Engineering Consultants after completing his Civil Engineering in 2003. He completed his MSc. degree with distinction in 2005. During his M.Sc., he was appointed as research associate in a project 'stochastic flood zoning' in the Centre of Excellence in Water Resources Engineering, Lahore, Pakistan due to his extra ordinary academic performance. He then joined Pakistan's national space agency (SUPARCO). He started his PhD at TU Delft, the Netherlands, under the supervision of Prof. Dr. Ir. N. C. van de Giesen in August 2007.

In the course of his PhD work, he has written several journal articles and presented his work at conferences in Europe and Asia. At one occasion, he received the 'best research paper award'. At another occasion, his contribution was selected for the follow-up special issues of an international peer reviewed journal. In addition, he was invited to write an article as technical expert for 'Reuters' and for a seminar lecture at Rotterdam University, the Netherlands. He assisted several master students and fully supervised a PI project of five engineering students.

He plays Ping-Pong and enjoys chats and discussions with friends. He prefers to attend the company of elders to listen to their life experiences. Life is a onetime experience and we must help all people to make their lives a good experience.