UNDERSTANDING THE ECONOMICS OF FLOOD RISK REDUCTION

A PRELIMINARY ANALYSIS

KATE HAWLEY, MARCUS MOENCH AND LEA SABBAG

International Strategy for
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Preface

Limited evidence on the returns to investments in risk reduction has represented a major challenge for those interested in reducing the impact of disasters for years. Agencies, municipalities, local governments, international organizations, and others investing in risk reduction increasingly need to show clear results and demonstrate financial returns to national and international financial organizations. As a result, there is increasing demand for concrete examples of risk assessment at local and national levels.

The Organisation for Economic Co-operation and Development and the United Nations Office for Disaster Risk Reduction (UNISDR) have been collaborating on the development of a Methodological Framework for Risk Assessment and Risk Financing, which was called for by G20 Ministers of Finance. As part of this collaboration, the UNISDR and its partners provided evidence from recent experience with investments in risk reduction across the globe. This report, produced with support from the World Bank's GFDRR, presents available evidence on the returns to local and national flood risk reduction activities worldwide, evidence that supports the urban risk and Making Cities Resilient campaign housed at UNISDR, and evidence in support of municipal governments, many of which are increasingly seeking guidance on how to address flood risks in urban areas in the form of explicit insights from real country and city experience.

Furthermore, the Global Assessment Report (GAR) and its associated global work streams support and promote the development of national level multi-hazard risk assessments that combine analytical models with empirical data. This publication supports these efforts from the bottom-up by providing an overview of recent experience in flood risk assessment at local and national levels.

Marcus Moench
President and Founder
ISET-International

Executive Summary

Flood disaster impacts are growing significantly as population levels increase, development occurs in flood plains, and populations shift to urban centers. The purpose of this desk review is to explore literature on the costs and benefits of the flood risk reduction strategies being implemented by cities, local agencies, and national authorities. Using available information, we develop an overall framework for differentiating the factors that affect returns in various contexts and the critical assumptions underlying evaluation of these returns. Key insights from the study are briefly listed below.

VARIABILITY AND RANGE OF ECONOMIC RETURNS ON INVESTMENTS.

Returns to investment in flood risk reduction are highly context dependent and vary according to the local situation. Therefore, the adoption of any flood risk reduction strategy should undergo analysis tailored to local contexts before implementation. The studies reviewed also highlight the range of assumptions and factors considered during a typical cost-benefit study. This suggests that developing a broader and consistent approach to analysis is essential to enable comparison across studies. Despite the variability in the analyses undertaken, a few key flood mitigation strategies did standout:

FLOOD PLAIN RESTORATION. Restoration of natural dynamics of river pathways is the only strategy evaluated that had a consistently positive return across contexts. This may be due to that fact that this solution reduces the lack of catastrophic failure and has relatively few downsides or negative externalities.

FLOOD PROOFING OF RESIDENTIAL INFRASTRUCTURE. Overall, flood proofing of residential infrastructure is lower cost than most other strategies for flood risk reduction. Studies highlighted, however, that the cost of this exercise is borne by those owning the houses.

EARLY WARNING SYSTEM. Early warning systems rarely have benefit-cost ratios below one. These systems address multiple hazards and are effective when the response time available is short. Early warning systems are, however, most effective when events are frequent. If an event has a frequency period of 200 years, early warning systems are unlikely to be cost-effective (Rogers and Tsirkunov 2010).

GAPS IN ECONOMIC EVALUATION

The literature on the costs and benefits of flood risk reduction contains numerous gaps. These include:

BEHAVIORAL RESPONSE MODIFICATION AND EXPOSURE REDUCTION/ PROPERTY MODIFICATION. Response and property modification strategies are evaluated much less frequently than non-structural and structural flood modification strategies. This is probably due to the complexity of evaluating, and perhaps inexperience of evaluation of, these more 'soft' approach solutions. It may also be due to the large investments and easily available cost data for structural approaches to flood modification. There is a particular gap in research and information available on the returns to soft investment in such things as building regulations, zoning, preparedness, and voluntary purchase. Voluntary purchase is the landowner's right to sell or not sell to a purchasing authority (BTRE 2002).

PREPAREDNESS**.** From a technical perspective, preparedness is often identified as one of the most effective strategies that communities can employ (Khan 2012), however, very few studies identified the overall costs and benefits of different preparedness strategies. As a result, there was little information concerning quantitative economic returns.

LIVES SAVED**.** The value of lives saved due to a flood reduction strategy is challenging to quantify. Very few of the reviewed studies attempted to address this element quantitatively and those that did often used assumptions that could be challenged on ethical or other grounds. As a result, where lives are concerned, it is suggested that a systematic process be put in place to estimate the investment required per life saved rather than to establish the "value" of lives.

PSYCHOLOGICAL TRAUMA. During catastrophic events, the most common trauma experienced by households is the psychological stress. In a recent ISET study in Pakistan, for example, the primary concern of the households recovering from the 2010 floods was the psychological impacts (Khan 2012). This is often qualitatively addressed in the studies, but not scientifically. As a result, research is required to improve understanding of psychological losses and the economic impacts of such losses.

NEXT STEPS

The research uncovered a significant amount of data concerning assumptions and the factors that affect economic returns to investments such as discount rates and local conditions. This is further illustrated the Findings section of this report. However, due to the fragmented nature of the literature, the variety of methods utilized and the absence of any systematic basis for evaluating many of the factors affecting both costs and benefits, it is currently impossible to draw conclusive arguments regarding returns from investments across the full range of different strategies. For this reason the authors strongly suggest that:

- Evaluations are undertaken to estimate the returns to strategies, such as preparedness as well as flood response and property modification, which are widely advocated but where little information is currently available.

- That standardized procedures are developed to ensure the factors considered and the assumptions made in evaluating the economic returns to investment in flood risk reduction are reported.

The above steps are essential in order to target and justify investments in flood risk reduction.

Introduction

Global urbanization, population, and development trends combined with climate change are driving rapid increases in flood related disaster losses. Over the coming decades, intensification of land use and movement into vulnerable areas will further increase exposure to climatic shocks, especially in locations such as coastal areas, major river basins, and areas prone to flash flooding. In the case of Thailand, land use change has drastically altered the landscape. The 2011 Thailand floods were as much a man-made disaster as it was a natural one. Even before the season rains began in July, dams were already at the full capacity, however, lack of communication resulted in failed discharge procedures (Kertbundit 2011). The floods not only impacted the local economy, but also had a devastating impact on global supply chains. Many sectors (automotive, electronics, agriculture, and tourism) reported significant disruptions. Toyota, Honda, Nissan, and Ford are all experiencing setbacks in production. In addition, Apple, Sony, Canon, and Toshiba were forced to close their facilities (Chachavalpongpun 2011).

This type of failure leads to both greater losses and a sense of urgency for local and national governing agencies to implement better solutions. These impacts have placed significant pressure on local and regional governments to determine viable flood risk strategies for their communities. The question arises as to what is a viable flood risk reduction project or program. Dams, dikes, drains, and diversions are often viable risk reduction strategies against flooding, however, while they offer some level of protection, they can create a vicious cycle where overconfidence in the effectiveness of structural measures creates conditions that can lead to further disaster. Furthermore, many such interventions only redistribute risks rather than reducing them overall. Such is the case for Bangkok's dikes and floodwalls, which shifted flood risks to other regions (Lebel et al. 2008; Manuta et al. 2006; Molle 2009).

These are the types of questions that the paper attempts to address as it looks at the returns of structural and non-structural flood risk reduction measures. Overall, the paper investigates the types of flood risk reduction strategies that have undergone ex-ante or ex-post analysis to build a clearinghouse of information concerning flood returns. The following sections discuss 1) the overall method used to build the database; 2) overall findings; 3) findings by flood risk reduction type; and, 4) conclusions. The Findings section of this desk review, includes a comprehensive breakdown of each strategy, factors impacting return, critical assumptions and economic returns.

Methods

OVERVIEW

The research methodology consisted of an extensive global literature search to *first* develop a systematic framework that identifies the types of flood risks in different ecological zones, *second* to identify the range of activities typically undertaken to manage flood risks in each zone, and *third* to collect and analyze available information concerning the financial returns of types of flood risk reduction. The overall objective of the study was to develop and present a framework for understanding the economics of flood risk reduction, taking into consideration the following:

> DIVERSITY OF CONTEXTS. The impacts of flooding vary greatly depending on the nature of the event and the location. In upper basins, for example, flash flooding is the dominant risk. This contrasts with the central and coastal areas of large basins where inundation and/or the impact of large storms are the most important concerns. Since responses differ in their effectiveness depending on such local conditions, economic returns will differ as well. As a result, the framework needs to capture the diversity of contexts.

CRITICAL ASSUMPTIONS. A wide variety of assumptions often need to be made in order to complete a cost-benefit analysis. In the case of a voluntary purchase strategy employed by the City of Bathurst, the Bureau of Transport and Regional Economics (BTRE) in Australia assumed that no agricultural losses were associated with flooding when identifying voluntary sale of land by farmers and purchase by the city to maintain flood plains as a viable flood mitigation technique (BTRE 2002). Similar assumptions are often made on a wide variety of factors (discount rates, the environmental or other "values" to be considered, etc.) that can have a significant impact on estimated returns. As a result it is essential to ensure that the readers understand the assumptions that are embedded in the cost-benefit analysis if they are to interpret the end findings.

STANDARD METRICS FOR COMMUNICATING FINANCIAL RETURNS. Initial reviews of the literature suggested that returns to investments are reported in a wide variety of ways. As a result, in order to compare results, the methodological framework needed to include a relatively standardized system for comparison. The financial returns typically reported in the evaluation of the costs and benefits of each flood risk reduction strategy include net present values, benefit-cost ratios, internal rate of returns, and avoided costs.

APPLICATION OF DISCOUNT RATES. Discount rates play a critical role in determining determine net present value, benefit-cost ratios, and internal rates of returns. As part of the framework, discount rate information was captured.

To capture the above considerations, a framework was designed that captured flood risk management type and enabled us to identify factors affecting returns and the assumptions made. In addition, the framework enabled comparison of strategies based on the range of metrics used in the published literature.

Given the above, we first undertook a search for existing frameworks that met at least some of the needs for systematic evaluation of available information. Based on an initial review, the approach developed by the BTRE appeared both useful and appropriate. BTRE classifies flood risk reduction strategies under three primary headings: 1) flood modification activities; 2) property modification activities; and, 3) response modification activities. We adapted these categories to ensure comprehension across the categories. Structural and non-structural flood control (also known as BTRE flood modification) strategies are typically structural in nature and modify or adjust the flow of flood water (BTRE 2002). Exposure reduction and property modification strategies attempt to avoid or reduce loss by ensuring that flood water is kept away from areas of habitation or other activities or structures are designed in ways that are flood-adaptive. For example, zoning of development areas to ensure that building does not occur in a flood prone area or if it is constructed in a flood prone area that it is raised so that habitable spaces are above likely flood levels (BTRE 2002). Behavioral response modification strategies attempt to adjust human behavior to respond adequately to floods. For example, the implementation of a flood warning system or introduction of flood-resistant crops can be considered a response mechanism (BTRE 2002). The resulting classification table is shown below.

TABLE 1

CLASSIFICATION TABLE

Sample Measures	Structural or Non-Structural
STRUCTURAL AND NON-STRUCTURAL FLOOD CONTROL	
Levees	Structural
Dams	Structural
Diversions and channel improvements	Structural
Flood gates	Structural
Restoration of Flood Plain	Non
Detention basins	Structural
EXPOSURE & PROPERTY MODIFICATION	
Zoning and land use planning	Non
Voluntary purchase or acquisition	Non
Building regulations	Non
House raising	Non
Other flood-proofing (not necessarily residential)	Non
BEHAVIORAL RESPONSE MODIFICATION	
Information and education programmes	Non
Preparedness	Non
Forecasts and warning systems	Non
State and national emergency services response	Non

* Adapted from BTRE 2002

The BTRE framework outlined above focuses primarily on the nature of the risk management strategy and does not address key elements in the locational context. As a result, the framework was expanded to reflect locational attributes (such as type of hazard) and other key elements (such as assumptions) identified in each study. We did this by considering locational and hazard criteria as outlined below.

Watershed Location

To understand the nature of certain types of flood risk reduction strategies, each strategy was categorized by basin location. The categories include:

DELTAIC

The point at which the river reaches the sea.

CENTRAL

These areas are defined by a gradual slope of the terrain where the transporting capacity of the river has slowed significantly and leading to deposition. Usually the central basins cover large areas.

UPPER

Those areas where the gradient is high and increased velocity leads to quicker flow streams. Usually fed by many tributaries.

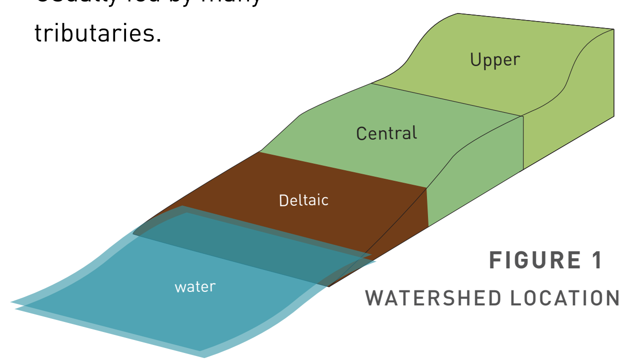


FIGURE 1
WATERSHED LOCATION

Type of hazard

Flood risk reduction strategies were identified by type of flood most often occurring in that area.

COASTAL FLOOD

Occurs along coastal areas and can be caused by hurricanes or tropical storms causing heavy flooding.

INUNDATION FLOOD

Typical flooding that occurs in central basins, usually due to larger amounts of river flow resulting in overflow of its banks.

FLASH FLOOD

Occur within minutes or a few hours after heavy rainfall, a tropical storm, or failure of large systems.

Context

Each study is defined as rural or urban, if identified in the study.

RURAL

Projects completed in or by villages or outside major urban areas.

URBAN

Projects completed in major cities.

Factors not systematically considered in the methodological framework

In addition to the above criteria, a wide variety of other factors affect one's understanding of the returns reported to investments in flood risk reduction. Key factors are listed below. These were evaluated and considered in the analysis where possible. Due, however, to the limited number of studies available and gaps in what they reported as part of their methodology, analysis, and discussion sections, not all studies were able to be categorized and, therefore, these could not be systematically evaluated.

TYPE OF REPORT. Most cost-benefit analyses are completed either ex-ante or ex-post. ex-ante analyses are completed before the project takes places and ex-post are post-evaluations of the project.

DISTRIBUTIONAL CONCERNS. Some studies took into consideration the impact of flood risk reduction strategies on different groups of individuals and evaluated the strategy via those impacted. This is referred to as the distributional impacts of a development outcome (Pearce et al. 2006). For example, Pearce et al. describes a case concerning distributional impacts of different strategies for managing transport in London where users of the roadways are charged a higher fee during peak period times to enter central London in efforts to reduce congestion.

FUTURE LAND USE. With future climate impacts, studies were investigated to see if they looked at future land use trends as part of the probabilistic approach to flooding scenarios. Therefore, we asked the question if future land use concerns were integrated into the analysis. For example, did city authorities identify land use trends when identifying areas for zoning in relation to future flooding disasters?

NON-MARKET VALUES CONSIDERED. Non-market values can be considered those goods and services that are not bought or sold directly and, therefore, do not have a monetary value associated with them. They play a critical role in determining overall benefits and costs. For each study, we asked the question if non-market values were considered in the analysis.

PROBABILISTIC APPROACH TAKEN. Some of the studies looked at future probabilistic scenarios of increased flooding due to climate impacts. Did the author/authors integrate probability scenarios into the cost-benefit analysis?

METHODS DISCUSSED. As a general criterion, we asked if the authors discussed the methods used to develop their financial returns. This ensures that some deeper understanding occurs when reading into the financial returns and drawing conclusions.

STANDARD METRICS WERE USED. In general, flooding scenarios seemed to have been categorized systematically in the studies. Did the author/authors discuss their results and inputs in standard metrics understood by a broader audience? For example, flooding scenarios are often expressed in 10-year flood, 50-year flood, 100-year flood, and Probable Maximum Flood.

THRESHOLD EFFECTS CONSIDERED. In terms of climate change, threshold effects may not be typical in the future with increases in extremes. Did the author/authors define or integrate maximum threshold effects?

PORTFOLIO STRATEGIES: While many of the flood mitigation studies reviewed included structural and non-structural measures, most were focused on evaluating a single strategy. With the single strategy approach, the research attempted to draw comparisons between individual strategies and did not address portfolio approaches.

METHODOLOGICAL LIMITATIONS

A limited number of articles are available concerning the costs and benefits of flood mitigation strategies. Therefore, the sample size of the results is not large enough to draw statistical significance and, as outlined in the preceding section, it was impossible to systematically compare many of the factors that are central to interpreting results of each study present in the literature. As a result, it was often not possible to compare strategies against one another. In addition, assumptions were made related to the type of hazards, regional occurrence of the flooding event, and classification of each strategy. These assumptions are informed by the expertise of the research team, however, could be subject to debate. Overall, the examined information is provided mostly in tabular results to avoid assumptive result making due to the complexities of each cost-benefit study and those elements that were integrated or not integrated.

Findings

Each study reviewed chose to investigate the returns to investment in flood risk modification strategies differently. Some studies focused their attention on benefit-cost ratios (BCR), while other studies used net present values. A few studies looked at the avoided costs or damages.

Each of the measures is only somewhat comparable by looking at each study's economic returns. In theory, the benefit-cost ratio is an overall economic evaluation that incorporates all societal costs and values, not just the financial returns to a project. A benefit-cost ratio of greater than one, as a result, suggests the investment has returns that are at minimum competitive with other readily available forms of investment (such as leaving the funds in a bank at current interest rates). The benefit-cost ratio takes the discounted benefits divided by the discounted costs. The higher the benefit-cost ratio, the better the investment. Net Present Value (NPV) provides similar information but in absolute rather than relative terms. A positive NPV suggests that the project should be adopted. This is after the discounted benefit and cost cash flow streams are subtracted from one another. Another measure of economic efficiency is the use of the internal rate of return (IRR). IRR represents the rate of growth participating parties require in order to make an investment. Avoided costs and damages do not incorporate information on the size of the investment and are frequently presented as absolute numbers over the lifetime of an investment that may or may not be discounted to current values. Avoided costs or damages can be thought of as the annual or aggregated flood damages in absence of a flood risk reduction strategy minus the flooding damages that would occur with the implementation of that risk reduction strategy. For example, the construction of a diversion channel would reduce flooding, however, not by 100%. Therefore, subtracting the avoided damages without the measure from avoided damages with the measure results in the overall benefit (Woodruff 2008).

Table 2, on page 14, illustrates the range of results aggregated from the studies. The table exhibits the range of positive and negative returns to investment that are present with each mitigation type. If we further aggregate the table's benefit-cost ratios it shows likeness between non-structural and structural flood modification and behavioral response modification strategies, 0.06 to 104.96, 0.96 to 70, respectively. This demonstrates that structural approaches to flood modification can, depending on local context, design, and a host of other factors, either represent very poor or very good investments while most investments in response modification are likely to be positive. To put it another way, soft investments in response modification have a relatively low risk of loss and can generate high returns while structural measures have a higher downside potential. This is probably due to the high costs of many structural measures in comparison to softer behavioral measures, along with the numerous location specific factors that can increase their costs or reduce their effectiveness. These general points aside, however, it is important to recognize that direct comparisons cannot be made between the results reported below due to the nuances and assumptions made during each study.

In addition to the above, data presented in the table below suggest that non-structural and structural flood modification strategies are the most evaluated of the types of strategies employed closely followed by behavioral response modification strategies. Exposure reduction and property modification is much less widely evaluated and was only 17% of the total flood risk reduction strategies for which published estimates are available in the literature. Furthermore, information on the returns to investment in both property and response modification is more rare than for structural flood mitigation. Some investments, such as in preparation, have limited information on returns available while other investments in zoning, building regulations, etc. only report avoided costs. Overall, economic evaluations focus heavily on the large structural investments where cost data are readily available.

Further exhibited in the table below are discount rates and the range used by type of strategy. The discount rate has a significant impact on determining if a project should move forward or not and the table suggests that there is no common metric under utilization. Holland (2008) states that many economists argue that communities as a whole have lower discount rates since they are willing to wait longer for benefits, compared with private or commercial entities.

TABLE 2

OVERALL RESULTS BY CATEGORY

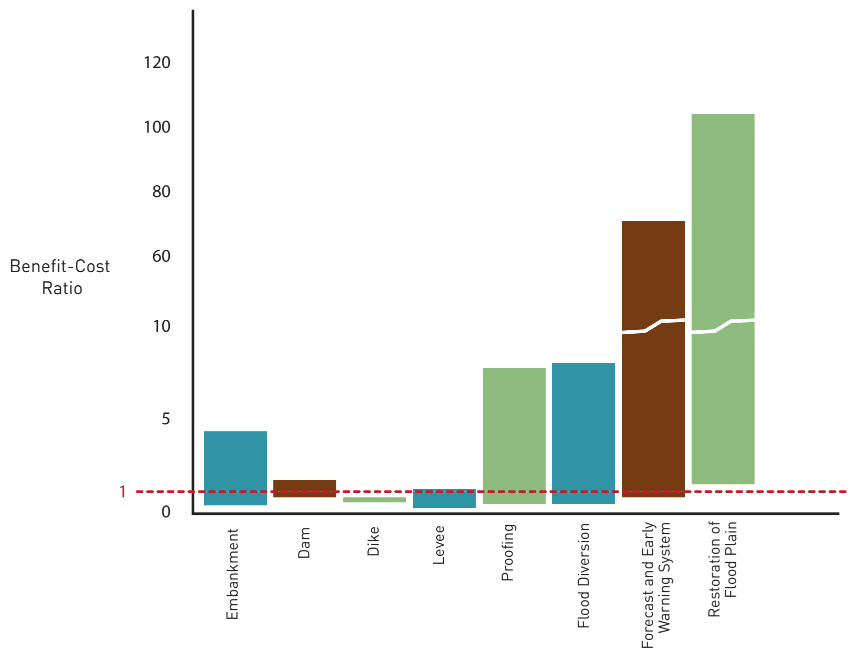
CATEGORY	TYPE	BC RATIO	NPV (USD 2010)	IRR	AVOIDED COSTS	DISCOUNT RATE
Structural And Non-Structural Flood Control	Dam	0.7–1.34	-8,131,000 – 4,492.488	7.1–12.9%	–	10%
	Dike	0.67	–	–	–	4, 10%
	Flood Diversion	0.06 – 8.55	1,392,468– 86,789,133	10.6 – 31%	–	3, 7, 10, 12%
	Levee	0.29 – 1.03	-8,436,120 – 635,556	1.6 – 10.3%	–	10%
	Drainage	–	–	50% OR GREATER	–	none given
	Embankment	0.38 – 4.9	–	–	–	3, 7, 10%
	Restoration of Flood Plain	1.34–104.96	16,893,147– 1,089,497,481	–	–	4–7.23%
Exposure Reduction And Property Modification	Proofing	0.53 – 8.07	5871	–	–	3, 3.5, 7, 10%
	Zoning	–	–	–	AUS $ 29 M	–
	Building Regulations	–	–	–	AUS $ 6.5 M	–
	Voluntary Purchase	–	–	–	AUS $ 1.8 M	–
Behavioral Response Modification	Forecast And Early Warning System	0.96 – 70	5,171,118	30%	–	–
	Preparedness	3.5 – 24	242,426	–	–	–

DISCUSSION BY MODIFICATION TYPE

Further investigation into each strategy type illustrates the overall inconsistency and range of results found by those studying returns. Figure 2, below, depicts the range of results found by each flood risk reduction strategy that used the benefit-cost ratio as the common metric. As seen below, restoration of flood plain returns are all above one with a large range of positive returns.

FIGURE 2

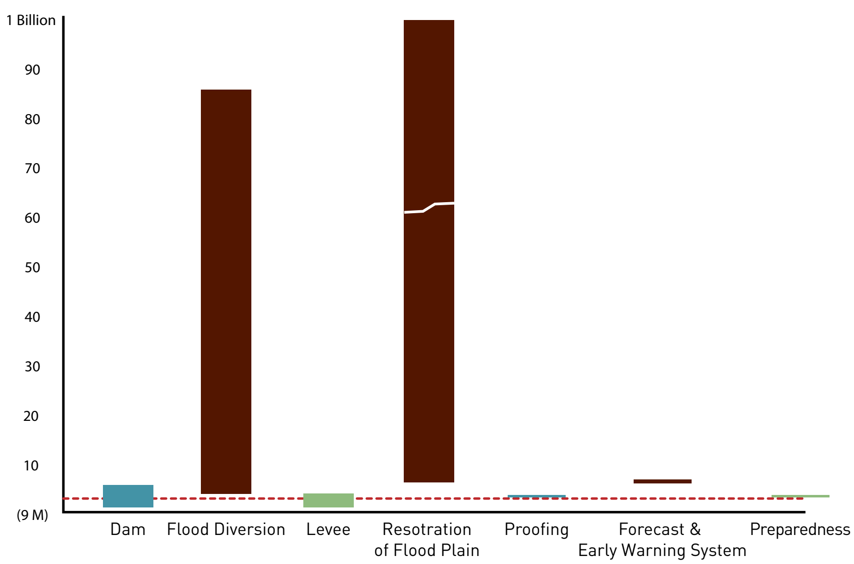
BENEFIT-COST RATIO BY STRATEGY TYPE



To further expand, net present values were found for multiple strategies. Dams were most often found to have a negative net present value while restoration of flood plains still have high positive returns.

FIGURE 3

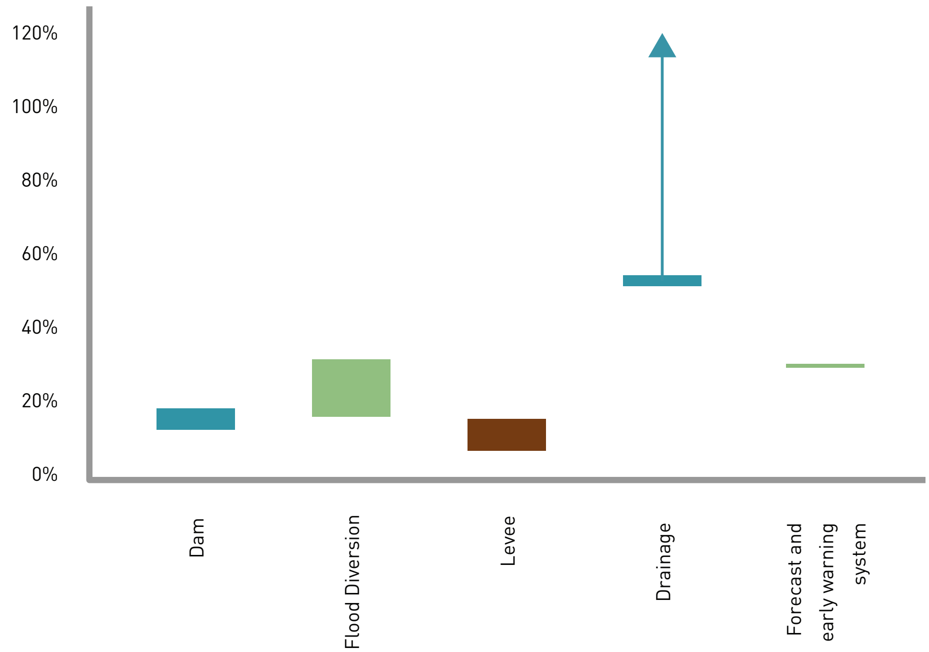
NET PRESENT VALUE BY STRATEGY TYPE



The internal rate of return was used much less often than other metrics. In certain studies, the internal rate of return was very high, such as drainage as well as forecast and early warning systems.

FIGURE 4

INTERNAL RATE OF RETURN BY STRATEGY TYPE



GEOGRAPHIC CONTEXT OF RESULTS

The following graphs illustrate the manner in which results are distributed in relation to geographic typologies. The below percentages are based on the count of strategies employed in each type location. For example, one study may have investigated multiple strategies and each of those strategies is considered a data point. Of the flood risk reduction measures identified, 71% of the measures were completed in urban areas while only 29% were completed in rural areas. The concentration of urban measures signals that flood risk reduction most often results in larger scale systems that will prevent assumed larger scale losses. Approximately 47% of the mitigation measures were implemented in deltaic areas, which aligns with the fact that most of the mitigation measures were categorized as coastal floods. Overall, the mitigation measure most reviewed was structural and non-structural flood modification. In summary, flood modification measures are most implemented in deltaic, urban areas and in response to coastal floods. Flash floods in higher areas of basins and the value of protection in rural areas are relatively under represented.

FIGURE 5

TOTAL % OF MITIGATION MEASURES BY REGIONAL CONTEXT

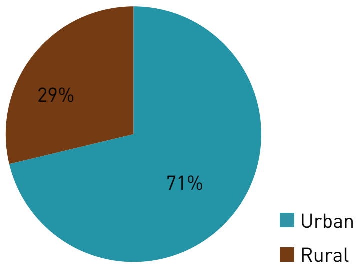


FIGURE 6

TOTAL % OF MITIGATION MEASURES BY WATERSHED LOCATION

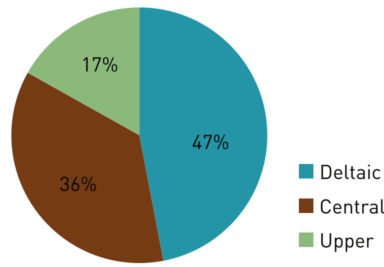


FIGURE 7

TOTAL % OF MITIGATION MEASURES BY TYPE OF FLOOD

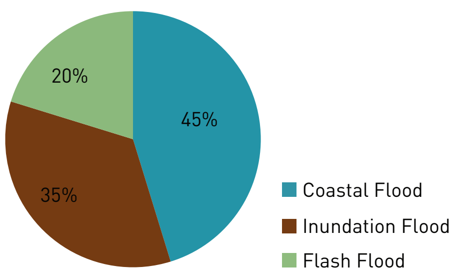
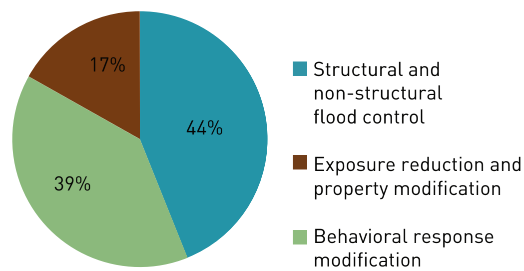


FIGURE 8

TOTAL % OF MITIGATION MEASURES BY FLOOD MITIGATION TYPE



To provide further analysis, the data was characterized by watershed location and type of strategy. As discussed earlier, the percentages are based on the count of strategies employed. It is interesting to note that more structural flood modification strategies are used in central and deltaic areas, while upper basins host primarily response strategies. This seems logical for upper basin scenarios where communities are more often faced with flash flooding events. In those situations, response systems (early warning) may be the only viable solution.

FIGURE 9

FLOOD RISK REDUCTION STRATEGY BY WATERSHED LOCATION

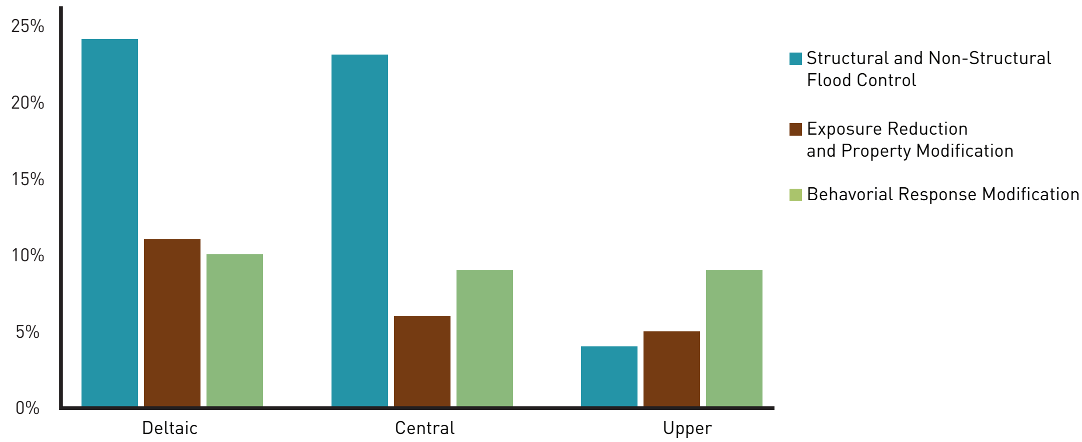


Figure 9, below, illustrates that in urban areas strucural and non-structural flood control measures are implemented the most. However, in rural areas there seems to be a mixture of behavior responses completed in upper basins and structural responses completed in delatic areas. In rural areas, behavioral response mechanisms are used in upper basins while structural and non-structural flood control is used in rural deltaic areas.

FIGURE 10

FLOOD RISK REDUCTION STRATEGY BY WATERSHED LOCATION AND CATEGORIZED BY RURAL OR URBAN

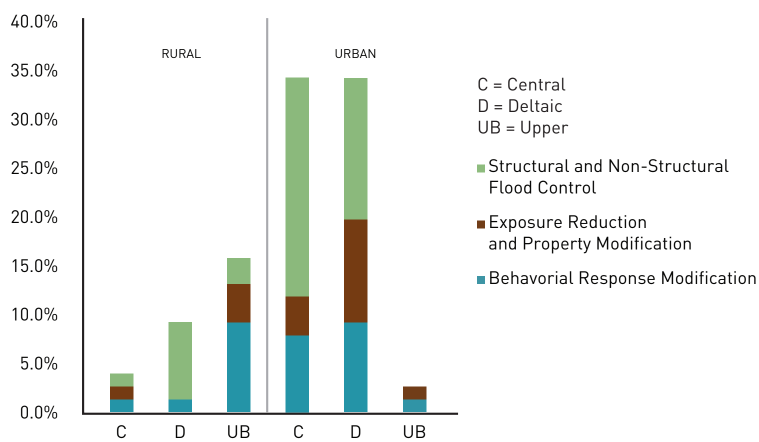
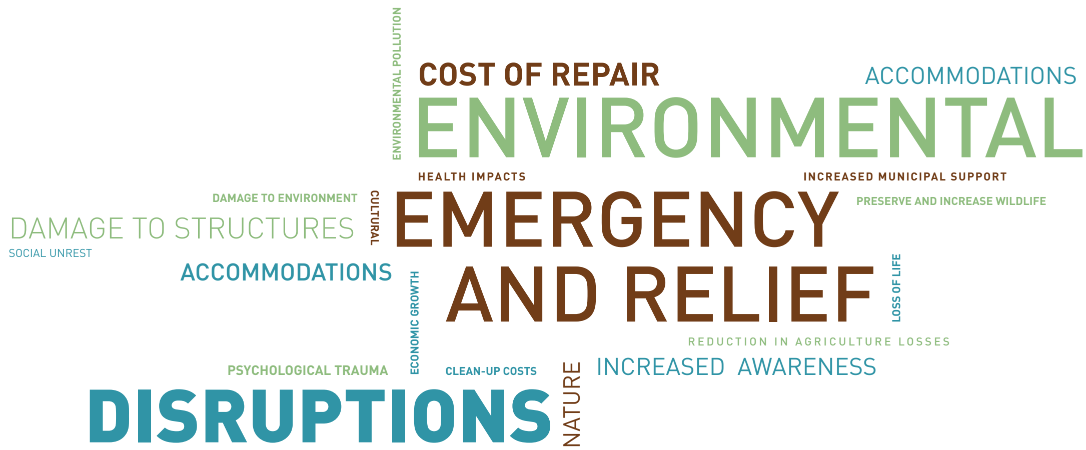


FIGURE 11

KEY WORD COUNT



Emergency And Relief =137 • Environmental =129 • Disruptions (Business, Networks, Public Services) =114 • Damage to Properties =79 • Cost Of Repairtotal =50 • Damage to Structures =45 • Accommodations =38 • Increased Awareness =38 • Nature =36 • Damage to Environment =19 • Loss of Life =14 • Reduction in Agriculture Losses =12 • Health Impacts =10 • Cultural =10 • Preserve And Increase Wildlife =8 • Increased Municipal Support =4 • Psychological Trauma =4 • Environmental Pollution =3 Economic Growth =2 • Social Unrest =1 • Clean-Up Costs =45

COSTS AND BENEFITS

In order to get a sense of the factors considered in most analyses of the economic returns to investments in flood risk management, a key word count was conducted on all the articles reviewed that had returns on investments. The results of this word count are shown in the above diagram. The larger the text the more frequent that variable was identified in the study. The results highlight the high levels of attention given to costs related to emergency relief, environmental, and business and public service disruption. These three categories parallel some of the most important organized constituencies (disaster response organizations, environmental groups, and those dependent on key business services) whose functions are directly affected by floods. Interestingly, other high priority social values (loss of life, economic growth, psychological trauma) are relatively rarely mentioned. Furthermore with the exception of environmental values (where substantial attention has focused among economists on developing valuation techniques) most of the other costs reflected in the key word count represent areas where financial or other cost data are relatively available or can be collected. Information on damage to structures, properties and costs of repair, for example, is often collected by insurance agencies. Business and service disruption are also often insured costs. Emergency relief costs are well documented by organizations involved in such activities and are readily available from their budgets and project accounts. In contrast, cultural values, health impacts, social unrest, and similar costs are areas where far less data tend to be available and quantification requires special techniques.

The word count further illustrates that those elements difficult to quantify are not taken into consideration. For example, social unrest and psychological trauma are not considered in most cost-benefit analyses because of the inconsistent or unrealistic ways of valuation. Furthermore, increased municipal support is mentioned in one article, which suggests the difficulty in differentiating between increased and ongoing services that municipalities often have to adopt in order to provide risk reduction services. Municipalities bear most the costs associated with flood risk reduction.

FLOOD RISK REDUCTION STRATEGY DISCUSSION

In an ideal world, flood mitigation strategies should consider a range of measures to reduce potential risk to floods (Heidari 2009). These measures can be structural or non-structural in nature. Structural measures are considered those measures that involve the construction of a structure that is designed to be defensive in the event of a flood (Hendel 2010), while non-structural measures are measures where the solutions are managing humans versus managing nature (Hendel 2010, Blackett et al. 2010). Faisal et al. (1999) argues that the use of structural measures does not ensure resilience against floods and is further reiterated by Heidari's (2009) thoughts concerning that a flood mitigation plan should include both.

The above analysis of data from studies on the economics of flood risk reduction, however, clearly illustrate the tendency to focus analysis on structural solutions rather than on the wide array of non-structural "soft" measures for mitigating flood impacts.

The discussion below explores the nature of analysis typically undertaken for each type of intervention strategy.

DAM

The use of dams as a flood modification measure has, over recent decades, become more controversial. As a result, detailed cost-benefit studies would seem to be particularly important in order to guide decision-making in individual cases. Few studies were found, however, that determined the overall cost-effectiveness of dams, let alone discuss the distributional benefits and costs of dams. Duflo and Pande (2007) introduce the realism of how costs and benefits of dams are differentiated by area. Their study reveals that those downstream from dam sites benefit more from increased irrigation than those living in the vicinity and immediately upstream. In fact, those inhabitants near the vicinity of the dam experience higher rates of poverty.

Of the two studies reviewed, one study looked at the overall benefit of the avoided damages to reduce flooding, while the other study focused on the overall benefits of improved irrigation. One factor that plays a role in the return is the determination of the flood damage rate, which involved the review of historical data for flood magnitudes and frequency analysis of the floods. Software and simulation modeling was used to understand flood frequency and flood depth. The flooding model assumed probable maximum floods to determine return periods and the detention dam height were left at maximum probable height (Heidari 2009). Furthermore, the catchment area is an area that can impact overall return. Duflo and Pande (2007) addressed the reduction in productivity of the submerged reservoir and increased waterlogging, salination and worsening land quality within the upstream catchments. Their study expressed the cost of dam construction in terms of irrigating an additional hectare by the dam. Heidari (2009) did mention the incorporation of tangible and intangible risk costs, however, it was not apparent how those were calculated or integrated into the overall costs.

DAM			
Factors Impacting Return	**Critical Assumptions**	**Financial Returns**	**Author**
Location, size, and operation conditions of different alternatives (Heidari 2009) Use of historical data for flood magnitudes and frequency analysis (Heidari 2009) Upper storage reservoir flood control simulation (Heidari 2009) Detention dam height was determined based on maximum feasible height regardless of flood magnitudes (Heidari 2009) Flood volume impacts on reservoirs (Heidari 2009)	Optimum return period was considered 25 years for river training measures such as dikes and diversion based on the guidelines (Heidari 2009) Focuses on areas where damages and losses are greatest (Heidari 2009)	BC Ratio: 0.7 – 1.34 NPV: -8 – 4.42 Million USD IRR: 7.1 – 12.9%	(Heidari 2009)

FLOOD DIVERSION

In a total of five studies, the flood diversion strategies discussed consisted of construction of upstream ponds, diversions into existing estuaries and channels, and development of a polder system, which is considered an artificial retention system encircled by a dam in an upstream area (Environmental Resources Management 2005; Mechler 2005). In most cases, flood diversion strategies were a positive NPV or above one benefit-cost ratio. Most of the factors that impact return vary between study and the elements that cross cut the studies are time and area of the flooding inundation. It is interesting to note that Mechler determined a benefit from quantifying the storage of water that the polder would collect during the rainy season for irrigation use (2005). The critical assumptions that played a common role in the analysis were the project life variable and the flood expectancy, which the authors based their results on a 100-year flood.

FLOOD DIVERSION

Factors Impacting Return	Critical Assumptions	Financial Returns	Author
Quantifying the storage of water that the polder will collect during the rainy season to use for irrigation (added benefit) (Mechler 2005) Area to be flooded (Mechler 2005) Area used for agriculture (Mechler 2005) % of total agriculture area (Mechler 2005) Direct loss based on past data (Mechler 2005) Incomplete damage assessments. Data is not available for all relevant direct and indirect effects (Mechler 2005) Spatial distribution of damages. Damages are partially referred to the whole department they had to be downscaled (Mechler 2005) The benefits of risk reduction estimates were not included (Mechler 2005) Value of life estimate includes $150,000 soles per fatality and does not include other adverse health effects (Mechler 2005) Costs of digging through bedrock (Woodruff 2008) Cost of building the road over the channel (Woodruff 2008)	Intervention occurs in sparsely or non-populated areas of cities (Risk to Resilience Study Team 2009) Current flood protection in basin with existing dikes is not considered sufficient (Mechler 2005) Protect up to a 100-year event (Mechler 2005) Other potential effects not considered include no human settlements or economic activity (Mechler 2005) Discount rate (Mechler 2005) Recurrence of hazards estimates are based on two data points (Mechler 2005) Creation of fragility curves (Mechler 2005) Exposure was not included – past dynamics are accounted for (Mechler 2005) Did not assume the reduction in health care costs (Woodruff 2008) Estimated life of the diversion channel is 50 years (Woodruff 2008) Assumed that the damages associated with flood events with a 1-in-100 year return period or less could be completed avoided with construction of the diversion channel (Woodruff 2008) Did not consider the costs of resettlement (Woodruff 2008)	BC: 8.55 Million PKR NPV: 2,234 Million PKR	(Risk to Resilience Study Team 2009)
		BC Ratio: 0.06 – 0.09	(Woodruff 2008)
		BC Ratio: 1.1 NPV: 1.37 Million USD IRR: 10.6 %	(Heidari 2009)
		BC Ratio: 3.8 NPV: 77.7 Million USD IRR: 31%	(Mechler 2005)
		BC: 4	(Rogers and Tsirkunov 2010, Forester et al. 2005)
		BC: 0.1	(Rogers and Tsirkunov 2010, Gocht 2004)

LEVEE/DIKE

Four studies reviewed incorporated information on levees/dikes. Overall, the major factors impacting return for levees and dikes are the total costs of the systems and the linkages that the systems have with other systems. For example, in the case of the Netherlands, their dike systems are built with redundant dike rings and the study assumed that all the dike rings would be flooding in the analysis which increases the overall amount of damages incurred due to flooding (Jonkman et al. 2004). Venton and Burton (2009) had limited data available for their study concerning levees and experienced ongoing recall bias from surveying past households. They made assumptions that the benefits would accrue over the lifetime of the dike if regular maintenance was carried out and that no deaths or schools days were lost when experiencing flooding events, which were not calculated into the overall avoided damages.

In almost all the cases of levees and dikes, distributional impacts, future land use, and non-use values were not considered in the studies. In one case, distributional concerns were taken into consideration. The levees were found to be impractical due to their impact on flood behavior and the ability to become a high hazard area where people would be evacuated (BTRE 2002). This, therefore, resulted in choosing an alternative flood risk reduction strategy. Furthermore, Heidari (2009) explains that a certain area slated for construction of a dike would increase the damage in comparison to the "without scenario" resulting in a negative net present value. The benefit-cost ratios and net present values show that both levees and dikes, more often than not, had a below one ratio or negative net present value.

LEVEE			
Factors Impacting Return	**Critical Assumptions**	**Financial Returns**	**Author**
Location of the levee	Assumed that regional economies were not affected by the flooding (Olsen et al. 1998) Assumed that a reduction in economic output and loss of availability (Olsen et al. 1998) Assumed that loss of life or environmental damages did not occur (Olsen et al. 1998)	BC Ratio: 0.29 – 1.03 NPV: -8.3 – 0.1 Million USD IRR: 0.016 – 8.4%	(Heidari 2009)
		NPV: 1.15 Million AUD	(BTRE 2002)
		Avoided Costs: 3.2 Million AUD	(BTRE 2002)

DRAINAGE

Two articles discusss drainage as a strategy. Drainage was not employed as much as other larger scale solutions. In this context, drainage was defined as the maintenance and construction of key points along the river to reduce the flood cycle. A key aspect of drainage is ensuring that operations and maintenance occurs so as not obstruct flow and it was assumed that this reduces overall damage losses in flooding events (Risk to Resilience Study Team 2009).

DRAINAGE			
Factors Impacting Return	**Critical Assumptions**	**Financial Returns**	**Author**
Maintenance of key drainage points was considered to reduce losses to all categories (Risk to Resilience Study Team 2009)		Capital Costs: 151 Million INR Annual O&M: 10 Million INR	(Risk to Resilience Study Team 2009)
		IRR: 50% or greater	(Environmental Resources Group 2005)

EMBANKMENT

In four studies, embankments were used in all types of flooding hazards: flash, coastal, and inundation floods. A few of the issues that arose with the use of embankments include the restriction of nutrient replenishment to the flood plain, water logging, and the cause of waterborne diseases (Risk to Resilience Study Team 2009). Capital costs were not included in the India case study, which was a key factor impacting the return due to the fact that the embankments had already been constructed and the analysis was mostly concerned about the maintenance. Furthermore, the inclusion of real land compensation costs and a true reflection on the maintenance costs associated with the embankment were addressed in the analysis lowering the overall benefit-cost ratio (Risk to Resilience Study Team 2009). In a similar embankment case in Samoa, lack of data and not incorporating health, trauma, and stress costs were elements impacting the return. In addition, failure of the floodwalls and extreme floods were not considered in the analysis (Woodruff 2008). For both studies, the discount rate had a significant impact on the overall return of the projects, where in the India case study embankment maintenance just hovered above one, while in Samoa the embankment intervention was below one.

Distributional benefits were not considered in the India case study showing the challenge to adequately address this issue. Assumptions made include that rainfall and large-scale data was accurate, flood losses were linearly related to the flood area, and future exposure was represented by projected population growth (Risk to Resilience Study Team 2009).

EMBANKMENT

Factors Impacting Return	Critical Assumptions	Financial Returns	Author
Restriction of nutrient replenishment to flood plain (Risk to Resilience Study Team 2009) Water logging which causes waterborne and vector based diseases (Risk to Resilience Study Team 2009) Crop destruction (Risk to Resilience Study Team 2009) Insufficient maintenance that leads to failure (Risk to Resilience Study Team 2009) Management of the basin (Risk to Resilience Study Team 2009) Embankments have been encroached upon and used as agricultural areas (Risk to Resilience Study Team 2009)	Used real land compensation costs (Risk to Resilience Study Team 2009) Typical discount rate of 10 – 12% (Risk to Resilience Study Team 2009) Distributional benefits not considered (Risk to Resilience Study Team 2009) Data representative of entire basin (Risk to Resilience Study Team 2009) Rainfall and large-scale data is accurate (Risk to Resilience Study Team 2009) Flood losses are linearly related to the flood area (Risk to Resilience Study Team 2009) Future exposure is representative by project populations (Risk to Resilience Study Team 2009)	BC Ratio: Greater than 1	(Risk to Resilience Study Team 2009)
Floor height and building material (Woodruff 2008) Acquiring private lands and accessing channels through private properties (Woodruff 2008)	Distribution of losses where the flooding occurred (Woodruff 2008) Extreme events were not considered (Woodruff 2008)	BC Ratio: 0.38 – 0.64	(Woodruff 2008)

RESTORATION OF FLOOD PLAIN

The six studies that addressed restoration referred to it as an investment made in strengthening the river. This may be the result of strengthening bottlenecks and restoration of the flood plain itself, i.e. wetland or mangrove restoration. One option in minimizing the impact of flooding is to increase the rivers discharge capacity as adopted in the Netherlands. This is achieved by expanding the flood plain or by adding discharge compartments, also known as "green rivers" (Vis et al. 2003). A key insight into this strategy is that for every study completed on restoration of flood plains, the benefit-cost ratios were above one and the present values were positive. This strategy seems to employ some of the highest returns to investment socially, economically, and environmentally.

Factors that impact overall return are the ecological benefits of the restoration, if considered or not considered, and the benefit of cleaner water. Overall, cleaner and increased groundwater was addressed in multiple studies as a result of flood plain restoration. In certain cases of restoration, the timeframe of planting and loss of agricultural land are key areas impacting the overall return. A few overlying key assumptions were the frequency of the events, inclusion of distributional concerns and socio-economic benefits as well as the lifetime of the intervention. In the case of the Lai flood plain, ecological restoration would result in the relocation of communities and current resettlement laws would not compensate the most vulnerable (Risk to Resilience Study Team 2009).

RESTORATION OF FLOOD PLAIN

Factors Impacting Return	Critical Assumptions	Financial Returns	Author
Relocation costs (Risk to Resilience Study Team 2009) Market value of building units (Risk to Resilience Study Team 2009) Considered future land use (Brouwer and van Ek 2004)	Did not consider the ecological benefits to river restoration (Risk to Resilience Study Team 2009) Did not consider the costs of piping sanitation to all households and treating sewage (Risk to Resilience Study Team 2009)	BC Ratio: 1.34 NPV: 15,321 Million PKR	(Risk to Resilience Study Team 2009)
4% discount rate used as required by the Dutch Treasury (Brouwer and van Ek 2004)	Considered the benefits of cleaner ground water (Risk to Resilience Study Team 2009)	BC Ratio: 28.86–104.96	(Viet Nam Red Cross 2011)
Discounted over a 100-year period (Brouwer and van Ek 2004) Financial and economic costs of expropriation and compensation payments (Brouwer and van Ek 2004) Economic prices are based on opportunity costs, lost earnings from current and future agricultural and industrial activities calculated on the basis of time series analysis (Brouwer and van Ek 2004) Financial prices are fixed by the government (Brouwer and van Ek 2004)	Assumed ability to relocate communities into new areas (Risk to Resilience Study Team 2009) For every 2.7 miles of wetlands, storm surges are reduced by approximately 1 foot per year (Cigler 2007) Used willingness to pay meta-analysis to identify societal benefits of restored environment (Brouwer and van Ek 2004) Exclude taxes (such as the V.A.T) (Brouwer and van Ek 2004)	NPV: -2.1 Billion Euro (without socio-economic benefits) NPV: 860 Million Euro (with socio-economic benefits)	(Brouwer and van Ek 2004)
Hydraulic and hydrological flood flow changes are assessed (Brouwer and van Ek 2004) Timeframe of planting (Viet Nam Red Cross 2011) Planting inputs and outputs (Viet Nam Red Cross 2011) Reduced costs of dike repair due to mangrove restoration (Viet Nam Red Cross 2011) Similar storms comparison with nearby cities for damage data (Viet Nam Red Cross 2011)	Reduction in future damages by changing the nature of economic activities. This is not included in the model, however, learning to live with floods through land use changes and flood plain restoration is believed to increase public awareness and appreciation of water system dynamics. (Brouwer and van Ek 2004) Did not include the future costs of dike strengthening (Brouwer and van Ek 2004) With controlled flooding, less people have to leave their homes. It is assumed that the societal disruption is smaller and the flood damage will be substantial (Jonkman et al. 2004) Assumed a ten year frequency between major typhoons in the studied communes (Viet Nam Red Cross 2011)	BC Ratio: 25 NPV: 1,359 Million PKR	(Risk to Resilience Study Team 2009)

PROOFING

Possibly the most discussed strategy (addressed in eight studies) is proofing, which ensures that structures are resilient to flooding events; this may be housing, roads, public buildings, etc. Raising the plinth level of houses, building on tall pillars, constructing flood walls along properties, and moving assets to upper floors are considered proofing activities (Faisal et al. 1999). Other elements of proofing for houses include the filling of basements with sand and suitable fill, constructing vestibules and installing flood shields to allow water to enter the vestibules in times of flooding (FEMA 1997). Proofing can occur at any scale, including the use of bitumen in order to seal roads, for example. Bitumen is designed to impede the flow of flood water and reduce the region of road shoulders from flooding (BTRE 2002). Furthermore, in India the raising of hand pumps was used as a proofing activity because of the silt and debris carried by the flood water (Venton and Venton 2004). Factors specific to proofing that impact return include where the materials are sourced (BTRE 2002) and the height and type of structures built (Woodruff 2008). It is interesting to note that the Risk to Resilience Study Team (2009) determined that such 'people-centered' approaches lead to dynamic starting points for other benefits and can shift the benefit and cost calculations. Holub and Fuchs (2008) stated the assumption that the enhanced constructions and sealed openings were only suitable to protect buildings in certain zones implying the challenge in ensuring that all proofing measures work in different flood events.

Overall, limited economic analysis has been completed concerning proofing as a viable solution to flooding. This suggests that this more 'personal' and smaller flood prevention interventions allow for integration of values that normally to challenging to incorporate. Furthermore, of the studies completed, the benefit-cost ratios were above one.

There has been little economic analysis completed on the returns of zoning probably due to the complexity of the studies. The costs of determining zoning are somewhat unknown and quantifying those elements leads to complex discussions.

Benefits	Costs
Improved enhancement and cooperation amongst governments;	Loss of property tax revenue to municipalities;
Elevated level to technical competency;	Legal and administrative costs to landowners;
Improved design standards and policies for infrastructure;	Costs of updating flood plain maps and studies;
Used for other purposes (flood forecasting);	Loss of real estate value of existing properties;
Created businesses related to flood-prone mapping; and,	Landowners requesting public agencies to purchase their flood-vulnerable land;
Recognition of the need for watershed planning.	Limiting available construction footprint; and,
	Cost of retention ponds outside regional flood line.

* Source: Loe and Wojtanowski 2001

PROOFING				
Types	**Factors Impacting Return**	**Critical Assumptions**	**Financial Returns**	**Author**
Stilt/elevated houses Flood shelters Elevated hand pumps and toilets Flood resistant roads Relocation of additional structures	Different people centered interventions lead to dynamic starting points for other benefits (can increase or decrease benefits) (Risk to Resilience Study Team 2009) Location source of materials can impact the costs (FEMA 1997) Varies with the type of structure and the height to which it is raised (Woodruff 2008) Less expensive if introduced during new construction (Woodruff 2008)	Non-flood benefits were difficult to quantify (Risk to Resilience Study Team 2009) Shift to community toilets would reduce the spread of disease (Risk to Resilience Study Team 2009) Safety benefits of bitumen road versus graveled were not considered (BTRE 2002) Environmental benefits of the new type of road were not considered (BTRE 2002) Bitumen sealed roads will impede the flow of flood water and inhibit the erosion of road shoulders (BTRE 2002) Bitumen road requires less maintenance (BTRE 2002) Assumed raised floor height reduces potential household losses from flooding to zero (Woodruff 2008)	Elevated Kuccha House: Capital Costs: 0 INR Annual O&M: 11 Million INR Pukka House: Capital Costs: 0 INR Annual O&M: 102 Million INR Raising Fodder Storage Unit: Capital Costs: 88 Million INR Annual O&M: 44 Million INR	(Risk to Resilience Study Team 2009)
			New Home: BC Ratio: 2.22 – 44.38 Existing Home: BC Ratio: 0.53-8.07	(Woodruff 2008)
			Food Shelters: Capital Costs: 419 Million INR Annual O&M: 1 Million INR	(Risk to Resilience Study Team 2009)
			Elevated hand pumps and toilets: Capital Costs: 28 Million INR Annual O&M Costs: 20 Million INR	(Risk to Resilience Study Team 2009)
			Elevated hand pumps: BC Ratio: 3.2 NPV: 228,330 INR	(Venton and Venton 2004)
			Bitumen sealed roads: Total cost difference between gravel road and bitumen road: 9.87 Million AUD	(BTRE 2002)

ZONING

Zoning as a property modification strategy was also investigated and identified in three studies. Zoning is defined as land use regulations (Faisel et al. 1999) and planning (BTRE 2002). In Katherine, Australia, overflow damages were estimated in the same manner for both residential buildings and commercial buildings. It was assumed that the damage incurred would result during probable maximum floods, and that during other flooding events structures would not be damaged. In calculating the avoided damages, business disruption costs were integrated by value of gross output minus the value of the intermediate outputs. The use of stage damage curves allowed for estimation of ground and elevated levels and allowed for probability analysis of events. To account for the fact that people take steps to minimize damage, actual damage is determined by multiplying the estimated potential damage cost by a Damage Reduction Factor (BTRE 2002). A study completed mainly on the qualitative benefits and costs of land zoning made apparent certain elements that were hard to quantify. Some of the benefits and costs elevated were:

TABLE 1

QUALITATIVE REVIEW OF ZONING COSTS AND BENEFITS

Benefits	Costs
Improved enhancement and coopera-tion amongst governments;	Loss of property tax revenue to municipalities;
Elevated level to technical competency;	Legal and administrative costs to landowners;
Improved design standards and policies for infrastructure;	Costs of updating flood plain maps and studies;
Used for other purposes (flood forecasting);	Loss of real estate value of existing properties;
Created businesses related to flood-prone mapping; and,	Landowners requesting public agencies to purchase their flood-vulnerable land;
Recognition of the need for watershed planning.	Limiting available construction footprint; and,
	Cost of retention ponds outside regional flood line.

* Source: Loe and Wojtanowski 2001

ZONING

Types	Factors Impacting Return	Critical Assumptions	Financial Returns	Author
Decision to build in non-flood prone area	Used stage damage curves (BTRE 2002) Damage to both ground level and elevated level (BTRE 2002) Aerial photographs to estimate housing levels (BTRE 2002) Proportion percentage of houses flooded (BTRE 2002) To account for the fact that people take steps to minimize damage, actual damage is determined by multiplying the estimated potential damage costs by a damage reduction factor (BTRE 2002) Existing warning system that reduces avoided costs (BTRE 2002) Value added costs (value of gross output minus the value of intermediate outputs) (BTRE 2002) No allowance in building failure into the PMF calculations (BTRE 2002) Loss of property tax revenue to municipalities (BTRE 2002) Legal and administrative costs to landowners (BTRE 2002) Costs of updating maps and studies Loss of real-estate value (BTRE 2002) Cost of retention pond outside regional flood line (BTRE 2002)	Assumed the existence of a probable maximum flood (BTRE 2002) Houses that would be damaged are based on similar past data (BTRE 2002) Overflow damage is estimated similarly for residential buildings as for commercial buildings (BTRE 2002) Nominal damage value based on actual damage to schools during the other floods and proportional to over-floor depth for houses (BTRE 2002) Number of hours volunteered to determine clean-up costs (BTRE 2002) Limited available construction footprint (BTRE 2002)	Avoided Costs at AEP of 1%: 29 Million AUS	(BTRE 2002)
			Avoided costs at PMF: 19 Million AUS	(BTRE 2002)

BUILDING REGULATIONS

Building regulations were investigated in only one study and were kept separate from proofing because of the interpretation of the strategy. The regulation is a requirement that may or may not lead to proofing. In this case, the cost of requiring minimum floor levels would be minimal when added to the construction of the home and amortized over the life of the house. The factors impacting return include enforcement of the regulation, the size of sample group used during the study, and low velocity of water, which reduces overall damages. The study team assumed that the costs for upgrades would be paid and implemented by the owner, that a certain amount of properties would avoid inundation due to floor levels, that there was a relatively small difference between a 100-year flood and 10-year flood in terms of depth, and that the solution would not fail even if the disaster was greater than assumed. Overall, the avoided damages were high enough to ensure that implementation would lead to risk reduction (BTRE 2002).

BUILDING REGULATIONS

Types	Factors Impacting Return	Critical Assumptions	Financial Returns	Author
Minimal floor levels for all residential properties	Only reduces internal damages, does little to reduce external losses or risk to life (BTRE 2002) Low velocity of water which the property is subject to (BTRE 2002) Costs are paid by the owner (BTRE 2002) Number of properties that avoided inundation due to floor levels (BTRE 2002) Sample size (BTRE 2002) Small difference in depth between a 100-year flood and 10-year flood (BTRE 2002)	Data and information collected around pre-building regulations and post-building regulations show evidence of the benefits. A degree of uncertainty in the reported data and the inability to extrapolate conditions across a sufficient sample group (BTRE 2002) Enforcement of the regulations has occurred (BTRE 2002) The floor levels that properties would have otherwise had and the external flood levels affecting those properties (BTRE 2002) Assumes the costs is born by the users of the flood plain and will pay (BTRE 2002) Assumed a 100-year flood and cost of failure could be larger with greater than 10-year flood event (BTRE 2002)	Number of properties externally flooded: Built before 1991: 93 After 1991: 24	(BTRE 2002)

VOLUNTARY PURCHASE

As above, analyses completed on voluntary purchase (VP) programs are rare, and the study completed by the BTRE was the only one highlighted in this report that addresses VP. According to the BTRE team, the choice of implementing the VP program actually resulted in lower benefit-cost ratios than alternative solutions. However, when hazard and safety levels were taken into account the distributional benefits to the community were greater with the VP program, therefore, it was adopted. Avoided costs were calculated at $1,835,248 Australian dollars. Factors impacting the return include the stage damage curves that significantly underestimate the damages, over-floor water depth that was used to calculate the damage for each house, losses in agricultural use of purchased land, and determining the height of the flooding within the properties. The team did not consider the agricultural costs of flooding, intangible and damages to community infrastructure was not included, and the full benefits of the VP scheme have not been fully captured (BTRE 2002).

VOLUNTARY PURCHASES				
Types	**Factors Impacting Return**	**Critical Assumptions**	**Financial Returns**	**Author**
Cost-purchasing of private land	High-hazard ration for the 1% AEP (BTRE 2002) Previous experience with over-floor flooding (BTRE 2002) Determining the height of flooding within the properties (BTRE 2002) Establishing the appropriate stage-damage curves (BTRE 2002) Estimate the damage of each property (BTRE 2002) Over-floor water depth was used to calculate the damage cost for each house (BTRE 2002) Existing flood warning system (BTRE 2002) Agricultural use of purchased land (BTRE 2002)	The property is owner occupied (BTRE 2002) Included the use of hazard and safety levels are taken into account in deciding the VP projects (BTRE 2002) Assumed no agricultural costs associated with flooding (BTRE 2002) Intangible costs and damage to community infrastructure was not included (BTRE 2002) The full benefits of the VP scheme have not been captured (BTRE 2002) Each property suffered the maximum damage represented in the stage-damage curves (BTRE 2002)	Avoided Costs: AUD 1,835,248 Million AUS	(BTRE 2002)
			NPV: -2.15 million AUD	(BTRE 2002)

PREPAREDNESS

Preparedness is made up a number of solutions that can lead to resilience in flooding events. This includes mobility, support from family and social networks, community grain banks, community seed banks, self help groups, purchasing of a community boat, flood adapted agriculture, and strengthening healthcare. The financial analysis completed on these strategies included a look at the capital costs and annual operations and maintenance costs. There was limited discussion on the factors that impacted overall returns made during the analysis and only investigated by the Risk to Resilience Study Team (2009).

TABLE 2

PREPAREDNESS STRATEGIES (IN INR MILLION)

Type of Preparedness Strategy	Capital Costs	Operations and Maintenance Costs
Community Grain Bank	5	2
Community Seed Bank	2	1
Self help groups	5	2
Purchase community boat	46	4
Flood adapted agriculture	0	440
Strengthen overall healthcare	56	24

* Risk to Resilience Study Team 2009

PREPAREDNESS

Factors Impacting Return	Critical Assumptions	Financial Returns	Author
Mobility Support from friends family and personal savings Relying on social networks Community grain bank Self-help groups Purchase community boat Flood adapted agriculture Strengthen overall healthcare Hanging footbridge	Self-help groups do not lead to a financial burden on members (Risk to Resilience Study Team 2009) Benefits accrue to the community for 15 years (Venton and Burton 2009)	BC Ratio: 24	(Venton and Burton 2009)
		Community Grain Bank: Capital Costs: 5 Million INR Annual O&M: 2 Million INR	(Risk to Resilience Study Team 2009)
		Community Seed Bank: Capital Costs: 2 Million INR Annual O&M Costs: 1 Million INR	(Risk to Resilience Study Team 2009)
		Self Help Groups: Capital Costs: 5 Million INR Annual O&M Costs: 2 Million INR	(Risk to Resilience Study Team 2009)
		Purchase Community Boat: Capital Costs: 46 Million INR Annual O&M: 4 Million INR	(Risk to Resilience Study Team 2009)
		Flood Adapted Agriculture: Capital Costs-:0 Annual O&M: 440 Million INR	(Risk to Resilience Study Team 2009)
		Strengthen Overall Healthcare: Capital Costs: 56 Million INR Annual O&M: 24 Million INR	(Risk to Resilience Study Team 2009)

FORECAST AND EARLY WARNING SYSTEMS

Early warning systems act as an opportunity for those potentially affected by the disaster to remove themselves from the event before it occurs. This strategy was the most mentioned out of all the studies. If the warning is enabled early enough, people are able to protect at least some of their assets and remove themselves from the situation. In one town in Texas, the advance warning enabled 25% reduction in damages and was further reiterated by officials at Vandenburg Air Force Base, which estimated the reduction of half the excepted losses due to the early warning system (BTRE 2002). With the time enabled by warning systems, people avoid later sickness by having time to store clean water and potential reduction of days lost due to reduced injuries. Furthermore, humanitarian agencies may need to provide less medical, food, and other assistance to those people enabled to leave the area (Holland 2008). Rogers and Tsirkunov (2010) revealed a study that generated $31.5 billion in benefits compared to the cost of $5.1 billion. However, costs of warning systems itself may be high relative to the benefit if that system is used solely for infrequent events, such as a 200 year flood, therefore, early warning systems may be more economical if events are more frequent. Reasonable application of early warning systems needs to be considered. In the case of Samoa, flood forecasting water levels several hours in advance is difficult due to the steep and relatively small catchments and rainfall events (Woodruff 2008).

Key factors impacting overall returns include the actual amount of warning time enabled by the system (lead time). Lead-time allows those experiencing the hazard to undergo a range of responses and varies significantly with the type of flood. Floods enabled by snowmelt have a longer lead-time than floods that are potentially caused by excessive rainfall and breeches of large structures (Teisberg and Weiher 2009). Access to technology to enable the warning system (via cell phone, radio tower, etc.) is just as important. In certain areas, these costs can be expensive. A soft cost factor that is often overlooked is the strategies and systems integrated around the early warning systems. If effective communication and evaluation strategies have not been put in place, the early warning system could be rendered ineffective. Evaluating costs with the life span of the technology involved is another element impacting return (Holland 2008). One factor impacting return that was not often discussed was the resulting effect that early warnings systems have for multiple hazards. There was no attempt to calculate the co-benefits of implementing a system that could work for flood, earthquake, fire, etc.

Assumptions commonly made during analysis include both the value of household contents and the value of warehouse stocks that can be removed in the warning time window provided (Risk to Resilience Study Team 2009). Many authors stated that the greatest benefit associated with early warning systems was the protection of human life (Woodruff 2008). The calculation of reduction in injuries and deaths is calculated by using quality-adjusted life years (QALY). This approach is particularly useful in evaluating the effectiveness of early warning systems since they have the biggest impact in reducing loss of life and injury (Rogers and Tsirkunov 2010).

The overall economic returns of early warning system varied greatly by study. In general, most of the returns were found to be positive with a few instances of below one benefit-cost ratios. These lower benefit cost ratios are probably due to the overall cost of implementation.

FORECAST AND EARLY WARNING SYSTEMS

Factors Impacting Return	Critical Assumptions	Financial Returns	Author
Shorter response times on the Lai River (Risk to Resilience Study Team 2009) Amount of warning time (Risk to Resilience Study Team 2009) Access to technology to receive warnings (Risk to Resilience Study Team 2009) Communication and strategies around warning systems (Risk to Resilience Study Team 2009) Forecasting flood water levels (Woodruff 2008) Sufficient flood warning time (Holland 2008) Limited data available on impact of flooding (Holland 2008) Losses sustained were averaged across districts (Holland 2008) Included government losses, business disruption, humanitarian aid costs (Holland 2008) Accuracy of seasonal events (Adams et al. 2003) Boat size for pulling in the boat (Khan et al. 2012) Lead time of the storm warning given to fishers to take in their boat (Khan et al. 2012) Subsidized boat winching costs during emergencies (Khan et al. 2012) Labor cost for boat winch operators (Khan et al. 2012)	Value of household contents and the value of warehouse stocks that can be removed in the short time provided by the early warning system (Risk to Resilience Study Team 2009) Four hours of warning (Woodruff 2008) Assumed that no structural damage can be prevented (Woodruff 2008) Assumed that no benefits are realized until the second year (Woodruff 2008) Assumed that households and businesses can act upon flood advisories by taking appropriate actions (Woodruff 2008) Assumed a discount rate lower than current commercial bank rates (Holland 2008) Assumed 10% of building protection would be saved (Holland 2008) Assuming a major flood happens only once every 20 years (Holland 2008) Using the winch system saves time (Khan et al. 2012) Assumed that pulling a boat manually requires about 15 days (Khan et al. 2012) Winch life is 30 years (Khan et al. 2012) Assumed that a winch would save 5% of the boats (Khan et al. 2012)	BC Ratio: 0.96 NPV: 416 Million PKR	(Risk to Resilience Study Team 2009)
		IRR: 30%	(Adams et al. 2003)
		Boat Winch: BC Ratio: 3.5 NPV: 4.7 Million VND	(Khan et al. 2012)
		BC Ratio: 1.10 or greater	(Holland 2008)
		BC Ratio: 1.72 – 1.92	(Woodruff 2008)
		Capital Costs: 6 Million INR Annual O&M: 2 Million INR	(Risk to Resilience Study Team 2009)
		BC Ratio: 4.6	(Rogers and Tsirkunov 2010, Schroter et al. 2008)

Conclusion

This desk review explored available information on the costs and benefits of the flood risk reduction strategies being implemented by cities, local agencies, and national authorities.

In general, the evidence base on the costs and benefits of flood risk reduction is limited. Although relatively few studies are available, most economic research focuses on the returns to hard structural investments (dams, levees, etc). Very few studies are available on the returns to institutional or other "softer" investments in flood risk reduction.

Overall, as a result, there are major gaps in the literature regarding the costs and benefits of flood risk reduction. Further analysis is essential to support effective decision-making on the following:

> EXPOSURE REDUCTION AND PROPERTY MODIFICATION (strategies that focus on soft measures, such as flood zoning, and flood adapted design for housing and other structures to reduce exposure to floods). In comparison to direct structural protection where investment levels are high, relatively little evidence is available on the costs and benefits of strategies that rely on property modification to reduce exposure to flood risks. Such approaches can be extremely effective in reducing exposure to flood impacts, however, in comparison to structural

protection, exposure reduction and property modification require relatively low levels of direct investment to implement. As a result, logic suggests they should be highly cost-effective. The lack of studies and documented evidence on this is, consequently, a major gap that is of direct relevance for policy making.

BEHAVIORAL RESPONSE MODIFICATION (strategies that focus on changing the behavior of exposed populations). Actions that change in behavior are widely recognized as one of the most technically effective mechanisms for reducing flood losses, however, major gaps exist in the literature on the costs and benefits of response modification. Early warning systems are a common strategy employed and the economic returns to some systems have been evaluated. Very few studies were found. This suggests that further analysis on the returns to preparedness strategies is critical to inform decision-makers.

THRESHOLD EFFECTS. Out of the studies reviewed, very few evaluate the presence or consequence of thresholds that could greatly affect returns for investments in flood risk management. Dam, dikes, and other structures tend to provide full protection until floods exceed their design capacity, at which point they often fail catastrophically. As a result, if thresholds are likely exceeded or if the presence of structures provides a false sense of security, such strategies can be maladaptive and result in an overall increase in loss levels. As a result, the lack of consideration of such effects in the cost-benefit literature on flood risk reduction represents a major gap of significant importance to policy.

PORTFOLIO APPROACHES. Little evidence exists concerning the returns to portfolios of flood management investments. Logic suggests, however, that a portfolio of approaches should lead to increased resiliency during extreme events. For example, the combined use of early warnings systems, zoning, and drainage improvements should result in a much greater reduction in flood losses when implemented as a package rather than as "stand-alone" activities. The gap in evidence on this is, as a result, a significant limitation for decision-makers.

INTEGRATION OF ECONOMIC MEASURES. Economic measures, such as the cost-benefit ratio, are often reported as the primary guidance for decision-making. This reduces the importance given to other objectives (such as lives saved or environmental values preserved) where the economic value is difficult or inappropriate to estimate. As a result, economic values should be evaluated in conjunction with other indicators that reflect investments required to adhere to specific objectives. This applies to many non-market values. Other measures such as cost per life saved and cost per hectare of land preserved would provide a better indication of the returns for a given investment.

SOFT STRATEGIES AT A DISADVANTAGE. The metrics used to evaluate softer approaches to flood risk reduction are often challenging to quantify. As a result, such measures are often evaluated qualitatively, which places them at a disadvantage in relation to investments where returns can be quantified.

The review suggests that research and economic analysis to address the gaps mentioned above is of fundamental importance to guide policy and investment decisions on alternative strategies for flood risk reduction. Most published evidence relates to the returns on more easily quantified aspects of investment in hard structural measures. The wider literature, however, suggests that softer strategies for flood risk management are more technically effective, particularly under conditions of uncertainty, and are highly likely to be much more cost-effective.

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